PLNGS Technical Planning Basis

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1. DEFINITIONS AND ACRONYMS

1.1 Definitions

Beyond Design Basis Accident	Postulated failure of equipment and safety systems that is deemed to be too improbable to take into account in the design of the plant.
Beyond Design Basis Release	Release of radioactive material of a magnitude and composition that is representative of Beyond Design Basis Events with a partially impaired containment
Cloud Shine	External radiation from the radioactive contamination in the air
Design Basis Accident	Postulated failure of equipment and safety systems that is taken into account in the design of the plant
Design Basis Release	Release of radioactive material of a magnitude and composition that is representative of Design Basis Accidents
Deterministic effects	Acute health effects that may occur as a direct result of the exposure to radiation
Early Protective Action	Protective action in the event of a nuclear or radiological emergency that can be implemented within days to weeks and still be effective
Effective dose	Weighted average of the dose received by all organs in the body from both internal and external exposure; the effective dose is related to the increased risk of latent cancer
Emergency planning zone	The area in which implementation of operational and protective actions are or might be required during a nuclear emergency, to protect public health, safety and the environment
Equivalent dose	Dose received by an organ
Gray (Gy)	Derived unit of Ionizing radiation. 1 Gy equates to 1J/kg
Ground shine	External radiation from the radioactive contamination deposited on the ground
Intervention level	Avertable dose above which the benefit of taking a protective action outweighs its cost or detriment

MELCOR Accident Consequence Code Systems (MACCS)	Radiological risk calculation program used to estimate the doses and health risks from nuclear accidents
Mortality	Death
Operational intervention level (OIL)	Level that is measurable using common instruments (e.g. hand-held dose rate meter) that corresponds to the intervention level
Pasquill	Measure of the atmospheric stability; "A" corresponds to the most unstable (most dispersive) conditions; "F" corresponds to the most stable (least dispersive) condition.
Precautionary Urgent Protective Action	An urgent protective action taken before or shortly after a release of radioactive mater, or an exposure, based on the prevailing conditions to avoid or to minimize severe deterministic effects.
Protective Action	An action for the purposes of avoiding or reducing doses that might otherwise be received in an emergency exposure situation or an existing exposure situation.
Reduction factor	Factor by which a given protective action reduces the dose that would be received by an individual
Severe accident	Accident leading to significant fuel damage and release of fission products to the containment
Severe Accidental Release	Release of radioactive material of a magnitude and composition that is representative of severe accidents with impaired containment
Sievert (Sv)	Unit of effective or equivalent dose
Stable iodine	Iodine prophylaxis, usually in the form of pills, ingested to protect the thyroid gland against the harmful effects of radioactive iodine
Stochastic effects	Latent health effects (cancer) associated with exposure to radiation; the incidence of stochastic effects can only be determined through epidemiological studies that measure the increase of cancers in a large population
Urgent protective action	A protective action in the event of a nuclear or radiological emergency which must be taken promptly (usually within hours to a day) to be effective, and the effectiveness of which will be markedly reduced if it is delayed.

1.2 Acronyms

ASDV	Atmospheric Steam Discharge Valves
BDBA	Beyond Design Basis Accident
CNSC	Canadian Nuclear Safety Commission
CPZ	Contingency Planning Zone
CSA	Canadian Standards Association
CSDVO	Condenser Steam Discharge Valves
CsI	Cesium Iodine
CV	Calandria Vault
DBA	Design Basis Accident
DNGS	Darlington Nuclear Generating Station
DPZ	Detailed Planning Zone
ECC	Emergency Core Cooling
EME	Emergency Mitigation Equipment
EP	Emergency Preparedness
EPD	Extended Planning Distance
EPRC	External Plant Release Categories
EPS	Emergency Power System
EWS	Emergency Water Supply
GSR	General Safety Requirements
HC	Health Canada
IAEA	International Atomic Energy Agency
ICPD	Ingestion and Commodities Planning Distance
IPZ	Ingestion Planning Zone
KI	Potassium Iodine
LAC	Local Air Cooler
LOCA	Loss of Coolant Accidents
LPZ	Long Term Protective Action Zone
OIL	Operational Intervention Level
PAG	Protective Action Guides
PAZ	Precautionary Action Zone
PHTS	Primary Heat Transport System
PLNGS	Point Lepreau Nuclear Generating Station
PSA	Probabilistic Safety Assessment
RCW HX	Recirculated Cooling Water Heat Exchanger
REGDOC	Regulatory Document
RbI	Rubidium Iodine
RIVM	Dutch Environmental Protection Agency
SBO	Station Blackout

SGTR	Steam Generator Tube Rupture
SOARCA	State of the Art Reactor Consequence Analyses
UPZ	Urgent Protective Action Zone
ZPP	Population Protection Zone
ZST	Enhanced Surveillance Zone

2. INTRODUCTION

2.1 Background

Establishing a planning basis for the Point Lepreau Nuclear Generating Station (PLNGS) Emergency Preparedness (EP) program is a requirement by the Canadian Nuclear Safety Commission (CNSC). CNSC REGDOC 2.10.1 [1] includes the following statement:

An effective EP program is based on the following four components:

1. ***Planning basis**: an analysis of the risks and hazards that the EP program will address*
2. ***Emergency response plan and procedures**: a comprehensive description of how a response will be executed, with accompanying support material*
3. ***Preparedness**: the processes to ensure that people, equipment and infrastructure will be ready to execute a response according to the emergency response plan and procedures*
4. ***Program management**: the management system aspects that assure the effectiveness of the EP program*

The planning basis, or hazard assessment in the terminology of the International Atomic Energy Agency (IAEA), is a document that informs the emergency response plans and procedures. Taken together, the planning basis and the emergency response plans and procedures help answer the question "Do we know what to do when there is an emergency?" The answer to this question should cover a wide range of possible emergencies.

Preparedness and the program management help answer another question: "Can we do what is in our emergency response plan during a real emergency?" The answer to that question will involve the plant, but also off-site authorities who decide on the level of effort and the resources that are dedicated to emergency preparedness. For this reason, information from the planning basis should be provided to regional and provincial off-site authorities.

The technical planning basis is for *planning purposes* only. It is not intended as a document to be used during the response to a nuclear incident or accident.

2.2 Report Objective

This report presents an analysis of a range of potential nuclear accidents involving the PLNGS reactor. Its aim is to provide the practical information necessary to develop sound, effective and reasonable emergency response plans and capabilities. The information contained here will support the emergency planning activities of New Brunswick Power, Point Lepreau Nuclear Generating Station and New Brunswick Emergency Measures Organization (NB EMO).

This document focuses on protecting the health of persons during postulated accidents in accordance with Canadian and internationally accepted principles for emergency intervention. It meets the requirements of CNSC REGDOC 2.10.1 [1], CSA standard N1600-16 [2] and IAEA GSR Part 7 guidance [3].

2.3 Emergency planning zones

Emergency planning zones and distances are defined as areas where specific levels of preparedness and emergency response arrangements need to be established to effectively manage potential emergencies. The level of preparedness depends on the distance from the source of the hazard, the potential impacts of an emergency and the speed at which this impact could be felt.

The size of the emergency planning zones has many consequences. The larger they are, the more people who could theoretically be effectively evacuated or sheltered during an emergency. However, larger emergency planning zones and distances also have effectiveness and cost implications. As an example, if the reception centres for evacuees are located very far, it may make the evacuation difficult to implement in practice.

Very large evacuation zones can also have negative psychosocial impacts by unduly implying, in the public perception, that the risk is greater than what it really is. Therefore, choosing the right emergency planning zones and distances is a decision that needs to be carefully made.

The IAEA has warned that taking protective actions that do not follow the emergency plans, or that were overly conservative, or inconsistent with accepted international principles, can be harmful, and result in severe adverse economic and psychosocial consequences [4].

2.4 Important parameters

While there is consensus in the international community that the determination of the emergency planning zones and distances must be based on a hazard assessment, a safety analysis or a probabilistic safety assessment, the approach and how to determine the zones shows wide variations among jurisdictions.

The important characteristics that need to be considered in the basis for the emergency planning zones and distances are the following:

- Accident(s) considered. This can include anything from design basis accidents to severe accidents with containment challenge. It will affect the source term(s) used in the assessment of the potential impacts of accidents. Some approaches may consider a single reference accident, while others look at a range of potential scenarios.
- Accident dynamics. The speed at which an accident is expected to lead to core melt and major releases affects the emergency response strategy and, therefore, could have an impact on emergency planning zones and distances.

- Weather. The weather pattern used in the calculations of the dose impact can have orders of magnitude impacts on the emergency planning zones and distances.
- Receptor. The assumption for the individual dose calculations affects the dose impact. Typically, the receptor can be an average individual or the most exposed representative individual. This can also have orders of magnitude impact on the sizes and distances.
- Criteria. Thresholds used to delimit the emergency planning zones and distances are typically related to emergency intervention levels (action levels) or safety criteria. The choice of those criteria has a direct impact on the sizes and distances.
- Zone definition and strategy. It is important to understand the underlying strategy used in the determination of emergency planning zones and distances. The intended strategy can affect the meaning of the emergency planning zones. To compare emergency planning zones and distances between various approaches, we need to take into account how these zones and distances are defined in terms of intended emergency actions.

Other important factors include the accident analysis models, fission product behaviour models, and dispersion assumptions. In Canada, these are covered by regulatory requirements and CSA standards on dispersion calculations and nuclear safety modeling.

2.5 Deterministic vs. Stochastic Effects

The consequences of a nuclear accident would most likely be limited to stochastic effects, which are not directly observable in individuals but can be detected statistically in a large population. They include cancer and generally involve a period of latency of several years. The measure of the risk of stochastic effects is the effective dose, expressed in Sieverts (Sv).

In extreme cases, which are extremely unlikely, a few individuals could hypothetically be exposed to very high dose rates, leading to some deterministic effects. Deterministic effects include early illness or death. The exposure thresholds above which these effects are possible are very high. For gamma and beta radiation, these thresholds can be expressed in terms of absorbed dose, measured in Grays (Gy) or equivalent dose to major organs, measured in Sieverts (Sv). The thresholds for deterministic effects depend on the dose rate, i.e. on the level of exposure and on the duration of exposure.

3. METHOD

The main references that were reviewed to identify the approach to developing the planning basis include Canadian and IAEA documents, described in Annex C.

This section describes the concepts and the methodology that are used to calculate the size of the emergency planning zones.

3.1 Protective Actions

Nuclear emergency protective actions include:

- Urgent protective actions, which must be taken within hours of an accident to be effective. These include evacuation, administration of stable iodine and sheltering; and
- Early protective actions, which may need to be adopted in a matter of days following an accident. These include control of foodstuff, relocation and resettlement.

This technical planning basis focuses on the urgent protective actions but includes consideration early protective actions, which are longer-term measures.

3.1.1 Sheltering

Sheltering in place involves keeping members of the population indoors, closing all ventilation and blocking all air paths into the dwellings to reduce radiation exposure from cloud shine, ground shine and inhalation. In addition to protecting the population, sheltering allows better and more effective communication with the affected population. Sheltering is not recommended for a period exceeding 48 hours [5]. In practice, it is difficult to maintain for more than 24 hours. Beyond that period, evacuation or relocation needs to be considered.

Sheltering is a protective action that requires a low level of planning and preparedness. It is also a protective action that can be extended further with a minimum level of effort. For these reasons, the distance where sheltering could be required is calculated for completeness, but has little weight in the sizing of the planning zones.

3.1.2 Evacuation

Evacuation is the prompt removal of the population from the affected area. It is generally the most effective protective action against major airborne releases of radioactivity. Mass care facilities must be available for a substantial fraction of the evacuated population. In North America, it is generally assumed that up to 20% of the evacuated population would use designated mass care facilities. If it becomes clear that evacuation will last longer than a week, considerations should be made to relocate temporarily to more substantial accommodations [5].

The dose that can be averted by evacuation is the projected dose that would be received by an individual staying outside, under the plume, for the duration of the evacuation, i.e. for a maximum of seven days.

Evacuation requires a high level of planning and preparedness and this protective action is a key driver for the size of the planning zones.

3.1.3 Administration of Stable Iodine

Radioactive iodine tends to concentrate in the thyroid gland and can cause early or latent effects such as thyroid cancer. Ingesting stable, non-radioactive iodine, before or immediately after exposure to radioactive iodine saturates the thyroid gland and prevents the absorption of radioactive iodine.

The dose that can be averted by thyroid blocking just before exposure to the release is equal to the projected dose to the thyroid from inhalation without the administration of stable iodine.

Administration of stable iodine during an emergency requires a high level of planning and preparedness. As a result, it is a key element in the determination of the planning zones size.

3.1.4 Temporary Relocation and Resettlement

Temporary relocation is used when there is a need to keep the population out of the affected area for a period exceeding approximately seven days but not more than a few months. This measure requires that mass care facilities be provided to the affected population. It is expected that the temporarily relocated population will be able to return to their homes.

By definition, resettlement is permanent. It is adopted when the dose to the affected population over a lifetime would exceed a certain criterion. However, decisions in that later stage rely on a detailed analysis of the consequences, land use and exposure pathways. They are also strongly influenced by social and political factors. Considerably more time is available for making those decisions than the time allowed for urgent protective action recommendations.

Relocation and resettlement are longer term protective actions that require separate planning distances.

3.1.5 Food Ban and Food Control

Protective actions related to food include:

- An immediate ban on the consumption of locally grown food in the affected area;
- The protection of local food and water supplies by, for example, covering open wells and sheltering animals and animal feed; and

- Long term sampling and control of locally grown food and feed.

Control of milk is generally considered particularly important because it is a significant part of children's diets.

Food ban and food control are typically implemented on the basis of measurements taken after an accident. A separate planning zone is included for these protective actions.

3.1.6 Criteria

Criteria for emergency protective actions are determined by provincial authorities, in this case the Province of New Brunswick. The province has adopted protective action criteria that are consistent with the guidance of the IAEA [3] and Health Canada [6]. These criteria are expressed in terms of projected dose, or the dose that would be expected if no protective action is taken.

The emergency action levels criteria and operational intervention levels need to be derived for a representative person with account taken of those members of the public that are most vulnerable to radiation exposure (i.e. pregnant women and children) [3].

Table 1: Criteria for protective actions based on IAEA recommendations [3]

Protective action	Criterion
Stable iodine thyroid blocking	50 mSv equivalent dose to thyroid only due to inhalation of radioiodine projected in first 7 days
Sheltering; evacuation; prevention of inadvertent ingestion; restrictions on food, milk and drinking water and restrictions on the food chain and water supply; restrictions on commodities other than: food; contamination control; decontamination; registration; reassurance of the public	100 mSv effective dose projected in first 7 days 100 mSv equivalent dose to fetus projected in first 7 days Sheltering may be ordered at lower doses if justified and optimized
Temporary relocation; prevention of inadvertent ingestion; restrictions on food, milk and drinking water and restrictions on the food chain and water supply; restrictions on commodities other than: food; contamination control; decontamination; registration; reassurance of the public	100 mSv projected effective dose in the first year 100 mSv equivalent dose to fetus projected over the full period of in utero development

The criteria for protective actions are expressed in the following dosimetric quantities in the Health Canada guidance [6] presented in Table 2: E is effective dose, $H_{thyroid}$ is equivalent dose to the thyroid; H_{fetus} is equivalent dose to the fetus. The generic criteria should be compared with the projected doses for the most sensitive or susceptible population group (e.g., often infants or developing fetuses are more sensitive to radiation exposure).

Table 2: Current for protective actions based on Health-Canada recommendations [6]

Protective action	Criterion
Stable iodine thyroid blocking	50 mSv in the first 7 days ($H_{thyroid}$)
Evacuation	100 mSv in the first 7 days (E or H_{fetus})
Sheltering	10 mSv in 2 days (E) (averted dose)
Temporary relocation	100 mSv in the first year (E) or 100 mSv for the full period of in utero development (H_{fetus})
Restriction of distribution and ingestion of potentially contaminated drinking water, milk, and other foods and beverages	3 mSv/y (1 mSv/year for each of the following categories: drinking water, milk and other foods and beverages) (E)

3.2 Planning Zones

The New Brunswick Nuclear Off-site Emergency Plan [7] currently defines three Emergency Planning Zones around PLNGS (Figure 1):

1) **Precautionary Action Zone (PAZ)**, which corresponds to NB EMO Warden Zones 1, 2 and At-Sea 1.
2) **Urgent Protective Action Zone (UPZ)**, which corresponds to NB EMO Warden Zones 1 to 6, 9, 13, At-Sea 1 and 2.
3) **Longer-term Protective Action Zone (LPZ)**, which corresponds to all NB EMO Warden Zones.

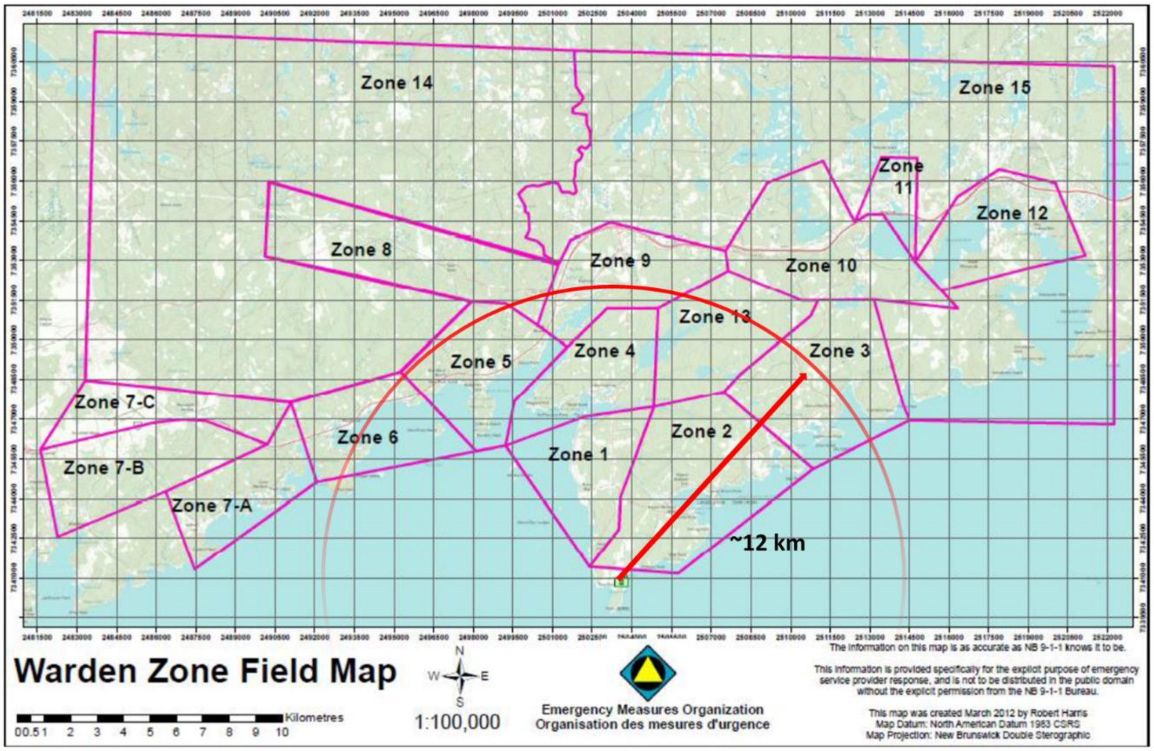


Figure 1: Provincial warden zones around PLNGS vs 12km UPZ

In addition, as stated in the Provincial Health Nuclear Emergency Plan [8], the New Brunswick Annex to the Federal Emergency Plan has established two planning zones around PLNGS:

1) **Plume Exposure Emergency Planning Zone**, a 20 km radius circle around the station. Planning and preparation for this zone includes ensuring that appropriate measures against exposure to a radioactive plume (such as sheltering-in-place or evacuation) can be applied in a timely and accurate manner.
2) **Ingestion Exposure Emergency Planning Zone**, an 80 km radius circle around the station. Its purpose is to enable planning and preparation for measures against exposure from ingestion of radioactive material.

Both the CSA N1600-16 Standard [2] and IAEA GSR Part 7 [3] recommend a four-zone approach to emergency planning around the nuclear power plant. This approach will be used for the calculation of the planning zones in this document. Table 3 shows the correspondence between the planning zone terminologies used by different organizations.

Table 3: Comparison of planning zone terminology

CSA N1600-16	IAEA GSR Part 7	NB EMO Warden Zones
Automatic Action Zone	Precautionary Action Zone	1 & 2 At-Sea 1
Detailed Planning Zone (DPZ)	Urgent Protective Action Zone	All NB EMO Warden Zones
Contingency Planning Zone (CPZ)	Extended Planning Distance	All NB EMO Warden Zones
Ingestion Planning Zone (IPZ)	Ingestion and Commodities Planning Distance	All NB EMO Warden Zones

3.2.1 Automatic Action Zone

The Automatic Action Zone in CSA N1600-16 terminology corresponds to the Precautionary Action Zone (PAZ) in IAEA GSR Part 7 [3], and in the PLNGS Planning Basis from 2004 [9].

This zone is where urgent protective actions are required in order to substantially reduce the risk of severe deterministic health effects. The type of accidents that will determine the size of this zone include Beyond Design Basis Accidents at the more severe end of the scale, since Design Basis Accidents and fully mitigated Beyond Design Basis Accidents do not lead to off-site deterministic health effects. In addition, accidents that have fast dynamics (early release) should be considered. This approach is consistent with the IAEA Safety Standards and guidelines, as well as the Canadian Standard CSA N1600-16.

The Automatic Action Zone size will correspond to the distance where severe deterministic health effects (fatalities from acute health effects) could occur in adults for average weather conditions, with additional calculations using more limiting weather scenarios to confirm the robustness of those obtained using the average weather (CSA standard N288.2:19, section 4.2.1.2 [10]).

3.2.2 Detailed Planning Zone

The Detailed Planning Zone in CSA N1600-16 corresponds to the Urgent Protective Action Zone (UPZ) in IAEA GSR Part 7 [3], and in the PLNGS Planning Basis from 2004 [9].

This is the zone where urgent protective actions are required in order to avert dose in accordance with the appropriate reference level.

As discussed in Section 3.1.6, in New Brunswick [7], the generic criteria for evacuation are a projected effective dose of 100 mSv over seven days of exposure, an averted effective dose of 10 mSv over two days for sheltering. An equivalent dose to the thyroid of 50 mSv for the inhalation component of the exposure to radioactive iodine over seven days is the criterion for the distribution of stable iodine tablets.

In addition, the Province of New Brunswick could trigger protective actions based on measured dose rates using Operational Intervention Levels, shown in Table 4.

Table 4: Operational Intervention Levels after a release

Measurement	OIL	Recommended Protective Action
Ambient dose rate H*(10)	1 mSv/h	Evacuate within a day
	100 µSv/h (measured within 10 days)	Initiate temporary relocation after evacuation
	25 µSv/h (measured after 10 days)	
	1 µSv/h	Implement restriction of distribution and ingestion of potentially contaminated drinking water, milk and other food

The Detailed Planning Zone size will correspond to the distance where dose intervention levels for urgent protective actions that require advance planning and preparedness (evacuation and thyroid blocking) are exceeded in adults for average weather conditions, with additional calculations using more limiting weather scenarios to confirm the robustness of results obtained using the average weather (CSA standard N288.2:19, section 4.2.1.2 [10]).

3.2.3 Contingency Planning Zone

The Contingency Planning Zone corresponds to the Extended Planning Distance (EPD) in IAEA GSR Part 7 [3].

This is the zone where protective actions would be justified to reduce the risk of stochastic health effects on the basis of monitoring and assessment of the radiological situation following a significant release of radioactive material. Within this zone, upon declaration of a General Emergency, instructions would be provided to members of the public to reduce inadvertent ingestion, and dose rate monitoring of deposition would be conducted to locate hotspots following a release.

Following the end of the release, the decision to promptly evacuate, or temporarily relocate the population would be based on exposure to contaminated ground. The dose intervention level for evacuation is 100 mSv over seven days, and the temporary relocation of the population would be based on an intervention level of 100 mSv in the first year following an accident.

In addition, the Province of New Brunswick could trigger protective actions based on measured dose rates using Operational Intervention Levels, shown in Table 4.

The Contingency Planning Zone size will correspond to the distance where dose intervention levels for urgent protective actions that require advance planning and preparedness (evacuation and thyroid blocking) are exceeded in adults for average weather conditions, with additional calculations using more limiting weather scenarios to confirm the robustness of results obtained using the average weather (CSA standard N288.2:19, section 4.2.1.2 [10]).

3.2.4 Ingestion Planning Zone

The Ingestion Planning Zone corresponds to the Ingestion and Commodities Planning Distance (ICPD) in IAEA GSR Part 7 [3], and the Long-Term Planning Zone (LPZ) in the PLNGS Planning Basis from 2004 [9].

This is the zone where response actions are taken to protect the food chain and water supply following a significant radioactive release.

The Province of New Brunswick could potentially trigger protective actions based on measured dose rates using Operational Intervention Levels, shown in Table 4. If an average dose rate of 1 µSv/h is assumed over one month, this would correspond to a dose of 0.72 mSv. This assumption is not strictly correct since the dose rate decreases over time, but it is required to estimate the zone size. The ingestion planning zone criterion is therefore 0.72 mSv over one month of exposure to ground shine.

3.3 Accident Scenarios

CSA N1600-16 states that a planning basis must consider the following events:

- Design basis accident (DBA);
- Beyond design basis accident (BDBA);
- Other emergencies leading to nuclear emergencies (e.g., conventional emergencies and severe weather);
- Multi-unit accident scenarios (if applicable); and
- Irradiated fuel-bay scenarios.

The consequences of loss of spent fuel storage/reception bay inventory or cooling initiating events are considered bounded by the cases that lead to severe core damage and large releases, and therefore, not included in the scope of this assessment [11]. Since PLNGS is a single-unit facility, only the first three points will be considered in the update of the planning basis.

As is commonly done in the nuclear industry, the Point Lepreau level 2 Probabilistic Safety Assessment (PSA) has categorized event sequences involving large releases into six external plant release categories (EPRCs) representing various event sequences that lead to roughly the same end state in terms of releases to the environment. Event sequences belonging in a given category would have similar off-site consequences and would lead to similar off-site emergency actions.

In order to assess the off-site consequences of severe accidents and support the off-site emergency planning, a review of the key elements of the most important contributing event sequences in each event category has been performed [11]. External Plant Release Category 0 and External Plant Release Category 3 have been retained since they have the largest contribution to the large external release frequency. External Plant Release Category 1 and External Plant Release Category 2 have a relatively smaller contribution to the large external release frequency and their consequences are bounded by other External Plant Release Categories. External Plant Release Category 4 to External Plant Release Category 6 has been retained even if the contribution to the large external release frequency is negligible because the external release potentially starts from the time of accident initiation (time zero).

Table 5 includes an overview of the three PSA release categories that are covered in the planning basis analysis. The sequence of events analysed in the PSA does not credit calandria make-up or emergency filtered venting capabilities that were installed during the refurbishment of Point Lepreau nuclear generating station. The PSA does not credit any of the emergency mitigating equipment and additional upgrades that were installed in response to the event at Fukushima Daiichi.

A filtered venting variation of External Plant Release Category 3 (labeled EPRC3a) has been added as a mitigated severe accident representative of the consequences of Design Basis Accidents. This release category credits the emergency filtered venting capability.

In summary, in the context of severe accidents, the results of the technical planning basis are conservative or bounding for the three unmitigated release categories that were considered (EPRC0, EPRC3, EPRC4-6), and representative of the likely consequences of a severe accident for the mitigated release category that was analyzed (EPRC3a).

Table 5: Accidents scenarios for analysis in updated planning basis

Category	Contribution to Large External Release Frequency % (year^{-1})	Reference Scenario
EPRC0 Early failure of containment isolation	22.5% (1.35E-07)	Stagnation feeder break scenario – SFB Case A3 release category, as described in 87RF-03500-AR-018 [12]
EPRC3 Late containment failure	65.2% (3.92E-07)	Station blackout case D – SBO Case D1 release category, as described in 87RF-03500-AR-015 [13]
EPRC3a Filtered station blackout	n/a[1]	Filtered station blackout case D – SBO Case D1 release category, as described in 87RF-03500-AR-015 [13], but filtered release instead of late containment failure
EPRC4-6 Containment bypass event	Negligible (7.55E-12)	Complete loss of heat sinks initiated by steam generator tube rupture – Steam Generator Tube Rupture Event SGTR Case B2, as described in 87RF-03500-AR-019 [14]

Note 1: The frequency of the station blackout case D with emergency filtered venting being credited has not been calculated, but the case with the filter being credited (EPRC3a) is more likely than the case where the filter is not credited (EPRC3).

The cumulative release fraction of the initial core inventory for each external plant release category is presented in Table 6. The timing of the bulk of the noble gas release is based on the release rate shown in Figure 2 and cumulative releases shown in Figure 3. Similar data for iodine and cesium releases is shown in Figure 4 and Figure 5.

Table 6: Cumulative release fractions of initial core inventory for each release category

Element	Group	EPRC0 SFB-A3-2B	EPRC3 SBO D1A	EPRC3a SBO D1A	EPRC4-6 SGTR B2
Xe, Kr	1	0.675	0.795	0.795	0.998
I, Br	2	0.002	0.029	1.54E-04	0.024
Cs	3	0.003	0.024	2.4E-06	0.034
Rb	4	0.003	0.024	2.4E-06	0.035
Te, Se	5	0.001	0	0	0.026
Sb, As	6	3.8E-04	0.058	5.8E-06	0.005
Sr	7	2.4E-08	1.0E-04	1.0E-08	2.0E-04
Ba	8	3.9E-07	0.001	1.0E-07	0.0001
Mo, Zr, Nb, Cd, Tc, Ru, Rh, Pd, Ag	9	1.0E-04	0.015	1.5E-06	0.001
La, Pr, Nd, Sm, Eu, Y	10	4.6E-10	1.7E-05	1.7E-09	1.0E-05
Ce, Cm, Pm, Np, Pu	11	1.7E-08	6.6E-05	6.6E-09	1.0E-04
Delay before release (h)		2	76	76	18
Duration of release (h)		4	4	4	4
Release height (m)		0	0	0	0

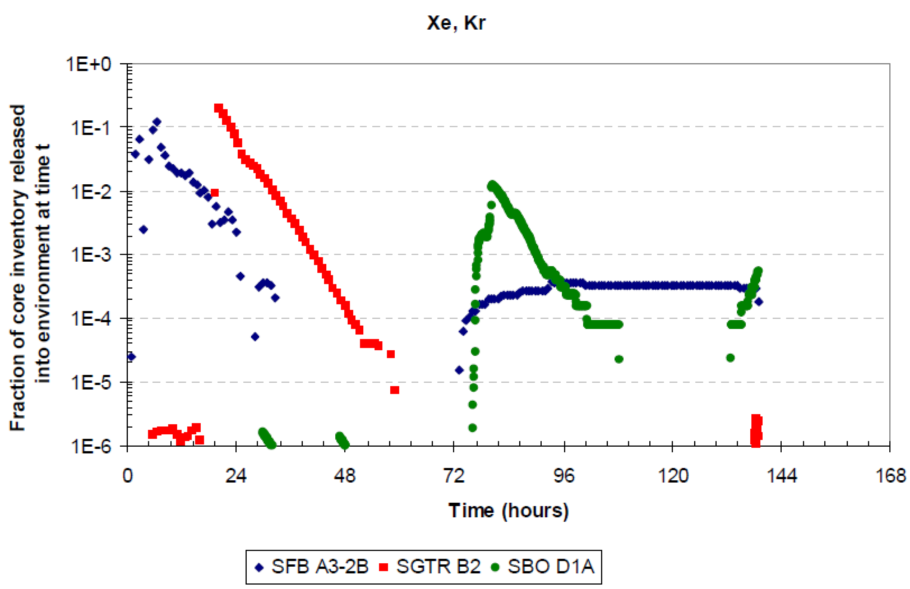


Figure 2: Noble gas release rate for the three unmitigated release categories

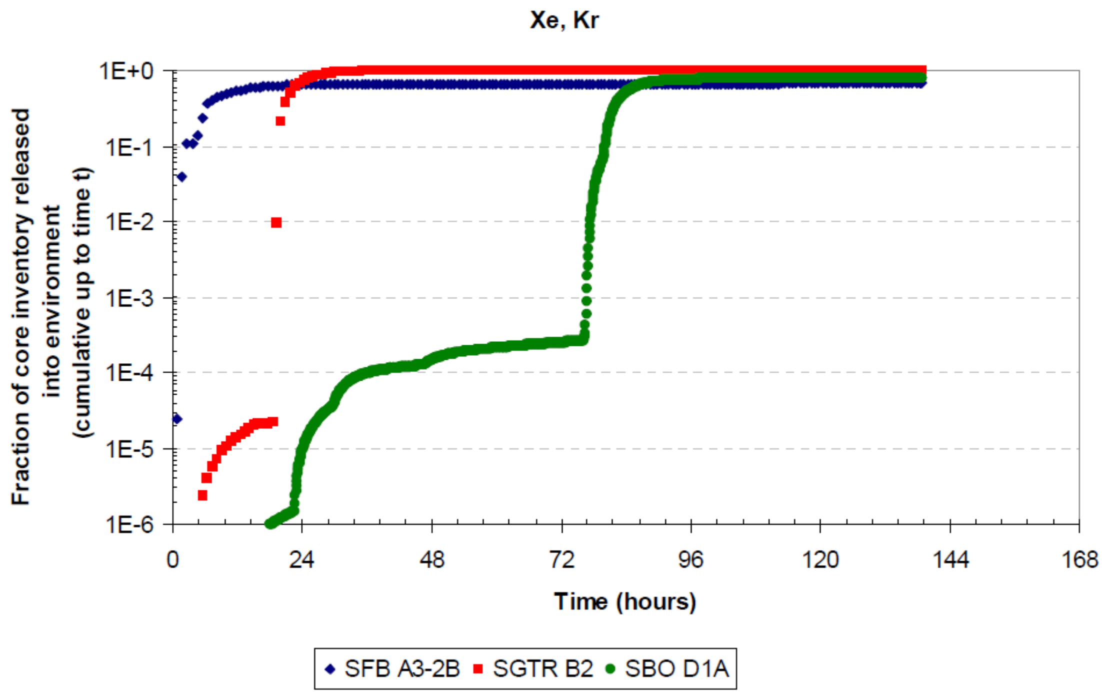


Figure 3: Noble gas cumulative release for the three unmitigated release categories

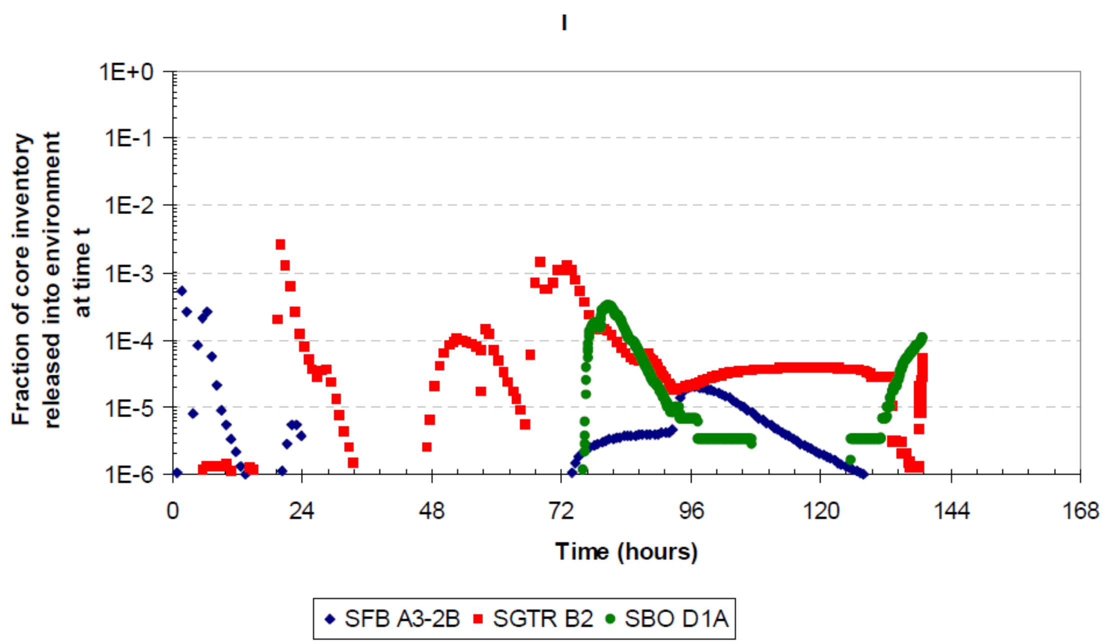


Figure 4: Iodine and cesium release rate for the three unmitigated release categories

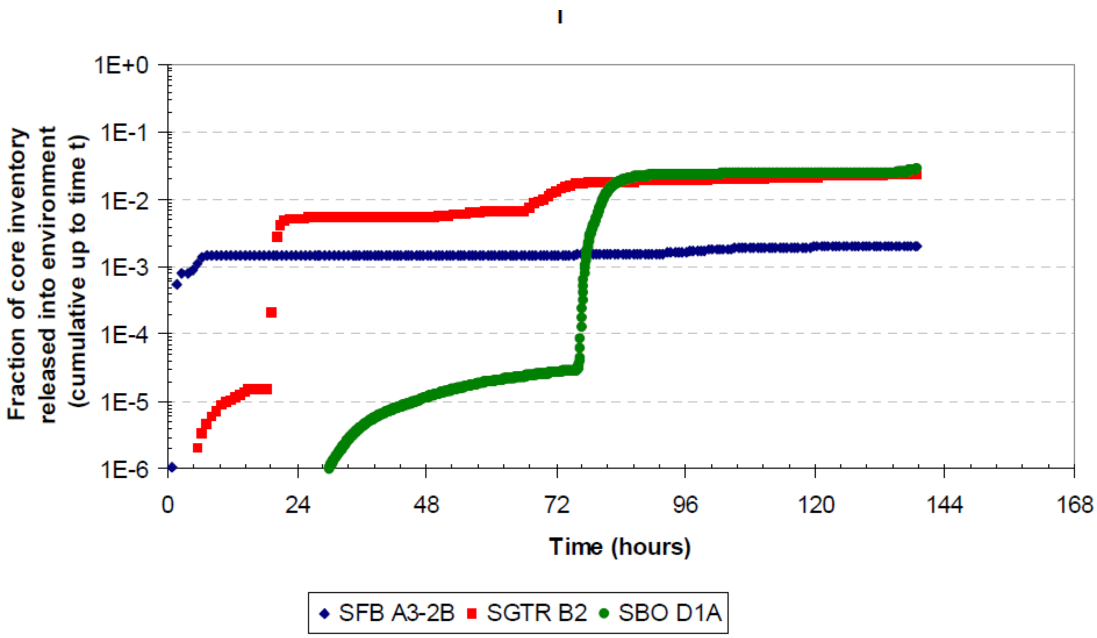


Figure 5: Iodine and cesium cumulative release for the three unmitigated release categories

A detailed description of each release category follows.

3.3.1 External Plant Release Category 0 – Early Release Due to Failure of Containment Isolation

The type of events that are the main contributors to EPRC0 are in-core Loss of Coolant Accidents (LOCA) with impaired containment isolation. Such LOCA's are characterized by the fact that they lead to the drainage of the moderator which for other events, provides an additional heat sink when Emergency Core Cooling (ECC) is not available. In-core LOCA's include events such as feeder stagnation break, pressure tube with calandria tube rupture, channel flow blockage, as well as fire initiators that lead to such events. These events normally rapidly trigger containment isolation; in order to lead to an EPRC0 type of release, the containment isolation has to be assumed failed and no operator credited for a significant period of time (24h) to manually initiate isolation.

In summary, typically the following combination of failures, which frequency is of the order of 10^{-8} y^{-1} or less, are required to lead to EPRC0:

- An in-core LOCA with consequential loss of moderator (from failure of bellow);
- Failure of containment isolation with no operator action to isolate for the first 24 h after the event;
- ECC High Pressure (HP), Medium Pressure (MP), and Low Pressure (LP) or automatic main Primary Heat Transport (PHT) Pump Trip not available and no operator action to correct the situation;
- End shield cooling not available;

- Emergency power system (EPS) not available; the EPS supplies the emergency water supply pumps and valves, the emergency core cooling pumps, certain emergency core cooling valves, and Group 2 safety and control systems;
- The Emergency Mitigation Equipment (EME) is not deployed to restore cooling or to restore power; and
- For this event, the availability of the Local Air Coolers (LACs) (15) prevents containment failure and emergency venting does not have to be credited.

These assumptions are such that there is no heat sink available and consequentially lead to core disassembly. As such, this event is a Beyond Design Basis Accident.

The timing of the release is relatively rapid (Figure 6):

- The core collapse onto the Calandria Vault (CV) for both loops occurs at about 1.6 h and 2.4 h, much earlier that the manual containment isolation assumed at 24 h.
- The release of 15% of the total noble gas release to the environment starts almost immediately; at 5 h to 6 h, 20% of the total noble gas is released; at 24 h, almost 95% of the total noble gas has been released.
- The ex-vessel (outside the calandria vault) and environmental iodine (CsI and RbI) releases start once the CV has failed and energetic core-water interaction starts, around 28 h. This is long after the containment has been isolated and therefore the releases to the environment are small and caused by containment leakage.

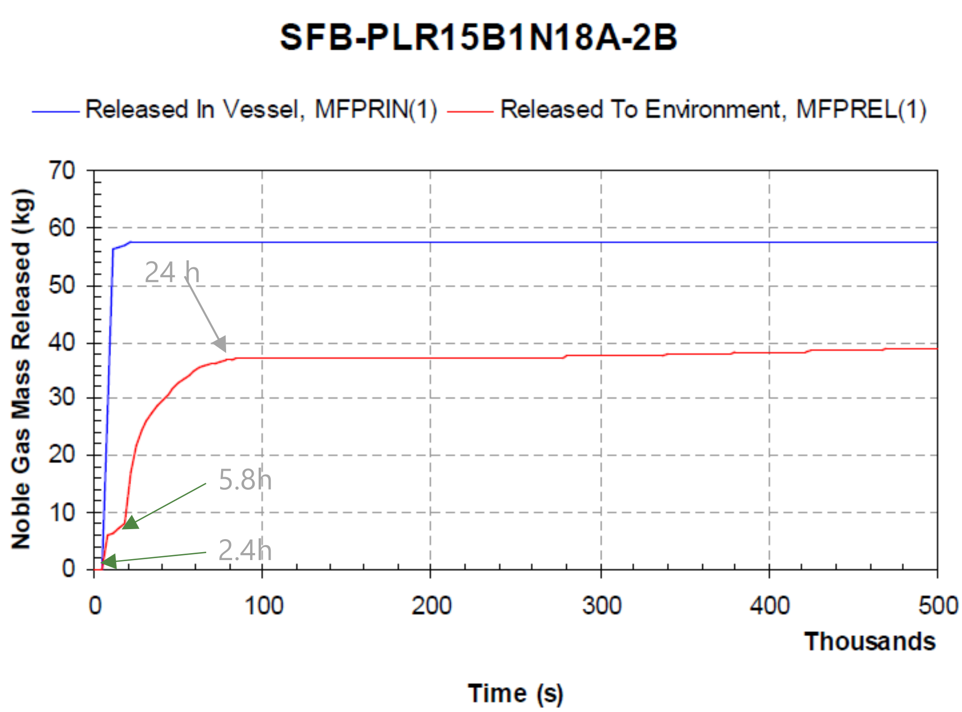


Figure 6: Timing of cumulative release to environment for EPRC0

The accident progression assumes that many actions that could be taken by the operators are not taken or are not effective.

This scenario will be used to assess the size of the Detailed Planning Zone.

3.3.2 External Plant Release Category 3 – Late Containment Failure

For this release category, the containment is initially intact, but late containment failure occurs after 24 to 72 hours due to the progression of the severe accident which raises the pressure inside the containment.

The main contributors to a late containment failure (EPRC3) are typically grouped under the category of Station Blackout (SBO), which also includes other events with complete loss of heat sinks. The events that are relatively more likely (order of 10^{-8} event/y) to lead to a station blackout are fires in various rooms associated with essential power equipment.

It is noted that what is common to all the event sequences is that they involve a loss of long-term heat sink from the Emergency Water Supply (EWS) and a failure to depressurize the containment by using the emergency venting system. These losses of systems can be caused by system failures or by failure of the operator to initiate them.

- A fire or similar event causes a loss of power from the grid (Class IV) and backup diesel generators (Class III);
- Emergency Power Supply (EPS) is available for the first 72h and supports the operation of HP, MP and LP Emergency Core Cooling (ECC) system; EPS is assumed to fail after 72 h because of failure to refuel or other equipment failure;
- The loss of the EWS removes the ability to cool the atmosphere in the containment, and the long-term cooling of the core;
- The emergency mitigation equipment is not effective at restoring power or water supply; and
- The emergency venting system is not functional and fails to reduce the pressure in the containment;

The timing of the release is delayed until containment fails by overpressure (Figure 7):

- Containment fails at the small airlock seals at 22.7 h;
- Beginning of core disassembly at around 76 h;
- Loop 1 massive core debris relocation to calandria vessel bottom at around 76 h;
- Most of the release takes place between 76 h to 85 h, when the core breaches the calandria and relocates in the calandria vault.

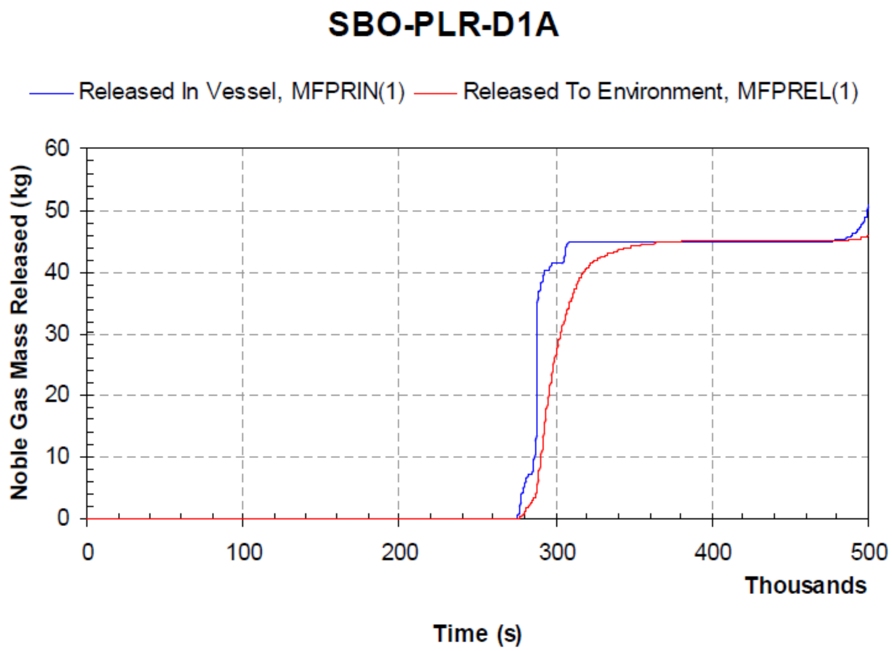


Figure 7: Timing of cumulative release to environment for EPRC3

Since the core is severely damaged, this release category is a Beyond Design Basis Accident.

The accident progression assumes that many actions that could be taken by the operators are not taken or are not effective. The magnitude of the release would be very different if the emergency venting system was activated before containment failure. This is discussed in the next section.

The EPRC3 release category will be used to determine the size of the Contingency Planning Zone.

3.3.3 External Plant Release Category 3a – Filtered station blackout

The case where the emergency venting is activated and credited is also analyzed as a mitigated severe accident with consequences representative of Design Basis Accidents and is labeled EPRC3a, which will be considered in the assessment of the Detailed Planning Zone.

3.3.4 External Plant Release Category 4-6 – Containment Bypass

External release frequencies of 7.55E-12 y^{-1} associated with containment by-pass events (EPRCs 4 to 6) make a negligible contribution to total large external release frequency. However, because the external release potentially starts from the time of accident initiation (time zero) for this type of event, a representative case of this category is selected for the off-site consequence assessment.

The Modular Accident Analysis Program - Canada Deuterium Uranium (MAAP-CANDU) steam generator tube rupture case B has been selected as the representative case for the containment bypass event.

In a Steam Generator Tube Rupture scenario, when the Steam Generator tubes fail and the secondary side has boiled off, the fission products can be released outside the containment through the broken Steam Generator tubes and then through the Main Steam Safety Valves (containment bypass scenario).

Steam generator tube failure(s) are considered in the design basis and their analysis are documented in the Safety Report. Assuming normal mitigating system behavior and adequate operator actions, their consequences are benign. When the operators are able to open the Condenser Steam Discharge Valves (CSDV) and Atmospheric Steam Discharge Valves (ASDV) to crash cooldown the steam generators and isolate them, the release to atmosphere is very small and would not lead to an evacuation. In the case analyzed here, the operators are unable to perform the normal mitigating operations and the event leads to a full core melt.

- For the purpose of off-site consequences assessment, a single steam generator tube rupture is a typical event associated with containment by-pass events and the related source term. Other possible contributors to the containment by-pass large releases are Raw Cooling Water Heat Exchanger (RCW HX) tube rupture;
- Crash cool down of the steam generators is not available;
- Main feed water to the steam generators is not available, and auxiliary feed water is available for a limited time;
- Moderator cooling is not available;
- End-Shield cooling is not available;
- Emergency Core Cooling system is not available;
- The emergency filter venting system is available, but it has limited impact since the containment is bypassed;
- The power from the grid (Class IV) and diesel generators (Class III) is available, but does not help in this scenario;
- The emergency mitigation equipment fails to provide cooling to the calandria vault; and
- The fuel channels collapse and the calandria vessel fails with molten corium flowing inside the calandria vault.

Since the containment is bypassed, the timing of the release is immediate once the core fails (Figure 8):

- A release pathway occurs immediately, leading to a small release once the fuel bundles are uncovered inside the fuel channels from lack of cooling water at 9 h;

- Core collapse in both Primary Heat Transport System Loops occurs at 18 h, which leads to the bulk of the noble gas release; about ~79 % of the initial inventory of noble gases in the core is released to environment at the end of the simulation; and
- The majority of the release of volatile radionuclides (Cs, Rb and I) occurs a bit later, at around 66 h, when the molten corium-concrete interaction begins in the calandria vault. The total fraction of the initial core inventory for these fission products is about 3.4%.

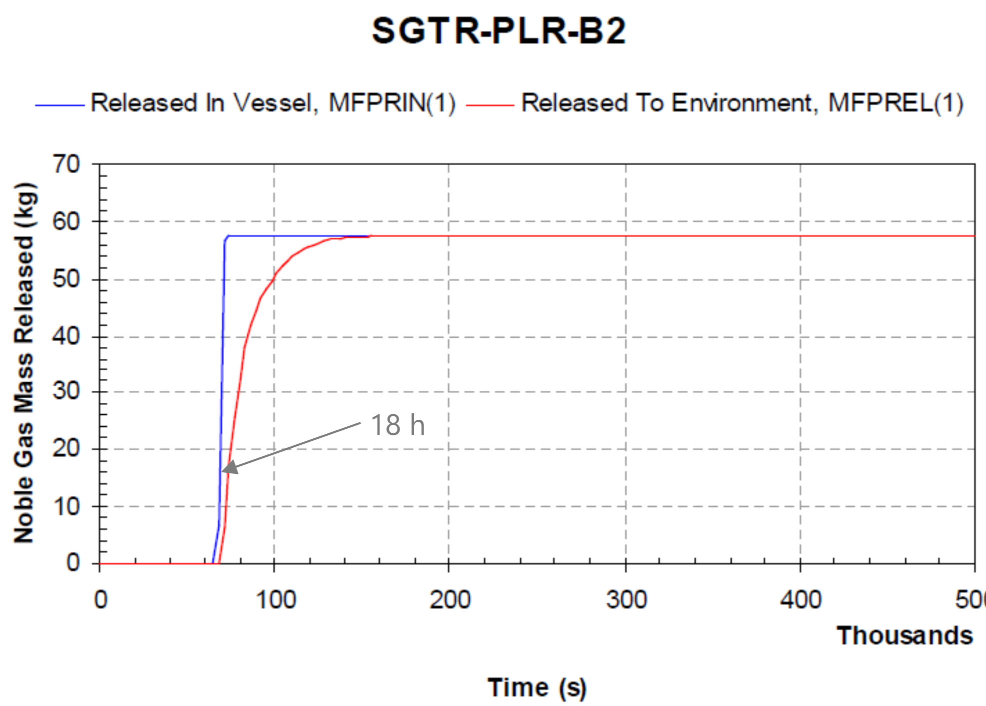


Figure 8: Timing of cumulative release to environment for EPRC4-6

This sequence of events for this third release category corresponds to a Beyond Design Basis Accidents at the more severe end of the scale that leads to unmitigated consequences.

3.4 Site Characteristics

The releases are assumed to originate at ground level and to contain negligible heat and low velocity. The height of the building near the release point is set at 40 m. The cross section of the building is between 3528 m^2 and 5054 m^2. An average value of 4291 m^2 for the cross section of the building is used in the calculations. Dispersion over land assumes grass or forest cover, which is usually described as "mixed rural area" [11].

3.5 Weather

Meteorological data for the PLNGS site for the year 2015 are used for the calculations.

The average weather is used, as recommended by CSA Standard N288.2:19, section 4.2.1 [10]. CSA N288.2:19, section 4.2.1.2.2 suggests that additional dose calculations should be performed with more limiting weather scenarios to confirm the robustness of those calculated using average weather (or Pasquill D). In this report, the 50th, and 90th percentile of the weather scenarios were considered in addition to the average over the weather.

Weather statistics for the Point Lepreau site are obtained from the MetMon application for the meteorological towers at PLNGS. Daily precipitation average data was obtained from Environment Canada for the PLNGS site since those are not provided by MetMon.

Deposition velocity is the default for the code. The mixing height has been set for mid-afternoon, as recommended in CSA Standard N288.2:19 [10].

3.6 Receptor

The representative individuals include receptors for an adult and a 1 y old child. The breathing rate for the adult is 2.66E-04 m^3/s and for the child it is 5.90E-05 m^3/s (Table 2.34 [15].

The sheltering protection factors are applied to sheltered receptors in accordance with N288.2:19 [10].

Table 7: Protection factors applied to sheltered receptors

Exposure Pathway	Protection Factor
Cloudshine	0.6
Groundshine	0.2
Inhalation	0.7

For long term dose assessment (time of residence greater than 7 days), the code MACCS applies an effective protection factor of 0.33 to the dose from groundshine to account for the time spent indoor during normal occupancy of an area that is not under a protective action order.

3.7 Limitations of Dose Calculations

The dose calculations were done in accordance to the CSA Standard N288.2:19 [10]. As discussed in Clause 6.1.4 of the Standard, “The accuracy of the Gaussian model limits its application for calculation of individual dose to distances less than 50 km”, and in Clause 7.2.6 “Local atmospheric dispersion models should not be used for calculating the dose to the representative individual at distances greater than 50 km, as the models have limited accuracy beyond 20 km and are unreliable beyond 50 km." The reason the models used for calculating the dose become unreliable at large distances is based on empirical evidence from past severe accidents, and on theoretical reasons.

The contamination pattern observed after the accident of Fukushima is shown in Figure 9. The contamination pattern beyond about 50 km (in blue and dark brown on the map) is not well represented by a simple Gaussian plume model. Maps of ground contamination at Chernobyl and Three Mile Island show similar patterns.

The models used to calculate the dose assume that the meteorological data from the on-site meteorological tower is representative of the weather for the whole region around the site. In fact, the wind direction, and critically, the precipitations are non-uniform in the region around the site. Topography (ocean, lake, hills, and mountains) can affect the local wind direction. In addition, the plume is carried by the wind at relatively low speed (10 – 20 km/h). After the plume has travelled 50 km, 2.5 to 5 hours have elapsed, and there is a high likelihood that meteorological conditions have changed. There is no theoretical model that can represent this complex situation at the planning and simulation stage, well before a potential accident takes place.

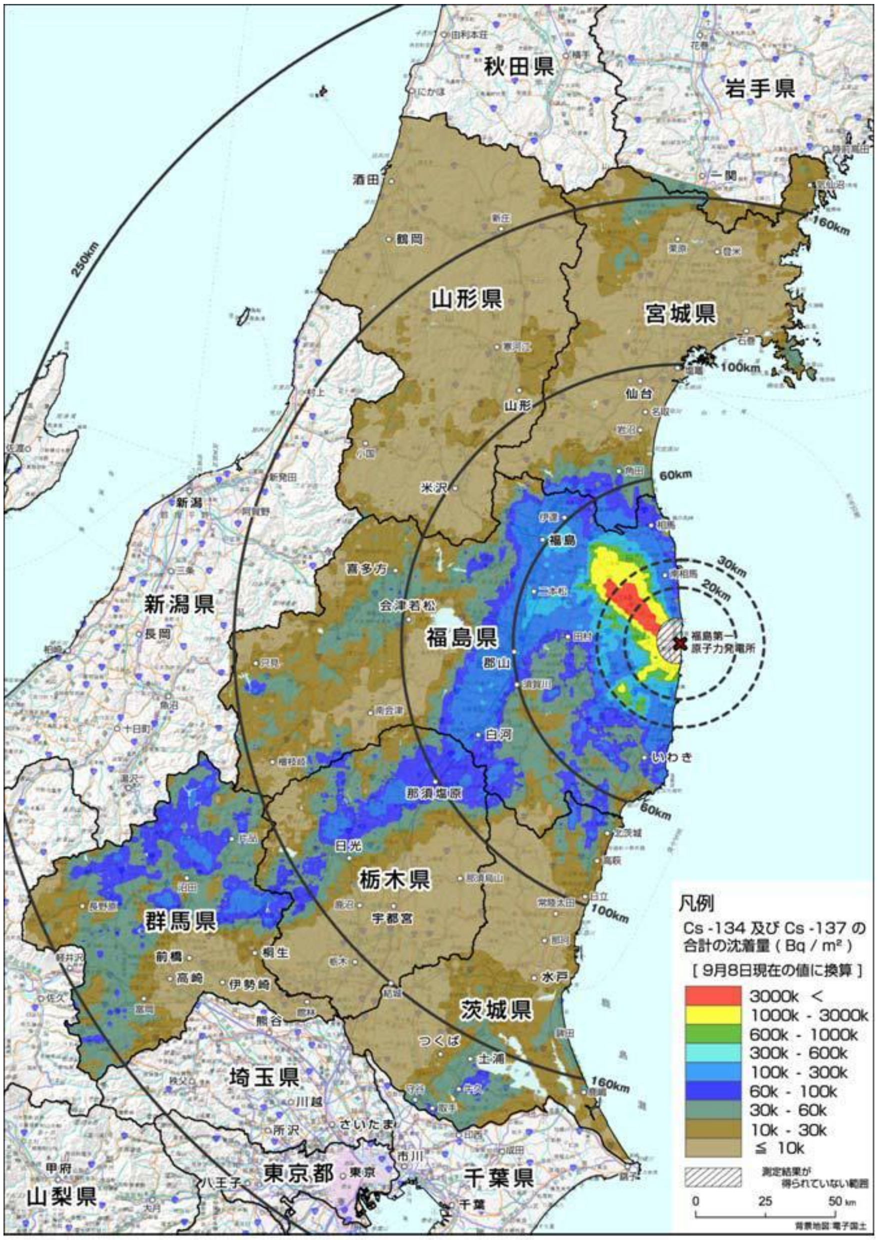


Figure 9: Ground contamination pattern at Fukushima [16]

3.8 Modeling and Assumptions

The consequence calculations are performed with MACCS2 (MELCOR Accident Consequence Code Systems), a code developed and distributed by US-NRC [16]. MACCS2 models the radioactive release to the atmosphere of nuclear power plant accidents and calculates the dose and health effect consequences for the public. MACCS2 meets the requirements of CSA Standard N288.2:19 and is therefore a recognised code for this type of calculation.

A statistical sampling of the dose consequences as a function of the weather scenario was performed by using the probability meteorological sampling function in MACCS2. This function presents results of the dose as a function of distance for the average over all weather scenarios, and for different percentile levels. A percentile is the percent of the trials (each trial is a weather scenarios) that produce consequences lower than the presented value.

For the planning basis, the average, 50th percentile, and 90th percentile are presented. The dose vs distance curves corresponding to the 90th percentile bound the dose consequences for 90th percent of all the weather scenarios. It is therefore a conservative assessment of the dose consequences during a hypothetical accident.

When comparing the results of this calculation with those of the PLNGS Planning Basis from 2004 [9], which used the COSYMA code, it must be recognized that MACCS2 calculates the percentile of the weather scenarios differently than COSYMA. COSYMA includes in the percentile calculation all the sectors, including those that are not affected by the plume, while MACCS2 only includes the sector downwind from the release. Depending on the dose being calculated, the 90th to 99th percentile in the current MACCS2 calculations is equivalent to the 99.9th percentile in the previous COSYMA calculations.

As discussed in Section 3.7, results beyond 50 km from modelling software are unreliable, and have limited accuracy beyond 20 km. Therefore, for all graphs presented in this report, the results are shown up to 50 km. Additionally, the dose curves use a dashed line past 20 km to indicate the limited accuracy of the results beyond 20 km.

3.9 Zone Size Determination

The zone size where protective actions may be required is obtained by calculating the distance where the intervention level for a protective action is exceeded for a range of accidents.

The Automatic Action Zone size is based on the maximum distance where fatalities due to deterministic health effects are expected for any of the release categories (EPRC3a, EPRC0, EPRC3, and EPRC4-6). In order to substantially reduce the risk of severe deterministic health effects, the 95th percentile over all weather scenarios is used to calculate the distance. Cases 1 to 4 in Table 8 are used for this calculation.

The Detailed Planning Zone requires consideration of urgent protective actions for release categories representative of Design Basis Accidents (EPRC3a), and the less severe Beyond Design Basis Accident (EPRC0). Separate calculations are performed for:

- Evacuation;
- Sheltering in place; and
- Thyroid blocking.

Cases 5 to 10 in Table 8 form the basis of the zone size calculation. The size of the Detailed Planning Zone is based on consideration of the distance where the intervention level for each urgent protective action is exceeded, but more weight is given to evacuation and thyroid blocking because these protective actions require more preparedness in terms of location of emergency facilities and distribution of iodine tablets.

The Contingency Planning Zone considers the same protective actions, except that the more severe Beyond Design Basis Accidents (EPRC3 and EPRC4-6) are used for the assessment. Cases 11 to 16 in Table 8 are used for this calculation.

Another set of calculations was performed for Relocation, a longer-term protective action. Cases 17 to 20 in Table 8 are used for this calculation.

The ingestion planning distance uses the dose accumulated within the first 30 days after the release phase ended. Cases 21 to 24 in Table 8 are used for this calculation.

3.10 Calculation Case Matrix

Table 8 shows a summary of the calculations performed for this planning basis document.

Table 8: Calculations performed for calculating zone sizes based on the New Brunswick protective action levels

#	Relevant Zone	Purpose	Release Category	Exposure Time	Criterion	Dose	Calculation
1	Automatic Action	Early Fatalities	EPRC0	n/a	n/a	n/a	PLGS001
2	Automatic Action	Early Fatalities	EPRC3	n/a	n/a	n/a	PLGS002
3	Automatic Action	Early Fatalities	EPRC3a	n/a	n/a	n/a	PLGS003
4	Automatic Action	Early Fatalities	EPRC4-6	n/a	n/a	n/a	PLGS004
5	Detailed Planning	Evacuation	EPRC0	7 days	100 mSv	Projected dose	PLGS013
6	Detailed Planning	Evacuation	EPRC3a	7 days	100 mSv	Projected dose	PLGS015
7	Detailed Planning	Sheltering	EPRC0	2 days	10 mSv	Averted dose	PLGS005
8	Detailed Planning	Sheltering	EPRC3a	2 days	10 mSv	Averted dose	PLGS007
9	Detailed Planning	KI	EPRC0*	7 days	50 mSv	Averted dose	PLGS017
10	Detailed Planning	KI	EPRC3a*	7 days	50 mSv	Averted dose	PLGS019
11	Contingency Planning	Evacuation	EPRC3	7 days	100 mSv	Projected dose	PLGS014
12	Contingency Planning	Evacuation	EPRC4-6	7 days	100 mSv	Projected dose	PLGS016
13	Contingency Planning	Sheltering	EPRC3	2 days	10 mSv	Averted dose	PLGS006
14	Contingency Planning	Sheltering	EPRC4-6	2 days	10 mSv	Averted dose	PLGS008
15	Contingency Planning	KI	EPRC3*	7 days	50 mSv	Averted dose	PLGS018
16	Contingency Planning	KI	EPRC4-6*	7 days	50 mSv	Averted dose	PLGS020
17	n/a	Relocation	EPRC0	365 days	100 mSv	Projected dose	PLGS001
18	n/a	Relocation	EPRC3	365 days	100 mSv	Projected dose	PLGS002
19	n/a	Relocation	EPRC3a	365 days	100 mSv	Projected dose	PLGS003
20	n/a	Relocation	EPRC4-6	365 days	100 mSv	Projected dose	PLGS004
21	n/a	Ingestion	EPRC0	30 days	0.72 mSv	Projected dose	PLGS013
22	n/a	Ingestion	EPRC3	30 days	0.72 mSv	Projected dose	PLGS014

#	Relevant Zone	Purpose	Release Category	Exposure Time	Criterion	Dose	Calculation
23	n/a	Ingestion	EPRC3a	30 days	0.72 mSv	Projected dose	PLGS015
24	n/a	Ingestion	EPRC4-6	30 days	0.72 mSv	Projected dose	PLGS016

* Note: The source term for the calculation of the dose to the thyroid includes only Iodine, Sb and Te (parents of iodine)

4. RESULTS

The assessment of the zone sizes and distances presented in this section is based on the current New Brunswick emergency intervention levels.

4.1 Automatic Action Zone

As described in Section 3.2.1, the Automatic Action Zone size corresponds to the distance where severe deterministic health effects (fatalities from acute exposure) could occur for the average person. The receptors are assumed to carry on with their normal activities for seven days.

For each of the release categories, the distance where the probability of fatalities from acute health effects becomes less than 1% for the 95th percentile of the weather scenarios is presented in Table 9. The graphs showing the probabilities of deterministic health effects are presented in Figure 10.

Table 9: Distance where the risk of fatalities from acute health effects becomes negligible

Scenario	Distance (km)	
	Adult	Infant
EPRC 3a	N/A	N/A
EPRC 0	2.1	2.1
EPRC 3	3.3	3.5
EPRC 4-6	3.5	3.7

It should be noted that for accident scenarios using the emergency venting system, there are no acute health effects. This result is representative of all Design Basis Accidents.

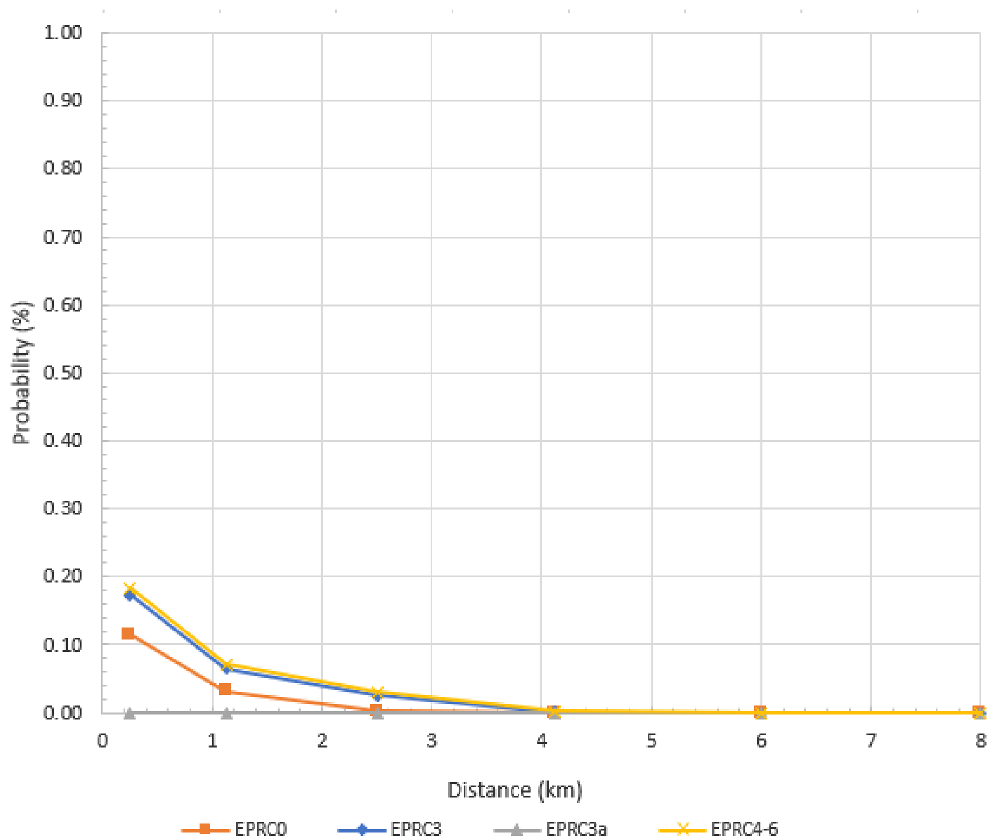


Figure 10: Probability of infant acute health effects as a function of distance

An immediate precautionary evacuation up to a distance of about 4 km would prevent most of the risk of severe deterministic health effects during a severe accident.

As a consequence, the off-site emergency plans should include the capability to alert residents of the need to promptly evacuate within 4 km of the reactor building, upon declaration of a general emergency.

4.2 Detailed Planning Zone

The Detailed Planning Zone is where urgent protective actions are required in order to avert a dose in accordance with the appropriate reference level.

The Detailed Planning Zone includes distances for planning evacuation, sheltering, and thyroid blocking. The accidents considered in the assessment include a mitigated severe accident which consequences representative of Design Basis Accidents, and a Beyond Design Basis Accident.

4.2.1 Evacuation

The quantity of interest for comparison with the current New Brunswick evacuation intervention level is the projected dose over seven (7) days.

The distance where the intervention level for evacuation (100 mSv) is exceeded is shown in Table 10. Figure 11 and Figure 12 show the effective dose as a function of distance for the two selected release categories.

Table 10: Distance where the intervention level for evacuation is exceeded

Scenario	Percentile of weather scenarios	Distance (km)	
		Adult	Infant
EPRC 3a	Average	N/A	0.3
	50th	N/A	N/A
	90th	0.6	1.0
EPRC 0	Average	7.5	8.4
	50th	5.5	6.3
	90th	10.8	12.0

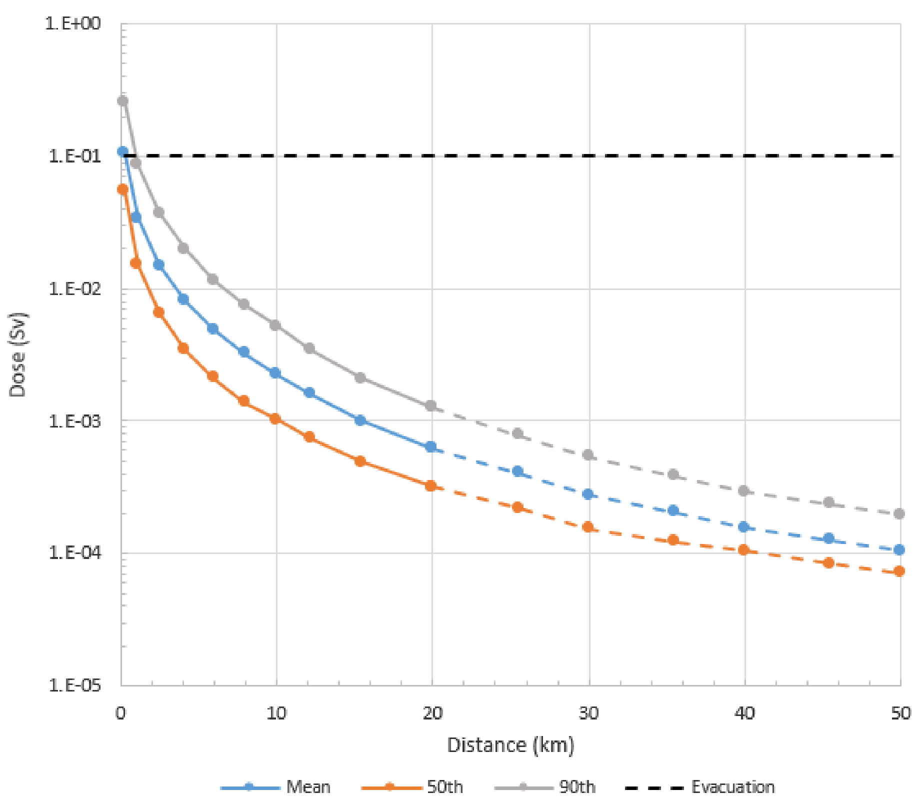


Figure 11: Infant effective dose for 7 days of exposure for EPRC3a

For EPRC3a, which is a mitigated severe accident representative of the consequences of a Design Basis Accident, the evacuation distance barely exceeds the exclusion boundary of the PLNGS site.

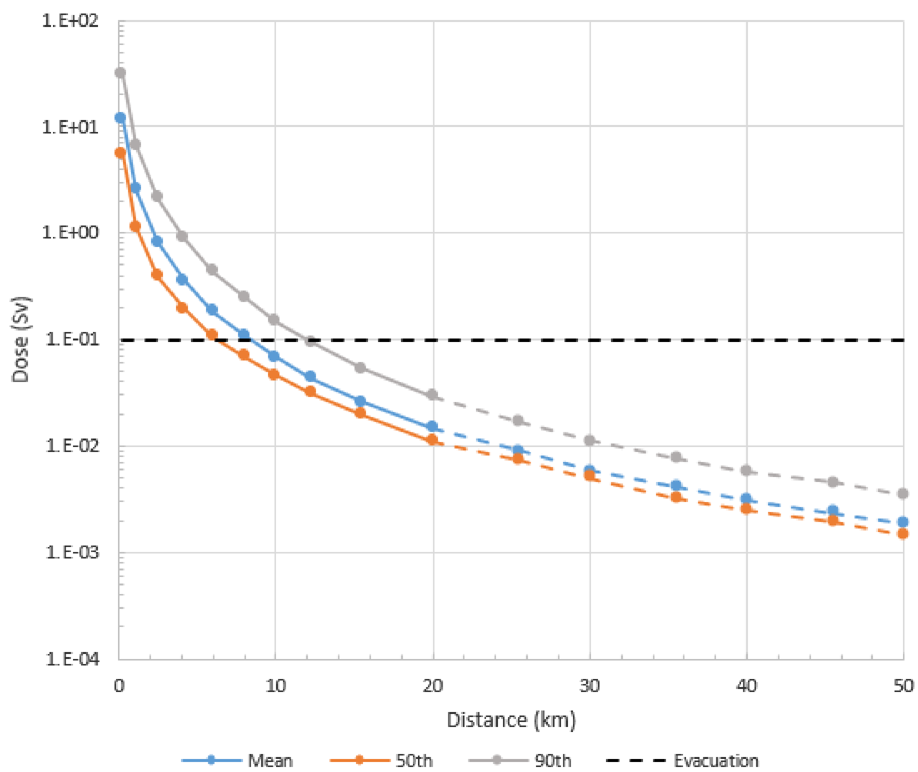


Figure 12: Infant effective dose for 7 days of exposure for EPRC0

For EPCR0, which is a Beyond Design Basis Accident, the distance at which the evacuation intervention level is exceeded is about 12 km at the 90th percentile of the bounding weather scenarios.

The results of this calculation show that reception centres for evacuees and off-site emergency operation centres should be located further than 12 km.

4.2.2 Sheltering

The sheltering intervention level proposed by Health Canada is 10 mSv, based on the averted dose received over two days.

The distance where the intervention level for sheltering is exceeded is shown in Table 11. Figure 13 and Figure 14 show the effective dose as a function of distance for the two selected release categories.

Table 11: Distance where the intervention level for sheltering is exceeded

Scenario	Percentile of weather scenarios	Distance (km)	
		Adult	Infant
EPRC 3a	Average	1.2	2.2
	50th	0.6	1.0
	90th	2.9	4.5
EPRC 0	Average	14.9	16.6
	50th	12.1	14.0
	90th	20.0	22.9

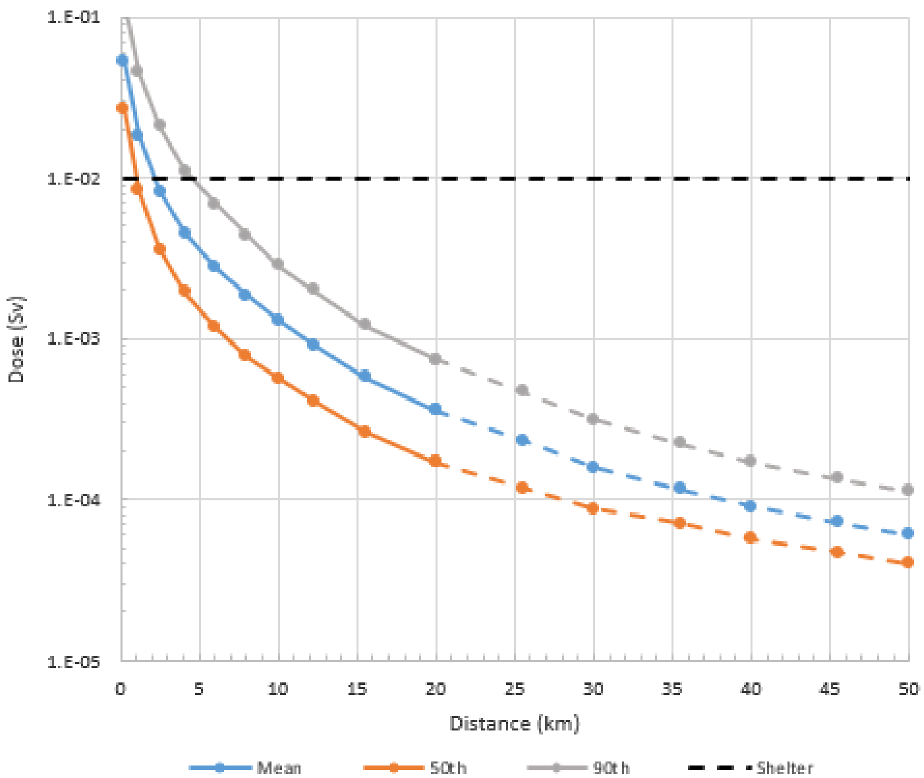


Figure 13: Infant effective dose for 2 days of exposure for EPRC3a

For EPRC3a, a mitigated severe accident representative of the consequences of a Design Basis Accident, the sheltering distance extends to about 5 km at the 90th percentile of the weather scenarios.

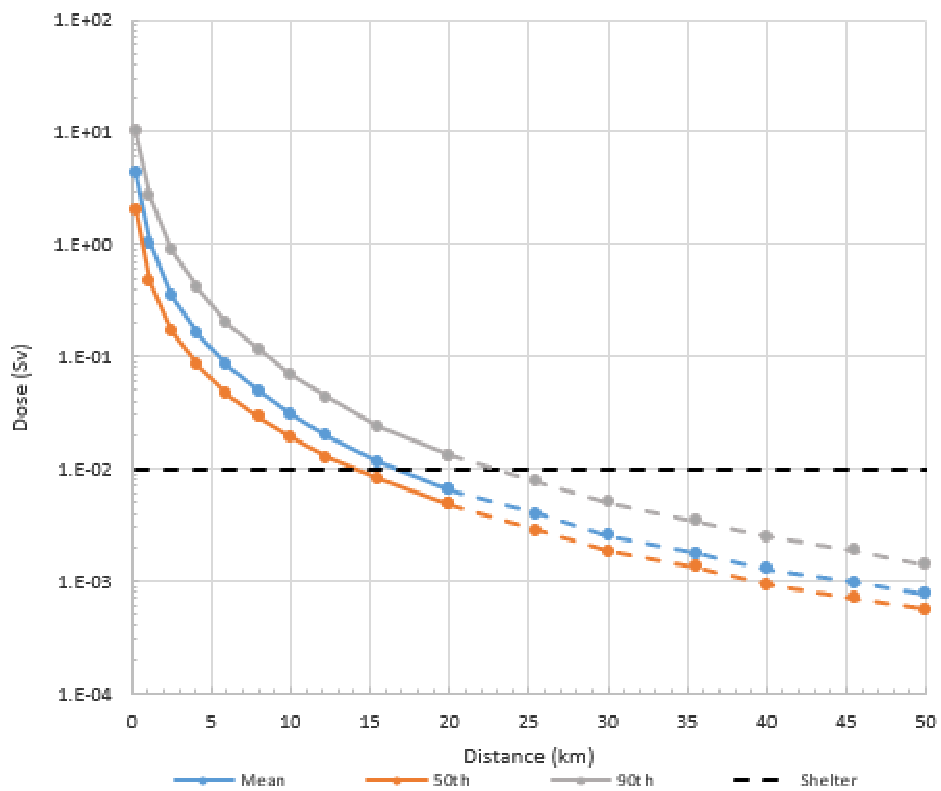


Figure 14: Infant effective dose for 2 days of exposure for EPRC0

For EPRC0, representative of Beyond Design Basis Accidents, the sheltering distance is about 17 km for the average over all weather scenarios, and 23 km at the 90th percentile.

These results show that plans for sheltering in place could potentially extend to about 23 km.

4.2.3 Thyroid blocking

The intervention level for thyroid blocking is 50 mSv equivalent dose to the thyroid expressed as dose averted over 7 days. This can be calculated by limiting the source term to iodine (I), Antimony (Sb), and Tellurium (Te), which are parents in a decay chain that creates iodine and including only the thyroid dose from the inhalation pathway.

The distance where the intervention level for thyroid blocking is exceeded is shown in Table 12. Figure 15 and Figure 16 show the equivalent dose to the thyroid as a function of distance for the two selected release categories.

Table 12: Distance where the intervention level for thyroid blocking is exceeded

Scenario	Percentile of weather scenarios	Distance (km)	
		Adult	Infant
EPRC 3a	Average	1.4	2.3
	50th	0.8	1.2
	90th	2.6	3.8
EPRC 0	Average	8.1	11.9
	50th	6.5	10.4
	90th	11.4	16.8

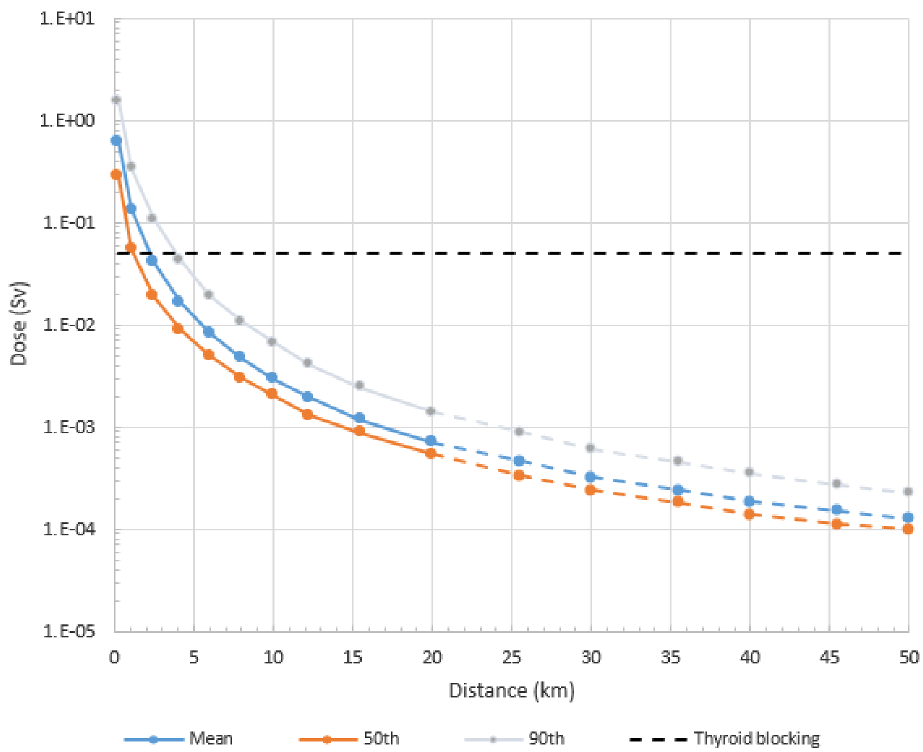


Figure 15: Infant equivalent dose to thyroid for inhalation of iodine for EPRC3a

For EPRC3a, a mitigated severe accident representative of the consequences of Design Basis Accidents, the distance where the thyroid blocking intervention level is exceeded is about 4 km at the 90th percentile of the weather scenarios.

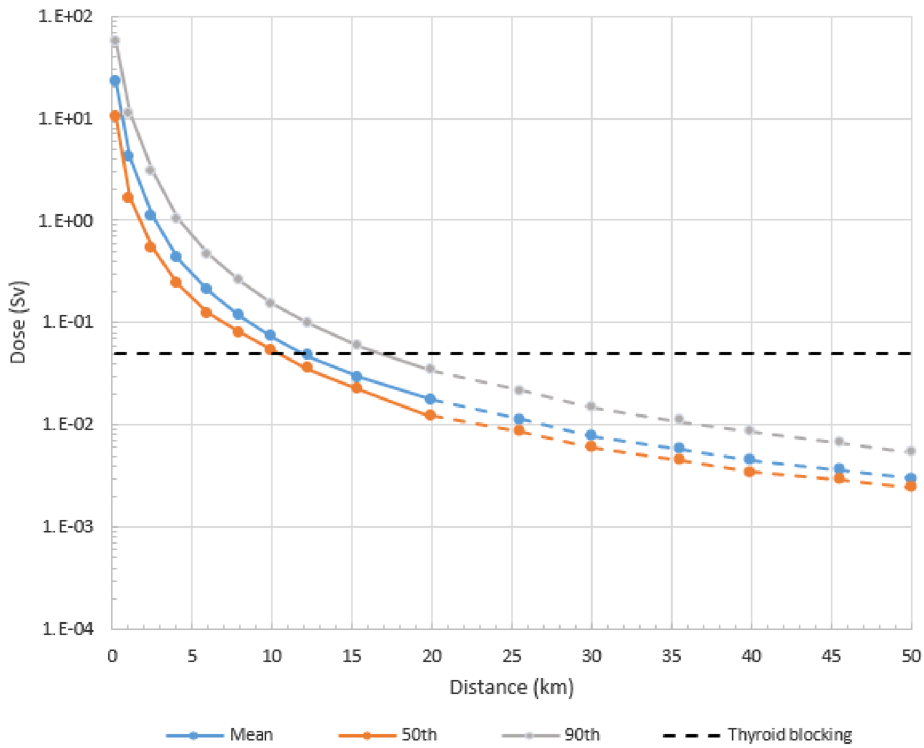


Figure 16: Infant equivalent dose to thyroid for inhalation of iodine for EPRC0

For EPRC0, a Beyond Design Basis Accident, the distance where the intervention level is exceeded is about 17 km at the 90th percentile of the weather scenarios.

Under the current New Brunswick intervention levels for thyroid blocking, the detailed plans for the distribution of KI tablets to a distance of about 17 km would be justified.

4.3 Contingency Planning Zone

The Contingency Planning Zone is where protective actions would be justified to reduce the risk of stochastic health effects on the basis of monitoring and assessment of the radiological situation following a significant release of radioactive material.

The Contingency Planning Zone is an area surrounding a reactor facility (beyond the Detailed Planning Zone), where contingency planning and arrangements are made in advance. Such proactive planning ensures that during a nuclear emergency, protective actions can be extended beyond the Detailed Planning Zone, as required, to reduce potential for exposure.

For the more severe Beyond Design Basis Accidents, urgent protective actions such as evacuation, sheltering, and thyroid blocking could be justified beyond the distances calculated for the Detailed Planning Zone, on the basis of radiological measurements taken at the point of release, and off-site. In particular, measurements compared with Operational Intervention Levels should be used as a trigger to initiate additional protective actions.

4.3.1 Evacuation

The distance where the current intervention level for evacuation is exceeded for the two release categories considered is shown in Table 13. Figure 17 and Figure 18 show the effective dose over seven days as a function of distance for the two selected release categories.

Table 13: Distance where the intervention level for evacuation is exceeded

Scenario	Percentile of weather scenarios	Distance (km)	
		Adult	Infant
EPRC 3	Average	11.7	13.0
	50th	10.3	11.2
	90th	16.5	18.2
EPRC 4-6	Average	11.9	13.9
	50th	10.4	12.4
	90th	16.9	19.4

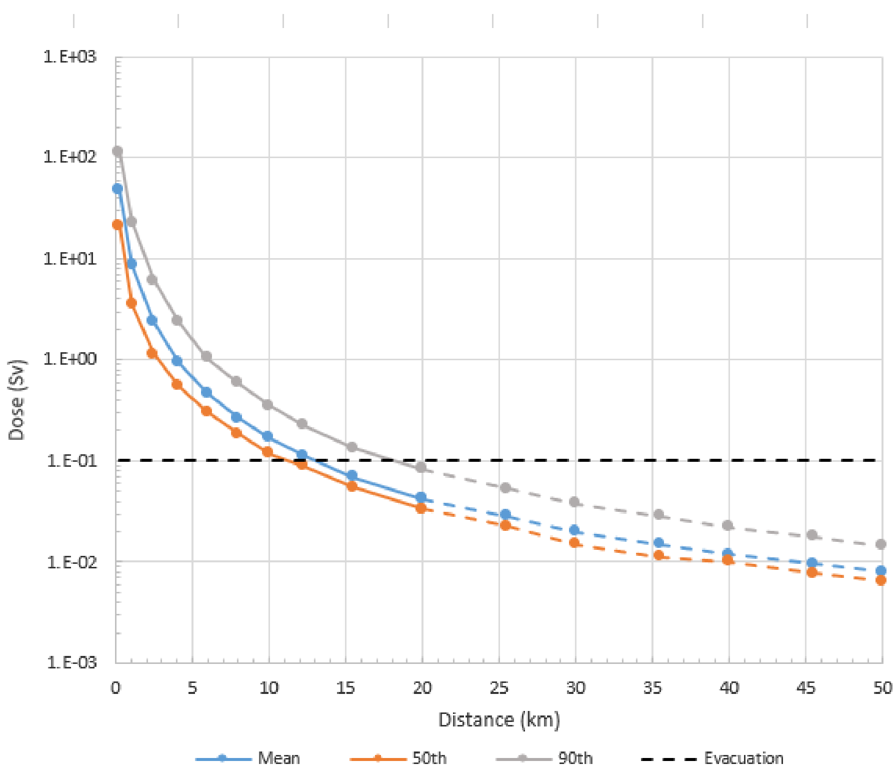


Figure 17: Infant effective dose for 7 days of exposure for EPRC3

For EPRC3, a severe Beyond Design Basis Accident, the distance where the evacuation intervention level is exceeded is about 18 km at the 90th percentile of the weather scenarios.

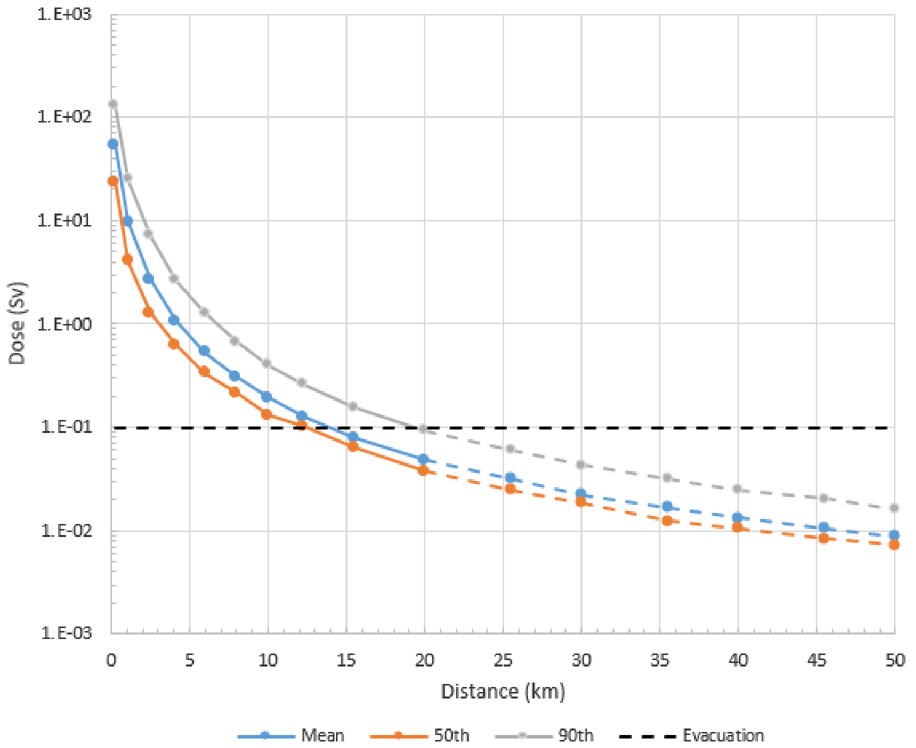


Figure 18: Infant effective dose for 7 days of exposure for EPRC4-6

For EPRC4-6, a severe Beyond Design Basis Accident, the distance at which the evacuation intervention level is exceeded is about 19 km at the 90th percentile of the weather scenarios.

If the reception centres and emergency operation centres are located just outside the Detailed Planning Zone and within 19 km, this calculation shows that they may have to be relocated in extreme conditions.

4.3.2 Sheltering

The current sheltering intervention levels is 10 mSv, expressed as the dose averted by the protective action over two days.

The distance where the current intervention level for sheltering is exceeded is shown in Table 14. Figure 19 and Figure 20 show the effective dose as a function of distance for the two selected release categories.

Table 14: Distance where the intervention level for sheltering is exceeded

Scenario	Percentile of weather scenarios	Distance (km)	
		Adult	Infant
EPRC 3	Average	18.3	20.3
	50th	15.5	17.2
	90th	26.3	28.9
EPRC 4-6	Average	17.4	22.3
	50th	14.8	18.6
	90th	24.9	30.5

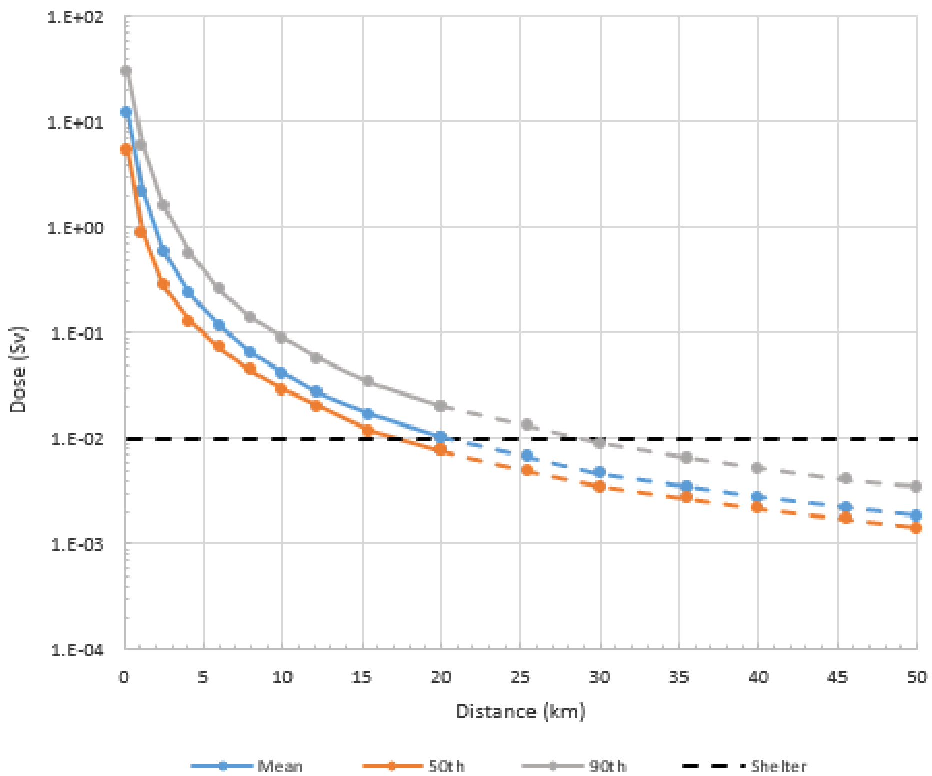


Figure 19: Infant effective dose for 2 days of exposure for EPRC3

For EPRC3, representative of a severe Beyond Design Basis Accident, the sheltering distance is about 20 km for the average over all weather scenarios, and 29 km at the 90th percentile.

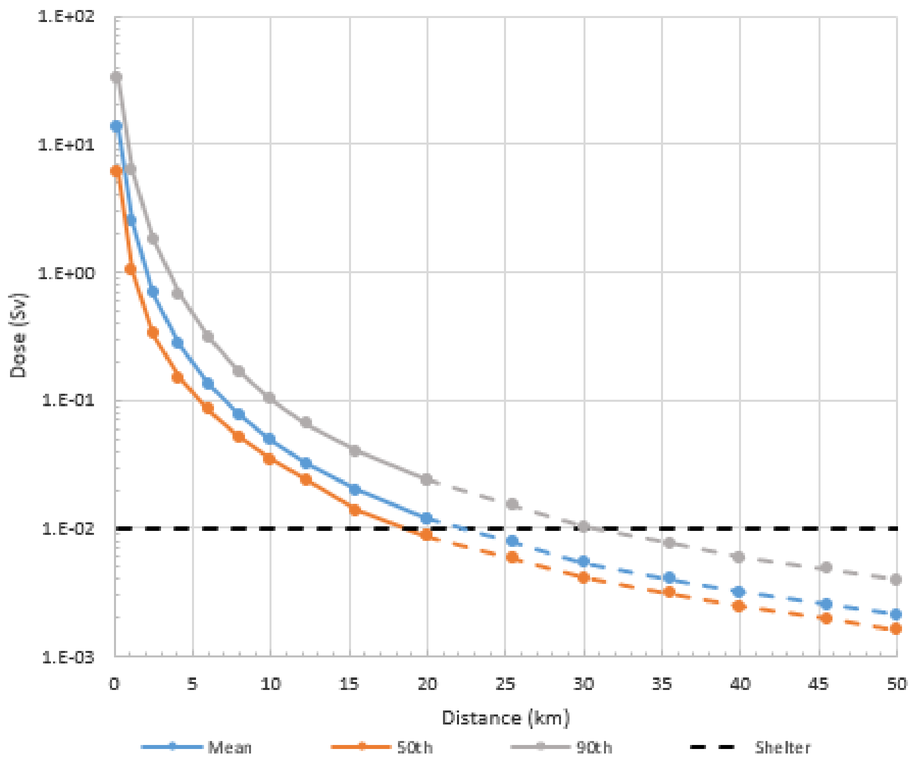


Figure 20: Infant effective dose for 2 days of exposure for EPRC4-6

For EPRC4-6, representative of a severe Beyond Design Basis Accident, the sheltering distance is about 22 km for the average over all weather scenarios, and 31 km at the 90th percentile.

Contingency plans should be in place to verify conditions on the ground by taking radiological measurements within 31 km from the plant and comparing them to the Operational Intervention Level for sheltering. There should be plans to extend sheltering in place beyond distances already implemented, if the measurements exceed the Operational Intervention Levels. Emergency operation centres that are located within 31 km need to provide substantial sheltering.

4.3.3 Thyroid Blocking

The current intervention level for thyroid blocking is 50 mSv equivalent dose to the thyroid.

The distance where the intervention level for thyroid blocking is exceeded is shown in Table 15. Figure 21 and Figure 22 show the effective dose as a function of distance for the two selected release categories.

Table 15: Distance where the intervention level for thyroid blocking is exceeded

Scenario	Percentile of weather scenarios	Distance (km)	
		Adult	Infant
EPRC 3	Average	22.5	32.7
	50th	19.2	28.4
	90th	31.2	45.5
EPRC 4-6	Average	25.8	38.3
	50th	21.9	33.6
	90th	35.4	52.5

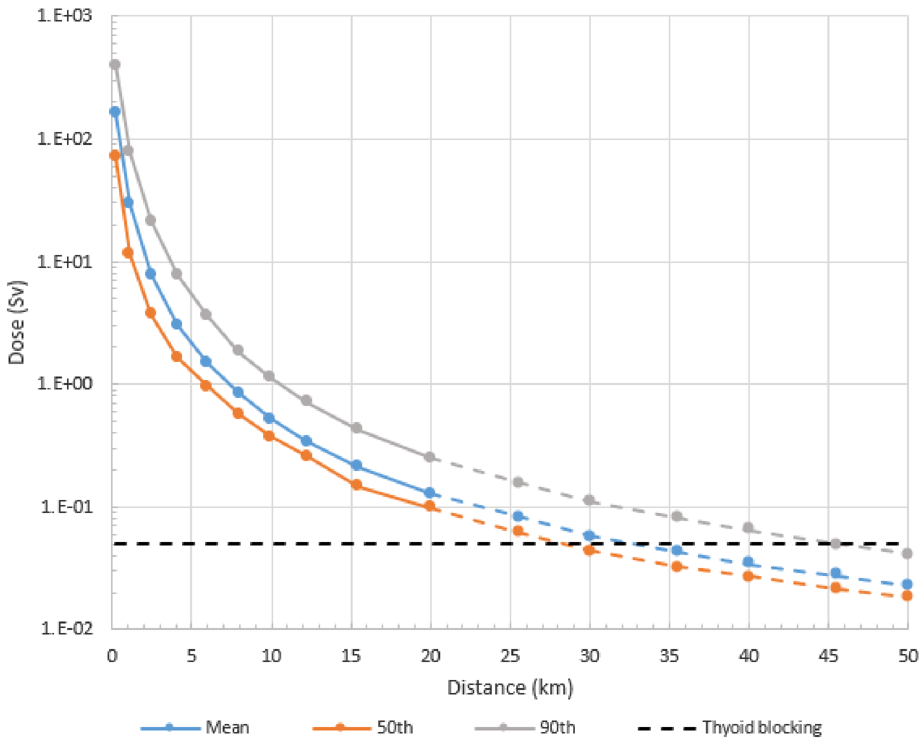


Figure 21: Infant equivalent dose to thyroid for inhalation of iodine for EPRC3

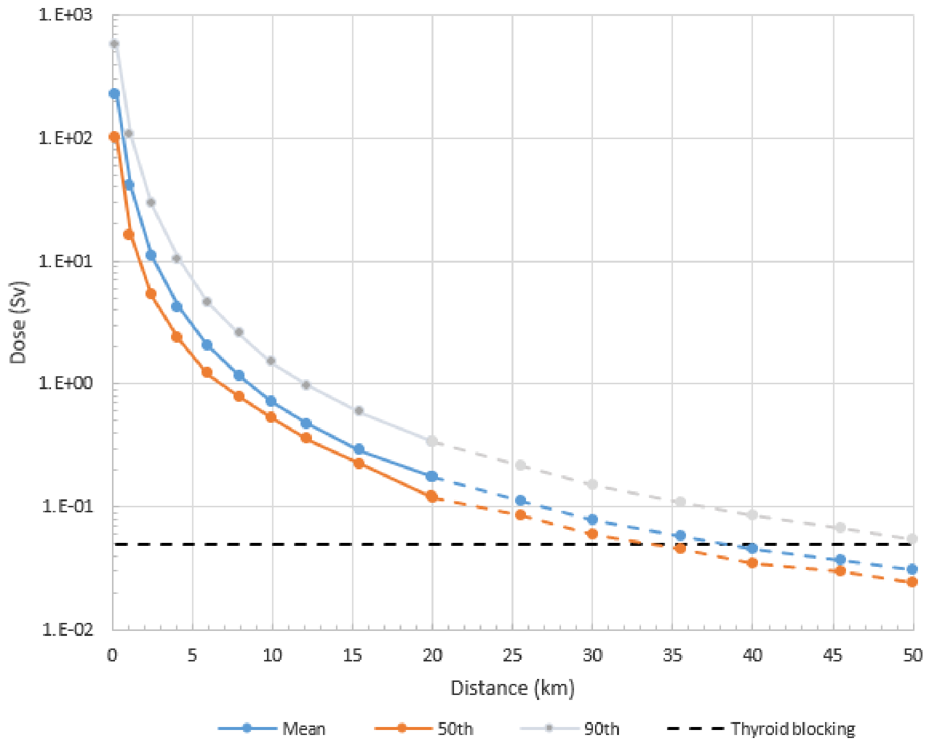


Figure 22: Infant equivalent dose to thyroid for inhalation of iodine for EPRC4-6

EPRC3 and EPRC4-6 represent severe Beyond Design Basis Accidents, and the results show that the distance where the intervention level is exceeded is about 33 - 38 km for average over all weather scenarios, and 46 – 53 km at the 90th percentile of the weather scenarios.

With an intervention level for thyroid blocking of 50 mSv, contingency plans for the distribution of KI tablets to a distance of about 53 km would be justified.

4.4 Ingestion Planning Zone

As discussed in Section 3.2.4, the Ingestion Planning Zone criterion is based on the dose rate exceeding the Operational Intervention Level of 1 µSv/h following the release; this equates to a dose of 0.72 mSv over one month of exposure to ground shine. Note that the ground shine dose calculated by MACCS includes the long-term residency shielding factor LGSHFAC = 0.33. This factor was undone to obtain the raw dose from ground shine.

The distance where the intervention level for ingestion is exceeded is shown in Table 16. Figure 23 and Figure 24 show the effective dose as a function of distance for the two selected release categories.

Table 16: Distance where the ingestion monitoring criterion is exceeded

Scenario	Percentile of weather scenarios	Distance (km)	
		Adult	Infant
EPRC 3a	Average	4.4	5.0
	50th	3.4	3.9
	90th	6.7	7.5
EPRC 0	Average	34.9	38.7
	50th	30.1	34.2
	90th	50.4	56.6

For EPRC3a, a mitigated severe accident representative of the consequences of Design Basis Accidents, the Ingestion Planning Zone extends to 7.5 km for the 90th percentile. For EPRC0, a Beyond Design Basis Accident, the Ingestion Planning Zone is about 39 km for the average over all weather scenarios, and 57 km for the 90th percentile.

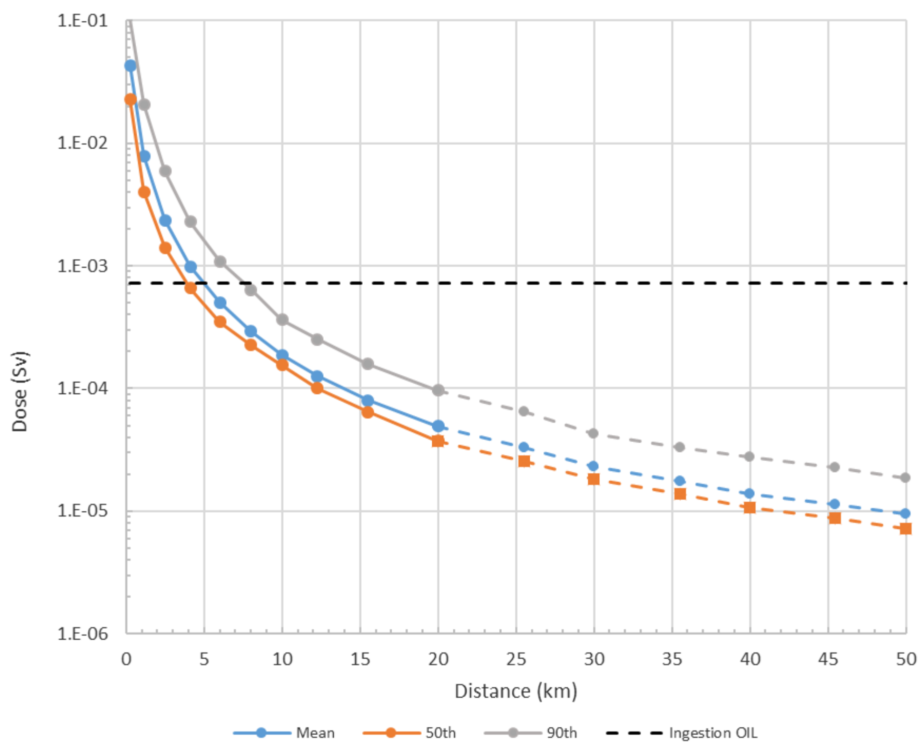


Figure 23: Infant effective ground dose over 30 days for EPRC3a

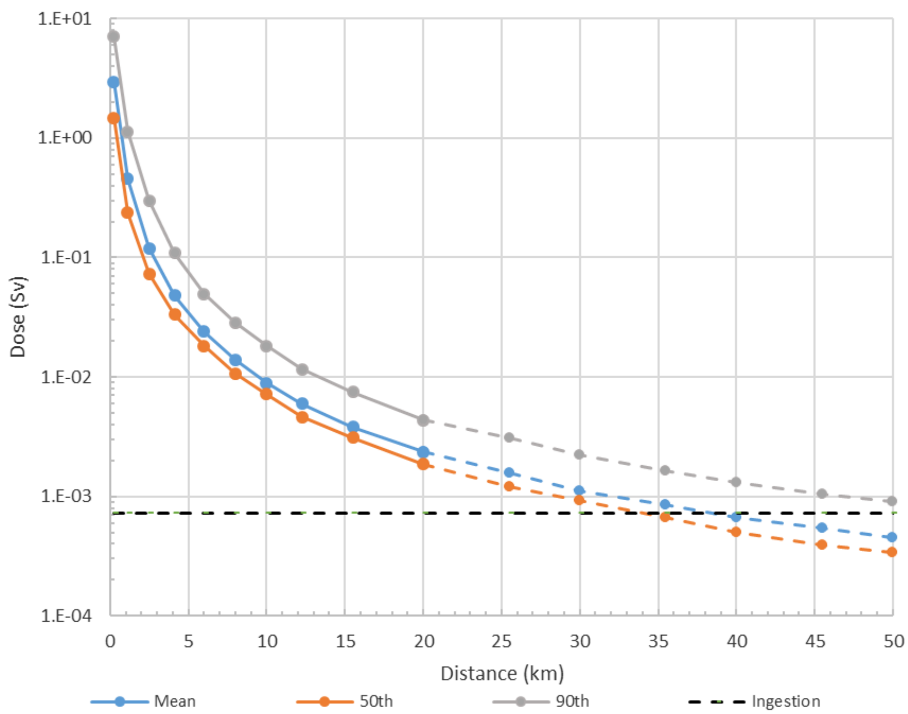


Figure 24: Infant effective ground dose over 30 days for EPRC0

4.5 Additional Considerations

Calculations were also performed to estimate the distances where relocation might be required based on the criterion currently defined in New Brunswick.

4.5.1 Relocation

Temporary relocation is the non-urgent removal of people in order to avoid longer term exposure from radioactive material deposited on the ground. The current dose intervention level for temporary relocation of the population is 100 mSv in the first year following an accident.

The distance where the intervention level for temporary relocation is exceeded is shown in Table 17. Figure 25 and Figure 26 show the effective dose integrated over 1 year as a function of distance for the two selected release categories.

Table 17: Distance where the current intervention level for temporary relocation is exceeded

Scenario	Percentile of weather scenarios	Distance (km)	
		Adult	Infant
EPRC 3a	Average	N/A	N/A
	50th	N/A	N/A
	90th	N/A	N/A
EPRC 0	Average	2.5	2.9
	50th	1.9	2.2
	90th	4.0	4.4

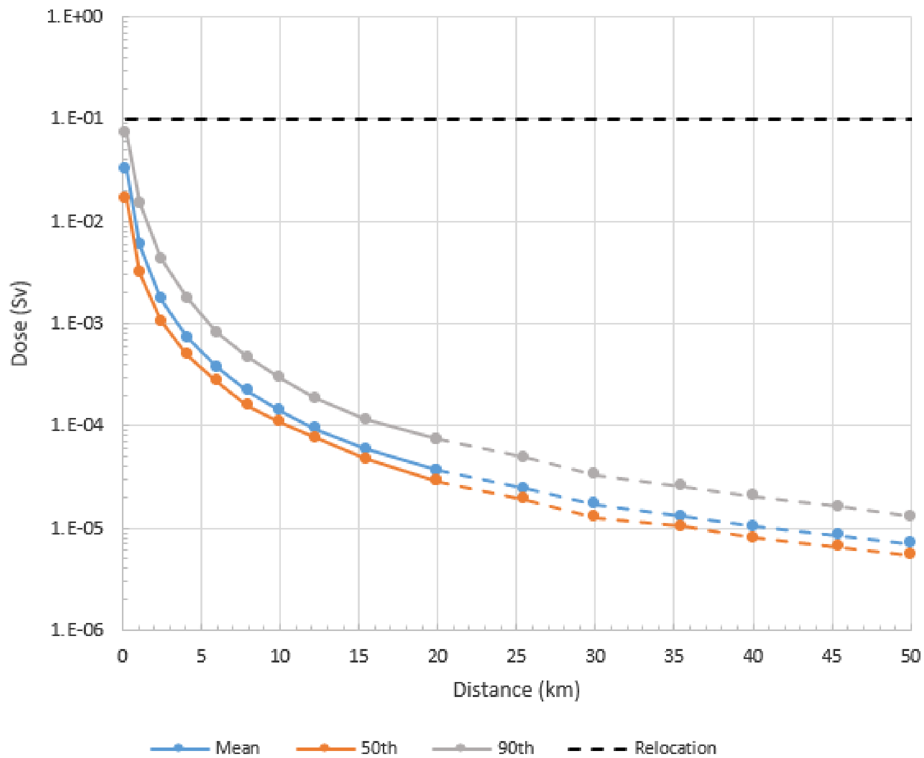


Figure 25: Infant effective dose over 1 year for EPRC3a

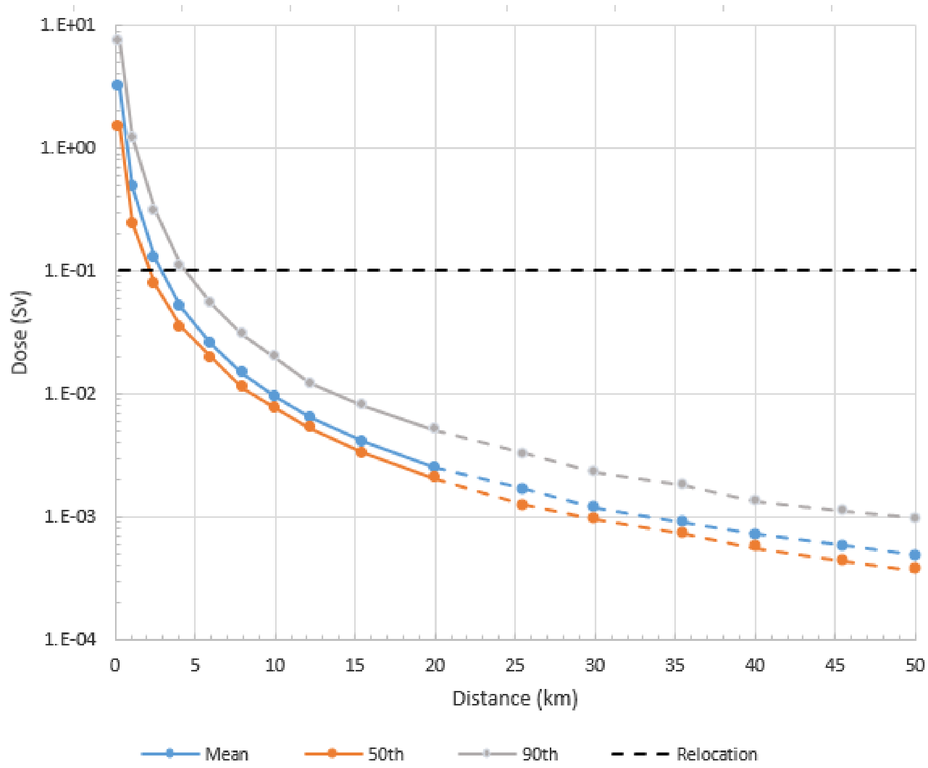


Figure 26: Infant effective dose over 1 year for EPRC0

For EPRC0, a Beyond Design Basis Accident, temporary location could be required up to a distance of about 4 km. For Design Basis Accidents, the evacuation distance barely exceeds the exclusion boundary of the PLNGS site.

5. SUMMARY OF PLANNING ZONES DISTANCES

The summary of the planning zones calculated in Section 4 is presented in Table 18 for the current New Brunswick intervention levels.

The size of the Detailed Planning Zone takes into consideration the distance at which the urgent protective actions that require advanced planning and preparedness (evacuation and thyroid blocking) are exceeded. Considering that the evacuation and thyroid blocking distances are 12 km and 17 km respectively, and the sheltering distance extends up to 23 km, an overall detailed planning distance of 20 km is reasonable.

The size of the Contingency Planning Zone is also based on the projected dose for the urgent protective actions that require advanced planning and preparedness. An overall contingency planning distance of 50 km covers the distances for evacuation, sheltering, and thyroid blocking.

Table 18: Summary of planning zone distances for the current New Brunswick intervention levels

Automatic Action Zone	
Early fatalities	*4 km*
Overall planning distance	**4 km**
Detailed Planning Zone	
Evacuation	*8 – 12 km*
Sheltering	*17 – 23 km*
Thyroid Blocking	*12 – 17 km*
Overall planning distance	**20 km**
Contingency Planning Zone	
Evacuation	*14 – 19 km*
Sheltering	*22 – 31 km*
Thyroid Blocking	*38 – 53 km*
Overall planning distance	**50 km**
Ingestion Planning Zone	
Overall planning distance	**57 km**
Relocation Distance	
Overall planning distance	**4 km**

A map showing the Automatic Action Zone, Detailed Planning Zone, and Contingency Planning Zone can be seen in Figure 27.

For reference, a map showing critical infrastructure around the PLNGS site is presented in Figure 28 [7].

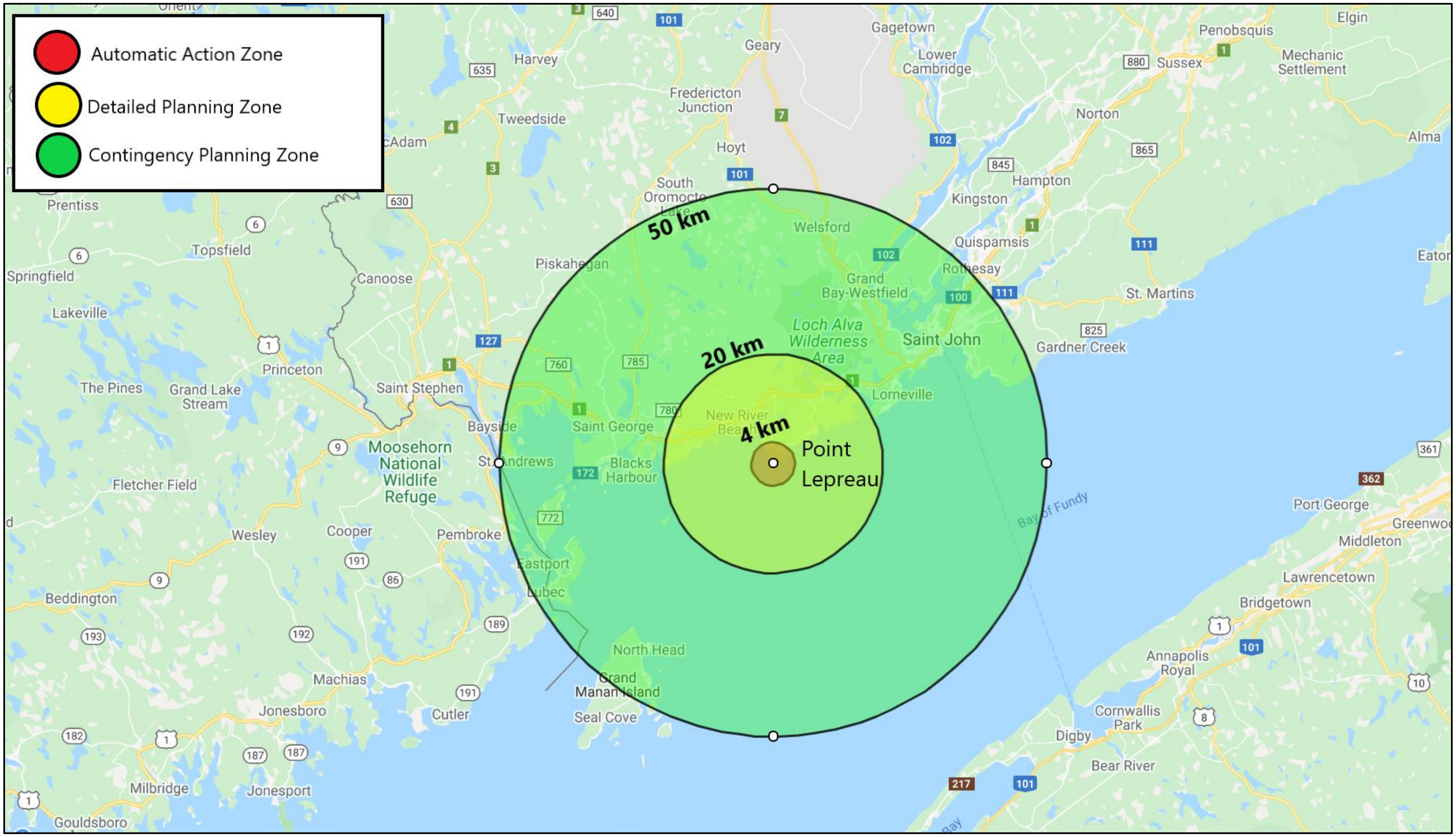
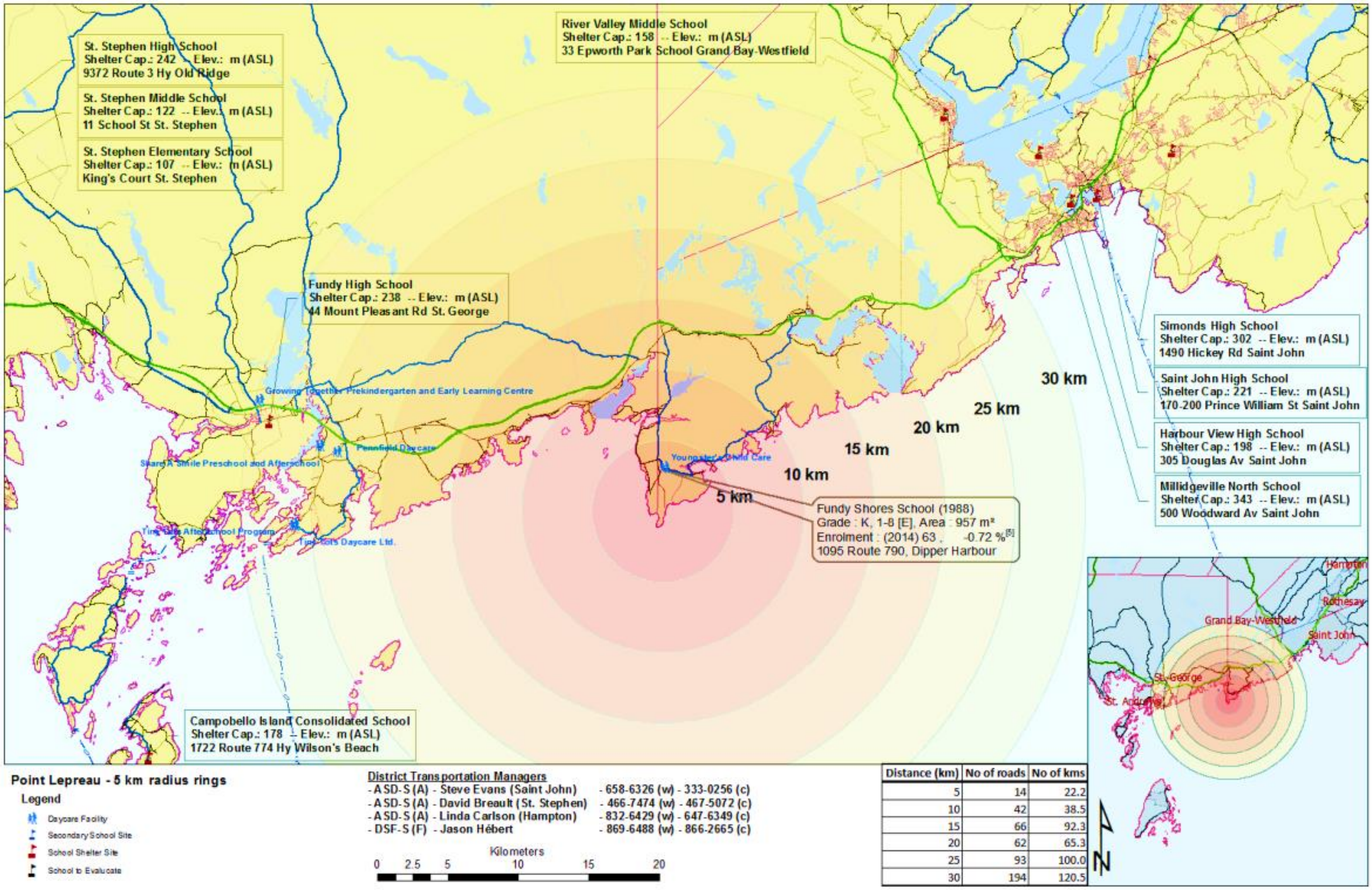


Figure 27: Planning zones around PLNGS based on the current New Brunswick guidelines



Distance (km)	No of roads	No of kms
5	14	22.2
10	42	38.5
15	66	92.3
20	62	65.3
25	93	100.0
30	194	120.5

Figure 28: Critical structures around the PLNGS site [7]

6. RECOMMENDATIONS

The following contains recommendations for emergency planning zones based on the findings of this report.

The Automatic Action Zone should extend to 4 km. This is the area immediately surrounding PLNGS where pre planned protective actions would be implemented by default based on reactor conditions to prevent early fatalities and acute health effects.

As a consequence, off-site emergency plans should include the capability to immediately alert residents of the need to promptly evacuate within 4 km of the reactor building, upon declaration of a general emergency.

The Detailed Planning Zone should extend to 20 km. The implementation of protective actions in the detailed planning zone is based on reactor facility conditions, dose modelling, and environmental monitoring. These protective actions serve to preclude or mitigate the occurrence of stochastic health effects (cancer over a long period of time).

The results of this calculation show that reception centres for evacuees, decontamination centres, and off-site emergency operation centres should be located outside of the Detailed Planning Zone. The detailed preparedness arrangements for sheltering in place would require the ability to notify the public during an emergency through good notification protocols. In addition, emergency centres (emergency operation centres, reception centres, etc.) must provide substantial sheltering, which is normally the case for public buildings.

The Contingency Planning Zone should extend to 50 km. While a fully implemented and tested capability is not required for this zone outside of the Detailed Planning Zone, contingency planning and arrangements should be made in advance of an emergency. Such proactive planning ensures that during a nuclear emergency, protective actions can be extended beyond the detailed planning zone, as required, to reduce potential for exposure. Examples of preparedness arrangements appropriate for the Contingency Planning Zone include:

- A generic concept of operation on how to alert the public and keep them informed;
- A detailed evacuation plan is not required, but consideration should be given to extended evacuation planning along with responsibilities which are defined
- Reception centres for evacuees and off-site emergency operation centres that are in the Contingency Planning Zone could potentially be impacted if conditions exceed the Operational Intervention Levels;
- There should be plans to extend sheltering in place beyond distances already implemented, if the measurements exceed the Operational Intervention Levels. It is relatively simple to extend a sheltering order for the public during an emergency if good notification protocols are place; and
- No pre-distribution of iodine tablets to residents within the Contingency Planning Zone

is required, but iodine tablets in sufficient quantities should be available at local depots (pharmacies) and a generic plan on how to make them available to the public should be prepared.

The calculations show that the Ingestion Planning Zone should extend to 57 km, although in practice food monitoring will be based on radiological measurements taken after the release phase. The Ingestion Planning Zone is the area surrounding PLNGS where plans or arrangements are made to protect the food chain and drinking water supplies, as well as restrict the consumption and distribution of potentially contaminated food and non-food commodities.

7. CONCLUSIONS

This technical planning basis is based on the evaluation of hypothetical accidents that have been selected according to emergency planning principles, which take into account the severity of accident scenarios and their likelihood. However, determining an acceptable level of preparedness does not solely depend on an appreciation of the theoretical risk, but it also takes into account:

- The acceptance of that risk compared with other risks;
- The cost of emergency preparedness;
- Practical considerations such as the current availability of resources and the geography; and
- The ability to promptly expand the implementation beyond the planning zone based on existing capabilities (i.e. the ability to improvise).

The measures proposed in this technical planning basis represent the best estimate of a degree of preparedness that is justified and that would lead to an effective response. It is based on technical and practical considerations. However, other considerations such as risk acceptance, political, socio-economic and demographic factors could affect the final planning requirements.

The results of the new analysis are consistent with those of the 2004 study [9] and show that minor adjustments, rather than major changes, may be appropriate, both in distance and in zone terminology to align with current standards.

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ANNEX A. CANDU CORE INVENTORY

Table 19: CANDU Core Inventory

Nuclide	Inventory (Bq)	Group	Nuclide	Inventory (Bq)	Group	Nuclide	Inventory (Bq)	Group
Kr-85	4.62E+15	1	Te-131	2.04E+18	5	Tc-104	2.84E+18	9
Kr-85m	6.50E+17	1	Te-131m	4.48E+17	5	Ru-103	3.04E+18	9
Kr-87	1.30E+18	1	Te-132	3.44E+18	5	Ru-105	2.28E+18	9
Kr-88	1.81E+18	1	Te-133	2.68E+18	5	Ru-106	3.70E+17	9
Xe-131m	2.68E+16	1	Te-133m	2.24E+18	5	Rh-105	1.91E+18	9
Xe-133	4.78E+18	1	Te-134	4.34E+18	5	Pd-109	6.70E+17	9
Xe-133m	1.50E+17	1	I-130	1.24E+18	2	Ag-110m	6.62E+14	9
Xe-135	4.26E+17	1	I-131	2.40E+18	2	Ag-111	1.10E+17	9
Xe-135m	1.03E+18	1	I-132	3.54E+18	2	Ag-112	5.44E+16	9
Xe-138	4.24E+18	1	I-133	4.96E+18	2	Ba-139	4.44E+18	8
As-77	5.42E+15	6	I-134	5.52E+18	2	Ba-140	4.34E+18	8
Se-83	1.46E+17	5	I-135	4.70E+18	2	Ba-141	4.00E+18	8
Br-82	1.89E+15	2	Cs-134	2.06E+16	3	Ba-142	3.78E+18	8
Br-83	3.08E+17	2	Cs-136	3.04E+16	3	La-140	4.42E+18	10
Br-84	5.68E+17	2	Cs-137	5.12E+16	3	La-141	4.06E+18	10
Rb-86	5.74E+14	4	Cs-138	4.60E+18	3	La-142	3.92E+18	10
Rb-88	1.87E+18	4	Sr-89	2.14E+18	7	Ce-141	3.68E+18	11
Rb-89	2.40E+18	4	Sr-90	3.68E+16	7	Ce-143	3.80E+18	11
Cd-113m	1.08E+13	9	Sr-91	3.14E+18	7	Ce-144	1.15E+18	11
Cd-115	1.69E+16	9	Sr-92	3.30E+18	7	Pr-143	2.91E+18	10
Cd-115m	5.96E+14	9	Y-90	3.96E+16	10	Pr-144	2.20E+18	10
Sb-122	2.76E+14	6	Y-91	2.60E+18	10	Pr-145	2.07E+18	10
Sb-124	1.40E+14	6	Y-91m	1.82E+18	10	Pr-147	1.33E+18	10
Sb-125	4.56E+15	6	Y-92	3.32E+18	10	Nd-147	1.52E+18	10
Sb-126	6.30E+14	6	Y-93	2.48E+18	10	Nd-149	8.56E+17	10
Sb-127	2.02E+17	6	Y-94	3.96E+18	10	Pm-147	1.38E+17	11
Sb-128a	3.64E+16	6	Y-95	4.18E+18	10	Sm-153	3.88E+17	10
Sb-128b	3.70E+17	6	Zr-95	3.24E+18	9	Eu-154	9.66E+14	10
Sb-129	7.76E+17	6	Zr-97	3.98E+18	9	Eu-155	1.18E+15	10
Sb-130	2.76E+17	6	Nb-95	2.58E+18	9	Eu-156	1.36E+17	10
Sb-131	1.88E+18	6	Nb-95m	0.00E+00	9	Eu-157	4.02E+16	10
Te-127	1.88E+17	5	Nb-97	3.90E+18	9	Np-237	1.28E+11	11
Te-127m	1.91E+16	5	Mo-99	4.48E+18	9	Pu-239	5.91E+14	11
Te-129	7.24E+17	5	Tc-99m	4.00E+18	9	Cm-242	2.08E+15	11
Te-129m	1.30E+17	5	Tc-101	4.04E+18	9			

ANNEX B. VERIFICATION OF METEOROLOGICAL DATA

Meteorological data was required for the MACCS2 computer code. The MetMon data, provided by PLNGS, was available for one-minute intervals for the year of 2015. To analyse the data, the results were then averaged and transferred into one-hour intervals. Using vector computations, the average wind speed was calculated in meters per second and the average wind direction in degrees [17]. The standard deviation of the horizontal component of the wind (sigma-theta) was found using the Yamartino method and is represented in degrees [17]. The stability class (A-F) was identified using the Pasquill-Gifford stability classification method based on sigma-theta [17]. Daily precipitation average data was obtained from Environment Canada for the PLNGS site for the year of 2015.

The average wind speed frequency distribution histogram is shown in Figure 29. The frequency increases to reach its maximum value at an average speed of 2.5 m/s.

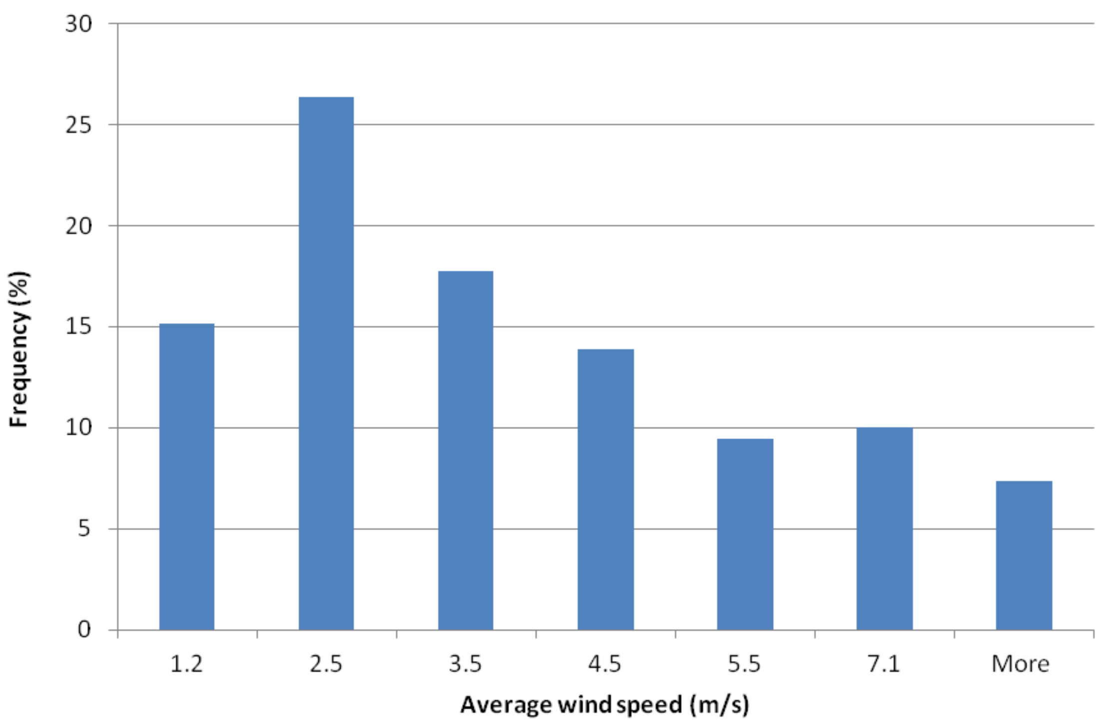

Figure 29: 2015 average wind speed frequency distribution

The wind rose diagram consists of 16 cardinal directions of 22.5 degrees segments, and their frequency of occurrence are shown by Figure 30. For the year of 2015 for PLNGS, the wind blows mostly from the west (9%).

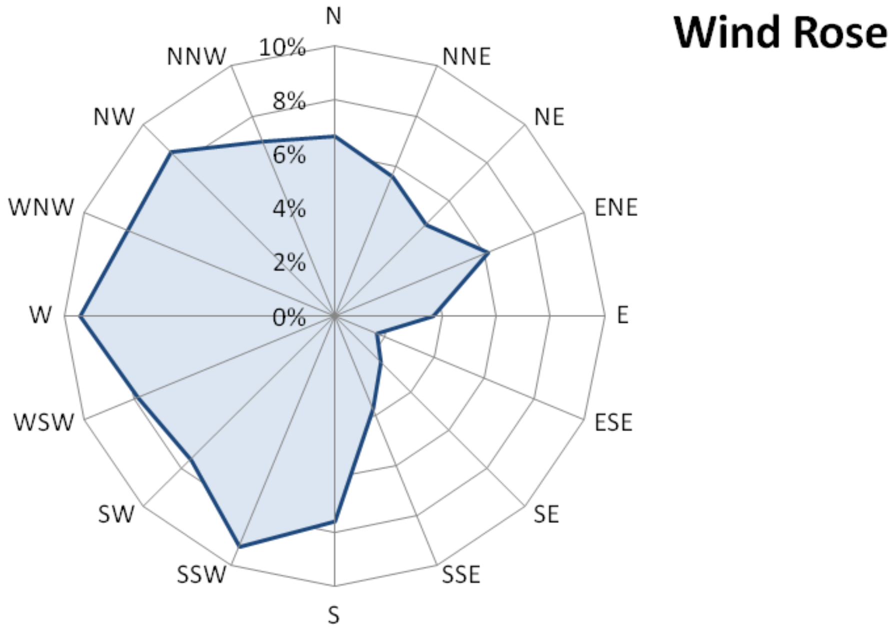

Figure 30: Wind Rose

The data obtained from MetMon was 98% complete; therefore, a sigma-theta histogram was generated (Figure 31) for use in determining wind stability. The obtained histogram shape was verified and compared to a typical histogram of sigma-theta data from CSA standard N288.2:19 [10]. The obtained shape did not present any discontinuity or abnormal distribution (e.g. multiple peaks). The highest frequency of occurrence is present around 13-15 degrees and decrease as the sigma-theta value increase.

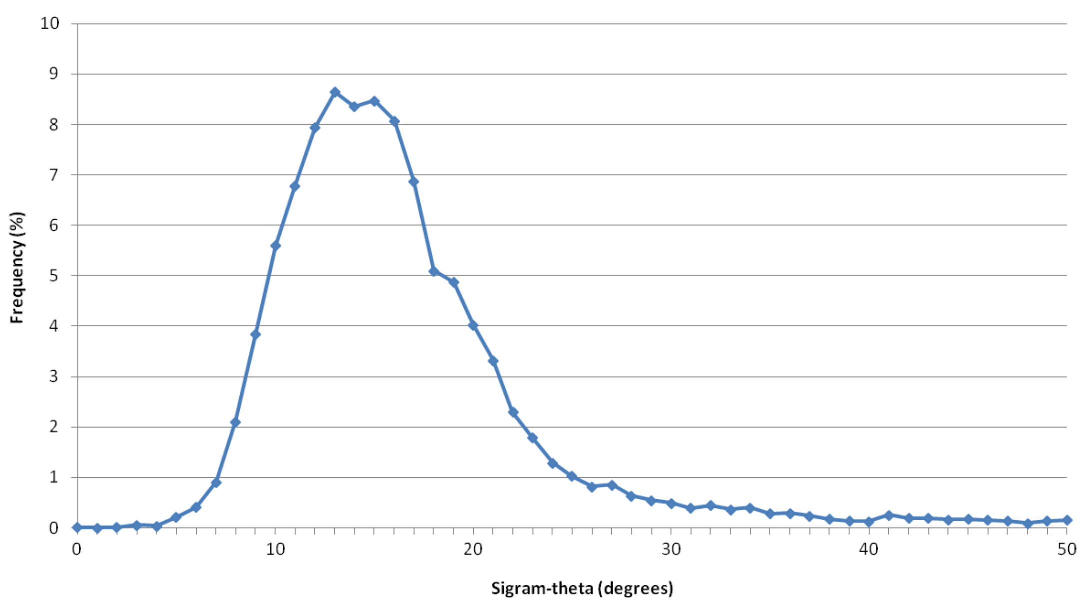

Figure 31: Sigma-theta histogram

As shown on Figure 32, the highest frequency for the 2015 PLNGS Met Data stability class is D with 51% followed by stability class C with 19%.

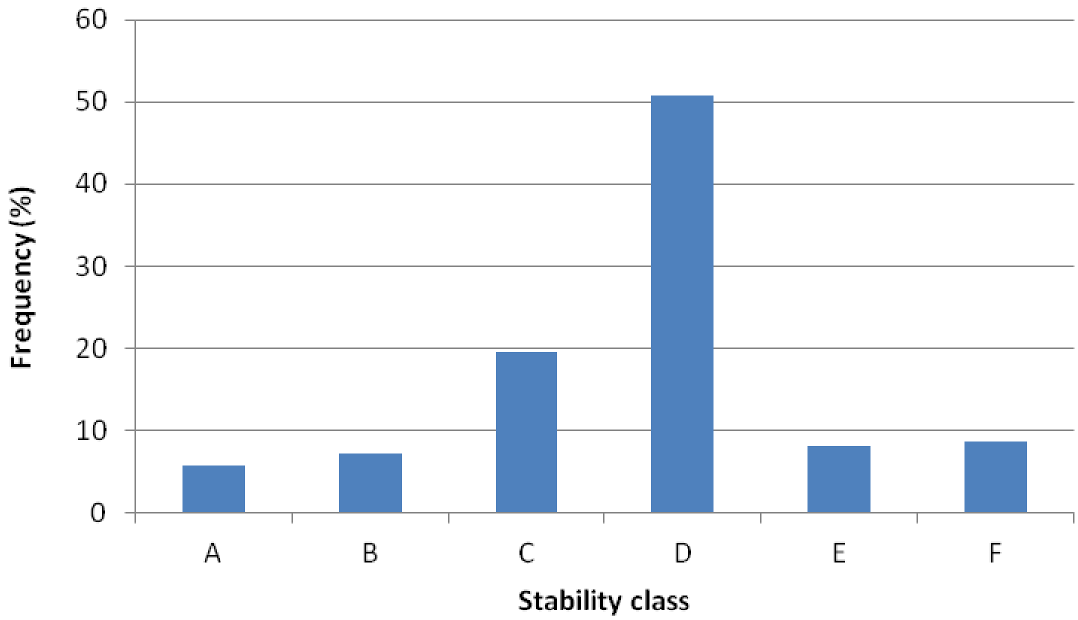

Figure 32: 2015 PLNGS Meteorological (MET) Data - Stability

The average wind speed was calculated for each stability class (A-F). The distribution is represented in Figure 33. The highest average wind speed is at stability class D (neutral) with a value of 4.44 m/s.

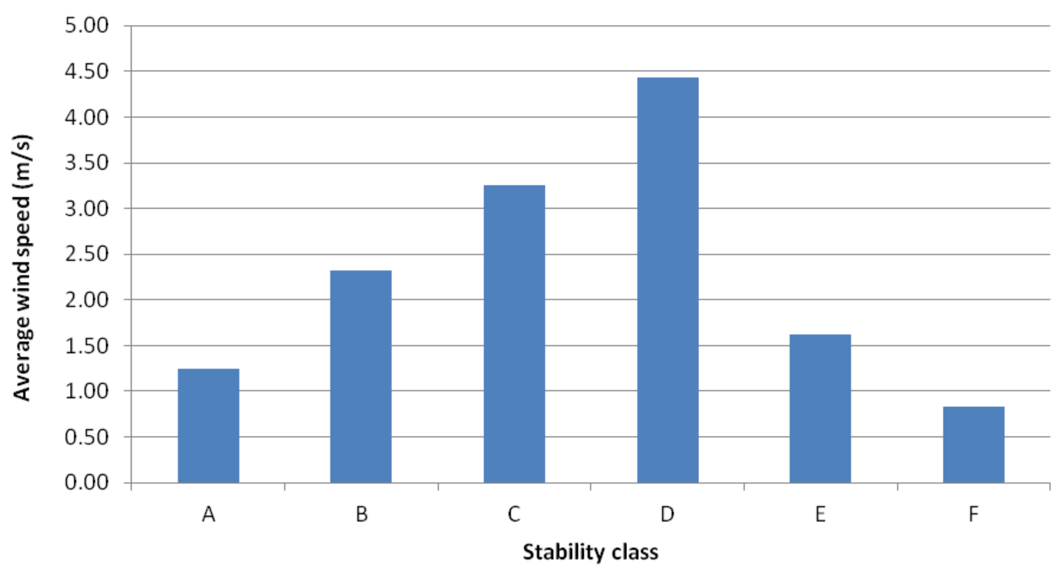

Figure 33: Average wind speed for each stability class

The average standard deviation of the wind direction was also calculated for each stability class (A-F). The highest standard deviation is present in stability class A with a value of 37 degrees, it decrease for each stability class until it reaches the lowest value of 13 at stability class D. Therefore, it increases again for stability class E and F. This suggests that when the atmosphere is stable (stability class E and F), there is considerable wind meandering in the horizontal direction.

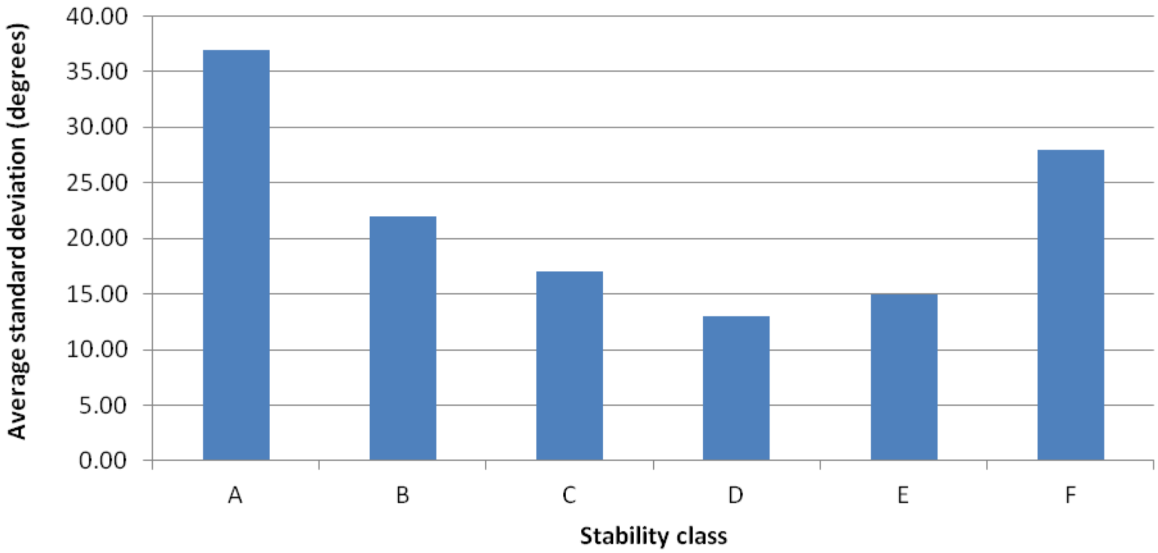

Figure 34: Average standard deviation of wind direction for each stability class

ANNEX C. LITERATURE REVIEW OF APPROACHES TO DEVELOPING A PLANNING BASIS

There are currently many approaches used around the world for determining "appropriate" emergency planning zones and distances. This annex includes a review of several national approaches to developing a planning basis:

C.1 THE CANADIAN APPROACH

The **Canadian approach**, as described in the following documents:

- *CNSC REGDOC-2.10.1, Emergency Management and Fire Protection, Nuclear Emergency Preparedness and Response* [1]. This is a regulatory document in Canada and therefore has a great bearing on the approach that will be adopted by PLNGS.
- *CSA standard: N1600-16 - General requirements for nuclear emergency management programs* [2]. This is a Canadian standard that must be complied with.
- *CNSC Study of Consequences of a Hypothetical Severe Nuclear Accident and Effectiveness of Mitigation Measures* [18]. This document, published in 2015, defines a generic large release source term for emergency preparedness studies related to the Darlington Nuclear Generating Station. Though not applicable to PLNGS, it provides an insight into what the CNSC considers a reasonable basis for emergency planning and therefore for the definition of emergency planning zones.
- *Health Canada, Generic Criteria and Operational Intervention levels for Nuclear Emergency Planning and Response* [6]. This document, published in 2018, provides guidelines on the criteria to be used for trigger protective actions. These guidelines are not mandatory for the provincial authorities.
- *CSA standard N288.2:19 Guidelines for calculating the radiological consequences to the public of a release of airborne radioactive material for nuclear reactor accidents* [10]. This document provides guidance on how to calculate doses, including dispersion modeling and assumptions.

C.1.1 Accident(s) considered

CSA standard N1600-16 states that "*The reactor facility planning basis shall include the following: Design Basis Accidents (DBA); Beyond Design Basis Accidents (BDBA); other emergencies leading to nuclear emergencies; and, for multi-unit power reactor facilities, multi-unit accident scenarios*". It does not stipulate specifically the severity of the accidents to consider nor the manner in which they should be analyzed.

CNSC REGDOC-2-10.1 makes specific reference to severe accidents and states that the planning basis should consider all analyzed accidents as well as internal or external events, including multi-unit accidents scenarios and extended loss of power. There is no reference to cutoff frequencies. The document explains that the planning basis should be used to determine the scope and depth of the Emergency Preparedness (EP) program requirements. This suggests that the level of planning could depend on the likelihood of the accidents under consideration. The document does not explain how this could be done.

The CNSC has prepared a separate document, *Study of Consequences of a Hypothetical Severe Nuclear Accident and Effectiveness of Mitigation Measures* [18], describing a severe accident source term for multi-unit stations that could be used for emergency planning. The release fractions for this severe accident source term are shown in Table 20.

Table 20: Proposed severe accident release fractions from the Canadian Nuclear Safety Commission

Fission product group	Release fraction
Noble gases (e.g., xenon)	4.12 x 10-1
Halogens (e.g., iodine)	1.52 x 10-3
Alkali metals (e.g., cesium)	1.52 x 10-3
Alkaline earths	2.30 x 10-8
Refractory metals	2.53 x 10-4
Lanthanides	8.51 x 10-9
Actinides	5.16 x 10-8
Barium	1.68 x 10-7

This source term corresponds to the safety goals which have been specified for the design of new reactors facilities in CNSC *REGDOC 2.5.2, Design of Reactor Facilities: Nuclear Power Plants* [19]. REGDOC 2.5.2 defines a “large release” as a release of radioactive cesium (Cs-137) greater than $1x10^{14}$ becquerels (Bq) over the duration of the accident. The release described in Table 20 corresponds to this regulatory limit for a “large release”.

Although the current reactor at PLNGS has not been licensed under the requirements contained in CNSC REGDOC 2.5.2, the release fractions selected by the CNSC are similar to release categories in the PLNGS Probabilistic Safety Assessment.

C.1.2 Accident dynamics

In the guidance for licensees, CNSC REGDOC-2-10.1 [1] suggests that the information provided to the offsite authorities on the planning basis should include the possible release start time and duration of potential accidents. It is up to the offsite authorities to determine how this information can be used in the planning. Accident dynamics is not a factor in the determination of the emergency planning zones and distances.

C.1.3 Zone Definitions and Strategy

CSA standard: N1600-16 suggests the following emergency planning zones and corresponding strategy:

- *Automatic action zone*, an area immediately surrounding a reactor facility where pre-planned protective actions would be implemented by default based on reactor facility conditions. These protective actions serve to preclude or mitigate the occurrence of severe deterministic effects.
- *Detailed planning zone*, an area surrounding a reactor facility (incorporating the automatic action zone), where pre-planned protective actions are implemented, as required. The implementation of protective actions in the detailed planning zone is based on reactor facility conditions, dose modelling, and environmental monitoring. These protective actions serve to preclude or mitigate the occurrence of stochastic effects.
- *Contingency planning zone*, an area surrounding a reactor facility (beyond the detailed planning zone), where contingency planning and arrangements are made in advance. Such proactive planning ensures that during a nuclear emergency, protective actions can be extended beyond the detailed planning zone, as required, to reduce potential for exposure.
- *Ingestion planning zone*, an area surrounding a reactor facility where plans or arrangements are made to protect the food chain and drinking water supplies, as well as restrict the consumption and distribution of potentially contaminated food and non-food commodities.

Figure 35 shows the emergency planning zones defined in CSA standard N1600-16.

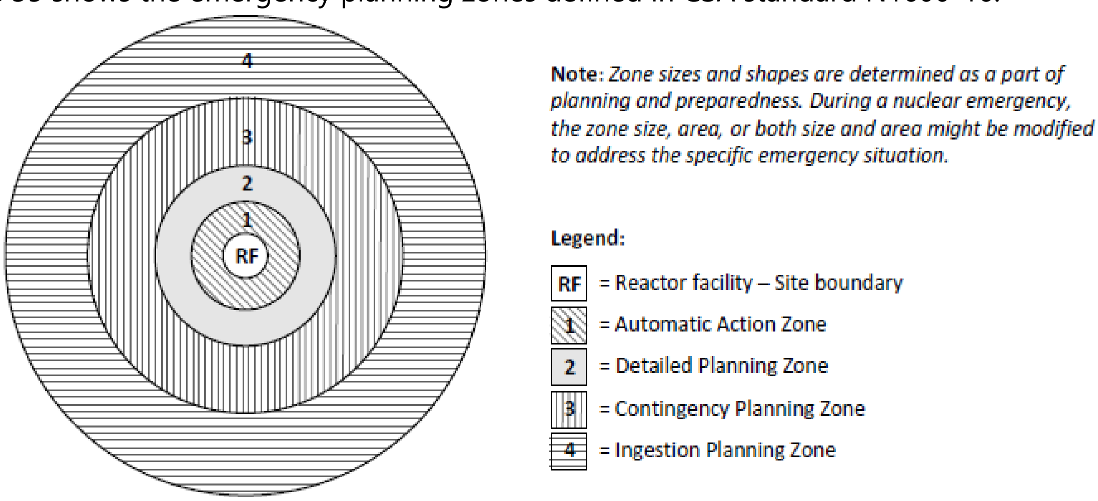

Figure 35: Canadian Standards Association N1600-16 emergency planning zones

Section 7.6.1.3 stipulates that the size and shape of emergency planning zones must be established in advance, using the results of the hazard identification and risk assessment. The size and shape of these zones must consider the likelihood of exceeding the dose criteria and other factors (such as topography, geography, and transportation networks).

C.1.4 Weather

The weather that should be used in the dose calculations for determining zone sizes and distances is addressed in CSA standard N288.2:19, section 4.2.1 [10]. *The average weather pattern should be used*. Most often, it is said to correspond to a neutral Pasquill D wind stability condition.

C.1.5 Receptor

CSA standard N288.2:19 recommends that for site-specific emergency planning evaluations the representative individual for the general population should be an adult. The Standard also recommends that were appropriate, and as outlined by the authority having jurisdiction, protective measures should be assessed on the basis of the doses calculated for the vulnerable population.

C.2 THE INTERNATIONAL ATOMIC ENERGY AGENCY SAFETY STANDARDS AND GUIDANCE

The **International Atomic Energy Agency (IAEA) standards and guidance**, as defined in the following documents:

- IAEA Safety Standards in Emergency Preparedness and Response [3] [20] [4]. These are international standards. Although non-mandatory, those represent consensus agreements amongst all IAEA Member States, including Canada.

C.2.1 Requirements

GSR Part 7 [3], the latest in the International Atomic Energy Agency series of safety standards on emergency preparedness and response, requires a wide range of accidents to be considered in the hazard assessment.

> *4.20. The government shall ensure that for facilities and activities, a hazard assessment on the basis of a graded approach is performed. The hazard assessment shall include consideration of:*
> *(a) Events that could affect the facility or activity, including events of very low probability and events not considered in the design;*
> *(b) Events involving a combination of a nuclear or radiological emergency with a conventional emergency such as an emergency following an earthquake, a volcanic eruption, a tropical cyclone, severe weather, a tsunami, an aircraft crash or civil disturbances that could affect wide areas and/or could impair capabilities to provide support in the emergency response;*

(c) Events that could affect several facilities and activities concurrently, as well as consideration of the interactions between the facilities and activities affected;
(d) Events at facilities in other States or events involving activities in other States.

This is repeated in the rest of the safety standards, although those documents do not explain how to use these accidents.

C.2.2 Guidance for Calculations of Planning Zones

The IAEA GS-G-2.1 Safety Standard [4], Appendix II.3 gives the following guidance:

Each State may carry out an independent analysis to determine its own zone sizes that are appropriate in view of the specifics of the State, provided that the analysis: (a) addresses the full range of possible emergencies, including those of low probability, as required by the Requirements (Ref. [2], para. 4.48); and (b) is carried out with the goal of meeting the requirements for establishing these zones as established in the Requirements (Ref. [2], para. 4.48).

The key point to note is the statement "addresses the full range of possible emergencies, including those of low probability", which points to the inclusion of less severe accidents, which have a higher likelihood, along with more severe accidents, which have a low probability.

The same IAEA document offers more guidance on how to calculate the zone size:

TABLE 8. SUGGESTED EMERGENCY ZONES AND AREA SIZES (a)

Facilities	*Precautionary action zone (PAZ) radius (b),(c)*	*Urgent protective action planning zone (UPZ) radius (d)*
Threat category I facilities		
Reactors >1000 MW(th)	*3–5 km*	*5–30 km (e)*

(a) The radius is the approximate default distance from the facility at which the boundary of the zone should be established. Variation by a factor of two or more during application is reasonable. A different distance should be used when this is substantiated by a detailed safety analysis.
(b) The suggested radii are the approximate distances for which the acute (2 day) dose to the bone marrow or lung could (with a very low probability) approach levels that are life threatening (i.e. exceed the values in Annex II of Ref. [2]). A maximum radius of 5 km is recommended, as discussed elsewhere in this appendix. The source term (release) used for reactor emergencies is typical of that postulated for the range of low probability accidents that could potentially lead to severe deterministic effects off the site.
(c) The radii were selected on the basis of calculations performed with the RASCAL 3.0 computer model [41]. For the purpose of the calculation, average meteorological conditions, no rain, a ground level release and an exposure for 48 hours to ground shine are assumed, and the centreline dose to a person outside for 48 hours is calculated.
(d) The suggested radii are the approximate distances for which the total effective dose for inhalation, cloud shine and ground shine for 48 hours will not exceed 1–10 times the GIL for evacuation, with a maximum radius of 5–30 km, as recommended for the reasons discussed elsewhere in this appendix.
(e) A distance of between 5 and 30 km may be considered reasonable if supported by a site specific analysis.

Note a) states that the radius of the zone is the approximate default distance from the facility at which the boundary of the zone should be established. Variation by a factor two or more from that default distance is reasonable when applying it to geographical boundaries.

Notes b) and c) recommend that the Precautionary Action Zone (PAZ) radius be based on calculations using a source term that is typical "for the range of low probability accidents that could potentially lead to severe deterministic health effect off the site". This calculation should use average meteorological conditions, no rain, a ground level release, and an exposure of 48 hours to ground shine for a person exposed outside, on the centre line of the release.

For the calculation of the Urgent Protective Action Zone (UPZ) radius, the guidance under note d) states that "the total effective dose for inhalation, cloud shine and ground shine for 48 hours will not exceed 1 – 10 times the GIL for evacuation, with a maximum radius of 5 – 30 km". Note e) offers "A distance of between 5 and 30 km may be considered reasonable if supported by a site specific analysis."

C.2.3 Other Considerations

The zone size for emergency planning is also based on other considerations, such as historical data from previous severe accidents at nuclear power plants, the time available to implement the protective actions, the time available to conduct surveys off-site, and the residual risk for non-evacuated members of the public.

IAEA GS-G-2.1 Safety Standard [4] offers additional guidance on other considerations for the zone size.

The suggested sizes for the PAZ are based on expert judgment made in consideration of the following:

- *Urgent protective actions taken before or shortly after a release within this radius will avert doses exceeding the thresholds for early death for the vast majority of major emergencies postulated for these facilities.*
- *Urgent protective actions taken before or shortly after a release within this radius will prevent doses exceeding the urgent protective action GILs for the majority of emergencies postulated for the facility.*
- *Dose rates that could be fatal within a few hours were observed at these distances during the Chernobyl accident.*
- *The maximum reasonable radius for the PAZ is assumed to be 5 km because:*
    - *a) except for the emergencies with the most severe consequences, it is the distance limit out to which doses that would lead to early deaths are postulated [25, 26];*
    - *b) it provides a reduction in dose by a factor of about ten in comparison with the dose on the site;*
    - *c) it is very unlikely that urgent protective actions will be warranted at a significant distance beyond this radial distance;*
    - *d) it is considered the practical limit of the distance to which substantial sheltering or evacuation can be promptly implemented before or shortly after a radioactive release; and*
    - *e) implementing precautionary urgent protective actions to a larger radius might reduce the effectiveness of the actions for the people nearer the site who are at the greatest risk.*

The suggested sizes of the UPZ for Threat Category I facilities are based on expert judgment made in consideration of the following:

- *These are the radial distances, studies [26] suggest, out to which monitoring to locate and evacuate hot spots (due to deposition) within hours may be warranted to significantly reduce the risk of doses that would lead to early deaths in the emergencies with the most severe consequences postulated for power reactors.*
- *At these radial distances there is a reduction by a factor of approximately ten in concentration (and thus risk) due to a release in comparison with the concentration at the PAZ boundary.*
- *This distance provides a substantial base for the expansion of response efforts.*
- *A distance of 5–30 km is assumed to be the practical limit for the radial distance within which to conduct monitoring and to implement appropriate urgent protective actions within a few hours.*
- *For average meteorological (dilution) conditions, beyond this radius, for most postulated emergencies with severe consequences the total effective dose to an individual would not exceed the urgent protective action GILs for evacuation.*

These considerations highlight the fact that the zone size is not solely a technical hazard assessment issue but is also a preparedness issue.

C.3 THE UNITED STATES APPROACH

The **United States approach**, as defined in:

- *NUREG 0396, Planning Basis for the Development of State and Local Government Radiological Emergency Response Plans in Support of Light Water Nuclear Power Plants* [21]. This document, while published in 1978, remains the basis for the current emergency planning zones in the United States.
- *NUREG 1935, State-of-the-Art Reactor Consequence Analyses (SOARCA)* [22]. This report is useful in terms of how best-estimate accident consequences can or should be calculated, but it does not provide direct guidance on how to determine emergency planning zones and distance.

C.3.1 Accident(s) considered

The US approach considers a broad range of postulated accident scenarios, from DBAs to severe accidents with containment failure, tempered by probability considerations. This is a semi-probabilistic approach that differs from the purely deterministic method used in most other references.

The report states that "both the design basis accidents and less severe core-melt accidents should be considered when selecting a basis for planning predetermined protective actions and that certain features of the more severe core-melt accidents should be considered in planning to assure that some capability exists to reduce the consequences of even the most severe accidents.

The 10 mile (16 km) emergency planning zone, for the plume exposure pathway, is based on the fact that protective action guides (PAG), which are in terms of whole body dose, are unlikely to be exceeded beyond that distance, for the limiting weather scenario (5 percentile meteorology and straight line trajectory). The 50 mile (80 km) ingestion pathway emergency planning zone is based on the fact that, beyond that distance, also for the limiting weather scenario, the PAG for the thyroid dose via milk consumption to an infant is unlikely to be exceeded.

These distances are confirmed by the analysis of severe accidents. When all core melt accidents are considered with their probabilities, the results show that the probability of severe deterministic health effects (200 rem whole body, or 2 Sv) drop significantly after 10 miles (16 km). A similar argument is made for the probability of exceeding ingestion PAGs beyond 50 miles (80 km).

C.3.2 Accident dynamics

NUREG 0396 specifically refers to accident timing as a key factor in the determination of emergency planning zones. This does not affect the planning zone sizes but it impacts the response time requirements. It is estimated that the time from initiation to major release could be 30 minutes to one day; the release duration, from 30 minutes to several days; the time for the bulk of thee release from 30 minutes to one day following release start; and the travel time to exposure point at 5 miles (8 km) from 30 minutes to 2 hours, and at 10 miles (16 km) from 1 to 4 hours. This information is used to calculate the potential effectiveness of protective actions in the emergency planning zones, particularly in the plume exposure zone.

Results show that, within 5 miles (8 km), evacuation is more effective in reducing the probability of deaths than sheltering. From 5 to 10 miles (8 to 16 km), the distinction is less clear. Beyond 10 miles (16 km), there is no difference between evacuation and sheltering on the death probability reduction and time is less of an issue.

C.3.3 Weather

Limiting weather conditions (5 percentile meteorology and straight-line trajectory) are used for calculation of doses for DBAs. Wind persistence (2-4 hours) is discussed and considered but not used in the calculations, except to justify the relatively short ingestion planning distance. Probabilistic weather is used in the calculation of the probability of exceeding deterministic thresholds for severe accidents.

C.3.4 Receptor

The receptor for whole body dose calculations is an “individual”, assumed to mean an average individual. The receptor for dose to the thyroid is an infant.

C.3.5 Criteria

The PAGs used in NUREG 0396 are as follows:

Table 21: Suggested protective actions in United States

Protective action	Criteria
Sheltering and evacuation	1 to 5 rem whole body dose to individuals (10 to 50 mSv effective dose)
Stable iodine	5 to 25 thyroid dose to individuals (50 to 250 mSv equivalent dose to thyroid)
Ingestion control	30 rem thyroid to individual (300 mSv equivalent dose to thyroid) 10 rem thyroid to infant (100 mSv equivalent dose to thyroid)

C.3.6 Zone Definitions and Strategy

The US defines two emergency planning zones: an emergency planning zone (EPZ) plume of 10 miles (16 km) and an EPZ-ingestion of 50 miles (80 km). In practice, though not documented in the reference, following the declaration of a general emergency (meaning that a release is imminent or in progress), a radius of 2 miles (3.2 km) all around the plant and 5 miles (8 km) downwind would be evacuated.

C.4 THE NETHERLANDS APPROACH

The **Netherlands approach**, as explained in the following document:

- *RIVM (Dutch Environmental Protection Agency), Inventory and classification of countermeasure zones in the case of a nuclear accident* [23]. This document is an example of how a European country attempts to define emergency planning zones and distances to reach consistency with its neighbours, in a context where every European country uses different assumptions and criteria to define the zones.

C.4.1 Accident(s) considered

Previously, the emergency planning zones were based on the WASH 1400 PWR-5 accident scenario [24], scaled to the power output of Borssele nuclear power station. This corresponds to a core melt with failure to properly isolate containment isolation and penetration (no containment structural failure). In 2008, this basis was revised, with no major change to the emergency planning zone sizes. In the 2008 study, three accident categories are considered:

- WASH-1400 PWR-5 [24];
- STSC-CON1, MER-1993 [25]; and
- STC-3, MER-1996 [26].

The main differences between these scenarios are the relative fractions of noble gas, iodine and cesium released. STC-CON1 involves late containment failure. STC-3 involves a short, one hour release after four hours of containment retention. The study is deterministic and provides a range of possible emergency planning zone sizes based on these three scenarios.

C.4.2 Accident dynamics

Accident dynamics is not specifically addressed in the determination of the emergency planning zone sizes.

C.4.3 Weather

Distances are calculated for two bounding weather conditions: the 95th percentile and the 68th percentile.

C.4.4 Receptor

The receptor is an average individual for calculations related to sheltering and evacuation, and an infant for those related to stable iodine.

C.4.5 Criteria

The protective actions used in the Netherlands are as follows:

Table 22: Suggested protective actions in the Netherlands

Protective action	Criteria
Sheltering and evacuation	200 mSv effective dose
Stable iodine	100 mSv thyroid dose to one-year old infant
Ingestion control	Not addressed in the study

C.4.6 Zone Definitions and Strategy

The emergency planning zones in the Netherlands around Borssele nuclear power station are:

- 5 km for evacuation;
- 10 km for stable iodine; and
- 20 km for sheltering.

The implementation of protective actions in each zone is based on an analysis of the plant parameters at the time of the accident and on dose projections based on actual weather conditions. There are no automatic (reflex) emergency protective actions.

C.5 THE FRENCH APPROACH

The recently modified **French approach**, as described in, amongst others, the following documents:

- *Décret n°2005-1158 du 13 septembre 2005 relatif aux plans particuliers d'intervention concernant certains ouvrages ou installations fixes et pris en application de l'article L741-6 du code de la sécurité intérieure* [27]. This is an official government document instructing responsible authority on emergency arrangements to establish and the distances to which planning must be implement.
- Rapport de l'ASN sur l'état de la sûreté nucléaire et de la radioprotection en France - *Chapitre 05, Les Situations d'urgence Radiologique et Postaccidentelles* [28]. This document provides a comprehensive view of the French approach and strategy for nuclear and radiological emergency preparedness. It explains clearly the actions corresponding to each emergency planning zone, highlighting the differences with respect to the international standards.
- *Les Études d'Évaluation des Termes Sources sur les REP* [29]. This document describes the new accident sequences considered for the determination of planning zone sizes.

C.5.1 Accident(s) considered

Previously, the reference source term for the determination of emergency planning zones was "S3", a source term based on the WASH-1400 Reactor Safety Study, adapted to the French reactors. S3 corresponds to a partial core melt with delayed leakage of fission products from the containment, with significant retention. Containment bypass and failure was not considered.

The new study of source terms reviews and revises this approach. Three source terms are considered, corresponding to variations on a scenario involving a core melt with containment impairment. Note that in all scenarios most of the release takes place through pre-filters and sand filters according to a controlled release strategy to prevent over-pressurization of the containment.

C.5.2 Accident dynamics

The basis for emergency planning zones considers two broad categories for the accident kinetics: releases likely within 6 hours and in more than 6 hours. The first case leads to reflex actions over the reflex evacuation zone, independent of the weather. The second leads to "concerted" decisions based on plant parameters, dose projections and actual weather.

C.5.3 Weather

No information is available at the time of writing on the weather scenarios used for the dose calculations.

C.5.4 Receptor

No information is available at the time of writing on the receptor used for the dose calculations.

C.5.5 Criteria

The intervention levels used in France are as follows [30]:

Table 23: Suggested protective actions in France

Protective action	Criteria
Sheltering	10 mSv effective dose
Evacuation	50 mSv effective dose
Stable iodine	50 mSv thyroid dose

Protective action	Criteria
Ingestion control	Not used in the determination of emergency planning zones

C.5.6 Zone Definitions and Strategy

The emergency planning zones are as follow. Note that they include a reflex evacuation zone for accidents in which a release is expected in less than 6 hours. Also note that the distances were very recently revised by governmental decree in 2016.

Table 24: Emergency planning zones in France

Zone	Distance
Reflex evacuation zone for releases within 6 hours	5 km
Detailed planning zone (PPI) for sheltering, evacuation and stable iodine, based on plant parameters and dose projection using actual weather	20 km
Ingestion control - Population protection zone (ZPP) - Enhanced surveillance zone (ZST)	These zones are determined during the emergency based on field monitoring and dose projection calculations.

ANNEX D. LITERATURE REVIEW SUMMARY

Table 25: Summary findings from planning zone literature review

Factor	Canada	USA	Netherlands	France	IAEA
Accidents	DBA and BDBA but with some credit given to the containment (in the case of DNGS).	BDA and core melt scenarios with containment failure.	Core melt with partial isolation failure.	Core melt with containment impairment.	Core melt with containment failure.
Accident dynamics		Timing of released and plume travel time considered in the zone sizes.		Release time<6 hour: reflex zone evacuation.	10 hour release.
Weather	Average weather.	5 percentile for DBA; probabilistic weather for severe accidents.	68^{th} to 95^{th} percentile.	Not available.	Pasquill D with 90 degree rotation over release duration.
Receptor	Representative individual.	Whole body dose: average individual; thyroid dose: infant.	Effective dose for sheltering and evacuation: average individual; thyroid dose: infant.	Not available.	Average individual and fetus, taking into account sheltering.
Criteria	Shelter: 5 mSv in one day Evacuation: 50 mSv in 7 days Iodine: 100 mSv committed equivalent dose Relocation: 50 mSv/y Food control: 1 mSv/y	Shelter/evacuation: 1-5 rem (10-50 mSv) Iodine: 5-25 rem Th (50-250 mSv) Food: 10 rem (100 mSv) thyroid infant; 30 rem (300 mSv) thyroid to individual.	Shelter and evacuation: 200 mSv Iodine: 100 mSv one-year dose to infant	Shelter: 10 mSv Evacuation: 50 mSv Iodine: 50 mSv th	Severe deterministic effects: 1 Gy red bone marrow Stochastic effects: 100 mSv fetus from inhalation by the mother.
Zone definition and strategy	Automatic action zone Detailed planning zone Contingency planning zone Ingestion planning zone	EPZ-plume: 10 miles (16 km) EPZ-ingestion: 50 miles (80 km) Keyhole evacuation under general emergency of 2 miles (3.2 km) around the plant and 5 miles (8 km) downwind.	Evacuation: 5 km Shelter: 20 km Iodine: 10 km	Reflex zone: 5 km Detailed planning zone: 20 km.	PAZ: 3-5 km evacuated at general emergency UPZ: 25-30 km EPD: 100 km ICPD: 300 km.