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1. Introduction

1.1 Background

Accidents that could lead to a significant radiological impact are very unlikely. Nevertheless, emergency response plans are part of a sound safety management program. To be effective, practical and realistic, emergency plans must be based on a sound *technical planning basis*. The technical planning basis document provides a practical description of potential accidents, including the range of potential events, their likelihood, their consequence, their timing and the effectiveness of protective actions. The technical planning basis also leads to the definition of emergency planning zones and planning strategies that take into account the risk of accidents and of health effects and provide a basis for the efficient and reasonable investment of resources at the planning stage.

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.

1.2 Aim

This document contains the technical planning basis for Point Lepreau Nuclear Power Station (PLGS). Its aim is to provide the practical information necessary to develop sound, effective and reasonable emergency response plans and capabilities.

This document focuses on protecting the health of persons during postulated accidents in accordance with internationally accepted principles for emergency intervention.

1.3 Scope

This report covers nuclear accidents involving the PLGS reactor. It focuses on the short-term countermeasures; longer-term protective actions such as relocation, resettlement, large-scale food control, remediation and recovery are not specifically addressed. These issues are the object of on-going work at the International Atomic Energy Agency (IAEA) and involve socio-political decisions that are beyond the scope of the present work. Some guidance on the definition of zones where detailed food sampling plans can be established is contained in [IAE953].

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1.5 Definitions and Acronyms

Beyond Design Basis Event	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 (BDBR)	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
Contingency zone	Zone within which urgent protective actions can be implemented based on available resources and capabilities; safety extension of the UPZ to take into account the very unlikely combination of beyond design basis events.
COSYMA	Radiological risk calculation program used to estimate the doses and health risks from nuclear accidents
Design Basis Event (DBE)	Postulated failure of equipment and safety systems that is taken into account in the design of the plant
Design Basis Release (DBR)	Release of radioactive material of a magnitude and composition that is representative of Design Basis Events
Deterministic effects	Acute health effects that may occur as a direct result of the exposure to radiation
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	Zone within which plans are developed to take protective actions in case of a nuclear accident
Equivalent dose	Dose received by an organ
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
Longer-term protective action zone (LPZ)	Zone within which plans are developed to control agricultural products
Morbidity	Illness that does not result in death
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 action zone (PAZ)	Zone that should be automatically evacuated or sheltered in the event of an imminent release to prevent deterministic effects in the population
Reduction factor	Factor by which a given protective action reduces the dose that would be received by an individual

Severe Accidental Release (SAR)	Release of radioactive material of a magnitude and composition that is representative of severe accidents with impaired containment
Severe accident	Accident leading to significant fuel damage and release of fission products to the 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	Protective action that is taken within the first few days after an accident and includes sheltering, stable iodine, evacuation and immediate ban on locally grown food
Urgent protective action zone (UPZ)	Zone within which plans are developed to take protective actions if the environmental surveys and plant parameters indicate the need to do so.

2. Concepts and Principles

2.1 Emergency Planning Principles

Emergency preparedness can be defined as the measures that enable individuals and organizations to stage a rapid and effective emergency response. In the context of nuclear emergencies, protective actions include measures to limit the exposure of the public to radioactive contamination through external exposure, inhalation and ingestion. The objectives of these actions are to minimize the risk of stochastic effects (cancer) and to prevent deterministic effects (radiation illness or death).

The decision to plan for or to implement protective actions should follow three general principles [SS109]:

- all possible efforts should be made to prevent deterministic effects;
- the intervention should be justified in the sense that introduction of the protective action should achieve more good than harm; and
- the level at which the protective action is introduced should be optimized so that the action will produce a maximum net benefit.

ICRP 40 [ICR40] establishes the basic principle on which emergency preparedness for any type of accident should be based:

> *"The preparation of emergency plans should be based on consideration of a wide range of potential accidents, including those having low probabilities of occurrence … [but]… the degree of details in plans should decrease as the probability of the accident decreases."*

ICRP 60 [ICR60] elaborates on this principle and states that organizations should plan in detail for probable events in order to minimize stochastic effects, and make provisions (less detailed plans) for less probable events in order to prevent deterministic effects, or death. This does not mean that accidents with lower probabilities should be ignored, but rather that the emergency preparedness efforts and resources should be invested wisely. On the other hand, from a practical point of view, low probability events with large consequences would require more extensive protective actions over a larger area. The planning challenge therefore consists of determining the appropriate level of preparedness effort required to protect the public against possible serious consequences.

In Canada, the Ontario Provincial Working Group #8 [OWG88] attempted to quantify the existing international guidance on the need for detailed emergency preparedness as follows:

> For events with an occurrence frequency of 10^{-5} per year or greater, *"planning [should] assure public exposure to radioactive doses be kept less than the protective action levels",* where the protective action levels are well below levels which could lead to early health effects. For events with an occurrence frequency lower than 10^{-5} per year, or which cannot be quantified, *"planning [should] protect against the onset of early morbidity and the onset of early mortality in a member of the public"*.

In practice, this means that the emergency plans should aim at:

- minimizing stochastic effects for the credible accident scenarios;
- preventing deterministic effects for severe accidents[1]; and
- enabling the expansion of emergency measures outside the detailed planning zones should it be required at the time of the accident.

This is the basic premise of this document.

2.2 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
- longer-term protective actions, which may need to be adopted in a matter of days following an accident. These include control of foodstuff, relocation and resettlement.

Longer-term protective actions are defined later. However, this technical planning basis focuses on the urgent and short-term protective actions.

2.2.1 Sheltering

Sheltering 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 [SS109]. In practice, it is difficult to maintain for more than 24 hours. Beyond that period, evacuation or relocation needs to be considered.

Report [ISR01] contains a detailed analysis of reduction factors for sheltering. Table 1 presents the dose reduction factors for the average Canadian house. The dose reduction factors for inhalation vary with the duration of the release due to slow air ingress into the house.

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[1] Severe accidents are defined as the class of accidents where significant fuel damage occurs.

Table 1: Dose reduction factors for sheltering

Exposure pathway	Release duration (hours)	Reduction factor (RF)*
Cloud shine	Not applicable	0.8
Ground shine	Not applicable	0.4
Inhalation	0.5	0.2
	1	0.3
	4	0.6
	24	0.7

* Note: Dose with protection = dose without protection x RF

In this work, an average dose reduction factor of 0.5 is used. This means that the avertable dose from sheltering is one half the projected one-day dose for an unprotected individual. Conservative results can also be obtained by assuming that sheltering is 100% effective; in this case, the avertable dose is maximized resulting in the largest planning zone sizes. This would be the case, for example, for very modern homes, designed for extremely low air leakage, and where individuals can shelter in a well-built concrete basement. In this case, the dose that can be averted by sheltering is equal to the projected dose that would be received by an individual standing outside, under the plume, for one day.

2.2.2 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. Evacuation is not recommended for a period exceeding seven days [SS109].

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.

2.2.3 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 taking stable iodine just before exposure to the release is equal to the projected dose to the thyroid from inhalation without the administration of stable iodine.

2.2.4 *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.

2.2.5 *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;
- 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.

2.3 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)[2]. The thresholds for deterministic effects depend on the dose rate, i.e. on the level of exposure and on the duration of exposure.

The ISR technical note entitled *Program to Calculate the Influence of Protective Actions on Deterministic Effects* [ISR03] presents the mathematical model used to calculate the

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[2] The equivalent dose is not always the appropriate quantity for use in relation to deterministic effects because the values of the radiation weighting factors have been chosen to reflect the relative biological effectiveness (RBE) of the different types of radiation in producing stochastic effects. However, for beta and gamma radiation, which is low-energy-transfer radiation, the use of the equivalent dose is appropriate. For this type of radiation, with a radiation-weighting factor of 1, the absorbed dose (in Gy) and the equivalent dose (in Sv) are the same.

probability of deterministic effects as a function of equivalent dose and duration of exposure. The calculated dose thresholds represent the levels at which the effect would occur in 1% of the cases. Values obtained are consistent with internationally recommended thresholds [SS115].

2.4 Intervention Levels

Protective actions are implemented to prevent deterministic effects and to minimize stochastic effects. Protective actions have an inherent “cost” in terms of social, psycho-social and economic disruption.

Protective actions that limit the exposure to levels that are below the deterministic thresholds prevent deterministic effects. In this case, the benefit of implementing a protective action almost always outweighs the cost associated with the protective action.

Protective actions also reduce the risk of stochastic effects by an amount proportional to the effective dose ***averted***. In this case, the benefit of the protective action, which is expressed in terms of dose averted, does not always outweigh the cost associated with the protective action. For this reason, intervention levels are defined as the level of averted dose at which a protective measure, if introduced, is likely to produce more benefit than harm.

Table 2 lists the intervention levels for urgent protective actions for use in this document. These levels are consistent with international guidance [ICR63]. The International Atomic Energy Agency (IAEA) has adopted the same intervention levels of 10 mSv and 50 mSv for sheltering and evacuation, respectively [SS109]. The value corresponds to the dose averted for the time during which the protective measure is in effect. For evacuation, this should not be greater than seven days. For sheltering, although the IAEA [SS109] suggests two days as a maximum, in practice, this measure should not be in effect for more than about one day.

Intervention levels are planning values. During an actual emergency, the criteria adopted will most likely need to take into account socio-economic and political factors, particularly in the case of longer-term protective actions, when there is considerably more time available to make decisions. Table 2 describes the intervention levels used in New Brunswick.

Table 2: Intervention levels for use in this document

Protective action	**Effective dose (mSv)**	**Equivalent dose to thyroid (mSv)**
Sheltering	10 / 1 day	N/A
Evacuation	50 / 7 days	N/A
Temporary relocation	30 / first month	N/A
Stable Iodine administration	N/A	100 (inhalation component)

2.5 Emergency Planning Zones

Emergency planning zones represent the areas in which planning for given protective actions should take place based on health risk. The zones are based on the assessment that the health risk in those areas justifies the investment of resources and efforts required for detailed planning. It *does not* mean that, when an accident occurs, response will extend to the entire zone, or that it will be limited to these zones. Indeed, plans must have provisions to extend protective measures outside the planning zone.

International guidance [IAE953] suggests three planning zones as defined below. These definitions will be used throughout this document.

2.5.1 Precautionary Action Zone (PAZ)

The PAZ is the area where there is a risk of ***serious*** deterministic effects for the worst possible accident. Given that such severe accidents are extremely unlikely, the risk is very small indeed. Nevertheless, due diligence and the emergency planning principles stated in section 2.1 call for the need to take extraordinary precautions in the area where deterministic effects could occur, even for the most unlikely scenarios.

When an accident occurs, experience has shown that it is not always possible to determine with certainty the severity of the accident. There may also be little time to implement effective countermeasures close to the plant. Therefore, as a precaution, and for the purpose of preventing deterministic effects, it is prudent to evacuate the PAZ as soon as there are strong indications that a significant reactor core failure may be in progress. Hence, evacuation of the PAZ should be initiated automatically as soon as plant parameters indicate the possibility of core failure. As an alternative, automatic sheltering may be considered if the situation precludes an ordered and well-coordinated evacuation of that zone. The protective action would be implemented over a full 360 degrees as a precaution against a change in wind direction.

For planning purposes, postulated accidents that should be considered in the definition of the PAZ are those that lead to a core melt. Such accidents are extremely unlikely and are only to be considered in terms of the potential serious deterministic health effects that they may cause, in accordance with the planning principles of section 2.1.

2.5.2 Urgent Protective Action Zone (UPZ)

The UPZ is the area where the risk of exceeding intervention levels for stochastic effects is high but where the risk of deterministic effects is negligible. In this area, plans are developed to promptly implement sheltering, evacuation, stable iodine administration and immediate food bans. The decision to implement such countermeasures will depend on the situation and is not necessarily automatic. Plant parameters, accident trends and environmental measurements must be considered in deciding whether or not to implement the protective actions.

Due to the potential risk of contamination within that zone, emergency facilities such as evacuee centres and off-site Emergency Operations Centres (EOC) should be located outside the UPZ.

For planning purposes, postulated accidents that should be considered to define the

UPZ are those where fuel damage is limited and where the release, if one occurs, is mitigated by the containment system. These generally correspond to design-basis-accidents (DBA), which are considered in the design of the plant's safety systems and are analyzed as part of the licensing basis for the station.

However, to adequately understand the potential impact of the extent of fuel damage and the effectiveness of the containment system on the UPZ size, this technical planning basis also considers postulated accidents where partial fuel melt may occur and where the containment system may be partially ineffective due, for example, to containment isolation failure or containment bypass. The analysis of such postulated accidents provides a *safety* margin in the determination of a cautious UPZ size that is contingent on the assumptions made in the analysis. For this reason, we refer to the larger UPZ obtained from this analysis as the contingency zone in which plans should be developed to extend, if required, the planned capabilities for sheltering, evacuation and stable iodine administration.

2.5.3 Longer-Term Protective Action Zone (LPZ)

The LPZ is defined as the zone where, if there is an accident with a major release, protective actions such as relocation, resettlement and long-term agriculture countermeasures may be required. The precise definition of the LPZ depends greatly on the population distribution, land use and socio-economic factors around the station. [IAE953] recommends an LPZ of at least 50 km around a nuclear power plant. This is the immediate priority area for food sampling and the control of agricultural products and, indeed, food sampling arrangements should extend well beyond this radius.

3. Postulated accidents Used in the Technical Planning Basis

Postulated accidents considered in this technical planning basis are based on the postulated accidents contained in [TTR221]. These cover a wide range of possible scenarios that could lead to significant environmental releases.

Three types of release scenarios are considered in this technical basis:

- Design-basis releases (DBR), where the fuel damage is limited and most of the fission products are retained within the containment envelope;
- Beyond-design-basis releases (BDBR), where fuel damage may be more extensive and containment bypass may occur, thereby releasing a larger quantity of fission products to the environment; and
- Severe accidental releases (SAR), where fuel damage is extensive and the containment system fails.

For each release type, one representative accident drawn from [TTR-221] was selected. The representative accidents are described in the following sections.

3.1 Design-Basis Release (DBR)

Design-basis accidents are events that are taken into account in the design of the safety systems. They include, for example:

- 100% reactor outlet header break with failure of ventilation outlet dampers to close automatically;
- 100% reactor outlet header break with partial failure of dousing; and
- 60% reactor outlet header break with coincident loss of emergency core cooling.

DBRs are *unlikely*; safety systems are designed to mitigate the consequences of such events and to prevent further degradation of the situation. The fission product mix, release fractions to the environment and release timing vary depending of the accident.

However, this family of accidents is bounded by one of the events covered in TTR-221, i.e. a LOCA combined with loss of normal heat sink with both loops affected. In this case, the moderator acts as the ultimate heat sink. After about one hour, fuel damage occurs in both loops but the fuel does not relocate and does not melt. It is assumed that containment remains intact and that leakage to the environment occurs at 5% of the containment volume per day and lasts for approximately 8 hours.

This event is representative of the most conservative design-basis releases and has been selected as the reference DBR.

3.2 Beyond-Design-Basis Release (BDBR)

This family of accidental releases corresponds to events where additional failures occur, leading to greater release fractions to the environment. BDBRs are *very unlikely* due to the number of failures that must occur in order to get significant releases of radioactive products into the environment.

A representative case starts like a design basis accident but is compounded by a coincident with an impairment of the emergency cooling system that leads to a containment bypass. The release of radioactive fission products from the primary heat transport system bypasses the containment through the emergency core cooling system and would result in significant quantities of fission products in the environment.

This event is representative of significant releases that could occur following a serious accident with impairment of the containment system. It has been selected as the reference BDBR.

3.3 Severe Accidents Releases (SAR)

Severe accidents occur when the safety systems are impaired and are unable to prevent significant core damage, with the greatest release fractions. Such events are *extremely unlikely* because a large number of coincident failures of process and safety systems would need to occur. Furthermore, in some scenarios, the accident may threaten the integrity of the containment envelope. These are the worst case scenarios.

One such extremely rare postulated event is a power excursion with impairment and/or failure of the cooling systems leading to early core failure and disassembly. In this postulated event, the shutdown system fails to prevent a significant and prompt power increase. The resulting pressure pulse damages the pressure tubes and the calandria, thereby incapacitating long-term cooling through the moderator. This results in extremely high fuel temperatures, generation of hydrogen through the zirconium-steam reaction and subsequent hydrogen deflagration. The containment fails and the subsequent release of fission products to the environment is large and prompt. It is assumed that most of the release would occur in 30 minutes.

This event represents one of the worst case scenarios for CANDUs and has been selected as the reference SAR.

Table 3 summarizes the main characteristics of the reference events selected to represent the DBR, BDBR and SAR, respectively.

Table 3: Release categories [from TTR-221]

Release category	**SAR**	**BDBR**	**DBR**
Corresponding release category in TTR-221	CANDU-1b	MHS&CBTE	CANDU-4
Release fractions			
Xe-Kr	0.42	0.11	8×10^{-3}
Iodine aerosol	4×10^{-2}	1×10^{-3}	1×10^{-5}
Iode organic-elemental	(4×10^{-4})	(1×10^{-5})	(1×10^{-7})
Cs-Rb	4×10^{-2}	0	0
Te-Sb	4×10^{-2}	0	0
Sr	4×10^{-2}	0	0
Ru-Mo-Pd-Rh-Tc	4×10^{-2}	0	0
La-Y-Zr-Nb	4×10^{-2}	0	0
Ce-Nd-Eu-Pr-Pu-Sm-Np	4×10^{-2}	0	0
Ba	4×10^{-2}	0	0
Release parameters			
Frequency (per reactor-year)	2.5×10^{-8}	4.9×10^{-7}	2.2×10^{-6}
Likelihood	Extremely unlikely	Very unlikely	Unlikely
Release duration (h)	0.5	3	8
Release height (m)	30	10	20
Heat content (MW)	50	0	0

4. Accident Consequences

4.1 Modelling and Assumptions

The CANDU core inventory used in the calculations is described in ANNEX A: CANDU Core Inventory. Projected consequences for all postulated accident scenarios were calculated using an internationally-accepted code called COSYMA. A detailed description of the code, modelling assumptions and individual calculations carried out are contained in ANNEX B: Modelling and Assumptions. A list of all runs performed is contained in ANNEX C: Table of Calculations Performed.

4.2 Weather

Weather statistics for the Point Lepreau site were obtained from Environment Canada for a period of two years. They are summarized in Table 4. As can be noted, Pasquill D is the average weather condition. Pasquill F, which is the least dispersive weather (and the worst for near-ground releases) occurs less than 10% of the time.

Table 4: Weather statistics for the Point Lepreau site

Pasquill stability	Frequency	Average wind speed (m/s)
A	4.1	1.4
B	8.4	2.6
C	19.0	3.7
D	45.1	4.2
E	15.2	2.4
F	8.2	1.4

4.3 Consequences of DBRs

Effective doses (committed over 50 years for the average individual) resulting from the reference DBR were calculated for periods of exposure of one and seven days for average and worst weather conditions (Pasquill D and F, respectively)[3]. The results are shown in Figure 1 and Figure 2.

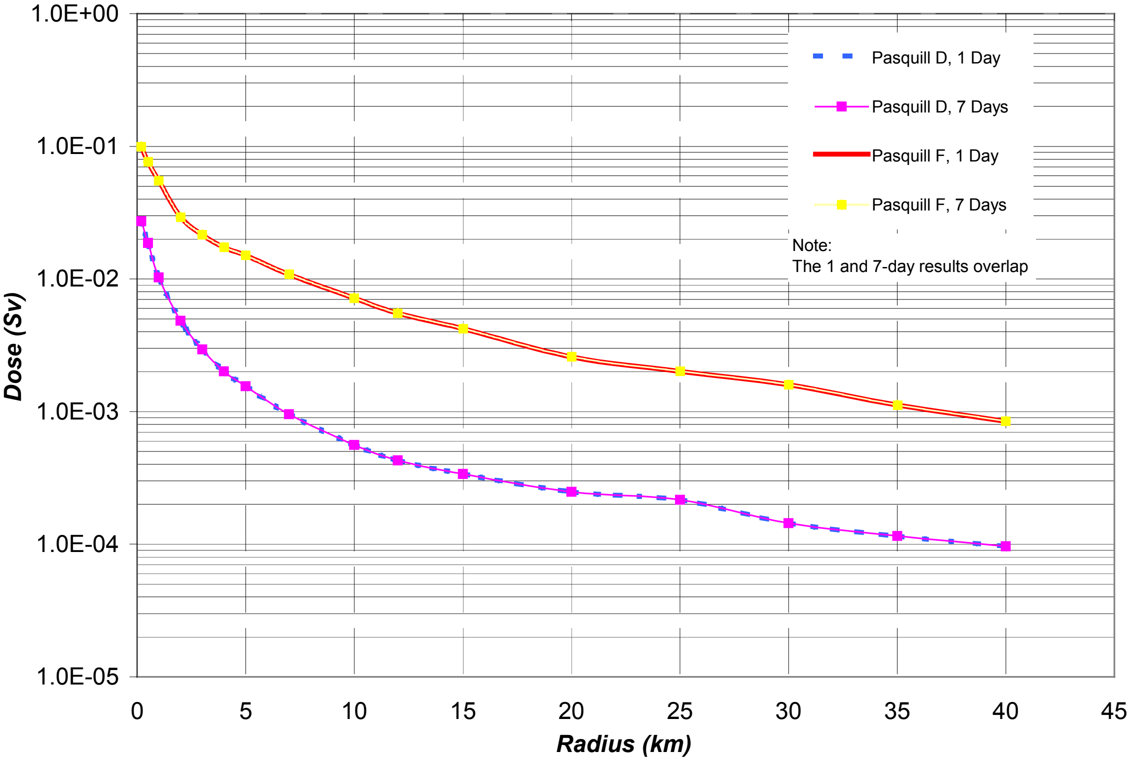

Figure 1: Effective dose for the DBR

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[3] The DBR is a near-ground release with no heat content. The worst weather for such a case, in terms of the distance at which high doses are reached, is always Pasquill F. It is important to note that, for Pasquill F, the area potentially affected is much narrower than for more dispersive weather conditions.

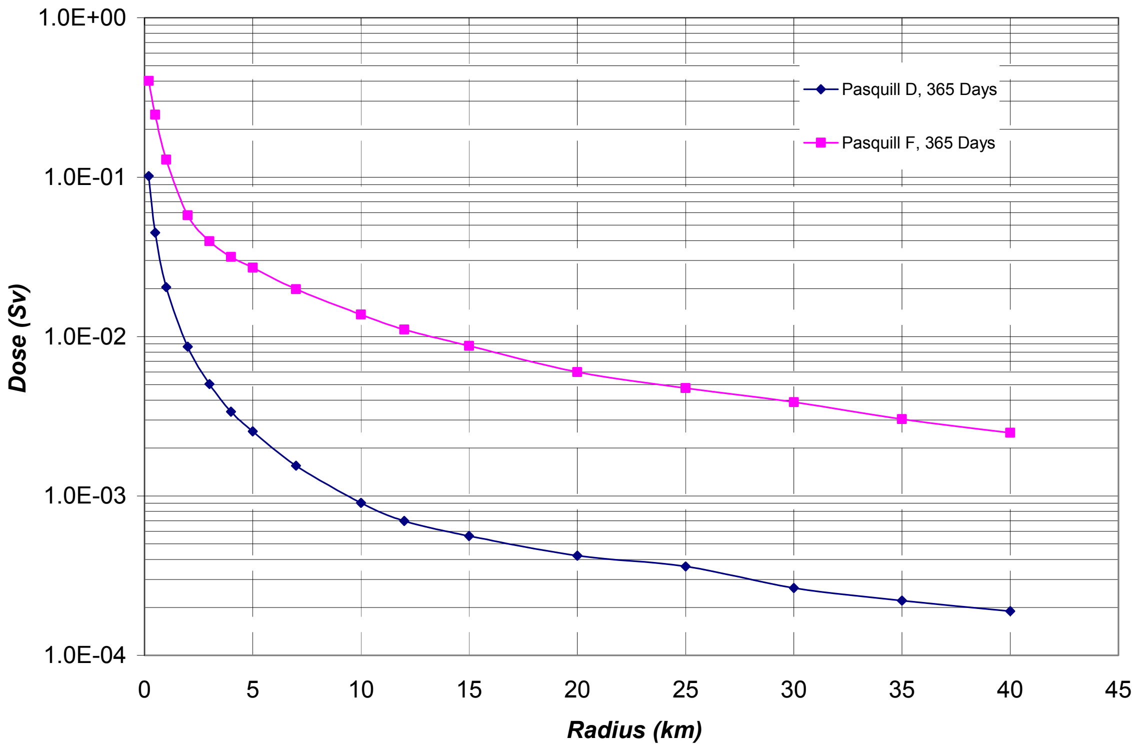

Figure 2: Thyroid dose for the DBR

As can be seen, doses vary significantly with weather category but the seven-day and one-day doses are almost identical. This is explained by the fact that the source term contained very little quantities of material that deposit on the ground. The resulting ground shine is extremely small.

Most of the thyroid dose comes from the inhalation pathway.

The distances at which the intervention levels for sheltering (10 mSv for one-day exposure), evacuation (50 mSv for seven-day exposure) and stable iodine administration (100 mSv thyroid) are reached are summarized in Table 5.

Table 5: Distances for intervention levels for the DBR

Case	Sheltering intervention level (10 mSv in one day) reached at:	Evacuation intervention level (50 mSv in seven day) reached at:	Intervention level for stable iodine(100 mSv thyroid) reached at:
DBR, Pasquill D	1 km	< 1 km	< 1 km
DBR, Pasquil F	7.5 km	1 km	1.3 km

4.4 Consequences of BDBRs

Effective doses (committed over 50 years for the average individual) resulting from the reference BDBR were calculated for periods of exposure of one and seven days for average and worst weather conditions (Pasquill D and F, respectively)[4]. The results are shown in Figure 3 and Figure 4.

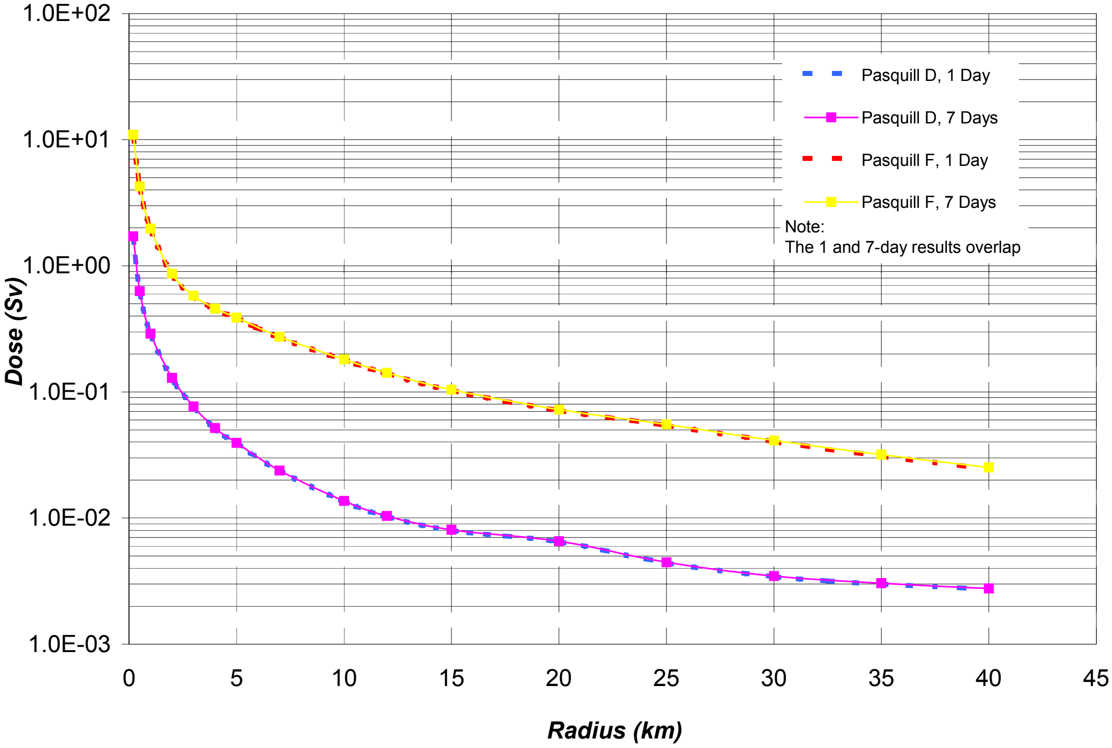

Figure 3: Effective dose for the BDBR

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[4] The BDBR is also a near-ground release with no heat content.

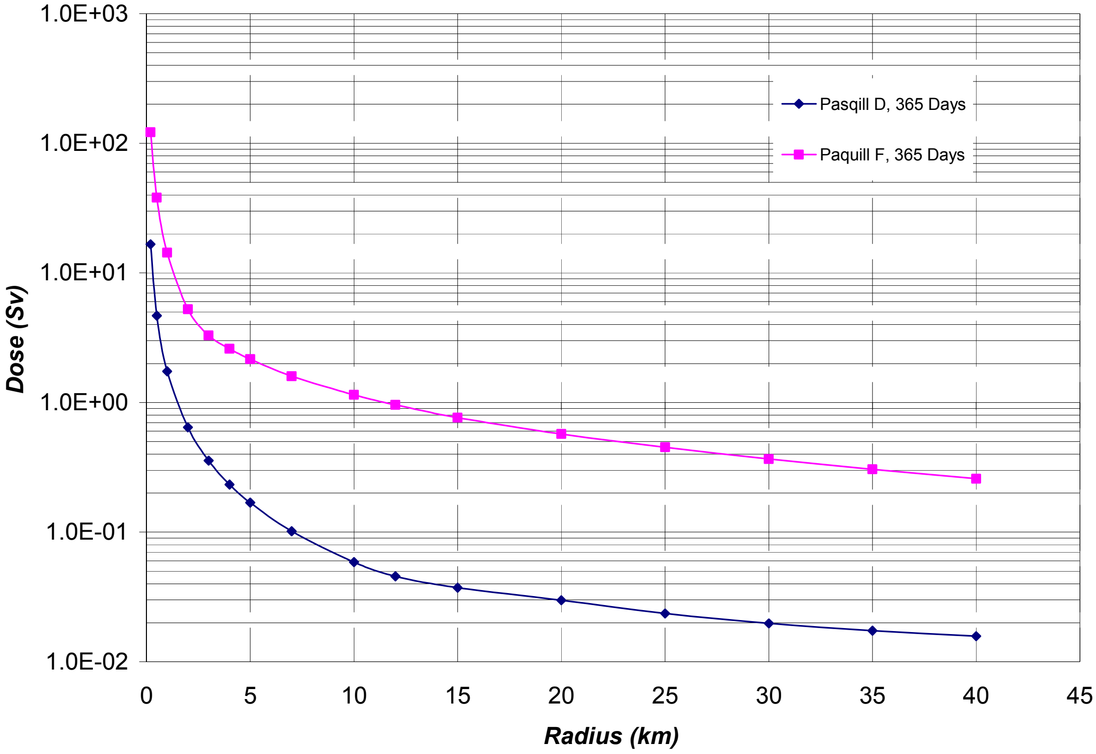

Figure 4: Thyroid dose for the BDBR

As for the DBRs, the deposition on the ground is minimal. As a result, the one and seven-day doses are practically identical.

The distances at which the intervention levels for sheltering (one-day exposure), evacuation (seven-day exposure) and stable iodine administration are reached are summarized in Table 5.

Table 6: Distances for intervention levels for the BDBR

Case	Sheltering intervention level (10 mSv in one day) reached at:	Evacuation intervention level (50 mSv in seven day) reached at:	Intervention level for stable iodine(100 mSv thyroid) reached at:
BDBR, Pasquill D	12 km	4 km	7 km
BDBR, Pasquil F	>40 km	26 km	>40 km

4.5 Consequences of SARs

The SARs are used to determine the distance at which deterministic affects could potentially result. Therefore, for SARs, only the deterministic doses to critical organs were calculated.

Figure 5 shows the result of calculations of the probable risk of morbidity vs distance for the reference SAR with an elevated release[5]. This probabilistic risk takes into account historical weather conditions at the site as measured by Environment Canada. It also takes into account the variability in wind direction. In other words, the fractile is the confidence interval that the risk of deterministic effect will not exceed the value given by the curve at a given distance. For example, the results show that:

- beyond 3 km there is a 99.4% probability that the risk of deterministic effects (morbidity or mortality) will be zero;
- beyond approximately 1 km, there is a 99% probability that the risk of deterministic effects will be zero.

The risk of mortality for the same confidence intervals has also been calculated but it is zero beyond 0.5 km.

To estimate the sensitivity of the results to the heat content and release elevation, the same calculations has been performed for a release with no heat content. The results, shown in Figure 6 for the risk of morbidity, show that there is no risk of deterministic effects beyond 4 km for a 99% confidence interval). Within a 99.4% confidence level, the risk is significantly reduced (by a fact 10) at 5 km and disappears beyond 7 km.

The calculations performed for the risk of mortality show that the risk disappears beyond 3 km for a 99.4% interval.

The risk of deterministic effects can be significantly reduced through sheltering of the populations. Table 7 shows the distances at which deterministic thresholds for specific organs may be exceeded for the SAR with Pasquill D and no heat release. As can be noted, sheltering is very effective in reducing the risk of deterministic effects.

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[5] The release is elevated because the heat content required to have the postulated severe failure of the containment would loft the plume.

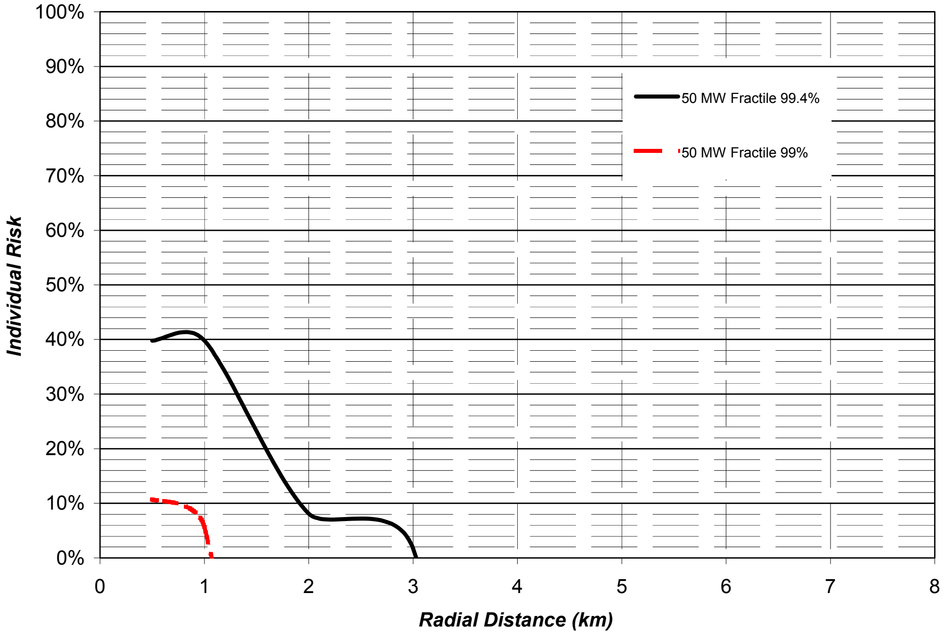

Figure 5: Individual morbidity risk for SAR with elevated release (50 MW)

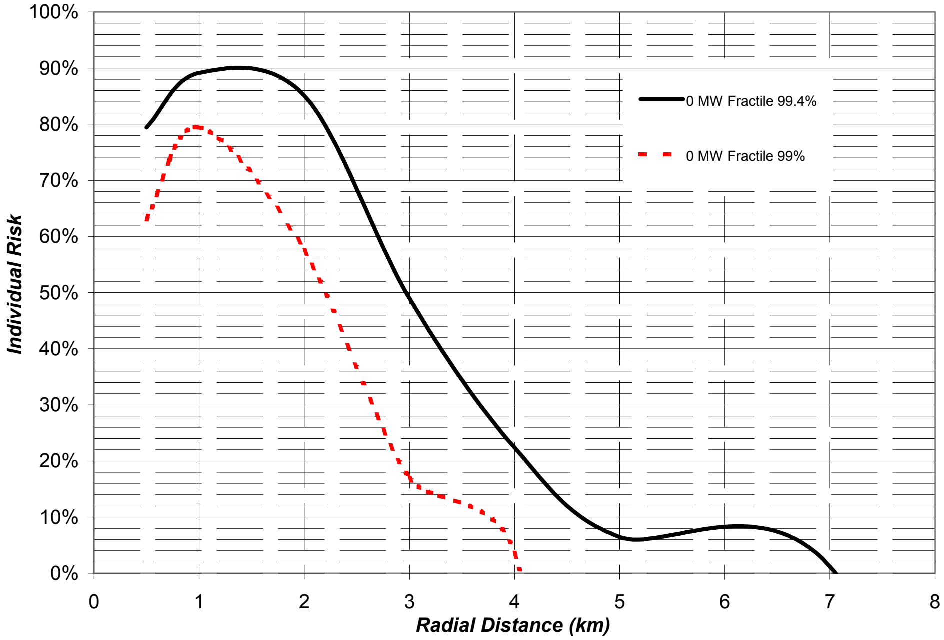

Figure 6: Individual morbidity risk for SAR with ground release (0 MW)

Table 7: Effect of protective actions on deterministic distances for SARs, Pasquill D, no heat content

Effect	**Protective action**	
	None	**Sheltering**
Mortality	Distance (km)	
Lungs	1.16	0.24
Bone marrow	2.54	0.00
GI track	2.40	0.00
Morbidity		
Lungs	1.53	0.47
Thyroid	3.02	0.00

4.6 Ratio of Measured Dose Rate to Effective Dose

When responding to an emergency, the most readily available data on the magnitude of the hazard is the measured dose rate, or ambient dose rate. This is a measure of the external hazard and it does not account for the internal dose that may be received by an individual. Nevertheless, it is an important quantity that will be used in section 5.3 for the calculation of operational intervention levels.

The following ratios were calculated:

- ambient dose rate to effective dose rate in the plume;
- one-day ambient dose to seven-day effective dose from ground exposure, including the internal dose from resuspension; and
- one-day ambient dose to 30-day effective dose from ground exposure, including the internal dose from resuspension.

The results are shown in Figure 7, Figure 8 and Figure 9.

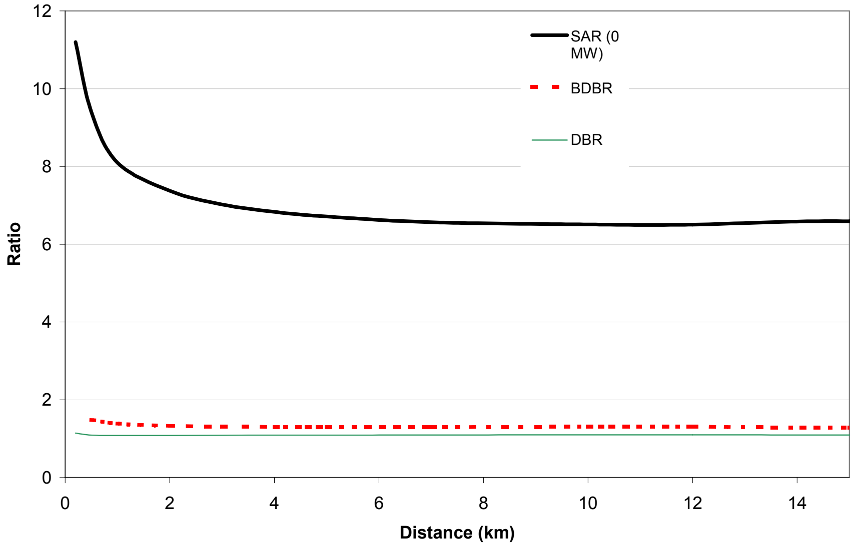

Figure 7: Ratio of effective over ambient dose rate in the plume

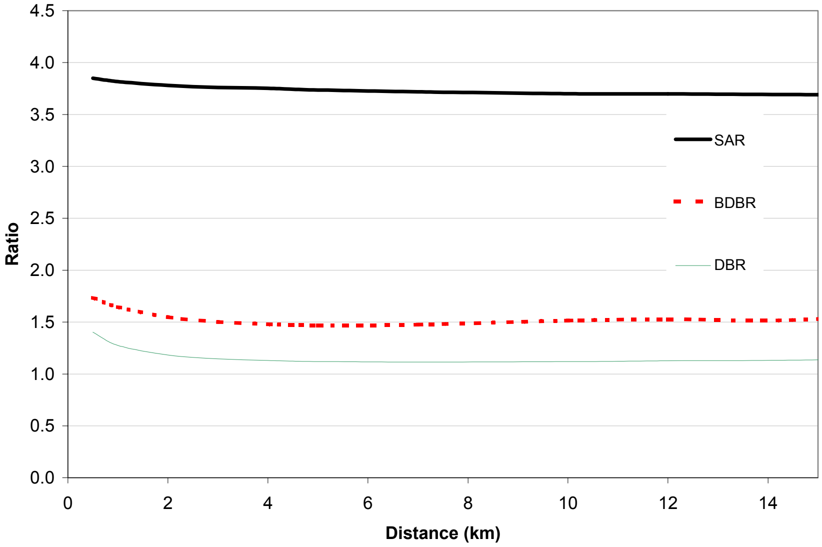

Figure 8: Ratio of seven-day effective dose from ground shine over one-day ground shine ambient dose

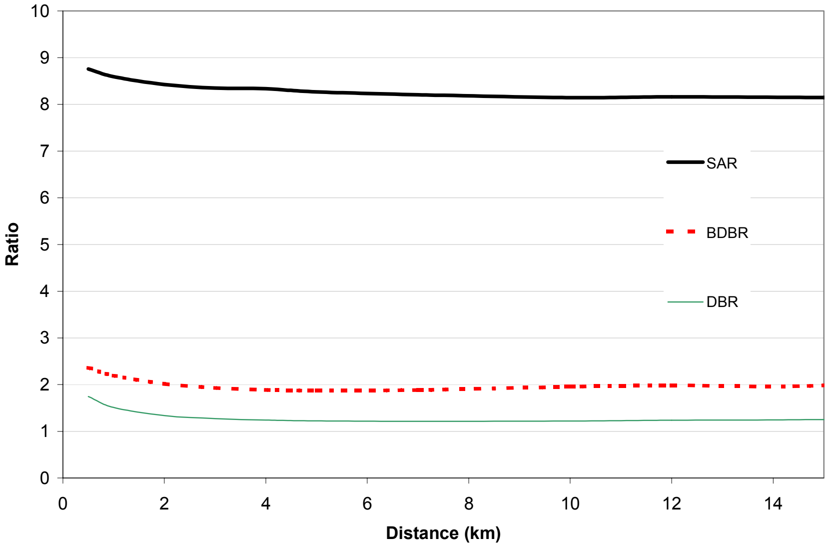

Figure 9: Ratio of 30-day effective dose from ground shine over one-day ground shine ambient dose

4.7 Exposure by Pathway

The importance of each exposure pathway (cloud shine, inhalation and ground shine) depends on the accident type, i.e. the release composition. Table 8 shows the typical contribution of each exposure pathway for the reference accidents examined. It shows that, in the case of smaller releases (DBR and BDBR), cloud shine is the main contributor to dose. The inhalation component is much more important for BDBR. For the severe release (SAR), the pathway contribution depends on the deterministic effect being considered. Not surprisingly, for effects associated with the lungs or the thyroid, the inhalation component dominates. For others, the external exposure from the cloud and the ground are most important.

Another interesting result is that the ground shine component only becomes significant for severe accidents. The significance of this result is that evacuation or relocation ***after*** the release would only be effective for severe accidents. In all other cases, prompt protective actions before or during the release will be the only effective means of reducing the dose to the public.

Table 8: Exposure by pathway for seven-day exposure duration

Release type	**Exposure pathway contribution to dose (%)**		
	Cloud shine	**Inhalation**	**Ground shine**
DBR (effective dose)	92	7	1
BDBR (effective dose)	75	23	2
SAR (organ doses)			
Lung	17	69	14
Thyroid	14	75	11
Cataracts	55		45
Hematopoietic syndrome	51	7	42
Neonatal impacts	49	7	44

5. Implications for Emergency Planning

Emergency planning decisions are based on a practical interpretation of the results presented in the last section. This interpretation must take into account the consequences of accidents and their likelihood while considering the cost of planning vs. its benefit.

The following discussion stems from the emergency planning principles stated in section 2, which involve a prioritization of the needs based on considerations of likelihood. A systematic evaluation of the analysis discussed in the previous section is made in terms of emergency planning. However, more weight is given to consequences that have a higher likelihood of occurrence. That is the only way to reach a proper balance between the benefits, the practicality and the cost of planning.

The following discussions are based on intervention levels listed in section 2.4. Distances at which certain measures are justified will refer to the distance beyond which the dose that can be averted is lower than the intervention level. The definitions of the UPZ and PAZ were given in section 2.5.

5.1 PAZ

Section 4.5 shows that there is no risk of deterministic effects beyond 3 km with a 99.4% confidence and beyond 4 km, even for the worst case scenario with no heat content, with a 99% confidence interval. Therefore, a PAZ size of 4 km around the station is recommended.

The results also show that sheltering, if properly implemented, can eliminate or significantly reduce the probability of deterministic effects within the PAZ.

5.2 UPZ

Section 4.3 shows that intervention levels for urgent protective actions (sheltering, evacuation and stable iodine administration) would not be exceeded beyond 7.5 km for DBR, even for the worst weather scenario. Section 4.4 shows that sheltering may be required up to 12 km for the BDBR combined with an average weather scenario. Therefore, based on considerations of likelihood, there is a strong justification for the establishment of urgent protective action plans up to 7.5 km around the station and for contingency arrangements up to 12 km to cover the very unlikely case of BDBRs.

As shown by the results for the even more unlikely case of a BDBR combined with the worst weather condition, it is possible that protective actions be required outside the UPZ of 12 km. However, given the very low likelihood of such a combination of events, extending the size of the contingency zone beyond 12 km may not be justified.

Therefore, a UPZ size of 12 km around the station is recommended.

Should an accident occur and environmental surveys, plant conditions and weather data indicate that the intervention levels may be exceeded beyond 12 km, protective actions would need to be implemented beyond that distance.

5.3 Operational Intervention Levels (OILs)

During an emergency, the decision to implement protective actions must be based on avertable dose. This quantity is difficult to estimate. It involves making field measurements, relating them to dose rate, estimating the time required to implement the protective action, guessing the duration for which people would be exposed without the protective action and finally calculating the dose that can potentially be averted. This process takes time and gives rise to discussions amongst specialists that can delay the introduction of the protective action and adversely affecting the effectiveness of emergency response in the immediate phase.

To assist prompt decisions in the initial phase of the emergency, Operational Intervention Levels (OILs) are introduced. An OIL is the value of commonly measured parameters (e.g. ambient dose rate) that corresponds to the intervention level for a specific protective action. It is based on a number of assumptions regarding exposure pathway, release composition and exposure durations. However, what is lost in terms of accuracy is gained in terms of rapidity of decision-making, which is critical in the initial phase.

OILs are well defined in IAEA's TECDOC 955 [IAE955]. There are several OILs, including OILs for sheltering, for evacuation based on ambient measurements in the plume, for evacuation based on ground shine measurements and for relocation based on ground shine measurements.

OILs are used when prompt decisions are required. They can also be used as a guide when more time is available to make decisions. For example, OILs for relocation based on ground shine should only be used to indicate if relocation needs to be considered. Before a drastic decision such as relocation is made, detailed isotopic analyses of the ground contamination and of the potential exposure pathways would have to be carried out.

All these OILs are based on assumed ratios of effective to ambient dose rates for the exposure pathways considered and for given exposure times.

5.3.1 OILs for Sheltering and Evacuation in the Plume

IAEA TECDOC 955 describes in detail the methodology for calculating and revising the OILs. The equation used is as follows:

$$OIL = \frac{GIL}{c \times T \times R} \qquad (1)$$

where:

OIL = operational intervention level for a given protective action
GIL = generic intervention level for that protective action
T = the assumed exposure time if no action is taken, which is assumed to be four hours based on wind persistence statistics for the North American continent
c = the ratio of effective to ambient dose rate
R = reduction factor for protective actions already taken

There are several possible OILs, depending on the type of protective action considered. As shown in Figure 7, the ratio “c” of effective to ambient dose rate is highest for the SAR and varies between 7 and 10 in the first five kilometres. Adopting a default value of 10 would be conservative since it would lead to lower OILs for the protective actions considered. This value is the same as that proposed by the IAEA in TECDOC 955. Therefore, it is proposed to use the same OILs as those recommended by the IAEA in TECDOC 955: 0.1 mSv/h for sheltering and stable iodine administration[6] and 1 mSv/h for evacuation. Details of the calculation are given in [IAE955]

5.3.2 OILs for Evacuation Based on Ground Shine

The OIL for evacuation based on ground shine is calculated from the following assumptions:

- The exposure time without evacuating would be seven days, which is the practical limit recommended for an evacuation.
- Credit is taken for the fact that people would spend most of their time indoors, with a reduction factor given earlier of 0.5.

In this case, except for exposure through the re-suspension of contaminants, there is no internal dose from the ground shine, and the ratio of effective to ambient dose rate is 1. Hence, equation (1) can be replaced by the following:

$$(OIL \times 24) = \frac{GIL}{c' \times R} \qquad (2)$$

where:

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[6] A similar equation can be used to calculate an OIL for stable iodine administration. In that case, c is the ratio of thyroid to effective dose. In its calculations [IAE955], the IAEA does not take into account the reduction factor for sheltering. This yields an OIL of 0.125 mSv/h. The OIL for sheltering calculated using equation 1 would be 0.25 mSv/h. For practical reason, the IAEA suggested that sheltering and stable iodine should be combined and the lower value of 0.1 mSv/h was retained.

c’ = ratio of seven-day dose to one-day dose from ground shine, which is not equal to 7 due to the decay of deposited fission products

Figure 8 shows that c’ is approximately 4 for the worst case (SAR) in the first five kilometres, which yields an OIL of 1.3 mSv/h. This is very close to the value of 1 mSv/h suggested by the IAEA. Hence, the latter is recommended as an OIL for evacuation based on ambient ground shine measurements.

5.3.3 OILs for Relocation Based on Ground Shine

The method for calculating this OIL is the same as the previous one, except that this time the factor c’ is the ratio of the 30-day dose to the one-day dose. The GIL for relocation is 30 mSv in the first month. Figure 9 shows that the values of c’ for the worst case is approximately 8, which yields an OIL of 0.4 mSv/h. This is of the same order of magnitude as the IAEA OIL of 0.2 mSv/h for this protective action. Since the IAEA value is slightly more conservative, it is the one being recommended.

5.3.4 OIL for Food Bans Based on Ground Shine

The only way to determine if food contamination exceeds standards for consumption is to sample and analyze the food. Hence, an OIL for a food ban based on ground shine is only suggested as a screening tool for the very early stage of an emergency. The IAEA suggested a value of 0.001 mSv/h. This is not based on a careful technical analysis. This value is meant to be approximately 10 times normal local background and is only used as a positive indication that there are high levels of ground contamination. Follow-on recommendations for food bans must be based on isotopic analysis of the ground contamination and of the potential exposure pathways.

5.3.5 Summary of OILs

The recommended OILs are listed in Table 9.

Table 9: Recommended OILs

Measurement	OIL	Protective action
Ambient dose rate in the plume	1 mSv/h	Evacuate or provide substantial sheltering.
	0.1 mSv/h	Shelter and administer stable iodine, if available.
Ambient dose rate from deposition, after the plume has passed	1 mSv/h	Evacuate.
	0.2 mSv/h	Consider relocating people. Perform isotopic analysis.
	10 times normal local background	Immediately restrict consumption of potential contaminated food until more detailed analyses can be made.

5.4 Emergency Response Strategy

When an accident occurs, it is practically impossible to assess if the situation will evolve into a DBR or an SAR. It is also very difficult to predict if there will be a release, or how large the release will be. The accident at Three Mile Island highlighted the complexity of predicting the outcome of an accident at the time it occurs. For example, operators did not know until several weeks later how much of the core had melted, nor were they aware at the time of the accident that a release would take place. Hence, the initial protective action strategy must rely on very little information and should err on the safe side.

Based on the discussion above on the PAZ and the UPZ, the following initial protective action strategy is recommended:

- When an accident that could lead to core melt is detected, immediately evacuate or shelter the full PAZ around the station (PAZ). The action is implemented over the full 360 degrees as a precaution against possible wind shifts.
- Immediately dispatch survey teams downwind to monitor ambient radiation levels and air contamination to detect a release.
- Once a release is imminent or has been detected, shelter people within the UPZ downwind from the station. If the wind direction changes, adjust the sectors in which the protective action is implemented.
- Conduct environmental radiation surveys within the UPZ to determine if further protective actions are required.
- If readings are high compared with OILs, expand the area surveyed and adjust protective actions where required.

6. Conclusion

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 improvide).

The measures proposed in this technical planning basis represent our 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.

ANNEX A: CANDU Core Inventory

References: [REID-97], [REID-98]

Table 10: Steady state core inventory for CANDU-600

Isotope	Inventory (Bq)	Isotope	Inventory (Bq)	Isotope	Inventory (Bq)
KR-85	4.62E+15	SB-131	1.88E+18	ZR-95	3.24E+18
KR-85M	6.50E+17	SB-132	1.14E+18	ZR-97	3.98E+18
KR-87	1.30E+18	SB-132M	1.04E+18	NB-95	2.58E+18
KR-88	1.81E+18	SB-133	1.49E+18	NB-97	3.90E+18
KR-89	2.28E+18	TE-127	1.88E+17	MO-99	4.48E+18
KR-90	2.42E+18	TE-127M	1.91E+16	MO-101	4.04E+18
XE-131M	2.68E+16	TE-129	7.24E+17	MO-102	3.74E+18
XE-133	4.78E+18	TE-129M	1.30E+17	MO-104	2.68E+18
XE-133M	1.50E+17	TE-131	2.04E+18	TC-99M	4.00E+18
XE-135	4.26E+17	TE-131M	4.48E+17	TC-101	4.04E+18
XE-135M	1.03E+18	TE-132	3.44E+18	TC-102	7.50E+16
XE-137	4.48E+18	TE-133	2.68E+18	TC-104	2.84E+18
XE-138	4.24E+18	TE-133M	2.24E+18	TC-105	2.30E+18
XE-139	3.12E+18	TE-134	4.34E+18	RU-103	3.04E+18
AS-77	5.42E+15	I-130	1.24E+18	RU-105	2.28E+18
AS-79	3.22E+16	I-131	2.40E+18	RU-106	3.70E+17
SE-83	1.46E+17	I-132	3.54E+18	RH-105	1.91E+18
BR-82	1.89E+15	I-133	4.96E+18	PD-109	6.70E+17
BR-83	3.08E+17	I-134	5.52E+18	AG-110M	6.62E+14
BR-84	5.68E+17	I-135	4.70E+18	AG-111	1.10E+17
BR-87	1.02E+18	I-136	2.08E+18	AG-112	5.44E+16
RB-86	5.74E+14	I-136M	1.06E+18	AG-113	3.02E+16
RB-88	1.87E+18	CS-134	2.06E+16	BA-139	4.44E+18
RB-89	2.40E+18	CS-136	3.04E+16	BA-140	4.34E+18
RB-90	2.20E+18	CS-137	5.12E+16	BA-141	4.00E+18
RB-90M	7.14E+17	CS-138	4.60E+18	BA-142	3.78E+18
RB-91	2.94E+18	CS-139	4.28E+18	LA-140	4.42E+18
CD-113M	1.08E+13	CS-140	3.82E+18	LA-141	4.06E+18
CD-115	1.69E+16	SR-89	2.14E+18	LA-142	3.92E+18
CD-115M	5.96E+14	SR-90	3.68E+16	CE-141	3.68E+18
SB-122	2.76E+14	SR-91	3.14E+18	CE-143	3.80E+18
SB-124	1.40E+14	SR-92	3.30E+18	CE-144	1.15E+18
SB-125	4.56E+15	Y-90	3.96E+16	ND-147	1.52E+18
SB-126	6.30E+14	Y-91	2.60E+18	PM-147	1.38E+17
SB-127	2.02E+17	Y-91M	1.82E+18	SM-153	3.88E+17
SB-128	3.64E+16	Y-92	3.32E+18	EU-154	9.66E+14
SB-128M	3.70E+17	Y-93	2.48E+18	EU-155	1.18E+15
SB-129	7.76E+17	Y-94	3.96E+18	EU-156	1.36E+17
SB-130	2.76E+17	Y-95	4.18E+18	EU-157	4.02E+16
SB-130M	1.05E+18	Y-96	3.72E+18	CM-242	2.08E+15

ANNEX B: Modelling and Assumptions

1. Dispersion and dose calculations

1.1 Methodology

Dispersion calculations and dose projections were performed based on the source term provided in ANNEX A: CANDU Core Inventory, for each reference release considered. A well-established computer code, COSYMA [HAS91], was used to carry out this analysis.

COSYMA calculates the acute doses and the corresponding deterministic risk of early effects in the **Near-Early module** (NE). The equivalent doses by organ and the effective dose (50 years committed) are calculated in the **Near-Late module** (NL).

The organs considered for the calculation of deterministic effects are the key radiosensitive ones for nuclear reactor accidents, namely:

- the lungs;
- the thyroid;
- the red bone marrow; and
- the gastro-intestinal tract.

The analysis also examines the impacts of residence time and of protective actions on dose and on distances up to which deterministic effects are possible.

1.2 Codes

1.2.1 COSYMA Software

The COSYMA computer code [HAS95] is a flexible software package developed by the Kernforschungszentrum Karlsruhe (KfK, FRG) and the National Radiological Protection Board (NRPB) for the European Union. This program was developed to carry out probabilistic risk assessment of postulated accidents at nuclear power plants. The mainframe version of the code was selected over the more commonly used PC-COSYMA release, due to its additional flexibility and more powerful output options.

The data entered into COSYMA is processed by an atmospheric dispersion module, based on the MUSEMET model. The resulting nuclide-specific activity concentrations are then fed into the dose and risk consequence module (see COSYMA User Guide [HAS95]).

Prior to its use in the context of this study, COSYMA was extensively verified and validated using the methodology for computer program QA outlined in Appendix A of "*Corporate Policies -- Nuclear Analysis*" [ISR04]. The results of this validation are described in "*Cosyma 95/1: Program Implementation Guide*" [ISR05].

1.2.2 Post-Processing Code

This program, *CosymaRunParserV4.VBP* [ISR02], developed by ISR, allows the COSYMA output to be parsed, processed and displayed in a user-friendly format. The program does not modify but rather copies the numbers produced by COSYMA, making it simple to validate.

1.2.3 Spreadsheet Program

The results for the deterministic doses are processed by a spreadsheet program called *LDLM2000.XLS*, which was developed by ISR. It calculates the distance beyond which the risk of deterministic effects is negligible. This program is described in detail in the report "*Program to Calculate the Influence of Protective Actions on Deterministic Effects*" [ISR03].

1.3 Models and assumptions

1.3.1 Inventory

The COSYMA isotope library contains the 200 most radiologically significant radionuclides. The core inventory calculated with ORIGEN, contains about one thousand nuclides. Those that are not included in COSYMA are assumed to play a minor role in the calculation of dose.

The remaining nuclides were then filtered using the "SOURCE" program included in the COSYMA code, in order to obtain a list of the 60 most important nuclides in the early timeframe (less than a year), along with the 60 most relevant nuclides in the late timeframe (50 years). Both lists were generated using a tolerance of about 2%, and are identical, except for the presence of Y-93 and Cm-242 in the early timeframe vs. Sb-131 and Te-131 in the late timeframe. The resulting lists of isotopes are presented in Annex A of this document.

Deposition parameters for the nuclides were based on the default COSYMA values for five different groups of nuclides: noble gases, aerosols, elemental iodine, organically bound iodine, and aerosol iodine.

1.3.2 Release Duration

COSYMA's dispersion parameters are appropriate for a release duration of one hour. When the duration is different, adjustments to the horizontal dispersion parameters are required [CO85].

The effect of release duration on the atmospheric dispersion parameters was modelled using the correction suggested by equation 5.8 of CAN/CSA 288.2 [CSA91].

$$\sigma_y(x,t_d) = \sigma_y(x,t_r) \cdot \left(\frac{t_d}{t_r}\right)^{0.2}$$

where

σ_y is the horizontal dispersion (sigma) parameter (m)
x is the downwind distance (m)
t_r is the reference duration of the release (one hour for COSYMA)
t_d is the release duration (h)

COSYMA sigmas are expressed as:

$$\sigma_y(x, t_r) = p \cdot x^q$$

The parameters *p* and *q* are empirical factors that depend on the atmospheric stability. The release duration correction only affects p. Default values used in COSYMA are for a one-hour release duration. Others are shown in Table 11.

Table 11: Correction of horizontal sigmas (*p*) for release duration

1 hour							
	Height	A	B	C	D	E	F
Rural	50 m	0.946	0.826	0.586	0.418	0.297	0.235
	100 m	0.946	0.826	0.586	0.418	0.297	0.235
	180 m	0.946	0.826	0.586	0.418	0.297	0.235
Urban	50 m	1.503	0.876	0.659	0.640	0.801	1.294
	100 m	0.170	0.324	0.466	0.504	0.411	0.253
	180 m	0.671	0.415	0.232	0.208	0.345	0.671
0.5 hour							
	Height	A	B	C	D	E	F
Rural	50 m	0.824	0.719	0.510	0.364	0.259	0.205
	100 m	0.824	0.719	0.510	0.364	0.259	0.205
	180 m	0.824	0.719	0.510	0.364	0.259	0.205
Urban	50 m	1.308	0.763	0.574	0.557	0.697	1.126
	100 m	0.148	0.282	0.406	0.439	0.358	0.220
	180 m	0.584	0.361	0.202	0.181	0.300	0.584
3 hours							
	Height	A	B	C	D	E	F
Rural	50 m	1.178	1.029	0.730	0.521	0.370	0.293
	100 m	1.178	1.029	0.730	0.521	0.370	0.293
	180 m	1.178	1.029	0.730	0.521	0.370	0.293
Urban	50 m	1.872	1.091	0.821	0.797	0.998	1.612
	100 m	0.212	0.404	0.581	0.628	0.512	0.315
	180 m	0.836	0.517	0.289	0.259	0.430	0.836
8 hours							
	Height	A	B	C	D	E	F
Rural	50 m	1.434	1.252	0.888	0.634	0.450	0.356
	100 m	1.434	1.252	0.888	0.634	0.450	0.356
	180 m	1.434	1.252	0.888	0.634	0.450	0.356
Urban	50 m	2.278	1.328	0.999	0.970	1.214	1.961
	100 m	0.258	0.491	0.706	0.764	0.623	0.383
	180 m	1.017	0.629	0.352	0.315	0.523	1.017

1.3.3 Weather

There are two ways to define the weather in COSYMA:

- as fixed weather in terms of stability class, wind speed and direction, and precipitation; or
- as a weather data file that contains hourly meteorological data for a minimum of one year.

The second method allows multi-phase releases to be modelled. It also allows risk calculations over the entire geography and population distribution.

Based on historical data provided by Environment Canada for the Point Lepreau site, the reference weather scenario used is Pasquill D, wind speed 4.2 m/s and mixing height of 500 m. For releases with heat content, the sensitivity of the results was evaluated for all stability categories and as a function of wind speed and mixing height. For releases with no heat content, Pasquill F with a wind speed of 1.4 m/s were used. Table 12 shows the parameters used for each stability category.

Table 12: Weather scenarios used in the calculations

Stability category	Wind speed (m/s)	Mixing height (m)
A	1.4	1000
B	2.6	1000
C	3.7	500
D	4.2	500
E	2.4	200
F	1.4	100

COSYMA also allows statistical calculations to be performed on the basis of the weather frequency. Weather scenarios were obtained from a two-year record provided by Environment Canada for the Point Lepreau site. To perform statistical calculations, COSYMA randomly samples the weather file, which contains hourly data for stability, wind and wind direction over the two-year duration. The results of a large number of runs are ranked in terms of the probability of exceeding given dose levels. The output is provided in terms of confidence interval, i.e. the probability that a dose or health effect will be less than a given threshold 90%, 99% or 99.9% (for example) of the time, based on the possible weather scenarios.

1.3.4 Receptor

The dose is calculated for an average adult in accordance with ICRP-60 [ICR60].

The dose to risk relationship for deterministic effects is based on models published by NRPB [NRP88] and the USNRC [NRC90].

A breathing rate of 3.333×10^{-4} m^3/s was selected for all runs, in both the near-early and near-late subsystems. This is slightly higher than the rate suggested by the Canadian standard (2.70×10^{-4} m^3/s). Table 13 and Table 14 list the breathing rates recommended by various organizations. The rate used in COSYMA is consistent with the value suggested by ICRP-75.

Table 13: Breathing rates recommended by various organizations

Age group	EPA, ICRP-23 & ICRP-75		CAN/CSA		US-NRC & ICRP-2	
	(m^3/a)	(m^3/s)	(m^3/a)	(m^3/s)	(m^3/a)	(m^3/s)
Infant	-	-	-	-	1.9E3	6.02E-5
Child	-	-	1.4E3	4.4E-5	2.7E3	8.56E-5
Adolescent	-	-	-	-	5.1E3	1.62E-4
Adult	1.05E4	3.33E-4	8.4E3	2.7E-4	7.3E3	2.31E-4

Table 14: Breathing rate as a function of age [UNSCEAR 2000], [ICRP-71]

Age group	(m^3/a)	(m^3/s)
0-12 months	1.04E+03	3.31E-05
1-2 years	1.88E+03	5.97E-05
3-7 years	3.18E+03	1.01E-04
8-12 years	5.59E+03	1.77E-04
13-17 years	7.34E+03	2.33E-04
Adults (>17 years)	8.11E+03	2.57E-04

1.3.5 Spatial grid

Dose calculations for fixed weather scenarios were calculated over a 16-point distance grid. Doses are provided under the plume centreline and therefore represent the maximum dose that could be received by the target individuals.

Dose calculations for the probabilistic weather scenarios were performed over a 16-sector, 16-point distance grid. Wind direction was allowed to change from run to run.

2. Doses

2.1 Deterministic Effects

2.1.1 Assumptions

Calculations calculate the distance beyond which the risk of deterministic effects is negligible. The method used for this calculation is described in report [ISR03]. The method takes into account the fact that the deterministic dose threshold varies with dose rate, and that dose rate varies with distance and time following the release.

The times after the accident at which COSYMA calculated the deterministic doses were 1, 7, 30 and 365 days. A constant dose rate was assumed for each period (dose received in time period divided by the period duration).

Table 15: Dose integration for deterministic calculations

Run #	Dose integration	Parameter IDTIME
1	1 day	1
2	7 days	7
3	30 days	30
4	365 days	365

The risk of deterministic effects was considered negligible if it was lower than 1%.

To calculate the impact of protective actions on the distance for deterministic effects, the contribution of the dose by pathway (which is provided as a COSYMA output) is multiplied by the appropriate reduction factor for the applicable protective action [ISR08]. For example, assuming that 60% of a 100 mSv dose (or 60 mSv) is from inhalation, and that the sheltering reduction factor is 0.5, the inhalation dose if sheltering is implemented is 30 mSv. This calculation is repeated for all exposure pathways.

2.1.2 Health effects model

Deterministic health effects were calculated using the following model:

$$P(D,t) = 1 - e^{-H}$$

where

$$H = \ln 2 \cdot \left(\sum_i \frac{D_i}{D_{50}^i} \right)^S$$

D_i is the dose integrated over time *i*

t_i is the integration time *i* (1 j, 7 j, 30 j or 365 j)

S is a form factor

D_{50}^i is the dose level at which 50% of the exposed population will suffer from a specific effect and D_{50}^{i} is defined as:

$$D_{50}^{i} = D_{\infty} + \frac{D_0}{D_i / t_i}$$

These parameters are summarized in Table 16.

Table 16: Deterministic health effects parameters in Cosyma [COS95]

Organ/tissue dose		Effect	Parameters					
internal	**external**	**mortality**	**Form factor S**	**D_∞ [Gy]**	**D_0 [Gy^2/h]**	**RBE**[7]	**Integration time (days)**	**Dose thresholds**[8] **[Gy]**
Lungs	Lungs	Pulmonary syndrome	7.0	10.0	30.0	7.0	1, 7, 30, 365	5
Bone marrow	Bone marrow	Hematopoietic syndrome	6.0	4.5	0.1	2.0	1, 30	2.3
Other organs		Gastro-intestinal syndrome	10.0	15.0	0.0	-	1, 7,30	10
Ovaries	Uterus	Pre-natal and neo-natal death	3.0	1.5	0.0	20.0	1,30	0.1
		morbidity						
Lungs	Lungs	Pulmonary deficiency	7.0	5.0	15.0	7.0	1, 7, 30, 365	2.3
Thyroid	Thyroid	Hypo-thyroid	1.3	60.0	30.0	0.0	1, 30	2.0
Skin		Skin erythema	5.0	20.0	5.0	0.0	1, 7, 30	23.
Cornea		Cataracts	5.0	3.0	0.01	0.0	1, 7, 30	1.0
Ovaries	Uterus	Mental retardation (new born)	1.0	1.5	0.0	20.0	1, 30	0.1

---

[7] For alpha emitters (plutonium), the RBE factor is used to multiply the absorbed dose (Gy) in each organ to take into account the biological efficiency in each organ relative to LET.

[8] Dose thresholds are from *Cosyma User Guide*, EUR 13045, 1995.

2.2 Effective Doses

2.2.1 Assumptions

By default, COSYMA calculates the effective doses over 50 years, unless protective actions are implemented. For our purposes, it was important to know how the effective doses vary with time. Hence, a protective action model was used.

COSYMA incorporates protective action models in the form of reduction factors that can be applied or withdrawn at times that are set by the user. For cases with no protective actions, all reduction factors are set to one.

In COSYMA, “evacuation” is not permanent, since people are allowed to return after seven days. A permanent evacuation is called a “resettlement” (or permanent relocation in COSYMA terminology). Resettlement was thus used to terminate the exposure after given times. Four cases were considered:

- no protection (no evacuation or resettlement);
- resettlement after one day;
- resettlement after seven days; and
- resettlement after 30 days.

It is important to note that changing the residence time does not change the dose integration time for the calculation of effective dose due to inhalation, which is always the committed dose over 50 years. Calculations were performed for 1, 7, 30 days and 50 years. Hence, by varying the exposure time, it is possible to estimate the effectiveness of protective actions.

For example, evacuation is normally for seven days. Therefore, it is possible to estimate the avertable dose for evacuation by calculating the dose for an exposure duration of seven days. The distance within which the intervention level for evacuation is exceeded is the distance for which evacuation plans are justified. Table 17 shows the parameters used for the various exposure durations.

Table 17: Exposure duration for effective dose calculations

<table>
<tr><th rowspan="2">Run #</th><th rowspan="2">Exposure duration</th><th colspan="4">Parameters</th></tr>
<tr><th>NOEXPO</th><th>DILREL</th><th>DILRES</th><th>ITUMS</th></tr>
<tr><td>1</td><td>1 day</td><td>1,1,1,0,0</td><td>3*0</td><td>0</td><td>1</td></tr>
<tr><td>2</td><td>7 days</td><td>1,1,1,0,0</td><td>3*0</td><td>0</td><td>7</td></tr>
<tr><td>3</td><td>30 days</td><td>1,1,1,0,0</td><td>3*0</td><td>0</td><td>30</td></tr>
<tr><td>4</td><td>50 years</td><td>0,0,0,0,0</td><td>$3*10^{30}$</td><td>10^{30}</td><td>0</td></tr>
<tr><th>Run #</th><th>Exposure duration</th><th>NOODOS</th><th colspan="2">NOOPOP</th><th>NOOSIT</th></tr>
<tr><td>5</td><td>No protection measure</td><td>0</td><td colspan="2">0</td><td>0</td></tr>
</table>

For runs with fixed weather scenario, parameters contained in Table 18 were used. For probabilistic runs, parameters listed in Table 19 were used.

Table 18: Parameters for fixed weather scenario

Stability category	Parameter IDIKAT	Wind speed (m/s)	Parameter IWNDG	Mixing height	Parameter MIXLH
A	1	1.4	140	1000 m	1000
B	2	2.6	260	1000 m	1000
C	3	3.7	370	500 m	500
D	4	4.2	420	500 m	500
E	5	2.4	240	200 m	200
F	6	1.4	140	100 m	100

Table 19: Parameters for probabilistic weather runs

Parameter	Fixed weather	Probabilistic weather
JMAX	72 (default)	16
IDFOUT	1	0
IAROUT	1	0
NOOTMT	1	2
NOODOS	1	0
NOORSK	1	2
NOOPOP	1	0
LKZ	1,7,50,75,90,115, 14*0 (default)	1,5*0
IACT	7*1	2*0,1,22*0
ICCFD	0	1
METIN	1	0
MIXIN	1	0
NOSHFT	0	2
NJAHRE	1	4

ANNEX C: Table of Calculations Performed

The following Tables contain a number of runs performed to analyze CANDU events. Not all runs were used in this technical basis. However, the results are available for comparison purposes and are all presented here for sake of completeness. The correspondence between release categories (RC) nomenclature used in these Tables and the release types described in this document is as follows:

Release category	**Corresponding release type**
RC-3	Severe Accident Release (SAR)
RC-6	Beyond Design Basis Release (BDBR)
RC-8	Design Basis Release (DBR)

Table 20: Reference runs

REFERENCE CASES									
Run #	Weather scenario			Release category	Integration time NE (days)	Integration time NL (years)	Permanent evacuation (relocation) after	Heat content	Release duration (hours)
	Stability category	Wind speed	Mixing height						
RC-6: Beyond Design Basis Release (BDBR)									
201	D	4.2 m/s	500 m	RC-6	1	50	1 days	0 MW	3
202	D	4.2 m/s	500 m	RC-6	7	50	7 days	0 MW	3
203	D	4.2 m/s	500 m	RC-6	30	50	30 days	0 MW	3
204	D	4.2 m/s	500 m	RC-6	365	50	None	0 MW	3
205	F	1.4 m/s	100 m	RC-6	1	50	1 days	0 MW	3
206	F	1.4 m/s	100 m	RC-6	7	50	7 days	0 MW	3
207	F	1.4 m/s	100 m	RC-6	30	50	30 days	0 MW	3
208	F	1.4 m/s	100 m	RC-6	365	50	None	0 MW	3
RC-8: Design Basis Release (DBR)									
209	D	4.2 m/s	500 m	RC-8	1	50	1 days	0 MW	8
210	D	4.2 m/s	500 m	RC-8	7	50	7 days	0 MW	8
211	D	4.2 m/s	500 m	RC-8	30	50	30 days	0 MW	8
212	D	4.2 m/s	500 m	RC-8	365	50	None	0 MW	8
213	F	1.4 m/s	100 m	RC-8	1	50	1 days	0 MW	8
214	F	1.4 m/s	100 m	RC-8	7	50	7 days	0 MW	8
215	F	1.4 m/s	100 m	RC-8	30	50	30 days	0 MW	8
216	F	1.4 m/s	100 m	RC-8	365	50	None	0 MW	8

Table 21: Weather probabilistic runs

Probability of effects based on weather frequency distribution						
Run #	**Release category**	**Integration time NE (days)**	**Integration time NL (years)**	**Permanent evacuation (relocation) after**	**Heat content**	**Release duration (hours)**
RC-3: Severe Accident Release (SAR)						
217	RC-3	1	50	1 days	50 MW	0.5
218	RC-3	7	50	7 days	50 MW	0.5
219	RC-3	30	50	30 days	50 MW	0.5
220	RC-3	365	50	None	50 MW	0.5
221	RC-3	1	50	1 days	0 MW	0.5
222	RC-3	7	50	7 days	0 MW	0.5
223	RC-3	30	50	30 days	0 MW	0.5
224	RC-3	365	50	None	0 MW	0.5