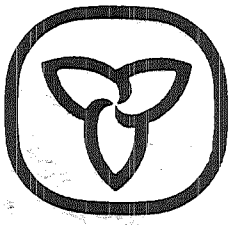
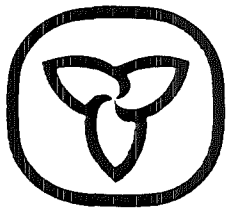


REPORT OF

PROVINCIAL WORKING GROUP # 8

THE UPPER LIMIT FOR DETAILED NUCLEAR EMERGENCY PLANNING

JUNE 30, 1988



Ontario

REPORT OF

PROVINCIAL WORKING GROUP # 8

THE UPPER LIMIT FOR DETAILED NUCLEAR EMERGENCY PLANNING

JUNE 30, 1988

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REPORT

OF

PROVINCIAL WORKING GROUP #8

EXECUTIVE SUMMARY

The Working Group was constituted to consider and make recommendations on the reference radiological situation which would define the upper limit for detailed nuclear emergency response planning in Ontario, and related matters.

Composition

Chairman:

Dr. K.G. McNeill	University of Toronto

Members:

Dr. J.H. Aitken	Ministry of Labour*
Mr. F.B. Ali	Ministry of the Solicitor General
Mr. G. Armitage	Ontario Hydro
Mr. L.N. Carling	Atomic Energy Control Board
Mr. J.Q. Howieson	Atomic Energy of Canada Limited
Mrs. L. Pearson	University of Toronto**

Secretary:

Ms. P.R. Gomes	Ministry of the Solicitor General

* Left the Working Group in April 1988 on leaving the public service

** Replaced Dr. Aitken in April 1988

Summary of Recommendations

1. The Working Group recommends that two tiers of emergency planning are needed:
   (i) the first tier (termed the Maximum Planning Accident or MPA) provides detailed planning for accidents which can be quantitatively determined to be as low as once in 10^5 station-years. For this tier the Working Group recommends that planning assure public exposure to radioactive doses be kept less than the Protective Action Levels
   (ii) the second tier (termed the Worst Credible Radiation Emission or WCRE) provides planning for accidents which are lower in frequency or whose frequency cannot be quantified (gross human error or hostile action). For this tier the Working Group recommends planning to protect against the onset of early morbidity (sickness) and the onset of early mortality (death) in a member of the public.
2. The Working Group recommends that for detailed planning of emergency measures to provide a safety net in case of engineering failures (the Maximum Planning Accident), the maximum doses given as a function of time and distance in Tables 6.2, 6.3, and 6.4 of the Report be used for the Pickering, Bruce, and Darlington

stations respectively.

3. The Working Group recommends that for planning of emergency measures to deal with the possible effects of a Worst Credible Radiation Emission the doses given as a function of time and distance in Tables 7.2 and 7.3 of the Report be used for the Pickering, Bruce and Darlington stations. In utilizing these data to determine the extent of emergency planning that is required, the Province should take into account the improbability of the occurrence of some of these events, the preventable nature of others, the conservative nature of the calculations, the public's perception of its need for protection, and the alternative use of economic resources.

4. The Working Group recommends that the only planning that should be done for this type of emission is to prevent early morbidity or mortality, for which we recommend threshold levels to be taken as 50 rem whole body or 3000 rem thyroid for early morbidity and 150 rem whole body for early mortality.

5. Based on all of the above recommendations the Working Group recommends that the size of the Primary Zones for Pickering, Bruce and Darlington nuclear stations should be 13 km.

6. Around Chalk River Nuclear Laboratories the Primary Zone should remain unchanged at 10 km from the NRU

reactor (see sections 8.6 and 8.7).

7. In Essex County the Primary Zone should remain unchanged at 21.5 km from the Fermi reactor with reconsideration when the Fermi-2 Probabilistic Risk Assessment is available in the fall of 1988 (see sections 9.2 and 9.3).

8. The Working Group recommends that the Province consider taking appropriate measures within the context of the above recommendations in the following areas:

   (a) the availability and distribution of potassium iodide pills.

   (b) the need for early warning systems for the public.

   (c) the need for adequate medical facilities to deal with possible acute radiation exposure.

   (d) the advisability of restricting new housing construction near nuclear facilities.

9. The Working Group recommends that the Province of Ontario review the present Protective Action Levels in the light of world norms.

CHAPTER 1

INTRODUCTION

1.1 Safety

1.1.1 All man-made facilities should be designed to be safe, whether they be football stadia, chemical factories, houses or nuclear power generating stations. What is "safe" is normally defined by government at some level or other, or by professional bodies so authorised by government. Despite building to codes specified by these governmental bodies, sports arena guard rails break, resulting in injury and death, toxic emissions from factories kill people, and houses and hotels collapse in hurricanes or burn to the ground with loss of life. The nuclear accident on April 26, 1986 at Chernobyl in Russia has shown that nuclear power stations can also cause very large emissions of radiation resulting in loss of life and sickness. All the above are recent examples of disasters; all were "unexpected"; in all instances, emergency measures had to be initiated to cope with unusual circumstances (situations that should not have happened).

1.1.2 For many emergency situations, such as house

fires in a city, outbreak is so common that fire-fighters are kept continually on standby to cope with the statistically predictable incidence of fires. Note that although the total number and rate of occurrence of fires are statistically predictable, any particular fire is unexpected. However, in rural areas, fires are sufficiently rare that volunteer brigades suffice; these consist of persons with regular jobs who are normally available in time of need and who have been trained in fire-fighting. For even less common accidents, such as major floods or tornados or major oil or gas explosions, society may rely on persons with general training and ability in dealing with such problems, together with the opportunity of bringing in persons with expert knowledge from outside the local community. In general, society does not make detailed emergency plans for events which, however potentially hazardous, are not expected to occur more than once in a hundred years or so.

1.2 Effects of Nuclear Radiation

1.2.1 Nuclear radiation is potentially hazardous because it has the ability to ionize, and thus to break-up molecules, some of which may

be of biological importance. If very many are broken, there may be, within days or weeks, clinical symptoms which, in the worst cases, may result in death. Below these high doses which may result in early morbidity (illness) or mortality (death), nuclear radiation may so disrupt molecules that latent cancer is induced, with the possibility of overt cancer, and possible resulting death, some decades later.

1.2.2 Early morbidity in the form of vomiting may occur at a "whole body dose somewhat in excess of 0.5 Gy [see section 1.2.3] received over a period of not more than 1 - 2 days"[1*]. "The value for the median lethal dose within 60 days ($LD_{50/60}$) is thought to be in the range 2.5 to 5 Gy; below about 1.5 Gy there is little possibility of early death"[1].

1.2.3 The Gray (Gy) is a unit of dose. In this report we will conform to the present usage of the Ministry of the Solicitor General and use rems and Sieverts (Sv) as units of dose equivalent; 1 Sv = 100 rem. In the context of emergency planning, it is justifiable to write the values of paragraph 1.2.2 above as

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* References are given after the body of the Report

stating that early morbidity does not arise below 50 rem (0.5 Sv) received within 1 or 2 days, and that early mortality is very unlikely below 150 rem (1.5 Sv). For comparison, natural background radiation from gamma and beta rays is about 0.15 rem (1.5 mSv) per year.

1.2.4 On the "linear hypothesis", any dose of radiation is potentially able to cause cancer, with lower doses being proportionately less able to do so. From this follows the ALARA principle, that radiation doses be kept as low as reasonably achievable, social and economic reasons being taken into account.

1.2.5 Iodine is an important element produced in the fission of uranium. In the body this element concentrates in the thyroid gland. The gland is small, but a quarter of all ingested iodine goes to the thyroid under normal circumstances. As a result, when iodine is ingested the thyroid receives a very large dose compared to the rest of the body (roughly 1000 times as much).

1.2.6 When dealing with low doses, when there is no probability of immediate morbidity, while on

the other hand induction of latent lethal cancers is the main concern, the total risk to the person is obtained by adding together the individual dose equivalent to thevarious irradiated organs or tissues, H_T, using a weighting factor, W_T, peculiar to the tissue, T. Then the "effective dose equivalent" H, equals $\sum_T W_T H_T$. For adults, the International Commission on Radiological Protection,in ICRP 26[2], recommends W_T = 0.03. However, for emergency planning purposes a higher value, W_T = 0.045, is taken to account for the greater sensitivity of the juvenile thyroid. For instance, if the thyroid received 100 rem, and the rest of the body 10 rem, H = 0.955 x 10 + 0.045 x 100 = 14 rem. For most practical purposes the factor 0.955 can be approximated by 1.

1.2.7 At higher doses more immediate effects may Be induced in the thyroid. Sufficiently high dose will "ablate" the thyroid, that is, completely inactivate it. Such doses are in fact used therapeutically. Lower doses may be used medically for partial ablation, whilst lower doses still are used diagnostically. "Total ablation of the thyroid within the first year ... requires

at least 27 000 rad[3]. However, smaller doses can cause hypothyroidism within 5 years (for example, 45 % probability with 20,000 rem, 20 % with 8000 rem). There is some late hypothyroidism induced at doses above 1000 rad[3]. The Working Group has taken 3000 rem to the thyroid as a threshold for early effects.

1.2.8 The uptake of iodine by the thyroid may be "blocked" by taking an excess (100 mg or so) of iodide or iodate. If this be done prior to, and if necessary during, possible exposure to radioiodine, uptake of the radioiodine may be almost completely eliminated. Primary emergency actions may well be to see that KI pills are taken; other actions, including evacuation, may then be decided on in the light of the dose to the rest of the body.

1.3 Safety of Nuclear Power Stations

1.3.1 The same general principles of safe design outlined in Section 1.1, coupled with planning to cope with an unexpected emergency, apply to nuclear power stations. In addition, however, the public perception of the dangers of nuclear radiation is such that emergency plans are in place to deal with accidents whose probability, on the

basis of sound engineering design, is much less than once in a hundred years.

1.3.2 In particular, plans are made for ensuring the safety of persons living close to a nuclear power station. These persons are at risk from the effects of radioactive emission but do not necessarily derive any particular benefit from their locality. In this latter respect they differ from, say, off-shore oil rig workers, or airline passengers or crew. Instead they are comparable to persons who live near chemical plants, who obtain no more benefit from the products of the plant than do others in the community, but who are far more likely to suffer as a result of toxic emissions or explosions. The questions that immediately arise are what is meant by "ensuring the safety", and what is meant by "living close to"; that is, the goals and limits for emergency planning have to be set.

1.4 Working Group #3

In 1983 a Working Group (Provincial Working Group #3) was set up to advise the Province on these matters, including the methods to be used for "ensuring the safety". It recommended

a) that the worst accident for which detailed

planning needs to be done (the Maximum Planning Accident, MPA) is one that gives a dose of 25 rem to an unsheltered person 1 km from the nuclear station (that is, the assumed boundary fence). The 25 rem MPA was based on the assumption of good engineering practice and the operating experience to that time, together with the particular properties of CANDU* reactors, especially that the moderator could act as an additional heat sink in case of failure of both the normal and the emergency cooling systems (and so prevent severe core damage), and the belief that detailed planning was unnecessary for events of probability less than once per million reactor years in situations where there are about 10 reactors per power station.

b) that the methods available to deal with any nuclear emergency situation were sheltering, evacuation, and food and water control; ingestion of potassium iodide (KI)** is a further powerful method of mitigating the effects of radioactive emission, and a separate Working Group (Working Group #2) dealt with this aspect of emergency planning concurrently with

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* CANDU is an acronym for Canadian Deuterium Uranium

** the action of "blocking the thyroid" by potassium iodide is discussed in Section 1.2.8

Working Group #3.

c) that the goal of emergency planning in accidents of severity of up to and including this maximum planning accident of 25 rem was to prevent any increase in the number of latent cancers which, in any one sector of 5,000 people or so, would be statistically significant. The lower limit of action was set to avoid "serious economic loss to many at a radiation dose level which would .... be less than 2 % of that which a radiation worker could legally receive in each year"[4].

d) in the case of accidents which were in fact more severe than the MPA, authorities should be able to cope by improvising on the plans which would already be in existence based on the MPA.

e) that "25 rem (250 mSv) effective dose at the plant boundary [be used] as the upper limit for current detailed planning, recognizing that experience in the future may cause this to be modified either way"[4]. The Government subsequently set up a Technical Advisory Committee to monitor all relevant situations.

1.5 Recent Events

1.5.1 Since the report of Working Group #3, there has been a great deal of consideration of the "source term" expected (that is, the

radiation emission) from a severe accident with a water cooled and moderated reactor, and there has been the accident at the Chernobyl nuclear power station. The "source term" work, to a considerable degree sparked by the unexpectedly small emission of radio-iodine from the Three Mile Island (TMI) accident, has led gradually to a lowering of the expected radio-iodine emission from such a water-moderated station; whereas, Chernobyl, itself graphite-moderated, has shown that accidents can occur leading to exposures exceeding 25 rem in such reactors (that is, RBMK reactors or similarly designed reactors) as a result of gross human error.

1.5.2 The Chernobyl accident caused considerable concern all over the world with respect to the safety of nuclear reactors and the adequacy of existing emergency plans. The Government of Ontario set up an Ontario Nuclear Safety Review (Commissioner F.K. Hare) to examine in depth the overall matter of safety, and a Working Group (Provincial Working Group #8) to examine specific issues relating to emergency planning and to re-examine the upper limit for detailed emergency planning in Ontario.

CHAPTER 2

THE WORKING GROUP AND ITS TERMS OF REFERENCE

2.1 General

The Provincial Cabinet approved the setting up of a Working Group to examine the appropriate level of emergency planning for Ontario on March 11, 1987. Provincial Working Group #8 was constituted under the authority of the Ministry of the Solicitor General on June 22, 1987. The memorandum establishing the Working Group is given in Appendix A.

2.2 Terms of Reference

2.2.1 The terms of reference of the Working Group are given in Appendix B. The WG is required to make recommendations on the following:

a) An upper limit for detailed emergency planning and preparedness in Ontario given in terms of the radiological situation off-site.

b) Whether any consequence mitigation measures need to be adopted as a result of the upper limit recommended by the Working Group in addition to those prescribed in or under the current Provincial Nuclear Emergency Plan, and

whether any of these latter measures need to be modified.

2.2.2 In recommending an upper limit for planning, the Working Group is required to consider not only a scientific assessment of the risks of various types of accidents, but also risks, such as those due to hostile action, which cannot be scientifically assessed, public perceptions, the probable effectiveness of emergency improvisation, safety margins, and any other factors the Working Group can justify.

2.3 Composition

The Working Group consisted of 6 persons well versed in emergency planning and/or nuclear power and/or health physics, together with an engineer as the research assistant/secretary. The composition of the Working Group is given in Appendix C. In addition, the staff scientist of the Ontario Nuclear Safety Review sat as an observer and participant at the Working Group's meetings. The members served on the Working Group in their individual capacities, and not as representatives of their employing organizations.

CHAPTER 3

ACTIONS OF THE WORKING GROUP

3.1 Meetings

The Working Group has held 22 meetings in the period July 1987 to June 1988.

3.2 Interviews

3.2.1 The Working Group has interviewed

a) Dr. R. Wilson who is a professor of physics at Harvard University. Dr. Wilson was one of few Westerners to visit Chernobyl after the accident there.

b) Dr. J. Ahearne who is an ex-commissioner and ex-chair of the U.S. Nuclear Regulatory Commission.

c) Dr. J.T. Rogers who is a professor of mechanical and aeronautical engineering at Carleton University. Dr. Rogers has been a member of many Canadian committees on nuclear safety.

d) Sir Frank Layfield who was the Inspector of the Sizewell B inquiry in the U.K.

3.2.2 We would like here to acknowledge the value of these interviews and to thank the four persons for their time.

3.3 Ontario Nuclear Safety Review (ONSR)

3.3.1 Great use was made of the existence of the

ONSR, and we are grateful to all its members for their assistance, and particularly to the Commissioner, Dr. F.K. Hare.

3.3.2 The chairman of the Working Group has attended, as an observer and participant, meetings of the Advisory Panel of the Ontario Nuclear Safety Review (ONSR).

3.3.3 All members of the Working Group attended the ONSR's Workshop held in September of 1987 at which, over three days, presentations were made by "intervenors"*, by nuclear agencies, and by consultants. The chairman of the Working Group chaired one of the whole day sessions of the Workshop.

3.3.4 The ONSR library was an important source of information.

3.3.5 The staff scientist of the ONSR became an observer and participant at the meetings of the Working Group.

3.4 Public Notification

Shortly after its formation, the Working Group sent notification of existence/request for submission letters to organizations and individuals who had previously shown interest in these matters, and to

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* "Intervenors" are persons or groups who felt and were felt by the ONSR that they could make useful contributions to the work of the ONSR. Many of these were financed by the ONSR for their work.

municipalities in the proximity of nuclear power stations. A notice of the Working Group's existence which at the same time requested submissions was placed in two major newspapers - The Toronto Star and The Globe and Mail (provincial distribution). A list of respondents and a resume of the points made are given in Appendix D.

3.5 Libraries

The Working Group acknowledges with thanks its extensive use of the library facilities of Ontario Hydro, Atomic Energy of Canada Limited (AECL), and Atomic Energy Control Board (AECB).

3.6 Public Opinion Poll

3.6.1 A public opinion poll was arranged with a professional polling organization with considerable experience in the nuclear field. The poll was designed, amongst other things, to compare the views and opinions of persons living within 10 km of Pickering nuclear power station with those of persons living outside of the 10 km zone but within 20 km of the station. Another reason for the poll was to gain information on what persons inside and outside of the 10 km detailed planning zone would do if there were an emergency situation at Pickering's station. Since a poll of this nature has never before been

undertaken the Working Group felt that it was very important that such a poll be carried out. Unfortunately, permission to conduct the opinion poll was not given by the Provincial Government.

3.6.2 In early 1987 a secondary school student polled 100 randomly selected residents of Ajax and Pickering on their concern or lack of concern about the proximity of the Pickering nuclear power station. The questionnaire and the results of this poll have been considered by the Working Group, and are given in Appendix E.

3.7 Canadian Radiation Protection Association

The chairman and the research assistant attended the annual meeting of the Canadian Radiation Protection Association, and presented a paper on the Working Group's work.

3.8 Municipalities

The Working Group consulted municipalities which contain nuclear power stations, or which are adjacent to such areas, about their abilities to improvize emergency measures in excess of those for which there are current plans. This matter is discussed in Section 5.6 below.

3.9 Correspondence

The Working Group corresponded with various nuclear

agencies on specific areas in which the Working Group required information. These nuclear agencies included the Atomic Energy Control Board, Chalk River Nuclear Laboratories of Atomic Energy of Canada Limited, Ontario Hydro, the United States Nuclear Regulatory Commission, and the Ontario Nuclear Safety Review.

CHAPTER 4

THE EXISTING NUCLEAR EMERGENCY PLAN

4.1 Maximum Planning Accident

The Province of Ontario's Nuclear Emergency Plan states that the most serious nuclear accident for which detailed planning and preparation shall be done is one producing an effective dose of 25 rem (250 mSv) at a distance of 1 km from the nuclear reactor.

4.2 Planning Zones

The plan requires the area around each nuclear facility to be divided into the following zones:

(a) the Primary Zone is a 10 km radius around the reactor within which it would be prudent to plan and prepare measures against plume exposure, including evacuation. Within the Primary Zone is a 3 km radius Contiguous Zone, in which an increased level of emergency planning and preparedness may be advisable. (In the case of the U.S. Enrico Fermi reactor, the Primary Zone inside Essex County extends approximately 21.5 km from the reactor).

(b) the Secondary Zone is a 50 km radius around the reactor within which it would be prudent to plan and prepare measures against radioactive contamination of the food chain, and the consumption of contaminated food and water. (In

the case of Enrico Fermi 2 and other U.S. reactors which could affect Ontario the Secondary Zone is taken as 80 km).

4.3 Protective Action Levels (PALs)

These serve as aids to planning and decision-making. The lower level is the projected dose at or above which the protective measure should be applied unless valid reasons exist for deferring action. The upper level is one at which action must be taken, barring exceptional circumstances. The PALs prescribed in the plan are shown in Table 4.1.

TABLE 4.1

PROTECTIVE ACTION LEVELS

Measure	Lower Level		Upper Level	
	Effective	Thyroid	Effective	Thyroid
Sheltering	0.1 rem (1 mSv)	0.3 rem (3 mSv)	1 rem (10 mSv)	3 rem (30 mSv)
Evacuation	1 rem (10 mSv)	3 rem (30 mSv)	10 rem (100 mSv)	30 rem (300 mSv)
Thyroid Blocking	--	3 rem* (30 mSv)	--	30 rem (300 mSv)
Banning Food/Water Consumption	0.05 rem (0.5 mSv)	0.15 rem (1.5 mSv)	0.5 rem (5 mSv)	1.5 rem (15 mSv)

* The Working Group has been informed by Emergency Planning Ontario that this level is only for advising persons already in possession of potassium iodide pills to ingest them.

Note: These PALs are expressed in terms of the projected dose likely to be received by the most exposed individual in the relevant critical group.

4.4 Thyroid Blocking

The Province's policy on stocking and distribution of potassium iodide (KI) pills is basically as follows:

(a) Municipalities shall make arrangements with nuclear facility operators for the stocking and distribution of KI pills for the entire Primary Zone population.

(b) These arrangements shall ensure that people living within the Contiguous Zone (approximately 3 km) can receive the pills within 4 hours of distribution being ordered. If this is unlikely to be achieved, the pills should be pre-distributed.

4.5 Public Alerting

The current arrangements for alerting, made by municipalities with areas inside the Primary Zones of nuclear facilities for alerting the public to the occurrence of an emergency, generally consist of emergency vehicles traversing populated areas with their sirens on. This would indicate to people the need to tune to pre-designated radio stations, on which announcements regarding the emergency would be broadcast. It is generally considered that it would take about 4 hours from the occurrence of a problem to warn people living within 3 - 5 km of the facility.

4.6 Nuclear Facilities Covered

The Provincial Plan covers the following nuclear facilities which this Working Group also has to take into account:

(a) Ontario Hydro's nuclear power stations at Pickering, Bruce, and Darlington.

(b) AECL's Chalk River Nuclear Laboratories

(c) The Enrico Fermi 2 nuclear power station in the U.S.

CHAPTER 5

ANALYSIS OF THE ISSUES

5.1 Task Assigned

The Working Group is required to make recommendations on the "reference radiological situation off-site which should define the upper limit for detailed emergency response planning", considering the following factors:

(a) Scientific assessment of the risk of different types of accidents.

(b) Risks which cannot be systematically assessed (for example, those resulting from hostile action).

(c) Public perception and public expectations.

(d) Probable effectiveness of improvising emergency response measures.

(e) A safety margin to allow for uncertainties not already allowed for.

5.2 Scientific Risk Assessment

5.2.1 The most systematic and scientific method of estimating the risk of nuclear accidents (that is, their probabilities of occurrence multiplied by the consequences of that occurrence) is through the Probabilistic Risk Assessment (PRA) methodology, which is also referred to as a Probabilistic Safety

Evaluation (PSE).

5.2.2 However, PRAs cannot provide a complete assessment of nuclear accident risk for the following reasons:

(a) Certain types of accidents are often explicitly excluded from consideration, for example, those caused by earthquakes, floods, fires etc.

(b) Certain types of initiating causes are not considered because it is not possible to quantify them, for example, deliberate hostile action, or gross human error.

(c) While the methodology seeks to be as comprehensive as possible, it is possible that some combination of events, though possible, may escape consideration.

(d) In many areas there are no statistical or experimental data available, hence reliance has to be placed on judgement, albeit expert judgement.

(e) Combinations of events below a certain level of probability are not considered because, at these low levels, discussion can only be highly speculative.

5.3 Public Perception and Expectation

There is a considerable amount of material available on this subject some of which is listed as

references 5 to 8. A survey of it leads to the conclusion that the main features of public expectations regarding nuclear emergency planning are the following:

(a) The public expects nuclear emergencies to be planned for at a level much higher than other emergencies, such as floods or hurricanes. This implies higher levels of preparedness for a hazard which may be much less likely to occur.

(b) The public is mostly concerned with the consequence or effects side of the risk equation, and is not primarily interested in the probability (or improbability) of occurrence of the events which could result in those consequences.

(c) The public expects measures to be taken to protect it against the worst case possible.

5.4 The Approach Adopted

Having examined in depth the factors upon which it was required to base its recommendations, the Working Group came to the conclusion that it could not come up with one planning basis which could adequately reflect all these factors. Therefore, it decided to recommend two criteria:

(a) A Maximum Planning Accident (MPA), which would give the maximum consequence of any accident whose probability is above a predetermined

value. This predetermined probability of occurrence, or cut-off probability, is to be set low enough to take into account public expectations regarding emergency planning for nuclear accidents. The MPA would then form the basis for the type of emergency planning and preparedness currently being done.

(b) A Worst Credible Radiation Emission (WCRE), which would be defined as the maximum consequences possible from any nuclear disaster within the limits of physical and chemical realities. There would be no probability limits set. Emergency planning and preparations should be done for the WCRE only to the extent of mitigating its worst consequences - early morbidity or mortality.

5.5 Justification for the Approach

5.5.1 Even if the probability of occurrence ofthe MPA is set at several orders of magnitude below the level at which other types of emergencies are prepared for, this would still be within the band of probability considered in scientific assessments of risk such as PRAs/PSEs. The MPA concept thus would allow detailed emergency planning to be based upon both public expectations as well as a scientific assessment of the likely

hazard which should be prepared for. The MPA would cater for the effects of engineering and human failures, assessed in a comprehensive and systematic manner, and thus would provide a rational, justifiable, and economical basis for the expenditure of resources on detailed emergency planning and preparation.

5.5.2 The WCRE indicates the very worst that could happen; the maximum effects possible from any accident, however caused or however developed. Therefore, it makes possible accounting for the following:

- deliberate, hostile action
- gross human error
- events explicitly excluded from PRA s/PSE s
- combinations of events which may not have been predicted
- very low probability combinations of events
- the public's desire to be protected from the worst that could happen
- a safety margin

5.5.3 Comparing the WCRE to the MPA it can be seen that the former covers the following range of possible events:

(a) Accidents with extremely low probabilities of occurrence - that is, lower than the MPA's low frequency level.

(b) Events whose probability of occurrence cannot be estimated - that is, those due to hostile action, gross human error, excluded events (earthquakes, floods, fires etc.), and unpredictable events.

5.5.4 The Working Group's recommendation that, within an overall budget for emergency planning, planning and preparation should only be done for the worst consequences of the WCRE is based upon the following considerations:

(a) Society's resources are better spent in trying to remove the causes listed in 5.5.3 (b) above (through such measures as ensuring effective security at nuclear stations, better training of operators, better operating procedures, effective fire prevention, etc.) rather than in preparing to deal with the effects of such preventable events.

(b) There does not appear to be any sound justification for expending scarce resources on elaborate measures to deal with all the effects of extremely

improbable accidents. Such resources are much better spent in protecting people from the possible effects of the less unlikely scenarios covered by the MPA.

(c) However, the most severe consequences of the WCRE (early morbidity or mortality), however remote the likelihood of their occurrence, are extreme enough to warrant consideration in planning, and the preparation of plans to prevent their happening.

5.6 Improvisation

The Working Group decided that the possibility of improvisation of emergency measures had to be considered when drawing conclusions about planning for emergencies. As noted in section 3.8 above, the Working Group consulted relevant authorities about their abilities to improvise if called upon to do so in case of a larger than anticipated event. Although immediate and effective improvisation was not thought to be possible, after 24 hours of warning municipal and Provincial authorities could effectively build on existing plans. The Working Group felt that it was a sound assumption that resources for emergency planning and preparedness, for nuclear and other emergencies, would inevitably be limited. If there were mitigating measures which

could be effectively improvised during an emergency, then it is obviously uneconomical to expend resources to implement them in advance of the event. Such resources were far better spent on measures which could not be improvised at the time of an emergency.

CHAPTER 6

THE MAXIMUM PLANNING ACCIDENT

6.1 General

6.1.1 As discussed in Chapter 5, the Working Group decided to recommend a Maximum Planning Accident (MPA) which should serve as the technical basis for detailed emergency planning and preparedness (of the type being currently done under the Ontario nuclear emergency plan). The MPA would be expressed in terms of its radiological effects, since it is these which affect emergency planning rather than the cause or sequence of the accident. However, these effects need to be related to both time and space.

6.1.2 This chapter deals only with the MPA for CANDU reactor stations. Chalk River Nuclear Laboratories and the Enrico Fermi 2 station are dealt with in Chapters 8 and 9 respectively.

6.2 Probability of Occurrence

6.2.1 Nuclear accidents cover a wide spectrum in terms of probability of occurrence and magnitude of effects. Generally speaking, and especially within the range contemplated for the MPA, the more severe the likely

consequence of an accident, the lower is the probability of its occurrence. Accordingly, the Working Group decided to select the MPA at a probability low enough to take into account public expectations that the risk from nuclear accidents be dealt with more comprehensively than that from other types of hazards.

6.2.2 Some persons and groups wish the probability of a nuclear accident to be identically zero - that is, that there be no nuclear power stations. However, there are such stations, and the Working Group has to recommend a reasonable cut-off probability. ICRP 26 states "a risk in the range of 10^{-6} to 10^{-5} per year would likely be acceptable to any individual member of the public"[2].

6.2.3 Detailed planning is not normally done by governments for accidents when the probability is less than 10^{-2}/year (that is, less than once per 100 years). Thus, although Hurricane Hazel took 78 lives in greater Toronto[9] it is not probable that such a storm will hit again in the next 100 years, and no detailed planning is done to cover such an emergency. Remedial actions have been taken as a result of it, and regulations

are in place to prevent building on land that probably would be flooded, but there are no detailed plans sent to riparian residents dealing with evacuation routes or emergency housing. On the other hand, it is expected (as at the train wreck at Mississauga) that the police and the fire and ambulance services would, by improvization, cope with any events of so unlikely a probability (less than 10^{-2}/year) .

6.2.4 However, the Working Group is aware of the very different public perception of nuclear risks as compared to conventional risks such as fire and flood. Therefore, the cut-off frequency has to be well below (a thousand or more times below) the corresponding frequency for conventional risks. Taking into account scientific assessment and public perception, the Working Group recommends that 10^{-5}/station-year (that is, 10^{-6}/reactor-year, as there are approximately ten reactors at each of Pickering and Bruce) be used as the lower limit of probability - accidents of probability less than once per million years of reactor operation, or once per one hundred thousand years of station operation, are so unlikely that detailed planning for their

consequence need not be done.

6.3 Scientific Risk Assessments

6.3.1 The most sophisticated method of calculating the probabilities of possible accidents and their likely effects is the Probabilistic Risk Assessment (PRA), which is also referred to as the Probabilistic Safety Evaluation (PSE). At the time of the setting up of the Working Group, it was known that such an analysis was being carried out by Ontario Hydro for the Darlington station, and was expected to be available in 1987. The Darlington Probabilistic Safety Evaluation (DPSE) became available in March 1988. Following normal procedure, the DPSE has been sent to the AECB for evaluation of its validity, but there has not been sufficient time for this assessment to be done. Indeed the AECB's review of the DPSE will probably not be completed until sometime in 1989.

6.3.2 Corresponding analyses for U.S. reactors are probably not more than indicative of possible results for CANDUs since the evaluations of U.S. nuclear power stations show themselves to be very site and design dependent. Equally, the DPSE, in so far as it is useful in the present context, need not be

applicable to other Ontario reactors.

6.3.3 Since no PRAs/PSEs were available for any nuclear station in Ontario other than Darlington, and the Darlington PSE became available towards the end of the Working Group's term, it became necessary to look towards other sources for systematic assessments of the probability of occurrence and resulting consequences of accidents in CANDU reactors. The first such area examined was the design and licensing basis for these reactors.

6.4 CANDU Design and Licensing Basis

6.4.1 In the licensing procedure the potential operator of a station (for Ontario, the operator is Ontario Hydro, except in the case of the Chalk River nuclear facility) has to show that the probabilities of failures which could result in releases giving doses above specified levels are below prescribed limits (in particular, no more than 25 rem at the boundary not more than once in 3000 years). However, this Design Basis does not require operators to consider accidents of probability of less than once in 3000 years, which is far higher than the probability of once in a million reactor years chosen by the

Working Group for the Maximum Planning Accident.

6.4.2 Approaches to an extension of this Design Basis have been made by an Interorganisational Working Group (IOWG) set up by the AECB and the AECB's Advisory Committee on Nuclear Safety (ACNS). They agree on most points. The report ACNS-4[10] recommends, amongst other things, that reactors should be so designed that, down to a probability of once in ten million (10^7) reactor years, no accident should result in a dose at 1 km of more than 100 rem (1 Sv). The recommendations of IOWG and ACNS have not yet been accepted by the AECB. But it is clear that these recommendations are far from scientific proof that the reactors will behave as well as, or indeed as poorly as, these criteria.

6.4.3 The Working Group concluded that neither the current AECB licensing basis, nor proposals to modify it, provided any valid basis for inferring the likely effects of a nuclear accident which had a probability of occurrence of once in a million (10^6) reactor years.

6.5 Establishing an MPA - General Considerations

6.5.1 The Working Group was thus compelled to establish its own parameters for an MPA - that is, an accident with a probability of occurrence of once in a million (10^6) reactor years. It did this by surveying the available data and information relating to CANDU reactors.

6.5.2 For CANDUs there are no data on severe accidents (one for which there is a significant off-site dose) although there are data on accidents, both minor and costly, and on unavailability of safety systems[11]. Looking abroad, in the most serious accident with a water moderated reactor (at Three Mile Island, TMI), only a relatively minor emission occurred (that is, probably none of Ontario's Protective Action Levels (PALs) would have been triggered). There is a considerable body of data from the disaster at the graphite moderated Chernobyl reactor, but these data are not readily applicable, if at all applicable, to Ontario's reactors.

6.5.3 For there to be a serious emission of radiation, there has to be damage to the reactor core. Loss of coolant (a loss of coolant accident, or LOCA) can potentially

lead to a rise of fuel temperature and consequential fuel cladding failure and fission product release to containment. This is an example of a "process failure". Immediately on occurrence of such a LOCA, operator intervention may shut the reactor down or, automatically, safety systems may be initiated to shut it down. Under the worst conditions, this shut down has to be rapid (within 2 seconds).

6.5.4 After shut down, another safety system, the emergency core cooling system (ECCS), will be brought in. This has the capability of keeping the core cool in case of a LOCA. For there to be a possibility of fuel overheating, the ECCS would also have to fail, as well as there being a LOCA.

6.5.5 Once the reactor is shut down, there is still emission of heat from the core, but at a rate only of about 5 % of that at full power (and decreasing with time). At these levels, even without the ECCS, the separate system for cooling the moderator is able to stop, at least for some hours, melting of the fuel (although the fuel rods will be distorted) and thus to prevent a major release of fission products into containment[12].

6.5.6 If there is release of fission products into containment from damaged fuel rods, chemical and physical processes may prevent some of them being available for release to the outside environment even if containment fails. In general gases will be available for release, but water soluble compounds (for example, CsI) will be trapped either by the aqueous conditions in a reactor building in which there has been a LOCA, or by the water dousing that takes place in the vacuum building connected to CANDU reactor buildings in the event of an accident.

6.5.7 Even with undamaged containment, venting of radioactive airborne materials has eventually to be carried out because of the inevitable in-flow of air to the reactor building. This venting will release fission products. The longer the time that the fission products can be held-up in containment the better, as short-lived radioisotopes will decay away. Filters may remove most of all but gaseous products. In the case of damaged containment, some or all of the airborne radioisotopes may escape directly to the atmosphere without filtration and without hold-up.

6.6 Establishing an MPA - Numerical Values of Probability

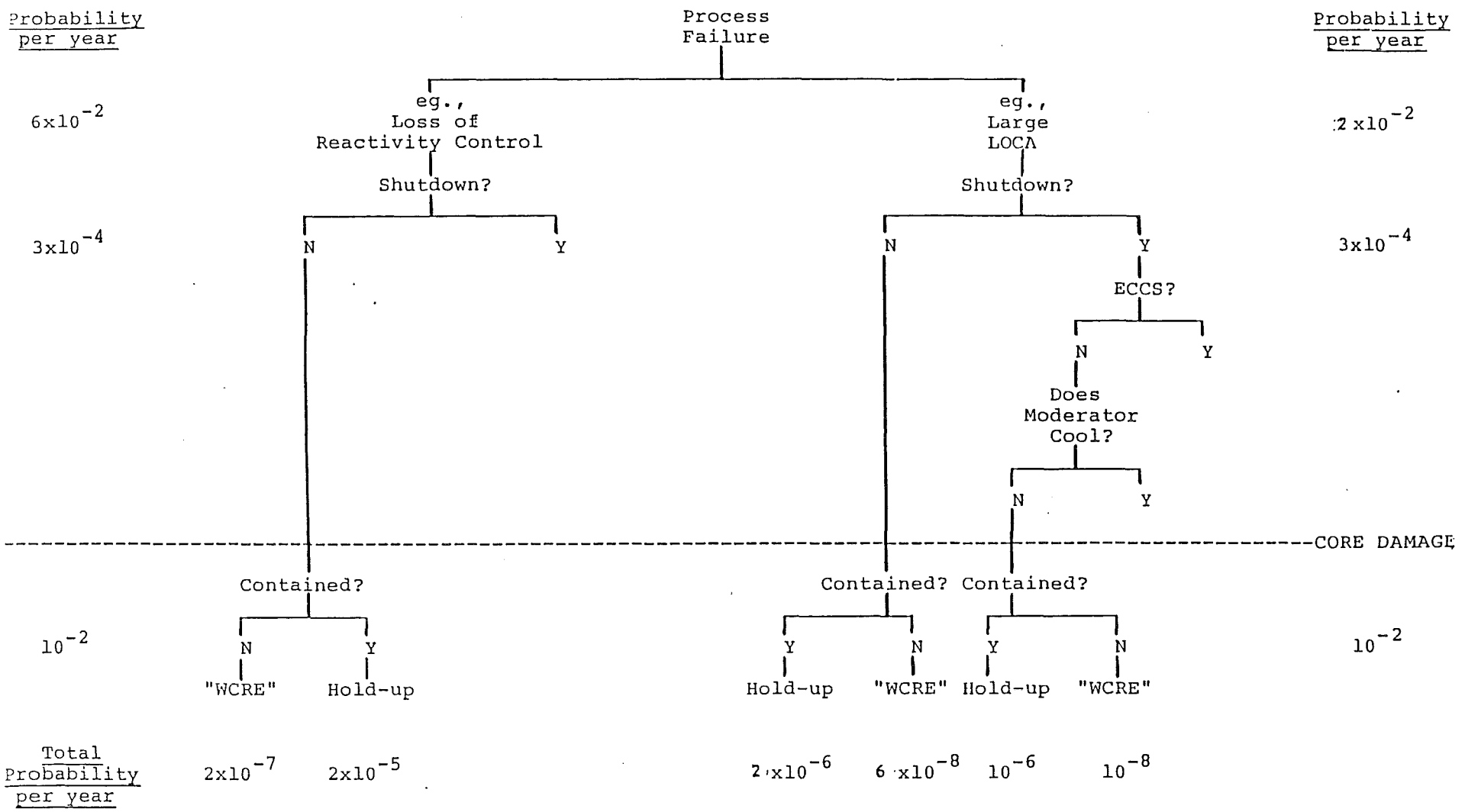
6.6.1 In recent years, more data has become available on the likelihood of serious process failures in CANDU reactors, and on the unavailability of safety systems. These are based on 128 reactor years of experience.

6.6.2 Using these experimental data, more reliable conclusions can now be reached on overall probabilities of severe accidents than were available five or ten years ago. Such data are included, for instance, in the Darlington PSE. Two possible initiating events are shown in Figure 6.1.

6.6.3 Loss of regulation (reactivity control) is taken as one such initiating event. In 128 reactor years there have been 8 such events (7 before 1980, one in 1982)[11]. This gives an overall probability of 6×10^{-2}/reactor-year.

6.6.4 Such a loss of regulation requires a fast shut down of the reactor. Pickering A has only one fast shut down system (later models have two), and therefore, for conservatism, we consider this station. The unavailability of the Pickering A shut down system over the last 10 years has been zero[11]. The average figure is 3×10^{-4} year/year[11];

FIGURE 6.1


Probability per year
Process Failure
Probability per year
6x10^-2
eg., Loss of Reactivity Control
eg., Large LOCA
2 x10^-2
Shutdown?
Shutdown?
3x10^-4
N
Y
N
Y
3x10^-4
ECCS?
N
Y
Does Moderator Cool?
N
Y
CORE DAMAGE
Contained?
Contained?
Contained?
10^-2
N
Y
Y
N
Y
N
10^-2
"WCRE"
Hold-up
Hold-up
"WCRE"
Hold-up
"WCRE"
Total Probability per year
2x10^-7
2x10^-5
2 x10^-6
6 x10^-8
10^-6
10^-8

we adopt this figure (it implies an unavailability of the shut down system of 3 hours per year).

6.6.5 Then, by the multiplication of probabilities, the probability of a loss of regulation coincident with the unavailability or failure of the fast shut down system is $6 \times 10^{-2} \times 3 \times 10^{-4} \approx 2 \times 10^{-5}$/year. Such an event would cause severe core damage.

6.6.6 Two possible initiating events are shown in Figure 6.1. The logic questions (abbreviated forms of, for example, "does the reactor shut down"), and the two possible answers Y(es) and N(o) are shown in Figure 6.1, together with the probabilities of failure to act, given at the sides of the Figure.

6.6.7 Even if severe core damage resulted, the containment is still there to prevent uncontrolled release to the outside. For Pickering A there has been reduced containment system capability, over the life of the station, of approximately 10^{-2} year/year (and zero in the last 6 years).

6.6.8 The probability then of loss of regulation and of failure to shut down quickly and of failure of containment is $6 \times 10^{-2} \times 3 \times 10^{-4} \times 10^{-2} = 2 \times 10^{-7}$/year. Such a

probability is well below the cut-off probability of 10^{-6}/year adopted for the MPA. On the other hand, the probability of loss of regulation together with shut down failure but with intact containment is 2×10^{-5}/year, above the cut-off probability. In such a situation there will be hold-up of activity in containment, but eventual release to the environment of fission products.

6.6.9 The second initiating event considered here is a large loss of coolant accident (LOCA) again followed by failure of the shut down system in Pickering A. This is the case which gave concern to the ONSR, and led to the full analysis of the event by Argonne National Laboratory (an American scientific research company) and Ontario Hydro. The study indicated that although there would be a prompt critical excursion and severe core damage, containment would not be permanently breached, though there would be a 20 second release to the environment through temporary cracks in containment.

6.6.10 There have been no large LOCAs in the 128 reactor years of experience which required safety systems to operate, though there have been two major ruptures of pressure tubes

resulting in release of coolant (at Pickering A in 1983 and Bruce in 1986). A value of two LOCAs in 128 reactor years (2×10^{-2}/year) as the probability of a large LOCA which requires safety systems is fair.

6.6.11 Again, if the shut down system fails (probability of 3×10^{-4}/year), there will be severe core damage. Again, if containment fails, there will be immediate release to the environment; the probability of this total sequence, $2 \times 10^{-2} \times 3 \times 10^{-4} \times 10^{-2} = 6 \times 10^{-8}$/year is well below the cut-off probability. However, the probability of a large LOCA and failure to shut-down, but with intact containment (apart from the 20 second cracking) is 2×10^{-6}/year, which is above the cut-off frequency.

6.6.12 Figure 6.1 also shows the logic path for an accident in which a large LOCA is followed by shut down but emergency core cooling fails, as does the moderator cooling. This accident has been studied by Dr. J.T. Rogers. AECL assigns to it a probability of 10^{-6}/year. Severe core damage results. There will be immediate release to the environment if containment also fails, but this has an overall probability of 10^{-8}/year. With

intact containment (probability of 10^{-6}/year), the activity released is much reduced by the hold-up of activity in the containment.

6.6.13 We have concentrated above on Pickering A because it has only one fast shut-down system. For all other stations, two independent fast shut-down systems reduce the possibility still further. For these stations, unavailability of the two systems simultaneously is required to be less than 10^{-6} year/year. This frequency has not been met, although except for one station in 1981, the figure has always been less than 10^{-3} year/year[11]. For all the other stations for which the ONSR report gives figures, safety system unavailabilities are not dissimilar to those quoted above for Pickering A.

6.6.14 In an analysis of CANDU 600 reactors, the predicted probability of core melt is given as 4.6×10^{-6}/year[12]. In the Darlington PSE*, the fuel damage category FDC0 gives potentially the most severe ex-plant release of activity. The sum of possible accident

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* The Working Group would like to express its thanks to Keith Dinnie, Mike White, and Mike Milicev of Ontario Hydro for their presentation at a Working Group meeting on the Darlington PSE.

probabilities leading to an FDC0 is 4×10^{-6}/year (for this to be coincident with failure of containment would push the probability down to about 5×10^{-9}/year).

6.6.15 These calculations concerning severe accidents all give probabilities for severe core damage with intact containment which, within errors, are of the same general order of probability as the Working Group's cut-off probability of 10^{-6}/reactor-year. As a result the Working Group decided that calculations should be carried out on probable doses resulting from these types of severe accidents with major release to containment, but taking into account the fact that, even with a prompt-critical power runaway, containment would still be intact. Severe core damage together with loss of containment is too improbable to be considered in the MPA category.

6.6.16 <u>End Fitting Failure</u>

(a) As stated in 6.5.3, for there to be a serious emission of radiation, there has to be damage to the reactor core. In paragraphs 6.6.1 to 6.6.15 we have considered a number of accident scenarios which could result in severe

damage to much of the core but in which containment remained intact. Such accidents potentially give the highest doses in the MPA category.

(b) However, there is another type of accident within the cut-off probability (10^{-6}/year) which has to be considered. This is the "end-fitting failure accident with impaired containment", in which the end of the fuel channel comes off and fuel is ejected onto the floor of the reactor building. Depending on various factors, more or less of the fission products of the fuel of the channel may be released. The probability of this happening while containment is impaired is above the cut-off frequency.

(c) This type of accident has been extensively studied, for example, in Ontario Hydro Report No. 85088[13] which was in fact initiated for a previous Working Group, as well as in the Safety Reports of the stations. Results are discussed in Section 6.8.7 below.

6.7 MPA Parameters

6.7.1 Based upon the above considerations the

Working Group has taken as its parameters for the Maximum Planning Accident (MPA) at Pickering NGS those shown in Table 6.1.

TABLE 6.1

MAXIMUM PLANNING ACCIDENT (MPA) PARAMETERS
PICKERING

Reactor Status	Equilibrium
Hold-up Time in Containment	24 hours*
Power Level	1750 MW (th)
Plume Release Height	20 m
Releases to the Environment	
Noble Gases	100 % of core inventory**
Iodines	0.1 % of core inventory**
Removal Time	1 day
Weather(from end of hold-up period)	Pasquill F weather for first 6 hours (wind speed of 1 m/s) Pasquill D weather for next 18 hours (wind speed of 5 m/s)
Wind Direction	Steady for 24 hours
Wind Meander	22.5°

* Changes to be made in the up-coming years to the Pickering site will result in a longer hold-up time.

** During hold-up, much of the noble gases (and iodine) inventory will decay by radioactivity. The actual release is then less than 100 % (or 0.1 %).

6.7.2 These values are all conservative. No more than 100 % of the noble gases core inventory can be released. At Three Mile Island less than one-millionth of the iodine core inventory was released (<0.0001 %); the figure of 0.1 % of the iodine core inventory adopted by the Working Group is taken from the analysis of failure of the CANDU 600 reactor[12]. It takes into account any momentary cracking of containment before resealing. The hold-up time (the time the vacuum vessel and the reactor building take to reach atmospheric pressure at which point venting is required) is based on the Pickering NGS* B Safety Report[14].

6.7.3 The weather selected by the Working Group is conservative, in that Pasquill F weather gives the worst overall dose and in that it is expected to occur only 10 % of the time. We have also assumed a very low wind speed of 1 m/s for Pasquill F weather[15]. Another factor of improbability is included when it is assumed that the wind remains steady in direction throughout 24 hours. Thus, the Working Group feels that the probability of

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* NGS is the acronym for Nuclear Generating Station

the dose calculated from the above parameters is likely to be well below the cut-off probability, and that doses corresponding to the cut-off probability are likely to be substantially less than those indicated below (see sensitivity analysis in Appendix G).

6.7.4 A release height of 20 m was selected as a result of considerable discussion on this matter by the Working Group. 20 m is the default value assigned in the Province of Ontario's atmospheric dispersion model.

6.7.5 The Working Group used the same percentage releases, release height, and weather for Bruce NGS and Darlington NGS as used for Pickering NGS. The power levels are different (thus, the absolute inventories are different), as are the hold-up times. For Pickering NGS, the power level is 1750 MW (th) and the hold-up time is 24 hours compared with 2600 MW (th) and 52 hours for Bruce NGS, and 2900 MW (th) and 160 hours for Darlington NGS.

6.7.6 The Working Group notes that France has recently adopted[16], as the basis for emergency planning, a "reference radiological situation" based upon 100 % of the noble gases core inventory, 0.35 % of the iodine

core inventory, and 0.1 % of the particulates core inventory being emitted, over a period T + 24 hours, to T + 72 hours, that is, a similar 24 hour hold-up time but a 48 hour release period compared with the 24 hour release period adopted by the Working Group for Pickering NGS. The Working Group understands that other European countries are moving in the same direction.

6.8 MPA Dose Calculations

6.8.1 Calculations of the resultant doses for Pickering NGS have been done, independently, by 2 members of the Working Group using different models. P.M. Fraser, acting as a consultant to the Working Group, has also made extensive calculations which are detailed in Appendix F. All three results agreed well. Synopses of the results for Pickering NGS are given in Tables 6.2. Results for Bruce NGS and Darlington NGS were calculated from those for Pickering NGS and are given in Tables 6.3 and 6.4.

TABLE 6.2
MAXIMUM PLANNING ACCIDENT - PICKERING
DOSES IN rems (1 rem = 0.01 Sv)

Distance (km)	Thyroid dose (rem)			Whole body dose (rem)			Effective dose (rem)		
	Time* (hours)			Time* (hours)			Time* (hours)		
	4	6	24	4	6	24	4	6	24
1	200	300	400	5	8	10	15	25	30
3	70	90	120	2	3	4	5	7	9
5	30	40	50	1	2	2	2	4	5
10	5	10	15	0.2	0.6	0.8	0.4	1	1.5
15	0	3	6	0.1	0.2	0.3	0	0.4	0.6

* Time from commencement of emission (which occurs 24 hours after commencement of accident)

6.8.2 The Working Group understands that the hold-up time at Pickering NGS is to be increased to 48 hours in the coming years. This will reduce all doses in Table 6.2 by approximately 12 %.

TABLE 6.3
MAXIMUM PLANNING ACCIDENT - BRUCE
DOSES IN rems (1 rem = 0.01 Sv)

Distance (km)	Thyroid dose (rem)			Whole body dose (rem)			Effective dose (rem)		
	Time* (hours)			Time* (hours)			Time* (hours)		
	4	6	24	4	6	24	4	6	24
1	300	400	600	7	10	13	20	30	40
3	90	100	150	3	4	5	6	9	12
5	40	50	70	1	3	3	3	5	6
10	6	13	20	0.3	0.8	1	0.6	1.5	2
15	0	5	8	0	0.3	0.4	0	0.5	0.8

* Time from commencement of emission (which occurs 52 hours after commencement of accident)

6.8.3 As the power level of Bruce NGS is higher than that of Pickering NGS, there is a 60 % increase in the radionuclides which could be emitted. However, the hold-up time for Bruce NGS is longer that that of Pickering NGS, so that nuclear decay reduces the available emission by about a quarter. Overall, the doses are increased (at corresponding distances and times of emission) by 30 % over the Pickering NGS figures.

TABLE 6.4
MAXIMUM PLANNING ACCIDENT - DARLINGTON
DOSES IN rems (1 rem = 0.01 Sv)

Distance (km)	Thyroid dose (rem)			Whole body dose (rem)			Effective dose (rem)		
	Time* (hours)			Time* (hours)			Time* (hours)		
	4	6	24	4	6	24	4	6	24
1	150	250	300	4	6	8	12	20	25
3	50	70	90	2	3	4	4	6	7
5	20	30	40	1	2	2	2	3	4
10	4	10	15	0.2	0.5	0.6	0.3	0.8	1.2
15	0	3	5	0	0.3	0.4	0	0.3	0.5

* Time from commencement of emission (which occurs 160 hours after commencement of accident)

6.8.5 As the power level of Darlington NGS is higher than that of Pickering NGS (and also that of Bruce NGS), there is a 60 % increase in radionuclides which could be emitted. However, the hold-up time for Darlington NGS is considerably longer than that of Pickering NGS (and also that of Bruce NGS), so that nuclear decay reduces the available emission by 50 %. Overall, the doses are only 80 % of those at Pickering NGS (at corresponding distances and times of emission).

6.8.6 In the above tables the whole body dose is the dose to the body from external

irradiation and inhalation, and includes the contribution to these from the radioiodines. The effective dose is arrived at by adding to the whole body dose the thyroid dose multiplied by a factor of 0.045 (see Section 1.2.6).

6.8.7 End-Fitting Failures

(a) For the end-fitting failure with impaired containment, dose estimates are calculated in the Ontario Hydro Safety Reports and in Ontario Hydro Report No. 85088. The Pickering Safety Report quoted in Table II.4 of Ontario Hydro Report No. 85088 gives a "short term" dose at 1 km of 83 rem to the thyroid resulting from ejection of a high power channel and a whole body dose at 1 km of 0.06 rem under the same conditions.

(b) In Table III.1 of Ontario Hydro Report No. 85088 there is quoted a total whole body dose of 0.38 rem at 1 km from ejection of an average power fuel channel with failure of the ventilation damper to close, and Pasquill F weather.

(c) Using figures in Ontario Hydro Report No. 85088, for a high power channel (for which the probability of occurrence will

be less) the dose will be about 6 times greater, about 2 rem, of which half is received in the first day.

(d) The thyroid doses are slightly smaller, stated to be 0.28 rem for the average channel (thus, again about 2 rem at 1 km for a high power channel); they are much smaller than the Safety Report's figures, reflecting more recent views of plating-out and dissolving of iodine under accident conditions. We note again that these releases will not be delayed since the accident scenario assumes impaired containment.

6.9 Comparison with other Estimates

6.9.1 The Darlington PSE[17] gives as the maximum quoted individual dose (at 1 km) a value of 24 rem (0.24 Sv) with an uncertainty factor of 3.5.

6.9.2 At Three Mile Island the maximum dose to an individual was estimated to be 0.1 rem (10^{-3} Sv). In this actual case of severe core damage but intact containment the wind direction was very variable.

6.9.3 The expected dose from a runaway power accident at Pickering NGS (studied by Argonne National Laboratory[18] and Ontario Hydro[19]) is

believed to be "less than the permitted doses"[12], which would mean less than 25 rem at the boundary.

6.9.4 The Reactor Safety Study (WASH-1400)[20] gives doses which are greatly in excess of the ones calculated here. The reason is the assumption in WASH-1400 of large iodine releases (up towards 100 % of the iodine core inventory). The Reactor Risk Reference Document (NUREG-1150)[21] carried on the methodology of WASH-1400. Its results include, within error bands, the WASH-1400 estimates.

6.10 Basis for Conclusions

In drawing conclusions from the dose calculations given above, the context within which these numbers must be considered is as follows:

(a) The Ontario Protective Action Levels (PALs) (see Table 4.1) for evacuation are a lower level of a 1 rem effective dose (under standard conditions evacuation should take place), and an upper level of a 10 rem effective dose (under most conditions evacuation must take place). The Ontario lower PAL for ingestion of pre-distributed potassium iodide is a 3 rem thyroid dose, and the upper PAL (for making potassium iodide available) is a 30 rem thyroid dose.

(b) The maximum delay in commencing evacuation (due to the risk to evacuees from travelling in severely adverse weather conditions) is not likely to be more than 24 hours at any nuclear site (communication from Emergency Planning Ontario).

(c) Any group of sectors within a 30^{o} arc from any nuclear station in Ontario could be evacuated within 6 hours of the commencement of evacuation.

(d) It is possible (see section 5.6) to improvise protective measures such as evacuation after 24 hours from the onset of an accident provided there is sufficient infrastructure for emergency response in existence for the areas around the nuclear site.

6.11 MPA Conclusions

6.11.1 Considering the MPA dose figures within the context stated above leads to the conclusions which follow.

6.11.2 Pickering Nuclear Station

(a) In the light of 6.8 (c) and (d) above, a critical figure is the maximum distance at which there is an effective dose of 1 rem or greater or a thyroid dose of 3 rem or more within 24 hours. This figure will only occur in the impaired containment scenario as in

other cases (intact containment) there is a 24 hour hold-up. Taking the most conservative of the end-fitting failure dose estimates quoted in 6.8.7 (that is, a 83 rem thyroid dose at 1 km), a 30 rem thyroid dose will not be exceeded at distances greater than 3 km, and a 3 rem thyroid dose will not be exceeded at distances greater than about 10 km.

(b) For the severe core accident with intact containment type of Maximum Planning Accident, protective measures would not in principle be required earlier than 24 hours. Such measures could be improvised (see section 6.10 (d) above) provided a sufficient infrastructure was in existence. There are two notes with respect to these comments - (i) some voluntary evacuation and desire for potassium iodide pills would commence immediately upon public notification of the accident, that is, long before the end of the hold-up period, and provision is needed to cope with these reactions, (ii) there already exists detailed planning around Pickering station out to 10 km.

(c) Table 6.2 indicates (by interpolation) that on the basis of effective dose there is no need for evacuation or ingestion of potassium iodide pills beyond 12 km from the damaged reactor up to 48 hours after the onset of the accident, and if potassium iodide pills were ingested in potentially affected areas out to this distance there would be no need for evacuation beyond 10 km.

6.11.3 Bruce Nuclear Station

(a) The power level of a high power channel, and therefore the radio-nuclide inventory, is 15 % higher for Bruce NGS than for Pickering NGS. Taking this into account would push out only slightly the limit to which thyroid doses would be greater than 3 rem in the case of an end-fitting failure with impaired containment (by a factor of 1.1, that is, out to 11 km).

(b) The 52 hour hold-up time with intact containment, more than double that of Pickering NGS, makes any improvisation more practicable. Again we note that there would be voluntary reaction to the announcement of an accident, and that

detailed planning already exists out to 10 km.

(c) Table 6.3 indicates (by interpolation) that on the basis of effective dose there is no need for any mitigation measures beyond 13 km up to 76 hrs after the accident, and that with potassium iodide pill ingestion out to 15 km, there is no need for consideration of evacuation beyond 10 km.

6.11.4 Darlington Nuclear Station

(a) The power levels of Darlington NGS reactors are also greater than those of Pickering. The power level of a high power channel and therefore, the radionuclide inventory is 23 % higher for Darlington NGS than for Pickering NGS. Taking this into account would push out only slightly the limit to which thyroid doses would be greater than 3 rem in the case of an end-fitting failure with impaired containment (by a factor of 1.15, that is, out to 11.5 km).

(b) With a hold-up time of 160 hrs, improvisation is again even more practicable.

(c) The dose levels caused by severe core

damage (but with intact containment) are lower at Darlington NGS than at Pickering NGS due to the greater decay in the containment. However, again on the basis of effective dose, thyroid blocking may be needed out to 11 km. When this is done, there is no need for consideration of evacuation beyond 10 km.

6.11.5 Sensitivity

In Appendix G there is a section on the sensitivity of dose estimates to the assumed parameters. Here we simply note that the quoted figures are for Pasquill F weather for 6 hours with the wind direction steady and the wind speed at 1 m/s (3.6 km/hr), and that, for instance, an increase to 7 km/hr will halve the dose.

CHAPTER 7

WORST CREDIBLE RADIATION EMISSION (WCRE)

7.1 General

7.1.1 As stated in Chapter 5, the Working Group also decided to consider a second criterion, namely, the Worst Credible Radiation Emission. This would define the maximum emission of radioactive materials possible from a nuclear disaster, however caused, but within the bounds of physical and chemical reality.

7.1.2 This chapter deals only with the WCRE for CANDU reactor stations. Chalk River Nuclear Laboratories and the Enrico Fermi 2 station are dealt with in Chapters 8 and 9 respectively.

7.2 Probability of Occurrence

The various types of events that would be covered by the WCRE were listed in paragraph 5.5.2. Some of these are much less probable than the criterion chosen for the MPA. Others are such that no probability of occurrence can be assigned to them. The Working Group decided that in general no probability could be associated with the WCRE, and none should be. It represents the bounding case which subsumes all events, however low their

probability.

7.3 Establishing WCRE Parameters

7.3.1 The release of radioactivity from a reactor in a Worst Credible Radiation Emission would result from the failure of a large number of fuel elements in a short period of time, with a simultaneous breach of containment.

7.3.2 The Worst Credible Radiation Emission is bounded only by chemical and physical realities - thus, no more radioactivity can come out of a reactor than is in it, and the presence of large amounts of water around a failed CANDU reactor would ensure that most of the iodine and cesium are kept in the reactor buildings as dissolved cesium iodide. On the other hand, under conditions where the containment has been breached, in principle all the noble gases released from the fuel elements could escape. There would be no lengthy hold-up within reactor and vacuum buildings but on the other hand physical realities would prevent the instantaneous evolution of gases from fuel elements.

7.3.3 There is some evidence available on catastrophic nuclear events although not for CANDU reactors. At Chernobyl the emissions from this graphite moderated reactor were

about 100 % of the noble gases core inventory, 50 % of the iodines core inventory, and a few percent of the refractory radionuclides core inventory. At Three Mile Island only about three parts in ten million of the iodines escaped (3×10^{-5} %) because of decay in containment and the presence of large amounts of water (both CANDUs and TMI have a water moderator while Chernobyl had a graphite moderator). In the SL-1 accident in Idaho (1961) only 0.1 % of the iodine core inventory escaped into the environment from a reactor building that was "little more than a shed" and with a ventilation system that was giving 1.5 volume changes of air per hour. At Windscale in the U.K. a graphite moderated, air cooled, plutonium production reactor burnt in 1957. Some 12 % of iodine in damaged fuel escaped to the environment (2×10^4 Ci) together with 100 % of noble gases from that fuel. In addition to this experiential data, there has been extensive research in Canada and elsewhere on what is expected to happen to the iodine core inventory in the event of a failure[13].

7.3.4 On the basis of all available information, the Working Group has taken as its parameters for the Worst Credible Radiation Emission (WCRE) at Pickering NGS those shown in Table 7.1.

TABLE 7.1
WORST CREDIBLE RADIATION EMISSION
PICKERING NGS

Reactor Status	Equilibrium
Hold-up Time	Zero
Power Level	1750 MW (th)
Plume Release Height	20 m
Releases to the Environment	
Noble Gases	100 % Core Inventory
Iodines	1 % Core Inventory
Rates of Release	
Noble Gases	10 % per hour
Iodines	1 % in first hour
Weather	Pasquill F weather for first 6 hours (wind speed of 1 m/s)
	Pasquill D weather for next 18 hours (wind speed of 5 m/s)
Wind Direction	Steady for 24 hours
Wind Meander	22.5 ^{o}

7.3.5 The emission of 100 % of the noble gases core inventory is clearly conservative. The rate of release of the gases is governed, at the worst, by the rate at which the fuel elements could release gaseous fission products in a core disruption. This matter has been studied by Ontario Hydro[19] in the joint study with the Argonne National Laboratory[18] commissioned by the ONSR.

7.3.6 The availability of iodine has also been studied in the above Ontario Hydro/Argonne work. This study indicates that although 2 % of iodine will be released to containment at t = 0 (that is, within seconds), only 0.02 % will be available for release after 1 hour (because of plate-out and dissolving in water). We have then taken that 1 % is released in the first hour (and none thereafter). We are aware that the Reactor Safety Study (WASH-1400)[20] and the more recent Reactor Risk Reference Document (NUREG-1150)[21] uses much higher percentage releases. We have noted previously (see Sections 7.3.2 and 7.3.3) the extensive work done in this field in the last decade which indicates much lower releases of iodine.

7.3.7 The weather conditions are those of the MPA

(paragraph 6.7.3). As stated there, these are conservative.

7.4 WCRE Dose Calculations

7.4.1 As with the MPA, three calculations were done (each using slightly different models) of the doses to be expected at Pickering NGS under the conditions given above. They all agreed well. Table 7.2 gives the results. The Pickering NGS figures were scaled up in proportion to reactor power (and thus fission product inventory) to give corresponding figures for Bruce NGS and Darlington NGS. These results are given in Table 7.3.

TABLE 7.2
WORST CREDIBLE RADIATION EMISSION - PICKERING
Doses in rems (1 rem = 0.01 Sv)

Distance (km)	Thyroid dose (rem)			Whole body dose (rem)		
	Time* (hours)			Time* (hours)		
	4	6	24	4	6	24
1	$2x10^4$	$2x10^4$	$2x10^4$	400	600	900
3	$6x10^3$	$7x10^3$	$7x10^3$	150	200	300
5	$3.5x10^3$	$3.5x10^3$	$3.5x10^3$	60	90	150
10	$1.5x10^3$	$1.5x10^3$	$1.5x10^3$	10	25	50
13	$1.0x10^3$	$1.0x10^3$	$1.0x10^3$	3	15	30
20	0	500	500	0	1	10

* Time from onset of WCRE event

TABLE 7.3
WORST CREDIBLE RADIATION EMISSION - BRUCE/DARLINGTON
Doses in rems (1 rem = 0.01 Sv)

Distance (km)	Thyroid dose (rem)			Whole body dose (rem)		
	Time* (hours)			Time* (hours)		
	4	6	24	4	6	24
1	$3x10^4$	$3x10^4$	$3x10^4$	600	1000	1400
3	$1x10^4$	$1x10^4$	$1x10^4$	250	300	500
5	$6x10^3$	$6x10^3$	$6x10^3$	100	150	250
10	$2.5x10^3$	$2.5x10^3$	$2.5x10^3$	15	40	80
13	$1.5x10^3$	$1.5x10^3$	$1.5x10^3$	5	25	50
20	0	$8x10^2$	$8x10^2$	0	1.5	15

* Time from onset of WCRE event

7.4.2 In the above tables the whole body dose is the dose to the body from external irradiation, and includes the contribution to these from the radioiodines.

7.4.3 The calculations for the WCRE have been carried out on the assumption that 1 % of the iodine core inventory comes out in the first 1 hour and none thereafter. The major part of the iodine dose is thus "committed" within one hour of the plume reaching an individual - at larger distances this will be hours after the event because of the

(conservatively chosen) low wind speeds.

7.4.4 Roughly two-thirds of the dose to the whole body, but not including the thyroid, comes from ground contamination, mainly from iodines. After the plume has passed, this contamination will continue to give radiation. The dose from this will depend very much on whether a person is outside or indoors. As an indication, the dose received in total in days 2 - 7 inclusive might equal that received in day 1.

7.4.5 Clearly the Working Group's statement that the emission will take less than 1 day is an extremely conservative assumption (at Chernobyl emissions lasted for 10 days and during that time nuclear decay reduced the total emission). Furthermore, it is not credible that the wind would be in the same direction indefinitely, and if there were emission after 1 day, the doses to persons exposed to such emissions would be very much less (below MPA levels, probably below PALs) because of the decay of activity in the 24 hours before the wind veered to the new direction. The bounding case is then the dose received or committed in the first 24 hours.

7.5 WCRE Conclusions

7.5.1 Pickering Nuclear Station

Referring to Table 7.2, the furthest distance at which 50 rem whole body is received in 24 hours is 10 km. At slightly over 5 km, 50 rem whole body is reached in four hours after the onset of emission. With respect to thyroid doses, 3000 rem is not received at distances greater than 6 km (by interpolation). Within this distance, larger doses could be committed within one or two hours.

7.5.2 Bruce and Darlington Stations

Referring to Table 7.3, the furthest distance at which 50 rem whole body is received is 13 km. At 7.5 km (by interpolation) 50 rem whole body is reached in four hours after the onset of emission. With respect to thyroid doses, 3000 rem is not received at distances greater than 9 km (by interpolation). Within this distance, larger doses could be committed within one or two hours.

7.5.3 Sensitivity

We repeat the caution of 6.11.5 with respect to the estimated doses. A doubling of wind speed, 3.6 km/hr to 7.2 km/hr, would halve the dose but would also halve the time in

which any early protective action has to be taken at a given distance.

CHAPTER 8

CHALK RIVER NUCLEAR LABORATORIES (CRNL)

8.1 General

At Chalk River Nuclear Laboratories (CRNL) there are four reactors. Of these National Research Universal (NRU) is the most powerful. Therefore, an accident with this reactor is potentially the most serious. Thus, it was the only one the Working Group considered.

8.2 NRU Characteristics

NRU has a power of 135 MW (th), 8 % of the power of a Pickering reactor. There is no vacuum building, nor any strong containment; as a result there is no lengthy hold-up of any fission products released from any damaged fuel. This means that there will be less plating-out of iodine than at Pickering NGS, and thus more radio-iodine available for release. The boundary of the Chalk River Laboratories is 5 km from the reactor.

8.3 Release Parameters

The CRNL Safety Note[22] quotes values of the releases to containment for the worst case accident to be 50 % of the noble gases core inventory and 12.5 % of the iodine core inventory. The Working Group accepts these numbers as conservative.

8.4 Filtration

After release of fission products from damaged fuel,

two possibilities exist:

(a) Fission products are released to the atmosphere via filters (the emergency ventilation system) which are quoted in the CRNL Safety Note to be 99.5 % efficient for removing iodine; this scenario would correspond to a Maximum Planning Accident.

(b) As a result of failure of the (weak) containment the iodine is released without filtration. This case would constitute the Worst Credible Radiation Emission.

8.5 Maximum Planning Accident Parameters

The parameters accepted by the Working Group are shown in Table 8.1. They are those used for the CANDU power reactors, except as specified in 8.2, 8.3, and 8.4 above.

TABLE 8.1
CHALK RIVER (NRU) MAXIMUM PLANNING ACCIDENT

Reactor Status	In Equilibrium
Power	135 MW (th)
Releases to the Environment	
Noble Gases	50 % of core inventory
Iodines	0.0625 % of core inventory
Hold-up Time	Zero
Rates of Release	
Noble Gases	5 % per hour
Iodines	0.0625 % in one hour
Weather	Pasquill F weather for first 6 hours (wind speed of 1 m/s) Pasquill D weather for next 18 hours (wind speed of 5 m/s)
Wind Direction	Steady for 24 hours
Wind Meander	22.5^{o}

8.5 Maximum Planning Accident - Results

8.5.1 Calculation of Maximum Planning Accident (MPA) doses were carried out by taking Pickering NGS's Worst Credible Radiation Emission (WCRE) doses and factoring in the noble gases and iodine releases as discussed in sections 9.3 and 9.4 above. Pickering NGS's WCRE doses are used for the NRU's MPA because there is zero hold-up time at NRU. The dose results are shown in Table 8.2.

TABLE 8.2
MAXIMUM PLANNING ACCIDENT - NRU

Distance (km)	Thyroid dose (rem)			Whole body dose (rem)			Effective dose (rem)		
	Time* (hours)			Time* (hours)			Time* (hours)		
	4	6	24	4	6	24	4	6	24
5	17	17	18	1.5	2.2	2.5	2	3	3.5
10	7	7	7	0.3	0.6	0.8	0.6	1	1
20	0	3	3	0	0	0.6	0	0	0.7

* Time from commencement of emission and of accident

8.6.2 CRNL's Nuclear Safety Note[22] gives a figure of approximately 2 rem whole body dose at the boundary and 1 rem whole body dose at 10 km. This is in good agreement with the results of Table 9.2.

8.6.3 Based on these figures, the Working Group does not believe that any change need be made in the present plans, which call for detailed planning up to 10 km from the reactor.

8.7 Worst Credible Radiation Emission

8.7.1 The difference between the Maximum Planning Accident for NRU and the Worst Credible Radiation Emission for NRU is that in the latter no credit may be taken for the filtration of iodine. All other parameters are as shown in Table 9.1. This considerably alters the plume dose and that due to ground deposition. The dose due to iodine is increased 200 fold if it is assumed that all of the 12.5 % of the iodine core inventory available to be emitted is released to the atmosphere.

8.7.2 Doses resulting from a WCRE at NRU are shown in Table 8.3 as a function of time and distance.

TABLE 8.3
WORST CREDIBLE RADIATION EMISSION - NRU

Distance (km)	Thyroid dose (rem)			Whole body dose (rem)		
	Time* (hours)			Time* (hours)		
	4	6	24	4	6	24
5	3400	3400	3500	30	50	100
10	1400	1400	1400	8	16	40
20	0	600	600	0	2	10

* Time from commencement of emission and of accident

8.7.3 Doses are such that no early morbidity is expected at distances greater than 10 km. The Working Group notes that current plans include plans for evacuation of residents living within 10 km of NRU.

CHAPTER 9

ENRICO FERMI 2

9.1 The Fermi 2 Station

The Fermi 2 nuclear power station in the State of Michigan in the U.S. consists of a single Boiling Water Reactor (BWR) of power 3300 MW (th). The nearest Canadian point is 10 miles (16 km) from the station.

9.2 Maximum Planning Accident

9.2.1 The Fermi 2 Updated Final Safety Analysis Report (UFSAR) discusses various types of accidents. The "limiting fault" discussed (and indeed the only one discussed with a significant release) is a Loss of Coolant Accident (LOCA) with intact containment. Limiting faults are "occurrences which are not expected to occur ...". This loss of coolant accident with "fuel damage approaching melt conditions" but intact containment is similar to the Working Group's definition of the MPA.

9.2.2 Releases of 100 % of the noble gases core inventory and 50 % of the iodines core inventory are assumed into containment, but containment is intact. With intact containment 99.5 % of the iodine activity is trapped.

9.2.3 This emission gives, at 1 km, a whole body dose of 6.5 rem and a thyroid dose of 10 rem; at 5 km, a whole body dose of 1.7 rem and a thyroid dose of 6.7 rem; at 10 miles, an estimated whole body dose of 0.3 rem and a thyroid dose of 1.1 rem, that is, a total effective whole body dose of approximately 0.3 rem.

9.2.4 Using these values as the MPA, and Ontario's Protective Action Limits (PALs), no evacuation of any Ontario residents need be contemplated as a result of such an accident.

9.3 Worst Credible Radiation Emission

9.3.1 The Fermi-2 Environmental Statement (ES)[23] discusses "Class 9" accidents, in which there is "deterioration of the capability of the containment to perform its intended function" as well as "substantial physical deterioration of the fuel in the reactor core". All the Class 9 accidents quoted have probabilities at (in one case) or below 10^{-5}/station-year. From these two criteria, it is reasonable to categorize them as "Worst Credible Radiation Emissions".

9.3.2 The assessment methodology used in the Environmental Study is based on that of the Reactor Safety Study[20] but the sets of

accident sequences considered have been updated ("rebaselined"). One scenario includes releases of up to 45 % of the core inventory of iodine.

9.3.3 We have previously discussed this matter of iodine release, noting the actual amounts of iodine emitted in the TMI, SL-1, Windscale, and Chernobyl accidents. We also note the guarded comments by the American Physical Society Study Group on Radio-active Release[24], chaired by Dr. R. Wilson which states that "new calculations indicate that significantly smaller quantities of radionuclides reach the environment than calculated in the Reactor Safety Study". Further, "there is good evidence that the iodine reacts with cesium to form cesium iodide ... which would either dissolve in water or condense to form an aerosol. Some of the aerosols would deposit on surfaces in the primary reactor system or ... on surfaces in the containment building; in either case, the release to the environment would be reduced".

9.3.4 The American Nuclear Society, in its Report of the Special Committee on Source Terms[25] found that the reductions in the source

estimate of the Reactor Safety Study "could range from more than a factor of ten to several factors of ten for the critical fission products".

9.3.5 The Reactor Risk Reference Document (NUREG-1150)[21] records the latest results of source term research carried out for the U.S. NRC. These results generally agree with the trend to lower source terms, but there do exist large uncertainty bands. For the Boiling Water Reactor (BWR) station considered in NUREG-1150 (Peach Bottom) the report states "It should be noted that recent calculations performed for the NRC staff suggest that this building [the containment] may retain more radioactive material than assessed in the Sandia risk analyses supporting this report".

9.3.6 The Working Group has attempted to gain more information on Fermi 2 from the U.S. Nuclear Regulatory Commission (U.S. NRC) but have failed to do so because, according to the U.S. NRC, they have no information further to the published information to which we refer.

9.3.7 In the light of accident experience with water moderated reactors, and of experimental and theoretical work in source terms, the Working Group has had to decide if releases

of up to 45 % of the iodines core inventory were credible. For CANDU reactors, the Working Group has stated that a 1 % release of the iodine core inventory is the "worst credible"; a similar belief seems justified for a boiling water reactor (BWR). As normal in this Report, 100 % of the noble gases core inventory are assumed released from a BWR as from a CANDU.

9.3.8 Then using the Pickering NGS WCRE dose estimates given in Table 7.2, but noting that the Fermi 2 power (and inventory) is approximately twice that of Pickering NGS, the Fermi 2 external whole body dose at 10 miles (16 km) from Fermi 2 is estimated to be 50 rem under worst weather conditions, and the thyroid dose is estimated to be 1500 rem. The arrival time of the plume giving rise to these doses is 4 hours after the event at Fermi 2.

9.3.9 If one accepts the release of 45 % of the iodine core inventory (and 100 % of the noble gases core inventory), the release is very similar to the Chernobyl situation.

9.3.10 This matter of the iodine source term is clearly of great importance. We are told by the Fermi nuclear facility operator, Detroit

Edison, that a full Probabilistic Risk Assessment is under-way and will be available in the fall of 1988. We believe that the correct approach at the present time is to adopt the 1 % iodine release figure and to plan on the basis of the resulting numbers, and to re-assess the situation when the PRA is published.

CHAPTER 10

CONCLUSIONS AND RECOMMENDATIONS

10.1 General

We commenced this Report with the statement that all facilities should be designed to be safe. The ONSR has studied the safety of Ontario's nuclear facilities intensively, and has concluded that they are being operated safely; nevertheless, the safety net of emergency planning (be it fire brigades or nuclear emergency planning) is provided for all eventualities whose probability exceeds a pre-determined level, and so nuclear emergency plans exist. This pre-determined level should take into account social and economic considerations including the public's perception of nuclear accidents. Moreover, the ONSR has stated that emergency plans for nuclear power stations should be based on the maximum credible releases of radioactive materials.

Recommendation 1:

The Working Group recommends that two tiers of emergency planning are needed:

(i) the first tier (termed the Maximum Planning Accident or MPA) provides detailed planning for accidents which can be quantitatively determined to be as low as once in 10^5 station-years. For this tier the

Working Group recommends that planning assure public exposure to radioactive doses be kept less than the Protective Action Levels.

(ii) the second tier (termed the Worst Credible Radiation Emission or WCRE) provides planning for accidents which are lower in frequency or whose frequency cannot be quantified (gross human error or hostile action). For this tier the Working Group recommends planning to protect against the onset of early morbidity (sickness) and the onset of early mortality (death) in a member of the public.

10.2 Maximum Planning Accident

We believe that despite good design and prevention of man-made disasters there still must be the safety-net of emergency planning. An infrastructure of detailed planning must exist in primary zones around each station, on which, in the very unlikely event that it is called upon, improvisation can be built. In these primary planning zones, residents should know about, for instance, evacuation routes, sources of potassium iodide pills and sources of information. This is already being done in Ontario. The sizes of these planning zones depend upon the anticipated off-site doses resulting from different types of events.

Recommendation 2:

The Working Group recommends that for detailed planning of emergency measures to provide a safety net in case of engineering failures (the Maximum Planning Accident), the maximum doses given as a function of time and distance in Tables 6.2, 6.3, and 6.4 be used for the Pickering, Bruce, and Darlington stations respectively.

10.3 Worst Credible Radiation Emission

10.3.1 In Chapter 5 the Working Group has examined the situations which could conceivably account for a Worst Credible Radiation Emission (WCRE). These fall into two categories - very low probability (typically, much less than once in a million years), and unquantifiable.

10.3.2 In Chapter 7 the Working Group calculated the potential doses from such an event. The potential doses are very high.

10.3.3 It is the belief of the Working Group that the correct way of guarding against the potential consequences of a WCRE is to prevent such events from occurring.

10.3.4 In the Working Group's opinion the most likely cause of severe events is human action, either deliberate or unintentional.

(a) With respect to hostile action, for example, terrorist action, we did not ask to be, and have not been made, privy to details of plans to prevent such action, though we understand that such plans do exist. We believe that it is essential that all necessary measures be taken to ensure that no person or group of persons can gain control of a nuclear station in any way that can lead to the off-site emission of more than normally permitted levels of radiation.

(b) With respect to gross human error affecting safety, the Ontario Nuclear Safety Review has conducted an extensive review of the impact of human performance on nuclear safety. We endorse their recommendations in this area.

10.3.5 As long as there exist severe accident scenarios whose probabilities are unquantified, they will give rise to concern. A thorough Probabilistic Safety Evaluation of each station should enable such possible scenarios to be identified and quantification to be made; of particular value is the fact that weak links in safety chains can be

identified, and fixed; if on the other hand the probability of potential accident chains are quantified and found to be highly unlikely, public concern will be reduced. We note Recommendation #8 and the recommendation in Volume 2, Appendix II, paragraph 272 of the Report of the Ontario Nuclear Safety Review regarding these issues and endorse them.

Recommendation 3

The Working Group recommends that for planning of emergency measures to deal with the possible effects of a Worst Credible Radiation Emission the doses given as a function of time and distance in Tables 7.2 and 7.3 be used for the Pickering, Bruce and Darlington stations. In utilizing these data to determine the extent of emergency planning that is required, the Province should take into account the improbability of the occurrence of some of these events, the preventable nature of others, the conservative nature of the calculations (for example, see Appendix G), the public's perception of its need for protection, and the alternative use of economic resources.

Recommendation 4:

The Working Group recommends that the only planning that should be done for this type of emission is to prevent early morbidity or mortality, for which we recommend threshold levels to be taken as 50 rem whole body or 3000 rem thyroid for early morbidity and 150 rem whole body for early mortality.

10.4 Primary Planning Zones

Recommendation 5:

Based on all of the above recommendations the Working Group recommends that the size of the Primary Zones for Pickering, Bruce and Darlington nuclear stations should be 13 km.

10.5 Chalk River Nuclear Laboratories

Recommendation 6:

Around Chalk River Nuclear Laboratories the Primary Zone should remain unchanged at 10 km from the NRU reactor (see sections 8.6 and 8.7).

10.6 Enrico Fermi 2

Recommendation 7:

In Essex County the Primary Zone should remain unchanged at 21.5 km from the Fermi reactor with reconsideration when the Fermi-2 Probabilistic Risk Assessment is available in the fall of 1988 (see sections 9.2 and 9.3).

10.7 Mitigation Measures

Recommendation 8:

The Working Group recommends that the Province consider taking appropriate measures within the context of the above recommendations in the following areas:

(a) the availability and distribution of potassium iodide pills.

(b) the need for early warning systems for the public.

(c) the need for adequate medical facilities to deal with possible acute radiation exposure.

(d) the advisability of restricting new housing construction near nuclear facilities.

10.8 Protective Action Levels

Consultants to the Working Group (see section 3.2) tended to feel that Ontario's Protective Action Levels were too low.

Recommendation 9:

The Working Group recommends that the Province of Ontario review the present Protective Action Levels in the light of world norms.

CONCURRENCE

The members of the Working Group, in token of their concurrence with the recommendations made in this report, append their signatures below:

K.G. McNeill

27 June 1988
F.B. Ali

G. Armitage
(See object to Dissenting Minute)
1988 June 30.
[See after Appendix G]

L.N. Carling 27/6/88

J.Q. Howieson 88/06/28

L. Pearson June 27, 1988

P. Gomes
P.R. Gomes 27/6/88

GLOSSARY

ACNS	Advisory Committee on Nuclear Safety (of the AECB)
AECB	Atomic Energy Control Board
AECL	Atomic Energy of Canada Limited
BWR	Boiling Water Reactor
CANDU	Canadian Deuterium Uranium
Committed Dose	The dose that will be received by an organ or a tissue of the body of a person from radioactive substances in the body during the 50 years immediately following the intake of those substances.
Contamination	The deposition of unwanted radioactive material on the surfaces of structures, areas, objects, or personnel.
Coolant	A substance circulated through a nuclear reactor to remove or transfer heat. The most commonly used coolant is water. Other coolants include heavy water, air, carbon dioxide, helium, liquid sodium, and sodium-potassium alloy.
CRNL	Chalk River Nuclear Laboratories
Dose, Whole-Body	The average uniform absorbed dose or dose equivalent received by a person whose whole body is exposed to ionizing radiation from an external source.
DPSE	Darlington Probabilistic Safety Evaluation
ECCS	Emergency Core Cooling System
Effective Dose	The sum of the weighted doses received by the organs and tissues of the body of a person.
EP	Emergency Planning
ES	Environmental Statement

Gray	The SI unit of absorbed radiation dose in J/kg.
Half-life	The time in which half the atoms of a particular radioactive substance disintegrates to another nuclear form. Measured half-lives vary from millionths of a second to billions of years.
Heat Sink	Anything that absorbs heat
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
Ionization	The process of adding one or more electrons to, or removing one or more electrons from, atoms or molecules, thereby creating ions. High temperatures, electrical discharges, or nuclear radiations can cause ionization.
IOWG	Interorganizational Working Group
LOCA	Loss of Coolant Accident
Moderator	A material, such as ordinary water, heavy water, or graphite, used in a reactor to slow down high-velocity neutrons, thus increasing the likelihood of fission.
MPA	Maximum Planning Accident
NCRP	National Council on Radiation Protection and Measurements
Noble Gas	A gaseous chemical element that does not readily enter into chemical combination with other elements. An inert gas.
NRU	National Research Universal
Nuclear Reactor	A device in which nuclear fission may be sustained and controlled in a self-supporting nuclear reaction. The varieties are many, but all incorporate certain features, including fissionable material or fuel, a moderating material (unless the reactor is operated on fast neutrons), a reflector to conserve escaping neutrons, provisions for

	removal of heat, measuring and controlling of instruments, and protective devices.
ONSR	Ontario Nuclear Safety Review
PALs	Protective Action Levels
PRA	Probabilistic Risk Assessment
PSE	Probabilistic Safety Evaluation
rad	100 rad = 1 Gray
Radiation	Any atomic or sub-atomic particle or electromagnetic wave emitted or produced by a prescribed substance or a nuclear facility and having sufficient energy to produce ionization.
RBMK	Light water cooled, graphite moderated nuclear power reactor of the Soviet design.
rem	Acronym of Roentgen equivalent man. The unit of dose of any ionizing radiation that produces the same biological effect as a unit of absorbed dose of ordinary X-rays.
Sievert	A unit, in the International System of Units (SI), of dose equivalent which is equal to 100 rem.
Source Term	The quantities of radioactive materials released from a nuclear reactor in an accident.
TMI	Three Mile Island
WCRE	Worst Credible Radiation Emission

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APPENDIX A

Ontario

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June 22, 1987

NUC 7.1.8

MEMORANDUM TO: Distribution List

SUBJECT: PROVINCIAL WORKING GROUP # 8 - LEVEL OF EMERGENCY PLANNING AND PREPAREDNESS

REF: Our memorandums dated January 29, 1987 and March 25, 1987

The Provincial Cabinet has approved the setting up of a working group to examine the issue of an appropriate level of emergency planning and preparedness in Ontario for dealing with nuclear emergencies, and to report thereon.

Provincial Working Group # 8 is hereby constituted under the authority of the Solicitor General. The composition of the working group is given in Annex A attached. The members were nominated by their respective organizations, but will serve on the working group in their individual capacities and not as representatives of their organizations. The terms of reference of the working group are given in Annex B attached. These were developed in consultation with appropriate organizations and individuals.

The Working Group is required to complete its work and submit its report as early as possible, but no later than June 30, 1988.

K.J.W. Reeves
Coordinator
Emergency Planning Ontario

Encl.

Distribution:

Chairman and Members, Provincial Working Group # 8
Dr. G.R. Wright, Ministry of Labour
Mr. M.W. White, Ontario Hydro
Mr. B. Gay, AECL
Mr. T. Diamantstein, AECB

APPENDIX B

Ontario

PROVINCE OF ONTARIO

NUCLEAR EMERGENCY PLAN

WORKING GROUP # 8

LEVEL OF EMERGENCY PLANNING AND PREPAREDNESS

TERMS OF REFERENCE

The fourth Guiding Principle of the Provincial Nuclear Emergency Plan states, in part:

> An appropriate balance shall be struck between risk and cost when assessing the level of emergency planning and preparedness required.

To assist the Province in applying this principle, the Working Group is required to examine the issue and make recommendations on the following aspects of it:

(1) The reference radiological situation offsite which should define the upper limit for detailed emergency response planning and preparedness in Ontario.

(2) In the context of the above, whether any consequence mitigation measures need to be adopted in addition to those prescribed in or under the Provincial Nuclear Emergency Plan, and whether any of these latter measures need to be modified.

In recommending an upper limit for detailed planning, the following factors should be considered:

(1) Scientific assessments of the risk of different types of accidents (in terms of estimated probabilities and effects), and the validity of such assessments.

(2) Risks which cannot be systematically assessed (e.g. those relating to hostile action).

(3) Public perceptions of the danger from nuclear accidents, and public expectations of consequence mitigation.

(4) The probable effectiveness of improvising emergency response measures in areas beyond those for which detailed plans and preparations have been made.

(5) A safety margin, where not already incorporated, to allow for the uncertainties involved.

(6) Any other factors the Working Group can justify as meriting consideration.

The Working Group shall make publicly known the fact of its constitution and the subject of its deliberations, and shall receive and consider relevant submissions from all affected and interested parties, including members of the public.

The Working Group shall submit its report as early as feasible, but no later than June 30, 1988.

Attached as Appendix 1 are background notes on the issue which the Working Group is tasked to study. These notes are meant to assist the group in interpreting and amplifying these Terms of Reference and in conducting its study.

BACKGROUND NOTES

1.0 Emergency Planning and Preparedness

1.0.1 Emergency planning and preparedness seeks to mitigate the consequences of a nuclear accident. The level of this planning and preparedness is related to:

(a) The area covered by plans and preparations.

(b) The measures that are taken in this area in advance of an emergency and during it.

Both these items are prescribed in the Provincial Nuclear Emergency Plan, and the Working Group is concerned with both of them, though only indirectly with the first.

1.0.2 The area to be covered by plans and preparations for dealing with the consequences of an accident at a nuclear facility is primarily determined by a postulated radiological situation adopted as a reference standard. To enable this area to be derived the radiological situation should be defined in both time and space. (The standard currently adopted in the Provincial Plan is an effective dose of 25 rem (250 mSv) at 1 km from the nuclear reactor).

1.0.3 The types of measures which should be undertaken to mitigate the consequences of a nuclear accident are fairly standard, and the Working Group is unlikely to need to spend much time considering them. However, it is possible that the reference radiological situation recommended by the Group may have implications for the application of some of these measures, such as, for example, alerting of the potentially affected public, availability and use of stable iodine compounds, etc.

2.0 Analysis of Risk

2.0.1 The principle quoted in the Terms of Reference speaks of a balance being struck between risk and cost. Risk, in this context, is defined as follows:

$$\text{Risk} = \text{Probability of Occurrence} \times \text{Magnitude of Consequences}$$

2.0.2 Even though the Working Group is required to express its main recommendation as a reference magnitude of consequences, it still needs to consider probabilities of occurrence of various events to arrive at this recommendation. However, the Group is not required to adopt or even pronounce upon any scheme of probabilities of various events, or a reference probability as a basis for emergency planning and preparedness.

3.0 The Issue of Cost

3.0.1 The amount of resources to be devoted to nuclear emergency preparedness is a political and policy decision to be made by the Government of Ontario and, within their spheres, by municipalities and other organizations concerned. The Working Group is not required to go into the question of what expenditure of resources is or is not appropriate for nuclear emergency preparedness. It is sufficient for the Group to assume that nuclear emergency preparedness has to compete with other needs for a share of limited resources, and, therefore, its recommendations (which require resource expenditure) have to be justifiable in terms of necessity and importance.

3.0.2 It will be seen that the Working Group is required to concern itself almost exclusively with the risk side of the risk-cost relationship postulated in the Plan principle. It is for the Government of Ontario to strike the appropriate balance by assessing the cost of the Group's recommendations, and deciding whether those costs should be met. Should it decide to expend less than these costs, it will be taking a policy decision to accept risks higher than those recommended as acceptable by the Working Group. This is the prerogative of the Government.

4.0 Public Perception

The need to factor in public perceptions and expectations into the assessment of an appropriate level of emergency preparedness is based on the following considerations:

(a) Emergency preparedness is required not only to protect people and property in the event of a nuclear accident, but also to provide sufficient reassurance to the public so as to maintain an

adequate level of support for the continued functioning of the nuclear industry. The public's perception of the danger, and its views on what constitutes adequate protection are, thus, relevant factors.

(b) Mass means of communication and individual means of transportation provide people living in the vicinity of nuclear facilities with the ability to make their own personal decisions on safety and to implement them, possibly independently of the instructions being issued by the authorities. Emergency plans and preparations should take into account what people are likely to do in an emergency.

(c) Since the final decision on expenditure of resources on emergency preparedness will be based also on political considerations (see 3.0.1 above), and these are shaped to a considerable degree by public perceptions and expectations, the Working Group's recommendations are likely to be much more useful if it takes them into account.

5.0 Improvisation

Whenever limits are placed on the quantum of emergency preparations and the area to be covered by them, this is usually qualified by the assurance that additional measures needed in an emergency, or extending response measures to other areas, would be improvised at the time. Since the Working Group's recommendations will also be in the nature of placing limits on emergency preparedness, and this qualification is likely to be implied or explicitly stated, it would be appropriate for the Group to assess the extent to which this is a valid expectation.

6.0 Hostile Action

6.0.1 The Terms of Reference include a reference to hostile action. This is defined in the Provincial Nuclear Emergency Plan as follows:

> "Any action, or threat of action, which could adversely affect, to a significant degree, the plant, materials, systems, operations or operators of a nuclear facility."

6.0.2 This definition does not extend to cover war situations.

APPENDIX C

PROVINCE OF ONTARIO

NUCLEAR EMERGENCY PLAN

WORKING GROUP #8

LEVEL OF EMERGENCY PLANNING AND PREPAREDNESS

COMPOSITION

Chairman

Dr. K.G. McNeill	University of Toronto

Members

Dr. J.H. Aitken	Ministry of Labour*
Mr. F.B. Ali	Ministry of the Solicitor General
Mr. G. Armitage	Ontario Hydro
Mr. L.N. Carling	Atomic Energy Control Board
Mr. J.Q. Howieson	Atomic Energy of Canada Limited
Mrs. L. Pearson	University of Toronto**

Secretary

Ms. P.R. Gomes	Ministry of the Solicitor General

* Left the Working Group in April 1988 on leaving the public service

** Replaced Dr. Aitken in April 1988

APPENDIX D

PUBLIC RESPONSE

As mentioned in section 3.4, the Working Group wrote letters which announced the existence of the Working Group and requested submissions. In addition an advertisement was placed in two newspapers. Included in Appendix D is a list of the names of the organizations and individuals who responded to the letters and advertisements.

As expected, many of the comments were not specific to the task of the Working Group - three organizations referred to their more general submissions to the ONSR. Here we will mention only the points germane to the Working Group.

(1) A call for larger primary zones, noting that in the U.S. the equivalent zone is 10 miles and that after Chernobyl people were evacuated out to 30 km (and children further). [See Recommendation 5].

(2) Pre-distribution of potassium iodide pills (in one case, a request for this to 100 km) [See Recommendation 8].

(3) Early warning systems (out to 30 km) and automatically trigerred. [See Recommendation 8].

(4) Probabilistic Risk Assessment of high consequence/ low probability events including for instance, aircraft crashes and bombing.[See Section 10.3.5]

(5) A realization that human error is the most

important problem. [See Recommendation 1].

(6) Planning should be based on the maximum credible accident. [See Recommendations 3 and 4].

(7) The composition of the Working Group (stated to have only nuclear industry and regulatory representatives on it and therefore, neither impartial or credible). [See Chapter 2 and Appendix C].

LIST OF RESPONDENTS

Person and/or Organization

M. Joe and A. Hansen

Corporation of the Town of Newcastle

Nuclear Awareness Project

The Regional Municipality of Durham

St. John Ambulance

B. Beach

T.J. Jamieson

H. Hansen

Z. Domaratzki
Atomic Energy Control Board

S. Farlinger

J. Costanzo

M. Masse
Minister of Energy, Mines and Resources

C. Winter
The Conservation Council of Ontario

C. Mann
Mayor, Town of Kincardine

N. Rubin
Energy Probe

R. Bertell
International Institute of Concern for Public Health

Canadian Environmental Law Association

Corporation of the County of Essex

J. Epp
Minister of National Health and Welfare

The Corporation of the City of Windsor

Canadian Physicians for the Prevention of Nuclear War

The Regional Municipality of York

R. Veilleux
Atomic Energy of Canada Limited

City of Scarborough

Scarborough Environmental Advisory Committee

Anonymous

APPENDIX E

STUDENT'S PUBLIC OPINION POLL

QUESTIONNAIRE

1. Do you live within a five mile radius of the Pickering Nuclear Power Station?

2. Were you concerned about the plant when you moved here?

3. Do you think that nuclear power generation is essential to Ontario Hydro's needs now or in the future? Do you think that another form of energy production should have been pursued more fully?

4. Are you concerned about the possibility of accidents at the Pickering Plant? Is it a source of anxiety for you?

5. What percentage chance do you feel that there is of a life-threatening accident at the Pickering Plant within the next ten years?

6. Do you feel a sense of anxiety towards the possibility of a life-threatening accident within the next ten years?

7. Do you have a plan in case of an accident? If so, what is that plan?

8. Do you think that children should be practised in evacuation techniques?

9. Do you feel that this preparation would needlessly increase their anxiety?

10. Do you think that Ontario Hydro and/or the Government of Ontario should have a communicated evacuation plan in place?

11. Have you received pills to be taken in case of radiation leakage from the Pickering Station?

12. If these pills were to be offered to you, would you like to have them?

13. Would you like to see the Pickering Plant and others in Ontario closed?

14. How much of the power in Ontario do you feel is nuclear generated?

15. Have you ever toured the plant?

16. After the Chernobyl incident did you feel concerned as to your proximity to the plant?

17. Do you feel that Ontario has

    (a) sufficient generating capacity?
    (b) insufficient generating capacity?
    (c) more generating capacity than required?

18. Are you concerned about the disposal of spent nuclear fuel rods and waste?

RESULTS

1. 100 % of people surveyed lived within a five mile radius of the plant.

2. 88 % of the participants felt that the plant was not a concern when they moved here.

   8 % of the people were concerned about the power plant when they moved here.

   4 % of the participants already lived here at the time construction.

3. 12 % of the participants felt that nuclear generation was not essential to Ontario Hydro's needs now or in the future.

   84 % of the people surveyed felt that nuclear generation was essential to Ontario Hydro's needs either now or in the future.

   4 % of the participants were unsure but felt that some type of power generation was required.

4. 64 % of the people surveyed felt concerned about the possibility of accidents within the next ten years.

   36 % of the participants did not feel concerned about the possibility of accidents within the next ten years.

5. In an average of the people surveyed, it is believed that there is a 21.44 % chance of a life threatening accident occurring within the next ten years at the Pickering Plant.

6. 28 % of the people surveyed felt a sense of anxiety towards the possibility of accidents at the Pickering Plant within the next ten years.

   60 % of the participants did not feel a sense of anxiety towards the possibility of accidents at the Pickering Plant within the next ten years.

   12 % of the people surveyed occasionally feel a sense of anxiety towards the possibility of accidents at the Pickering Plant within the next ten years, however, they do not find it to be a major concern.

7. 84 % of the participants do not have a plan of attack in case of an accident at the Pickering Plant.

   12 % of the people surveyed would evacuate north.

   4 % of the people surveyed would evacuate to the basements of their homes.

8. 84 % of the participants feel that children should be practiced in evacuation techniques.

   16 % of the people surveyed feel that children should not be practiced in evacuation techniques.

9. 56 % of the people surveyed felt that preparing children in these techniques would needlessly increase their anxiety.

   40 % of the participants felt that this process would not needlessly increase their anxiety.

   4 % of the people surveyed are undecided as to whether or not this process would needlessly increase their anxiety.

10. 92 % of the people surveyed feel that Hydro and/or the Government of Ontario should have a communicated evacuation plan in place.

    4 % of the survey group is not sure.

    4 % of the participants do not think there should be an evacuation plan in place.

11. 100 % of the participants have not received pills to be taken in case of radiation leakage.

12. 64 % of the people surveyed would like to have these pills in their home.

    28 % of the participants would not like to have these pills in their home.

    8 % of the people surveyed are unsure as to whether or not they would like to have these pills in their home.

13. 92 % of the participants do not want to see this or other similar plants closed.

    8 % of the people surveyed do want to see the plant closed.

* A major concern of a lot of the people surveyed is that they feel that it was not a wise idea to construct a nuclear power plant so close to a residential area.

14. It is believed that 39.83 % of power generated in Ontario is done using nuclear methods. Eight percent of the people surveyed had no idea and refused to comment.

15. 68 % of the people surveyed have never toured the plant.

    32 % of the participants have toured the plant.

16. 52 % of the participants felt concerned after the Chernobyl incident.

    44 % did not feel concerned after the Chernobyl incident.

     4 % felt a little concerned after the Chernobyl incident.

17. 52 % felt that Ontario has sufficient generating capacity.

    40 % felt that Ontario has more generating capacity than required.

     4% felt that Ontario does not have sufficient generating capacity.

     4 % were undecided and did not wish to comment.

18. 92 % of the people are concerned about the disposal of spent nuclear rods and waste.

     8 % of the participants are not concerned about the disposal of spent nuclear rods and waste.

Appendix F

Calculation of Whole Body and Thyroid Doses for the Maximum Planning Accident and the Worst Credible Radiation Emission

By Peter Fraser

Summary

The attached report was commissioned by Province of Ontario Nuclear Emergency Plan Working Group #8 as an aid to its examination of the appropriate level of nuclear emergency planning and preparedness in the Province of Ontario. This report summarizes the methods used to calculate the whole body and thyroid doses for two types of nuclear emergencies, the Maximum Planning Accident (MPA) and the Worst Credible Radiation Emission (WCRE). The amount of radioactive material released and the weather conditions during the release for each emergency were specified by the Working Group. Doses are calculated for an individual standing outdoors at 1, 3, 5, 10, and 15 kilometres downwind from the accident. The analysis has considered each emergency occurring at Pickering, Bruce or Darlington Nuclear Generating Station (NGS). The doses are summarized in Tables 8-14 of the attached report.

The computational methods and assumptions follow those used in the CSA standard N288.2 (7th draft) for calculating the dispersion and exposure of people to the radioactive plume. Data reported by Ontario Hydro for the Pickering site and radionuclide inventory were used. The results for Pickering were scaled for Bruce and for Darlington taking into account the differences in radionuclide inventory and capability of each containment to delay the release.

For the MPA at Pickering, the whole body dose is calculated to be 30 rem (0.30 Sv) at 24 hours at 1 km. The thyroid dose is estimated to be 400 rem (4 Sv). The effective whole body dose has fallen to 1.5 rem at 10 km and below 1 rem at 15 km. Doses will be 30 percent larger at Bruce because of the large radionuclide inventory. The dose at 15 km is just below 1 rem. However, at Darlington, the estimated delay before releases begin is estimated to be 160 hours. Thus the MPA doses are about 80 percent of those at Pickering.

For the WCRE, the doses are much larger. At 1 km, the thyroid dose after four hours could be as large as 20000 rem (Pickering) or 30000 rem (Bruce or Darlington) and 400 rem (600 rem at Bruce or Darlington) to the whole body. Doses are larger at Bruce and Darlington because of the larger radioiodine

inventories. Doses from ground contamination produce a significant fraction of the whole body doses.

The results of this analysis have been compared with the assessments of two Working Group members. Agreement is good in most instances, and where not good, differences are attributable to the use of different parameters.

1.0 Introduction

Nuclear Emergency Plan Working Group #8 was commissioned by the Province of Ontario to examine and make recommendations concerning the appropriate level of nuclear emergency planning and preparedness in Ontario. In particular, the Working Group is required to examine and to make recommendations concerning the appropriate upper limit for detailed emergency response to a nuclear emergency and what, if any, additional consequence mitigation measures need to be taken beyond those outlined in the current Provincial Nuclear Emergency Plan.

As part of this exercise, the Working Group has identified two nuclear reactor accident scenarios, called the Maximum Planning Accident (MPA) and the Worst Credible Radiation Emission (WCRE). The radiological consequences of these postulated events has been used to guide the group's recommendations concerning nuclear emergency preparedness. The author of this report was hired by the Working Group to calculate and report on these consequences.

This report is in fulfillment of that contract. The following pages outline the method and results of computations of the doses received by individuals exposed following a hypothesized Maximum Planning Accident (MPA) or Worst Credible Radiation Emission (WCRE) at Pickering, Bruce or Darlington Nuclear Generating Stations. The accident specifications were established by the Working Group.

The next section provides details of the method employed to calculated the doses, detailing both the models and assumptions used to calculate the dispersion of radioactivity and the dose equivalent received by exposed individuals. The methods follow closely the methods recommended in the draft CSA standard N288.2, Guidelines for Calculating Radiation Doses to the Public from a Release of airborne Radioactive Material Under Hypothetical Accident Conditions in Nuclear Facilities.

Following this, a description of each scenario (the MPA and the WCRE) and the results of the dose calculations are presented. The report concludes with a summary of these results.

2.0 Assumptions and Methods

2.1 Atmospheric Dispersion Assumptions

The assumptions chosen for the dispersion of radioactivity from the cloud are consistent with the draft of the CSA standard N288.2, "Guidelines for Calculation of Radiation Doses to the Public From a Release of Airborne Radioactive Materials Under Accident Conditions from Nuclear Power Stations" (7th Draft, June 1985). Data used by Ontario Hydro in the Pickering NGS B Safety

report has been used in calculating the dispersion factors. For the sake of simplicity a single roughness length (10 cm) was chosen rather than using three different values as used in the Pickering B accident analysis. Table 1 is a list of parameters used in the calculations.

Table 1
Site Data needed to calculate
Atmospheric Dispersion Factors
For the MPA and the WCRE

Building Area	7100 sq. m.
correction factor C	0.5
Roughness length	10 cm.
Sector angle	22.5 degrees

The Working Group specified the weather scenario and the average wind speeds to be used as well as the effective height of the release. This information is presented in Table 2.

Table 2
Weather Scenarios

CASE I	Time After Release Begins (h)	Stability Class	Dispersion Type	Height of Inversion (m)	Average Wind Speed (m/s)
	0-6	F	Prolong	100	1
	6-24	D	Prolong	600	5

Pasquill F conditions were chosen because these give the least dispersion of all six weather categories. Pasquill F occurs approximately 10 percent of the time at Pickering and other reactor sites. The wind direction is assumed to be constant throughout the first 24 hours but to meander within a 22.5 degree sector spreading the release uniformly within that sector. The wind speed for Pasquill F conditions (1 m/s) is lower than the average wind speed for these conditions (2 m/s) [1].

At six hours the weather changes from F to D weather. This change is presumed to be a front which sweeps past the station at

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1 See Ontario Hydro, Pickering NGS B Safety Report, Section 13.3.5.2, 1983 for weather data on the Pickering site.

six hours travelling at 5 m/s. Thus the change in weather conditions 10 km downwind from the station occurs 33 minutes later.

From these assumptions the dispersion of radioactivity, called the dispersion factors, can be calculated at various distances from the station. The method of calculation is the same as that used in the draft CSA standard, section 3. The results of these calculations are shown in Table 3.

Table 3
Atmospheric Dispersion Factors Used
in MPA and WCRE Calculations

Distance (km)	Prolonged term F U=1 m/s	Prolonged term D U=5 m/s
1	4.74e-5	7.12e-6
3	1.42e-5	1.37e-6
5	7.65e-6	6.01e-7
10	3.16e-6	1.99e-7
15	1.90e-6	1.06e-7
20	1.33e-6	6.88e-8

(note 4.74 e-5 = 0.0000474)

2.2 Dose Equivalent

The biological damage sustained by an individual exposed to radioactivity is quantified by dose equivalent, commonly measured in Sv the SI unit or rem the unit presently used in the emergency plan (1 Sv = 100 rem). In this report, dose equivalent has been expressed in rem to be consistent with the current emergency plans.

Three sources of exposure from a release of radioactive material are considered in these calculations.

(i) Exposure to an individual from a passing plume of radioactive material
(ii) Exposure from inhalation of radioactive material
(iii) Exposure from ground contamination

This study considers the effect of exposure from radioiodines and from the radioactive noble gases. Both types of

material contribute to the external irradiation of an individual from a cloud. Iodine can also be a significant hazard because of ground contamination and, most notably, because of its tendency to accumulate in the thyroid gland when inhaled.

The external dose equivalent to an individual from direct exposure to the plume is given by:

$$\text{Dose Equivalent} = 0.42 \sum_{\substack{\text{all} \\ \text{radionuclides}}} \chi_i \; Ei \; Ci$$

where:

χ_i is the time integrated concentration (s/m3) of the ith radionuclide which is proportional to the dispersion factor and the amount of activity released and takes into account the decay of the activity and the duration of the exposure.

Ei is the average photon energy per disintegration of the ith radionuclide (in Joules) e.g. for Xe-133 the photon energy is 80 keV but only 35% of the time does the Xe-133 decay in this manner. The average energy per disintegration is 80,000 x 0.35 x 1.6 x e-19 Joules.

Ci is a geometric correction factor for the chance that one of the ith radionuclides is absorbed or radiates upwards without hitting the exposed individual.

These contributions to the whole body dose are summed over each radionuclide. External dose from both radioiodines and noble gases are considered separately.

2.2.1 External irradiation by radioiodines

The factor 0.42 x Ei, is the dose conversion factor given in Table 7a of the CSA standard. This number is calculated for each isotope. Corrections are made for decay of the radioiodines in transit by multiplying the release of iodine by exp(-xL/U) where x is the distance from the plant along the plume centreline, L is the decay constant of the isotope, and U is the average wind speed. The time-integrated concentration is corrected for the duration of exposure.

Corrections are also made for the finite size of the cloud. The correction factors are derived using the method described in the draft CSA standard (section 4.2.1.5.(b)). The results are given in Table 4 below.

Table 4
Geometric correction factors

Distance	Correction Factor
1	0.38
3	0.56
5	0.65
10	0.74
15	0.78
20	0.82

2.2.2 External Irradiation by Noble Gases

As the calculation of the noble gas dose equivalent is more difficult given the number of isotopes that would have to be accounted for, a simpler method was used.

Appendix VII of the Gentilly-2 safety report describes an easy method to calculate the doses attributable to the noble gases. The dose equivalent is given by the following equation:

$$\text{Dose Equivalent (Noble Gases)} = 0.42\ \Psi\ S\ DEC\ C$$

where:

Ψ is the dispersion factor in s/m3

DEC is the correction for decay which occurs in transit averaged over all noble gases.

C is the averaged geometric factor.

S is the total power of noble gas photons released (in Bq.J).

If the flow of air out of containment is constant and is well-mixed, S is equal to the time-averaged release of photon power by the following equation:

$$S = \frac{1}{(t-t0)} \int_{t0}^{t} S(t)\, dt = Savg(t)$$

where:

t is the time in hours after reactor shutdown.

t0 is the time in hours after reactor shutdown when the release

begins.

S(0) is the value of the noble gas photon power at reactor shutdown in Bq.J

S(t) is the value of the noble gas photon power at time t in Bq.J.

The values of S(t)/S(0) are given in Figure VII-5 of the Gentilly-2 Safety Report. These are given in Table 5 along with the values of Savg(t)/S(0).

Savg(t)/S(0) is calculated by using the trapezoidal rule. Table 5 also lists the average energy per disintegration (in MeV) of noble gas photons.

Table 5

Photon Power, Time-Averaged Photon Power and Average Decay Energy of Noble Gas Photons Following Reactor Shutdown

Time After Reactor Shutdown (sec)	Photon Power S(t)/S(0)	Time-Average Photon Power Savg(t)/S(0)	Average Photon Energy per disintegration (MeV)
100	1.0	1.0	0.66
1000	0.73	0.88	0.68
3000	0.59	0.73	0.68
3600 (1 hr)	0.56	0.71	0.68
5000	0.47	0.64	0.64
10000	0.34	0.54	0.52
14400 (4 hr)	0.25	0.47	0.41
20000	0.16	0.43	0.29
21600 (6 h)	0.16	0.40	0.29
28800 (8 hr)	0.13	0.33	0.22
36000 (10 h)	0.09	0.29	0.17
43200 (12 hr)	0.052	0.25	0.13
86400 (24 hr)	0.029	0.15	0.074

Source: Extracted from Figure VII-5 of the Gentilly-2 Safety Report.

As an example, if a release from containment begins at the time of reactor shutdown and lasts for four hours of steady flow, the release rate of photon power at four hours is only 25 percent of the initial release rate. The cumulative release is only 47 percent of the release had the entire amount been released from containment at the time of reactor shutdown.

From the Gentilly-2 Safety report, the initial photon power can be derived to be 1.97 e6 BqJ. Accounting for the difference in thermal power between the two stations, the expected noble gas power at Pickering NGS A at the time of reactor shutdown is:

$$S(0) = 1.67 \text{ e6 BqJ}$$

The decay correction for the noble gases must account for the time required for the cloud to reach the exposed individual. In addition, the time integrated concentration must account for the amount of time an individual is exposed. This is calculated by subtracting the energy released during the travel time from the total energy released by the cloud during the interval. Thus a for a time interval ti being considered we have the following correction factor for decay:

$$DEC=(Savg(t)-Savg(t0))(1-(Savg(td+t0)-Savg(t0))/(Savg(t)-Savg(td)))$$

td = travel time of cloud = distance/average wind speed

2.2.3 Irradiation of Thyroid from inhaled iodine

Inhaled radioiodines make the overwhelming contribution to the thyroid dose. The thyroid dose equivalent is expressed as:

$$\text{Dose Equivalent} = \sum_{\substack{\text{all} \\ \text{iodines}}} Qi \; DCFi \; DECi$$

where DCFi is the dose conversion factor.

The relevant data for radioiodines is listed in Table 6 below:

Table 6
Radioiodine Data for Calculating Thyroid Doses

Isotope	Half Life (days)	Inventory EBq [2]	Dose Conversion Factor (DCF) (Svm3/TBq/s)
I-131	8.03	1.93	160
I-132	0.0944	2.85	1.6
I-133	0.844	4.07	32
I-134	0.0364	4.40	0.38
I-135	0.277	3.77	7.3

[2] For Pickering A source: Ontario Hydro Design and Development Division Report 85362 "Pickering 1&2 Restart Analysis", pg. 258 Table 3.8.3.5-1

Thyroid dose equivalent owing to the noble gases is calculated by multiplying the noble gas whole body dose by 1.1.

2.4 Ground Contamination Dose

Ground contamination doses are calculated in accordance with the CSA standard using equations 3.23 and 4.9 therein. A deposition velocity of 0.03 m/s was chosen as appropriate. Dose conversion factors for ground contamination are given in Table 9 of the standard.

3.0 Accident Scenarios and Results

3.1 Maximum Planning Accident

3.1.1 Description of the MPA

The maximum planning accident (MPA) is a scenario where the reactor core is assumed to have been severely damaged but the containment to have remained intact. Thus, the vacuum building is able to reduce the pressure inside the affected reactor unit below atmospheric pressure and delay the onset of releases.

The time taken to repressurize the containment to atmospheric pressure might take as little as a day at Pickering, but is expected to take 52 hours at Bruce and 160 hours at Darlington. The larger inventories of fission products at Bruce and Darlington are thus offset by this increased delay.

When the containment has repressurized, releases begin to occur. It is assumed that all the remaining noble gases (mostly xenon 133) are available to be released. Also, it is assumed that 0.1 percent of the remaining radioiodines (principally iodine 131 and iodine 133) are available to be released.

It is also assumed that the entire containment volume is released uniformly over a 24 hour period i.e. f=1/24 hr.

3.1.2 Assumptions (for Pickering)

The noble gas power has declined to 2.9 percent of its original value (Savg(t=24 hr)/S(0)), much of it Xe-133. I assume that the power continues to decay according to the Xe-133 decay rate.

The case being considered here is a controlled release, thus one might expect the efflux of containment air to be balanced by an influx of the same amount of air. Good mixing of this influxed air is assumed. Thus the concentration of a given radionuclide is decreasing through dilution at a rate exp(-f(t-t0)).

Therefore, at time t, the release rate of the ith species of radionuclides released is given by the following formula:

$$Qi(t) = A0i\ f\ \exp(-f(t-t0))\ \exp(-Li(t-t0))$$

where A0i = activity in containment at t= t0 Li = decay constant
The cumulative release at time t>t0 is:

$$Qi(t) = A0i\ f\ (1 - \exp(-(Li+f)(t-t0)))/(Li+f) = A0i\ F$$

The fractions released for key radionuclides in the MPA are given in the table below.

Table 7

Fraction of concentration F to be released in the MPA for f= 1/24h

Time Period (h)	Fraction of radionuclides released F		
	I-131	I-133	Xe-133
0-1	0.041	0.040	0.041
0-4	0.153	0.144	0.152
0-6	0.219	0.201	0.218
0-24	0.610	0.460	0.599
6-24	0.391	0.259	0.381

Finally, a correction to the integrated concentration must be considered to account for decay during the travel of the radionuclides from the reactor building to the exposed individual. In fact, this term makes negligible (less than 2 percent) difference to the results as all the short half-life radionuclides has decayed away by 24 hours.

3.1.3 Results for Pickering

Doses at 4, 6, and 24 hours are considered. The results for Pickering are summarized in Table 8. The results are rounded to reflect the inexactness of the modelling. Table 9 presents a breakdown of the contributions from the noble gases and from the radioiodines.

Table 8

Maximum Planning Accident
Thyroid and Effective Doses
Pickering NGS

Dist. (km)	Thyroid Doses (rem) at:			Effective Doses (rem) at:		
	4 h	6 h	24 h	4 h	6 h	24 h
1	200	300	400	15	25	30
3	70	90	100	5	7	9
5	30	40	50	2	4	5
10	5	10	15	0.4	1	1.5
15	0.0	3	6	0.0	0.4	0.6

Table 9

Breakdown of Doses for the Maximum Planning Accident
Pickering NGS

Dist. (km)	Type	Thyroid Doses (rem) at:			Effective Doses (rem) at:		
		4 h	6 h	24 h	4 h	6 h	24 h
1	Committed	230	330	430	10	15	20
	External NG	6	9	11	5	8	10
	Ground Con.				0.2	0.5	0.7
	TOTAL	240	340	430	15	23	31

Dist. (km)	Type	Thyroid Doses (rem) at:			Effective Doses (rem) at:		
		4 h	6 h	24 h	4 h	6 h	24 h
3	Committed	68	87	110	2.7	4.1	5.0
	External NG	2	3	4	1.9	3.3	4.0
	TOTAL	70	90	110	4.6	7.4	9.0

Dist. (km)	Type	Thyroid Doses (rem) at:			Effective Doses (rem) at:		
		4 h	6 h	24 h	4 h	6 h	24 h
5	Committed	30	40	50	1.2	2.0	2.4
	External NG	1	2	2	1.0	2.0	2.4
	TOTAL	31	42	52	2.2	4.0	4.8

Table 9 continued

Dist. (km)		Thyroid Doses (rem) at:			Effective Doses (rem) at:		
	Type	4 h	6 h	24 h	4 h	6 h	24 h
10	Committed	5.0	12	16	0.2	0.5	0.7
	External NG	0.2	0.6	0.7	0.2	0.6	0.8
	TOTAL	5.2	13	17	0.4	1.1	1.5
Dist. (km)		Thyroid Doses (rem) at:			Effective Doses (rem) at:		
	Type	4 h	6 h	24 h	4 h	6 h	24 h
15	Committed	0	3	6	0	0.2	0.3
	External NG	0	0.2	0.3	0	0.2	0.3
	TOTAL	0	3	6	0	0.4	0.6

The highest calculated doses occur for a young child standing at 1 km (440 rem thyroid and 30 rem whole body). At 10 kilometres, the dose at 24 hours is approximately 1.5 rem. About one third of this dose is received between 6 and 24 hours. Note that at this distance, no exposure is encountered for the first 2.75 hours because of the low wind speed.

By 15 kilometres, the whole body dose has fallen to 0.6 rem.

At all distances, committed dose from iodine makes up about 50 percent of the effective whole body dose and nearly all of the thyroid dose.

3.1.4 Results for Bruce and Darlington

The doses for Bruce and for Darlington can be derived from the Pickering doses by taking into account the differences in containment holdup time and radionuclide inventory. The latter varies with the total reactor fission power. Bruce is approximately 1.5 times as large as Pickering, and Darlington is

1.6 times as large. The longer hold up times means that the noble gas and radioiodine inventories have decayed further. At Bruce, the additional decay results in a reduction of 14 percent of the dose. At Darlington, the much longer holdup period means that approximately half the radioactivity that was in containment at 24 hours has decayed. Thus doses at Bruce can be expected to be 1.5 x 0.86 = 1.3 times as large as at Pickering and at Darlington they will be 1.6 x 0.5 =0.8 times as large. Thus for Bruce, one might expect doses as high as 0.8 rem at 15 kilometres. At Darlington, doses at 15 kilometres would 0.5 rem and would be 1 rem at 10 kilometres. Tables 10 and 11 give the doses expected as different distances downwind for the two stations.

Table 10

Maximum Planning Accident
Thyroid and Effective Doses
Bruce NGS

Dist. (km)	Thyroid Doses (rem) at:			Effective Doses (rem) at:		
	4 h	6 h	24 h	4 h	6 h	24 h
1	300	400	600	20	30	40
3	90	100	150	6	9	12
5	40	50	70	3	5	6
10	6	13	20	0.6	1.5	2
15	0	5	8	0	0.5	0.8

Table 11

Maximum Planning Accident
Thyroid and Effective Doses
Darlington NGS

Dist. (km)	Thyroid Doses (rem) at:			Effective Doses (rem) at:		
	4 h	6 h	24 h	4 h	6 h	24 h
1	150	250	300	12	20	25
3	50	70	90	4	6	7
5	20	30	40	2	3	4
10	4	10	15	0.3	0.8	1
15	0	3	5	0	0.3	0.5

3.2 Worst Credible Radiation Emission

3.2.1 Description of the Scenario

The Worst Credible Radiation Emission (WCRE) envisages a severe nuclear accident occurring which results in the destruction of the reactor core and the release of significant fractions of the radioactive fission products from the reactor to the atmosphere. There is no holdup time from the time of the event to the beginning of release of radioactive materials. One percent of the iodines are presumed to be released in the first hour and none thereafter. Noble gases are released from containment at the rate of ten percent of the total inventory per hour. The noble gas release is corrected for decay within containment.

The WCRE, unlike the MPA, is not considered to be a controlled release. As a result, no inflow of containment air is assumed to occur. Ten percent of the containment volume is assumed to be vented per hour (f = 0.1/h).

For such large thyroid doses, it is inappropriate to use the effective whole body dose. Thus the whole body doses stated are attributable to external irradiation from the cloud and from ground contamination.

3.2.2 Results for Pickering

Doses are given in Table 12 for 4, 6, and 24 hours after the release begins. A breakdown of the doses into their various

components (external iodine, committed iodine, ground contamination, and noble gas dose) is given in Table 13.

Table 12
WCRE Thyroid and Whole Body Doses
Pickering NGS

Dist. (km)	Thyroid Doses (rem) at:			Whole Body Doses (rem) at:		
	4 h	6 h	24 h	4 h	6 h	24 h
1	20000	20000	20000	400	600	900
3	6000	7000	7000	150	200	300
5	3500	3500	3500	60	90	150
10	1500	1500	1500	10	25	50
15	0.0	700	700	0.0	10	20
20	0.0	500	500	0.0	1	10

Table 13
Breakdown of Doses for WCRE
Pickering NGS

Dist. (km)	Type	Thyroid Doses (rem) at:			Whole Body Doses (rem) at:		
		4 h	6 h	24 h	4 h	6 h	24 h
1	Committed	22000	22000	22000			
	External I	20	20	20	21	21	21
	External NG	230	300	310	210	280	290
	Ground Con.	230	320	700	210	290	640
	TOTAL	22500	22700	23000	440	590	950

Table 13 continued

Dist. (km)		Thyroid Doses (rem) at:			Whole Body Doses (rem) at:		
	Type	4 h	6 h	24 h	4 h	6 h	24 h
3	Committed	6300	6300	6300			
	External I	10	10	10	9	9	9
	External NG	78	110	110	71	100	100
	Ground Con.	53	78	190	48	71	170
	TOTAL	6400	6500	6600	130	180	280

Dist. (km)		Thyroid Doses (rem) at:			Whole Body Doses (rem) at:		
	Type	4 h	6 h	24 h	4 h	6 h	24 h
5	Committed	3300	3300	3300			
	External I	6	6	6	5	5	5
	External NG	38	58	59	35	53	54
	Ground Con.	21	34	91	19	31	83
	TOTAL	3400	3400	3500	59	89	140

Dist. (km)		Thyroid Doses (rem) at:			Whole Body Doses (rem) at:		
	Type	4 h	6 h	24 h	4 h	6 h	24 h
10	Committed	1300	1300	1300			
	External I	3	3	3	3	3	3
	External NG	7	17	17	6	15	15
	Ground Con.	5	15	45	2	7	29
	TOTAL	1300	1300	1400	11	25	47

Table 13 continued

Dist. (km)		Thyroid Doses (rem) at:			Whole Body Doses (rem) at:		
	Type	4 h	6 h	24 h	4 h	6 h	24 h
15	Committed	0	710	710			
	External I	0	2	2	0	2	2
	External NG	0	3	3	0	3	3
	Ground Con.	0	4	19	0	4	17
	TOTAL	0	720	730	0	9	22
Dist. (km)		Thyroid Doses (rem) at:			Whole Body Doses (rem) at:		
	Type	4 h	6 h	24 h	4 h	6 h	24 h
20	Committed	0	480	480			
	External I	0	1	1	0	1	1
	External NG	0	<1	<1	0	<1	<1
	Ground Con.	0	<1	10	0	<1	9
	TOTAL	0	480	490	0	1	10

Radioiodine commitment accounts for nearly all of the thyroid dose. Dose to the thyroid amounts to 20000 rem at 1 kilometre. This dose commitment will be reached in the first hour following the accident. Thyroid doses have dropped to 500 rem by 15 km and continue to fall slowly with distance.

External whole body doses are very large at 1 km distance from the station. At 4 hours, the doses are already 400 rem and have increased to 900 rem by 24 hours. Ground contamination and noble gas exposure make roughly equal contributions up to six hours. After that time, the principal source of irradiation comes from ground contamination.

3.2.3 Results for Bruce NGS and Darlington NGS

Results for Bruce NGS and Darlington NGS are obtained by multiplying the Pickering doses by the ratio of the power Bruce

(or Darlington) and Pickering. This implies that doses will be a factor of 1.5 larger at Bruce (1.6 at Darlington) than at Pickering. The differences between the doses for the two stations are much smaller than the uncertainties. Thus, the predicted doses for Darlington are used to represent both stations. The doses are presented in Table 14 below.

Table 14
WCRE Thyroid and Whole Body Doses
Bruce or Darlington NGS

Dist. (km)	Thyroid Doses (rem) at:			Whole Body Doses (rem) at:		
	4 h	6 h	24 h	4 h	6 h	24 h
1	30000	30000	30000	600	1000	1400
3	10000	10000	10000	250	300	500
5	6000	6000	6000	100	150	250
10	2500	2500	2500	15	40	80
15	0.0	1000	1000	0.0	15	30
20	0.0	800	800	0.0	1.5	15

Whole body doses arising from external irradiation exceed 1000 rem by six hours at 1 kilometre. This dose has dropped to 40 rem at 10 kilometres and 15 rem at 15 kilometres. After 6 hours, the dose increases primarily because of ground contamination. The dose at 24 hours at 10 kilometres reaches 80 rem.

Thyroid doses at 1 kilometre from the station are estimated to be 30000 rem. This dose is received in the first hour. At 5 kilometres this dose is 6000 rem and would be 2500 rem at 10 kilometres.

4.0 Summary

This report summarizes the methods used to calculate the whole body and thyroid doses for the Maximum Planning Accident (MPA) and the Worst Credible Radiation Emission (WCRE) at a Pickering, Bruce or Darlington Nuclear Generating Station (NGS). Doses are calculated for an individual standing outdoors at 1,

3, 5, 10, and 15 kilometres downwind from the station. The doses are summarized in Tables 8-14.

The computational methods and assumptions follow those used to that used in the CSA standard N288.2 (7th draft) for calculating the dispersion and exposure of people to the radioactive plume. Data reported by Ontario Hydro for the Pickering site and radionuclide inventory were used. The results for Pickering were scaled for Bruce and for Darlington taking into account the differences in radionuclide inventory and capability of each containment to delay the release.

For the MPA at Pickering, the whole body dose is calculated to be 30 rem (0.30 Sv) at 24 hours at 1 km. The thyroid dose is estimated to be 400 rem (4 Sv). If evacuation out of the affected sector took place as early as four hours after the release began, doses would be 15 rem (0.15 Sv) whole-body and 200 rem (2 Sv) to the thyroid. The effective whole body dose has fallen to 1.5 rem at 10 km and below 1 rem at 15 km. Doses will be 30 percent larger at Bruce because of the large radioiodine inventory. The dose at 15 km is just below 1 rem. However, at Darlington, the estimated delay before releases begin is estimated to be 160 hours. Thus the MPA doses are about 80 percent of those at Pickering.

For the WCRE, the doses are much larger. At 1 km, the dose after six hours could be as large as 20000 rem (Pickering) or 30000 rem (Bruce or Darlington) to the thyroid and 600 rem (1000 rem at Bruce or Darlington) to the whole body. At 10 kilometres, the whole body dose is estimated to be 25 rem (40 rem Bruce and Darlington). Doses at 24 hours at 10 kilometres are 50 rem (80 rem Bruce and Darlington). Doses at Bruce and Darlington are larger because of the larger radioiodine inventory. Doses from ground contamination produce a significant fraction of the whole body doses.

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Appendix G

Sensitivity Analysis

By Peter Fraser

1.0 Introduction

The purpose of this appendix is to assess the sensitivity of the analysis results presented in Appendix G to the three most significant uncertainties. These uncertainties are: the weather at the site during the release, the wind speed and the fraction of radioactive iodine released from containment. The values chosen for each of these quantities will be varied to determine the sensitivity of the results. Of particular interest is the effect that varying these parameters have on the distance at which criteria such as early morbidity (for the WCRE) or the lower protective action level for evacuation (for the MPA) are exceeded.

2.0 Site Weather

In the report, it is assumed that Pasquill class F weather persists throughout the first six hours. This weather, indicative of stable atmospheric conditions, occurs approximately 10 percent of the time at each reactor site. More turbulent atmospheric conditions, characterized by Pasquill C or D weather occur approximately 64 percent of the time. Categories C or D are also characterized by higher average wind speeds which help disperse the release. The conditions in neutral or unstable weather produce much greater dispersion further away from the station, drastically reducing the doses further away.

If category D weather with an average wind speed of 5 m/s were to occur during the first 24 hours of the WCRE doses would be reduced by a factor of 6.5 near the station to a factor of 20 at 20 kilometres. Figure 1 shows the thyroid doses predicted for the two cases. The criterion for early morbidity (3000 rem) is also plotted. Figure 2 shows the same comparison for the whole body doses. The thyroid and whole body doses are predicted to fall below the early morbidity threshold approximately 2 kilometres from the station.

If category D weather with an average wind speed of 5 m/s were to occur during the first 24 hours of the MPA doses would be reduced by approximately a factor of five near the station. Figure 3 shows the results of all sensitivity analysis for the MPA cases. For this scenario doses would fall below 1 rem, the lower protective action level for evacuation, at 5 km.

3.0 Wind Speed

The wind speed has two important effects on the radiological consequences that need to be considered in emergency response.

(i) The higher the wind speed, the better the dispersion. The dispersion factor varies inversely as the wind speed.

(ii) The higher the wind speed, the quicker the releases arrive at a given distance away from this station. This in turn implies that there is less decay during the travel of the radioactive plume and that exposures start sooner after the accident occurs than for a lower wind speed.

Near the station, the first consideration is by far the most important. Thus a doubling of the wind speed can expect to halve the dose. Further away, when the time taken for the cloud to arrive could be several hours, the second factor is an important consideration for estimating the dose at any time. This is particularly true for the WCRE, where a number of short-lived radionuclides can decay away during transit.

The Working Group specified that Pasquill F wind conditions should be accompanied by a 1 m/s wind speed. This wind speed is lower than the average wind speed of 2 m/s for Pickering NGS during F weather (Ontario Hydro, 1985). The sensitivity of the dose to the wind speed during Pasquill F weather has been examined.

Figure 1 and 2 illustrate the thyroid and whole body doses for the WCRE reference case and with the higher wind speed. If the wind speed during the first 6 hours of a WCRE is assumed to be 2 m/s, the dose at 6 hours is reduced by a factor of approximately 2. However, beyond 10 kilometres, the dose is actually greater for the higher wind speed because of the increased duration of exposure. The thyroid dose at 6 hours are approximately a factor of two lower at all distances, as the iodine exposure occurs over a relatively short period and so the effect of the duration of exposure is not important. The early morbidity criterion is exceeded for the thyroid out to 3 km; the whole body criterion is exceeded out to 5 km.

If the wind speed during the first 6 hours of the MPA is assumed to be 2 m/s, the dose at 6 hours is approximately half that for the reference case near the station but approximately equals the value for the reference case 18 kilometres from the station (see Figure 3). The effective dose at 24 hours falls below 1 rem at 10 kilometres.

4.0 Amount of Iodine released

The amount of iodine released from containment is an important uncertainty in the analysis. Prior to Three Mile Island, it was generally assumed that most of the iodine released from the fuel would leave containment. The effectiveness of Three Mile Island containment at retaining iodine has led to further research and claims that iodine releases would be less than one percent of the entire iodine inventory (Howieson et al.,

1988).

A recent report by the United States Nuclear Regulatory Commission (USNRC, 1987) was an attempt to update the estimates and the uncertainties surrounding iodine releases. Iodine releases were presented as large band of uncertainty, typically ranging from 0.5 percent to 50 percent, for cases in which core melting occurred with a breach of containment.

The sensitivity analysis employed here uses two sources for the amounts of iodine released. For a lower estimate, the amount of iodine assumed to be released is 0.35 percent, the amount assumed in the technical basis for emergency planning in France (Ali, 1988). This amount is assumed (for this analysis) to be released very quickly after reactor shutdown. The higher limit chosen is the observed for Chernobyl, which has been estimated to be a total of up to 60 percent, with about 6 percent of the iodine leaving containment in the first day (Warman, 1987). Since the WCRE is focussed on actions in the first day following the start of a release, it is assumed that one percent of the iodine is released in the first hour and 0.2 percent of the iodine is released per hour for 24 hours.

The results of this comparison are illustrated in Figure 4 (for thyroid doses) and Figure 5 (for whole body doses). The lower estimate, not surprisingly, reduces thyroid doses by a factor of 3 over the reference case. This means that thyroid doses would be lower than the early morbidity criterion within 3 kilometres. However, the whole body dose is not as greatly affected by iodine fraction because noble gases make up over half the dose. As a result, the early morbidity criterion for the whole body is exceeded out to 8 km at 24 hours.

For the 'Chernobyl' case, thyroid doses are higher at 24 hours by a factor of 2 near the station but only about 50 percent higher at 10 kilometres (see Figure 4). The early morbidity criterion is exceeded out to 9 kilometres. The thyroid dose increases by another 20 percent between six and 24 hours because of the continuing iodine release. Whole body doses at six hours are about 20 percent higher than the reference case (Figure 5). At 24 hours, the early morbidity criterion for the whole body dose is exceeded out to 11 kilometres. This is one kilometre larger than the reference case.

5.0 Summary

In this appendix, the sensitivity of the results to weather stability class, wind speed, and amount of iodine release have been examined. Table 1 gives the distance at which a whole body dose of 50 rem whole body and 3000 rem thyroid are exceeded for each WCRE case considered.

Table 1
Sensitivity of Analysis Results to Assumptions for the WCRE Pickering NGS

Case Considered	Distance at which 50 rem exceeded at 24 hours (kilometres)	Distance at which 3000 rem thyroid exceeded at 6 hours
Reference (Pasquill F weather with wind speed 1 m/s in the first six hours, 1 percent iodine released in first hour and Pasquill D weather with wind speed at 5 m/s from 6 to 24 hours)	10	5
As above except with Pasquill D weather with wind speed of 5 m/s during the first six hours	3	2
As in reference case except with Pasquill F weather with wind speed of 2 m/s during first six hours	5	3
As in reference case except Iodine release 0.35 percent	8	2
As in reference case except Iodine release 1 percent in first hour and 0.2 per cent per hour thereafter ('Chernobyl')	11	9

The sensitivity of the MPA analysis results was checked for the change in weather or wind speed and their effect on the zone that may require evacuation. Changing the weather from F to D produced a reduction in doses by a factor of 3 or so. Doses fall

below 1 rem, the lower protective action level for evacuation, within 5 km. If the wind speed during Pasquill F conditions is doubled the 1 rem dose at 24 hours is reached at 10 km. In the reference case, a dose of 1 rem is expected at 12 km.

References

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Ontario Hydro, 1985. Pickering NGS B Safety Report, Volume 2, Accident Analysis, revised 1985.

USNRC, 1987. United States Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Reactor Risk Reference Document, NUREG-1150, Draft for Comment, February, 1987.

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Figure 1: WCRE

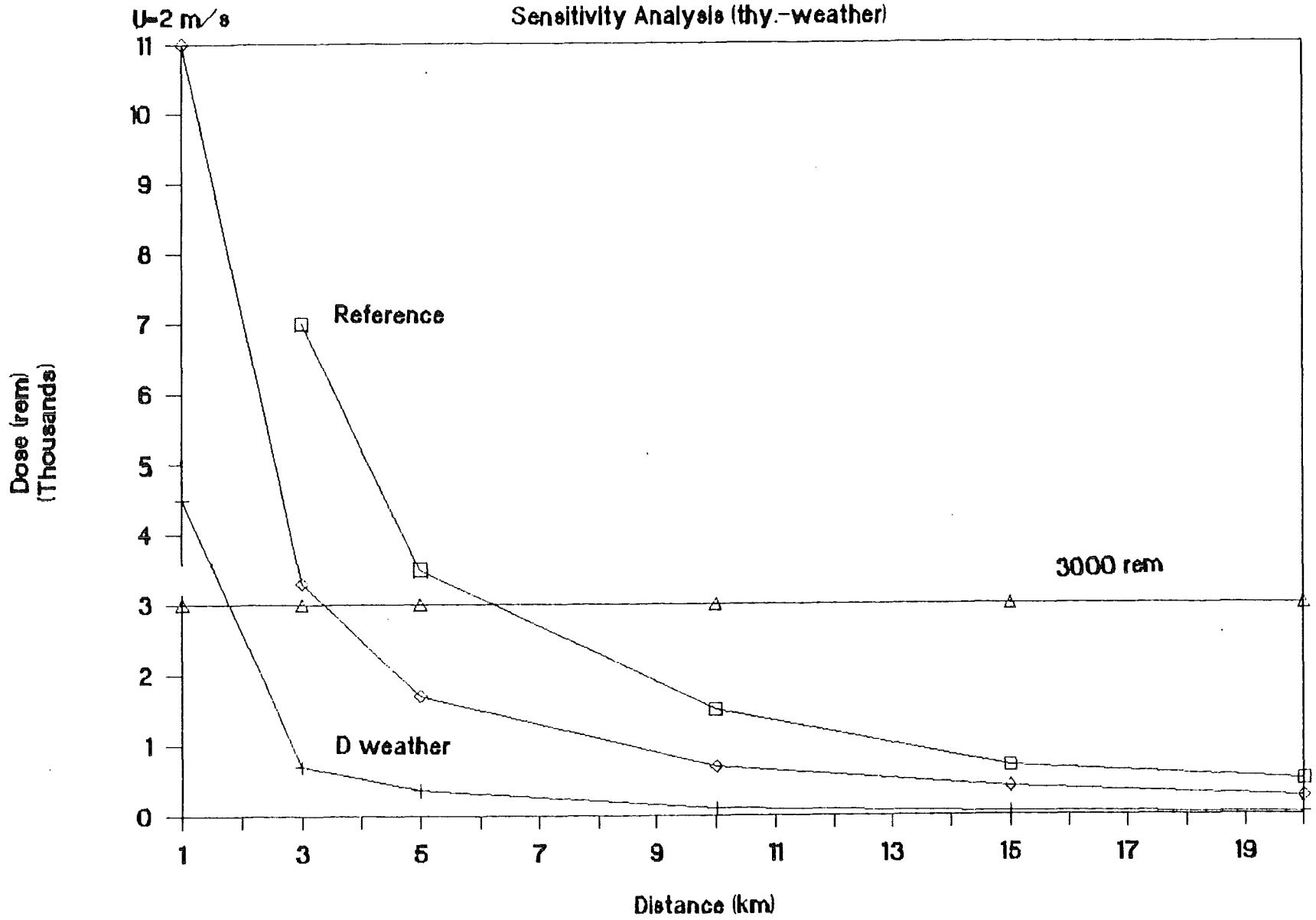


Figure 2: WCRE

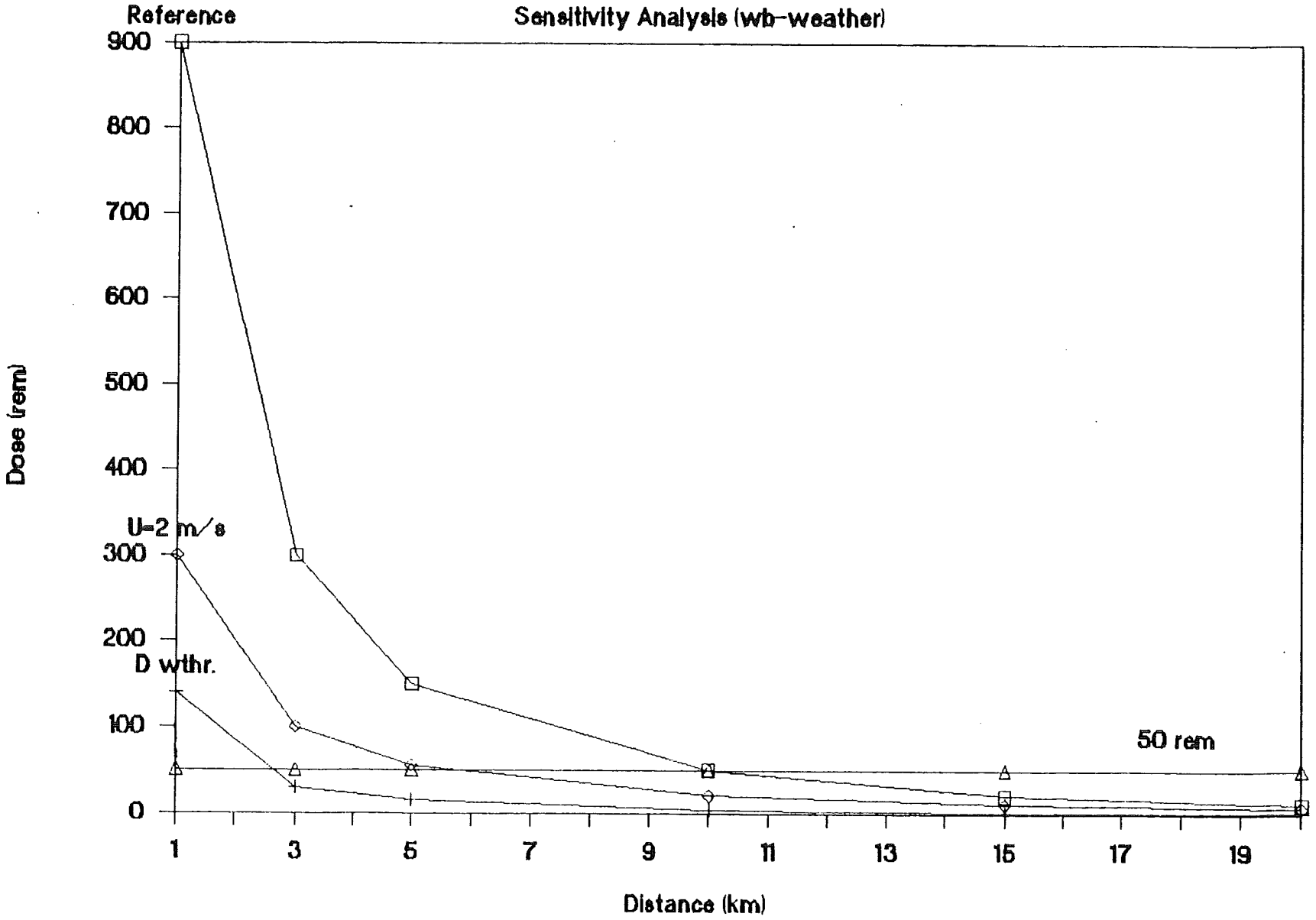


Figure 5: MPA

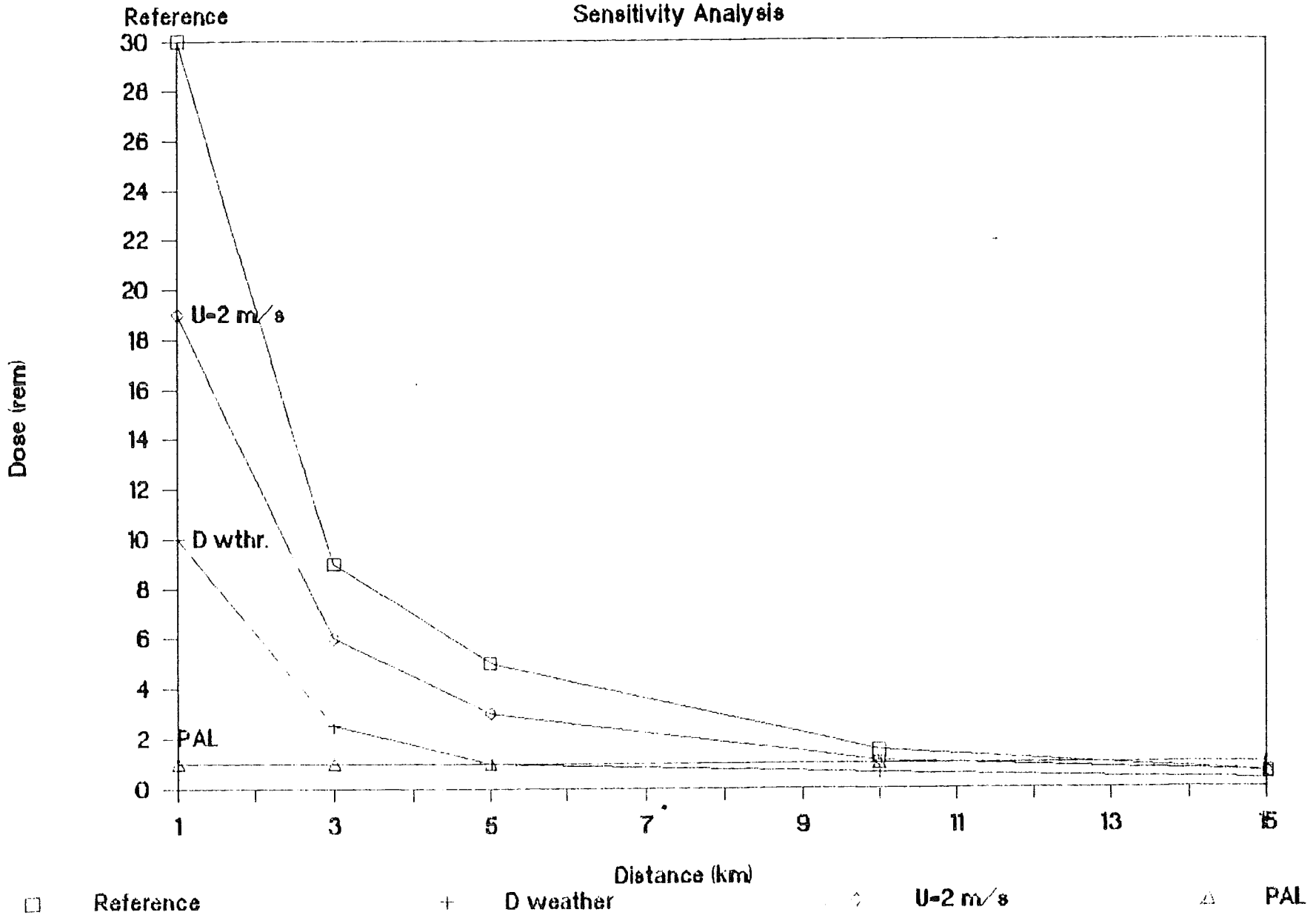

Reference
Sensitivity Analysis
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
U=2 m/s
D wthr.
PAL
1
3
5
7
9
11
13
15
Dose (rem)
Distance (km)
Reference
D weather
U=2 m/s
PAL

Figure 4: WCRE

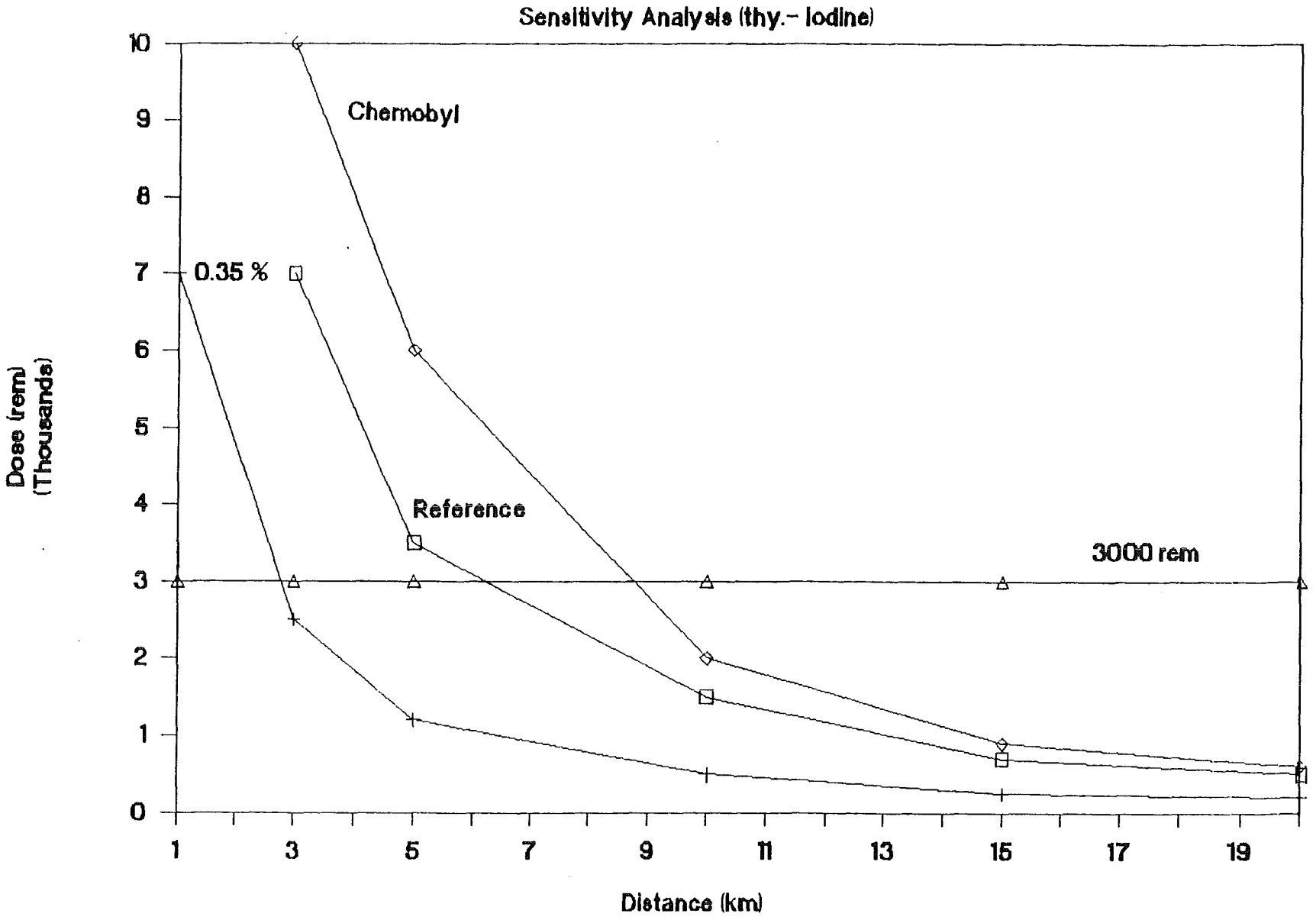
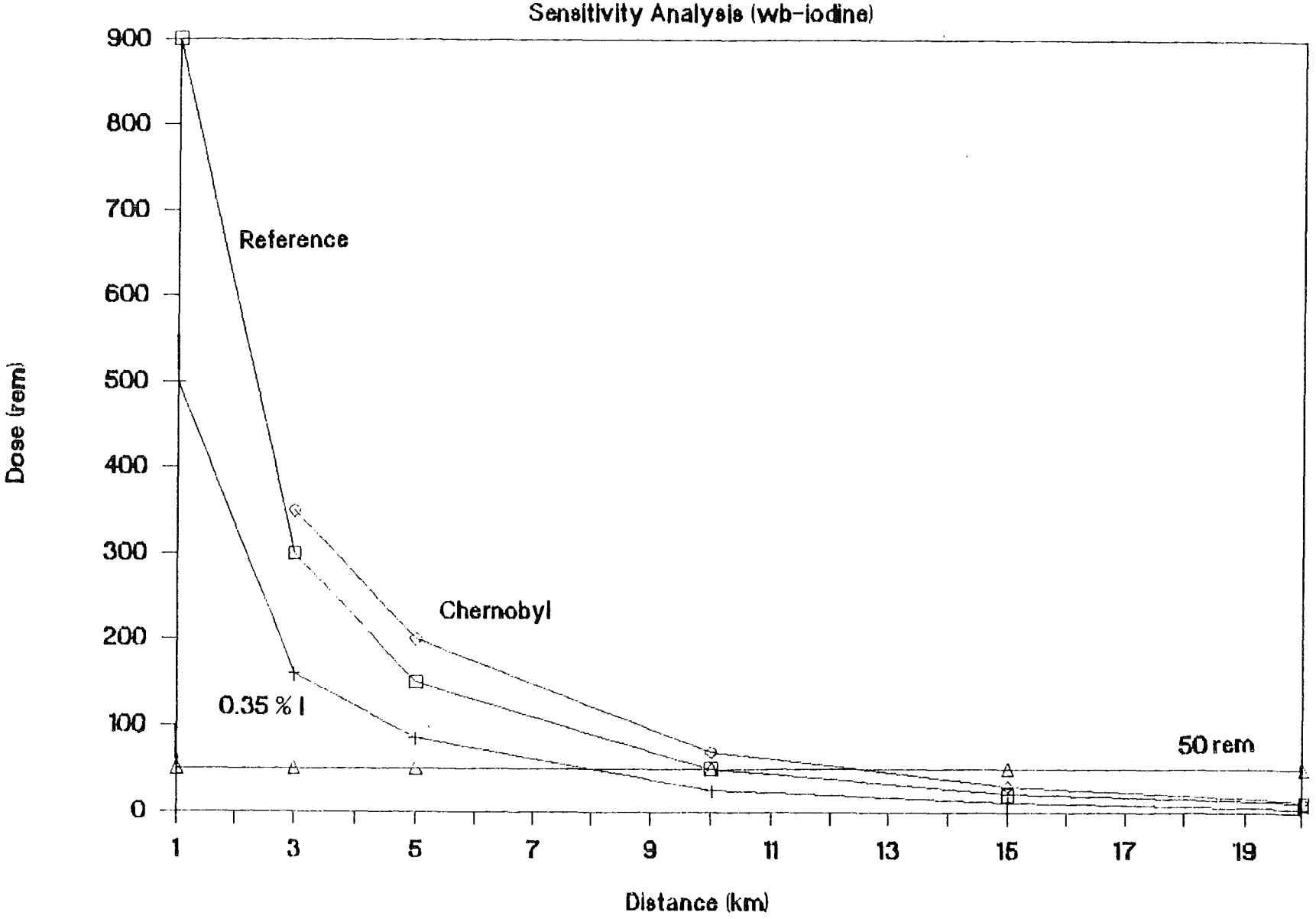


Figure 5: WCRE



DISSENTING MINUTE

A1. In general I agree with the conclusions and most of the Recommendations stated in Chapter 10; however, I cannot agree with Recommendations 5, 6 and 7 since they are at variance with Recommendations 2 and 3.

A2. It is clear from Recommendations 2 and 3 that the Working Group intended to leave decisions regarding the details of emergency planning to the Provincial Government, and that the information developed by the Working Group be used in the decision making process.

The reason for this was that some members of the Working Group recognized that such decisions could not be made purely on technical considerations, and that political considerations would also be important determinants.

Recommendations 5, 6 and 7 are not consistent with this process.

A3. If a decision on the size of Primary Planning Zones were to be made on the basis of technical considerations only, then it is my conclusion that the present 10 km Primary Zone is adequate.

The justifications for this conclusion may be stated as follows:

(a) The calculational method to produce the dose estimates given in Tables 6.2, 6.3 and 6.4 are very conservative. An indication of this conservatism is given in Appendix G. Further conservatism is included by assuming that individuals would remain outdoors for the whole period of the radioactive material release and in the plume. Any time spent inside a building or out of the plume would reduce the dose received.

(b) It is assumed that the direction of the plume remains constant within a 22 $1/2^0$ arc for the 24 hours of the release. Any change in wind direction will reduce the dose received.

(c) In most cases the time period over which the MPA doses would be received is at least 48 hours from the initiation of the causal event sequence. This period would allow sufficient time for extending the area in which mitigating actions can be effectively improvised.

(d) In the case of the WCRE, the dose consequences shown in Tables 7.2 and 7.3 are subject to same, conservatism described in (a) and (b) above.

(e) The probability of any individual member of the public actually receiving radiation doses of the magnitude described in Tables 6.2, 6.3, 6.4, 7.2 and 7.3 becomes diminishingly small when the probability of the conservative conditions occurring simultaneously with the MPA or the WCRE are taken into consideration.

A4. It is my opinion based on the information presented to the Working Group that no further funds, other than those required to properly implement and maintain the existing Provincial Nuclear Emergency Plan, should be expended on Nuclear Emergency Planning.

1988 June 30.

(Ontario Hydro - Armitage)