PROVINCE OF ONTARIO

NUCLEAR EMERGENCY PLAN

REPORT

OF

PROVINCIAL WORKING GROUP #3

April, 1984

REPORT

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EXECUTIVE SUMMARY

The Working Group was established by the Province of Ontario to make recommendations on certain technical bases of the Provincial Nuclear Emergency Plan.

Composition

Chairman: Dr. K.G. McNeill University of Toronto

Members:

Dr. J.H. Aitken	Ministry of Labour
Dr. M. Finkelstein	Ministry of Labour
Mr. F.B. Ali	Ministry of Solicitor General
Dr. I. Ramsay	Ontario Hydro
Mr. R.E. Utting	Atomic Energy Control Board
Dr. D. Myers	Atomic Energy of Canada Ltd
Dr. V. Snell	Atomic Energy of Canada Ltd
Dr. W. Paul	University of Toronto

Summary of Recommendations

1. An effective dose of 25 rem (250 mSv) at the nuclear power plant boundary should be the hazard defining the upper limit for detailed emergency planning in Ontario.

2. The following should be the Protective Action Levels:

Measure	Lower Level	Upper Level
Sheltering	0.1 rem (1 mSv)	1 rem (10 mSv)
Evacuation	1 rem (10 mSv)	10 rem (100 mSv)
Banning Food/ Water	0.05 rem (0.5 mSv)	0.5 rem (5 mSv)

The above effective dose levels should be multiplied by a factor of 3 to obtain thyroid dose PALs.

3. The sizes of Planning Zones should be:

   Contiguous Zone - a radius of 3 km
   Primary Zone - a radius of 10 km
   Secondary Zone - a radius of 50 km

   Distances should be taken from the reactor building(s).

4. Some typical accident sequences are described so as to provide guidance on planning times.

5. Evacuees may be permitted to return if the additional effective dose incurred thereby is under 0.5 rem (5 mSv). Return should not be allowed so long as the total projected dose after return exceeds 10 rem (100 mSv).

6. A system of emergency worker safety is recommended, including guidelines for assigning safety status to response sectors and the precautions to be observed for each status.

7. The Province should further examine the need for Immediate Protective Action on a station-by-station basis.

8. No recommendation is made on off-site alerting as this requirement was withdrawn by the Province.

REPORT

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Introduction

This Working Group was set up by the Ministry of the Solicitor General, Province of Ontario, on March 14, 1983, to examine and make recommendations upon certain technical bases of the draft Provincial Nuclear Emergency Plan. The memorandum establishing the Group is appended as Annex A. The composition of the Working Group is given at Annex B. The terms of reference assigned to the Group, as amended, are given at Annex C. The members served on the Group in their individual capacities, and not as representatives of their organizations.

The terms of reference assigned to the Group require it to examine the following issues:

(a) The extent to which detailed nuclear emergency planning and preparedness is justified

(b) Protective Action Levels

(c) Planning Zones

(d) Planning Times

(e) Guidelines for return of evacuees

(f) Emergency worker safety

(g) Immediate Protective Action

(h) Off-site alerting

The Working Group held the following meetings:

First meeting	-	June 2, 1983
Second meeting	-	June 29, 1983
Sub-committee meeting	-	July 21, 1983
Third meeting	-	August 11, 1983

In addition to the meetings, a considerable amount of discussion was held between the members through correspondence.

General Considerations

The responsibility of Working Group #3 has been primarily to make recommendations on the extent to which planning should be carried out, in any detail, in preparation for an accident in a nuclear generating station as a result of which radioactive material in excess of normal amounts is emitted from the station. The group has not exceeded its brief. It has not attempted to define the worst possible accident since, for planning purposes, only a certain severity of accident need be postulated, worse accidents appearing to be so much more unlikely that it would be uneconomical to plan in detail for them. It has not attempted to calculate accident probabilities for itself, but has received and considered the work of others.

These considerations of severity and probability have occupied a lot of the time of the Group, but the Group has always realized that no one can put hard numbers on probabilities of accidents with severe radiological consequences, and that "risk estimates" are just that: estimates. They are supported by observations of accidents of higher frequency and their consequences, by observed equipment failures which do not lead to accidents, and by detailed analytical modelling of the consequences of accidents, in many cases supported by experiment. However, it remains true that the combination of events which gives rise to an extremely serious accident has never been observed together, so that in that sense there is no direct check of the risk estimates.

The reason for this is a very good one: there have been no accidents with such consequences involving a generating station anywhere in the world. The risk associated with traffic accidents is, to our cost, well known; the risk of aircraft accidents (much less probable but usually resulting in more fatalities per accident) is also known, again because many of these have taken place. With respect to nuclear generating stations, there are statistics on the probabilities of minor accidents which do not result in excessive emission of radiation, but none on accidents with radiologically severe consequences. (At Three Mile Island the greatest amount of extra radiation that a member of the public could have received was less than that received each year by a Toronto resident due to natural causes).

We had available Design Bases(that is, requirements by the Atomic Energy Control Board of Canada (AECB) that generating stations have to be designed so as to ensure that accidents of given severity occur with lower than a stated probability), many papers by Atomic Energy of Canada Ltd (AECL) and Ontario Hydro, many papers from the USA and other countries, and the actual performance data of the Candu reactors*.

When considering limits to detailed planning, the Group was aware that the Province does not have detailed plans for emergencies (in <u>any</u> field) expected to have probabilities less than once in a hundred years or so (10^{-2} per year), whereas for what are unfortunately daily occurrences, such as fires or traffic accidents, emergency services are on continuous call. Because of the public concern about this relatively new industry and its associated safety aspects, however, we have felt it sensible to recommend planning for nuclear contingencies that appear on the usual time scale to be very improbable. Even at this low level of probability, it was questioned in the Group whether emergency planning, as it is usually understood, was at all necessary: emergency planning has, in the past, usually been taken to mean planning to cope with a situation where human life is in imminent danger, and all the information presented to the Group indicated that such a situation would not be expected to arise as a result of an accident at a nuclear generating station with a probability of more than once in 1,000,000 years. At the low dose levels that may result from accidents with a higher probability there could, however, be delayed nuclear radiation effects, and the Group has taken the position that the concept of emergency planning in this case should cover not only immediate danger but also potential latent hazard.

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* Candu is the acronym for Canada Deuterium Uranium. It is the name of the reactor type in use in Canada (and several other countries), which uses natural uranium fuel and a heavy water moderator.

Another issue that arises in such a discussion is whether emergency planning is at all justified when an operation is under regulatory control. Governmental regulation of an industry may be thought of as being based on the principle of establishing a fair relation between the benefits of the industry to society and the costs to society associated with the functioning of the industry (in terms of human lives, health and enjoyment of life). In addition to considering society as a whole, at least two sub-sets should, however, be considered separately: the workers in the industry, and the neighbours of the industrial plant.

The workers may be regarded as obtaining economic benefit from the industry, which can be set off against risks associated with it; but in addition society, through, for example, the Workmen's Compensation Board and through health care costs, attempts to recompense individuals who suffer a disproportionately large share of the total detriment. Similarly, the neighbourhood around a foundry, a coal burning plant, a chemical plant, or a railway or highway may suffer a disproportionate share of the total detriment that society suffers, but in this case without any balancing increase in benefit.

Society adopts other ways of trying to preserve a balance between individuals: in the Mississauga and Medonte train accidents, people were evacuated at (indirect) cost to society rather than leaving them to suffer physical damage and have society pay later in health costs. A further stage along this route is to put in place, where appropriate, an organization to prevent physical detriment in case of accident. Emergency Planning for nuclear generating station accidents would be such a "pay now, save later" programme.

The people around a nuclear station are more at risk from this particular source of potential hazard than are those far from the station, and yet they benefit no more than any other member of the community from the electricity produced by the plant. Regulatory bodies try to ensure that the benefit of the industry to the whole community greatly outweighs the total cost, but society can properly pay for planning and preparation which will ensure (as far as is humanly possible) that the actual physical detriment to people in the neighbourhood is not greatly out-of-balance with that to the rest of the community. Thus, Emergency Planning goes beyond regulatory process; it deals, not indeed with the individual, but with the individual neighbourhood, to mitigate any deleterious consequences of living near a nuclear plant. (Such a concept is equally applicable to neighbourhoods which are at risk from other natural and man-made hazards).

The answer to the question of whether such planning ought to be done in case of a particular type of hazard is very subjective; one notes that in the recent past no one in Ontario has died of rabies, but rabies is a very emotive issue, as shown by its periodic prominence in the news media, and great precautions are taken against a human fatality. Similarly, nuclear power is an emotive issue to many citizens, and Emergency Planning might be carried on at a level which could not be justified on cost-effectiveness grounds; that is, planning would be done for accidents which, by the usual standard of planning, are so unlikely that normally society would not plan for them at all. In areas of high public sensitivity, decisions on the level of emergency planning (and preparedness) will have to take into account both perceived risk as well as actual risk. Nuclear emergency planning is such an area.

In its discussions the Group has accepted a 'linear hypothesis' with respect to potential delayed effects of radiation: that is, small doses may create correspondingly small, but still finite, risks of latent effects. On this linear hypothesis, any dose creates some risk; ICRP puts this risk at 10^{-4} fatal cancers per rem (or per 10 mSv) as an average for both sexes and for all ages (1). This value is in reasonable agreement with those suggested by other scientific committees (2,3). A judgement may, however, be then required on the question of whether the saving in risk produced by some action which reduces radiation exposure may produce some other detriment which is more expensive in terms of human life or life quality - for instance, an informed person may not wish to give up a day's wages in order to save a few millirem (as an example, all Atomic Radiation Workers, of whom there are over 80,000 in Canada, do, in fact, make such decisions). The Group takes these ideas into consideration when making its recommendations with respect to Protective Action Levels.

The Upper Limit for Planning

The Atomic Energy Control Board (AECB) requires that the design of power reactors be such that, as a result of accident, not more than once in 3 years should a person exposed at the plant boundary (1 km) receive more than

0.5 rem (5 mSv) whole body dose equivalent*, and not more than once in 3000 years should such a person receive more than 25 rem (250 mSv). The corresponding maximum doses to the thyroid set by the AECB are 3 rem (30 mSv) and 250 rem (2.5 Sv)(4). (We are aware that AECB is currently reviewing its safety requirements (5a,b). However, this review does not affect the considerations upon which this report is based).

Evidence on the correctness of design to meet or better these Design Bases can only come with time. Currently there is the order of 100 reactor years of experience with Candu reactors in Canada. The average frequency of unsafe failure of reactor control systems has been one per 10 reactor years of operation. Of these failures of control systems which resulted in increase of reactor power, 6 occurred in the early years of the Pickering station. In each case shutdown systems ended the power increase and there was no damage to reactor fuel and no emission to the public (6). There has been one serious break in the coolant system (in the summer of 1983), but once again with no emission of fission products or fissile material to the public; in this case there was no "loss of cooling", as the coolant from the broken system was returned into the system. What evidence there is (and it is good that it is so slight) suggests that in practice Candu reactors are working better than the Design Basis requires, by perhaps a factor of 10 to 100. The US experience, based on the order of 1000 reactor years, is that there has never been an accident in a power reactor in which an individual off-site has received as much as 0.5 rem (5 mSv); Three Mile Island

500 mrem

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* Throughout the rest of this report "dose" is used also for "dose equivalent", and "dose equivalent" implies "committed effective dose equivalent" unless specified otherwise. For the most part, the highest absorbed doses considered in this report are within the range for which the quality factors used in radiation protection work still apply. Thus it is reasonable to use the concept of dose equivalent in most places.

100 mrem

gave a maximum of 0.1 rem (1 mSv). The UK and French experience with nuclear generating stations is even better than the US safety record. On the experimental evidence it would appear that, for the present, it is reasonable to consider that the nuclear power stations in Ontario have been designed better than required by the first Design Basis; it is not unreasonable to assume that this conservatism in design also affects the long term performance, and that the probability of an accident giving 25 rem (250 mSv) at the boundary is less than 1 in 3000 reactor years.

In the previous sentence the phrase "for the present" appeared. This is put in because effects of aging in the power generating reactor environment have not been tested, and although there is more experience with the reactors at Chalk River, and we understand that no known problems have arisen which have not been coped with in the design of power reactors, it would be perhaps over-optimistic to extrapolate for many years into the future. This simply means that the Government of Ontario will have to watch the situation closely, and if it appears necessary, modify its plans accordingly. But for the present, as stated, the performance appears to be much better than the Design Basis requires.

No comprehensive calculations have been carried out for Candu reactors of the type done in the USA by Rasmussen and his colleagues for the Reactor Safety Study (7). A Probabilistic Risk Assessment study is being carried out for the Darlington nuclear power station, but this will not be ready until 1986. Multiple failures in Candu reactors have been analysed to a limited degree using fault tree/event sequence calculations. These sequences of events have been followed to the point that either the plant is stable, or the probability of the initiating event times that of the subsequent event sequences falls to less than 10^{-7} per reactor year.

Very large releases of fission products will not take place except in the case of a significant fraction of the core melting. Calculations based on different possible failures (of more than one system) in the Candu reactor suggest that radiation doses at the boundary would be limited to 25 rem (250 mSv) or under so long as an engineered heat sink were available. There are no published calculations on Candus which give the probability of loss of the engineered heat sink (i.e. the moderator, the primary coolant and the emergency coolant). However, an official of Atomic Energy of Canada Ltd (AECL) has stated: "We do , however, in the design process, examine multi-event sequences, as noted above. We have found that sequences which might give 25 rem or more at the fence post, would require a sequence of operator and equipment failures, and weather conditions, any one of which would avoid or reduce the result. The likelihood of such sequences must be of the order 10^{-6} events per year or less" (8).

Such calculations, in a more comprehensive fashion, have been carried out for Light Water Reactors in the USA and other countries, e.g. in the USA Reactor Safety Study (7). These studies project accident scenarios in the above-mentioned frequency range with vastly more severe consequences. For example, one study based on the Reactor Safety Study postulated a group of accidents in the Pressurized Water Reactor with a mean frequency of 1.4×10^{-5} per reactor year which could produce, one mile away, individual whole body doses ranging from 1000 to 10,000 rems (10 to 100 Sv), depending on weather conditions (9). We also note that many of the conclusions of the Reactor Safety Study have been challenged.

We are inclined to accept the expert advice given to us that the results of such studies cannot be directly applied to Candu reactors, because of the many differences in design, and especially because of the availability of the moderator as an additional heat sink. These differences would materially affect the probabilities of various effects.

Based on the limited Candu reactor experience, the results of the Candu design safety studies, and the best available technical advice, we conclude that the probability of various levels of dose being produced as a result of Candu reactor accidents may be taken as shown in the graph at Annex D.

We recognize that this is an estimate based on technical judgement, and that it is fallible, being especially vulnerable to the unquantifiable element of human error. However, it is probably the best that can be done at present (and perhaps in the next few years), and has the virtue that, at least in the higher probability range, it is known by experience to be conservative.

In its decision to recommend 25 rem (250 mSv) as the upper limit for detailed emergency planning, we have been naturally much influenced by the shape of this graph. If one takes the graph at its face value, and uses normal criteria for emergency planning (hazard of around 10^{-2} per year frequency), then a dose of somewhat more than 10 rem (100 mSv) would be used as the maximum boundary dose for planning purposes (remembering that major nuclear generating stations such as Pickering and Bruce contain about 10 reactors each).

Against this can be set two mutually opposing ideas: that the public apprehension is such that planning should be for higher possible values (in concern that the design does not in fact meet the Design Basis)*; and that experience has shown that Candu reactor systems are operating better than required by the Design Basis.

The improbability of doses greater than 25 rem (250 mSv) without loss of the engineered heat sink implies that there is a considerable range of probability over which the dose will not exceed 25 rem (250 mSv). This gives a cushion to take up any error in the calculations. Even if the estimates of production of doses greater than 25 rem (250 mSv) are wrong by a factor of 100, so that they lie in the 10^{-3} per year range rather than 10^{-5} per year for a nuclear station with 10 reactors, this will still be short of normal emergency planning limits (10^{-2} per year); and indeed all the experience so far points to the actual probabilities being 10 to 100 times lower than the graph shows, rather than 100 times higher. Moreover, the fact that the Group has recommended that evacuation take place at less than 25 rem (250 mSv) (the PALs are 1 rem (10 mSv) and 10 rem (100 mSv) for lower and upper limits) means that detailed planning will be in existence to cope with the most likely protective action in case of more serious accidents.

For these reasons <u>we recommend</u> 25 rem (250 mSv) effective dose at the plant boundary as the upper limit for current detailed planning, recognizing that experience in the future may cause this to be modified either way.

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* A study in the USA found that the public expects nuclear power stations to be 10,000 times safer than, say, coal-fired stations (10).

Such detailed planning will include plans for evacuation of the population out to about 10 km. The Group notes that in the case of an accident of very much greater severity, of say 1000 rad (10 Gy) at the boundary, prompt evacuation of the population in this 10 km area will greatly reduce radiation effects and prevent any early deaths from radiation; and that in the case of such a 1000 rad (10 Gy) accident additional action would need to be taken outside the area, but that this could be taken reasonably effectively by the existing emergency organization by extending the pre-planned measures to areas outside the 10 km zone. We therefore feel that, using this upper planning limit, the Province will "be able to deal effectively with a broad spectrum of possible accidents extending from the minor to the major".

Protective Action Levels

After examining this subject we came to the conclusion that Protective Action Levels (PALs), as defined in the Provincial Nuclear Emergency Plan, were only required for the following protective measures*:

In Plume Exposure Control - Sheltering and Evacuation

In Ingestion Control - Banning consumption of a commodity

We accepted as valid the Plan concept of an upper and lower level for each PAL, which signify:

Lower Level. Below this there would normally be no justification for taking the action.

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* As another Provincial Working Group has been considering thyroid blocking by stable iodine compounds, we have not considered this measure.

Upper Level. At or above this the action should be taken unless special prevailing circumstances dictate otherwise.

Middle Range. Between the Lower and Upper Levels the advisability of taking the action should be considered, the decision being made on the basis of an assessment of benefit against detriment and risk.

The PALs for Sheltering and Evacuation recommended by the Group are in terms of Projected Dose as defined in the Provincial Plan, i.e., the total dose and dose commitment from all applicable exposure modes to the critical group in the population being considered.

We also considered the question of specifying separate PALs in terms of projected dose for single organs in addition to PALs expressed as effective dose. The philosophy of the ICRP (1) involving "effective dose" produces a factor for the weighting of dose to single parts of the body. Following this idea, one could have a "single organ PAL" which was so many times that for the whole body. In the situation that only the single organ was being irradiated (an unlikely event) the single organ PAL would be exceeded at exactly the same time as the effective dose PAL. A separate PAL is therefore not required. However, an exception needs to be made in the case of the thyroid. The ICRP weighting factors are based on fatal cancers and genetic disorders, and only 5% of thyroid cancers are fatal; the other 95%, which give rise to morbidity, should be taken into account in some way. We are of the view that non-fatal cancers of the thyroid should be given an appreciable weighting in the context of PALs*.

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* For other organs, these arguments do not apply. For most organs the proportion of lethal cancers is much higher and the ICRP weighting factors apply; for the skin non-fatal cancers are common, but these cancers are easily diagnosed and treated.

ICRP has suggested a risk of 0.05×10^{-4} fatal thyroid cancers per rem (10 mSv) received by the thyroid (1). However, only about 5% of radiation-induced thyroid cancers are fatal and the total risk is probably about 1×10^{-4} thyroid cancers per rem (10 mSv) received by the thyroid (2). The total number of fatal cancers, curable cancers and genetic disorders that might be induced by exposure of the whole body to radiation is roughly 3 times the total number of thyroid cancers that might be induced by exposure of the thyroid alone. It was decided to adopt this factor of 3 for deriving the thyroid PAL from the effective PAL.

In considering this subject, we also examined what PALs are in use in various jurisdictions. These are summarized in the table at Annex E.

We considered the question of having season- and site-specific PALs. In view of the system adopted in the Provincial Plan for use of PALs in the decision-making process, which allows local and current circumstances to be taken into account, the Group did not think there was need for recommending season- and site-specific PALs.

The values recommended for different PALs, and some of the considerations upon which they are based, are given below.

<u>PALs for Sheltering</u>

<u>We recommend</u> the following:

		Effective Dose	Thyroid Dose
Lower PAL	-	0.1 rem (1 mSv)	0.3 rem (3 mSv)
Upper PAL	-	1 rem (10 mSv)	3 rem (30 mSv)

The group noted that, with sheltering, at the upper PAL the dose to an individual would be reduced to 0.5 rem, (5 mSv) ("the annual limit for members of the public" recommended by ICRP (1)), assuming a mean dose reduction factor of 0.5. With respect to the lower limit, we felt that the Province could not strongly urge on the public an action which could cause serious economic loss to many at a radiation dose level which would (at less than 0.1 rem (1 mSv)) be less than 2% of that which a radiation worker could legally receive each year (11); and noted that, across the province, variations in the natural background rates were greater than 0.1 rem (1 mSv) per year.

PALs for Evacuation

We recommend the following:

	Effective Dose	Thyroid Dose
Lower PAL -	1 rem (10 mSv)	3 rem (30 mSv)
Upper PAL -	10 rem (100 mSv)	30 rem (300 mSv)

Lower Level

A height difference of 300 ft., roughly that between Lake Erie and Lake Ontario, produces a difference in background (due to cosmic radiation) of about 2 mrem/yr (0.02 mSv/yr), or about 150 mrem (1.5 mSv) lifetime. Within the city of Toronto background rates vary from 60 to 200 mrem/yr (0.6 to 2 mSv/yr). Similar variations in background radiation occur in different localities across the province of Ontario. Thus, living in one part of the province rather than another, or in one part of Toronto rather than another, can produce over a lifetime variations in received dose of around 10 rem (100 mSv). Average exposures to radon daughters from natural sources also appear to vary appreciably from one place in Ontario to another, from the equivalent of about 50 to 150 mrem (0.5-1.5 mSv) or more of whole body radiation per year.

In view of these variations in natural background, to which the population pays little or no attention when it comes to residence, and because experience across the world indicates that exposure due to nuclear generating plant accident is likely to be less than a once in a lifetime event, no evacuation should be contemplated when dose to the most exposed individual be less than 1 rem (10 mSv).

It is noted that this figure is one tenth of the lifetime variations noted above; it is twice the upper limit recommended by ICRP for <u>annual</u> exposure of individual members of the public (1); it is one-fifth the value permitted by law <u>annually</u> to an atomic radiation worker (11); on average the loss of life expectancy is less than 2 days; in a population of 5×10^3 persons, roughly the average population of the three sectors nearest the Pickering plant, the number of extra induced lethal cancers is less than one. In a population of 5000, approximately 1000 (20%) will die naturally of cancer.

Upper Level

If the projected dose (including committed dose) exceeds the upper PAL for evacuation, an order for evacuation would be expected to be given. This would be done on a sector-by-sector basis. The three sectors nearest to the Pickering plant have an average population of 5000 persons. With a dose of 10 rem (100 mSv), no immediate clinical effects at all would be expected, but 5 extra latent cancers would be induced in such a population; at 50 rem (500 mSv), 25 extra might be expected to be induced, a number which is on the edge of being statistically significant.

We recommend 10 rem (100 mSv) as the Upper PAL for evacuation, noting that

a. although the probability of delayed health effects is very small, and well below the level of statistical significance, nevertheless the probability of extra lethal cancers is such that a few are expected if the population be left in the sector even though they shelter (in this latter case 2 or 3 cancers would be expected); and that

b. the probability of having to evacuate more than a few sectors, that is, a few times 10^4 people, is so small (less than once in a lifetime) that there is no reason on practical grounds not to consider 10 rem (100 mSv) as the PAL rather than, say, 50 rem (500 mSv); and that

c. 10 rem is not far (see above) from the lifetime differential in background found in different parts of the Province which people appear willing to accept without feeling the need to relocate (though 50 rem is); and that

d. studies of evacuations (12) indicate that planned evacuations of tens of thousands can take place without injury; and therefore possible traffic deaths and injuries are very small compared with the 5 lethal cancers that might be induced if 5000 people were exposed to 10 rem (100 mSv); and that

e. an assessment of the cost-benefit relationship, even though necessarily based on assumptions that could be challenged, indicates that an evacuation level of 10 rem (100 mSv) is not unreasonable. Such an assessment is given at Annex F.

PALs for Ingestion Control

We recommend the following:

		Effective Dose	Thyroid Dose
Lower PAL	-	0.05 rem (0.5 mSv)	0.15 rem (1.5 mSv)
Upper PAL	-	0.5 rem (5 mSv)	1.5 rem (15 mSv)

If the projected dose likely to be received as a result of consuming foodstuffs which have become contaminated as a result of a nuclear accident equals or exceeds the Upper PAL, consumption of the relevant commodities should be banned until the levels of their activity were sufficiently reduced; if the projected dose exceeds the lower PAL, such action should be considered. These PALs have been fixed at comparatively low levels since minimal danger is associated with taking the action.

Application of PALs

The values for PALs recommended by the Group are related to the system given in the Provincial Plan for their application. We concur with the Plan concept of dividing the Primary Zone into a number of Response Sectors, which serve as the basic units within which protective measures are taken. The PAL, thus, serves as a guide to action only within the sector being considered, and is thus applied on a case by case basis to small areas and small populations.

We also note that the Provincial Plan recognizes that even the small population within each Response Sector comprises different categories of people with respect to radiation risk. The lower level PAL enables special categories (e.g. pregnant women) to be taken into account. On the other hand the group notes that others are comparatively more at risk from some possible protective measures (e.g. seriously ill patients in relation to evacuation). We expect that the PALs being recommended will be applied with full awareness of the degree of detriment and risk against which they seek to guard, and that, when decisions on taking action are being made, this risk will be weighed realistically against the risk and detriment of the proposed protective measure.

Planning Zones

We note that the Planning Zones used in the Provincial Plan are defined as follows:

> "Contiguous Zone. The zone immediately surrounding a nuclear facility within which, due to its proximity to the potential hazard, it may be advisable to have an increased level of emergency planning and preparedness, as compared to the rest of the Primary Zone.
>
> Primary Zone. The zone around a nuclear facility within which it would be prudent and cost-effective to plan and prepare for taking Plume Exposure Control measures, including evacuation. (The Primary Zone would include the Contiguous Zone).
>
> Secondary Zone. The zone around a nuclear facility within which it would be prudent and cost-effective to plan and prepare for taking Ingestion Control measures. (The Secondary Zone would include the Primary and Contiguous Zones)."

We recommend that the standard sizes of Planning Zones around the major nuclear generating stations of Pickering, Bruce and Darlington be approximately the following distances from the reactor buildings(s):

Contiguous Zone	-	a radius of 3 km
Primary Zone	-	a radius of 10 km
Secondary Zone	-	a radius of 50 km

The sizes of the Contiguous and Primary Zones were arrived at from a consideration of the planning limit of 25 rem (250 mSv) at the plant boundary (1 km) and the PALs for evacuation (1 rem (10 mSv) and 10 rem (100 mSv)). Using the generally accepted formula for reduction in dose rate with distance (viz, $d^{-1.5}$), 25 rem (250 mSv) at the boundary would result in a dose of over 10 rem (100 mSv) in Sectors lying within about 3 km of the plant, with the outer edges of these Sectors receiving about 5 rem (50 mSv). 25 rem (250 mSv) at the boundary would also result in a 1 rem (10 mSv) dose at about 9 km from the plant.

The size of the Secondary Zone was arrived at in a similar fashion, considering the equivalent planning limit of 250 rem (2.5 Sv) thyroid dose at the plant boundary. We are advised that an emission of approximately 1000 Ci (37 TBq) of Iodine -131 would produce such a dose. Using the dose calculation method recommended in the draft Canadian Standard N288.2 (13) we find that such an emission would produce in the critical group, through the milk ingestion pathway, a thyroid dose of 0.15 rem (1.5 mSv), which is the lower Thyroid PAL for Ingestion Control, at distances of up to 20 km if the release were protracted over 3-5 days, to 40 km if the release took place during a period greater than 1 hour, and up to 100 km in the case of a puff release. It is highly improbable that such a major release would take place over such a short time as a puff, and the recommendation is therefore that the Secondary Zone should extend out to 50 km. This recommendation is made with the realisation that the plans developed for the proposed Secondary Zone could be extended outwards if found necessary .

Planning Times

We are of the view that standard planning times should be based on the Pickering and Bruce type nuclear reactors, which have vacuum containment. From the information available to the Group, a loss of coolant accident (LOCA) in such a reactor would probably progress in the following stages:

(a) The flashing of pressurized water into steam could result in an overpressure in the reactor building, causing a "puff" of radio-activity to be released to the atmosphere before the "box-up" and vacuum building systems have time to react. The duration of the puff could vary from 2 minutes (large LOCAs) to 30 minutes (small LOCAs). 30 minutes might also be the duration with a large LOCA if there were, additionally, impaired containment.

(b) The vacuum building comes into play and reduces containment pressure below atmospheric pressure, and pressure remains low for a period of time. Gradually, as outside air leaks in and as instrument air is discharged, the containment repressurizes. Before it can reach atmospheric pressure the operator will normally discharge containment atmosphere through filters to the environment.

(c) The interval between the initial puff and the sustained emission could vary from half an hour (impaired containment) to approximately 5 days. The typical time for repressurization of a normally operating containment system would be 8 hours to several days.

(d) The duration of the sustained emission would be several days, and the emission could be continuous or intermittent, depending on the level of radioactivity in containment. The largest release of activity would generally occur during the first day of the sustained emission, because of progressive radioactive decay, plate-out and wash-out occurring in containment. We note that intermittent emission, where feasible, might be arranged to coincide with favourable meteorological conditions.

Return of Evacuees

We were asked to recommend the radiological conditions under which evacuees could be allowed to return to their homes.

We recommend that return should not be prevented if the additional projected dose (integrated over 1 year) due to the return be under 0.5 rem (5 mSv). However, so long as the total projected dose (integrated over the next 50 years) from the accident in an evacuated area exceeded 10 rem (100 mSv), no return should normally be allowed. In between these limits, the decision should be based on an assessment of the detriment versus the benefits of return.

We took into consideration, when arriving at the first level, that 0.5 rem (5 mSv) was the "annual limit for members of the public" as recommended by ICRP (1). With respect to the second, we noted that, as evacuation was to take place from a sector if the projected dose were to exceed 10 rem (100 mSv), it would not be logical to allow evacuees back with the projected dose exceeding this level. We recognize that there is a theoretical possibility of conflict between these two recommendations in that, if the contaminating nuclide were Cs-137, with a 30 year half-life, the one year dose could be less than 0.5 rem (5 mSv) while the 50 year dose could be greater than 10 rem (100 mSv). In this (most unlikely) case, return should be delayed despite the first recommendation until the matter had been further assessed.

Emergency Worker Safety

The Group was required to recommend guides for assigning a Safety Status (in terms of a colour code) to a Response Sector, and also the precautionary measures to be associated with each Status.

We discussed at some length the degree to which emergency workers (police, fire and ambulance personnel, etc) could be exposed to radiation. We recommend that such workers should not be exposed, during routine emergency functions, to more than 10 rem (100 mSv) projected dose. This is the upper PAL for evacuation of members of the public recommended by the Group.

We note that, from information available to us, police personnel in Ontario run an average risk of line-of-duty death of 4×10^{-3} during their police service. The equivalent death risk for firemen in Ontario is 2×10^{-2}. Thus, the lifetime risk of cancer mortality from an exposure of a maximum 10 rem (100 mSv) during a nuclear emergency (10^{-3}) would be less than the non-nuclear occupational risks of these two professions. (The occupational risk figures do not include deaths related to occupationally linked disease, which would be a truer basis of comparison).

We recommend that in special circumstances, including life-saving missions, volunteers may be exposed to doses higher than 10 rem (100 mSv). The actual amount of exposure should be decided in accord with the circumstances of each case.

We are of the view that the Safety Status to be assigned to a Response Sector should be based on the highest expected dose-rate in that Sector over the next few hours. This assessment should be reviewed every hour or so and the Status changed if appropriate.

We acknowledge the practical requirement that the Status assigned to a Sector bear some relationship to the protective action taken or being taken in that Sector for the general population. However, we note that this will not always be possible (for example, in the case of precautionary evacuation of a Sector before any emission commences). Generally, though, use of the dose-rate criteria recommended should ensure some correlation between Safety Status and protective action for the general public.

We recommend the following dose-rate criteria for assigning Safety Status:

Safety Status	Dose Rate (per hr.)	Maximum Shift Period
RED	> 2 rem (20 mSv)	to be prescribed
ORANGE	> 100 mrem (1 mSv)- 2 rem (20 mSv)	4 hours or as prescribed
YELLOW	> 2.5 mrem (0.025 mSv)- 100 mrem (1 mSv)	Normal shift or as prescribed
GREEN	≤ 2.5 mrem (0.025 mSv)	Normal shift

The recommended precautionary measures which Emergency Workers should take in a Response Sector assigned a certain Safety Status are listed at Annex G.

After Phase 1, the emergency phase, Safety Status should be assigned to Response Sectors and other areas outside the Primary Zone according to the prevailing circumstances.

Immediate Protective Action

The Group was required to review the concept of Immediate Protective Action contained in the Provincial Plan and make recommendations thereon. This concept envisages the population in a pre-designated area around the plant taking certain laid-down protective measures on being alerted to an accident by means of a sound signal or other such means. This concept is designed to meet the case of a sudden and unexpected release of a significant amount of radioactivity from a plant. Since the contingency management organization would not be in an operational state at this stage some special means may need to be devised to provide protection to the population which could be affected by this hazard.

We are informed that it could take up to 1 hour from initiation of an alert by the nuclear station for the local contingency organization to be mobilized. It could take up to another 2 hours for the population in the sectors nearest the plant to be alerted by normal means. Thus, it could take up to 3 hours from an alert before the people most at risk could be advised by normal methods to take appropriate protective measures. Depending on circumstances, this time could be even longer.

From the information available to the Group it appears that a significant release within 3 hours of the initiation of a reactor malfunction could only occur if containment were impaired.

We recommend that the Province examine this further, gaining more information if available and studying the issue on a station-by-station basis, and decide each one by balancing the cost against the risk involved. We do not envisage the need for instituting Immediate Protective Action outside the Contiguous Zone (3 km).

Offsite Alerting

The Province has intimated that the Group need not examine this issue.

CONCURRENCE

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

Dr. K.G. McNeill

Murray Finkelstein
Dr. M. Finkelstein

D. Myers
Dr. D. Myers
Subject to my minute of dissent
(See Annex H)

V.G. Snell 1984.02.14
Dr. V.G. Snell

Dr. I. Ramsay

William Paul
Dr. W. Paul

Dr. J.H. Aitken
84 02 15

R.E. Utting
Subject to my minute of dissent
(See Annex H)

F.B. Ali

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ANNEX A

Ontario

Ministry of the Solicitor General

Emergency Planning

25 Grosvenor Street
1st Floor
Toronto, Ontario
M7A 1Y6

Telephone: 965:6932

March 14, 1983

NUC 7.1.3

MEMORANDUM TO: Members of Working Group # 3

RE: NUCLEAR CONTINGENCY PLANNING
Technical Bases of Plan

As part of planning for peacetime nuclear contingencies a number of Provincial Working Groups are being set up to examine certain important issues and recommend policies in these areas to the Province. When accepted, these policies will be incorporated into the Province's Nuclear Emergency Plan.

The terms of reference of Working Group # 3 are at Annex A attached. The composition of the group is at Annex B attached, these being persons who have agreed to serve on the group. Members serve on the group in their individual capacities and not as representatives of their respective ministries/organizations. However, their participation in the work of the group has been cleared with their parent organizations.

Additional members may be co-opted on the group by the Chairman in consultation with the undersigned. Of course, it is open to the group to consult any expert who may be able to assist in the group's work. Where such consultation may involve a financial outlay the undersigned should be contacted first. The same procedure should be followed for any other assistance involving financial expenditure.

The deliberations of the Working Group will be organized and conducted by the Chairman. The results of the group's study should be forwarded in the form of a report to cover at least the following aspects of the problem:

(a) Analysis of the issue.

(b) Aspects examined, and considerations relating to each.

(c) Review of policy or practice adopted in other relevant jurisdictions.

(d) Policy recommended and reasons for recommendation.

(f) Implications, if any, of adopting this policy.

It is requested that the work of the group be completed as expeditiously as possible and its report forwarded to the undersigned.

K.J.W. Reeves
Coordinator
Emergency Planning for Ontario

ANNEX B

PROVINCE OF ONTARIO

NUCLEAR EMERGENCY PLAN

WORKING GROUP #3

TECHNICAL BASES OF PLAN

Composition

Chairman

Dr. K.G. McNeill	University of Toronto

Members

Dr. J.H. Aitken	Ministry of Labour
Dr. M. Finkelstein	Ministry of Labour
F.B. Ali	Ministry of the Solicitor General
Dr. I. Ramsay	Ontario Hydro
R.E. Utting	Atomic Energy Control Board
Dr. D. Myers	Atomic Energy of Canada Ltd
Dr. W. Paul	University of Toronto
Dr. V. Snell	Atomic Energy of Canada Ltd.

PROVINCE OF ONTARIO

NUCLEAR EMERGENCY PLAN

WORKING GROUP #3

TECHNICAL BASES OF PLAN

Terms of Reference

1. To examine Principle #4 in the draft plan and, if considered desirable, recommend an alternative formulation which would still meet the requirements of Principle #3, as amended. (See Appendix 1 attached for Principles #3 and 4.)

2. To review the quantitative values used in the various technical bases adopted in the draft plan (Part I - Provincial Master Plan) and assess their validity in the context of the general and specific conditions in which the plan will be applied. The items to be examined are:

   (a) Protective Action Levels. Chapter 4 (pp. 10-12) and Appendix 6 (pp. 63-67) of the draft plan, as amended (amended copy already circulated);

   (b) Planning Times. Chapter 4 (page 12) of the draft plan. (See Appendix 1 attached.);

   (c) Planning Zones. Chapter 4 (pp. 12-14) of the draft plan. (See Appendix 1 attached.).

   To make recommendations on alternative quantitative values where considered necessary. Consideration may also be given to arriving at season- and site-specific values, if considered desirable and feasible.

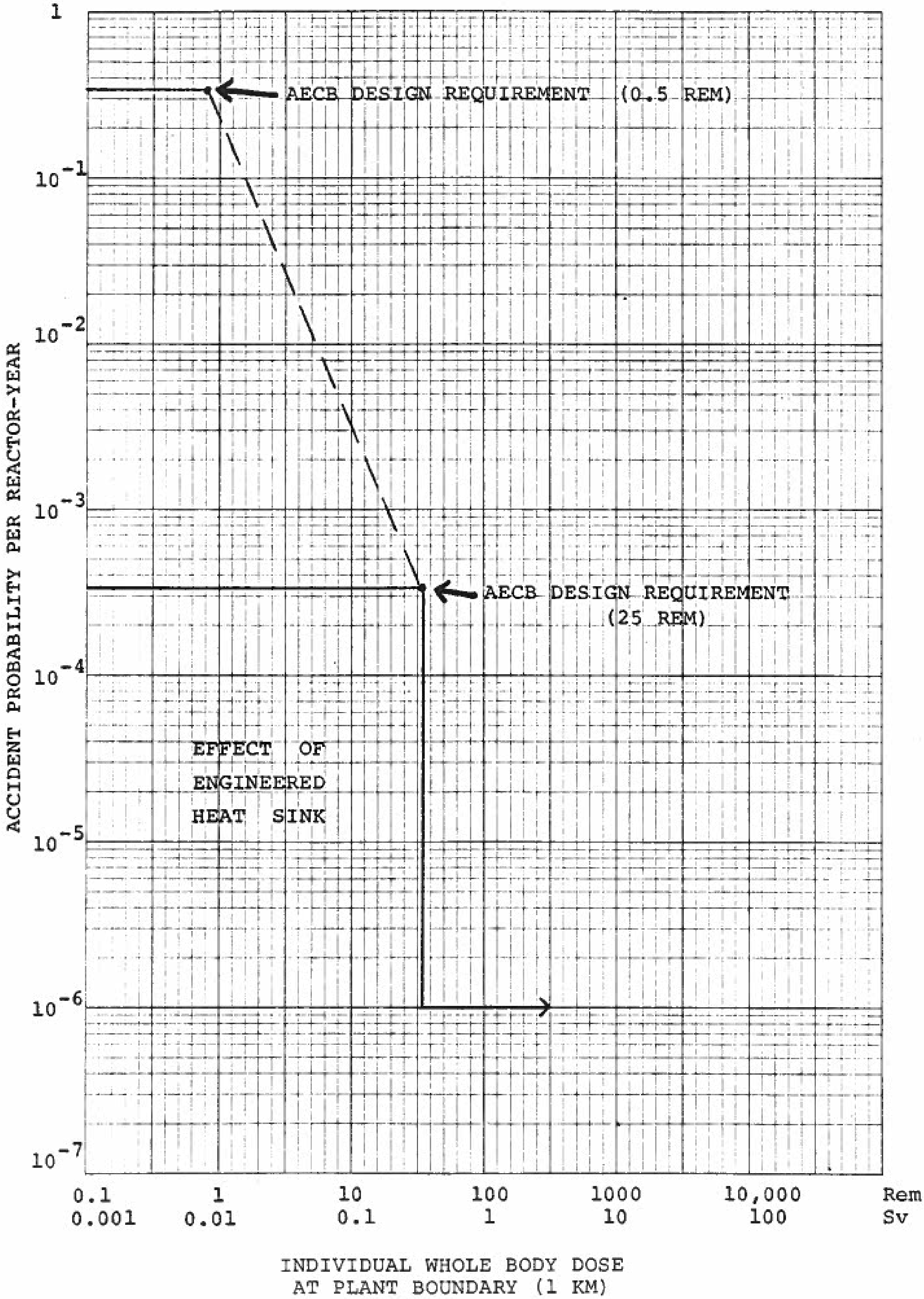
3. To make recommendations on values to be used as guides for assigning a Safety Status to each Response Sector, and on the precautionary measures to be associated with each Status. (See Appendix 2 attached for relevant reference material.)

4. To review the proposed concept of Immediate Protective Action and make recommendations thereon. (See Appendix 3 for relevant reference material.)

5. To review the proposed system for offsite alerting laid down in the draft plan and make recommendations thereon. (See Appendix 4 for relevant reference material.)

6. To recommend the radiological conditions under which evacuees can be allowed to return to their homes in an evacuated Sector.

ESTIMATED PROBABILITY - DOSE RELATIONSHIP - CANDU REACTORS



EMERGENCY ACTION/REFERENCE LEVELS IN OTHER JURISDICTIONS

PROTECTIVE MEASURE	ONTARIO HYDRO (14)[3]	ONTARIO[1] (15)	CANADA[2] (16)	USA (17, 18)	UK & EEC (19, 20)	RECOMMENDED BY WORKING GROUP
Restrictions on Beaches, Parks etc.	WB: 50 mrem (0.5 mSv) TH: 150 mrem (1.5 mSv)	—	EF: 5 mrem (0.05 mSv) -500 mrem (5 mSv) TH: 50 mrem (0.5 mSv) -5 rem (50 mSv)	—	—	—
Restrictions on Drinking Water	As above	WB: 50 mrem (0.5 mSv) TH: 150 mrem (1.5 mSv)	As above	WB: 500 mrem (5 mSv) -5 rem (50 mSv) TH: 1.5 rem (15 mSv) -15 rem (150 mSv)	WB: 500 rem (5 mSv) SO: 5 rem (50 mSv)	EF:50 mrem (0.5 mSv) -500 mrem (5 mSv) TH:150 mrem (1.5 mSv -1.5 rem (15 mSv)
Restrictions on Milk and Food	—	WB: 500 mrem (5 mSv) TH: 1.5 rem (15 mSv)	As above	As above	As above	As above
Thyroid Blocking	TH: 30 rem (300 mSv)	WB: 10 rem (100 mSv) TH: 30 rem (300 mSv)	TH: 5 rem (50 mSv) -100 rem (1 Sv)	TH: 25 rem (250 mSv)	TH: 5 rem (50 mSv) - 25 rem (250 mSv)	—
Sheltering	As above	As above	EF: 50 mrem (0.5 mSv) - 500 mrem (5 mSv) TH: 500 mrem (5 mSv) - 5 rem (50 mSv)	WB: 1 rem (10 mSv) TH: 5 rem (50 mSv)	WB: 500 mrem (5 mSv) - 2.5 rem (25 mSv) SO: 5 rem (50 mSv) - 25 rem (250 mSv) SK: --,,--	EF: 100 mrem (1 mSv) -1 rem (100 mSv) TH: 300 mrem (3 mSv) -3 rem (30 mSv)
Evacuation	WB: 10 rem (100 mSv) LU: 30 rem (300 mSv)	As above	EF: 5 rem (50 mSv) - 50 rem (500 mSv) TH: 100 rem (1 Sv) - 1000 rem (10 Sv)	WB: 1 rem (10 mSv) -5 rem (50 mSv) TH: 5 rem (50 mSv) -25 rem (250 mSv)	WB: 10 rem (100 mSv) - 50 rem (500 mSv) SO: 30 rem (300 mSv) - 150 rem (1.5 Sv) SK: 100 rem (1 Sv) - 300 rem (3 Sv)(EEC) /500 rem (5 Sv) (UK)	EF: 1 rem (10 mSv) -10 rem (100 mSv) TH: 3 rem (30 mSv) -30 rem (300 mSv)

DOSE SYMBOLS: WB = Whole Body TH = Thyroid EF = Effective SO = Thyroid, lung or other single organ SK = Skin LU = Lung

NOTES

1. Guidelines adopted by the Provincial Control Group in 1977.

2. Recommendations to the Atomic Energy Control Board by its Advisory Committee on Radiological Protection in 1983.

3. Sources for the above data are listed in the References against these numbers.

4. Single values are triggering levels. Where a range is given, the higher value is the triggering level, while

COST ANALYSIS AND DECISION-MAKING

Cost analysis should be able to help in deciding which of a number of possible actions should be taken in case of an accident at a nuclear generating station. However, major assumptions have to be made about the costs of both a man-rem (i.e. the cost of the detriment) and the costs of any protective action. The latter do not include planning costs as these will be the same for all actions taken at the time of an accident and, as they will already have been spent, should not be taken into account when considering future action. Protective action costs do include the cost of the specific action, losses of income, damage to property, and personal injury costs in case, for instance, of accidents during an evacuation.

In the following discussion, it will be assumed, for illustration purposes, that

1) a man-rem "costs" $100 (based on $1,000,000 per death and the assumption that 1 rem gives in an individual an extra 10^{-4} chance of induction of a lethal cancer).

2) a per diem for wages of $100.

3) a per diem for maintenance away from home of $50, payable in case of evacuation (either a family in a motel or the costs of running an evacuation centre).

4) cost of evacuation, per person, $50.

5) general property costs, $100 (1 house burns down, cost split between 1000 evacuees, in case of "gentle" evacuation).

6) $200 property costs plus $200 personal injury costs in case of a rapid (less than 4 hour) evacuation.

7) sheltering saves 50% of dose

Then for:

a) No action, total costs in dollar equivalents are
C_o = 100 x Dose (rems)

b) Sheltering: $C_s = 100t + 50D$
where t is time of sheltering in days and
D is dose in rems

c) Gentle Evacuation: $C_G = 150 + 150t + \frac{12-L}{24t-L} \times 100D$

where it is assumed that a "gentle evacuation" takes 12 hours; t is the time in days from the taking of the decision to evacuate to the time of return; L is the time in hours from the taking of the decision until the exposure commences (i.e. the lead time); if 12-L be negative, it is put equal to zero.

d) Rapid Evacuation $C_R = 450 + 150t + \frac{4-L}{24t-L} \times 100D$

The action of choice is that which results in the lowest total cost, that is, cost of detriment plus the costs of the action. On these figures, and under the following conditions, the apparently recommended actions are:

a) Zero lead time, dose spread over 1 day

with D = 1 rem recommended action is: No action
= 2 " " " ": No action or shelter
= 5 " " " ": Shelter
= 10 " " " ": Shelter or gentle evacuation
= 25 " " " ": Rapid evacuation

b) (i) 4 hour lead time, dose spread over the following 20 hours

D = 1 : No action
= 5 : Shelter
= 10 : Rapidly evacuate

(ii) 4 hr lead time, dose spread over following 2 1/2 days

D = 1 : No action
= 5 : Shelter or gentle evacuation
= 10 : Gentle evacuation
= 30 : Rapid evacuation

c) (i) 12 hour lead time, dose spread over next 12 hours

D = 1 : No action
= 3 : Shelter
= 5 : Gentle evacuation

(ii) 12 hour lead time, dose spread over next 2 1/2 days

D = 1 : No Action
= 5 : Shelter or gentle evacuation
= 10 : Gentle evacuation

We must emphasize the crudity of the assumptions, and therefore the uncertainty of the recommended action. These not unreasonable numbers do however suggest that evacuation levels around 1 - 10 rem are not in themselves unreasonable.

With respect to sheltering, it appears from the above as if this is not necessary below 1 rem or so. This however is based on there being an economic loss in sheltering. If the loss of income were zero (e.g. housewives and children), then clearly the level at which sheltering would be recommended decreases to approaching zero dose. This is discussed in the main report.

EMERGENCY WORKER SAFETY

PRECAUTIONARY MEASURES

RED — As specified at the time.

ORANGE

(1) Enter and exit Sector via Exposure Control Centre.

(2) Carry self-reading pocket dosimeter and TLD badge. Check dosimeter every 1/2 hour.

(3) Exit from Sector if dosimeter reading reaches 9 rem (90 mSv) (or personal limit prescribed by Exposure Control Centre).

(4) Wear plastic coverall over clothes.

(5) Use improvised breathing, e.g., a folded or crumpled handkerchief.

(6) Take Potassium Iodide pills, if prescribed.

(7) If duties permit, remain under shelter or inside vehicle.

(8) Stay in Sector limited to 4 hours at a time if no period prescribed by Exposure Control Centre.

YELLOW

(1) Enter and exit Sector via Exposure Control Centre.

(2) Carry self-reading pocket dosimeter and TLD badge. Check dosimeter every hour.

(3) Exit from Sector if dosimeter reading reaches 9 rem (90 mSv)(or personal limit prescribed by Exposure Control Centre.

(4) Wear outer garment over clothes, if available.

(5) Use improvised breathing shield (e.g., a folded/crumpled handkerchief) as far as possible.

(6) Take Potassium Iodide pills, if prescribed.

(7) If duties permit, remain under shelter or inside vehicle.

(8) Stay in Sector limited to period, if any, prescribed by Exposure Control Centre.

GREEN No precautions necessary. No limit on stay period.

ANNEX H

MINUTES OF DISSENT

Dr. D.H. Myers

The definitions of Primary and Secondary planning zones on page 23 include the words "and cost-effective". Convincing evidence concerning levels of expenditure at which planning might be cost-effective was not available.

Mr. R.E. Utting

The upper PAL for evacuation for thyroid irradiation of 300 mSv is too low in my opinion. This dose is equal to the current maximum annual thyroid dose for atomic radiation workers and is less than the maximum annual thyroid dose recommended by the ICRP (ICRP Publication 26.) There can, in my opinion, be little justification for insisting on evacuation of the population in order to prevent a dose that could, at least in theory, be received by an atomic radiation worker in the normal course of his employment. Similarly, the lower PAL for thyroid irradiation of 30 mSv is equal to the current maximum annual thyroid dose for members of the public and less than that recommended by the ICRP and proposed by the AECB. Therefore it seems unreasonable to give serious consideration to evacuation to prevent such doses. It is therefore suggested that the evacuation PALs for thyroid irradiation be increased by about an order of magnitude.