Protection of the population in the event of a nuclear accident

A Basis for Intervention

NUCLEAR ENERGY AGENCY

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A report by an NEA Expert Group

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Pursuant to article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

- to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, the Federal Republic of Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971) and New Zealand (29th May 1973).

The Socialist Federal Republic of Yugoslavia takes part in some of the work of the OECD (agreement of 28th October 1961).

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full Member. NEA membership today consists of all European Member countries of OECD as well as Australia, Canada, Japan and the United States. The Commission of the European Communities takes part in the work of the Agency.

The primary objective of NEA is to promote co-operation among the governments of its participating countries in furthering the development of nuclear power as a safe, environmentally acceptable and economic energy source.

This is achieved by:

- *encouraging harmonisation of national regulatory policies and practices, with particular reference to the safety of nuclear installations, protection of man against ionising radiation and preservation of the environment, radioactive waste management, and nuclear third party liability and insurance;*
- *assessing the contribution of nuclear power to the overall energy supply by keeping under review the technical and economic aspects of nuclear power growth and forecasting demand and supply for the different phases of the nuclear fuel cycle;*
- *developing exchanges of scientific and technical information particularly through participation in common services;*
- *setting up international research and development programmes and joint undertakings.*

In these and related tasks, NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has concluded a Co-operation Agreement, as well as with other international organisations in the nuclear field.

FOREWORD

During the years following the Chernobyl accident in 1986, the NEA actively participated in the international effort towards the improvement and better harmonisation of the international and national criteria for the protection of the public in the event of a nuclear accident.

A first report on this matter, titled "Nuclear Accidents: Intervention Levels for Protection of the Public" was published by the NEA in 1989. Subsequently, the NEA Committee on Radiation Protection and Public Health set up a small Task Group to provide additional guidance, and to take into account recent developments in other international organisations. The purpose of this report is to contribute to the general international debate in this field.

It is intended to assist national authorities in the development of their policies and criteria for the management of the consequences of a nuclear accident. The report, which represents the views of the Task Group, is published under the authority of the Secretary General of the OECD and does not commit Member countries.

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1. INTRODUCTION

The report "Nuclear Accidents: Intervention Levels for Protection of the Public,"* published by NEA in January 1989, contained a critical review of the emergency response actions and intervention criteria adopted in Member countries during the Chernobyl accident of 1986. It identified those aspects of existing international guidance and recommendations where clarification, expansion or modification was needed and provided preliminary guidance on specific aspects of emergency response planning and the establishment and application of intervention criteria.

That report contributed to the parallel effort by several international organisations (ICRP, IAEA, WHO, FAO, NEA, CEC) to seek international harmonisation of the principles and criteria used to protect the public in the event of a nuclear accident.

As significant developments were still underway in these international organisations and some of the issues had not yet been satisfactorily resolved, the NEA Committee on Radiation Protection and Public Health (CRPPH) set up a small Task Group to provide additional guidance on these issues. (Members of the Task group are listed in Annex 1.)

Given that both the IAEA and the ICRP were considering a reformulation of the intervention principles to include the far-field and long-term aspects of accident management, thus making them more broadly applicable, the Task Group partially revised some of the concepts treated in the previous report. This was intended primarily to ensure co-ordination of the guidance to be issued eventually by the various international organisations.

The present report outlines the status of relevant international activities in the period following the preparation of the 1989 report, discusses the intervention principles and describes both the proposed accident management system and a general scheme for its application. It is to be noted that the principles and criteria for intervention discussed in this report, although developed with specific reference to reactor accidents, apply equally well to activities and possible accidents at other nuclear facilities.

The report briefly describes the transition from an "accident management" situation back to a "normal" situation and the related problem of changing criteria for the protection of the public.

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* See also: "The Radiological Impact of the Chernobyl Accident in OECD Countries", published by NEA in 1987. (Ref. 2 of the Report.)

In addition to the "traditional" exposure pathways - inhalation from the cloud, external irradiation from the cloud and the ground and ingestion of food - the report acknowledges the existence of special pathways, proposing criteria for protecting workers and the public and some examples of their application.

This report develops and completes the concepts included in the previous report. The two reports are not intended to be taken as definitive international guidance, but rather as a contribution to the international debate for the improvement and harmonisation of national and international criteria for the protection of the public in the event of a nuclear accident.

2. STATUS OF RELEVANT INTERNATIONAL ACTIVITIES IN THE FIELD OF EMERGENCY RESPONSE AND INTERVENTION CRITERIA

2.1. International Commission on Radiological Protection (ICRP)

In September 1987, the Commission approved the establishment of a small Task Group on the Revision of ICRP Publication 40 (Ref. 3). The Task Group was given the responsibility of drafting relevant sections for the forthcoming revision of the Basic Recommendations, as well as revising Publication 40 itself. Initial drafts formulated by the Task Group were submitted to ICRP Committee 4 for review at their meetings of 23rd - 27th May 1988 and 6th - 10th March 1989. Further developments are currently being considered by Committee 4 and the Main Commission within the context of the revision of the Basic Recommendations.

2.2. International Atomic Energy Agency (IAEA)

In February 1987, an IAEA Advisory Group reviewed the existing Agency guidance on intervention levels of dose, in the light of experience gained as a result of the Chernobyl accident. The Advisory Group concluded that, although the basic principles for the protection of the public, as set out in IAEA Safety Series No. 72 (Ref. 4), remained valid, further guidance on their application was necessary, particularly in the context of intervention associated with an accident having an impact over long distances and large areas, and extending over long periods of time. It therefore clarified and amplified several areas of the existing guidance, and commenced the development of further guidance in a number of specific areas of concern.

To present the initial conclusions and recommendations of the Advisory Group to a broader audience in order that they may be used in conjunction with the guidance currently presented in Safety Series No. 72, the Agency has published, in its Technical Documents series, an interim report, "Revised Guidance on the Principles for Establishing Intervention Levels for the Protection of the Public in the Event of a Nuclear Accident or Radiological Emergency", IAEA TECDOC 473.

Subsequently, the IAEA convened another Advisory Group in November 1988 to make further progress towards the revision of IAEA Safety Series No. 72.

The results of the IAEA Advisory Group meeting represent a further evolution of thinking on how to express intervention principles, criteria and decision-making. In particular, a "process" is elaborated for planning for intervention, as follows:

- <u>intervention should be justified</u> (i.e., the particular action being contemplated should do more good than harm for the group of people it will affect;

- protection of population should be optimised (i.e., the particular action should be implemented at the level which will produce the most good);

- risks to individuals should be constrained below unacceptable levels (i.e., the level of total radiation exposure to individuals should be maintained below that which is regarded as unacceptable for stochastic effects, and below that at which serious non-stochastic health effects could occur.

It is claimed that these "principles" are consistent with previous guidance in ICRP-40 and S.S. No. 72, albeit expressed in different terms.

Further progress in guidance was made by the Agency in a subsequent Advisory Group meeting, in December 1989, where the principles and concepts for the radiation protection management of a nuclear accident were reviewed and refined within the context of a more unified approach to the basic radiological protection criteria that should apply for a variety of unanticipated situations in which the conditions of exposure cannot be planned in advance. These situations, sometimes called "de facto" or "imposed" or "pre-existing" situations, include exposures that may be incurred under post-accident conditions and those due to enhanced natural background levels, to which the Agency's Basic Safety Standards (BSS) system of dose limitation does not fully apply. The Agency's Advisory Group also issued guidance on the protection of different groups of workers involved in accident recovery operations or subjected, in the course of their normal work, to additional exposure due to the contamination provoked by the accident. Another part of the Advisory Group report covered a detailed guidance on the practical application of the principles to the protection of the public as a revision of the previous Agency's Safety Series no. 72.

2.3. World Health Organisation (WHO)

WHO published a document entitled "Derived Intervention Levels for Radionuclides in Food" in June 1988 (Ref. 5). This document gives guideline values and a methodology which can be used by national authorities to set national standards. Following the publication of this document, the FAO/WHO Secretariat addressed to the Codex Committee on Food Additives and Contaminants (CCFAC) recommendations, based on this methodology, for the accidental contamination of food moving in international trade. These were discussed at the Committee meeting in The Hague in March 1989 and, with some amendments, were recommended for adoption by the Codex Alimentarius Commission at its meeting in Geneva in July 1989.

WHO has expanded the network of its collaborating centres on radiation emergency medical preparedness and assistance. The final number of such centres should be about ten. The network could provide medical assistance to overexposed persons in any country asking for such assistance. The machinery for that was reflected in the IAEA Manual on emergency notification and assistance in technical operations.

WHO, in collaboration with UNEP, has developed principles for a global environmental radiation monitoring network. It is expected that 40 to 50 countries could participate in it. The network carries out routine monitoring of radioactivity. In the case of abnormal levels, the exchange of information would be accelerated.

2.4. Food and Agricultural Organisation (FAO)

As previously mentioned, a document has been prepared which outlines proposed Joint FAO/WHO Recommendations to control foods in international trade that have been accidentally contaminated with radionuclides. This document has been discussed by the Codex Committee on Food Additives and Contaminants in The Hague, Netherlands, from the 13th - 18th March 1989, and that Committee agreed to forward the revised proposals to the Codex Alimentarius Commission for final adoption. The Codex Alimentarius Commission, at its meeting of July 1989, adopted this proposal establishing indirect limits of food contamination destined to regulate international trade of foodstuffs. According to the adopted guidance, when the established limits of contamination in given foodstuffs are exceeded, it is up to the concerned national authorities to decide if and under which conditions these foodstuffs can be imported and distributed in their countries.

Due to requests for assistance by several member countries, FAO has undertaken to organise, during 1989-1990, Regional Workshops on Methods of Analysis of Foods for Radionuclide Contamination. The first regional workshops were held in India from 15th - 26th May 1989 and in Kuwait from 6th - 17th November 1989, followed by workshops intended to be held tentatively in Ghana March-April 1990, in Barbados May to August 1990, and in Mexico late 1990. The main objectives of these workshops are to acquaint participants, who will be primarily national food control personnel, with various sampling techniques depending on foodstuff to be sampled, with various preparatory treatments for samples preceding measurement and with methodologies to determine presence of radionuclides in foods, with the emphasis on food import in application of the Joint FAO/WHO Recommendations outlined in the previous paragraph.

2.5. Commission of the European Communities (CEC)

In December 1987, the E.C. Council adopted a regulation (Euratom, No 3954/87) establishing maximum permitted levels of radioactive contamination of foodstuffs following a future nuclear accident. This regulation, however, gave only values for dairy produce and other major foodstuffs. Columns concerning maximum permitted levels in babyfood, liquid foodstuffs and feedingstuffs were left blank, and the E.C. Commission was asked to prepare a proposal.

Subsequently, in July 1989, the E.C. Council also adopted maximum permitted levels for babyfood and for liquid foodstuffs (Euratom No. 2218/89).

The Council has also adopted a regulation on the special conditions for exporting foodstuffs and feedingstuffs following a nuclear accident. It states that "Foodstuffs and feedingstuffs in which the level of radioactive contamination exceeds the relevant maximum permitted Levels laid down in Article 2 and 3 of Regulation (Euratom) No. 3954/87 may not be exported."

3. PRINCIPLES FOR INTERVENTION

3.1 Introduction

The following Chapter describes the proposed new accident management system and a general scheme for its application. The system is based, as far as is applicable, on the ICRP system of protection and includes the principles of justification, optimisation and limitation of individual risk in the application of protective measures. Dose limitation would be implemented by providing individual dose constraints for protective measures within a range between an Upper and a Lower Boundary. An Intervention Level for each specific accident situation would be derived by optimisation of the justified countermeasures within the above-mentioned range. The Intervention Levels are dependent on the level of ambition of the national authorities and by the resources available to them.

3.2 General Principles

The ICRP system of dose limitation, which applies to exposures resulting from sources under control (normal conditions), is presently based on the application of a logical sequence of principles which should govern decisions concerning the introduction and the operation of a practice. They are the well known principles of justification of the practice, optimisation of protection and limitation of individual risk.

This system applies to the control of sources by appropriate design and operation. In an accident situation, the "source" is obviously not under control and, therefore, the protection of the public and the workers cannot be sought by applying the system of dose limitation, which, by definition, only applies to sources under control. However, it appears appropriate, and feasible, that the planning and procedures for the protection of the public and the workers against the consequences of a nuclear accident should be based on a "system" approach conceptually similar to that used for the control of exposures in normal conditions.

In other words, the introduction of any protective measure (intervention) should be justified, the choice of types and levels of intervention should be optimised and the risks to individuals should be constrained below levels judged as unacceptable. These principles are a particular application of the general system of protection recommended in Publication ICRP 26 (Ref. 6), to the specific case of alleviation of the radiological consequences of a nuclear accident. This connection is summarised in Table 1.

Table 1

Principle	Normal case: Source under control	Accident: Source out of control
1.Justification	Justification of a practice	Justification of a protective measure
2.Optimisation of protection	Choice of the "best" protection option	Choice of the "best" intervention level and the most beneficial combination of protective measures
3.Constraints on individual risk	Dose limits for workers and for the public	The radiological risk for the individuals should be kept below unacceptable levels

In this specific application to accident situations the basic principles of the ICRP protection system can be restated as follows:

(i) the intervention should be justified, that is, the introduction of the protective measure should achieve more good than harm;

(ii) the level at which the intervention is introduced, and the level at which it is later withdrawn should be optimised so that it will produce the maximum good;

(iii) the doses to individuals should not exceed levels judged as unacceptable.

These principles, although expressed in different terms and applied with somewhat different procedures, are consistent with the three principles for intervention [principles a), b) and c)] stated in Publication ICRP 40 and IAEA Safety Series 72. One significant difference is in the space and time frameworks of their application. In fact, the principles a), b) and c) of Publication ICRP 40 were meant to apply primarily to the so-called "near-field" and in the relatively short-term, and problems were experienced when considering their applicability to the "far-field" (both with "direct" and "indirect" impact from a given source of accidental release*). These problems principally derived from the difficulty of defining a proper balance in the respective degrees of application of principle b) and principle c) as a function of increasing time and distance from the source of release.

* For the definition of "direct" and "indirect" far-field impact, see section 4.2.2 of Ref. 1.

With the new formulation of the principles for intervention, this difficulty is overcome, because the new principles of justification and optimisation of protective measures and of individual risk constraint are seen as generally applicable, irrespective of time and distance. In fact, although it may be useful for planning purposes, the division of accident situations into time phases and geographical areas of intervention is, in principle, of little relevance to the determination of intervention criteria. These criteria are linked to specific actions rather than to a time phase or the distance from the source.

3.3 Justification of Protective Measures

The introduction of any particular countermeasure entails some risk to the individuals affected and/or some harm to society in terms of financial costs and of social and economic disruption. Therefore, before establishing a protective measure, it should be shown that it can produce a positive net benefit for the people affected, that is, that it is justified. In other words, a given protective measure can be declared as justified if its benefits (in terms of radiation detriment averted) are greater than its associated detriments (in terms of non-radiological risks associated with it, its financial cost and other, less quantifiable consequences such as social disruption). Public anxiety, which can be either relieved or increased by a countermeasure, is another factor to be considered.

This principle of justification of protective measures can be conceptually expressed as follows:

$$B = (Y_o - Y_I) - (R + X) > 0$$

where B = net benefit achieved by the protective measure;
Y_o = cost of radiation detriment in the absence of the countermeasure;
Y_I = cost of the residual radiation detriment if the countermeasure is carried out;
R = cost of the other detriments introduced by the countermeasure itself;
X = cost of the countermeasure, including economical and social components;
$Y_o - Y_I$ = value of radiation detriment averted.

While the principle of justification of intervention is clear and conceptually simple, the process of its application may be complex. The detriment averted can be expressed in terms of collective dose averted, the cost of the protective measure is expressed in monetary terms, the social and psychological harm is not easily quantifiable. There are, therefore, inherent difficulties in expressing the various parameters involved on a common scale and comparing them directly in the decision-making process. This is a difficulty which is often encountered in decision-making, and several decision-aiding techniques have been developed to assist in this process. They include multi-attribute analysis, multi-criteria analysis and cost-benefit analysis. The principal merit of these techniques is to help to rationalise the decision process by making explicit all the factors involved and allowing an appreciation of their relative relevance.

The final outcome of the justification process will depend on the worth each decision-maker attributes to a unit of detriment saved and to the social disruption caused in a given society. It is, therefore, not appropriate, or it may be even impossible, to give any international quantitative guidance on the application of this principle, which is critically dependent on the specific features of each national or local community.

3.4 Optimisation of Protective Measures

If a protective measure is justified for use under a certain set of circumstances, it is necessary to establish an Intervention Level (IL), in terms of an appropriate parameter, such that the implementation of the countermeasure, should such circumstances arise, is triggered when the expected value of the chosen parameter exceeds the IL.

The choice of the IL should result from a process of optimisation of protection, where the radiation detriment averted by a protective measure is balanced against the cost and other detriments of the measure in such a way that the net benefit (B) achieved by the protective measure (as assessed by using, for example, the equation in Section 3.3) is maximised. On the assumption that the radiation detriment is due only to stochastic effects and is, therefore, proportional to the collective dose, the relevant radiation quantity in striking the optimisation balance for a given protective measure is the collective dose averted in the group affected by the intervention.

However, the relevant parameter for the expression of the IL must be liable to assessment and control in practical emergency planning. The IL, therefore, cannot be expressed in terms of collective dose, but it should, rather, be expressed in terms of individual dose. This is possible considering that the collective dose is simply the sum of the individual doses in the exposed group. Therefore, for reasons of simplicity, the average individual dose can be used in practice and it is obtained by dividing the collective dose by the number of persons in the group considered.

Thus, instead of in terms of a collective dose averted in the group affected by a given protective measure, the result of the optimisation of the level of intervention can be expressed as the average individual dose averted in that group. In other words, the intervention criterion can be expressed in terms of the dose to individuals which is expected to be averted by introducing a particular protective measure.

Usually, the justification process identifies a range of possible levels for a protective measure, which results in a range of individual doses averted (AD). Applying optimisation to this range, an optimised value of the individual dose averted (OAD) is then identified, and the intervention level should conceptually coincide with the OAD. However, when assessing the radiological impact of an accident from a given exposure pathway, the dose which results from calculation is usually the average individual projected dose (PD) committed in the group of people primarily affected by that pathway (reference group).

The projected dose (PD) is to be seen as composed of two terms, namely the dose which would be averted by the protective measure (AD) and the residual dose (RD) that would remain after its application. Therefore, it would seem appropriate and possible to express the intervention level in terms of a projected dose rather than an averted dose. This can be done by introducing the concept of efficiency of a protective measure, E, which is the ratio

$$E = \frac{AD}{PD}$$

between the averted dose and the projected dose. The value of E ranges between 0 and 1, and is determined from the characteristics of the particular protective measure and the specific circumstances under which it would be applied (for a better understanding of the use of the concept of efficiency of a protective measure, see Annex 2).

In order to express the intervention level in terms of projected dose, the following relationship involving the efficiency of the protective measure and the averted dose can be established using the above concept of efficiency:

$$PD = \frac{AD}{E}$$

As was previously stated, the value of dose averted by the considered protective measure which corresponds to the maximum benefit as a result of the optimisation procedure is the optimised averted dose OAD. Therefore, from the above equation, the intervention level can be expressed in practice in terms of projected dose as the ratio:

$$IL = \frac{OAD}{E}$$

Then, in the event of an accident the circumstances of which are comparable to those used to derive the IL, the projected dose can be compared with the IL and, if $PD \geq IL$, the protective measure should be implemented. In several practical cases the residual dose (RD) is a very small component, so projected dose and averted dose can be treated as numerically the same ($PD \simeq AD$); however, it is to be stressed that, in principle, the averted dose is the controlling parameter in deciding to implement a countermeasure. Examples of application of this procedure to the establishment and use of intervention levels are given in Annex 2 and Annex 3.

When the IL is expressed in terms of individual dose, it is possible and, for certain countermeasures, necessary in practice to establish Derived Intervention Levels (DIL) in terms of quantities which can be more easily measured or assessed (e.g., activity concentrations, gamma exposure rates, etc.).

In most cases, several different exposure pathways contribute to the radiological impact of an accident. The contribution from each potential pathway to the total exposure can vary with time and distance and from one group of people to another. Moreover, one protective measure can influence several pathways simultaneously. If it is assumed that in most cases accidental doses to the members of the public will be in the stochastic effect range, it is possible to consider separately each protective measure, provided that they are independent. Therefore, each protective measure should be justified and optimised separately and be characterised by a separate IL, independent of other protective actions.

As was previously mentioned, in most cases accidental exposures of members of the public will be in the stochastic range, and, therefore, the projected and averted doses can usually be expressed in terms of dose equivalent. However, there may be special situations (such as in the case of exposure to high levels of ground contamination, inhalation of hot particles or high radionuclide uptake by the thyroid) where doses in the deterministic* range can be reached. In this case, the exposures should be more correctly expressed in terms of absorbed dose.

In the management of accidents, there are two distinct phases in which optimisation of protective measures should be considered.

In the phase of planning and preparedness, prior to accidents, a <u>generic</u> optimisation of countermeasures should be studied, based on a <u>generic</u> accident scenario calculation (including source term, environmental conditions and typical values of protective measure efficiency) and should result, for each protective measure and each selected scenario, in an optimised "generic" IL, which is meant to be the first criterion for action to be used immediately and for a short time after the incurrence of an accident.

In the real situation of an accident, after some time from the beginning of the accident, specific information on its nature, consequences and evolution is expected to be available. In this case, a more precise and <u>specific</u> optimisation analysis, based on real data on the situation and the actual efficiency of protective measures, can be carried out and should result in a "specific" IL for each protective measure, to be used as the operational intervention criterion in the medium and long-term.

In some cases, several protective measures can be considered to reduce exposure of one and the same reference group from a given exposure pathway (e.g., evacuation, sheltering and stable iodine prophilaxis for the inhalation pathway). In this case, after protection in each countermeasure is separately optimised, it may be appropriate to consider these measures collectively in order to define the best strategy in the selection, or combination, of these various protective options. If a combination of two or more actions is selected, this two-stage process should be completed by an overall optimisation of the chosen combination of countermeasures.

It is to be noted that this search for the best strategy of selection of countermeasures is primarily applicable to the phase of <u>specific</u> optimisation. However, a preliminary review of available combinations of countermeasures can be made also during the phase of <u>generic</u> optimisation to

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* The term "deterministic" is currently being proposed by the ICRP to replace the term "non-stochastic" applied to biological effects of radiation on humans.

exclude a priori those which do not appear to be viable and to give indications for the choice of the most effective strategy in the event of an actual accident situation.

According to the definition given in the previous report (Ref. 1), the reference group for a given exposure pathway (sometimes also called critical group) is an "homogeneous group of the population which is representative of the more highly exposed individuals in that population from a given source of radiation." Important parameters involved in the definition of the reference group include the group's age distribution, its sources of food, dietary intakes and living habits. However, in some circumstances, there may be particular sub-groups of individuals within the above-mentioned reference group which may be exposed to a risk significantly higher than the average in the reference group. This may be due to their extreme dietary and living habits, or specific radio-sensitivities (e.g., fetuses), or exposure to special environmental conditions, or greater risk from particular protective measures. If such special sub-groups are identified, their protection may require special consideration, including additional protective measures, on an ad hoc basis.

The selection of an appropriate reference group will depend on whether the intervention level is intended for general application or whether it is specific to particular accident circumstances. For general application it is appropriate to consider average members of the public as the reference group, but for specific applications, whether at the emergency planning stage for a given site or in the case of an actual accident, the reference group could consist of, for example, infants or children.

The ILs resulting from a process of optimisation of protection are dependent on the level of ambition chosen by the decision-makers in implementing radiation protection and the resources available to them, as well as on local conditions and accident circumstances. Therefore, it is not possible to recommend values of ILs that are generally applicable to all situations and countries. Their definition is a matter of choice by national authorities, depending on their level of ambition and resources available. However, where the potential exists for the consequences of a nuclear accident to affect several countries, an effort should be made internationally to minimise unnecessary discrepancies in intervention criteria. One possible contribution to minimising such discrepancies between Member countries could be to reach an international consensus on generic accident scenarios and calculation methods for the derivation of generic ILs. This should provide indicative guidance as an aid to national authorities in establishing their own particular levels.

3.5 Individual Dose Boundaries

The above-mentioned recommended approach to the establishment of intervention criteria has its basis in the definition of a range of justified protective actions and the identification of the optimised level of intervention within that range. The need to minimise unnecessary discrepancies between Member countries, as well as to avoid unacceptable risks to individuals and unwarranted costs and social disruptions, suggests that the range of potential interventions and the corresponding range of doses should be constrained, as possible, by an upper and a lower boundary of individual dose. Some considerations for the definition of these boundaries are given in the following.

The principles of justification and optimisation of protective actions, as defined in the previous sections, are referred to individual interventions and are to be applied separately to each countermeasure. However, it may happen that a given group of people is exposed to several independent pathways and, therefore, the build up of doses to the individuals of this group from the different pathways might result in a total dose which is judged as unacceptable. This may require the establishment of an Upper Boundary (UB) on the total individual dose from all pathways affecting a given group of people, which should not be exceeded, if and as feasible, irrespective of the results of the justification and optimisation procedures applied to the individual protective measures.

In other words, when a number of countermeasures have been established, it should be verified that the sum of the residual doses to individuals, remaining after application of countermeasures on the various contributing pathways, should be lower than the UB (Σ RD < UB). If the UB is still exceeded, the strategy of intervention should be revised and protective measures should be upgraded even beyond the optimised values, particularly on those pathways where additional action is the most effective, so that the overall residual dose is lowered below the UB.

The UB should be expressed as <u>a residual total average individual dose</u> committed in the reference group <u>after exposure to all of the pathways</u> affecting the group, and its value should be established primarily on radiological grounds, irrespective of cost and other considerations.

In some cases, the projected average individual dose from a given exposure pathway is so low that even the mere application of the justification and optimisation process is not warranted and countermeasures are not justified on radiological protection grounds, irrespective of the fact that the corresponding costs may also be trivial. It appears, therefore, appropriate to establish <u>for each exposure pathway</u> a Lower Boundary (LB), expressed in terms of <u>projected average individual dose</u> committed in the reference group <u>after exposure to that pathway</u>, below which protective actions are unlikely to be justified on radiation protection grounds and even the application of the justification and optimisation process is not warranted.

The establishment of numerical values for the Upper Boundary (UB) (for the whole of exposure pathways) and the Lower Boundaries (LBs) (for the various exposure pathways) is a matter of judgement by national authorities. The choice of these values is, in fact, influenced by several factors which are specific to each individual country, including socio-economic considerations, ambition levels, resources available, environmental and demographic conditions, etc.

Experience has shown that, when faced with a real accident situation, authorities tend to adopt largely divergent approaches to accident management, depending on the different weight and pressure of the above-mentioned factors. In order to limit this diversity and its consequent disruptions (in transboundary and other international situations) in the application of the "system" of optimisation and justification to accident management, an appropriate international consensus should be reached on the basic criteria to establish the UB and the LBs and, possibly, on some unified values of an Overall Upper Boundary (OUB) and a Minimum Lower Boundary (MLB). Nationally established UBs and LBs should lay within the range defined by the OUB and MLB.

As far as the Overall Upper Boundary (OUB) is concerned, there is agreement that it should be set to a value of individual dose such that doses exceeding it are usually considered as unacceptable from both the deterministic and the stochastic viewpoint. The objective in fixing this value should be to avoid severe deterministic effects on the short-term (days to weeks) and a high probability of stochastic effects on the long-term (months to years).

The Task Group is of the opinion that the value of the OUB for the whole of the short-term exposure pathways should be set at the level of dose to organs or of whole body dose above which deterministic effects begin to occur. The suggested value of dose committed in a short time after the accident to be used as OUB for the whole body is 0.5 Gy.

As far as the long-term is concerned, the value of OUB should be set at a level of dose beyond which the corresponding probability of stochastic effects is usually considered as unacceptably high. In the opinion of the Task Group, such a level should result in a total probability of lethal cancer of the order of 10^{-2}. With the risk factors currently adopted or considered, this probability would correspond to an accumulated dose of the order of 0.3 - 0.5 Sv.

The OUB values of 0.5 Gy for the short-term and 0.3 - 0.5 Sv for the long-term are meant to apply to a general population structure including both sexes and all age groups. In the case of a particularly sensitive group of people (e.g., children), authorities may consider using smaller values for the Upper Boundary.

At the other end of the range, the Minimum Lower Boundary (MLB) should correspond to a level of individual risk sufficiently low to be generally judged of no particular concern both from the individual and societal viewpoint. This concept also absorbs and replaces the concept of "Non-Intervention Level" which has been proposed by some experts in the last few years.

In order to establish an appropriate value to be proposed for the MLB, consideration was given by the Task Group to the levels of radiological consequences which individuals might consider of no particular concern under the special circumstances of an accident, the current views on dose levels for exemption from regulatory control under normal conditions and the levels and fluctuations of natural radiation background.

Based on the above, the Group agreed that the criterion for the choice of the MLB should be conceptually similar (although not necessarily numerically identical) to that adopted for the establishment of exemptions from regulatory control in normal conditions and should be compatible with the range of values which are found in the unavoidable components of the natural radiation exposure (cosmic rays, potassium-40 in the body, gamma radiation from the earth's crust). This combination of reference criteria would suggest that the LMB value should lay in the range 0.1 - 1 mSv committed in the first year after the accident.

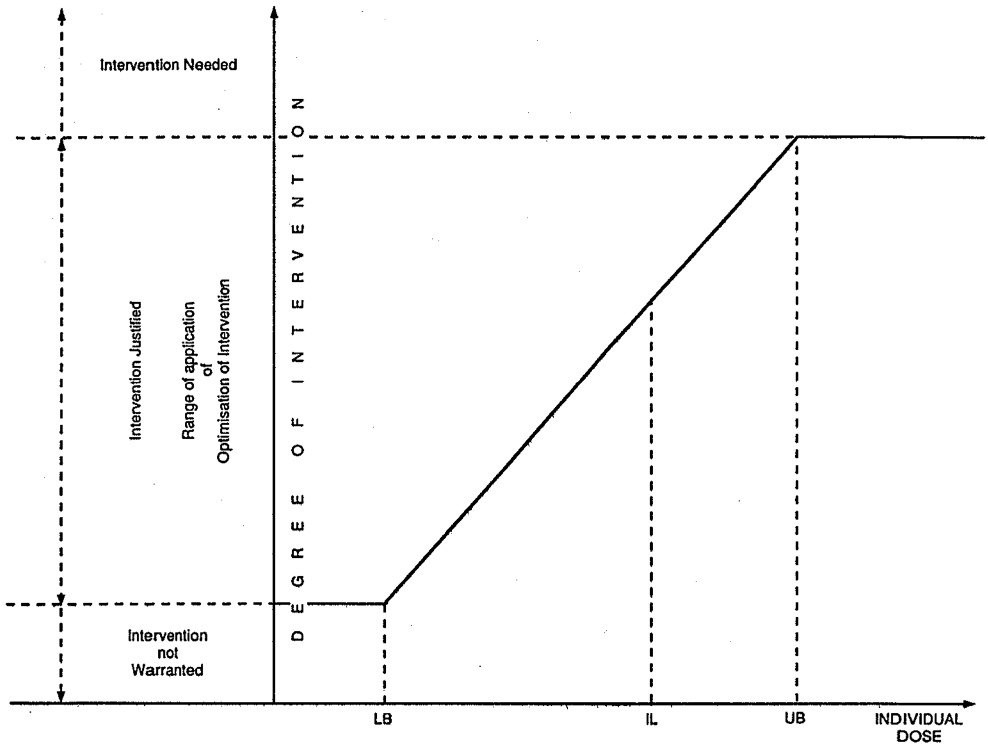
The numerical values suggested above for the OUB and the MLB are recommended as a contribution to improve harmonisation between Member countries. These recommended values are only based on radiological protection considerations. It is, however, to be recognised that there may be national considerations of a sociological and political nature (i.e., non-radiological) and/or practical constraints on the implementation of emergency plans which could influence the relevant authorities to adopt an off-site accident management strategy resulting in doses to individuals higher than the OUB or lower than the MLB.

For example, the environmental conditions during an accident can be so adverse (e.g., snow, ice) as to involve a high risk of accidents during an evacuation. In this case, authorities may prefer to avoid or defer evacuation of a large number of people even if some of them might receive a dose exceeding the OUB.

At the other extreme, some types of protective measures may be extremely cheap and simple to implement and involve practically no socio-economical disruption (e.g., washing fruit and vegetables; changing clothes and taking a shower after outdoors work; avoiding sunbathing and swimming). The concern for public opinion pressure or other socio-political considerations may suggest authorities to adopt these kinds of measures even if the doses to the people concerned are expected to be lower than the MLB. However, it is to be stressed that no purely radiation protection motivations should be invoked to justify these kinds of intervention.

3.6 General Scheme of Application of Intervention Criteria

On the basis of the considerations given in this report, the overall system for the establishment and implementation of intervention criteria can be summarised in the following scheme:



UB = Upper Boundary (individual dose for all pathways)
Maximum recommended values for UB:

0.5 Gy (short-term)
0.3 - 0.5 Sv (long- term)

LB = Lower Boundary (individual dose for a given pathway)
Minimum recommended value for LB:

0.1 - 1mSv (in the first year)

IL = Intervention level (individual projected dose corresponding to optimised individual averted dose for a given exposure scenario and protective measure).

In summary, the various actions to be considered in relation to the establishment and implementation of the intervention criteria are the following:

- if the total projected dose from all pathways is > UB, some protective measures are imperative;
- for each protective measure (in the range of justified actions) and exposure pathway, optimisation of protection is applied to establish IL;
- if the projected dose from that pathway PD > IL, the protective measure is adopted;
- if the projected dose from that pathway PD < IL, the protective measure is not adopted;
- if the projected dose from that pathway PD < LB, no action, including the optimisation process, is warranted;
- after the adoption of protective measures on several pathways, the total residual dose (total projected dose - total averted dose) is compared with UB;
- if this total residual dose is still > UB, additional protective measures are needed even if the individual residual dose for each pathway is < IL.

4. TRANSITION FROM ACCIDENT TO NORMAL CONDITIONS

The relationship between the "accident management" and "normal conditions" criteria for the protection of the public with regard to the time elapsed after an accident and to the increasing distance from the accident site has been the subject of extensive discussions after the Chernobyl accident in various countries and within international expert groups. This includes the problem of the possible need to differentiate intervention criteria and dose boundaries between the near-field and the far- and very far-field in the same time period, as well as the issue of the relationship between criteria for introducing protective measures and criteria for withdrawing them.

As far as the first question, the transition in space from the near-field to the far- and the very far-field, is concerned, many experts feel that in the very far-field, where the only possible impact of an accident is the import of contaminated goods, it is difficult for the authorities to claim that accident or emergency criteria should be applied, in particular as the exposure from those contaminated goods can be subjected to control, and therefore the control of the imported goods should be based on the normal system of radiological protection. Other experts argue that, according to radiological protection basic principles, what counts for control is the primary source of exposure, namely the nuclear facility undergoing the accident, which is obviously out of the control of the authorities of a far-field country. These experts argue, therefore, that the normal system of dose limitation is not fully applicable even in the very far-field, and, in particular, the individual dose limits cannot be applied to the control of exposures in a post-accident, "de-facto" situation.

In the opinion of the Task Group, the latter approach is formally correct, although it expresses a theoretical and doctrinal view, whilst the former approach, although it appears less rigorous, represents a more pragmatic attempt to cope with a difficult problem. The Task Group believes that the solution to this contrast can only be found in a compromise approach, whereby accident conditions and normal conditions should be kept conceptually separated, but it should be accepted that the respective numerical criteria for control should tend towards coinciding with increasing distance from the accident source. The above mentioned recommended choice of the value of the Minimum Lower Boundary is consistent with this approach.

Coming to the second question, the transition in time from accident management to normal or "quasi-normal" conditions management (in the long term), opinions have been expressed that the criteria for withdrawing a given protective measure might not necessarily be the same as those applied to introduce that countermeasure, because the conditions of their application may be different (modified environmental conditions and trends, different time durations, differing social costs with time, etc.) and the information available on the radiological impact and other parameters relevant to decisions will certainly be different (more complete and more accurate data) at the time of considering withdrawal of protective measures. Moreover, if the withdrawal of protective measures is meant to allow people to resume normal living, the numerical criteria which trigger the withdrawal of countermeasures should correspond to dose and contamination levels which are lower than the intervention levels used to trigger the introduction of those countermeasures.

However, it may well be that, even in the long-term and when a decision to resume normal living is to be taken, the levels of radiation and contamination in a given area still continue to exceed those existing before the insurgence of the accident, and which were due either to natural sources or to sources which were planned and under control. Depending on the environmental features and the radionuclides involved, this "de facto" situation might be prolonged over a very long time span. Therefore, the actions for return to normal living conditions should be justified, and the level of protection to be achieved should be optimised within appropriate individual dose constraints. The only difference from the system of protection for normal conditions should reside in the numerical values adopted for withdrawing countermeasures and keeping under control the exposure of people when they return to their pre-accident locations and living habits and diet. These values, in terms of annual individual doses and corresponding derived levels of radiation and contamination in the environment and the diet, may need to be higher than the corresponding limits used for normal conditions before the accident.

In conclusion, it is the opinion of the Task Group that the numerical criteria for the withdrawal of countermeasures should usually be lower than the corresponding intervention levels used for the introduction of the countermeasures (although there may be exceptions, for example for the DILs for food) and may be equal to or higher than the limits for normal conditions. The actual values of these criteria cannot be established internationally, because they depend on the results of a justification and optimisation process, which are inevitably affected by local conditions, national ambition levels in radiological protection and resources available. These values should, therefore, be established by the national authorities on a case by case basis.

5. SPECIAL EXPOSURE PATHWAYS RELATED TO ENVIRONMENTAL CONTAMINATION FOLLOWING A LARGE NUCLEAR ACCIDENT

5.1 Background

In the event of a major accident involving dispersal of radioactive material at large distances from the accident site~~, there may exist a number of~~ special routes of exposure to the public and workers, besides the exposure pathways which are normally considered such as inhalation from the cloud, external irradiation from ground contamination and ingestion of food.

Some examples of these special exposure pathways include:

a) contaminated sewage sludge resulting from processes of concentration of radionuclides in sewage treatment plants, which may raise problems related to its handling, disposal and use as fertiliser;

b) contaminated industrial air filters, tools and equipment used in industry and agriculture, resulting in occupational exposure problems as well as waste disposal problems;

c) contaminated wood, peat or other materials used for heating or energy production, resulting in problems related to activity released in stack emissions and disposal of ash containing concentrated activity.

This radioactive contamination might cause radiation protection problems to:

- persons dealing with or handling the contaminated substances during their normal occupational duties (not associated with the implementation of countermeasures or recovery operations in relation to the accident);

- the general public, due to the use, release and disposal of contaminated substances.

The particular impacts, referred to in this Chapter, that follow a large release of radioactive substances may need special consideration in relation to the exposure of the general public and some occupational groups. The establishment of intervention levels and monitoring programmes for these impacts will therefore be a useful and necessary part of the emergency response plans.

The international guidance for these particular exposure routes is very scarce and it is, therefore, necessary to direct some efforts towards establishing such a guidance. Questions which need to be considered are:

i) what intervention levels of dose would be appropriate?

ii) what should be the upper boundaries to restrict total individual doses?

iii) how to draw derived intervention levels from a specified level of dose?

Some examples of special exposure pathways identified during the Chernobyl accident and of the associated impacts and countermeasures are given in Annex 4.

5.2 Criteria and Guidance

General

Most of the special impacts referred to above relate to the late or the recovery phase of the accident (ICRP-40 terminology), when the extent of the environmental contamination is rather well known and the situation is transformed into what has been previously defined as a "de facto" (or "pre-existing") situation and should be under control. For some occupational groups, however, the exposure might take place during all phases of the accident and some protective actions might need to be taken during the initial phases of the accident without the support of sufficiently accurate and reliable information.

Moreover, these impacts are highly time-dependent and probably of most significance during the first year(s) after the accident, depending also on the season, meteorology, climate, etc.

Occupational Exposure Off-Site

The category of persons subjected to the above-defined special exposure pathways during their normal duties, not related to the accident response actions, includes such groups as:

- farmers exposed during their normal work, due to the contamination of the soil and working tools;

- persons employed in waste treatment, combustion and heating plants, as well as some other industrial workers, such as those changing air filters, all exposed in doing their normal work;

- other persons receiving a special exposure due to the accident by way of their occupations.

There was considerable discussion on the way in which these special groups should be considered and handled from the accident management viewpoint, particularly when their work activities are important for the collective interest. Should these groups be classified as doing work comparable to radiation workers and be within the ICRP system of dose limitation for occupationally exposed persons or should they be considered as members of the public? Or something in between?

In the opinion of the Task Group, when protective measures are implemented to protect the public, all those who are not involved in carrying out these interventions, but are, rather, the object of the protective measures, should be considered and treated as members of the public, irrespective of their own occupations. However, the special groups of persons described above, whose occupations have no connection with the mitigation of the accident, may be submitted to exposures directly linked to their professional activity which are in addition to the general exposure that they receive together with all the other members of the public.

For the control of occupational exposures resulting from these special pathways, the work activity should be justified, particularly in terms of the needs of society (even in the accident scenario), work procedures and protection precautions should be reviewed and established applying the principle of optimisation of protection, and the individual exposure of these persons should be monitored (only in special cases) or assessed and subject to an individual dose constraint which would be higher than the annual dose limit for members of the public. This constraint should be integrated in the Upper Boundary for the whole of pathways defined in Chapter 3.

This special control situation involving the above-defined specific worker groups should last throughout the time period in which the exposure of these persons from the special pathways exceeds levels comparable with those normally accepted for members of the public in the absence of accident. When the exposures of these special groups become so low, no specific control on their work activities is needed any longer and the specific annual dose constraint is not relevant any more.

Exposure of the General Public

In case of a widely spread contamination, like that experienced after the Chernobyl accident in the OECD Member countries, there will be a need to decide how much additional radiological impact, apart from existing ground and surface contamination, should be accepted because of industrial and agricultural practices concentrating radioactive substances or transferring them from one place to another and exposing the population to the above-mentioned special pathways. An example of this kind is discussed below.

Sewage Sludge, Ashes and Similar Media

The problem which has to be solved is whether normal procedures for the use and disposal of media like sewage sludge, ashes, etc., could be continued or if it is necessary to adopt other, temporary, solutions due to the presence of radioactive contamination.

The principle of optimisation of protection should be appropriate for aiding the decision-making process in these kind of problems. A typical kind of decision to be taken will probably be whether to use the sludge as a fertiliser or to dispose of it as waste and how to handle contaminated ashes from burned contaminated peat, wood, etc. The problem will be to calculate the radiological impact in the various options and the costs associated with them. The final results would vary by one or two orders of magnitude in terms of dose to the reference groups or to individuals of special concern.

Secondly, what would be the level of acceptable dose to the individuals concerned to be used as the constraint in the optimisation calculations? Should one specify an intervention level in advance for this kind of impact or should one make judgements at the time of interest considering the actual circumstances?

The experience after the Chernobyl accident shows that it will not mean unreasonable restrictions to require the individual doses from these routes of exposure not to exceed the doses caused by the food contamination, except in special cases. Therefore, as a rule of thumb, one could use the same intervention level of dose for these kinds of exposures as for food.

Furthermore, it should be useful to do some generic optimisation studies in order to derive some generic intervention levels for inclusion in the emergency response plans. When the actual situation becomes clear, more precise and specific intervention levels could be derived.

In Annex 5 is included an optimisation calculation for the utilisation of contaminated peat ash. This study was carried out after the Chernobyl accident and is based on the actual contamination in Finland as a consequence of the fall-out from the Chernobyl releases.

6. SUMMARY CONCLUSIONS

6.1 Introduction

This report develops and integrates the considerations and concepts illustrated in the previous report "Nuclear Accidents: Intervention Levels for Protection of the Public" (Ref. 1) published by the NEA in 1989. In the preparation of this second report the Task Group took due account of the developments being made by other international organisations, particularly the IAEA and the ICRP. The concepts proposed by the Task Group are generally compatible with those developments and this report should be seen as a contribution to the general international debate for the improvement and harmonisation of the international and national criteria for the protection of the public and the workers in the event of a nuclear accident. The main conclusions of this report are summarised in the following.

6.2 Principles for Intervention

The ICRP system of dose limitation does not apply as such to the protection of the public and the workers in the conditions of a nuclear accident. However, a similar "system" approach is suggested for application to the planning and procedures for protection against the consequences of an accident.

The basic principles of this "system" approach to accident management should, therefore, be the following:

(i) any intervention should be justified, that is, the introduction of a protective measure should achieve more good than harm;

(ii) the level at which an intervention is introduced, and the level at which it is later withdrawn, should be optimised so that it will produce the maximum good;

(iii) the doses to individuals should not exceed levels judged as unacceptable.

These principles are seen as generally applicable to all situations and in all circumstances, irrespective of time and distance from the source of the accident.

Justification of protective measures

As far as justification of protective measures is concerned, it should be shown that its benefits (primarily in terms of radiation detriment averted) are greater than its associated detriments (in terms of non-radiological risks, financial costs and social disruption). The expression of the relevant parameters to be considered is relatively simple with regard to the detriment averted (which can be expressed in terms of collective dose averted) and the financial cost of the protective measure (which can be expressed in monetary terms). This is more difficult with regard to other, non-quantifiable parameters, such as those of a political, social and psychological nature, which critically depend on specific features of each national or local community. The Task Group, therefore, felt that it would not be appropriate, or it could be even impossible, to give an international quantitative guidance on the justification of protective measures.

Optimisation of protective measures

The justification process usually leads to the definition of a range of possible protective measures, which would be all justified. It is the role of the principle of optimisation to identify the level of detriment averted which would maximise the net benefit achieved by a protective measure. This optimised level of detriment averted is called the Intervention Level (IL). On the assumption that the radiation detriment is due only to stochastic effects, the relevant radiation quantity in striking the optimisation balance for a given protective measure is the collective dose averted in the group affected by the intervention. However, for practical reasons the IL should be expressed in terms of individual dose, which can be derived, as explained below, from the collective dose averted in the group of people affected by the protective measure.

When assessing the radiological impact of an accident from a given exposure pathway, the dose which results from calculation is usually the average individual projected dose committed in the group of people primarily affected by that pathway (reference group). Therefore, it is appropriate, in practice, to express the IL as a projected dose (rather than an averted dose) in order to make it possible directly to compare the projected doses resulting from calculation of accident consequences (on a given exposure pathway) with the corresponding intervention level. This can be done by introducing the concept of efficiency of a protective measure, E, which is the ratio

$$E = \frac{AD}{PD}$$

variable between 0 and 1, between the averted dose AD and the projected dose PD.

As a consequence, if OAD is the optimised averted dose resulting from the application of optimisation to the range of available levels of justified protective measures, the intervention level can be expressed in practice in terms of projected dose as the ratio

$$IL = \frac{OAD}{E}$$

Thus, in the event of an accident whose circumstances are comparable to those used to derive the IL, a given protective measure should be implemented if the calculated projected dose PD $\geq$ IL.

In the management of accidents, there are two distinct phases in which optimisation of protective measures should be considered. In the phase of planning, prior to accidents, a generic optimisation of protective measures should be studied, based on a generic accident scenario calculation and should result, for each protective measure and each selected scenario, in an optimised "generic" IL, which is meant to be the first criterion for action to be used immediately and for a short time after the incurrence of an accident. In the real situation of an accident, a more precise and specific optimisation analysis, based on real data on the situation and the actual efficiency of protective measures, can be carried out and should result in a "specific" IL for each protective measure, to be used as the operational intervention criterion in the medium and long-term.

The ILs resulting from a process of optimisation of protection are dependent on the level of ambition chosen by the decision-makers in implementing radiation protection and the resources available to them, as well as on local conditions and accident circumstances. Therefore, it is not possible to recommend values of ILs that are generally applicable to all situations and countries. Their definition is a matter of choice by national authorities. However, in the opinion of the Task Group, an effort should be made to reach an international consensus on generic accident scenarios and calculation methods for the derivation of generic ILs. This would contribute to minimise undue discrepancies between Member countries in establishing their own intervention levels.

Individual dose boundaries

The need to minimise unnecessary discrepancies between Member countries, as well as to avoid unacceptable risks to individuals and unwarranted costs and social disruptions, suggests that the range of potential interventions and the corresponding range of doses should be constrained, as possible, by an upper and a lower boundary of individual dose.

. Upper Boundary

It may happen that a given group of people is exposed to several independent pathways and, therefore, the build up of doses to the individuals of this group from the different pathways might result in a total dose which is judged as unacceptable. This may require the establishment of an Upper Boundary (UB) on the total individual dose from all pathways which should not be exceeded, if and as feasible, irrespective of the results of the justification and optimisation procedures applied to the individual protective measures.

The UB should be expressed as a residual total average individual dose committed in the reference group after implementation of countermeasures and exposure to all of the pathways affecting the group, and its value should be established primarily on radiological grounds, irrespective of cost and other considerations.

The establishment of values for the UB is a matter of judgement by national authorities. However, in order to limit the possible diversity of such values between Member countries and the resulting difficulties, particularly in the event of accidents having transboundary implications, it would be appropriate to reach an international consensus on the basic criteria to establish the UB and, possibly, on a unified value of an Overall Upper Boundary (OUB) for international application. The criterion suggested by the Task Group for the establishment of the UB is that it should be set at a value of individual dose such that doses exceeding it are usually considered as unacceptable from both the deterministic and the stochastic viewpoint.

The objective in fixing this value should be to avoid severe deterministic effects on the short term (days to weeks) and a high probability of stochastic effects on the long-term (months to years). The values suggested by the Task Group in application of this criterion are a whole body absorbed dose of 0.5 Gy committed in a short time after the accident and an accumulated effective dose equivalent of 0.3-0.5 Sv on the long term.

. **Lower Boundary**

In some cases, the projected average individual dose from a given exposure pathway is so low that even the mere application of the justification and optimisation process is not warranted and countermeasures are not justified on pure radiological protection grounds, irrespective of the fact that the corresponding costs may also be trivial. It appears, therefore, appropriate to establish for each exposure pathway a Lower Boundary (LB), expressed in terms of projected average individual dose committed in the reference group after exposure to that pathway, below which protective actions are unlikely to be justified on radiation protection grounds and even the application of the justification and optimisation process is not warranted.

The establishment of values for the LBs is a matter of judgement by national authorities, being influenced by several factors which are specific to each individual country. However, also in this case it would be appropriate to limit unnecessary discrepancies between Member countries in the application of the "system" of justification and optimisation to accident management. This would suggest to make efforts to reach an international consensus on the basic criteria to establish the LBs and, possibly, on a unified value of a Minimum Lower Boundary (MLB) for international application.

In the opinion of the Task Group, the LBs should correspond to a level of individual risk sufficiently low to be generally judged of no particular concern both from the individual and societal viewpoint. On this basis, the Task Group felt that the criterion for the choice of the MLB should be conceptually similar (although not necessarily numerically identical) to that adopted for the establishment of exemptions from regulatory control in normal conditions and should be compatible with the range of values which are found in the unavoidable components of the natural radiation exposure. As a result, the Task Group suggested that the value of the MLB should lay in the range 0.1-1 mSv committed in the first year after the accident.

The numerical values suggested for the OUB and the MLB are only based on radiological protection considerations. It is, however, recognised that there may be national considerations of a sociological and political nature and/or practical constraints on the implementation of emergency plans which could influence the relevant authorities to adopt an accident management strategy resulting in doses to individuals higher than the OUB or lower than the MLB.

6.3 Transition from Accident to Normal Conditions

The relationship between "accident management" and "normal conditions" criteria for the protection of the public with regard to the time elapsed after an accident and to the increasing distance from the accident site involves the problem of the possible need to differentiate intervention criteria and dose boundaries as a function of distance in the same time period, as well as the issue of the relationship between criteria for introducing protective measures and criteria for withdrawing them.

As far as the transition in space from the near-field to the far- and the very far field is concerned, there are contrasting opinions among experts on the application of accident management criteria or of the normal system of dose limitation in the very far-field, irrespective of time, in the case, for example, of the control of importation and consumption of foodstuffs. The Task Group believes that the solution to this contrast can only be found in a compromise approach, whereby accident conditions and normal conditions should be kept conceptually separated, but it should be accepted that the respective numerical criteria for control should tend towards coinciding with increasing distance from the accident source.

Coming to the second question, the transition in time from accident management to normal or "quasi-normal" conditions management (in the long term), opinions have been expressed that the criteria for withdrawing a given protective measure might not necessarily be the same as those applied to introduce that countermeasure. Taking into account the various reasons supporting these opinions, which are discussed in Chapter 4 of the report, the Task Group suggests that the numerical criteria for the withdrawal of protective measures should be usually lower than the corresponding intervention levels used for the introduction of the countermeasures and may be equal to or higher than the limits for normal conditions. The actual values of these criteria cannot be established internationally, because they depend on the results of a justification and optimisation process, which are inevitably affected by local conditions, national ambition levels in radiological protection and resources available. These values should, therefore, be established by the national authorities on a case by case basis.

6.4 Special Exposure Pathways Related to Environmental Contamination Following a Large Nuclear Accident

In the event of a major nuclear accident there may exist a number of special routes of exposure to the public and workers, besides the exposure pathways which are normally considered (such as inhalation from the cloud, external irradiation from ground contamination and ingestion of food). Examples of sources of these special exposure pathways include contaminated sewage sludge to be treated, disposed or used as fertilizer; contaminated air filters, tools and equipment used in industry and agriculture; contaminated wood, peat or other materials used for heating or energy production.

These special exposure pathways may affect persons handling the contaminated substances during their normal occupational duties (not associated with the implementation of countermeasures or recovery operations in relation to the accident), as well as the general public due to the use, release and disposal of these substances. The category of persons subjected to the above-defined special exposure pathways during their normal duties, not related to the accident response actions, includes such groups as farmers, persons employed in waste treatment, combustion and heating plants, as well as some other industrial workers, such as those changing air filters.

The particular impacts referred to in this Chapter may need special consideration in relation to the exposure of the general public and the above-mentioned occupational groups. In the opinion of the Task Group, when protective measures are implemented to protect the public, all those who are not involved in carrying out these interventions, but are, rather, the object of the protective measures, should be considered and treated as members of the public, irrespective of their own occupations. However, if the special groups of workers described above are submitted (from the special exposure pathways directly linked to their professional activity) to an exposure which is in addition to the general exposure that they receive together with all the other members of the public, then the control of exposures resulting from these special pathways should be dealt with using a general approach similar to that applied to persons occupationally exposed to radiation. That is, the work activity should be justified, protection provisions should be optimised and the exposure of these persons should be assessed and subjected to an individual dose constraint. The value of this dose constraint would be higher than the annual dose limit for members of the public as long as the additional exposure resulting from the working activity exceeds levels comparable with those normally accepted for members of the public in the absence of accident.

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ANNEXES

ANNEX 1

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ANNEX 2

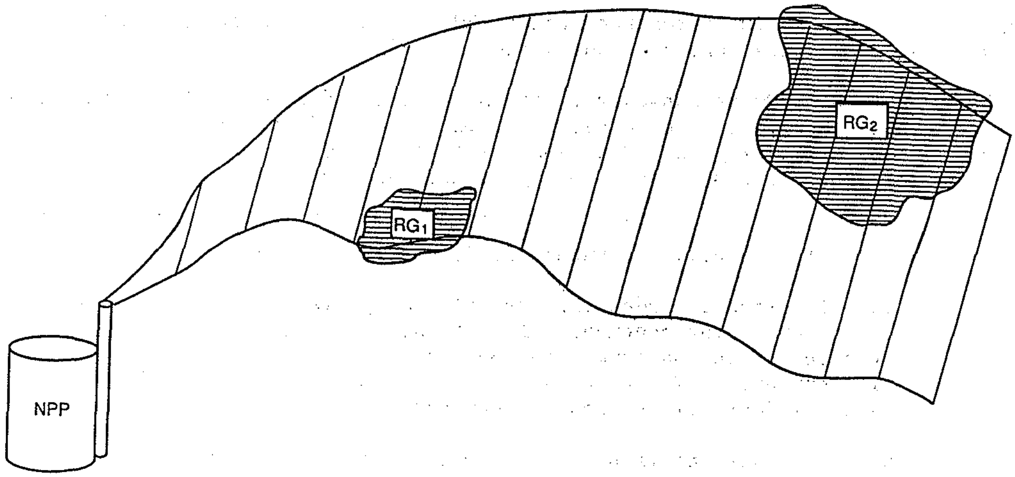
DERIVATION OF INTERVENTION LEVELS FOR PROTECTIVE MEASURES: EXAMPLES

At the time of an accident, there generally will be little time available to undertake justification and optimisation analyses. Thus, it is considered essential that emergency response plans be developed in advance. These response plans should provide a degree of flexibility for responding to accidents of different types, and should include numerical guidance (i.e., generic intervention levels) for implementing protective measures. These generic ILs may be based, <u>inter alia</u>, upon general assumptions for the source term, meteorological conditions, seasonal environmental and cultural conditions, etc. In addition, the costs associated with implementing the different protective measures available should be considered. The generic ILs should be established for the types of protective action likely to be needed in the event of specified accidents, and would provide a basis for making urgent decisions in the absence of detailed monitoring information.

The purpose of the following exercise is to show how the methodology described in this report can be used to derive these generic intervention levels. <u>The input data for this exercise are mostly arbitrary assumptions for explanatory purposes only and should not be used elsewhere.</u>

Premise for the Examples

An abnormal atmospheric release of I-131 is occurring from a nuclear power plant (see schematic below).



The dominant winds blow towards two reference groups. The first one (RG_1) is composed of a small agricultural community of 200 people at about 5 km from the NPP. The second (RG_2) is an urban community of 50,000 people at about 20 km from the NPP.

This example is concerned with intervening with protective measures for the early phase only. Measures considered here are (other interventions may be considered in real cases):

- evacuation;
- sheltering;
- administration of KI pills.

<u>Input Data for the Calculation of Intervention Levels Associated with Reference Group 1</u>

The following data are estimates loosely derived from the literature. They do not correspond to any specific real situation and are only given here to demonstrate the methodology in the report: <u>they should not be used for any other purpose</u>.

Number of people in the reference group: 200 (normal age distribution)
No special sub-populations are considered.

Alpha value: $10,000/person-sievert (this value has frequently been mentioned for developed countries with respect to fatal tumor induction).
Cost of 1 acute fatality (at 50 person-sievert): $500,000.
Duration of protective measure: 10 days (this value was arbitrarily selected).

EVACUATION

X = Cost of protective measure: $150,000 + $10,000/day

This function includes the cost of transportation, communication and life support for evacuees. An initial high cost is due to transportation and communication, followed by a linear increase for life support. (The numbers are largely based on results from a recent industrial accident in Canada).

R = Cost of other detriments* introduced by the protective measure: $5,000/day

This function includes the economic loss of evacuees. No health detriment is assumed.

E = Average efficiency of protective measure: 0.9 (derived from the literature).

SHELTERING	X =	Cost of protective measure: $8,000 + $3,000/day This function includes the cost of communication and minimal life support. A linear function is assumed.
	R =	Cost of other detriments* introduced by the protective measure: $3,000/day. This function includes the costs of socio-economic loss of sheltered people. No health detriment is assumed (this figure is lower than that for evacuation, because the sheltered life on a farm during winter may not cause as great an economic loss).
	E =	Average efficiency of protective measure: 0.4 (derived from the literature).

KI PILLS	X =	Cost of protective measure: $10,000 + $0/day (no cost for control is assumed). This function includes the cost of production and distribution of KI pills. No additional costs are assumed to occur throughout the accident.
	R =	Cost of any other detriments introduced by the protective measure: $0
	E =	Average efficiency of protective measure: 0.5 (derived from the literature.

* The costs of "other detriments" are lower for sheltering than for evacuation, because the farmers may have the option of continuing to perform some of their duties at home.

Input Data for the Calculation of Intervention Levels Associated with Reference Group 2

The following data are estimates loosely derived from the literature. They do not correspond to any specific real situation and are only given here to demonstrate the methodology in the report: they should not be used for any other purpose.

Number of people in the reference group: 50,000 (normal age distribution)
No special sub-populations are considered.
Alpha value: \$10,000/person-sievert
Cost of 1 acute fatality (at 50 person-sieverts): \$500,000
Duration of protective measure: 10 days (this value was arbitrarily selected).

EVACUATION	X =	Cost of protective measure: \$2,000,000 + \$100,000/day This function includes the cost of transportation, communication and life support for evacuees. An initial high cost is due to transportation and communication, followed by a linear increase for life support.
	R =	Cost of other detriments introduced by the protective measures: \$1,000,000 + \$300,000/day This function includes the economic loss of urban evacuees + 2 fatalities from a traffic accident are assumed.
	E =	Average efficiency of protective measure: 0.7 (derived from the literature).

SHELTERING	X =	Cost of protective measure: \$25,000 + \$500,000/day
		This function includes the cost of communication and minimal life support. A linear function is assumed.
	R =	Cost of other detriments* introduced by the protective measures: \$500,000/day
		This function includes the costs of economic loss of urban evacuees. No health detriment is assumed.
	E =	Average efficiency of protective measure: 0.4 (derived from the literature).

KI PILLS	X =	Cost of protective measure: \$500,000 + \$0/day (no cost for control is assumed).
		This function includes the cost of production and distribution of KI pills. No additional costs are assumed to occur throughout the accident.
	R =	Cost of any other detriments introduced by the protective measure: \$0
	E =	Average efficiency of protective measure: 0.5 (derived from the literature.

* The cost of "other detriments" to the urban dwellers is lower for sheltering than for evacuation, since they may decide to shelter themselves at their places of business.

Calculation of Intervention Levels

The Intervention Level for a specific combination of accident and protective measures is derived from the application of the general equation (see page 14) $B=(Y_0 - Y_I) - (R + X)$. The protective measure is justified in the region where $B \geq 0$. When $B=0$, ΔY ($= Y_0 - Y_I$) is equal to $(R + X)$ and is graphically represented in Figures 1 and 2, for reference groups 1 and 2, respectively, by the points H, which is the higher point of justification, and L, which is the lower point of justification. The Intervention Level corresponds to the point where B is a maximum. The X axis is defined in number of days, starting when the impact of the accident is first felt by the reference group. The Y axes are defined by units of individual dose on the right and, on the left, by the associated costs determined from the alpha value and the number of people in the reference group. The detailed process is as follows (see also the Figures).

1. Plot projected dose Y_0 based on the accident scenario.

2. Knowing the average efficiency of the protective measure under study, plot Y_I, which is $Y_0\ (1 - E)$.

3. Plot $\Delta Y = Y_0 - Y_I$.
   Note: in order to minimise the complexity of the figures and enhance their usefulness in explaining this process, Y_0 and Y_I are plotted in the first figure only; ΔY would be arrived at in the same manner for all the figures.

4. Plot R + X (total costs) according to their functions (here see pages 42 to 45)
   Note: Plot Y axis on the left in dollar units so that the data are comparable (i.e., multiply the projected average individual dose by the number of people, then use the alpha-value to convert into dollar units. For other health detriment, convert into dollar units by using "cost of fatality" figure of $500,000/death).

5. If the protective measure is justified, the ΔY and $(R + X)$ curves will intersect (points H and L). Between L and H, which is the justification region, find the optimum point, i.e. where the difference between the two curves is the greatest and therefore B is maximum.

6. Convert the optimum point on the ΔY curve to dose using the number of people and alpha-value to get the OAD (optimised averted dose). To calculate the intervention level (IL), divide the OAD by the efficiency of the protective measure, E.

Figure 1 Intervention Levels for Reference Group 1

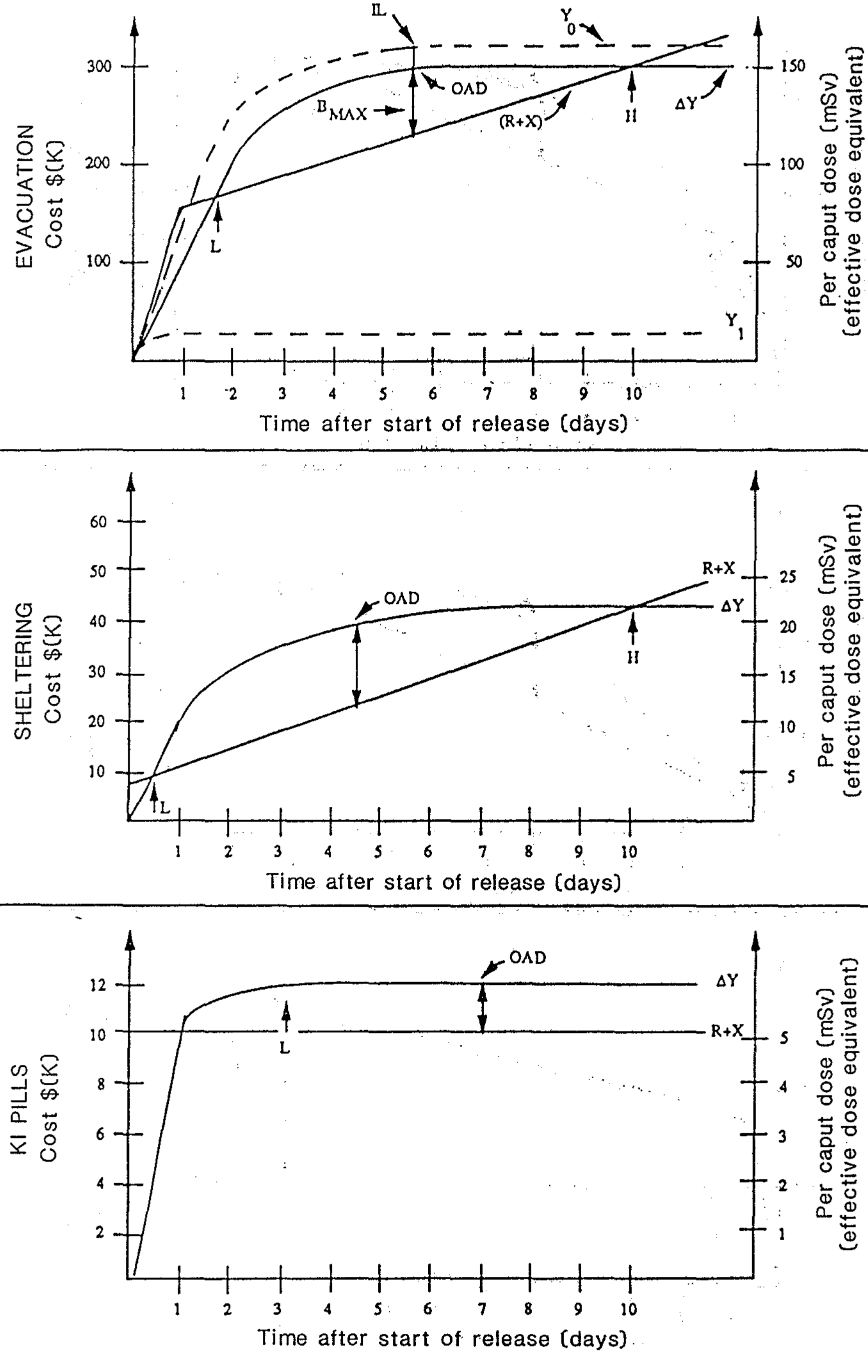
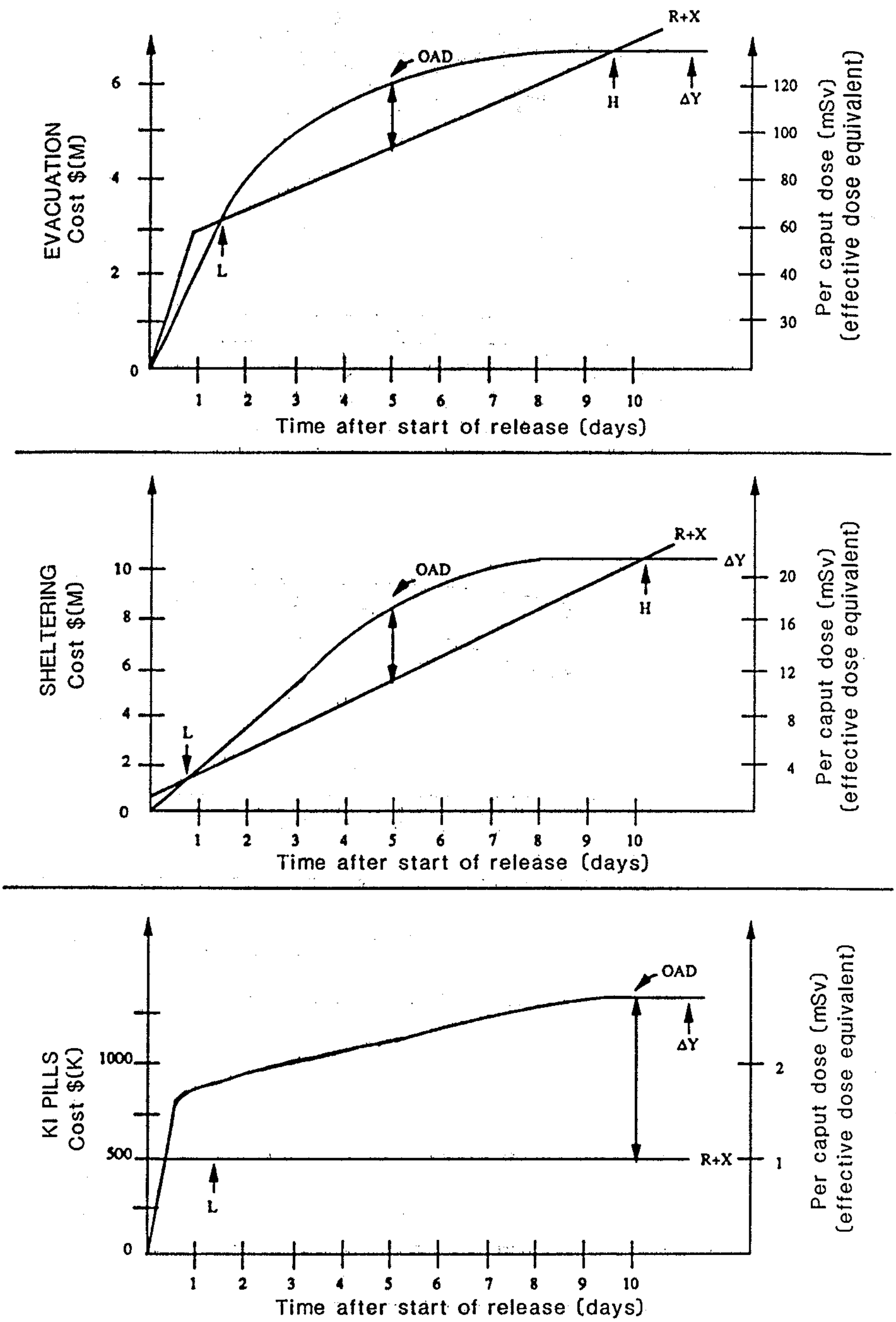


Figure 2 Intervention Levels for Reference Group 2



Intervention Levels for This Exercise

Following the above steps, the intervention levels calculated (rounded) for this exercise (see Figures 1 and 2), are as follows:

Protective Measure	IL Reference Group 1	IL Reference Group 2
Evacuation	155 mSv	170 mSv
Sheltering	50 mSv	40 mSv
KI pills	12 mSv	5 mSv

N.B. There is no relationship between compartments of the above table, since the calculations were done independently for each intervention level.

All doses are expressed as effective dose equivalents.

Considerations for Deriving Generic Intervention Levels at the Planning Stage

It must be recognised that intervention levels are only applicable to specific accidents and that their derivation is based on associated input parameters which can vary from one accident scenario to another. Such input parameters are addressed below:

1. Reference groups should be clearly determined. Examples of factors which affect the selection of the reference group are plume direction, geographic considerations, sensitive sub-populations.

2. Projected dose vs. time plots for each type of plausible accident should be determined.

3. The efficiency of protective measures should be determined. Average efficiency can be derived from the literature reporting on past accidents. A thorough knowledge should be obtained on the variation of the efficiency of protective measures with parameters such as weather conditions, number of people involved, life habits of individuals, time of day the accident occurs, whether the accident occurs on a holiday, a weekend or a weekday, etc. As an example, for this exercise the efficiency of evacuation for R_1 was 0.9, whereas for R_2 it was 0.7. The lower efficiency of evacuation for R_2 could be explained by the much greater number of people to evacuate which might cause traffic jams, or by inefficient means of communication, etc.

4. All costs associated with the implementation of the selected protective measures and how they vary with time should be thoroughly assessed in the planning stage.

5. An alpha-value should be set by the appropriate national authorities. (This can vary from country to country, depending upon the "level of effort" considered appropriate.)

6. A "cost of health detriment" should be set by the appropriate national authorities. For this exercise, the only health detriment considered was death. Other detriments such as broken limbs, stress, etc. may be considered by the national authorities.

This annex shows how to derive generic intervention levels for one accident scenario. During the planning stage, several accident scenarios should be examined and generic intervention levels derived. It should be noted that the larger the spectrum of accident scenarios examined and generic intervention levels derived, the more likely it is that the appropriate initial intervention, for the particular accident being faced, can be immediately selected from this information, without the need for comparing projected doses with intervention levels. However, since resources for emergency planning in most countries are not extensive, only a modicum of scenarios and interventions would probably be explored in the planning stage, requiring more calculations of ILs and comparisons with projected doses to be done at the time of the accident in order to choose the appropriate protective measure to be implemented initially. At later stages in the accident, when detailed information is available on the specific nature and potential impact of the accident, additional optimisation analyses may be conducted to verify the adequacy and applicability of the protective measures or to develop specific ILs for recovery actions. The use of these generic and specific intervention levels in emergency response plans as the basis for implementing one or more protective measures in the event of an accident will be discussed in Annex 3.

ANNEX 3

EXAMPLES OF THE USE OF INTERVENTION LEVELS

Introduction

The intervention levels developed in Annex 2 are used in this Annex to show how they would be applied when the accident occurs. For the sake of example, the accident scenario is assumed to closely approximate that described in Annex 2, so that those ILs would be appropriate.

Immediate Actions

The most important use of the intervention levels would be in the short-term emergency phase of the accident, when decisions must be based on incomplete information. In order to use the ILs to trigger protective measures, a value of the projected dose must be obtained. This is an average individual committed effective dose, and may be obtained from an estimate of the source term, or some measurements of air concentrations of radioactivity in the immediate vicinity of the nuclear facility, combined with an assessment of the current meteorological conditions and the appropriate dose conversion factors.

Once this estimate of projected dose is made, it is compared to the ILs, as developed in Annex 2. In practice, for each protective measure, there may be a number of ILs, based on different accident scenarios, and so the IL for the scenario most similar to the accident should be chosen. In the following numerical examples it is assumed that that choice has been made.

Once the projected dose has been obtained, it is compared to the ILs, and the protective measure with the highest IL that is still less than the projected dose, (i.e. where the difference between the PD and the IL is least) is implemented.

In most cases the efficiency of the measure will be less than one, and thus a residual dose will be left after the protective measure has been applied. This residual dose should be treated in the same way as the original projected dose to determine whether additional protective measures should be implemented.

Numerical Example

Assume that the accident, having the same scenario as that used in Annex 2, is estimated to give a projected dose of 190 mSv to reference group 2 in Annex 2. Inspection of the relevant ILs in Annex 2 shows that 190 mSv exceeds all of them, and therefore the protective measure with the highest IL, namely evacuation, IL = 170 mSv, would be carried out.

From Annex 2, the efficiency of evacuation for reference group 2 is 0.7. Therefore the residual dose will be:

(1 - 0.7) x 190 mSv = 57 mSv

The IL for sheltering is 40 mSv, and so theoretically sheltering would also be implemented. However, in practice evacuation and sheltering are incompatible when they are to be implemented simultaneously.

The next IL is then considered, namely that for KI pills (5 mSv effective dose), based on the thyroid dose from radioiodine and making the assumption that a substantial fraction of the release is radioiodine. This is exceeded by the residual dose of 57 mSv, and so the measure would be implemented, since this can be done in conjunction with evacuation. With a KI pill efficiency (see Annex 2) of 0.5, the new residual dose would be:

(1-0.5) x 57 = 28.5 mSv

If other protective measures were available, they could be tested in the same way against this new residual dose.

If, on the other hand, the <u>original</u> projected dose is only 60 mSv (instead of 190 mSv), then the highest IL that is less than this value is 40 mSv, for sheltering. This protective measure would be implemented, leaving a residual dose of:

(1 - 0.4) x 60 = 36 mSv

Again, this residual dose is greater than the IL for KI pills, and this protective measure would also be implemented.

One could have also considered a different combination of the available countermeasures (e.g., sheltering plus stable iodine administration without evacuation). However, in this example, a calculation confirms that the proposed sequence of actions is the optimum one.

<u>Later Actions</u>

When sufficient time has elapsed for more accurate and detailed dose projections to have been made, modifications to the implemented countermeasures may be made. The most easily variable factor is the duration of evacuation or sheltering and this should be adjusted in the light of updated dose information, using the procedures described in Annex 2.

In addition, further countermeasures such as restrictions on food consumption may be implemented, based on <u>derived</u> intervention levels.

As an example, a method of implementing protective measures for milk consumption is described. For this purpose, a Derived Intervention Level for iodine-131 in milk is set at 500 Bq/l.

For milk, the projected iodine concentration based on ground deposition (without sheltering of the cattle during the outdoor season) is estimated, assuming a conversion factor of 0.05-0.10 from grass to milk. The assumed deposition of 100 kBq/m^2 of radioiodine would give 5,000 to 10,000 Bq/l in milk. These peak values would be reached in a few days after the deposition and high values in milk would last for a couple of weeks and then decrease.

However, based on concentration of iodine in air, a decision was taken earlier to recommend sheltering of cattle. In that decision consideration was given to the availability and distribution possibilities of dry uncontaminated feedstuff, and alternative use of the milk (see calculation below).

A control programme was also established to follow the activity concentrations in grass and in the milk.

Discussion Concerning the Optimisation of Countermeasures

The following options are considered:

1. Not sheltering cows, and throwing away all milk above a level of 500 Bq/l. Milk below 500 Bq/l would be consumed.

2. Sheltering cows and throwing away all milk above a level of 500 Bq/l. Milk below 500 Bq/l would be consumed.

3. Not sheltering cows, and processing the milk above 500 Bq/l for other products. Milk below 500 Bq/l would be consumed.

Assumptions for the calculations (as indicated above), are the following:

1. Non-sheltered cows would give milk with iodine peak levels of 5,000 - 10,000 Bq/l; an average of 2000 Bq/l is assumed for the first 20 days. After those 20 days the levels in milk from non-sheltered cows are assumed to be below 500 Bq/l, and an average of 250 Bq/l is assumed during the next 10 days. The non-sheltered cows would give essentially iodine-free milk after a total of 30 days.

2. The sheltered cows are assumed to give milk with iodine peak levels of 500 - 1,000 Bq/l mainly due to inhalation of iodine, as well as due to some contamination of the stored fodder, but the iodine concentration is assumed to exceed 500 Bq/l for one day only. During the next ten days, the level would be on an average of 250 Bq/l. After about 20 days of sheltering, the levels would be almost zero. Sheltering is assumed to last for about 20 days, after which the cows are let outside. The levels of iodine in milk are then assumed to increase and reach an average of 250 Bq/l during the following 10 days, i.e., about the same situation is assumed to exist as in the "non-sheltering" case after 20 days.

3. 100,000 cows are concerned and are assumed to produce 3 million litres of milk per day.

4. All the milk above 500 Bq/l is assumed to be destroyed for options 1 and 2 and the cost for destroyed milk is assumed to be 1 dollar/l.

5. The costs for feeding the 100,000 cows for 20 days with iodine-free or almost iodine-free fodder is estimated to be 10 million dollars, assuming a consumption of 20 kg/day at a price of 0.25 dollars/kilo.

Calculations

The question to be discussed is now whether a decision to shelter the cows and feed them with uncontaminated (expensive) fodder gives a net benefit over letting the cows pasture outside and throwing away the milk or possibly processing it for other purposes.

Option 1: For the non-sheltering option the following calculation can be done:

Days 1 - 20: The milk is destroyed, because the levels of iodine are too high, i.e. above 500 Bq/l.
20 days x 3.10^6 l/day gives 60.10^6 l.
This milk is assumed to have an average concentration of iodine of 2,000 Bq/l. The dose averted because of the destruction of milk will therefore be:
60.10^6 l x 2 10^3 Bq/l x $1.1.10^{-7}$ Sv/Bq = 13,200 manSv. The dose conversion factor refers to effective dose to infants.
The cost for the destroyed milk is 60 million dollars.

Days 21 - 30: The milk is assumed to have an average concentration of iodine of 250 Bq/l. The corresponding projected dose will be:
10 days x 3.10^6 l/day x 250 Bq/l x $1.1.10^{-7}$ Sv/Bq = 800 manSv.
Thus, for non-sheltered cows the cost associated with destroyed milk is estimated to be 60 million dollars. There are no costs for additional fodder, because they go on pasture. The dose averted by destroying the milk is estimated to be 13,200 manSv, and the dose from consumption of contaminated milk from day 21 to 30 is calculated to be about 800 manSv.

Option 2: The sheltering option gives the following impact:

Day 1: Milk is destroyed, because the levels of iodine are above 500 Bq/l, as an average 1,000 Bq/l. The dose averted because of the destruction of milk will be
3.10^6l x 1.10^3Bq/l x $1.1.10^{-7}$Sv/Bq = 330 manSv.
3,000,000 l of milk destroyed correspond to a cost of 3 million dollars.

Days 2 - 11: Milk is assumed to have levels below 500 Bq/l, an average of 250 Bq/l is assumed.
10 days x 3.10^6 l/day x 250 Bq/l = $7.5.10^9$ Bq
This gives a projected residual dose of 800 manSv, assuming the same dose conversion factor as above.

Days 12 - 20: No dose.
Days 21 - 30: The milk is assumed to have an average concentration of iodine of 250 Bq/l, which corresponds to a projected residual dose of 800 manSv.
Thus, for sheltered cows the cost associated with destroyed milk is estimated to be 3 million dollars. The cost for uncontaminated or low contaminated fodder for 20 days is estimated to be 10 million dollars. The dose from consumption of contaminated milk for days 2 - 30 would be 1600 manSv. If the sheltering is not 100% effective the costs will, of course, increase somewhat.

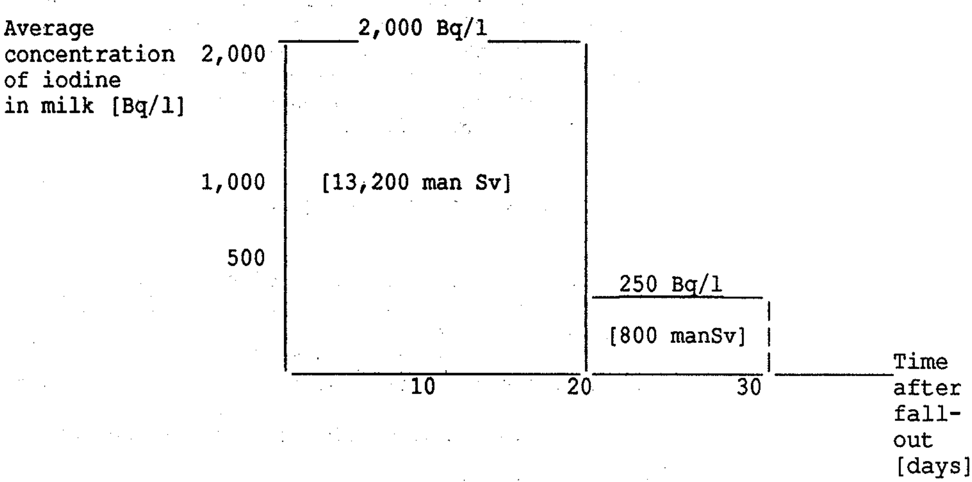
Option 3: Not sheltering cows, but processing the milk with iodine concentration above 500 Bq/l for cheese:

This means that no milk will be destroyed, instead it will be processed into cheese, which then can be consumed when the iodine contamination has decayed. This alternative should therefore give no dose consequences, apart from the residual dose received from consumption of milk after day 20, when it is assumed to have an iodine concentration of 250 Bq/l as average during 10 days.

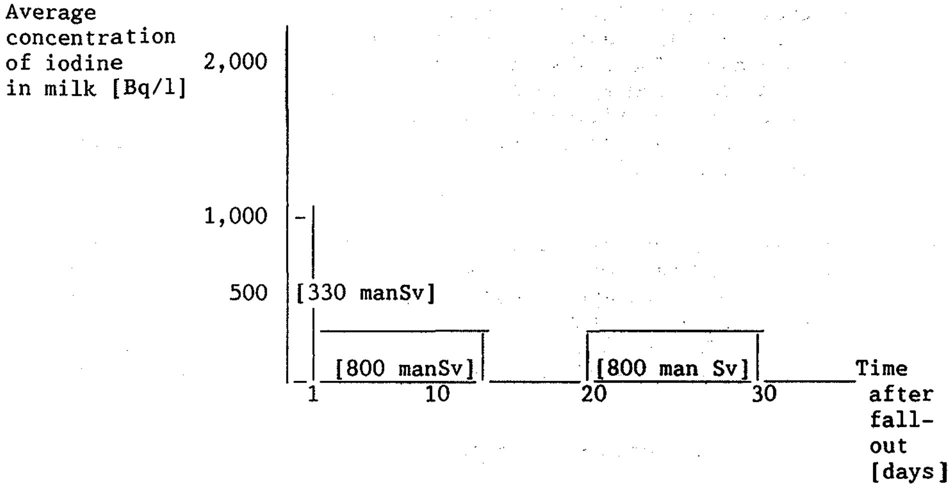
Discussion

The following figures are intended to illustrate options 1 and 2 as regards the dose impact from the consumption of iodine contaminated milk.

Option 1 [Non-sheltering]



Option 2 [sheltering]



The following observations can be made:

Option 1: The projected collective dose from this option during the relevant period of time considered is:

(a) 13,200 manSv, from the consumption of milk with iodine concentration above 500 Bq/l, and

(b) 800 manSv, from the consumption of milk with iodine concentration below 500 Bq/l.

Thus in total 14,000 manSv is projected. This is the collective dose which would be received if all milk were used for direct consumption. However, with an intervention level of 500 Bq/l, 13,200 manSv would be averted to a cost of 60 million dollars. The residual dose would be 800 manSv.

Option 2: In this case, where sheltering of the cows is assumed, the projected collective dose, during the same time period as in option 1, is:

(a) 330 manSv from the consumption of milk with iodine concentration above 500 Bq/l (day 1)

(b) 800 manSv from the consumption of milk during the following 10 days when the iodine concentration is assumed to be below 500 Bq/l, and finally

(c) 800 manSv from the consumption of milk with an average concentration of 250 Bq/l when the cows are fed with fresh pasture outdoors.

Thus, a total of 1,930 manSv is projected. This is the collective dose which would be received if all milk were used for direct consumption.

However, with an intervention level of 500 Bq/l, 330 manSv would be averted. The residual dose in this case would be 1,600 manSv. The costs involved in this option are related to the cost for feeding the cows with uncontaminated fodder, amounting to 10 million dollars for 20 days, and that associated with the destruction of milk which is contaminated above the intervention level.

Option 3: In this case the cows will not be sheltered and the milk from the first 20 days will be processed for later consumption, when the iodine has decayed. For reasons of simplification, no cost is associated with this option, because all milk is assumed to be used. The residual dose in this case would be 800 manSv, because milk below 500 Bq/l is assumed to be consumed directly.

Summary of Calculations

Options	Costs		Collective Dose Associated with the Options
	Destroyed Milk [million dollars]	Fodder [million dollars]	[manSv]
1. Non-sheltering			
a) No IL	-	-	14,000*
b) IL (500 Bq/l)	60	-	800
2. Sheltering (20 first days)			
a) No IL	-	10	1,930
b) IL (500 Bq/l)	3	10	1,600
3. Non-sheltering food processing (20 first days)	-	-	800

* Total collective dose in the absence of countermeasures.

The above calculations show that the least expensive option among the ones studied is to let the cows pasture outside and to use the contaminated milk for other food products, such as cheese or milk powder, which can be stored and consumed when the iodine has decayed. In the example considered, however, the decision-makers do not have this alternative, because enough processing capacities do not exist, and the contamination also includes long-lived radionuclides, such as caesium.

The two other options to reduce the impact of the iodine contamination of milk include, in option 1 the destruction of milk above a given intervention level, and in option 2 the sheltering of cows and the use of the same intervention level as above.

The first option costs 60 million dollars and averts 13,200 manSv, i.e., a cost-benefit ratio of 4,500 dollars per manSv.

The second option costs 13 million dollars and averts 12,400 manSv, i.e., a cost-benefit ratio of 1,000 dollars per manSv.

The second option, although involving a higher residual collective dose, is therefore chosen.

ANNEX 4

SOME EXPERIENCE WITH SPECIAL EXPOSURE PATHWAYS FROM THE CHERNOBYL ACCIDENT

Some examples of special exposure pathways, impacts and countermeasures are given below in order to illustrate the particular problems that can be experienced after a large environmental contamination with radioactive substances. These examples mainly refer to the Swedish experience, but similar situations have been observed in other countries.

Sweden

- **Agricultural contamination**

Besides the problems of food from contaminated agricultural areas, there was a concern among farmers and others, during the Chernobyl accident, about radiation exposures from inhaled dust during work on the fields, external exposure from large volumes of collected grass or hay, internal contamination caused by contaminated agricultural equipments and ashes from burned hay, etc.

The farmers were recommended to use simple protection procedures to avoid unnecessary exposure. This often meant the use of protection means which also served to reduce the conventional risks at work, like the use of an air filter on the tractor cabin to prevent inhalation of dust during ploughing.

These groups of workers are of course not traditional radiation workers and, therefore, were not subject to individual monitoring. Some monitoring was done, however, but the monitoring studies revealed no elevated external and internal exposure as a consequence of the work. A temporary level of intervention was established (5 mSv, effective dose equivalent, for the first year).

- **Vehicles and people arriving from the most affected areas**

Some vehicles arriving from the potentially most affected areas were also monitored. The results were evaluated on a case by case basis and no special protective actions were considered necessary.

- **Practices that increase the contamination levels**

Recommendations were given concerning the use, handling and disposal of sewage sludge, peat and ashes. For sewage sludge, there was a derived intervention level (20,000 Bq/kg dry weight of total gamma activity) temporarily established in order to prevent the sewage sludge with the highest levels of radioactive concentration from being spread on the fields as a fertilizer. For contaminated peat, a similar recommendation was issued. The activity limit was adjusted to take into consideration the amount normally spread on the fields or on private gardens.

Furthermore, activity concentrations in ashes when burning contaminated wood and peat at heating/power production plants were sometimes found to be rather high (~ 100,000 Bq/kg of cesium 137). This caused elevated radiation levels in some work places, and, therefore, some recommendations were issued concerning the protection of workers in some of these plants, in addition to some restrictions concerning the environmental impact (disposal of the ash, release into air).

Activity levels in conventional air filters in industries, large buildings, boats, etc., were sometimes of interest from the radiation protection point of view and some recommendations were given on practical protection methods like wearing gloves and face mask during change of filters, keeping some minimum distance from a filter bank during continuous stay, etc.

- **Others**

Other examples of potential or real exposure pathways were drinking rainwater (should be avoided if possible), contamination of washed clothes hung up outdoors for drying (no restrictions given), contaminated water in ditches near fields with grazing cows (could be a problem), military exercises in the forest (no restrictions given).

The basis for intervention in terms of dose was set to 1 mSv (effective dose equivalent, first year) for members of the public and 5 mSv (effective dose equivalent, first year) for persons exposed as a result of their occupational duties.

Other OECD/NEA Member Countries

Recommendations concerning several of these impacts were also issued in other Member countries, particularly for sewage sludge in order to avoid sludge with the highest concentrations of radioactive substances to be used as fertilizers. Disposal at ordinary waste disposal sites was recommended for the "most active" media.

Generally, it seems that recommendations concerning contaminated substances and environmental media were issued on comparative rather than absolute quantitative grounds. Some estimates were apparently made on the significance of these options in relation to the actual doses received from other pathways. If the total dose received was not significantly increased by the practice, then it was accepted to continue as before the contamination.

ANNEX 5

JUSTIFICATION AND COST-BENEFIT ANALYSIS ON RESTRICTION OF PEAT ASH UTILISATION AFTER RADIOACTIVE FALL-OUT

(An example from Finland)

Summary

Restriction of peat ash use for various applications is considered from the point of view of radiation protection. Interruption of peat ash use and removing the ash to dumps is considered as a protective action. The aim is to find the activity levels in peat ash at which this intervention is justified and optimised. The table shows the optimised intervention concentrations of ^{137}Cs in peat ash at different utilisation applications and the individual and collective committed doses at these intervention levels.

Use of peat ash (annual use amounts)	Optimised intervention level (kBq/kg of ^{137}Cs)	Committed Dose Equivalent Individual (mSv)	Collective (manSv)
Fertilizer use in agriculture 110,000 tons/year	290	0.73	74
Fertilizer use in silviculture 110,000 tons/year	450	0.72	72
As a landfill material 110,000 tons/year	200	110	110
In concrete for house construction 16,000 tons/year	1.4	3.0	54

Introduction

Peat combustion in Finland produces annually about 110,000 tons of dry peat ash. Peat ash has been used for several useful purposes. After the fall-out from the Chernobyl accident, it was evident that ash from the fuel peat harvested in the essential fall-out region in Finland would contain significant amounts of radionuclides.

This annex deals with justification and cost-benefit analysis on restriction of utilisation of contaminated peat ash. As a starting point we have a situation where peat ash is used as a fertilizer 1) in agriculture, and 2) in silviculture, as 3) a landfill material and as 4) a raw material in the concrete industry. Interruption of peat ash utilisation and removing ash to dumps is considered as a remedial measure of radiation protection. The aim is to find the activity levels in peat ash at which this protective measure is justified and optimised for different applications.

Formulation of the problem

Use of peat ash is a "pre-existing situation" and interruption of the use and removal of the contaminated ash to dumps is considered as a remedial measure. In cost-benefit terms, the decision of the intervention can be presented as:

$$B = (Y_o - Y_I) - (R+X) \qquad (1)$$

where B is the net benefit achieved by the remedial measure, Y_o is the radiation detriment cost if the remedial measure is not taken, Y_I is the remaining radiation detriment cost if the remedial measure is carried out, R is the detriment cost consequent upon the risks introduced by the remedial measure itself, and X is the cost of the remedial measure. $\Delta Y = Y_o - Y_I$ is the total detriment cost avoided by the remedial measure. The exposed individuals may get radiation dose from several exposure routes.

The interruption of peat ash use is justified only if the net benefit of the intervention is positive, i.e $B>0$. In the following, each way of peat ash utilisation is considered separately.

Fertilizer Use in Agriculture

Because of its alkalinity, peat ash has been used as a fertilizer in agriculture. Some radioactivity of peat ash will dissolve in soil water and become available for plants. Rough estimates of the radiation dose received from eating foodstuffs grown on fields fertilized with peat ash can be made by comparing the radioactivity deposited with peat ash and the radioactivity directly deposited as a fall-out from the Chernobyl accident, and by using the radionuclide concentrations of the Finnish agricultural products caused by the Chernobyl fall-out. In this estimation we assume that 10 tons of peat ash is spread over a hectare of tilled soil and that 15% of cesium isotopes in peat ash would be available for plants. In the dose estimates only the cesium isotopes, ^{137}Cs and ^{134}Cs are taken into account. The average consumption figures of different foodstuffs and intakes of ^{137}Cs in the first year after the fall-out are given in Table 1. The table also gives the estimates on ^{137}Cs intakes in the case where peat ash, with ^{137}Cs concentration of 1 kBq/kg, is spread on a hectare of tilled soil.

Let us assume that all the peat ash (110,000 tons/year) is spread on tilled soil, 200,000 persons are eating foodstuffs grown on these fields and 10,000 farmers are exposed to radioactive dust while spreading the ash and to external radiation on the fields. Using the ALI-values of 3.7×10^6 Bq for ^{137}Cs and 2.5×10^6 Bq for ^{134}Cs in oral intake we can estimate that one ton of peat ash, with ^{137}Cs concentration of 1 kBq/kg, will cause a collective dose equivalent of $S_1 = 2.1 \times 10^{-6}$ manSv/a through foodstuffs.

Table 1

Average consumption figures of different agricultural products and the mean intakes of ^{137}Cs from eating these products in the first year after the Chernobyl fall-out in Finland. The weighted mean of the ^{137}Cs deposition from the Chernobyl fall-out was 16 kBq/m². From these figures the intakes of ^{137}Cs from peat ash fertilization were estimated when 10 tons of peat ash with the ^{137}Cs concentration of 1 kBq/kg is spread on a hectare of tilled soil. 15% of cesium in peat ash is assumed to be available for plants. Activity of ^{134}Cs is assumed to be half of that of ^{137}Cs.

Foodstuff	Consumption (kg/a)	Intake of ^{137}Cs (Bq/a) From Chernobyl fall-out	From peat ash fertilization
Milk products	270	5,000	47
Cereals	72	140	1.3
Potatoes	67	200	1.9
Vegetables	34	77	0.72

When estimating the external radiation dose on the fields, the conversion factors from plane source to effective dose equivalent of 2.1×10^{-6} µSv/h per Bq/m² for ^{137}Cs and 5.4×10^{-6} µSv/h per Bq/m² for ^{134}Cs are used. The exposure time of a farmer is assumed to be 500 hours in a year. This means that one ton of peat ash, with ^{137}Cs concentration of 1 kBq/kg, will cause a collective dose equivalent of $S_2 = 2.2 \times 10^{-7}$ manSv/a from external exposure.

In the dust exposure, a dust concentration of 10 mg/m³, a breathing rate of 1.2 m³/h and an exposure time of 500 hours in a year are assumed. Using the ALI-values of 5.7×10^6 Bq for ^{137}Cs and 4.0×10^6 Bq for ^{134}Cs in inhalation intake we can estimate that one ton of peat ash, with ^{137}Cs concentration of 1 kBq/kg, will cause a collective dose equivalent of $S_3 = 8.2 \times 10^{-9}$ manSv/a through inhaled dust.

"The unit dose", S_o, from the use of peat ash in agriculture is the sum from these different exposure routes, being

$$S_o = 2.3 \times 10^{-6} \text{ manSv/a per ton per 1 kBq/kg of } ^{137}Cs \qquad (2)$$

If all of the peat ash is used for fertilization in agriculture, the use rate, m, is 110,000 tons/year = 12.6 tons/h. In a time period t the use of peat ash, with ^{137}Cs concentration of A(t), will cause a collective dose of

$$S(t) = S_o\, m\, t\, A(t), \qquad (3)$$

where A(t) is a function of time. If the use of peat ash is interrupted at the time t = 0 and the ash is transported to dumps, the collective dose avoided by this remedial measure during the time period, τ, is

$$\Delta S = S - S' = S_o m \left[\int_0^{\infty} A(t)dt - \int_{\tau}^{\infty} A(t)dt\right] = S_o m \int_0^{\tau} A(t)dt \qquad (4)$$

The corresponding avoided detriment cost is

$$\Delta Y(\tau) = \alpha\, S_o\, m \int_0^{\tau} A(t)dt \qquad (5)$$

where α is the cost assigned to the collective dose unit.

The dose received during the transport of ash is not taken into account, because the same dose is received whether the ash is transported for fertilizer use or to dumps. So the cost of the other detriments, R, can here be assumed to be zero. Also the storing of ash on dumps is not assumed to cause any radiation dose to the public.

The cost of the remedial measure, X, consists of the dump charges, a, (a = 6.6$ per ton) and of the cost, b, of soil-improving lime compensated by the peat ash (b = 23$ per ton of lime). One ton of peat ash compensates about 0.3 ton of lime, so one ton of peat ash will cost 0.3 x 23$ as a soil improving lime. The cost of the remedial measure during a time period, τ, is

$$X(\tau) = (a + 0.3b)\, m\, \tau \qquad (6)$$

The net benefit of the remedial measure as a function of the lasting time of the measure can be written

$$B(\tau) = \Delta Y(\tau) - X(\tau) = \alpha S_o m \int_0^{\tau} A(t)dt - (a+0.3b)m\tau \qquad (7)$$

$B(\tau)$ reaches the maximum value when $dB/d\tau = 0$, i.e

$$\alpha\, S_o\, m\, A_{\tau} - (a+0.3b)\, m = 0 \qquad (8)$$

After that time period, τ, the remedial measure has a decreasing net value and τ is the optimum time for terminating the remedial measure, i.e, the use of peat ash in agriculture would again be allowed. At the time τ the ^{137}Cs concentration in peat ash is

$$A_{\tau} = \frac{a + 0.3b}{\alpha S_o} \qquad (9)$$

With an α value of 20,000$/manSv we get the optimum level of 290 kBq/kg of ^{137}Cs to terminate the remedial measure. This same concentration is also the optimum intervention level to start the remedial measure, i.e. to interrupt the peat ash use in agriculture. If this kind of peat ash is used for fertilization in agriculture, the collective committed dose equivalent from one year consumption of peat ash (8760 hours) would be

$$S = S_o\ m\ 8760 \times 290 = 74 \text{ manSv}$$

This collective dose consists of 67 manSv from eating foodstuffs, 7 manSv from external radiation and 0.3 manSv from dust exposure. The individual committed doses from eating foodstuffs would be 0.34 mSv and, from external radiation and from dust exposure together, 0.73 mSv. If a lower value of α is used, a higher intervention concentration would result.

Figure 1 illustrates the situation where ash of fuel peat produced in successive summers after the fall-out is homogeneous concerning its activity. The activity in ash of peat harvested in the first summer is A_1, in the second summer A_2, in the third summer A_3. etc. In the figure, the straight line $X(t) = (a+0.3b)mt$ is as a limit for justification. Above the line, in the darkened area limited by ΔY, the remedial measure is justified (B>0).

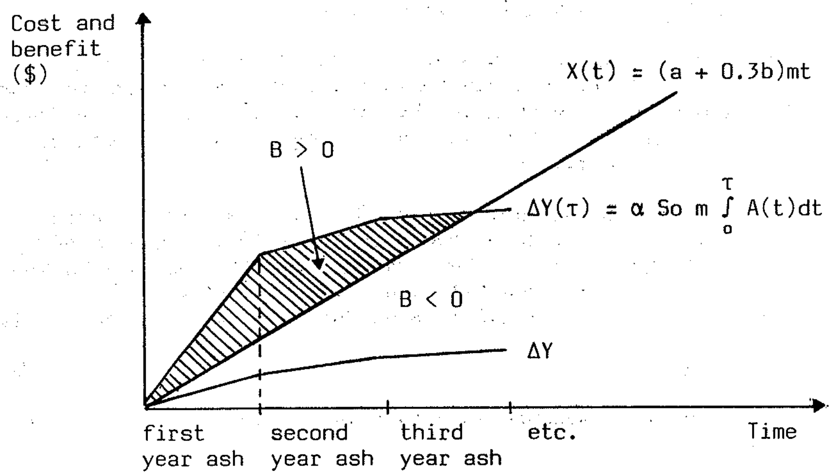


Figure 1. Cost X(t) of interruption of peat ash utilisation and the cost of the avoided dose Y(t) from interruption of peat ash utilisation, both as a function of time.

If ΔY were always below this straight line, the remedial measure would not be justified. If the first year activity, A_1, is greater than the intervention activity, A_τ, and, on the other hand, the second year activity, A_2, is smaller than the intervention activity, the remedial measure should be terminated when ash of the second year peat is started to be handled, in spite of the fact that the net benefit is still positive.

Fertilizer Use in Silviculture

Also here we assume that all of the ash is spread in forests with an amount of 10 tons per hectare, and people are exposed to radiation through three different routes: by eating wild mushrooms and berries gathered from forests fertilized with peat ash, from external radiation and from dust exposure while spreading the ash. Here we assume that 1,000 people are participating in ash spreading with an annual exposure time of 500 hours, and 100,000 people are exposed to radiation by eating mushrooms and berries and to external radiation while gathering these products. Their exposure time in forests is assumed to be 300 hours per year.

Estimates of the radiation dose from eating mushrooms and berries are made by comparing the deposited activities from the Chernobyl fall-out and from the peat ash fertilization, and by using the radionuclide concentrations of mushrooms and berries caused by the Chernobyl fall-out. As a result we get an estimate that one ton of peat ash, with ^{137}Cs concentration of 1 kBq/kg, will cause a collective dose equivalent of $S_1 = 1.6 \times 10^{-7}$ manSv/a through mushrooms and berries.

In a similar way as in the previous example we can estimate that one ton of peat ash, with ^{137}Cs concentration of 1 kBq/kg, will cause a collective dose equivalent of S_2 = 1.3 x 10^{-6} manSv/a through external radiation. The collective dose equivalent from dust exposure, in this case, will be S_3 = 8.3 x 10^{-10} manSv/a per ton of peat ash with ^{137}Cs concentration of 1 kBq/kg, if the dust concentration is 10 mg/m³.

"The unit dose", S_o, from the use of peat ash in silviculture is the sum from these different exposure routes, being S_o = 1.5 x 10^{-6} manSv/a per ton per 1 kBq/kg of ^{137}Cs.

The cost of the remedial measure, interruption of peat ash use and transporting the ash to dumps, consists of the dump charges, a, and of the cost, b, of soil improving lime compensated by the peat ash, being the same as in the previous example, formula (6). With the same routine as in the previous example we get 450 kBq/kg of ^{137}Cs for the optimum activity to terminate the remedial measure (α value of 20,000 $/manSv). This is also the optimum level to start the intervention, i.e, to interrupt the peat ash use in silviculture. If this kind of peat ash is used for fertilization in forests, the collective committed dose equivalent from one year's consumption of peat ash would be 72 manSv. This collective dose consists of 8 manSv from eating mushrooms and berries, 64 manSv from external radiation and 0.04 manSv from dust exposure. The individual committed doses from mushrooms, berries and external radiation would be 0.72 mSv (100,000 persons) and from dust exposure 0.04 mSv (1,000 persons).

Use as a Landfill Material

When peat ash is used as a landfill material, it is piled up in large amounts at one place. Usually, peat ash is handled moistened so the dust exposure is insignificant. The only exposure route is the occupational exposure to external radiation, provided that residents of the neighboring area stay away from the piling site. Here we assume that 1,000 workers are working at these kind of sites, their annual working time is 2,000 hours and the whole annual ash amount, 110,000 tons, is used for this purpose. At a large piling site the effective dose equivalent rate from ^{137}Cs is 0.12 µSv/h per 1 kBq/kg and, from ^{134}Cs, it is 0.15 µSv/h per 0.5 kBq/kg (thick and flat ash field). From these figures we can estimate that one ton of peat ash, with ^{137}Cs concentration of 1 kBq/kg, will cause a collective dose equivalent of S_o = 5.0x10^{-6} manSv/a.

Interruption of the use of peat ash and removing it to dumps is considered as a remedial measure. The cost of the remedial measure, X, consists of the dump charges (a = 6.6$ per ton), the cost of the soil material compensated by the peat ash (b = 1.1$ per ton) and the transport charges of the soil material compensated by the peat ash (c = 1.5$ per ton). According to the previous examples, the remedial measure can be terminated when $dB/d\tau$ = 0, corresponding to the optimum ^{137}Cs concentration of 200 kBq/kg. This activity is also the optimum intervention level to interrupt the peat ash use as a landfill material. If this kind of peat ash is used as a landfill material, the collective dose equivalent from one year's practice would be 110 manSv. The individual dose would be 110 mSv/a (1,000 workers) and the individual dose rate would be 55 µSv/h.

Use as a Raw Material in the Concrete Industry

In Finland, one concrete factory used peat ash in concrete production before the Chernobyl fall-out. The factory can use 16,000 tons of peat ash in a year. Here we assume that all this ash would go to the concrete of housing construction. The annual ash amount of 16,000 tons would be enough for 4,500 concrete dwellings, if 100 kg of ash is mixed in one cubic meter of concrete and 35m^3 of concrete is needed for one dwelling. About 18,000 persons would live in these dwellings. Individual dose equivalent caused by the cesium isotopes in concrete in this kind of dwelling would be, in the first year, 0.14 mSv/a, if the ^{137}Cs concentration in peat ash is 1 kBq/kg and the ^{134}Cs concentration in peat ash is 0.5 kBq/kg (0.06 mSv/a from ^{137}Cs and 0.08 mSv/a from ^{134}Cs). The individual committed dose equivalent during the next 50 years would be 2.1 mSv. From these figures we can estimate that one ton of peat ash, used as a raw material in concrete production, with ^{137}Cs concentration of 1 kBq/kg would cause a collective dose equivalent of $S_o = 2.4 \times 10^{-3}$ manSv/a.

Interruption in the use of peat ash and removing it to dumps is, also in this example, considered as a remedial measure. The cost of the remedial measure, X, consists of transport charges of ash to dumps (a = 10$ per ton; there are no transport costs when ash is used in the concrete factory, because, in this special case, the transmission set of pipes for peat ash has earlier been built directly from the power plant to the factory), of the dump charges (b = 6.6$ per ton), of the loss of the benefit from disposing of ash (c = 3$ per ton; in a normal situation the power plant sells the ash to the concrete factory) and of the cost of the fine grained filler sand compensated by the peat ash (d = 10$ per ton). In this example it is assumed that the consumption of filler sand in volume is the same as that of peat ash, i.e. 40,000 m^3/a, which means about 80,000 tons of sand per year. According to the previous examples, the optimum ^{137}Cs concentration of ash to start the intervention, and also to terminate it, is <u>1.4</u> kBq/kg. If this kind of ash is used in concrete, the collective committed dose equivalent from one year's practice would be 54 manSv. The corresponding individual dose commitment would be 3.0 mSv during the next 50 years. The individual dose in the first year would be 0.20 mSv.