R E P O R T

TO THE

MINISTRY OF ENERGY AND ENVIRONMENT

CONCERNING TWO TECHNICAL MATTERS

IN THE

PROVINCE OF ONTARIO'S NUCLEAR EMERGENCY PLAN

BY

ROYAL SOCIETY OF CANADA & CANADIAN ACADEMY OF ENGINEERING

W. R. BRUCE

L. W. SHEMILT

A. T. STEWART

NOVEMBER 1996

Ms. Debbie Farr P.Eng., Manager

Electricity Operations and Planning Section

Ministry of Environment and Energy

135 St.Clair Ave W

Toronto, ON Canada M4V 1P5

Dear Ms. Farr:

We are pleased to present to you our Report Concerning Two Technical Matters in the Province of Ontario's Nuclear Emergency Plan. You commissioned this Report in correspondence that started a year ago.

In the process of this study we have developed and clarified the background needed to address the questions which were posed. The narrative of the report presents this background, our recommendations, and develops the reasons for our conclusions.

We thank the many who provided facts, opinions and wisdom to assist us. We have benefited from the advice and help from the Ministry of the Solicitor General especially from Mr.W.D.Harrison who has helped several times. We have been supplied with documents, comments and answers to our many questions by Ontario Hydro, delivered patiently by Mr.L.D.Morrow. And to your

Ministry we are indebted for arranging to have the brief comments on a Draft of our Report by Officers of the Ministry of the Solicitor General and Officers of Ontario Hydro. Their suggestions have been useful in clarifying matters of both fact and opinion. Finally we are indebted to your office for courtesies, patience and understanding.

We hope the Report will be useful and shall be happy to answer any questions that may arise.

Yours cordially,

W. R. Bruce L. W. Shemilt A. T. Stewart

W.R.Bruce L.W.Shemilt A.T.Stewart

for the

Royal Society of Canada & Canadian Academy of Engineering

I N D E X

EXECUTIVE SUMMARY

The Royal Society of Canada / Canadian Academy of Engineering panel was asked for recommendations on two principal questions. One question concerned the basis for planning a mitigating response to an accident at one of Ontario's nuclear generating stations and the other concerned two technical details of the emergency plan itself.

Q.1. Basis for planning: In 1988 the Working Group No.8 of the Ministry of the Solicitor General and the Ontario Nuclear Safety Review recommended comprehensive planning for an accident called by the former, "Worst Credible Radiation Emission". Since 1988 risk analyses have been improved and updated and we think that now it is wiser to consider planning for a group of accident scenarios for which the summed probability of occurrence is greater than approximately 10^{-7} per reactor year. (It should be noted that some accident scenarios in this group are similar in severe consequences to Worst Credible Radiation Emission consequences except for the delayed emission of radioactive materials.)

Q.2a. Predistribution of KI: The risk to the thyroid gland from inhaling radioactive iodine from a CANDU accident seems to us to be less than had been previously thought and a small part of the risk to the whole body from such an accident. We therefore do not recommend predistribution of KI to residences.

Q.2b. The choice of 10 or 13 km for the outer boundary of the Primary Zone: In comparison to the wide range of consequences from a severe accident, 10 and 13 km are essentially the same number. Since the designation of zones should be for the purpose of developing and practising emergency responses, we find that a nominal 10 km is satisfactory.

In the Report of the Royal Society of Canada / Canadian Academy of Engineering the panel also suggests that since neither KI prophylaxis nor sheltering offer very much protection in a nuclear emergency, that sheltering be considered only as an automatic and immediate first step while arranging evacuation. There would then be one only action level for which we suggest 10-50 mSv - or, if a single number is preferred, 20 mSv..

SECTION 1 INTRODUCTION

1.1 The Province of Ontario's Nuclear Emergency Plan, in existence since 1986, was developed to protect the health and safety of the public in the event of a nuclear accident at any of Ontario's nuclear generating facilities. The Plan addressed both short term and long term impacts of a nuclear accident, established geographic zones as part of detailed planning for mitigation measures, and assigned implementation responsibilities. In 1986 the Ontario Government (Ministry of Energy) commissioned Dr.F.K.Hare to review the safety of Ontario's nuclear powered electricity generating plants and the associated measures for emergency action in case of accident. The report of the Ontario Nuclear Safety Review, appeared in 1988.

1.2 Concurrently the Ministry of the Solicitor General (which is responsible for nuclear emergency planning and preparedness) formed the Provincial Working Group No.8, chaired by Dr.K.G.McNeill, to make detailed recommendations for appropriate responses to accidents at nuclear generating stations which might imperil any member of the public. The Report from Working Group No.8 was also released in 1988. By and large the detailed recommendations of Working Group No.8 were compatible with the more general ideas of the Ontario Nuclear Safety Review and most were found acceptable by the organizations affected. However one member of the Working Group had reservations on technical grounds about some of the Group's recommendations and recorded his objections in an appended note of dissent. Late in 1988 Ontario Hydro developed more detailed comments expressing their concerns with a number of areas of the Working Group No. 8 report and forwarded these comments to the Ministry of the Solicitor General.

1.3 The office of Emergency Measures Ontario in the

Ministry of the Solicitor General intends to update the Provincial Nuclear Emergency Plan [43,44] and thus wishes to have a review of the issues that had arisen in response to the Report of Working Group No.8. The Ministry of Environment and Energy agreed to facilitate the review and to this end wrote the Royal Society of Canada (18 January 1995) to ask in a preliminary way if the Society would help resolve these technical issues. A more formal request followed (26 May 1995). The Society's Council responded positively and asked A.T.Stewart and W.R.Bruce to pursue the inquiry and if feasible to develop a contract (12 July 1995). The Canadian Academy of Engineering was contacted by the Society regarding its participation, and the Academy's nominee, L.W.Shemilt, was added as a third consultant. A contract/terms of reference was agreed to by all parties in December 1995. (These letters and the full terms of reference may be found in Appendix A.)

1.4 The remit assigned to the Royal Society of Canada/Canadian Academy of Engineering review committee reads as follows:

> The RSC/CAE review will be limited to review the following two outstanding points in the proposed new Provincial Nuclear Emergency Plan (PNEP):
>
> -- that KI pills should be pre-distributed within the approximate 3 km contiguous zone: and
>
> -- that the primary zone around the nuclear facilities should be expanded from 10 km to 13 km for both the Bruce and Darlington stations.
>
> Specifically, the RSC/CAE is being asked to respond to the following specific questions:
>
> 1. In view of the recommendation made by the Hare Commission which stated "that the Province of Ontario base its nuclear planning on the maximum credible releases of radioactive materials", is the description of a maximum credible release defined as "worst credible radiation emission" by Working Group #8 sound and reasonable in this context ?
>
> 2. Having responded to question #1, do the reviewers believe that the pre-distribution of KI pills within the approximate 3 km contiguous zone surrounding the Bruce, Darlington, and Pickering nuclear generating stations and

the extension of the primary zones around Bruce and Darlington follow logically from the Working Group definition of a maximum credible release ?

1.5 In what follows there is in Section 2 a discussion of the size and frequency of accidents at nuclear generating stations, and in Section 3 a brief review of intervention criteria. Section 4 is taken up with a discussion of the severity of accident for which detailed plans should be made. Section 5, relates these emergency plans to the potassium iodide tablet predistribution question. Section 6 contains a review of the boundary radius for the Primary Zone. This is followed by a short summary in Section 7. As mentioned above, Appendix A contains the letters leading to this study; Appendix B is a list of our meetings; Appendix C records the relevant documents we have examined; Appendix D identifies the RSC/CAE Panel; and Appendix E contains letters from reviewers.

SECTION 2 SIZE AND FREQUENCY OF ACCIDENTS

2.1 The subject of reactor safety and the description of possible accidents is long and detailed. This Section reviews the relevant recommendations of 1988 Ontario Nuclear Safety Review (ONSR) [38], and proposals for accident response by Working Group No.8 (WG-8) [48]. Later safety analyses of nuclear emergencies are discussed including the emission of radioactive iodine.

2.2 The Ontario Nuclear Safety Review of 1988 included a review of safety and accident analysis covering the development of Canadian practice. This was placed in the context of Canadian experience as well as of a world which had seen accidents such as Windscale (1957), Three Mile Island (1979), and Chernobyl (1986). Canadian approaches to risk analysis had moved into probabilistic risk assessment (sometimes termed probabilistic safety assessment) by the 1980s and Ontario Hydro was developing Safety Reports of this kind for each Nuclear Generating Station. The essence of this type of analysis is to identify realistic accident sequences which are examined in detail to identify the potential failure modes, the dominant risk sequences, and the probability of each occurring.

2.3 Three types of accident initiation specified in both the ONSR and the WG-8 report on the maximum credible radiation release, and which are unquantifiable in the usual probabilistic safety assessment methodology, were extreme natural seismic events, hostile action and gross human error. Hostile action as an initiating event for any catastrophe is not usually documented as a basis for emergency planning. Thus it should not be in the case of Ontario's nuclear plants. Security and safeguards should continue to be met as requirements under the regulatory authority with due regard to international guidelines and practice. The remaining matters of gross human error and natural events are mentioned below.

2.4 Up to the time of the ONSR, safety analysis had been conducted for each new nuclear generating station as part of the design, construction and licensing process. As part of the Review (ONSR) a severe accident sequence (a large loss of cooling accident (LOCA) accompanied by simultaneous inoperability of all shut-down systems) was analyzed both by Ontario Hydro and by the U.S. Argonne National Laboratory, [see 38]. This severe accident analysis was beyond any design planning (beyond "design-basis") and showed off-site radioactive contamination due to containment failure. The ONSR also supported a suggestion of the Atomic Energy Control Board that analysis could also be done on another severe accident sequence, viz., failure of regulation from any cause and failure to shut-down.

2.5 Following these studies it was noted by ONSR that "the best technical analysis finds the aggregate probability of [severe] accidents" was below 10^{-5} per reactor year and thus accident responses should be planned for "the most extreme credible event". Since health risks were the important criterion, it was recommended that nuclear emergency planning should be based on "the maximum credible release of radioactive materials".

2.6 The Report by Working Group No.8 was written with full knowledge of the ONSR Commissioner and staff, both groups having observer status in the other's deliberations and studies. The WG-8 Report also noted the need for probabilistic risk assessments for nuclear accidents and commented as well on their limitations. Public perceptions and expectations were a part of their concerns. The final recommendation of WG-8 was a two tier approach with a maximum planning accident (MPA) based on a predetermined probability of occurrence and a worst credible radiation emission (WCRE) with no limit to its probability and defined as the maximum consequences possible within physical and chemical realities.

2.7 The MPA was related to the requirements of the Provincial Nuclear Emergency Plan [46] that detailed planning and preparation be done for an accident that produced a radiation dose of 250 mSv or more at 1 km from the reactor. The MPA was thus defined in terms of the radiological consequences. Accident scenarios were then explored for selected meteorological conditions, for estimated radioactive releases, and for a holdup time - the time expected for the radioactive material that escapes from the reactor to be retained in the containment building - of 24 hrs. For scenarios with a probability of occurrence greater than 10^{-6} per reactor year, the radiation dose was calculated as a function of distance and time.

2.8 The WCRE as a higher level accident was the maximum imaginable, but possible, release of radioactivity. In the words of that Report, it was to be a "bounding case which subsumes all events, however low their probability", and included hostile action and gross human error. Radioactive releases were chosen for the WCRE and the resultant doses were again calculated as a function of distance and time.

2.9 Since the time of the WG-8 Report, (1988), modifications to operating conditions and design of safety features have been made that reduce the expected radioactive emissions in an accident. The holdup time used in very conservatively based estimates of emission to the environment should now be at least 48 hrs instead of 24 hrs in most accidents. Containment is expected to be unbreached - except for a possible brief time (seconds or minutes) - before the vacuum system takes over. And finally, to trap iodine, the water (H_2O) in the Emergency Cooling Injection System is maintained in a basic (alkaline) condition. (conversation with J.D.Morrow and K.S.Dinnie, 96-6-21) All these are factors that reduce possible releases of radioactivity and must be taken into account.

2.10 While a probabilistic safety evaluation was done for Darlington in 1987, the methods have continued to be improved and developed. The Darlington risk assessment [37] is currently being redone, and risk assessments for Bruce A and B are underway. For Pickering A, with its present containment design and site characteristics, an extensive risk assessment has recently been completed. Entitled "Pickering NGS A Risk Assessment" (PARA) [36] assesses the risk of accident at Pickering A reactors. Accident sequences that had consequences in common were assembled into categories. Two sets of categories were developed; first, Fuel Damage Categories (FDC) and second, Ex-Plant Release Categories (EPRC). Those categories that resulted in radioactive material being released outside the Plant were examined by us in order to understand the accident sequences and hence the credibility of the emission of radioactive material. These PARA studies, being based on current methodologies, were chosen as a realistic, reasonable and adaptable framework for comparison with the accident scenarios in the ONSR and in WG-8 for CANDU reactor stations.

2.11 As stated in PARA : "For a significant release of radioactivity to occur from the containment not only must there be a release into the containment building, but there must also be an opening in the containment envelope and a driving force to expel the radioactive materials through it. The opening could in turn be either *pre-existing* such as isolation failure or leakages through containment penetrations, or be caused by the accident itself, e.g., due to forces resulting from failure to shutdown the reactor, or hydrogen detonation. The driving force may be provided by inability, due to air cooling unit failure, to condense steam formed as a result of the accident, or a hydrogen burn due to failure of the hydrogen igniters to mitigate the build-up of hydrogen concentrations. Thus the magnitude and timing of the releases is dependent on the nature of the accident sequence and the state of the containment system." Accident sequences which could lead to radioactive releases beyond the plant boundary were assembled into seven categories; EPRC-1 to EPRC-7. The analyses of the releases were grouped into three time periods; 0-6 hrs, 6-24 hrs (0-24 hrs is sometimes called "early" release), and beyond 24 hrs. The following is a description of these categories as given in PARA.

Category	Description
EPRC-1	Pre-existing opening. Significant release in 6 hr and 24 hr driven by heat sink not available or by uncontrolled global hydrogen burn due to hydrogen igniter failure.
EPRC-2	Pre-existing opening, consequential containment envelope failure or containment bypass. Release primarily in 24 hr, driven mainly by steam surge since heat sink not available, or uncontrolled hydrogen burn due to hydrogen igniter failure.
EPRC-3	Pre-existing opening, early containment failure due to steam over-pressurization or late containment failure due to hydrogen explosion. Release after 24 hrs due to purging by noncondensable gas.
EPRC-4	Large pre-existing opening. Release in first few hours due to either early steam surge, instrument air or noncondensable gas leakage prior to activation of the filtered air discharge system. Containment available.
EPRC-5	Containment bypass events. Steam generator tube ruptures or emergency cooling injector blowback results in discharge pathway direct to atmosphere.
EPRC-6	Small pre-existing opening or early containment failure due to rapid overpressure by steam, all other containment systems operational.
EPRC-7	All containment systems intact and operational. Containment sub-atmospheric for the first day. Release of noble gases through the filtered system over a month.

2.12 The frequencies of the various categories of accidents, the EPRC's, and the dose as a function of distance were calculated. Both EPRC-1 and EPRC-2 have an extremely low frequency, and hence radiological consequences were calculated for only the remaining five Categories. The table below illustrates the dose calculated at 1 km and the estimated frequency of occurrence.

2.13 The early body doses shown in the table for the EPRC scenarios were calculated for the most exposed individual and on a probability basis for weather conditions. The methodology thus provided the most likely dose for the most exposed individual. In contrast, the figures given in the table for MPA and WCRE from WG-8 were determined as the maximum dose to the most exposed individual and for a particular weather condition. The wind speed used in WG-8 was lower than the mean of the distribution functions used in PARA for the EPRC scenarios. The single somewhat unusual meteorological condition used in WG-8 yields radiation fields higher by a factor of 3 or 4. This factor combined with the difference between maximum dose (WG-8) and most likely dose (PARA) is the basis for the difference

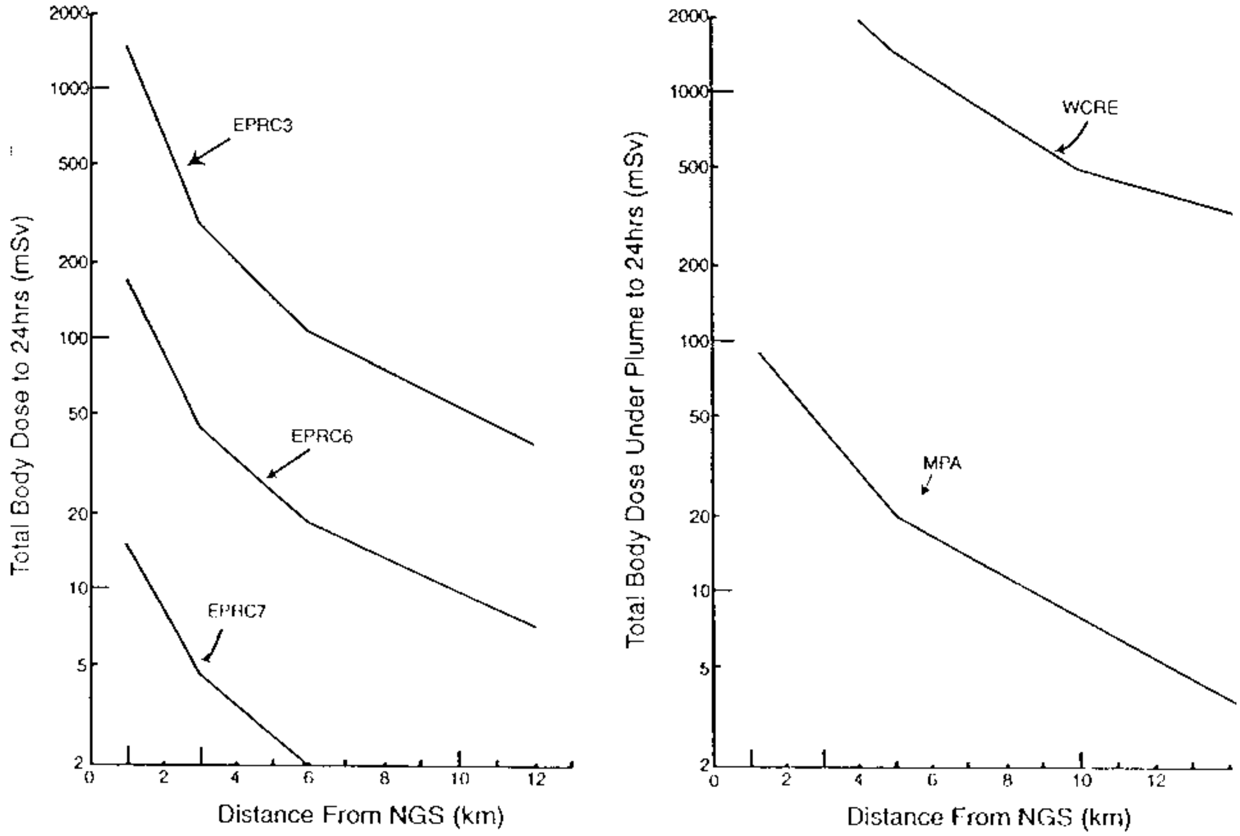
	Accident Category	Frequency events/reactor yr	Early Dose (mSv) at 1 km body	thyroid**
from PARA	EPRC-1	4×10^{-10}	--	--
	EPRC-2	5.9×10^{-9}	--	--
	EPRC-3	9.4×10^{-8}	1500	--
	EPRC-4	2.2×10^{-8}	630	1900*
	EPRC-5	1.8×10^{-8}	200	--
	EPRC-6	2.6×10^{-7}	170	230*
	EPRC-7	1.3×10^{-4}	15	15
from WG-8	WCRE	not defined	9000	200000
	MPA	greater than 10^{-6}	100	4000

(*Letter from L.D.Morrow, 14 Mar 96. **Committed dose)

shown between values for MPA and the EPRC-7 which are comparable accidents. Similar comments apply when comparing WCRE with EPRC-3 and EPRC-4.

2.14 The radiation doses shown in the table are calculated for a distance of 1 km from the source. The values are the early doses received after the initiation of the plume of radioactive materials. In the figure below can be seen these doses as a function of distance estimated for several of the accident scenarios. The PARA calculations are for the Pickering station with some safety improvements in place since the WG-8 study.

2.15 It can be seen from the table that the accident scenario EPRC-7 is thought to be the most probable - by a factor of 10^3 - and clearly must be considered in planning. After



this, accidents of estimated frequency down to 10^{-7}/reactor yr, are MPA, and EPRC-6 followed by EPRC-3. Of these EPRC-3 is the most devastating with a mean early whole body radiation exposure of 1500 mSv followed by a continuing emission of radioactive materials. The accident EPRC-6 is also serious and much worse than the MPA of WG-8. Note that WCRE of WG-8 is somewhat similar in severity to EPRC-3 and EPRC-4 though only these later have estimates of probability of occurrence. Calculations for Darlington done some time ago show a somewhat higher probability for comparable public exposure.

2.16 Thyroid dose from these accidents should also be noted. Since the thyroid gland is small and concentrates iodine, its radiation exposure can be much greater than the rest of the body. The ratio can be more than an order of magnitude (NUREG/CR 6310) [31] and WG-8 [48] or perhaps more likely, only as much as a factor of one to three, (letter from L.D.Morrow, 14

Mar 96), depending on the details of the accident. These details are described in many accident scenarios and the resulting radioactive iodine release varies widely. For example, note that accident EPRC-7 shows no iodine release; for it the ratio is clearly one. The largest releases are described in accident scenarios in NUREG/CR-6310 [31] for pressurized water reactors and cover a range from very little to several percent (one example is 25%) of core inventory. Calculations for the CANDU system in Ontario have shown smaller iodine releases. ONSR analyzed several severe accident scenarios and all showed releases less than 1%; the WG-8 estimate for MPA is 0.1% and for WCRE 1% was chosen. The PARA scenarios range from zero (EPRC-7) to 0.7% (EPRC-4). Accident EPRC-3 is expected to release twice as much iodine as the MPA and although the thyroid exposure is not calculated, by comparison with EPRC-4 and EPRC-6 it might be expected to be about 1000 mSv, which would lead to a dose under the plume comparable to the exposure estimated for MPA.

2.17 Over the last decade or so two factors have arisen that must enter into any estimation of iodine release. First, considerable new knowledge of iodine reactions and iodine interactions with solid surfaces has been gained (e.g. Wren et al, 1994 [64]) indicating limited iodine volatility. Secondly, additional safety features and containment modifications at Pickering A will further inhibit iodine release. (Longer holdup time allows radioactive decay) And as mentioned above, the alkalinity of the emergency cooling water increases considerably the solubility and retention of iodine. Some of these factors would apply both to an immediate "puff" release if there is containment failure and to controlled releases through the filtering system (EFADS) which has considerable over-capacity for iodine retention.

2.18 There are many uncertainties is these calculations of accident consequences and frequencies. These include the evaluation of the probability of each step in an accident sequence, the evaluation of exclusions of highly unlikely initiating events, the uncertainties associated with meteorological conditions, and the inevitable conservatism introduced by not crediting residual (post-accident) operating capabilities. Uncertainties are also introduced through assignment of certain containment failure mechanisms as not credible. It is recognized that uncertainties in models and data tend to raise doubts about their reliability. However the usefulness of the process in providing a coherent picture of the whole system is undoubted. A measure of the uncertainties involved in the analysis is given in the uncertainty bounds for severe core damage and for large release of radioactive materials where well over an order of magnitude separates the 5% and 95% probability limits [36]. A review [22] of estimated accident consequence offers the judgment that "recent studies of the uncertainties associated with severe reactor accident release estimation indicate that projections based on accident conditions are only accurate within a factor of 100, even if all reactor conditions are known". With this in mind, the calculations in the tables and graphs above must be viewed with caution and awareness of the uncertainties, keeping in mind that successive conservative estimates have become incorporated. To our knowledge however, even with their uncertainties, these calculations are the best guides available.

SECTION 3 RADIATION EFFECTS AND INTERVENTION CRITERIA

3.1 The review of nuclear accidents with their potential radiation exposures leads to a discussion of the biological effects of the radiation and to a consideration of the measures that might be taken to protect the public. The biological effects of ionizing radiation have been studied extensively and reviewed in national and international reports. Intervention measures have also been identified and reviewed [7,14,30,31]. In this Section are presented only those parts of the subject that bear directly on this study. In particular, the biological effects of radiation are considered in the context of a population of 10,000 with an age distribution like that in Ontario and which approximates the population in the Contiguous Zone (radius 1-3 km) at the Pickering station [36]. Thus a comparison can be made of the hazards of a nuclear accident with the normal hazards of daily living.

3.2 It is customary to consider the deleterious effects of radiation in two categories: One called "deterministic" effects, which can occur above a threshold dose and increase in severity with increasing dose, and the other called "stochastic" which are infrequent, have no threshold, and increase in frequency with dose. Deterministic effects include nausea and vomiting, bone marrow failure and, in severe cases, death. Stochastic effects include a wide range of cancers such as leukemias and thyroid tumors as well as presumed detrimental hereditary effects. The development of the embryo and foetus is a complex process and radiation can cause both deterministic and stochastic effects.

3.3 Nausea and vomiting can occur at doses above 250mSv, and bone marrow failure after 2,000 mSv. At higher doses a larger fraction of the population is affected until at 5,000 mSv about half the population will suffer serious illness and death.

3.4 In contrast, late onset (stochastic) effects are usually cancers in a variety of sites induced by the radiation at a rate that increases approximately linearly with dose. The number of leukemias, cancers of the breast, lung and other sites that eventually lead to cancer deaths after a dose of 1000 mSv to the whole body is estimated to be about 500 in the 10,000 population [15]. For smaller doses the fatalities are thought to be reduced proportionately, i.e. for a 100 mSv dose about 50 deaths among the 2,000 "natural" cancer deaths in a population of 10,000 individuals [27]. It should also be remembered that the long term detrimental effects of radiation include as well as cancer deaths, the suffering from non-lethal cancers, the presumed heritable damage and the effects on foetal development. Protective measures should certainly aim at reducing whole body doses to well below 100 mSv.

3.5 Cancer of the thyroid is a cancer of particular interest in nuclear accidents since radioactive iodine may be released and could then become concentrated in the thyroid gland. The number of thyroid cancer deaths resulting from a dose of 1000 mSv to the thyroid, is estimated to be about 8 in the 10,000 population or a statistical 0.8 thyroid cancer deaths from 100 mSv. However the dose to the thyroid cannot be predicted from the whole body dose because thyroid absorption is variable. Iodine may be concentrated in the thyroid gland resulting in a thyroid dose as much as 20 times that to the rest of the body [31]. That concentration however may not lead to an increase of 20 fold for the radiation sensitive cells. The iodine is concentrated in the coloid of the thyroid follicles and the effective dose to the lining cells could be 2 to 3 times lower depending on which isotopes of iodine are involved. Thus a whole body dose of 100 mSv would lead to a mortality from thyroid cancer of 0.8 lives if the iodine is not concentrated to as much as $0.8 \times 20 \times 1/2 = 8$ lives if the dose is primarily from radioactive iodine. This range, 0.8 - 8, of fatalities may be compared with the 6 deaths to be expected from thyroid cancers in the same population. The radiation induced cancers would occur in younger individuals.

3.6 Radiation and iodine deficiency are the two major risk factors for thyroid cancer [61]. In mechanistic studies iodine deficiency leads to a decrease in thyroid hormone and to an increase in thyroid stimulating hormone (TSH). TSH increases the susceptibility of the thyroid to carcinogenesis. The interaction of iodine deficiency and radiation on thyroid carcinogenesis is not known but it is probably large. In Japan where iodine intake is adequate thyroid cancer is rare and it was not common following the exposure to nuclear weapons. In the Ukraine where iodine intake is inadequate thyroid cancer is common and more children were likely affected after the Chernobyl accident [4,5,56,60]. In Ontario iodine intake is generally adequate and some individuals even show evidence of excess.

3.7 The understanding of carcinogenesis is incomplete. The generally accepted model is based on induced somatic mutation of the DNA of genes and the selection of more malignant clones of the affected cells through a process of promotion and progression. Several of the genes affected have been identified [61]. Somatic mutations can be induced by radiation, promoted by iodine deficiency, and exposure to TSH. In molecular studies, DNA damage or mutations produced by radiation can be shown to be repaired, the fraction repaired depending on the genetics of the irradiated individual and the proliferative status of the cells at risk. There do not appear to have been any studies that have systematically examined the effect of administered iodine on the proliferation of thyroid cells or of the effect of proliferation immediately after radiation on the sensitivity of these cells to carcinogenicity. Thus it cannot be said with certainty that iodine supplementation after irradiation would always lead to beneficial effects.

3.8 The general principles for intervention as recommended in 1994 by the IAEA [14] and now broadly accepted are:

"1. All possible efforts should be made to prevent serious deterministic health effects.

2. The intervention should be justified in the sense that introduction of the protective measure should achieve more good than harm.

3. The levels at which intervention is introduced and at which it is later withdrawn should be optimized, so that the protective measure will produce a maximum net benefit."

Application of these principles entails the development and use of protective measures for averting radiation exposures arising through various pathways. The major protective measures are sheltering, evacuation and relocation, administration of stable iodine, and control of the source of foodstuffs. This study is limited to sheltering, evacuation and the use of iodine. It is important to note that sheltering and evacuation are measures in common use for both man made and natural disasters.

3.9 The IAEA Safety Guide [14] established generic intervention levels which could be applied immediately as the first criteria for action following any accident. With appropriate flexibility they can be applied to any specific site or accident and can be adapted on a longer term basis for optimum effectiveness. The Guide points out that any particular protective action must take into account both the dose which might be received with no action and the dose which can be averted by some action. These considerations can be used to define the area and contained population group where it is of benefit to take protective action. Outside this area protective action would have more disadvantages than benefits. Using these guide lines the IAEA (Table III, ref 14) recommends:

Protective action	Generic intervention level (dose *avertable* by protective action)[ab]
Sheltering	10 mSv[c]
Evacuation	50 mSv[d]
Iodine prophylaxis	100 mGy[e]

[a]---These levels are of avertable dose, i.e. the action should be taken if the dose that can be averted by the action, taking into account the loss of effectiveness due to any delays or for other practical reasons, is greater than the figure given.

[b]---The levels in all cases refer to the average over suitably chosen samples of the population, not to the most exposed individuals. However projected doses to groups of individuals with higher exposures should be kept below the threshold for deterministic effects.

[c]---Sheltering is not recommended for longer than two days. Authorities may wish to recommend sheltering at lower intervention levels for shorter periods or so as to facilitate further countermeasures, e.g. evacuation.

[d]---Evacuation is not recommended for a period longer than 1 week. Authorities may wish to initiate evacuation at lower intervention levels, for shorter periods and also where evacuation can be carried out quickly and easily, e.g. for small groups of people. Higher intervention levels may be appropriate in situations where evacuation would be difficult, e.g. for large population groups or with inadequate transport.

[e]---Avertable dose to the thyroid. For practical reasons, one intervention level is recommended for all age groups.

3.10 Both the ONSR and the report of WG-8 pointed out that timely and effective intervention in an accident requires planning based on specific criteria. As WG-8 noted in their report, the Province of Ontario's Nuclear Emergency Plan, which they had been commissioned to examine, was based on a Maximum Planning Accident (MPA). The detailed planning and preparation was for an accident that produced an effective dose of 250 mSv at a distance of 1 km from the reactor. The Nuclear Emergency Plan (NEP) used three planning zones: a 3 km Contiguous Zone, a 10 km radius Primary Zone, and a 50 km radius Secondary Zone, which were applicable to the Pickering, Darlington and Bruce plants, with modifications for the Fermi reactor near Windsor. The NEP also recommended "thyroid blocking" with KI tablets and conditions for public alerting. As noted in the previous Section, the MPA assumed certain values of escaped radioactive materials and calculated the resulting doses as a function of distance and time. Their resulting recommendations were (Table 4.1 from WG-8):

Protective Action	Body dose	Thyroid dose
Sheltering	1 - 10 mSv	3 - 30 mSv
Evacuation	10-100 mSv	30-300 mSv
Thyroid blocking		30-300 mSv

These doses were understood to be the dose of the most exposed individual of the particular group, and the top and bottom of the range indicated "must" take action and "should" take action.

3.11 A comparison may be made of these intervention levels with those of the IAEA which were shown in a table above. The single values of the IAEA refer to an average dose while the WG-8 levels refer to the most exposed individual. With this distinction in mind it is seen that the recommendations are broadly similar with WG-8 recommending action at somewhat lower levels. For taking action in an emergency, single values are simpler and unambiguous.

3.12 In relating these intervention and protective action levels to the zones defined in the NEP, other important and practical factors must be considered. For example, if evacuation is called for, the municipal authorities must take into account the ease of traffic control, the problems of notification - day or night, and the condition of the roads. They have also to note the wind direction for the population in the up-wind direction is, initially at least, not in danger.

3.13 Iodine prophylaxis (thyroid blocking) requires further comment. The effectiveness of stable iodine in blocking thyroid uptake has been recently reviewed by the Group of Medical Advisors of AECB [7], and by consultants for the U.S. Nuclear Regulatory Commission [31]. All reviewers agree that a 130 mg KI tablet taken just before exposure to radioactive iodine and daily thereafter, provides almost total blocking of thyroid uptake. The effectiveness declines rapidly however, and at two or three hours after exposure taking a tablet is only half as useful [20,31]. Not all reviewers agree on the radiation level at which the thyroid gland is in danger; a range of intervention levels spanning two orders of magnitude (from 10-1000 mSv) is cited in the NUREG 6310 review. While iodine prophylaxis does protect the thyroid gland from radioactive iodine (if taken in time) it does not protect any other part of the body. Until evacuation is possible, sheltering must accompany taking the tablets since other radioactive releases in an accident are probably more dangerous. Evacuation reduces the risk both to the thyroid and the much larger risk to the rest of the body as well.

3.14 Summary: Radiation and cancer risks. From Section 3.5 and continuing: In an Ontario population of 10,000, about 2,000 will die of cancer of which 5-6 will be from thyroid tumors. If that population receives a whole body dose of 100 mSv, there will be eventually an additional 50 cancer deaths of which 0.8 are from thyroid cancers. If in addition much of that dose came from radioactive iodine which was inhaled and concentrated in the thyroid, the dose to that gland could be 10 times greater (for PWR accidents Ref 31, p 7-8) and result in 8 not 0.8 cancer deaths. Of course none of these 50 or so "irradiation" deaths could be identified in the 2,000 "natural" deaths.

It should be noted that all accident scenarios from PARA for Pickering A show iodine releases at least an order of magnitude lower, compared to noble gas releases, than releases from PWR (Surry) quoted in reference 31. Thus the number of thyroid cancer deaths from radioactive iodine intake from a CANDU accident that resulted in a 100 mSv whole body dose to the population is likely to be an order of magnitude or more lower than the 8 quoted above; more like 0.8 or less, making the risk of thyroid cancer from inhaling iodine less than the risk of thyroid cancer from whole body radiation. In this scenario thyroid blocking with KI tablets provides little additional mitigation.

SECTION 4 FOR WHAT ACCIDENT SHOULD WE PLAN ?

4.1 Previous Sections have outlined the severity and estimated frequency of various possible accident scenarios, the several harmful effects of radiation on people, and presented a discussion of the level of radiation which should be used as a condition for invoking some kind of remedial action. This Section joins these themes and addresses the question of what kind of accident should be the basis for detailed planning.

4.2 As discussed in Section 2 the ONSR recommended "comprehensive planning" for the "maximum credible releases of radioactive materials". The phrase "maximum credible" was indicated as probably lying in the higher of a two tier classification of accident severity. The two tier picture was developed by Working Group No.8, the lower one being the "maximum planning accident", MPA, and the upper one the "worst credible radiation emission", WCRE. Considerable progress has been made since that time in describing accidents and their consequences. **WE FIND IN THE CONTEXT OF PRESENT DAY EMERGENCY PLANNING THAT IT IS NOT REASONABLE TO DEFINE THE "MAXIMUM CREDIBLE RELEASE" FOR "COMPREHENSIVE PLANNING" AS THE WCRE OF WG-8. WE RECOMMEND THAT DETAILED EMERGENCY PLANNING SHOULD BE DONE FOR ACCIDENTS RESULTING FROM A CREDIBLE SERIES OF EVENTS WHICH COULD OCCUR WITH A PROBABILITY OF APPROXIMATELY 10^{-7}/REACTOR YEAR. (ONCE IN TEN MILLION YEARS PER REACTOR.)**

4.3 In Canada, for reactor licensing, it is thought prudent to take seriously severe accidents that may occur once in about 10^{7} years and to regard as unrealistic for detailed planning those that are less frequent. (Discussed in PARA, 13-1, [36]) We consider this a sound and reasonable frequency level on which to base the limit of credibility of accidents. Thus several of the accident scenarios sketched in **2.10-2.13** for Pickering, including EPRC-3, -6, -7, and MPA, the central thrust of WG-8, and comparable scenarios for Bruce and Darlington, are candidates for emergency planning.

4.4 Many accident scenarios can be identified in this range of estimated frequency. Starting with EPRC-7, the most probable of the categories; the consequences of this accident are not very harmful to the environment and unless something exacerbated the accident the controlled release of inert gases could be done with very little risk. The next in frequency are MPA, and EPRC-6,. Both of these clearly exceed the evacuation threshold at 1 km and under the plume, EPRC-6 exceeds it much beyond 3 km as well. These accident scenarios combined with very poor meteorological conditions make a sound and reasonable basis for emergency planning. There are many reasons for this judgment:

* These accidents, though of very low probability, have significant release of radioactive materials. It is necessary to plan so that public exposure is kept below the intervention levels.
* These accidents have physical, chemical and engineering reality including recognition of design and operating features and the accident sequences are thus internally consistent. They provide extreme credible accident scenarios as a basis for emergency planning and still lie within the range of probabilistic safety assessments made for each station.
* To this collection of accidents can be added any new analyses of other scenarios if of comparable probability.
* The emergency plan developed in response to these accidents may be used in mitigating the damage of some very improbable natural event.
* As noted in WG-8 for MPA the probability of one of these accidents happening is orders of magnitude below the level of other accidents for which emergency plans are made, thus allowing for the public perception that nuclear accidents are different.
* These accidents and the emergency response provides a framework for developing a cost-benefit analysis of emergency planning - a philosophy endorsed by both the ONSR and the WG-8 report.

4.5 In making detailed plans for the accidents discussed above it must be kept in mind that even more serious accidents are possible though less likely. Accidents due to natural causes, hostile actions, or gross human error, or some unforeseen combination of these are also possible though much less likely. Some imagined consequences of such disasters are included in WCRE of WG-8, and are of a severity that according to WG-8 warranted consideration in planning. We support this idea. Even though no probability can be fully justified and assigned to these occurrences, some thought and planning should be given to them. It is noted that the accident EPRC-3 is of comparable severity to WCRE. EPRC-3, for which radioactive releases are delayed at least 24hrs after the beginning of the accident, could require evacuation from the Primary Zone. The radioactive releases are expected to continue for a day or so after the initiation of the plume. Thus it is possible to conceive from a set of credible accident sequences, more severe consequences than were postulated in WCRE. Note too that the EPRC-3 accident is only slightly less probable than the MPA or EPRC-6 which are probable enough that detailed planning is recommended.

4.6 Continuing risk analysis, including in addition to mechanical and equipment failures, the less quantifiable human and natural disasters, leads to better understanding of the Nuclear Generating Station and its operation and can result in technical modifications to further reduce the probability of accident.

4.7 Accident analysis, including both the probability of occurrence and the consequences in radiation doses has major uncertainties attached as noted in 2.18 above. None the less it is useful to examine a wide range of accident conditions and scenarios and the associated probabilities of occurrence. From this wide range it is necessary to select a few of the more probable ones for response training. Only by planning and rehearsing the actions for a set of realistic accidents can the necessary response skills and flexibility be developed. Such planning and rehearsing makes a sound base which can most effectively be extended if ever a larger disaster were to occur.

4.8 In summary, we find that WCRE is not a good basis for detailed emergency planning. It may be considered not credible because the radioactive emissions have been assumed rather than being deduced from a credible accident scenario. However, using the 10^{-7}/reactor-year criterion for planning, there are many accident categories listed in PARA that qualify. These include EPRC-3, -6, -7, (and perhaps -4, and -5 if the uncertainties are kept in mind). EPRC-3 for example may require evacuation of the Primary Zone and possibly even parts of the Secondary Zone. These accidents scenarios provide a good basis for emergency planning. Finally note that the assumed emissions made in 1988 by WG-8 for WCRE are similar to EPRC-3 except for the delay.

SECTION 5 POTASSIUM IODIDE TABLETS OR NOT ?

5.1 This Section contains a discussion of whether or not potassium iodide tablets should be predistributed to individuals in the 3 km Contiguous Zone. Arguments are developed that show that the protective actions of KI tablets has been overemphasized. From these arguments **WE CONCLUDE THAT POTASSIUM IODIDE PROPHYLAXIS IS NOT THE APPROPRIATE PRIMARY MITIGATION FOR INDIVIDUALS IN THE CONTIGUOUS ZONE, AND THEREFORE DO NOT RECOMMEND COMPLETE PREDISTRIBUTION OF THE TABLETS. THE MAJOR EFFORT SHOULD BE EVACUATION FROM THE RADIATION AREA FOR WHICH WE PROPOSE A SINGLE ACTION LEVEL OF 10-50 mSv. AVERTABLE DOSE.** Potassium iodide can be predistributed to groups in controlled areas, e.g. schools, factories, etc, if the later use of the tablets does not delay evacuation.

5.2 It is well known (Section 3.13) that KI tablets taken before exposure to radioactive iodine, and daily afterwards, are very effective in blocking further uptake of iodine. They are inexpensive and safe, and thus provide an excellent method of preventing thyroid irradiation. They must however be taken just before exposure and are of little value if not taken until a few hours afterward. They are especially useful to children who are more sensitive to the carcinogenic effects of radioiodine. In spite of the value of KI tablets, there are several overlapping rationales for our emphasis on evacuation.

5.3 First: Thyroid cancer represents but one of the many deleterious effects of exposure to radiation. We noted earlier that although thyroid doses resulting from nuclear accidents can be as much as 20 times the whole body dose, the detrimental stochastic effect of the whole body dose, including leukemias and cancers at other sites, is still greater. As illustrated in Section 3.4 and 3.5 above, a total body dose of 100 mSv results in 0.8 to 8 thyroid cancer deaths in a total of

50 tumor deaths in a population of 10,000. Thus even if the reactor accident led to high levels of radioactive iodine emission, and if KI prophylaxis was entirely efficient, the reduction in cancers would be less than 20% and probably much less in a CANDU accident from which iodine emissions are expected to be very small. (See Section 3.14)

5.4 Second: Because iodine prophylaxis by itself is so ineffective it is always accompanied by sheltering to reduce total body dose. Together they can be thought of as providing inexpensive protection from low level radiation. However the shelter provided by the average house and most schools and commercial buildings is very limited, less than 50% in many cases [16, see reference Brown J.]. The protection achieved by the combination of iodine prophylaxis and sheltering is thus very limited.

5.5 Third: Thyroid blocking by KI is critically dependent on timing, a delay of a few hours reduces the effectiveness to half or less [7,31]. In some situations, such as schools and hospitals where the tablets are readily stored and lines of communication are clear, it might be possible to use KI and sheltering effectively but in private homes a delay in the administration of KI is very likely.

5.6 Fourth: Sheltering and KI prophylaxis are fortunately not needed if there is a clear period of time to leave the area of potential contamination with minimal exposure to radiation. In accident EPRC-7 containment is intact and release of noble gases could be made after evacuation. In accident EPRC-3 there is a explosive release of iodine but this occurs more than 24 hours after the initiation of the accident. Again there is time for orderly evacuation. In accident EPRC-6 there is an initial loss of containment but subsequent containment limits the exposure in the Contiguous Zone for a period that could be used for evacuation in case there is a further release. This leaves the less likely events, EPRC-4 and

EPRC-5 together with events involving hostile action as the only cases in which there could be large immediate releases of iodine. In these accidents KI tablets would be even less useful because they would likely be administered late.

5.7 Fifth: Predistribution of KI focuses attention on a not very effective method of radiation mitigation and might leave individuals with the impression that they have done something important to reduce their risk. It could lead to a reduced effort at rapid evacuation; the most appropiate action especially if deterministic effects are expected.

5.8 Sixth: Experiments with predistribution of KI tablets to populations around nuclear facilities show that the tablets become lost and procedures forgotten [11]. They also show that a large effort is needed to predistribute and monitor the possession of tablets to all individuals and that this effort has little practical value.

5.9 Seventh: Bad weather preventing prompt evacuation needs to be discussed. Heavy snow storms occur half a dozen times a winter, i.e. about 2% of the time. The probability of such a storm at the same time as a very severe accident (10^{-7}/yr) is thus of the order of 10^{-9}/yr and normally omitted from consideration. However even if such an accident and a bad storm occured together and no KI tablets were available, the risk of radiation induced cancer in the thyroid is still small compared to the risk of many other types of cancer in the whole body.

5.10 Eighth: Other jurisdictions: It should be noted that recent writings from the U.S. Nuclear Regulatory Commission have expressed somewhat similar views. We quote from F.Kantor, R.Hogan and A.Mohseni in a presentation to the Stockholm 1994 Conference, published as an O.E.C.D. Document, Nuclear Energy Agency "The Implementation of Short-term Countermeasures After a Nuclear Accident", p.268:

"The use of the thyroid-blocking agent potassium iodide (KI) is not considered an adequate substitute for prompt evacuation or sheltering by the general population near a plant in response to a severe reactor accident. Ingestion of KI will serve only to help reduce the dose to the thyroid caused by intake of radioiodine. The primary risk to the population from a severe accident is whole body dose, not the radioiodine dose to the thyroid. In addition KI is not considered to be an effective countermeasure for protection against the ingestion pathway in the U.S.."

5.11 Thus we are of the opinion that evacuation is the appropriate primary mitigation measure in the Ontario context and recommend a single protective action level of 10 - 50 mSv.

Protective action	**Intervention level** (averted dose)
Evacuation	10-50 mSv

5.12 This single action level effectively combines the three levels of the IAEA Safety Series No.109 [14] and the three protective action levels which were presented in WG 8. There are several arguments for the single action level:

* As discussed above sheltering and KI prophylaxis is effective, but for only a very narrow range (about 10-50 mSv) of radiation fields. Any very severe accident will almost certainly require evacuation even if some people in the radiation field have initially sheltered.

* There are many different action levels recommended by various organizations that have studied the matter. The 10-50 mSv we recommend is compatible with WG-8 and IAEA.

* If the iodine content of the plume is relatively high, and the thyroid/whole body dose ratio is 20 [31], the thyroid dose may be in the range 200-1000 mSv. If the iodine content is relatively low as is expected for accidents in CANDU reactors, and using a dose ratio of 2, the thyroid dose may be in the range 20-100 mSv. In either case the recommended evacuation covers the usual thyroid action levels.

* The evacuation range we recommend, 10-50 mSv from an

accident, is several times the naturally occurring radiation dose we all receive in one year.

* In an emergency, one intervention level would be simpler and more practical than the range 10-50 mSv. If a single value is needed we recommend 20 mSv.

* If a single action level were to be adopted, it would be feasible for some members of the Police emergency team to carry simple gamma ray detectors for direct assessment of the radiation field and consequent action.

5.13 In summary: In nuclear emergency planning, the emphasis that has been placed on KI prophylaxis, is unwarranted. Even sheltering, by itself, while useful against particulate fallout and the inhalation of gases, offers limited protection. The radiation field inside houses will be reduced by only 10 to 50 %. Thus sheltering should be the automatic response until evacuation is possible.

SECTION 6 PRIMARY ZONE, 10 or 13 km?

6.1 In our modern society there are many industries that can create a risk for the surrounding population if an accident were to occur. How close should one live to an oil refinery, to an explosives factory, to a chemical manufacturing plant, or in our case, how close to a nuclear powered electricity generating plant ? Of course it is safer to be far away. The risk diminishes with distance as was shown in the Figure in Section 2. It is also evident from the Figure that the range of severity of possible accidents is enormous. This wide variability of accident consequences makes planning a response very difficult. It seems wasteful to spend much public money on detailed planning for very improbable accidents. Thus an informed and pragmatic judgment must be used in making the rules and plans for any response to an emergency.

6.2 Risk of exposure in a nuclear accident decreases with distance from the site of the accident and thus plans for action in an emergency are also a function of distance. For practical planning, the distance is divided into zones. [43]

* The Exclusion Zone, with its 1 km radius, is property of the Utility and surrounded by a fence.
* The Contiguous Zone, with a boundary approximately 3 km radius around the plant, is an area for which detailed plans can be developed. Because of its limited size relatively fast action is possible. High population density and possible bad weather could make evacuation difficult and this zone should have a small population and preferably be restricted to parkland or industrial park use.
* The Primary Zone, which has a radius nominally 10 km, is more difficult to plan for because of its larger area, larger population, and more varied use. (It should be noted that 10 km corresponds to the distance at which the dose is about 10 mSv in accident scenario MPA in WG-8)
* The Secondary Zone is beyond the 10 km boundary. Here

also some thought must be given and plans made for notifying and evacuating the population which is in the direct line of a possible radioactive plume.

6.3 For the Primary Zone notification of need to evacuate is more difficult than for the Contiguous Zone, and depending on the distribution of population, the evacuation itself may be much more difficult to organize. The exact boundary of this Primary Zone should be based on practical considerations. These include the various natural divisions, rivers, forests other topographic features, even power line and railway rights of way. In view of the great variability of a disaster, there is little real difference between 10 or 13 km. **WE THEREFORE CONCLUDE THAT 10 KM AS A NOMINAL RADIUS, APPLIED WITH PRACTICAL FLEXIBILITY, IS CONSISTENT WITH THE NEEDS OF THE PROVINCIAL NUCLEAR EMERGENCY PLAN FOR ALL OF ONTARIO'S NUCLEAR GENERATING STATIONS.** The most important criterion is the ability to make zone boundaries that are practical in an emergency. In addition, the use of 10 km implies a reasoned generality while 13 km implies a precision which does not exist.

6.4 Similar advice arises from European experience:
"... the 10 km planning zone is chosen as a suitable general planning basis from which to establish an emergency response structure and operating platform. Irrespective of zone size, countermeasures can still be implemented on an ad hoc basis for events with larger consequences and affecting areas beyond the formal plume exposure zone boundary." (Quoted from the Ontario Hydro Submission, Mar 1996) [35].

6.5 In summary, it is appropiate to plan for accidents by zones defined by radii from the station and to use a radius of 10 km for the outer limit of the Primary Zone for which detailed plans should be made.

SECTION 7 SUMMARY OF RECOMMENDATIONS

7.1 The first "specific question" put to the RSC/CAE committee is answered in Section 4: WE FIND IN THE CONTEXT OF PRESENT DAY EMERGENCY PLANNING THAT IT IS NOT REASONABLE TO DEFINE THE "MAXIMUM CREDIBLE RELEASE" FOR "COMPREHENSIVE PLANNING" AS THE WCRE OF WG-8. WE RECOMMEND THAT DETAILED EMERGENCY PLANNING SHOULD BE DONE FOR ACCIDENTS RESULTING FROM A CREDIBLE SERIES OF EVENTS WHICH COULD OCCUR WITH A PROBABILITY OF APPROXIMATELY 10^{-7}/REACTOR YEAR. (ONCE IN TEN MILLION YEARS PER REACTOR).

7.2 The second "specific question" is answered in Section 5: WE CONCLUDE THAT POTASSIUM IODIDE PROPHYLAXIS IS NOT THE APPROPRIATE PRIMARY MITIGATION FOR INDIVIDUALS IN THE CONTIGUOUS ZONE, AND THEREFORE DO NOT RECOMMEND COMPLETE PREDISTRIBUTION OF THE TABLETS. THE MAJOR EFFORT SHOULD BE EVACUATION FROM THE RADIATION AREA FOR WHICH WE PROPOSE A SINGLE ACTION LEVEL OF 10-50 mSv.
and in Section 6: WE THEREFORE CONCLUDE THAT 10 KM AS A NOMINAL RADIUS, APPLIED WITH PRACTICAL FLEXIBILITY, IS CONSISTENT WITH THE NEEDS OF THE PROVINCIAL NUCLEAR EMERGENCY PLAN FOR ALL OF ONTARIO'S NUCLEAR GENERATING STATIONS.

Ontario

Ministry of Environment and Energy

Ministère de l'Environnement et de l'Énergie

135 St. Clair Avenue West
Suite 100
Toronto ON M4V 1P5

135, avenue St. Clair ouest
Bureau 100
Toronto ON M4V 1P5

Tel: (416) 323-5646
Fax: (416) 323-5661

January 18, 1995

Dr. John Meisel
Chair
Royal Society of Canada
P.O. Box 9734
Ottawa, Ontario
K1G 5J4
613-991-6990
613-991-6996 (FAX)

Dear Dr. Meisel:

The Province of Ontario is currently reviewing its Provincial Nuclear Emergency Plan. There remain two outstanding technical issues which require resolution before the Plan can be updated. Specifically the issues relate to the pre-distribution of potassium idodide (KI) pills and the extension of the primary zone from 10km to 13km for two of the three nuclear generating facilities.

I am aware that at the time of the Hare Commission investigation into the Safety of Ontario's Nuclear Power Reactors the Royal Society of Canada undertook a review of the Commission's work. At this time I wish to alert the Royal Society of Canada to the fact that the Province of Ontario will be shortly formally requesting the Royal Society's review of the unresolved technical issues.

Currently the Province is working on formulating the specific question it wishes the Royal Society to investigate on the province's behalf. The Royal Society's work would be funded once the Terms of Reference, schedule and estimated costs are established and agreed by the parties. Should the Royal Society be able to undertake this project it would be of great assistance to the province in resolving the issues identified and allowing the province to proceed with revising the current Provincial Nuclear Emergency Plan.

I am making this initial contact to determine if the Society would be interested in this matter and what the timing might be for such a review. If you need any additional preliminary information please do not hesitate to contact me at (416) 323-5646.

On behalf of the Province of Ontario I thank you for the Society's attention to this matter and I look forward to the Society's response.

Sincerely,

Debbie Farr

D.E. Farr
Manager
Electricity Operations and Planning Section

bcc: Ian Kalushner
Rick Jennings
Les Horswill
Linda Liik, Ontario Hydro
Jim Ellard/Doug Harrison, Emergency Measures Ontario
John Boudreau

Ontario

FILE

A-3

Ministry of Environment and Energy

Ministère de l'Environnement et de l'Énergie

135 St. Clair Avenue West
Suite 100 6th Floor
Toronto ON M4V 1P5

135, avenue St. Clair ouest
Bureau 100
Toronto ON M4V 1P5

Telephone: 323-5646
Fax: 323-5661

May 26, 1995

Dr. John Meisel
Chair
Dr. A.T. Stewart
Royal Society of Canada
P.O. Box 9734
Ottawa, Ontario
K1G 5J4

Dear Dr. Meisel and Dr. Stewart:

In 1987 the Royal Society of Canada was invited to conduct a critical review of a report being prepared by the Ontario Nuclear Safety Review Commission chaired by Dr. Kenneth Hare. In March 1988, the Royal Society wrote to Dr. Hare and indicated that "the investigation has been performed with competence and thoroughness" and "the recommendations made and opinions expressed by the Commissioner (Dr. Hare) are soundly based and are adequately supported."

One of the recommendations which was supported by the Royal Society stated **"that the Province of Ontario base its nuclear emergency planning on the maximum credible releases of radioactive materials."** The determination of what constituted a maximum credible release of radioactive materials was one of the subjects reviewed by Working Group #8, a Provincial Committee which was convened to provide guidance to the Province on nuclear emergency planning. Although, Ontario Hydro participated in Working Group #8, the Corporation did not endorse all of the recommendations made by the group to the Province. This led to a dissenting opinion being formulated by Hydro and forwarded to the Provincial Government.

At this time, the Provincial government is reviewing the existing Provincial Nuclear Emergency Plan with an eye towards improving it. Two of the unresolved issues from Working Group #8 remain of concern. They are, the extension of the primary zones around the Darlington and Bruce nuclear generating stations from 10km to 13km and the pre-distribution of potassium iodide pills within the 3km contiguous zone surrounding the Bruce, Darlington, and Pickering nuclear generating stations in Ontario.

The reason the Province of Ontario has contacted the Royal Society of Canada is to seek the Society's review of the unresolved technical issues, and to provide guidance to the Province in its review of the existing Provincial Nuclear Emergency Plan. This has led to the following questions on which the Province would like the Society to comment.

1. In view of the recommendation made by the Hare Commission which stated "that the Province of Ontario base its nuclear emergency planning on the maximum credible releases of radioactive materials", is the description of a maximum credible release defined as worse credible radiation emission by Working Group #8 sound and reasonable in this context?

2. Having responded to question #1, does the Society believe that the pre-distribution of KI pills within the 3km contiguous zone surrounding the Bruce, Darlington, and Pickering nuclear generating stations and the extension of the primary zones around Bruce and Darlington follow logically from the Working Group definition of a maximum credible release?

The Province is mindful that the Royal Society of Canada will have to consider these questions before formally responding. It will be necessary, however, for the Province to discuss with the Society the terms of reference, the timetable for the Society's review, the membership of the Society's review committee, and the approximate costs of the review. Please contact me at your convenience to set up a meeting.

I would like to thank you for the Society's interest in this matter. The advice and guidance of the Society will be greatly appreciated since the Province seeks to resolve these two technical issues before proceeding with improving the existing Provincial Nuclear Emergency Plan.

If you need any additional preliminary information please do not hesitate to contact me at (416) 323-5646. On behalf of the Province of Ontario I thank you for the Society's attention to this matter, and I look forward to the Society's response.

Sincerely,

Deborah E. Farr

Deborah E. Farr
Manager
Electricity Operations and Planning Section

OFFICE OF THE PRESIDENT

CABINET DU PRÉSIDENT

THE ROYAL SOCIETY OF CANADA

LA SOCIÉTÉ ROYALE DU CANADA

July 12, 1995

Professor Alec Stewart
Department of Physics
Queen's University
Kingston, Ontario
K7L 3N6

Dear Alec,

At the last June 14th meeting of the Society's Council, the following motion was approved:

> "That the Society respond positively to the request from the Ministry of the Environment and Energy, and that Alec Stewart and Bob Bruce be asked to pursue the matter further".

I hope that you will continue your involvement with the project and keep me posted as to any further developments. I will also be willing to assist you in any way I can.

Yours sincerely,

N Schenk for

Robert H. Haynes, OC

225 Metcalfe Street, Suite 308
Ottawa, Ontario
K2P 1P9
Telephone: (613) 991-9005
Facsimile: (613) 991-6996

Ontario

Ministry of Environment and Energy

Ministère de l'Environnement et de l'Énergie

135 St. Clair Avenue West
Suite 100 6th Floor
Toronto ON M4V 1P5

135, avenue St. Clair ouest
Bureau 100
Toronto ON M4V 1P5

Telephone: 323-5646
Fax: 323-5661

no date ?

Ms. Linda Liik
Technical Superintendent
Emergency Preparedness Section
Ontario Hydro, A7-A4
700 University Avenue
Toronto, Ontario
M5G 1X6

Dr. Alex Stewart
Professor, Dept. of Physics
Queens' University
Kingston, Ontario
K7L 3N6

Mr. Doug Harrison
Deputy Director,
Emergency Measures Ontario
Ministry of the Solicitor General and Correctional Services
25 Grosvenor Street, 19th Floor
Toronto, Ontario
M7A 1Y6

Dr. Les Shemilt
Professor, Dept. of Chemical Eng.
McMaster University
Hamilton, Ontario
L8S 4K1

Dear Ms. Liik, Dr. Stewart, Mr. Harrison and Dr. Shemilt:

Attached is the Terms of Reference for the review by the Royal Society of Canada & Canadian Engineering Academy of outstanding questions relating to the proposed Provincial Nuclear Emergency Plan.

It has taken us a long time to agree on the process and terms of reference, however, I am pleased to note that the review has already started, at least informally. I would ask that you sign the attached Terms of Reference so we have an official record, and we can pay any invoices associated with the review.

Yours sincerely,

Deborah E. Farr

Deborah E. Farr
Manager
Electricity Operations & Planning Section
Electricity Policy Branch
Policy Division

Attach.

Terms of Reference for the Review by the Royal Society of Canada & Canadian Engineering Academy of Outstanding Questions relating to the Proposed Provincial Nuclear Emergency Plan

I. Scope of the Royal Society of Canada & Canadian Academy of Engineering (RSC/CAE) Review

The RSC/CAE review will be limited to review of **the following two** outstanding points in the proposed new Provincial Nuclear Emergency Plan (PNEP):

- that KI pills should be pre-distributed within the approximate 3 km contiguous zone; and
- that the primary zone around the nuclear facilities should be expanded from 10 km to 13 km for both the Bruce and Darlington stations.

Specifically, the RSC/CAE is being asked to respond to the following specific questions:

1. In view of the recommendation made by the Hare Commission which stated "that the province of Ontario base its nuclear emergency planning on the maximum credible releases of radioactive materials", is the description of a maximum credible release defined as worse credible radiation emission by Working Group #8 sound and reasonable in this context?

2. Having responded to question #1, do the reviewers believe that the pre-distribution of KI pills within the approximate 3 km contiguous zone surrounding the Bruce, Darlington, and Pickering nuclear generating stations and the extension of the primary zones and around Bruce and Darlington follow logically from the Working Group definition of a maximum credible release?

The RSO/CAE is being asked to provide their response to these questions and their supporting rationale.

It is expected that the RSC/CAE will base their opinion on the background materials provided, including the Hare Commission Report and the Working Group #8 Report, other information that may be provided by either Ontario Hydro or the Ministry of Solicitor General and Correctional Services (MSGCS) as part of their submissions on the matter, and any other published materials considered relevant by the RSC/CAE representatives.

II. Review Process and Timing

The Management Team seeking the advice and guidance of the RSC/CAE includes representatives of Ontario Hydro, Ministry of Solicitor General and Correctional Services, and Ministry of Environment & Energy. The Chair of the Management Team is Debbie Farr, Manager of Electricity Operations & Planning Section, Ministry of Environment & Energy.

It is expected that the review period by the RSC/CAE will commence when the Terms of Reference are agreed by the parties, and for a period of approximately 3 months at the end of which time it is expected that the RSC/CAE will provide its written opinion and supporting rationale to the Chair of the Management Team seeking this advice.

The RSC/CAE will conduct information gathering sessions with both Ontario Hydro and MSGCS to understand the issues. Any written materials to be provided to the RSC/CAE by either party will also be copied to all parties on the Management Team by the party providing the materials to the RSC/CAE. RSC/CAE will provide a list of all written materials used in arriving at their conclusions in their final report.

Ontario Hydro and MSGCS may wish to provide a written submission to the RSC/CAE outlining their current positions on these issues, supporting rationale and any associated information they feel is relevant. This submission should be provided by **November 30, 1995.**

Once the information is gathered and the submissions from the parties have been received, questions generated by the RSC/CAE should be provided in writing to all parties of the Management Team so they may be given an opportunity to respond to those questions as they deem appropriate.

III. Advice to Other Stakeholders

It is agreed that the Management Team will determine and implement a Communications Plan to provide advice to the affected stakeholders (Appendix I) that a review is being conducted.

IV. Funding for the RSC/CAE Review

It is agreed that the funding for the review will up to a maximum of $40,000 for the RSC/CAE to complete this review unless otherwise agreed in writing by all parties.

The RSC/CAE will invoice the MOEE on a monthly basis; expenses will include professional fees and any other necessary expenses, eg. travel expense.

The MOEE will recover the full cost of the study from Ontario Hydro as the expenses are incurred.

We the undersigned agree to the preceding Terms of Reference.

Mr. Robert H. Haynes
Per: Royal Society of Canada

Ms. Linda Leek
Per: Ontario Hydro

Mr. Angus Bruneau
Per: Canadian Academy of Engineering

Mr. Doug Harrison
Per: Ministry of Solicitor General & Correctional Services

Ms. Deborah E. Farr
Per: Ministry of Environment & Energy

List of Affected Stakeholders

1. Emergency Measures Ontario, MSGCS
2. Ontario Hydro
3. Ministry of Environment & Energy
4. Durham Region
5. Bruce Region
6. Atomic Energy Control Board
7. Atomic Energy Control Limited
8. Metro Toronto

APPENDIX B lIST OF MEETINGS

Location abbreviations:

MOEE	Ministry of Energy and Environment
UofT	University of Toronto
OH	Ontario Hydro
EMO	Emergency Measures Ontario
OCI	Ontario Cancer Institute
AECB	Atomic Energy Control Board

95-Sept-25	MOEE	ATS	D.Farr, N.Jiwan L.C.N.Liik, L.D.Morrow W.D.Harrison
95-Oct-2	U of T	WRB ATS	R.H.Haynes K.G.McNeill
95-Oct-16	OH	WRB ATS	L.C.N.Liik, L.D.Morrow, A.Lew, D.W.Whillans, K.S.Dinnie
95-Oct-20	EMO	WRB ATS	J.L.Ellard, W.D.Harrison, A.A.Pilt
95 Oct 26	OH	WRB LWS ATS	L.D.Morrow, D.W.Whillans, R.J.Fluke, V.M.Raina, -.-.Henry, -.Arora, J.C.Luxat
95-Nov-10	EMO	WRB LWS ATS	J.L.Ellard, W.D.Harrison, A.A.Pilt
95-Nov-28	Montreal	WRB ATS	G.W.Grenier, N.Tremblay
95-Nov-24	Vienna	LWS	T.McKenna
95-Dec-1	OH	WRB LWS	L.D.Morrow and others
95 Dec 5	OCI	WRB LWS ATS	
95-Dec-11	AECB	ATS	J.W.Blyth and others
95-Dec-15	OCI	WRB LWS ATS	K.G.McNeill
96-Jan-19	MOEE	WRB LWS ATS	D.Farr, N.Jiwan
96-Feb-9	OCI	WRB ATS	

96-Feb-23	OCI	WRB ATS	
96-Mar-1	OCI	WRB LWS ATS	
96-Mar-7	OH	WRB ATS	L.D.Morrow, K.S.Dinnie
96-Mar-8	OCI	WRB LWS ATS	
96-Mar-15	OCI	WRB LWS ATS	incl briefly D.Farr and N.Jiwan
96-Mar-27 -28 -29	OCI	WRB LWS ATS	
96-Apr-3 -4	OCI	WRB LWS ATS	
96-Apr-10	OCI	WRB LWS	
96-Apr-17	OCI	WRB LWS	
96-Apr-22	U.S.A.	WRB	R.Hogan, U.S. N.R.C. Washington, D.C.
96-Apr-25	OCI	WRB LWS	
96-Apr-30	OCI	WRB LWS	
96-May-9 -10	OCI	WRB ATS	
96-May-21	OCI	WRB LWS ATS	
96-May-29	OCI	WRB LWS ATS	
96-Jun-4	OCI	WRB LWS ATS	

96-Jun-7	OCI	WRB ATS	
96-Jun-10 -11	OCI	WRB LWS ATS	
96-Jun-14	OCI MOEE	WRB ATS	D.Farr, N.Jiwan
96-Jun-24	OCI	WRB ATS	
96-Jul-5	OCI	WRB LWS ATS	
96-Jul-16	OCI	WRB ATS	
96-Aug-5	OCI	WRB ATS	
96-Sep-4	OCI	WRB ATS	
96-Sep-12	MOEE	ATS	N.Jiwan
96-Oct-9	OCI	WRB LWS ATS	
96-Oct-18	MOEE	WRB LWS ATS	Officers of Ont.Hydro and Sol. Gen. and D.Farr and N.Jiwan
96 Nov-6	MOEE	ATS	D.Farr and J.Young

. . . .
. . . .

Documents Reviewed

1. Abelin T. Thyroid cancer near Chernobyl. In: Hagen U, Jung H, Streffer C, eds. Radiation research 1895-1995: proceedings of the Tenth International Congress of Radiation Research (Würzburg, Germany, 1995). v.1 Congress abstracts. 1995:25.
2. Adams CA, Bonnell JA. Administration of stable iodide as a means of reducing thyroid irradiation resulting from inhalation of radioactive iodine. Health physics, 1962; 7:127-49.
3. Atomic Energy Commission. Calculation of distance factors for power and test reactor sites. Technical Information Document 14844. Wahington, D.C. March 23, 1962.
4. Balter M. Children become the first victims of fallout. Science 1996; 272: 357-360.
5. Baverstock K, Egloff B, Pinchera A, Ruchti C, Williams D. Thyroid cancer after Chernobyl. Nature, 1992; 359:21-2.
6. Bond VP. Medical planning for situations involving large populations. In: Hübner KF, Fry SA, eds. Proceedings of the REAC/TS international conference: the medical basis for radiation accident preparedness (1979, Oak Ridge, Tenn.). New York. Elsevier/North-Holland, 1980:477-9.
7. Canada. Atomic Energy Control Board. Group of Medical Advisors. Guidelines on the use of stable iodine as a prophylactic measure during nuclear emergencies. Ottawa. 1995.
8. Demidchik EP, Demidchik Y. Thyroid cancer promoted by radiation in children of Belarus. In: Hagen U, Jung H, Streffer C, eds. Radiation research 1895-1995: proceedings of the Tenth International Congress of Radiation Research (Würzburg, Germany, 1995). v.1 Congress abstracts. 1995:49.
9. Domann FE, Freitas MA, Gould MN and Clifton KH. Quantifying the frequency of radiogenic thyroid cancer per cell clonogenic cell in vivo. Radiation Research 1994; 137: 330-337.
10. Emergency planning: the effect of new source term data. Prepared by NUS Corporation; principle investigators, R. Sherry, G. Kaiser, M. Cheock. Prepared for Nuclear Safety Analysis Center, Electric Power Research Institute, Palo Alto, Calif., 1986.
11. Fowinkle EW, Sell SH, Wolle RH. Predistribution of potassium iodide - the Tennessee experience. Public health reports, 1983; 98:123-6.
12. Health and Safety Commission (U.K.). ACSNI Study Group on Human Factors. Third report: Organising for safety. London. HMSO, 1993.
13. International Atomic Energy Agency. Emergency planning and preparedness for accidents involving radioactive materials used in medicine, industry, research and teaching. Vienna. IAEA, 1989.
14. International Atomic Energy Agency. Intervention criteria in a nuclear or radiation emergency. Safety Series No. 109. Vienna. IAEA, 1994.
15. International Commission on Radiation Protection. Radiation Protection. ICRP publication 60. Pergamon Press, Oxford, 1990.

16. International Commission on Radiological Protection. Committee 4. Principles for intervention for protection of the public in a radiological emergency. Oxford. Pergamon Press, 1993.
17. Jones JA, Mansfield PA, Crick MJ. Uncertainty analysis of the predicted consequences of nuclear accidents using the NRPB code MARC-2A. London. HMSO Publications Centre, 1995.
18. Kerber RA, Till JE, Simon SL, Lyon JL, Thomas DC, Preston-Martin S, Rallison ML, Lloyd RD, Stevens W. A cohort study of thyroid disease in relation to fallout from nuclear weapons testing. JAMA, 1993; 270:2076-82.
19. Kovari M. Effect of time delay on effectiveness of stable iodine prophylaxis after intake of radioiodine. Journal of radiological protection, 1994; 14:131-6.
20. Kovari MD, Morrey ME. The effectiveness of iodine prophylaxis when delayed: implications for emergency planning. Journal of radiological protection, 1994; 14:345-8.
21. Mangano JJ. A post-Chernobyl rise in thyroid cancer in Connecticut, U.S.A. European journal of cancer prevention, 1996; 5:75-81.
22. McKenna TJ and Giiter JG. Accidental consequence projection. In CRC Handbook of Management of Radiation Protection Programs. ed. K.L. Miller. CRC Press, Ann Arbor, U.S.A., 1992.
23. Meneley DA, Rogers JT, Blahnik C, Snell VG, Nijhawan S. Coolability of severely degraded CANDU cores. Mississauga, Ont. AECL, 1995.
24. Mettler FA, Royal HD, Hurley JR, Khafagi F, Sheppard MC, Beral V, Reeves G, Saenger EL, Yokoyama N, Parshin V, Griaznova EA, Taranenko M, Chesin V, Cheban A. Administration of stable iodine to the population around the Chernobyl nuclear power plant. Journal of radiological protection, 1992; 12:159-65.
25. Miller KL, ed. CRC handbook of management of radiation protection programs. 2nd ed. Boca Raton, Fla. CRC Press, 1992.
26. Mosey, D. Reactor accidents: nuclear safety and the role of institutional failure. Guildford, Surrey, England. Nuclear Engineering International Special Publications in conjunction with Butterworths, 1990.
27. National Cancer Institute of Canada. Canadian cancer statistics 1994. Toronto, Canada, 1994.
28. National Council on Radiation and Measurements. Krypton-85 in the atmosphere - Accumulation, biological significance, and control technology. NCRP Report No. 44. NCRPM Washington, 1975
29. National Council on Radiation Protection and Measurements. Krypton-85 in the atmosphere-with specific reference to public health significance of the proposed controlled release at Three Mile Island. NCRPM, Washington, May 16, 1980.
30. National Research Council (U.S.). Beir V report: the harmful effects of low level radiation. Washington, D.C. National Academy Press, 1990.
31. Nuclear Regulatory Commission. An analysis of potassium iodide (KI) prophylaxis for the general public in the event of a nuclear accident. Washington, D.C. Division of Systems Technology, NUREG/CR-6310, Office of Nuclear Regulatory Research, 1995.

32. Nuclear Regulatory Commission. Reactor risk reference document, App. J-O, v.3, Draft for comment. NUREG-1150, 1987.
33. Ontario Hydro. Emergency Preparedness Section, Nuclear Safety Directorate. Emergency off-site radiological monitoring stategy for airborne releases of radioactive material. App. B. OHNEP-21, December, 1993.
34. Ontario Hydro. Emergency Preparedness Section. Nuclear emergency preparedness in Ontario Hydro: Ontario Hydro's rebuttal to plaintiff expert testimony. 1 July, 1993.
35. Ontario Hydro. Ontario Hydro's submission to the review by the Royal Society of Canada and the Canadian Academy of Engineering of outstanding Questions relating to the proposed provincial Nuclear Emergency Plan. 1996.
36. Ontario Hydro. Pickering NGS-A Risk Assessment (PARA) November, 1995
37. Ontario Hydro. The Darlington Probablistic Safety Evaluation. Chapters 12, 14. December 1987.
38. Ontario Nuclear Safety Review. The safety of Ontario's nuclear power reactors: a scientific and technical review. v.1 Report to the Minister, Technical Report, and Annexes. Toronto. Ontario Nuclear Safety Review, 1988.
39. Ontario Nuclear Safety Review. The safety of Ontario's nuclear power reactors: a scientific and technical review. Selected consultants' reports. Toronto. Ontario Nuclear Safety Review, 1988
40. Ontario Nuclear Safety Review. The safety of Ontario's nuclear power reactors: a scientific and technical review. v.2 Appendices. Toronto. Ontario Nuclear Safety Review, 1988.
41. Ontario Nuclear Safety Review. The safety of Ontario's nuclear power reactors: a scientific and technical review. Ontario Hydro submission to the Ontario Nuclear Safety Review. Toronto. Ontario Nuclear Safety Review, 1988.
42. Ontario Nuclear Safety Review. The safety of Ontario's nuclear power reactors: a scientific and technical review. A submission to the Ontario Nuclear Safety Review by Atomic Energy of Canada Limited. Toronto. Ontario Nuclear Safety Review, 1988.
43. Ontario Nuclear Safety Review. The safety of Ontario's nuclear power reactors: a scientific and technical review. Minister's report. F. Kenneth Hare, commissioner. Toronto. Ontario Nuclear Safety Review, 1988.
44. Ontario Nuclear Safety Review. The safety of Ontario's nuclear power reactors: a scientific and technical review. Minister's report. F. Kenneth Hare, commissioner. Toronto. Ontario Nuclear Safety Review, 1988.
45. Paquette J, Wren DJ, Ford BL. Iodine chemistry. In: Toth LM; et al., eds. The Three Mile Island accident: diagnosis and prognosis. Washington, D.C. American Chemical Society, 1986:194-210.
46. Province of Ontario Nuclear Emergency Plan. Pt.1 Provincial master plan. Toronto. Emergency Planning Ontario, 1986.
47. Provincial Nuclear Emergency Plan. Provincial Operations Centre. Technical Group Procedures. Third draft, January, 1995.

48. Provincial Working Group #8. Report. The upper limit for detailed nuclear emergency planning. June 30, 1988.
49. Ramsden D, Passant FH, Peabody CO, Speight RG. Radioiodine uptakes in the thyroid: studies of the blocking and subsequent recovery of the gland following the administration of stable iodine. Health physics, 1967; 13:633-46.
50. Rasmussen NC. A review of the Reactor Safety Study. In The Medical Basis for Radiation Accident Preparedness. K.F. Hubner and S.A. Fry eds. Elsevier North Holland Inc. 1980.
51. Ron E, Lubin JH, Shore RE, Mabuchi K, Modan B, Pottern LM, Schneider AB, Tucker MA, Boice JD Jr. Thyroid cancer after exposure to external radiation: a pooled analysis of seven studies. Radiation research, 1995; 141:259-77.
52. Rubery E, Smales E, eds. Iodine prophylaxis following nuclear accidents: proceedings of a joint WHO/CEC workshop (July, 1988). New York. Pergamon Press, 1990.
53. Shore RE, Hildreth N, Dvoretsky P, Pasternack B, Andresen E. Benign thyroid adenomas among persons X-irradiated in infancy for enlarged thymus glands. Radiation research, 1993; 134:217-23.
54. Shore RE. Issues and epidemiological evidence regarding radiation-induced thyroid cancer. Radiation research, 1992; 131:98-111.
55. Sternthal E, Lipworth L, Stanley B, Abreau C, Fang S-L, Braverman LE. Suppression of thyroid radioiodine uptake by various doses of stable iodine. New England journal of medicine, 1980; 303:1083-8.
56. Stsjazhko VA, Tsyb AF, Tronko ND, Souchkevitch G, Baverstock KF. Childhood thyroid cancer since accident at Chernobyl. BMJ, 1995; 310:801.
57. Tengs TO, Adams ME, Pliskin JS, Safran DG, Siegel JE, Weinstein MC, Graham JD. Five hundred life-saving interventions and their cost-effectiveness. Risk analysis, 1995; 15:369-90.
58. Von Hippel F. Potassium iodide for thyroid protection. Science, 1982; 218:1174, 1177.
59. Wald N. The Three Mile Island incident in 1979: the state response. In The Medical Basis for Radiation Accident Preparedness. K.F. Hubner and S.A. Fry eds. Elsevier North Holland Inc. 1980.
60. Williams D, Pinchera A, Karaoglou A, Chadwick KH, eds. Thyroid cancer in children living near Chernobyl: expert panel report on the consequences of the Chernobyl accident. Brussels. Commission of the European Communities. Directorate-General science, Research and Development, 1993.
61. Williams ED. Mechanisms and pathogenesis of thyroid cancer in animals and man. Mutation Research 1995; 333: 123-129.
62. World Health Organization. Regional Office for Europe. Guidelines for iodine prophylaxis. WHO, 1989.
63. World Health Organization. Regional Office for Europe. Nuclear power: accidental releases - practical guidance for public health action: report of a WHO meeting (Mol, Belgium, 1-4 October, 1985). Copenhagen. WHO Regional Office for Europe, 1987.
64. Wren JC, Ball JM and Chuaqui CA. The chemistry of iodine in containment. Candu Owners Group Program WP#4 pp57 Private. 1994

65. Yalow RS. Potassium iodide distribution. Science, 1982; 217:295.
66. Yalow RS. Potassium iodide: effectiveness after nuclear accidents. Science, 1982; 218:742.
67. Yalow RS. Risks in mass distribution of potassium iodide. Bulletin of the New York Academy of Medicine, 1983; 59:1020-7.
68. Young JP, Yalow RS, eds. Radiation and public perception: benefits and risks. Washington, D.C. American Chemical Society, 1995.
69. Zanzonico PB, Becker DV. Use of potassium iodide to minimize thyroid radiation from radioactive fall-out. In: Delange F, Dunn JT, Glinoer D, eds. Iodine deficiency in Europe: a continuing concern. New York. Plenum Press, 1993.

W. ROBERT BRUCE

Dr. W. Robert Bruce was born in 1929 in Hamhung, Korea. He obtained his B.Sc. in Chemistry from the University of Alberta in 1950 and Ph.D. in Physics from the University of Saskatchewan in 1956. He then obtained an MD from the University of Chicago in 1958 and a year later obtained the L.M.C.C. He was elected Fellow of the Royal College of Physicians and Surgeons in 1978.

Dr. Bruce joined the Ontario Cancer Institute in 1959 and became a member of the senior scientific staff. He has been a Professor of the Department of Medical Biophysics of the University of Toronto since 1965, a Professor of Nutritional Sciences since 1985. He was the Director of the Toronto Branch of the Ludwig Institute for Cancer Research at the Ontario Cancer Institute from 1980 to 1988. Through this period he has coached dozens of students and post-doctoral Fellows and, together with them, has published research in nearly 200 scientific articles and books. He is currently Associated Editor of the journals, *Cancer Epidemiology, Biomarkers and Prevention* and *European Journal of Cancer Prevention*.

In 1980 Dr. Bruce was elected Fellow of the Royal Society of Canada. He has also been honoured by medals and prizes from many research societies, from the Damashek Award of the American Society of Hematology in 1968 to the O. Harold Warwick Award of the National Cancer Institute of Canada in 1995.

Dr. Bruce's medical research interests began with his studies of cancer treatment, studies of radiation physics and radiobiology related to radiation therapy, and cell biology related to cancer chemotherapy. His interest then turned to the effect of environmental factors on the origin of cancer and to the possibilities for cancer prevention. He developed methods for examining the effects of toxic chemicals on reproduction. He pioneered computer studies of patient records that led to the development of the Cancer Registry in Ontario which is now being widely used in studies of the effect of work environment, lifestyle and genetic factors on cancer development in the Province. Beginning in 1975 his studies have focused primarily on the origin of breast and colon cancer, especially on the effect of diet on the development of these diseases in animal studies and in clinical trials. These studies presently suggest that specific processes in the preparation of our food lead to the markedly elevated rates of these cancers in our population.

Robert Bruce and Margaret MacFarlane married in 1957; they have one daughter and two sons. His chief recreation is raising the family vegetables through the winter hydroponically and swimming.

LESLIE W. SHEMILT

L.W. Shemilt received a B.A.Sc. (Hon.) in Chemical Engineering and a Ph.D. in Physical Chemistry at the University of Toronto, and an M.Sc. in Chemistry at the University of Manitoba. As well as several years in industry with Defence Industries Ltd. he has held professorships at the University of British Columbia, at the University of New Brunswick where he founded the Department of Chemical Engineering, and at McMaster University where he served for ten years as Dean of Engineering, in 1987 becoming a Professor Emeritus. He has also been visiting professor at universities in Switzerland, England, India, Australia, and Japan, and was an external examiner at the University of the West Indies. Dr. Shemilt is married and he and his wife, Elizabeth (MacKenzie) have one son in medical practice in North Bay, one daughter residing near Kingston, and four grandchildren.

Dr. Shemilt was the founding chairman of the New Brunswick Research and Productivity Council, served as Science Advisor to the Province of New Brunswick, and on the National Research Council of Canada. He was the President of the Chemical Institute of Canada in 1970-71 and the Vice-President of the Academy of Science of the Royal Society in 1991-92. He has received the Fellowships of several professional societies, most notably the Royal Society of Canada in 1985, and the Canadian Academy of Engineering in 1987 (as a Founding Fellow). Since 1979 he has been Chairman of the Technical Advisory Committee to Atomic Energy of Canada Limited on the Nuclear Fuel Waste Management Program, has twice led reviews of the Swedish program on nuclear waste disposal, and is currently involved in major international consultative efforts relating to the same field. He has served as consultant to several Canadian industries and government departments.

Dr. Shemilt's fields of research have been primarily in applied thermodynamics, mass transfer and electrochemical and corrosion engineering in which he has supervised 50 masters and doctoral theses, published over 80 papers and a number of contributed chapters to reference works and edited a number of scientific volumes. For 18 years he was editor of the Canadian Journal of Chemical Engineering and is now Honorary Editor.

Dr. Shemilt has received numerous awards and medals both national and international, and has been the recipient of three honorary doctorates. In 1991 he was appointed an Officer of the Order of Canada.

ALEC THOMPSON STEWART

Alec Stewart was born on a farm in Saskatchewan in 1925. The family - parents and two small boys - moved to Nova Scotia in the depression where he attended public schools and Dalhousie University, (B.Sc.'46). Originally planning to study chemical engineering, in the third year of that course at University of Toronto, he changed to physics and returned to Dalhousie for a M.Sc. in 1949. A scholarship took him to Cambridge where he did a Ph.D. in nuclear physics, leaving in 1952 for a position at the Atomic Energy of Canada in Chalk River. There he had the opportunity of collaborating in the first neutron scattering experiments designed to observe the motions of atoms in crystals. (This new field was explored and developed by B.N. Brockhouse for which he received the Nobel Prize in 1994.) Leaving Chalk River after five years, he taught at Dalhousie University, at the University of North Carolina in Chapel Hill, and at Queen's University. In most of his research he pioneered a new field, using positron annihilation as a probe of electron behaviour in solids and liquids and has contributed over 100 scientific articles in professional journals and books. Many students, post doctoral fellows and visiting scientists have worked in this subject in his laboratory. Dr. Stewart has been a visiting professor and lecturer in institutes and universities in India, China, Japan, a number of European countries as well as in the U.S.A. and Canada. Some honors include election to the Royal Society of Canada (1970), Canada 125 Medal, an honorary degree, Ll.D (Dal) in 1986, and the Canadian Association of Physicists Medal for Achievement in Physics in 1992.

Dr. Stewart has held administrative positions at Queen's University and in professional societies: President of the Canadian Association of Physicists and President of the Academy of Science of the Royal Society of Canada. He has served on very many review committees for various universities and especially for the research granting agencies of the National Research Council and the Natural Sciences and Engineering Research Council of Canada.

Alec Stewart and Alta Kennedy married in 1960; they have three sons. His chief recreation is yacht racing and cruising.