IAEA-TECDOC-1432

Development of an extended framework for emergency response criteria

Interim report for comments
jointly sponsored by IAEA and WHO

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International Atomic Energy Agency

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FOREWORD

One of the major lessons from past nuclear and radiological emergencies (such as the Chernobyl and Goiânia accidents) is that the non-radiological (e.g. detrimental economic, social and psychological) consequences may have been worse than the direct radiological consequences. Many authors indicated that the lack of pre-established guidance that was understandable to the public and officials at the time contributed to the occurrence of these non-radiological consequences.

In March 2002, the IAEA's Board of Governors approved a Safety Requirements publication, Preparedness and Response for a Nuclear or Radiological Emergency, jointly sponsored by seven international organizations, which establishes the requirements for an adequate level of preparedness and response for a nuclear or radiological emergency in any State. The Safety Requirements stipulate, that "…urgent protective actions, in accordance with international standards, shall be taken to prevent to the extent practicable the occurrence of severe deterministic health effects…." and "…optimized…intervention levels…shall be established that are in accordance with international standards…"

The IAEA's General Conference, in Resolution GC(46)/RES/9 (Measures to Strengthen International Cooperation in Nuclear, Radiation, Transport and Waste Safety, D para. 1), encouraged Member States "to implement, if necessary, instruments for improving their own preparedness and response capabilities for nuclear and radiological incidents and accidents, including their arrangements for responding to acts involving the malicious use of nuclear or radioactive material and to threats of such acts" and has further encouraged them to "implement the Safety Requirements for Preparedness and Response to a Nuclear or Radiological Emergency".

A rigorous examination of the response to past emergencies has shown that there is a need for additional consistent international guidance on taking protective and other response actions and for placing the guidance in a context that is both comprehensive for the decision makers and can be explained to the public. Simply stated, the public wants to know how response actions ensure their safety and that of their loved ones.

The purpose of the present report is to propose and to provide the basis for an extended framework of response criteria for nuclear and radiological emergencies, and to stimulate independent discussion and comment. The Secretariat recognizes that the International Commission on Radiological Protection is at the time of writing reviewing its recommendations on radiological protection. After a period of time to allow for feedback on the present report it is envisaged that a consensus on international guidance that is readily applicable in emergencies will be possible.

This report was co-sponsored by the World Health Organization (WHO). The IAEA officer responsible for this publication was E. Buglova of the Division of Radiation, Transport and Waste Safety.

EDITORIAL NOTE

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CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

Experience from response to recent nuclear and radiological emergencies has clearly demonstrated the importance of an efficient response system that includes, among other components, emergency plans, procedures, and internally consistent operational criteria. An analysis of lessons identified from recent responses has shown that a lack of crucial components in the emergency response system could result in major radiological and non-radiological consequences at the national level. One of the reasons for the overwhelming psychological consequences of the Chernobyl and Goiânia emergencies was public mistrust of decision-makers, who lost their credibility by frequently changing the criteria for taking action.

Moreover, national response arrangements that are incompatible among countries can result in major mistrust by the public. It is considered important to have internationally agreed criteria and guidance for emergency response established in advance of an emergency.

Currently there are several IAEA safety standards that contain recommendations for response to radiation emergencies, addressing principles and response criteria. The Safety Guide published in 1994 [1] provides radiation protection principles for intervention in a nuclear or radiological emergency. This guidance formed the basis for the relevant radiation protection requirements of the Basic Safety Standards on intervention in emergency situations, published in 1996 [2].

Mindful of the lessons identified from recent emergencies, the IAEA convened in November 2001 a technical committee meeting (TCM) to develop aspects of the technical basis for emergency response to radiation emergencies. At this meeting, the lessons from response to the Chernobyl, Goiânia and other emergencies over the past years were examined to identify where revisions were needed to the existing international guidance [1, 2] for response. In particular, the existing international criteria and guidance for taking protective and other actions[1] were examined in the light of these lessons.

The TCM concluded that while the nature and extent of past emergencies are dissimilar, the lessons concerning emergency response are very similar, e.g.:

- Non-experts (the public and decision makers) implement protective and other actions.
- The public and decision makers want to know that they and their loved ones are safe, so a rationale based only on cost benefit and averted dose is not helpful in addressing this concern.
- Criteria consistent with established radiation protection principles cannot be effectively developed during or after an emergency because the public will likely mistrust officialdom and because it will appear that such criteria are based not on science but political expediency.
- Non-radiological (e.g. economic, social and psychological) consequences may become worse than the radiological consequences due to a lack of pre-established guidance that is understandable to the public and officials.

[1] Other actions include providing public information, medical treatment and long term medical follow-up.

- Many response decisions are presently not supported by appropriate international guidance.

One of the most important lessons therefore is the need to have prepared a set of internally consistent intervention levels for taking protective and other action during the various phases of an emergency situation.

The TCM made the following recommendations:

- International guidance for implementing protective and other actions to alleviate the radiological consequences of an emergency ought to be based solely on radiation protection considerations[2].
- International guidance based on an internally consistent foundation need to be developed for the application of radiation protection principles and insights for the full range of protective and other actions, emergency conditions and phases. Criteria for implementation of protective and other actions needs to be consistent across all phases of the response[3].
- International guidance ought to be based on realistic assumptions, include a clear statement of the conditions under which it applies and specify when and how it should be revised. The basis for the realism of the assumptions needs to be documented[4].
- Internationally endorsed default operational intervention levels (OILs) and methods for revision of these OILs need to be developed. The OILs need to ensure that all members of the population are protected[5].

[2] In the years after the Chernobyl accident, the former Soviet Union – due to public pressure – adopted criteria for resettlement and other countermeasures that were not founded on established radiation protection principles. The results were laws and compensation schemes that, in the opinion of many radiation protection professionals, were not justified and may have done more harm that good. Much of this controversy can be attributed to the fact that the criteria and policies for implementation of post-emergency countermeasures had not been established before the emergency and thus were developed after the accident during a period of heightened emotions and mistrust of officials and the scientific community. During the response at Goiânia, it was also very difficult to set operational levels for post-emergency intervention that were consistent with internationally accepted scientific principles because of time constraints and political pressure. This resulted in the use of the dose limit for non-accidental (anticipated) exposure (5mSv/a) as a basis for intervention and consequently in protective actions, generation of contaminated waste and decontamination and disposal costs that do not appear to be justified. In addition, experience shows that introducing legislation after an emergency increases the mistrust of the public in the response. The ICRP [4] has pointed out that it is impossible to anticipate or address factors not directly related to radiation protection principles when developing radiation protection guidance. Attempting to consider other factors or anticipate what would be acceptable to the public would only undermine the technical foundation of the recommendations, making them difficult to apply consistently, adjust or explain. It is the role of the radiation protection expert to give the best professional advice, even if the decision maker, bowing to the pressure of political or public opinion, subsequently ignores it.

[3] Experience shows that present international standards [2] do not address all the conditions for which guidance is needed. For example, the guidance for foodstuffs applies only for the year following an emergency and only if there is ready access to replacement food. The international standards also do not address many post-emergency countermeasures that need to be implemented, in part, based on radiation protection principles and insights. These include personal monitoring and decontamination, decontamination of property, release of contaminated property for use, initial medical screening, long term medical follow-up, contaminated non-food products, compensation schemes for radiation induced injuries and termination of countermeasures (return to normality).

[4] The use of "conservative assumptions" during the Chernobyl accident led to action that many feel did more harm than good. The consistent use, during the Goiânia response, of conservative assumptions in developing the criteria for implementing countermeasures exacerbated the economic and social burden. For example, very low criteria were established for decontamination and temporary relocation ostensibly to "alleviate public concern" but resulted in extensive decontamination and disposal of personal property, which created an exaggerated public perception of the hazards. The use of conservative assumptions in development of recommendations can result in unjustified actions, inconsistent application, criteria that are difficult to justify and an unrealistically inflated risk in the eyes of the decision makers and the public. Unnecessarily conservative assumptions are often used because it is not clear how to deal with uncertainties and under which conditions the guidance applies. There is a general tendency to implement actions at levels below those recommended if it is unclear whether the guidance addresses the situation at hand.

- Scientifically based recommendations for implementing protective and other actions need to be accompanied by an explanation that enables the decision maker to understand, reasonably consider and be able to explain them to the public[6].

This document is the result of rigorous examination of the existing international guidance for response in the light of the lessons from past emergencies. The document builds on existing guidance and makes proposals concerning the criteria for protective and other actions to specifically address the lessons from past emergencies.

1.2. OBJECTIVES

The objectives of this document are:

(1) to propose an extension of existing criteria [1, 2] for undertaking protective and other actions during or following a nuclear or radiological emergency that:

- addresses the lessons from past emergencies,
- addresses the recently published emergency preparedness requirements [3], and
- provides an internally consistent foundation for the application of radiation protection principles and insights for the conceivable range of protective and other actions, and of emergency conditions across all phases of the response to an emergency.

(2) to propose a basis for a common language explanation to the public and to public officials that addresses the human health risks of radiation exposure and provides a basis for a response that is consistent with the known risk.

(3) to propose a complete and coherent set of generic reference levels (GRLs) that can form a basis for developing the operational levels needed for making decisions concerning protective and other actions to meet the emergency response objectives [3], namely:

- to prevent the occurrence of deterministic health effects in workers and the public;
- to render first aid and manage the treatment of radiation injuries;

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[5] Decisions about countermeasures are based on operational intervention levels (OILs). OILs calculated by different States could vary considerably even if calculated according to the same principles, and developing OILs during an emergency that are consistent with international guidance would be very difficult due to political pressure. Not having internationally harmonized OILs in place before an emergency would result in different protective actions being taken by States for the same measured levels. This would be difficult to explain to the public and this is what happened worldwide following the Chernobyl accident when States implemented controls on contaminated food. It has also been demonstrated that a reasonable set of optimized OILs for implementation of other post-emergency countermeasures can be developed for a set of potentially severe emergencies (e.g. reactor releases). Thus, where possible, default international OILs ought to be precalculated for the full range of emergency interventions.

[6] Following past radiation emergencies the public often took inappropriate and in some cases harmful action (interference in funerals of victims, shunning victims or people from the affected area, refusing to buy products from the area, refusing to sell airline tickets to people from the area, having abortions due to a fear of radiation induced effects, refusing to provide medical treatment to victims, and spontaneous evacuations due to fear and misunderstanding concerning radiation risks and how to reduce them. The Chernobyl and Goiânia accidents demonstrated that public officials made decisions concerning implementation of countermeasures affecting the public during the post-emergency phase of a radiation emergency. These officials were not radiation specialists and they made their decisions on the basis of their understanding of both the radiological risk and of societal and political concerns. This was recognized by the ICRP [4] when it recommended that guidance for taking post-emergency countermeasures based on scientific considerations of radiation protection should serve as an input into the wider decision-making process.

- to prevent, to the extent practicable, the occurrence of stochastic health effects in the population;
- to prevent, to the extent practicable, the occurrence of non-radiological effects on individuals and in the population;
- to prepare, to the extent practicable, for the resumption of normal social and economic activity.

Fundamentally the purpose of the current document is to provide a basis for discussion and comment aimed at reaching consensus on an enhanced international standard.

1.3. SCOPE

Values are proposed for the GRLs needed to develop operational and other criteria for implementing protective and other actions to protect the public and emergency workers. The development of operational quantities needed to apply the GRLs is described only in general.

The process of making decisions concerning protective and other actions is not limited to the consideration of attributes related to radiological protection. The decision makers and the public will also consider various social and psychological factors before making a final decision on the action they will take in response to a nuclear or radiological emergency. However, this document will focus solely on the radiation protection based input into this decision making process. The aim is to provide the decision makers (and the public) with scientifically based input into their decision making process.

In most cases, both decision makers and the public have little or no understanding of radiation protection principles, the risks associated with radiation exposure, and the appropriate action that can be taken to reduce these risks. Therefore, this document will also provide a plain language explanation of the basis for the radiation protection guidance in order to assist the decision maker and public in its communication.

1.4. STRUCTURE

The document starts from considerations of existing criteria and guidance, and discusses their shortcomings. It contains sections on a proposed framework of criteria for the public and for emergency workers. It also has a section on secondary emergency response criteria. Appendix I summarizes the basis for the values for the GRLs. Appendix II deals with the basis for numerical criteria addressing deterministic health effects. Appendix III presents epidemiological and statistical considerations for GRLs for long-term medical follow-up. To facilitate the decision making process, Appendix IV discusses some of the issues involved in communicating risk information to the public and provides a plain language explanation of the criteria and related risks. Finally, there are definitions and references used in development of the extended framework.

2. CONSIDERATIONS

2.1. EXISTING CRITERIA AND GUIDANCE

There are several relevant international guidance documents that contain recommendations for response to radiation emergencies.

The Safety Guide published in 1994 [1] lists the following three general principles as forming the basis for taking decisions on intervention (protective and other actions):

- All possible efforts should be made to prevent serious deterministic health effects.
- The intervention should be justified, in the sense that introduction of the protective measure should achieve more good than harm.
- The levels at which the intervention is introduced and at which it is later withdrawn should be optimized, so that the protective measure will produce a maximum net benefit.

The Safety Guide [1] also discusses the factors that need to be taken into account in developing and applying intervention levels or action levels when making emergency arrangements. It then presents consensus values for generic intervention levels (GILs), expressed as avertable doses, for evacuation, sheltering, iodine prophylaxis, temporary relocation, permanent resettlement; generic action levels (GALs) for taking countermeasures related to food, and generic levels of projected dose to avoid the occurrence of deterministic health effects. These GILs and GALs were justified and optimized for what can be considered normal (non hazardous) conditions during implementation. This guidance formed the basis for the relevant radiation protection requirements of the Basic Safety Standards on intervention in emergency situations, published in 1996 [2].

In 2000, ICRP published recommendations on Protection of the Public in Situations of Prolonged Radiation Exposure [4] including generic reference levels for protection of the public against prolonged radiation exposure to include that resulting from emergencies.

In 2002, the IAEA published requirements entitled *Preparedness and Response for a Nuclear or Radiological Emergency* [3], approved at the meeting of the IAEA's Board of Governors in March 2002. This document requires that operational criteria be established for the conceivable range of protective and other actions and of emergency conditions across all phases of the response to an emergency. However it does not provide additional numerical standards. The IAEA's General Conference in resolution GC(46)/RES/9 has encouraged Member States to "implement the Safety Requirements for Preparedness and Response to a Nuclear or Radiological Emergency". As reflected in GOV/2002/6, "…compliance with these requirements will make for greater consistency between the emergency response criteria and arrangements of different States and thereby facilitate the emergency response at the regional and the international level." The IAEA has produced technical documents that can help States to strengthen their national arrangements[7]. These documents have been used widely by the international community and have proved to be effective. The requirements [3] require that: 1) appropriate facilities make arrangements with the goal of taking precautionary urgent protective actions, before a release of radioactive material occurs or shortly after one begins, on the basis of conditions at the facility in order to substantially reduce the risk of severe deterministic health effects; 2) operational criteria be established for promptly assessing the results of environmental monitoring and monitoring of the contamination on people in order to implement effective urgent and longer term measures to protect workers and the public and 3) operational criteria be established to identify those needing immediate treatment of radiation induced injuries or those groups that are at risk of suffering detectable increases in

[7] Method for developing arrangements for response to a nuclear or radiological emergency (EPR-METHOD); Generic Procedures for determining protective Actions during a Reactor Accident (IAEA-TECDOC-955); Generic procedures for Monitoring in a Nuclear or Radiological Emergency (IAEA-TECDOC-1092); and generic Procedures for assessment and Response during a Radiological Emergency (IAEA-TECDOC-1162).

cancer incidence as a result of radiation exposure, in order to be monitored for early recognition of cancer and, therefore, more effective treatment at an early stage.

In 2003, the IAEA published requirements [5] entitled *Remediation of areas contaminated by past activities and accidents*, which proposes GRLs for identification of areas that might need remediation consistent with the ICRP recommendations for protection of the public against long term exposure [4]. The General conference resolution GC(47)/RES/7 encouraged Member States "…to incorporate this safety requirements into national regulatory programmes, to the fullest extent possible".

2.2. SHORTCOMINGS IN EXISTING CRITERIA

The existing generic criteria for taking protective and other action contained in references [1, 2] do not address the following goals of emergency response that need to be based in part on radiation protection principles:

- To render first aid and to manage the treatment of radiation injuries;
- To prevent, to the extent practicable, the occurrence of non-radiological effects on individuals and in the population;
- To prepare, to the extent practicable, for the resumption of normal social and economic activity.

The generic criteria in references [1, 2] do not address also the following protective and other action that need to be based in part on radiation protection principles:

- individual decontamination;
- immediate medical treatment;
- long term medical follow-up;
- medical consultation, especially for pregnant women following an exposure during an emergency;
- implementation of protective actions under difficult conditions.

The generic criteria in references [1, 2] do not address emergencies for which protective and other action, in order to be effective, must be taken before or shortly after the start of a release or exposure. In these cases, protective actions cannot await environmental monitoring or other radiological assessment, so they must be based upon observation of conditions at the scene or in the facility.

The guidance in Ref. [1] Table 2 and Ref. [2] Table IV-I, which relates to the occurrence of deterministic health effects, does not address all important organs or exposure pathways. For example, it does not address inhalation of radionuclides emitting particles with high LET.

In summary, the guidance in references [1, 2] does not provide a sufficient basis on which to develop a comprehensive and consistent system because not all protective and other actions are addressed. Finally, this guidance does not include a plain language explanation designed to assist the decision maker and the public when making their final decision on actions to be taken.

2.3. UNCERTAINTIES

There will always be uncertainty associated with decisions made during an emergency; nevertheless, protective and other action, in most cases, need to be taken before these uncertainties can be significantly reduced by the analysis of emergency specific data. Therefore, a protective action strategy is needed that accounts for uncertainties in a way that allows decisions to be made in time to be effective and that will most likely result in actions that do more good than harm.

Decisions based on observations at a facility or scene of an emergency, for the most part, will be made with the aim of taking precautionary urgent protective action (before or shortly after release) in order to prevent severe deterministic health effects. In general, precautionary urgent protective action is justified, considering the uncertainties, when:

- the very low probability *conditions necessary*, for a severe exposure (e.g. core damage) are present or suspected (e.g. finding a suspected unexploded radiological dispersal device);
- it is very difficult to predict or be adequately assured that the *conditions sufficient* to result in severe health effects (early containment failure or explosion of the bomb) will not occur; and
- the consequences of taking the precautionary actions themselves are tolerable, even if it turns out subsequently that no exposure has occurred.

The presence of the first two conditions is described as representing a *substantial risk*. Experience [6] and studies [7] demonstrate that one cannot predict the size and timing of a release (source term), movement of plumes, deposition and resulting doses sufficiently fast or accurately during an emergency at a nuclear facility for them to be the sole basis for making decisions concerning urgent protective actions. This is particularly true for those emergencies for which precautionary urgent protective actions must be initiated before or shortly after a release in order to be effective. Taking precautionary urgent protective action in all directions to a predetermined distance when severe conditions or release rates indicating a substantial risk are detected can reasonably account for these uncertainties. In these cases the precautionary protective action would be taken even under potentially hazardous conditions (severe weather).

Decisions based on OILs derived from avertable dose have uncertainties primarily associated with:

- the validity, for any particular member of the population, of the assumptions used in the calculation of the operational levels;
- the measurement and interpretation of measurements of the operational quantity; and
- the assumption on efficiency of the implementation of the protective actions.

The GRLs for avertable dose in this document were established at levels at which actions are generically justified with the aim of reasonably reducing the risk of stochastic health effects. The resulting GRLs are a small fraction of the thresholds for severe deterministic health effects.

Therefore, operational levels calculated on the basis of these reference levels should result in actions that keep the dose to any individual below the thresholds for severe deterministic

health effects for all foreseeable conditions. Taking action to avert doses for the general population at a significantly lower level would not be justified and may do more harm than good. Consequently, the GRL for avertable dose presented in this document do not need to be revised to account for uncertainties.

In addition in order to take action that most likely will do more good than harm, the operational levels for the reference levels should be calculated according to the central (best) estimates of the underlying assumptions and should not be biased by the use of unrealistic assumptions. However, if the conditions during an emergency are significantly different from those assumed, the operational levels may need to be revised. An examination of the assumptions used in calculating the reference and operational levels shows that the most likely causes of non-conservative protective actions involve assumptions concerning:

- the hazard associated with the protective action. The reference levels for avertable dose assume that the risk of the protective action is small. If this is not the case (e.g. evacuation during a severe storm), a higher operational level would be justified; however, protective action would always be justified to prevent severe deterministic health effects;
- the isotopes involved. This is a concern primarily for emergencies involving complex mixtures of isotopes that are difficult to characterize adequately in advance such as those in emergencies involving spent fuel, reactors or reprocessing plants.

These uncertainties should be addressed by having provisions in place to rapidly appraise and, if necessary, revise the operational levels at the time of the emergency to account for emergency specific information.

2.4. CONSISTENCY

The framework of emergency response criteria needs to be:

- as simple as possible and as complex as necessary;
- internally consistent; and
- logically consistent when viewed by the public and decision makers.

In addition, the framework needs to be subject to common sense logical constraints on applying different protective actions, such as:

- Urgent individual decontamination intended to avert doses from skin contamination resulting from ground deposition should be limited to the persons from territory for which evacuation is justified, but not beyond this territory. Decontamination that is not urgent should be intended to keep levels of contamination acceptable for unrestricted release of the contaminated person. Non-urgent decontamination should be limited to the persons from territory for which temporary relocation is warranted to protect against ground contamination. Decontamination of skin contamination resulting from ground deposition should not be required for persons living at territories returned to normal[8].

[8] For example, an area that does not have deposition levels that exceed the OILs for relocation may produce levels for personal contamination that exceed those established in guidance for decontamination received while living in the area. Such apparent inconsistencies should be avoided.

- Registration for long term medical follow-up or counselling of pregnant women should not be needed if either urgent or longer term protective actions are totally effective (i.e. protective actions are almost always justified to prevent doses that would warrant placing a person on the medical registry for long term medical follow-up[9] or counselling due to exposure of the foetus).
- Anyone who can be identified in advance as someone who may receive a dose sufficient to justify placing them on the medical registry for long term medical follow-up (e.g. emergency workers) or to receive counselling due to exposure of the foetus should give informed consent (See Appendix IV for ethical considerations).

2.5. CONCLUSION ON NEED FOR EXTENDED FRAMEWORK

Experience from response to past emergencies has clearly showed that an internationally endorsed fully integrated system of guidance should be developed for implementing consistent protective actions in all phases of a radiation emergency that will assure the public that they are safe. This system of guidance should build on the existing international guidance, have international consensus, and be subsequently implemented at the national level. Having implemented compatible systems at the national level will allow the objectives of emergency response to be met and help to avoid overwhelming non-radiological consequences.

3. PUBLIC CRITERIA FRAMEWORK

The expanded system of emergency response criteria for taking protective and other action for the public proposed here addresses the shortcomings listed above and combines the existing system with the concepts given in ICRP 82 [4] and the recently published IAEA requirements [3, 5].

The following principles form the basis for the expanded system of criteria:

(a) Response during the nuclear or radiological emergency should be planned and performed taking into account the following possible outcomes of emergency exposure:

- development of severe deterministic health effects in the exposed individual;
- detectable increase of stochastic health effects in the exposed cohort;
- not detectable, but theoretically predicted increased number of stochastic health effects in the exposed cohort;
- adverse non-radiological consequences as a result of public concerns that were not addressed.

(b) Response during the nuclear or radiological emergency should be planned and performed taking into account the following types of emergency exposure:

- projected exposure that may be controlled (managed) by precautionary urgent protective actions;
- ongoing and lasting exposure (individual or collective) that may be controlled (managed) by ongoing protective and other actions;

[9] For the purpose of early diagnosis and effective treatment of radiation-induced cancer. People need to be informed of practical purpose of registration. They also need to be informed if any scientific use of data is planned.

- received exposure, the outcome of which may be managed (mitigated) by medical actions, public information[10] or counselling.

(c) At very high levels of individual risk (substantial risk) of the development of severe deterministic health effects, precautionary and ongoing protective and other actions should be implemented before or shortly after the start of the event under any conditions to prevent their occurrence.

(d) At negligible risk of the development of severe deterministic health effects, justified and optimized protective and other actions should be implemented to reasonably reduce the risk of stochastic health effects. The implementation of justified and optimized protective and other actions [8, 9] should be based on OILs derived from avertable doses to the affected population.

(e) At particular levels of received dose, individuals should be provided with the appropriate medical actions including medical treatment, long term medical follow-up and psychological counselling.

(f) For all levels of dose and exposure that may result from an emergency situation, a plain language explanation of the risks should be provided to the public and decision makers to allow them to make an informed decision about the action they will take. This aims to reduce the non-radiological consequences.

(g) The guidance should build as much as possible on the existing guidance.

(h) The guidance should be logically consistent.

(i) The guidance should have international consensus.

Recognizing the importance of international exemption and clearance levels for international trade, it is planned to include them into guidance. This will be done on the basis of levels presented in the IAEA Safety Guide on "Application of the concepts of Exclusion, Exemption and Clearance" [10].

Table 1 summarizes the principles in the form of a concept that bridges possible consequences of the exposure and a dosimetric basis for implementation of protective and other actions.

Table 2 represents numerical values of GRLs along with corresponding protective and other actions.

[10] The public has rights to information on an emergency and actions being taken. Public information needs to cover instructions on what to do and what not to do under specific circumstances, as well as to put the risk in perspective. However, it is not limited to this information alone.

TABLE 1. SYSTEM OF PROTECTIVE AND OTHER ACTIONS DURING A NUCLEAR OR RADIOLOGICAL EMERGENCY

<table>
<tr><th rowspan="2">Possible health consequences of exposure</th><th colspan="3">Dosimetric basis for implementation of the protective and other actions</th></tr>
<tr><th colspan="2">Projected dose</th><th>Avertable dose</th><th>Received dose</th></tr>
<tr><td>Severe deterministic health effects</td><td>Urgent actions always justified</td><td>Take precautionary urgent protective actions, even under adverse conditions, to prevent severe deterministic health effects by preventing doses approaching the reference levels in Table 2 Section A. Inform and warn the public.</td><td>Not applicable</td><td>Take justified medical action to detect and treat severe deterministic effects; to detect and treat stochastic health effects and to provide comprehensive psychological counselling based on reference levels in Table 2 Section A.</td></tr>
<tr><td>Detectable increase in stochastic health effects</td><td rowspan="2">Only optimized and justified actions</td><td rowspan="2">Take precautionary urgent protective actions to reasonably reduce risk of detectable increase in stochastic health effects based on GRLs in Table 2 Section B. Inform and warn the public.</td><td rowspan="2">Take urgent and longer term protective action to reasonably reduce risk of stochastic health effects based on GRLs in Table 2 Sections D and E. Reassure the public that no radiation-induced health effects anticipated if protective actions are implemented efficiently.</td><td>Take justified medical action to detect and treat stochastic health effects. Provide advice and basic counselling based on reference levels in Table 2 Section C.</td></tr>
<tr><td>No detectable increase in stochastic health effects</td><td>No need for protective and other actions based on reference levels in Table 2 Section F. Inform the public to address concerns.</td></tr>
<tr><td>No detectable health effects and average dose is within the range of those occurring naturally in some regions of the world</td><td>No optimized actions (no generically justified actions)</td><td>Suspend protective and other intrusive actions based on reference levels in Table 2 Section F. Inform the public.</td><td>Not applicable</td><td>Suspend medical and other intrusive actions based on reference levels in Table 2 Section F. Inform the public.</td></tr>
</table>

TABLE 2. GENERIC REFERENCE LEVELS FOR PROTECTIVE AND OTHER ACTIONS DURING A NUCLEAR OR RADIOLOGICAL EMERGENCY [11]

GENERIC REFERENCE LEVELS		PROTECTIVE OR OTHER ACTIONS
(Section A) **Projected (substantial risk of) or received dose approaches the Section A GRLs:** Take precautionary urgent protective action to prevent or medical actions to treat severe deterministic health effects		
External exposure		**If dose is projected or substantial risk exists**: -Immediately take precautionary urgent protective actions, even under difficult conditions, to keep dose below the reference level -Provide public information and warning **If dose is received:** -Immediate medical examination, consultation and indicated treatment -Contamination control -Immediate decontamination (if applicable) -Immediate decorporation (if applicable) -Prescription of stable iodine (if applicable) (i) -Registration for long term medical follow-up -Comprehensive psychological counselling
AD_{Torso} (a):	1 Gy-Eq (brief exposure)	
AD_{Foetus}:	0.1 Gy-Eq (brief exposure)	
AD_{Tissue}:	25 Gy-Eq at 0.5 cm depth (contact - brief exposure) (b, c)	
AD_{Skin}:	10 Gy-Eq to 600 cm^2, (d) (brief exposure)(b)	
Internal exposure		
$AD(\Delta)_{Red\ marrow}$:	0.2 Gy-Eq for intake of actinides (Δ = 30 days(e),(f))	
$AD(\Delta)_{Red\ marrow}$:	2 Gy-Eq for intake of radionuclides other than actinides (Δ=30 days (e),(f))	
$AD(\Delta)_{Thyroid}$:	2 Gy-Eq (Δ = 30 days(e),(g))	
$AD(\Delta)_{Lung}$ (h):	30 Gy-Eq (Δ = 30 days(e))	
$AD(\Delta)_{Colon}$:	20 Gy-Eq (Δ = 30 days(e))	
$AD(\Delta)_{Foetus}$:	0.1 Gy-Eq (Δ = period of *in utero* development(e))	
(Section B) **Projected dose (substantial risk of dose) that exceeds the Section B GRLs:** Take precautionary urgent protective actions to reasonably reduce the risk of detectable increase of stochastic health effects		
$H_{Thyroid}$:	50 mSv	-Precautionary food, milk and water restrictions (j) -Public information and warning
(Section C) **Received dose that exceeds the Section C GRLs:** Take longer term medical action to early detect and effectively treat radiation-induced cancers (k) and other health effects		
E_T: $H_{Thyroid}$:	0.1 Sv in weeks - month 50 mSv	-Screening based on individual dose, to determine need for registration for long term medical follow-up -Advice and basic counselling
H_{Foetus}:	0.1 Sv in months	-Basic counselling to allow informed decisions to be made in individual circumstances
(Section D)(l) **Avertable dose that exceeds the Section D GRLs:** Take urgent protective actions to reasonably reduce the risk of stochastic health effects		
E_T:	10 mSv in 2 days (m)	-Sheltering
E_T:	50 mSv in 1 week (m)	-Evacuation, urgent decontamination, restriction of food, milk and water consumption (j)
$H_{Thyroid}$:	50 mSv (m),(n)	-Iodine prophylaxis and urgent decontamination (p)
H_{Skin}:	0.1 Sv in days (m),(o)	-Contamination control -Urgent decontamination
(Section E)(l) **Avertable dose that exceeds the Section E GRLs:** Take longer term protective action to reasonably reduce the risk of stochastic health effects		
E_T:	≈ 5 mSv (r) per annum	Replacement of food, milk and water (j)
E_T:	30 mSv in 1st month	Temporary relocation Discretionary decontamination (p)
E_T:	1 Sv in a lifetime	Permanent resettlement
H_{Skin}:	10 mSv in days	Discretionary decontamination

[11] See Appendix I and Definitions for terminology and abbreviations.

GENERIC REFERENCE LEVELS		PROTECTIVE OR OTHER ACTIONS
(Section F) **Projected or received dose that is less than the Section F GRLs:** Discontinue disruptive protective and other actions		
E_T:	10 mSv per annum [(s)]	No protective action except those without undue hardship such as: -Limited area/object decontamination -Limited restriction of food, milk and water consumption -Public information
H_{Foetus}:	0.1 Sv in months	
$H_{Thyroid}$:	50 mSv	
$H_{Any\ other\ organ}$:	0.1 Sv per annum	

(a) AD_{Torso} is used to address external exposure to the red marrow, lung, small intestine, gonads, thyroid and lens of eye from irradiation in a uniform field of strongly penetrating radiation. This would also be the dose of strongly penetrating radiation typically monitored by a personal dosimeter**.**

(b) Most likely only applicable for received dose.

(c) Dose delivered to depth of 0.5 cm in tissue from contact (e.g. source carried in hand or pocket).

(d) To approximate more than 1/3 of the surface of the body. The dose is to skin structures at a depth of 50 mg/cm^2 (or 0.5 mm) under the surface at which long term effects are expected [19].

(e) $AD(\Delta)$ is the dose delivered over the period of Δ by the threshold intake (I_{05}). The threshold intake is the amount that will result in the health effect in 5% of exposed people as described in Appendix II. The values of AD(Δ) were calculated as described in Appendix II.

(f) The actinides and other radionuclides have different biokinetic processes, hence different dynamics of dose formation in red marrow due to internal exposure. The difference of $AD(\Delta)_{Red\ marrow}$ among radionuclides (actinides and not actinides) reaches a factor of about 50, while the difference within each group doesn't exceed a factor of 3. Therefore, radionuclides have been divided into two groups. This allowed avoiding the over conservatism of single GRL, established on the lowest level.

(g) Only for internal exposure from radionuclides absorbed by thyroid as a critical organ: radioactive isotopes of tellurium, iodine, technetium, and rhenium.

(h) For purposes of this document "Lung" means the gas-exchange region of respiratory tract.

(i) Stable iodine is prescribed: a). if radioactive iodine is involved in the emergency, and b). only within short period after the internal intake of radioactive iodine.

(j) If replacement food/water is not available, a higher GRL should be used. However, actions to prevent doses approaching those in Section A are always justified.

(k) Upon conditions that radiation-induced cancer incidence could be detected.

(l) Reassure the public that no radiation-induced health effects are anticipated if protective actions are implemented effectively

(m) If implementation of the protective action is hazardous, a higher level should be used, but actions to prevent dose approaching those in Section A are always justified.

(n) The level differs from the criteria in Refs. [2] and [1].

(o) For skin structure to a depth of 7 mg/cm2 (or 0.07 mm) under the surface [2].

(p) Decontamination to prevent inadvertent ingestion.

(r) Dose is consistent with the generic action levels in Ref. [2] for foodstuffs.

(s) Includes dose from all sources.

3.1. PROJECTED DOSE AND SUBSTANTIAL RISK AS A BASIS FOR OPERATIONAL INTERVENTION LEVELS USED FOR DECISION MAKING

3.1.1. Projected dose

All reasonable actions should be taken to prevent severe deterministic health effects among the population. This can be best accomplished by taking protective action before the beginning of exposure. Therefore, the decision to take action should be based on the OILs derived from the projected dose or condition at the facility or scene.

The projected dose is the total dose to be expected if no protective or remedial action is taken and is usually defined by the dose received over a period of time from the beginning of the emergency via all pathways.

To represent the risk of effects in a particular organ, the projected dose to that organ within a time period (specific to the organ) is required.

The projected dose is used as the basis for operational criteria applied to make decisions intended to meet at least three objectives, as defined in the Ref. [3]:

- To prevent severe deterministic health effects by keeping the dose below those approaching the reference levels in Table 2 Section A at which urgent protective action are warranted under any circumstances and should be taken precautionary;
- To return to normality by suspending intrusive protective actions when the dose falls below the reference levels in Table 2 Section F at which protective measures are not normally justified;
- To ensure the safety of emergency workers.

As indicated by the first objective, protective action should always be introduced to avoid levels of individual dose approaching those at which, if received, severe deterministic health effects could occur.

It should be recognized that doses already received before intervention is considered could contribute to the induction of deterministic health effects. When assessing projected individual doses due to an emergency, it is important to consider both the assessment uncertainty and the dose distribution in the population in question. Therefore, in most cases where exposure to the public is being assessed, it should be assumed that this includes pregnant women.

Reference levels based on projected dose for intervention to prevent severe deterministic health effects are shown in Table 2 Section A. The values shown in the table are below those of the commonly accepted thresholds for severe deterministic health effects.

Severe deterministic health effects developing after acute external exposure or acute intake of radioactive material are the same by nature. Probability of their development depends upon RBE-weighted absorbed dose and RBE-weighted absorbed dose rate for external exposure and upon intake of radioactive material for internal exposure (see Appendix II for more details). The values shown in Table 2 are established for intake of radioactive material and external exposure separately. A value of 30-day committed RBE-weighted absorbed dose is used instead of threshold value of intake for development of severe deterministic health effect in the organ concerned in case of inhalation or ingestion of radioactive material. For a vast majority of possible emergencies, keeping the dose below the reference levels in Table 2 Section A will prevent all severe deterministic health effects in all age groups in case of separate external or internal exposure.

In the case of combined internal and external exposure a sum of indexes of RBE-weighted absorbed doses for intake of radioactive material and for external exposure may be used as a basis for calculation of OILs for decision making. An index of RBE-weighted absorbed dose for external exposure of the organ concerned is the ratio of projected RBE-weighted absorbed dose in the organ (or in the torso) to the threshold value for torso RBE-weighted absorbed dose. An index of RBE-weighted absorbed dose of internal exposure of organ concerned is the ratio of 30-day committed RBE-weighted absorbed dose in the organ to the relevant threshold value. Keeping the sum of index of external exposure and square of index of internal exposure below 1 will prevent severe deterministic health effects in organ concerned in case of combined internal and external exposure (see Appendix II for details).

The reference levels for severe deterministic health effects in Table 2 Section A should be used to derive OILs for taking urgent protective action to prevent severe deterministic health effects, as discussed later.

The projected dose should also be used to derive OILs for making decisions on when to return to normality by suspending intrusive protective and other actions. The reference levels at which suspension of intrusive protective action should be considered are shown in Table 2 Section F. The decision to return to normality should be based on OILs that were developed after careful assessment of the radiological situation.

3.1.2. Substantial risk

Emergencies have occurred or have been postulated that can result in early deaths and other severe deterministic health effects unless urgent protective action is taken before or shortly after the start of a release or exposure[12]. For many of these emergencies there is insufficient information, time or opportunity to project dose or conduct monitoring before acting. Examples include criticality emergencies, severe core damage at nuclear power plants and terrorist use of an explosive radiological dispersal device (RDD). In each of these cases, precautionary urgent protective actions would be justified when observed conditions indicate a substantial risk of a release or exposure that could result in severe deterministic health effects.

The requirements [3] address this issue by requiring appropriate facilities to have arrangements to promptly detect, classify and respond to emergencies (those with a substantial risk) for which precautionary protective actions should be taken to protect the public and workers from severe deterministic health effects. Reference levels, based on projected dose, for intervention to prevent severe deterministic health effects shown in Table 2 Section A should be used as the dosimetric criteria when defining those emergencies that have the potential for resulting in such effects.

Radiological emergencies involving dangerous sources (but not involving facilities) can occur for which precautionary urgent protective actions should also be undertaken before or shortly after the start of a release or exposure. These are addressed by the requirements [3] and include non-authorized activities such as those relating to dangerous sources obtained illicitly. They also include transport and other authorized activities involving dangerous mobile sources such as industrial radiography sources, nuclear powered satellites or radiothermal generators. The requirements oblige that the operator of a practice using dangerous sources be given basic instruction in the means of promptly protecting workers and the public in the vicinity. The reference levels in Table 2 Section A are used as the dosimetric criteria when defining those sources that should be considered dangerous [11].

3.2. AVERTABLE DOSE AS A BASIS FOR OPERATIONAL INTERVENTION LEVELS USED FOR DECISION MAKING

Avertable dose is used as the basis for GRLs and operational criteria that are justified and optimized [1] for the purpose of taking action to reduce the risk of stochastic health effects. The principles of justification and optimization of intervention each require consideration of the benefit that would be achieved by the intervention and the harm, in its broadest sense, that

[12] The requirements [3] define such an emergency as a ‘general emergency’ and a ‘site area emergency’ as one involving a major decrease in the level of protection for those on the site and near the facility.

would also result from it. An important aim of protective actions is to reduce the likely number of radiation-induced cancers as much and as effectively as reasonably possible. The reduction of the number of radiation-induced cancers is related to the avertable dose, i.e. the reduction in dose due to the different countermeasures.

Table 2 Sections D and E provide the recommended values of the GRLs for urgent and longer term protective actions for decisions based on OILs derived from avertable dose. The values satisfy the basic principles laid out in para. 310 of Ref. [1] in that deterministic health effects are avoided provided protective actions are executed in a timely manner; and the intervention is generically justified in that the risks averted by the actions are greater than those introduced by the protective actions themselves. The protection provided by applying these reference levels has been optimized on a generic basis for the general population, assuming non hazardous conditions at the time the protective actions are implemented. Proposed values *do not need to be adjusted* to account for any particular member of the population (e.g. children or pregnant women) because protective action taken to avert these doses will satisfy the basic principle for the whole population. Taking action at considerably lower levels may do more harm than good.

These levels were developed assuming a low risk from implementation. Therefore if implementation of an action involves a substantial risk (e.g. evacuation during hazardous weather conditions or restricting food when replacement food is not available), a higher value of GRL should be used but actions to prevent doses approaching those in Section A are always justified.

3.3. RECEIVED DOSE AS A BASIS FOR OPERATIONAL INTERVENTION LEVELS USED FOR DECISION MAKING

Received dose is used as the basis for operational criteria for decisions intended to:

- provide medical intervention to treat severe deterministic health effects when the dose received exceeds levels in Table 2 Section A.
- provide an opportunity to detect early, and hence effectively treat, radiation-induced cancers when the dose received exceeds levels in Table 2 Section C.
- provide counselling to those exposed, including pregnant women, in order that they can make informed decisions concerning the further course of their treatment when the dose received exceeds levels in Table 2 Section C.
- return to normality by suspending intrusive protective actions when the annual dose is below the references levels in Table 2 Section F.

Appendices I, II and III discuss the basis for these criteria.

The definition of a dose that results in no observable adverse health effects as *safe* requires the consideration of both individual and collective doses. It is clear that the risk to the individual must be low enough not to lead to adverse health effects. However, it is also important that there is no observable increase in radiation-induced cancers (or stochastic health effects) in the whole exposed population. This requires consideration not only of the collective risk to a population group, but also of the background rates of different cancers (See Appendix III). Where the background rate is very low, even a small increase in the number of cancers will be clearly recognized. The incidence of thyroid cancers in children after the accident at Chernobyl is a clear example of this. Many of the thyroid cancers

occurred in children who received relatively low thyroid doses (tens mSv), i.e. their individual risk was low. However, the collective dose and communal risk of radiation-induced thyroid cancer was high; hence, a large number of radiation-induced thyroid cancers occurred. Since the background incidence of thyroid cancer among children is low, the excess in incidence caused by radiation-induced cancers was revealed.

Received dose is used as a basis for urgent and longer term medical actions in response to radiation emergencies. Examples of urgent actions are medical triage and first aid at the scene of an emergency, and general and specialized treatment in hospital within the first few months after the emergency. One of the actions, which starts at the early stage after an emergency but has long-term duration and impact, is long-term medical follow-up of exposed people.

Experience of short-term and long-term medical response after the Chernobyl accident showed that scientifically grounded criteria should be developed and used for medical screening, treatment and long-term medical follow-up of the affected people.

Application of routine procedures for health care or social support in an acute stage of the emergency can lead medical personnel and policy makers into problems that will be difficult or even impossible for them to solve. It is important that medical records record only facts about a disease and do not wrongly attribute radiation exposure since this can lead to anxieties in the population and subsequent medical examinations that cannot be justified from a radiation medicine perspective.

From another point of view, when long-term follow-up is medically (and radiologically) justified, it could be very effective. Medical screening of the thyroid gland of exposed populations in Belarus and Ukraine after the Chernobyl accident has been effective for earlier diagnosis of the disease and, therefore, more efficient treatment. The number of deaths among those with thyroid cancer is significantly less than the international mortality rate for thyroid cancer.

There are different reasons to perform long-term medical follow-up of affected people, such as:

- to provide advanced medical care for affected people;
- to decrease public concern with regard to their health status, and
- to obtain new scientific knowledge.

Each of the reasons could form the basis for medical follow-up. However, for medical care of the affected population, the reason for establishing a registry and providing medical follow-up is: early detection, and hence effective treatment of cancer that may be induced by radiation. Having this as an objective, the following should be taken into account while establishing the registry: level of exposure expressed in dose and possibility to detect cancer among the exposed population.

Current data show that radiation induced cancer cases (excess above background cases) could be observed in humans at effective doses in excess of 0.1 Sv delivered at high dose rates [12]. These data are based on epidemiological studies of well-defined populations (e.g., the Japanese atomic bomb survivors and medical patients) exposed to high doses delivered at high dose rate. Epidemiological studies have not demonstrated such effects in individuals exposed to small doses (less than 0.1 Sv) delivered over a period of many years. UNSCEAR 2000 states "…further follow-up and improved information on the doses received will be

needed before the shape of the dose response at low doses for both morbidity and mortality can be determined with confidence at doses below about 100-200 mSv…"[12].

Long term medical follow-up has both potential benefits and risks. Early recognition of the cancer represents a net benefit both to the individual and to society. However, potential penalties both to the patient and to the medical care system should be also considered. Potential risk for the patient includes performing invasive and potentially harmful procedures (e.g., fine needle biopsy of thyroid), ultrasound detection of clinically insignificant nodules (leading to false positive results), and the psychological pressure of regular examination, which influences the quality of life.

The potential risks to the consequences for the medical care system, e.g. overload in terms of both personnel and equipment, need to be identified and appropriate cost- and risk-benefit analyses should be undertaken. Cost- and risk-benefit analysis should include not only morbidity and mortality associated with surgery, but also the need for long-term patient compliance and the necessity for life-long medication (e.g. replacement hormone therapy after removal of the thyroid gland) and follow-up. This should be of special consideration for countries with limited resources allocated for long-term medical follow-up of people with very low risk of radiation-induced cancer.

Having in mind the necessity of long-term medical follow-up for the purpose of early detection, and hence effective treatment of potential radiation induced cancer, it's necessary to establish dose criteria in advance.

4. EMERGENCY WORKERS' CRITERIA FRAMEWORK

Traditionally, emergency workers are assumed to be those individuals who can be identified in advance as possibly being involved in response to a radiological emergency. However, emergency workers could also include any individual responding to a radiological emergency at a location or time that could not be foreseen. This would include police, rescue personnel, firefighters and medical personnel.

The requirements (Ref. 3, para. 4.60) state:

> *"National guidance that is in accordance with international standards shall be adopted for managing, controlling and recording doses received by emergency workers. This guidance shall include default operational levels of dose for emergency workers for different types of response activities, which are set in quantities that can be directly monitored during the performance of these activities (such as the integrated dose from external penetrating radiation). In setting the default operational levels of dose for emergency workers the contributions to doses via all exposure pathways shall be taken into account."*

Ref. [2] (paras V.27, V.28, V.30 and V.32) provides the basic international guidance concerning protection of workers undertaking an intervention (emergency workers). It establishes guidance on the limits to be placed on the dose received by emergency workers undertaking different types of emergency activities. This guidance is provided in terms of multiples of the maximum single year occupational limits and forms a basis for the guidance contained in Table 3. The guidance in Ref. [2] is in terms of total effective dose (E_T), which is not the appropriate dosimetric quantity for consideration of deterministic health effects. Consequently, the guidance levels for doses for which severe deterministic health effects are a

concern are provided in RBE-weighted absorbed dose (AD_T) to any organ as discussed in Appendix I.

The following guidance also provided in Ref. [2]:

> *(Appendix V, para. V.27.) "except for life saving actions, in which every effort shall be made to keep doses below ten times the maximum single year dose limit in order to avoid deterministic effects on health. In addition, workers undertaking actions in which their doses may approach or exceed ten times the maximum single year dose limit[13] shall do so only when the benefits to others clearly outweigh their own risk."*
>
> *(Appendix V, para. V.28.) "Workers who undertake actions in which the dose may exceed the maximum single year dose limit shall be volunteers and shall be clearly and comprehensively informed in advance of the associated health risk, and shall, to the extent feasible, be trained in the actions that may be required."*
>
> *(Appendix V, para. V.30.) "Once the emergency phase of an intervention has ended, workers undertaking recovery operations shall be subject to the full system of detailed requirements for occupational exposure prescribed in Appendix I of Ref. [2]".*

In addition Ref. [3] requires (para. 4.64):

> *"When the intervention has ended, the doses received and the consequent health risk shall be communicated to the workers involved."*

Table 3 provides guidance for establishing the operational levels to be used by emergency workers responding to a nuclear or radiological emergency. This guidance is consistent with the guidance for the public presented in Table 2 since:

- doses approaching the thresholds for severe deterministic health effects (Table 2 Section A) are only allowed to be obtained by emergency workers for actions to prevent severe deterministic health effects among public or to prevent the development of catastrophic conditions;
- doses at which the worker would receive dose required long term medical monitoring (Table 2 Sections B, C, and D) are only allowed for actions to avert a large collective dose;
- doses within occupational exposure guidance are allowed other operations, including recovery and restoration (Table 2 Sections E and F).

No dose restrictions are recommended for life saving actions only if: 1) the benefit to others clearly outweighs the rescuer's own risk, and 2) the emergency worker can make an informed decision concerning their risk. The first of these conditions are assumed to exist if a life can be saved or if general emergency can be prevented.

Workers who may receive doses approaching those that warrant long term medical monitoring (Table 2 Sections C) should be provided with sufficient information concerning the risks of the exposure to allow them to provide informed consent (knowingly volunteer).

[13] It is assumed that the single year dose limit is an effective dose of 50 mSv (para. II-5. Ref [2]).

Emergency workers should receive medical attention associated with the dose they may have received as outlined in Table 2 Sections A and C. Female workers who become aware that they have become pregnant should notify the appropriate authority and would typically be excluded from emergency duties.

In virtually all emergency situations, at best only the dose from external penetrating radiation will be continually measured. Consequently, the operational guidance provided to emergency workers would be in terms of penetrating radiation (for example as displayed on a self-reading dosimeter). The dose from intake or skin contamination would need to be limited by means of protective equipment, use of iodine prophylaxis, or instructions concerning operations in potentially radiologically hazardous conditions[14].

TABLE 3. GUIDANCE LEVELS FOR EMERGENCY WORKERS

Tasks	Level
Life saving actions, such as: ⋕ rescue from immediate threats to life; ⋕ providing of first aid for life threatening injuries; ⋕ prevention or mitigation of conditions resulting in a general emergency in a threat category I facility.	In principle, no dose restrictions are recommended if, and ONLY IF, the benefit to others clearly outweighs the rescuer's own risk[(a)].
Actions, to prevent severe deterministic health effects, such as: ⋕ implementation of urgent protective actions, even under difficult conditions; ⋕ environmental monitoring of populated areas to identify where urgent protective actions (to be implemented even under difficult conditions) are needed; ⋕ rescue from potential threats of serious injury; ⋕ immediate treatment of serious injuries; ⋕ urgent decontamination of people. **Actions to prevent the development of catastrophic conditions, such as:** ⋕ prevention or mitigation of conditions resulting in a site area emergency.	$AD_{Torso} < 1.0$ Gy-Eq [(a),(b)] or $E_T < 1.0$ Sv [(a),(c),(d)]
Actions to avert a large collective dose, such as: ⋕ sample collection and analysis if required for implementation of urgent protective actions; ⋕ environmental monitoring of populated areas to identify where longer term protective actions or food restrictions may be needed; ⋕ localized decontamination if required to support implementation of urgent protective actions.	$E_T < 100$ mSv [(a)]
Other operations, including recovery and restoration, such as: ⋕ facility repairs not related to safety; ⋕ large scale decontamination; ⋕ waste disposal; ⋕ long term medical treatment and management; ⋕ recovery operations.	Occupational exposure guidance [(e)]

(a) Workers shall be volunteers and be instructed in the potential consequences of exposure to allow them to make an informed decision [Ref. 2–3].
(b) Total dose (external and internal).
(c) This value applies only to exposure from external penetrating radiation. The dose from intake or skin contamination would need to be limited, e.g. by means of respiratory protection or use of iodine prophylaxis.
(d) The guidance in Ref. [2] requires that every effort be made to keep doses below ten times the maximum single year dose limit in order to avoid deterministic effects on health while performing life saving actions.
(e) Para. II-5 of Schedule II in Ref. [2].

[14] Use of time, distance, shielding principles, prevention of inadvertent ingestion, and limiting inhalation.

5. SECONDARY EMERGENCY RESPONSE CRITERIA

Projected, avertable and received dose are not measurable quantities. Because of the need to act quickly in the case of a nuclear or radiological emergency, there is a need to establish — *in advance* — values of surrogate quantities for the generic reference levels for undertaking different protective and other actions. Ref. [3] requires that "…arrangements shall be made for … the application of OILs and arrangements to revise the OILs as appropriate to accommodate the conditions prevailing during the emergency."

The term 'OIL' is reserved for these quantities that can be more easily assessed at the time of decision on intervention, except for the criteria used for facility conditions. The predetermined operational quantities for assessing if facility conditions warrant implementation of protective measures on or off the site are termed emergency action levels (EALs), which are also used to classify the emergency. These criteria should be predefined, as required (Ref. [3]).

For facilities, the EALs used for classification and associated implementation of precautionary urgent protective actions are the operational criteria for events with substantial risk that warrant action. The development of EALs for a specific facility and operational levels for radiological emergencies is beyond the scope of this document.

For radiological emergencies, the operational criteria for implementing precautionary urgent protective actions should be predetermined on the basis of information that will be observable at the time of the emergency.

Ref. [3] require that default OILs be established along with the means to revise the OILs for:

- the results of environmental monitoring and monitoring of individual contamination in order to decide on or to adapt urgent protective actions to protect workers and the public.
- environmental measurements and radionuclide concentrations in food in order to decide on effective agricultural countermeasures, including a restriction of the consumption, distribution and sale of locally produced foods and agricultural produce.
- dose rates due to deposition and deposition densities in order to decide on effective implementation of temporary relocation.
- the identification of those warranting long term medical monitoring and treatment for groups of people at risk of sustaining a detectable increase in the incidence of cancers as a result of radiation exposure. The use of the criteria needs to provide an opportunity to recognize an increase in the incidence of cancers and to treat cancers more effectively at an early stage.

Ref. [3] requires guidelines for diagnosis and treatment of radiation injuries. These guidelines should include OILs for medical symptoms and test results.

In summary, OILs should be developed, as appropriate, in terms of:

- dose rate (plume, deposition);
- surface contamination density;
- activity concentration (air, soil, food, milk, water, excreta);
- dose rate from organs (thyroid, lung);

- medical symptoms and test results;
- situations and conditions observable at the scene (e.g. "dangerous goods" labels or placards).

The dosimetric basis for developing the OILs should use predetermined dosimetric models for the population affected by the emergency, with a set of postulated reference parameters characterizing the incidence of radiation factors of an emergency in reference members of the public. A 'reference member' of the public may be a composite of critical characteristics of different pathways and activities for a short period after the emergency. These models should include a full set of data important for the dose assessment that is needed for decision making in emergency response, taking the reference member's:

- habit parameters;
- biological parameters;
- dose factors for different pathways of exposure.

The dosimetric model and data should provide relatively good assurance that all members of the public and normal activities are considered. The central (reasonable) estimates for model parameters should be used in dose assessment. In the development of the OILs, the public need to be assured that all groups (e.g children playing on the ground) have been considered. Consequently, the OILs must be accompanied by a plain language explanation of the situation to which they apply (See Appendix III), how they address a safety/health concern and what their application means in terms of the risk to individuals or their loved ones.

Although flexibility is a necessary feature of emergency arrangements, experience shows (and ref. [3] requires) that default OILs be established to provide an immediate basis for decisions on the types of action likely to be needed. The appropriate protective action will be promptly invoked if these levels are exceeded, but the action will not normally be taken if the levels are not exceeded. These default OILs will be developed on the basis of assumptions concerning emergency conditions that may not accurately reflect those of the emergency in question. Consequently, the ref. [3] requires that means be established to revise the OILs to take into account conditions prevailing during the emergency. However, revising the OILs during an emergency may be disruptive and therefore they should be revised only if the situation is well understood and there are compelling reasons to do so. The public should be informed of the reasons for any change in the OILs.

Every effort should be taken to keep the system simple by keeping the number of OILs to a minimum. In principle, the default OILs should be that minimum set for each operational quantity (e.g. dose rate from skin contamination) that reasonably encompasses, considering the uncertainties, the protective action (e.g. urgent decontamination) and applicable GRLs and associated assumptions (e.g. emergency type or characteristics of the radiological hazard).

There are also several important practical issues that need to be addressed when developing the secondary criteria (e.g., application of different sampling techniques and methodologies, hot spots in sampling, etc.).

6. CONCLUSION

The proposed extended framework of emergency response criteria is built on the existing international guidance. The need for such a framework was clearly defined as a result of evaluating the lessons identified in response to past radiation emergencies. It was shown that in order to be effective, protection of the public should be based on an integrated internally

consistent system of response criteria. The system of guidance should have international consensus and be subsequently implemented at the national level.

The extended framework expands the existing guidance [1,2,3,4,5] to address individual decontamination; immediate medical treatment; long term medical follow-up; medical consultation, especially for pregnant women following an exposure during an emergency; and implementation of protective actions under difficult conditions. Therefore, the extended framework addresses, unlike current guidance, all objectives of emergency response as defined in Ref. [3].

The extended framework addresses health consequences from the external and internal exposure of specific target organs, for which the generic reference levels were developed. In order to address the requirements from Ref. [3] thresholds for severe deterministic health effects for both external and internal exposure were developed that could be directly related to full spectrum of important radionuclides.

Values of the Generic reference levels are based on current knowledge for the development of deterministic and stochastic health effects (see Appendixes I, II, and III for details). However, they could be subject of future review when new data will become available.

Finally, this document proposes a plain language explanation designed to assist the decision maker and the public when making their final decision on actions to be taken.

Appendix I

SUMMARY OF BASIS FOR GENERIC REFERENCE LEVELS

This appendix summarizes the basis for the GRLs in Table 2. Evaluation of the possibility for different types of health consequences of radiation exposure (deterministic and stochastic) and their effective management requires different types of dosimetric information. The dosimetric quantities of effective dose, radiation weighted dose, and RBE-weighted absorbed dose[15] are used in evaluating radiation induced consequences of a nuclear or radiological emergency. They are listed in Table I-1, illustrated in Figure I-1 and discussed below.

TABLE I-1. DOSIMETRY QUANTITIES USED IN A NUCLEAR OR RADIOLOGICAL EMERGENCY

Dosimetry quantity	Symbol	Purpose
RBE-weighted absorbed dose	AD_T	For evaluating deterministic health effects induced due to exposure of an organ or tissue.
Radiation weighted dose	H_T	For evaluating stochastic health effects induced due to exposure of an organ or tissue.
Effective dose	E	For evaluating detriment related to the occurrence of stochastic health effects in an exposed population.
Personal dose equivalent	$H_P(d)$	For monitoring external exposure of individual
Ambient dose equivalent	$H^*(d)$	For monitoring radiation field at site of emergency

The RBE-weighted averaged absorbed dose in the organ or tissue (RBE-weighted absorbed dose) (AD_T) is defined as a product of averaged absorbed dose in organ or tissue and the relative biological effectiveness (RBE):

$$AD_T = \sum_R D_{R,T} \times RBE_{R,T} \qquad \text{(I-1)}$$

The unit used to express the RBE-weighted absorbed dose in SI is Jkg^{-1} and is called the *gray-equivalent* (*Gy-Eq*) [13, 14]. Details on the RBE-weighted absorbed dose as a basis for the criteria related to deterministic health effects are discussed in Appendix II.

The weighted averaged absorbed dose (radiation weighted dose) (H_T) is defined as the product of the averaged absorbed dose in the organ or tissue and the radiation weighting factor w_R [2, 15]:

$$H_T = \sum_R D_{R,T} \times w_R \qquad \text{(I-2)}$$

It is expressed in *sieverts* (*Sv*) [13, 15] and it is an organ-specific quantity that may be used for assessment of the risk of any radiation-induced cancer in an organ.

[15] See Definitions for detail description.

The effective dose (*E)* is widely used for justifying and optimizing protective actions. The effective dose is defined as a product of the radiation weighted dose in an organ or tissue and the tissue weighting factor w_T [2, 15]. Its unit is called the *sievert* (*Sv*) [13]. The total effective dose (E_T) includes the dose from external penetrating radiation and intake.

$$E = \sum_T H_T \times w_T \qquad \text{(I-3)}$$

This is the quantity used for the GRLs at which certain protective actions are generically justified and optimized [1] for the reference levels for aiding decisions on remediation [5] and for the reference levels at which intervention may not be justified [4].

The quantities used for radiation monitoring are:

- ambient dose equivalent ($H^*(d)$), i.e. the *dose equivalent* that would be produced by the corresponding aligned and expanded field in the *ICRU sphere* at a depth *d* on the radius opposing the direction of the aligned field; and

- personal dose equivalent ($H_P(d)$), i.e. the *dose equivalent* in soft tissue below a specified point on the body at an appropriate depth *d*.

Their units in SI are Jkg^{-1} and are expressed as *sieverts* (*Sv*).

Ambient dose equivalent and personal dose equivalent are the operational quantities based on the quantity of dose equivalent. The dose equivalent is the product of the *absorbed dose* at a point in the tissue or organ and the appropriate *quality factor* for the type of *radiation* giving rise to the *dose* [16]:

$$H = \sum_R D_R \times Q_R \qquad \text{(I-1)}$$

Table I-2 presents a list of health effects that would be most critical during an emergency. Experience and research indicate that evaluation of the dose to these organs should provide a basis for OILs used for making decisions that will address the full range of potential adverse health effects.

The GRLs presented in this appendix are established with the aim of providing a basis for OILs used for decisions on undertaking:

- precautionary urgent protective actions to prevent the occurrence of severe deterministic health effects;

- medical actions to treat deterministic or stochastic health effects if they occur; and

- radiation protection actions to minimize consequences related to the health effects listed in Table I-2.

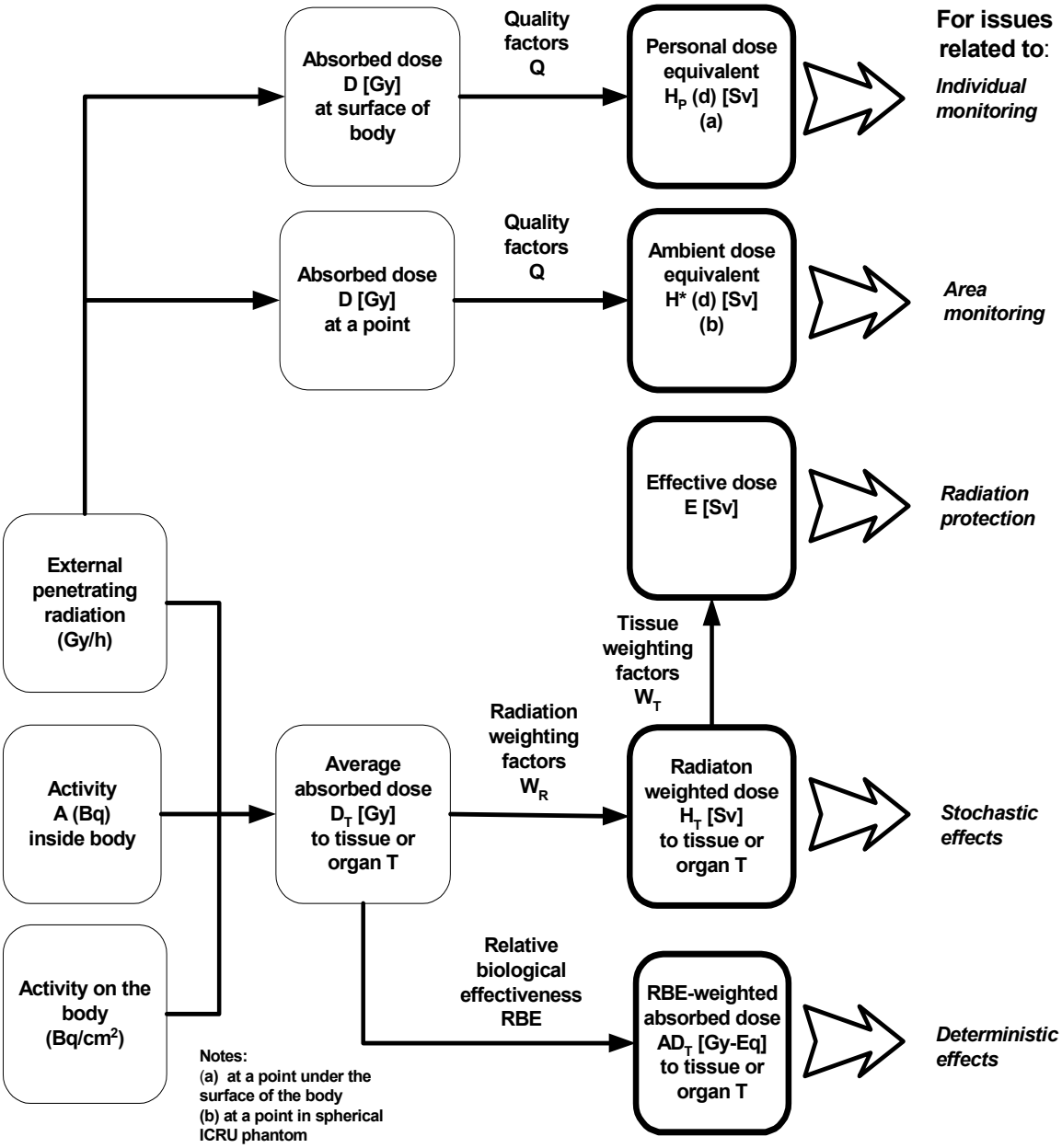

FIG. I-1. Dosimetric quantities and their application.

TABLE I-2. MOST CRITICAL RADIATION-INDUCED HEALTH EFFECTS DURING A RADIATION EMERGENCY

Health effect	Target organ or entity
Deterministic health effects	
Fatal	
Haematopoetic syndrome	Red marrow [(a)]
Gastrointestinal syndrome	Small intestine for external exposure [(a)] or Colon for internal exposure [(b)]
Pneumonitis	Lung [(a), (c)]
Embryo/foetal death	Embryo/foetus in all periods of gestation
Nonfatal	
Moist desquamation	Skin [(d)]
Necrosis	Soft tissue [(e)]
Cataract	Lens of the eye [(a), (f)]
Acute radiation thyroiditis	Thyroid [(a)]
Hypothyroidism	Thyroid [(a)]
Permanently suppressed ovulation	Ovum [(a)]
Permanently suppressed sperm counts	Testes [(a)]
Severe mental retardation	Embryo/foetus 8–25 weeks of gestation
Malformation	Embryo/foetus 8–25 weeks of gestation
Growth retardation	Embryo/foetus 8–25 weeks of gestation
Possible verifiable reduction in IQ	Embryo/foetus 8–25 weeks of gestation
Stochastic health effects	
Thyroid cancer	Thyroid
All stochastic health effects	All organs taken into account in definition of effective dose [2]

[(a)] External exposure to the red marrow, lung, small intestine, gonads, thyroid and lens of eye from irradiation in a uniform field of strongly penetrating radiation is addressed by AD_{Torso} as defined in Table 2.

[(b)] Different targets for gastrointestinal syndrome are proposed because of difference in dose formation in small intestine and colon in case of internal exposure. This is due to difference in kinetic of ingested material in gastrointestinal (GI) tract, which leads to much higher doses in colon then in small intestine after intake [14].

[(c)] For the gas-exchange (alveolar interstitial (AI)) region of the respiratory system [17].

[(d)] Skin structures at a depth of 50 mg/cm^2 (or 0.5 mm) under the surface [18, 19].

[(e)] To a depth of 0.5 cm in tissue [20, 21].

[(f)] Lens structures at a depth of 300 mg/ cm^2 (or 3 mm) under the surface [2].

I.1. Basis for Generic reference levels in Table 2 Section A

Table I-3 summarizes the basis for GRLs for projected and received dose in Table 2 Section A.

The GRLs in Section A of Table 2 are established with the aim of providing a basis for OILs used for decisions on taking precautionary urgent protective actions to prevent or medical actions to treat severe deterministic health effects. For assessing the risk of deterministic health effects developing in an organ or tissue (T) due to exposure to radiation, the OILs derived from the RBE-weighted absorbed dose (AD_T) ought to be used.

The GRLs for deterministic effects listed in Section A of Table 2 were determined by means of radiobiological models of developing severe deterministic effects in adults. The only exception are GRLs for embryo and foetus. The lack of radiobiological data doesn't allow developing the age-dependent radiobiological models in case of deterministic effects, hence age-dependent GRLs.

The values for GRLs are expressed in terms of RBE-weighted absorbed dose in an organ or tissue for external exposure and in terms of committed RBE-weighted absorbed dose in organ or tissue for internal exposure. For uniform external exposure to strongly penetrating radiation, the generic reference level of RBE-weighted absorbed dose for the torso is established as a quantity representative of a number of values characterizing irradiation of different organs and tissues in case of such an exposure. Definitions of these dosimetry quantities are presented in detail in Appendix II and in the Definitions.

The aim was to set the GRLs for severe deterministic health effects at the threshold level or slightly below the threshold level for their occurrence (i.e. the level at which the effect may be seen — though unlikely — in a few people only if large numbers of people have been exposed at these levels). Development of deterministic effects in irradiated group of people is random process characterizing by risk function as a function of RBE-weighted absorbed dose and other parameters of exposure. Therefore, the value for $AD_{T,05}$ is used as the threshold dose for the purpose of evaluating severe deterministic health effects in the affected population. By definition, $AD_{T,05}$ is the RBE-weighted absorbed dose that theoretically results in the effect in 5% of exposed people.

For external exposure, the threshold value of $AD_{T,05}$, strongly depends upon the dose rate. The threshold value used here for external exposure corresponds to brief irradiation at a very high dose rate. The value of the threshold would be higher for lower dose rates and thus for most emergencies, the value for $AD_{T,05}$, in Table I-3 is below the actual threshold. For most emergencies, the health effects would not be expected to be seen at the $AD_{T,05}$, GRLs listed in Table I-3 unless large numbers of people have been exposed at this level. However this conservatism is very important. Uncertainties of dose estimates during the emergency response will be very high due to luck of information. Theoretically, the $AD_{T,50}$, dose (the dose that would result in the health effect in 50% of those exposed), may be higher than two times the $AD_{T,05}$, value, but this difference would be within the uncertainties of initial dose assessment during an emergency.

For intake, the best indicator of the risk of developing severe deterministic health effects is I_{05}, i.e. the amount of a radionuclide that must be inhaled or ingested in order that 5% of exposed people will present severe deterministic health effects at some time, possibly long after intake. Unfortunately, the values for the radionuclide specific I_{05} calculated for a wide list of radionuclides[16] vary by more than a factor of 1000. So, as discussed in Appendix II, for practical reasons a quantity of committed RBE-weighted absorbed dose, $AD_{T,05}(\Delta)$ over a period Δ is used instead of I_{05}. The committed RBE-weighted absorbed dose in an organ or tissue T is defined as a time integral of the RBE-weighted absorbed dose rate in the organ (for more detail, see Appendix II):

[16] Based on results of evaluation of the I_{05} for about 750 radionuclides in case of inhalation and ingestion. Variations are related to differences among radionuclides from these lists.

TABLE I-3. GRLs OF RBE-WEIGHTED ABSORBED DOSE FOR SEVERE DETERMINISTIC HEALTH EFFECTS FROM EXTERNAL EXPOSURE

Disease/Status	Organ or entity	$AD_{T,05}$[(a)], Gy-Eq	GRL
Haematopoetic syndrome[(g)]	Red Marrow	3[(b)]	AD_{Torso} 1[(d)]Gy-Eq
Gastrointestinal syndrome[(g)]	Small Intestine	12	
Pneumonitis[(g)]	Lung	8[(c)]	
Cataract[(h)]	Lens of the eye	0.8[(i)]	
Hypothyroidism[(h)]	Thyroid	2	
Permanently suppressed ovulation[(h)]	Ovum	1.5	
Permanently suppressed sperm counts[(h)]	Testes	1	
Embryo/foetal death[(g)]	Embryo/foetus 0–18 days of gestation	0.3	AD_{Foetus} 0.1[(d),(j)]Gy-Eq
	Embryo/foetus 18–150 days	0.6	
	Embryo/foetus 150–term	2.0	
Severe mental retardation[(h)]	Embryo/foetus 8–15 weeks	0.6	
	Embryo/foetus 16–25 weeks	0.9	
Malformation[(h)]	Embryo/foetus 8–25 weeks	0.1	
Growth retardation[(h)]	Embryo/foetus 8–25 weeks	0.25	
Verifiable reduction in IQ[(h)]	Embryo/foetus 8–25 weeks	0.1	
Necrosis of deep tissue[(h)]	Soft tissue	25[(e)]	AD_{Tissue} 25 Gy-Eq
Moist desquamation[(g)]	Skin	12[(f)]	AD_{Skin} 10 Gy-Eq

(a) Central estimates of the values.
(b) For supportive medical management with only minimal treatment the $AD_{T,05}$ is 2 Gy-Eq.
(c) $AD_{T,05}$ is for children and for adults aged 40 and younger; for older individuals the GRL is 4 Gy-Eq.
(d) or uniform external exposure to strongly penetrating radiation, the GRLs for the torso or foetus are established at the lowest threshold for any of the health effects resulting from such an exposure.
(e) Delivered to a depth of 0.5 cm in the tissue from contact.
(f) For 600 cm^2, which is considered life threatening; calculated for skin structures at a depth of 50 mg/cm^2 (or 0.5 mm) under the surface [18, 19].
(g) Assumed to be fatal (in case of moist desquamation – if it occurs over substantial area of the skin).
(h) Non-fatal effect that is assumed to result in a reduction of the quality of life and is thus a severe deterministic health effect.
(i) For structures in the lens of the eye at a depth of 300 mg/ cm^2 (or 3 mm) under the surface [2].
(j) This related only to the risk of deterministic health effects from *in utero* irradiation to the embryo/foetus. This GRL was selected to be consistent with the recommendation of Ref. [22], which deals in part with the impact of exposure to the foetus. The deterministic health effects from foetal exposure include prenatal death, malformation and impairment of mental development over the background incidence of these effects. Most of these effects have a threshold above 100 to 200 mGy or higher [22]. However, during the period of 8–25 weeks post conception, a foetal dose of 100 mGy may result in a verifiable decrease in IQ. ICRP in Publication 84 [22] states; "At foetal doses of 100 mGy, the spontaneous incidence [without exposure] of mental retardation (3%) is much larger than a potential radiation effect on IQ reduction. On the other hand, at foetal doses of 1000 mGy 8–15 weeks post conception, the probability of a radiation induced significant decrease in IQ and resultant mental retardation rises to about 40%, which is much higher than the spontaneous rate of about 3%." ICRP-84 goes on to state: "Foetal doses below 100 mGy should not be considered a reason for terminating pregnancy. At foetal doses above this level, there can be foetal damage, the magnitude and type of which is a function of the dose and stage of pregnancy."

$$AD_T(\Delta) = \int_0^{\Delta} \dot{AD}_T(t)dt\,, \qquad \text{(I-5)}$$

where $\dot{AD}_T(t)$ is an RBE-weighted absorbed dose rate in the organ or tissue T at a time t after intake.

The committed RBE-weighted absorbed dose, $AD_T(\Delta)$ of internal exposure is a one-to-one function of a value of an intake and a time after intake, hence increasing with time. Thus committed dose of internal exposure and received dose of external exposure are not comparable. Therefore, $AD_{T,05}(\Delta)$ should not be compared with $AD_{T,05}$ from Table I-3. The value of $AD_{T,05}(\Delta)$ is used only for practical reasons as a substitute of the threshold intake I_{05}. Calculation of I_{05} values for about of 750 radionuclides shown that differences among I_{05} values for the radionuclides and effects concerned are huge. For instance, range of I_{05} values for development of pneumonitis is about of three orders of magnitude. This is caused by physical and chemical characteristics of radionuclides and nature of effect concerned. If Δ is fixed, value of $AD_{T,05}(\Delta)$ depends on the same physical and chemical characteristics of radionuclides and nature of effect concerned. However, it is a very weak function of these parameters, therefore range of $AD_{T,05}(\Delta)$ values will be narrow. For instance, difference of radionuclide specific $AD_{T,05}(\Delta)$ values for pneumonitis is less than a factor of 3 instead of a factor of 1000 for difference of I_{05} values calculated for the same set of radionuclides.

Duration of time after intake for calculation of the committed dose is a free parameter. The value of 30 days was chosen because it leads to minimal range of $AD_{T,05}(\Delta)$ values (see Table II-4 for comparison of $AD_{T,05}(\Delta)$ values for different duration of time after intake).

The values of $AD_{T,05}(\Delta)$ in Table I-4 represent the lowest values of the committed RBE-weighted absorbed dose chosen among those calculated for given period Δ after intake of the threshold quantity I_{05} of any of the radionuclides of concern (as discussed in Appendix II). Therefore, given values of $AD_{T,05}(\Delta)$ are considered as reasonably conservative estimates of the threshold values. The factor of conservatism is up to 3.

It is important to note that $AD_{T,05}(\Delta)$ is used only for practical reasons and should not be compared with $AD_{T,05}$ from Table I-3. The $AD_{T,05}(\Delta)$ in Table I-4 is the minimum committed RBE-weighted absorbed dose calculated from the intake of the threshold quantity I_{05} delivered by any of the radionuclides of concern over a period Δ as discussed in Appendix II. Since the variations of $AD_{T,05}(\Delta)$ are less than a factor of 3 for all the radionuclide specific values of I_{05}, the value of $AD_{T,05}(\Delta)$ given is considered a reasonably conservative estimate of the threshold value.

TABLE I-4. GRLs OF COMMITTED RBE-WEIGHTED ABSORBED DOSE FOR SEVERE DETERMINISTIC HEALTH EFFECTS FROM INTAKE

Disease/status	Organ or entity	$AD_{T,05}(\Delta)$, Gy-Eq	GRL
Haematopoetic syndrome[a]	Red marrow	0.5–8[b, c]	$AD_{Red\ marrow,\ 05}(\Delta)$ [b] - 0.2 Gy-Eq for intake of actinides - 2 Gy-Eq for intake of radionuclides other than actinides
Pneumonitis	Lung [d]	30–100[b, c]	$AD_{Lung,\ 05}(\Delta)$ [b] 30 Gy-Eq
Gastrointestinal syndrome	Colon	20–24[b, c]	$AD_{Colon,\ 05}(\Delta)$ [b] 20 Gy-Eq
Hypothyroidism[e]	Thyroid	2[b]	$AD_{Thyroid,\ 05}(\Delta)$ [b] 2 Gy-Eq
Acute radiation thyroiditis[e]	Thyroid	60[b]	
Embryo/foetal death	Foetus	0.6[f]	$AD_{Foetus,\ 05}(\Delta)$ [f] 0.1 Gy-Eq
Malformation and reduction in IQ[de]	Foetus	0.1[f]	

[a] For supportive medical treatment.

[b] Central estimate of the committed RBE-weighted absorbed dose $AD_{T,05}(\Delta)$ for Δ equal to 30 days (30-day committed RBE-weighted absorbed dose) from intake of the threshold quantity for the health effect.

[c] Range presents a variance of value of $AD_{T,05}(\Delta)$ for different radionuclides and their chemical forms.

[d] Gas exchange alveolar interstitial region of the respiratory tract.

[e] Non-fatal effect that is assumed to result in a reduction of the quality of life and is thus a severe deterministic health effect.

[f] The central estimates of committed RBE-weighted absorbed dose $AD_{T,05}(\Delta)$ for Δ equal to lifespan (lifespan committed RBE-weighted absorbed dose).

I.2. Basis for Generic reference levels in Table 2, Sections B and C

Table I-5 summarizes the basis for GRLs of projected and received dose in Table 2, Sections B and C.

The GRLs for the thyroid in Section B of Table 2 are established with the aim of providing a basis for OILs used for decisions on imposing precautionary (before monitoring) restrictions on the consumption of potentially contaminated food in order to prevent a detectable increase in thyroid cancers as occurred as a result of the Chernobyl accident.

The GRLs in Section C of Table 2 are established with the aim of providing a basis for (i) decisions concerning long term medical monitoring in order to detect and thus be able to treat these effects at an early stage and (ii) identifying those who should receive individual consultation concerning the health risks based on their estimated individual dose. An additional aim is to establish levels below which people can be reassured that their health risks are indistinguishable from those of people not exposed during the emergency. Therefore, these GRLs should be used to establish screening levels to determine the necessity for individual assessment based on an estimate of individual dose.

In meeting these aims, a very conservative approach is being taken by establishing the GRLs at levels at which effects will be detectable only by very careful study, in most cases, of very large cohorts. Consequently, the vast majority of the health effects incurred following an emergency among those who received doses above these GRLs will not be a result of their

emergency exposure. This approach is used in part because the GRLs should be established in advance and thus a reasonable upper bound was selected. Clearly the use of much higher GRLs would be reasonable for individual exposures or if the number of people in the exposed cohort is much smaller than the size that must be monitored to detect a significant increase in cancers. However, since GRLs should be established in advance, the use of higher GRLs at the time of the emergency may be difficult to explain to the public. Note that use of a higher GRL for foetal exposure is not considered to be appropriate since the levels are specified in ICRP Publication 84 [22].

For assessing risk of stochastic health effects developing in an organ or tissue (T) due to exposure to radiation, the quantity of radiation weighted dose (H_T) should be used. However, the generic reference level for screening based on individual dose after exposure of whole body to determine if registration is necessary for long term medical follow-up with the purpose of early identification of radiation-induced cancers of different localizations (except thyroid) is stated in terms of effective dose (E).

TABLE I-5. BASIS FOR GRLs IN TABLE 2 SECTIONS B AND C

GRL	Duration of exposure	Pathway of interest	Basis and comments
E_T: 0.10 Sv	Short term	External Ingestion Inhalation	There is substantial and convincing scientific evidence for health risks at high dose. Current summarized data, which represent international consensus, show that radiation induced cancer cases (excess above background cases) could be observed in humans at effective doses in excess of 0.1 Sv delivered at high dose rates [12]. These data are based on epidemiological studies of well-defined populations (e.g., the Japanese atomic bomb survivors and medical patients) exposed to high doses delivered at high dose rate. Epidemiological studies have not clearly demonstrated such effects in individuals exposed to small doses (less than 0.1 Sv) delivered over a period of many years. UNSCEAR 2000 states that the follow-up study of atomic bomb survivors indicates a "…significant increase in the risk of radiation-induced fatal solid cancers over the dose range of 0-50 mSv….Caution is needed in interpreting this finding, however, as an increased incidence of solid cancers is seen only at doses down to 200-500 mSv…" UNSCEAR 2000 concludes that "…further follow-up and improved information on the doses received will be needed before the shape of the dose response at low doses for both morbidity and mortality can be determined with confidence at doses below about 100-200 mSv…". Since the publication of the UNSCEAR 2000 report there were other comprehensive studies, which indicated a statistically significant risk of radiation-induced solid cancers in the range 0-0.1 Sv [23,24]. The current scientific knowledge has the following implication for radiation protection: the possibility that health effects might occur at small doses should not be entirely discounted. However risks of health effects after low dose exposure may be too small to be observed. Therefore, the criteria to be applied in an emergency should be based on current consensus data on subject aiming to achieve objectives of emergency response and addressing practical aspects of its implementation. The Strategic National Stockpile Radiation Working Group in their recommendations uses the criteria of 0.5-1.0 Gy as a ground for ambulatory monitoring, and 0.25-0.5 Gy – as criteria for epidemiologic monitoring in case of mass casualty radiation emergency [25]. The statistically determined sample size of the irradiated and controlled cohorts needed to detect a significant increase in cancer risk from whole body exposure of 100 mSv is about 100 000 (of each cohort). Long-lasting investigation (50-90 years after exposure) of such cohorts are needed to produce a study with more than 80% power, which would be acceptable from an epidemiological point of view. In general, a power of less than 80% is regarded as unacceptable, however for the purpose of public health care policy to address public concern and in consideration of the number of people that could be followed as a practical matter, cohorts of 10 000 each could be followed up with power of 50%.

GRL	Duration of exposure	Pathway of interest	Basis and comments
			The sample size of the irradiated 100 mSv dose to the bone marrow and controlled cohorts needed to detect a significant increase of excess cases for leukemia of is more than 100 000. Details are provided in Appendix III. The criterion is established for the short term exposure. It may need to be revised in the future if new data will become available. No consensus data are available for establishment of the criterion for the long-term exposure.
$H_{Thyroid}$: 50 mSv	Short term (from radioactive iodione)	Ingestion Inhalation	Children are considered to be the group most vulnerable to thyroid cancer following an intake of ^{131}I. Before the Chernobyl accident, there was little information concerning this risk. Since then, however, many studies have attempted to derive the risk of thyroid cancer as result of intake of ^{131}I after the Chernobyl accident. These studies found a statistically significant increase in the incidence of thyroid cancer among the cohort who were children at the time of the accident or were exposed *in utero,* and received an average thyroid dose of about 50 mGy [26]. In addition, the statistically determined sample size of the irradiated and controlled cohorts needed to detect a significant increase in the cancer risk from an exposure of 50 mGy to the thyroid from intake of ^{131}I is more than 10 000. ICRP Publication 88 [27] indicates that the dose to the foetal thyroid from intake of ^{131}I is about the same as that to the adult thyroid; consequently, exposure of foetal thyroid is not considered separately.
H_{Foetus}: 0.1 Sv	Months	External Ingestion Inhalation	An UNSCEAR report (See para. 537 in [12]) states: "For most tumour types in experimental animals and in man, a significant increase in risk is only detectable at doses above about 100 mSv. An exception is for human exposures *in utero* when a significant increase in tumour induction in children has been found for doses in the 10–20 mGy range [photons]. No such excess was observed in the studies of Japanese atomic bomb survivors irradiated *in utero*." Separate studies has shown an increase in childhood cancer incidence from diagnostic *in utero* exposures down to 10 mGy [28]. ICRP-84 [22] para. 156 states: "A conservative estimate of the lifetime risk of radiogenic induction of childhood cancer or leukemia at 100 mGy [from *in utero* exposure] is about one in 170." Probability that child will not develop cancer (age 0-19) is changing from 99.7% in case of exposure up to 5 mGy to 99.1% in case of exposure in 100 mGy [ICRP-84 Table 4]. Consequently, it was deemed unnecessary to establish a lower GRL for foetal exposure.

I.3. Basis for Generic reference levels in Table 2 Sections D and E

Concepts of averted (avertable) and projected doses are shown in Figure I-2. In the left-hand figure it is assumed that the decision on the introduction of protective actions is taken after the start of the exposure or release, and the avertable dose (above background) is the time integrated dose rate from beginning to end of the period for which the protective action is implemented. The dose received before the introduction of the protective action is not included in the avertable dose. In the right-hand figure it is shown that the projected dose is the total dose from the start of the exposure or release until the end of the implementation of a protective measure.

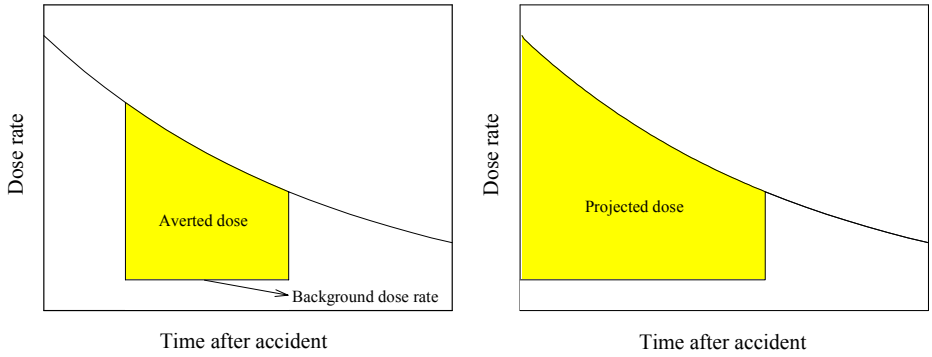

FIG. I-2. Concepts of averted (avertable) and projected doses.

In many practical cases where a protective action is very effective at reducing doses, the avertable dose will be equal to the entire projected dose from the same pathways and over the same time period, but this will not always be the case (See Figure I-2).

Table I-6 summarizes the basis for GRLs of avertable dose specified in Table 2 Sections D and E. These GRLs have been established with the aim of providing a basis for OILs used for decisions on taking reasonable (justified) protective actions to avert doses, satisfying the principles that:

- deterministic and detectable increases of stochastic health effects are avoided; and
- the intervention is generically justified if the risks averted by the actions are greater than those introduced by the protective actions themselves.

The protection provided by these intervention levels has been optimized on a generic basis for the general population, assuming normal conditions at the time of implementation. They *do not need to be adjusted* to account for any particular member of the population (e.g. children or pregnant women) because protective actions taken to avert these doses will satisfy the basic principle for all members of the population. However, in developing the operational criteria (OILs) for these GRLs, care must be taken to ensure that all segments of the population and activities (e.g. children playing on the ground) are considered. In addition, these levels were developed assuming a low risk during implementation. Therefore, if implementation of an action involves a substantial risk (e.g. evacuation during hazardous weather conditions or restricting food when replacement food is not available), actions could be taken at highest levels, which are still below the thresholds for deterministic effects. However actions to prevent doses that can result in severe deterministic health effects (above the values in Table I-3 and Table I-4) are justified under almost all conditions.

The GRLs related to effects in an organ or tissue (T) due to exposure to radiation are expressed as radiation weighted dose (H_T). The GRLs related to the detriment due to stochastic health effects in the exposed population are stated in terms of effective dose (E).

TABLE I-6. BASIS FOR THE GRLs IN TABLE 2 SECTIONS D AND E

GRL (Avertable dose)	Protective action	Basis and comments
Urgent protective actions		
E_T: 10 mSv in 2 days	Sheltering	The specified urgent protective action (intervention) is generically justified at these GRLs for otherwise normal conditions (e.g. usual weather) as described in Ref. [1]. These include dose from external sources (e.g. cloud and ground), inhalation of plume, inadvertent ingestion and inhalation from resuspension.
E_T: 50 mSv in 1 week	Evacuation	
	Urgent decontamination	This addresses decontamination to avert the dose from inadvertent ingestion, which is generically justified for otherwise normal conditions since they approach those at which medical screening would be warranted. Except for low energy beta/gamma emitters and alpha emitters, the skin dose GRL (H_{Skin} below) will be more important than inadvertent ingestion. In addition, it will be difficult to detect skin contamination levels sufficient to result in this dose from inadvertent ingestion.
$H_{Thyroid}$: 50 mSv	Iodine prophylaxis	This level is lower than that recommended for iodine prophylaxis in Ref. [1], and is selected in order to avert dose that could result in a detectable increase in thyroid cancers (See Table I-5).
	Urgent decontamination	This addresses decontamination to avert the dose from inadvertent ingestion, which is generically justified for otherwise normal conditions since they approach those at which medical screening would be warranted. The skin dose GRL (discussed below) will be more important than inadvertent ingestion. In addition, it will be difficult to detect skin contamination levels sufficient to result in this dose from inadvertent ingestion.
H_{Skin}: 0.1 Sv to skin in days	Urgent decontamination	This addresses decontamination to avert dose to the skin. This level was established somewhat arbitrarily to prevent cross contamination at levels 10 to 100 times those used for routine radiation protection purposes (e.g., decontamination in the laboratories) and with the knowledge that: 1) if ground contamination is the source of the skin contamination, it is unlikely that skin contamination levels in this range will occur outside the urgent evacuation zone, 2) for most beta/gamma emitters, these levels of skin contamination will be easily detected under emergency conditions, and 3) for many beta/gamma emitters, skin contamination of the order of a factor of ten above these levels may result in inadvertent ingestion warranting medical screening. This GRL is only a small fraction of the doses that would result in deterministic health effects to the skin and for most beta/gamma emitters the dose resulting from inadvertent ingestion of skin contamination of this range would be in the order of 10 mSv. Consequently unless the contamination is at a level well above this GRL, the contaminated person can be reassured that there is no significant health risk. As recommended by ICRP and ICRU, the skin dose should be calculated for a nominal depth of 0.07 mm while recognizing that lasting deterministic health effects arise mainly from exposures at deeper layers (> 0.3 mm) [18, 19].

GRL (Avertable dose)	Protective action	Basis and comments
Longer term protective actions		
E_T: – 5 mSv per annum from consumption	Replacement of food, milk and water	This addresses longer term intervention to control contamination of foodstuffs (food, water, milk) and is based on Ref.. [2, 3]. The guidance in these references is expressed in terms of the concentration (Bq/kg) in foodstuffs and not in terms of averted dose. These concentration levels are referred to generic action levels (GALs) in the reference guidance. These GALs were initially intended for international trade and were established at levels such that if the contaminated foodstuffs were consumed for an entire year, it would result in dose of the order of a few mSv. These levels should be applied only if replacement food is readably available. Foodstuffs with concentrations of 100 or more times these levels can be consumed safely (without exceeding the dose warranting medical screening) for short periods (weeks) until replacement food is available.
E_T: 30 mSv/1st month	Temporary relocation	The specified longer term protective action (intervention) is generically justified for application under otherwise normal conditions as described in Ref. [1] and applies to doses from external sources (e.g. ground contamination), inadvertent ingestion and inhalation from resuspension.
E_T: 1000 mSv/life time	Permanent resettlement	
H_{Skin}: 10 mSv to skin in days	Discretionary decontamination and reassurance	This level was established somewhat arbitrarily in the range of those levels used for routine radiation protection purposes. At these levels, the skin dose would be insignificant in terms of potential health effects and for most beta/gamma emitters the dose resulting from inadvertent ingestion from skin contamination in this range would be in the order of 1 mSv. Another consideration is that a person contaminated at this level can be reassured that there is no significant health risk. Also, skin contamination levels needed to result in these doses to the skin may be difficult to detect under emergency conditions.

I.4. Basis for Generic reference levels in Table 2 Section F

Table I-7 summarizes the basis for GRLs of the projected dose specified in Table 2 Section F. These GRLs are established with the aim of providing basis for OILs used for decision making process concerning discontinuation of disruptive protective or other actions and thus allowing a return to normality. The guidance would probably be most important when making decisions concerning long lived radionuclides (with long half-lives) that have contaminated either large areas or areas for which continued application of protective actions will be very disruptive and may in themselves do more harm than good.

ICRP in Publication 82 (See executive summary para. (w) in [4]) summarizes the issue addressed by these GRLs, which states: "Disruptive protective actions, such as evacuation or other restrictions in the 'normal' living conditions of people, may be required after … [emergencies] that have released radioactive substances into the environment. Eventually, in order to return to 'normality', such actions may need to be discontinued at some stage in spite of the continuous presence of a residual prolonged exposure. The simplest basis for justifying the discontinuation of intervention after an … [emergency] is to confirm that the exposures have decreased to the action levels that would have prompted the intervention. If such a reduction in exposure is not feasible, the generic reference level of existing annual dose below which intervention is not likely to be justifiable could provide a basis for discontinuing intervention. However, it may be difficult to discontinue protective actions that have been in force for many years: the decision may not be acceptable to the exposed population and the social pressures may override the benefit of discontinuing the intervention. In these cases, the participation of the stakeholders in the decision making process becomes essential. After intervention has been discontinued, the remaining existing annual dose should not influence the normal living conditions in the affected area (including decisions about the introduction of new practices), even if this dose is higher than that prevailing in the area before the ... [emergency]."

The most important radiation protection principles to be upheld when establishing guidance on when protective action may no longer justified are that:

(1) the dose to any individual living under otherwise normal conditions (following the discontinuation of the protective actions) should not approach the threshold for severe deterministic health effects;

(2) the dose to any individual living under otherwise normal conditions (following the discontinuation of the protective actions) should not entail a high risk of stochastic health effects; and

(3) discontinuation of the protective action should do more good than harm.

The first two principles can be met by not discontinuing any protective actions until there is reasonable assurance that it is unlikely that anyone will receive a dose exceeding the criteria in Section C of Table 2 once the actions have been discontinued.

Establishing criteria or guidance consistent with principle 3 is very difficult because it cannot be assessed on the basis of radiation protection principles alone and can be addressed only when the decision makers, in close consultation with the stakeholders, take the ethical, economic, and psychological factors into consideration. Furthermore, it will be very difficult to establish guidance on the radiation protection aspects alone because at the dose levels of concern there should not be any detectable health effects (in order to meet principles 1 and 2).

The basic approach taken here to address principle 3 is to state the radiation protection guidance in terms of dose levels that appear to be safe because they are within those received annually by large numbers of people worldwide with no known adverse health effects of radiation exposure. This is supported by the added understanding that taking any action to further reduce dose in this range could easily have detrimental effects that are greater than the risk associated with the dose being avoided (e.g. people may be relocated to areas where the normal (background) cancer rates are higher than those predicted for the affected area).

In this respect, the 'natural' existing annual effective doses experienced worldwide average about 2.4 mSv. For individuals, annual exposures ranging from 1 mSv to two or three times the world average are frequently encountered [29]. At the extreme, there are some populations that receive annual doses averaging above ~100 mSv per annum ([4] para. A11). It is important to realize that these are average doses for the population living within these regions and that in any given year, many individuals in each region will receive doses considerably higher or lower than these regional averages.

The GRLs that address principle 3 are based on the recommendations of ICRP 82 [4] (which are consistent with the IAEA requirements for remediation [5]), which states (Executive summary (r)) "it is considered that an existing annual dose approaching about 10 mSv may be used as a generic reference level below which intervention is not likely to be justifiable for some prolonged exposure situations. …Situations in which the annual (equivalent) dose thresholds for deterministic health effects in relevant organs could be exceeded should require intervention. An existing annual dose rising towards 100 mSv will almost always justify intervention, and this may be used as a generic reference level for establishing protective actions under nearly any conceivable circumstance". ICRP also states that (para. 73): "[these reference levels] should be used with extreme caution." If some controllable components of the existing annual dose are clearly dominant, the use of the GRLs should not prevent protective action from being taken to reduce these dominant components. ICRP (para. 80) emphasized that this type of "generic reference level is more useful in situations where there are no dominant components among the many constituting the existing annual dose. There might be situations where intervention to reduce one or more of these components might be justified at existing annual doses much lower than about 10 mSv. … As concern will usually be focused on one component, national authorities will find it useful to establish specific reference levels — such as an action level specific to that particular component — which could be based on appropriate fractions of the GRLs." ICRP (para. 84) also stressed "…the …values …refer to non-specific situations and provide broad boundaries to ranges of existing annual doses for which decisions on intervention may be considered. The Commission does not intend that the recommended values of GRLs acquire the status of 'restrictions' or 'limiting' levels, nor conversely as 'acceptable' levels, of any kind and expect that they will not be used in this way". This will require that the contamination in those affected be fully characterized and that a realistic assessment of the potential dose to various segments of the population be performed before specific recommendations, based on the radiological situation, are made.

The final decision concerning suspension of protective actions and return to normality will undoubtedly be made after considering many factors beyond the assessments and guidance given here. This decision process is assumed to include a process of providing the stakeholders (those directly affected by the decision) with an opportunity to make an informed decision as outlined in the section of this document on public information and ethical considerations. As stated earlier, the information here should be seen only as input into this decision making process.

The GRLs are for the annual dose (from all sources) that is projected to be delivered if the protective actions are discontinued. The GRLs related to risk from exposure to an organ or tissue (T) due to radiation are expressed as radiation weighted dose (H_T). The GRLs related to the general risk of cancers resulting from radiation exposure are stated in terms of effective dose (E).

TABLE I-7. BASIS FOR THE GRLs IN TABLE 2 SECTION F

GRL **Projected dose**	**Basis /Comments**
E_T: < 10 mSv per annum	This GRL applies to a typical person residing in the area after the disruptive protective actions have been discontinued and normal living conditions have been established within the area, and covers the dose from all sources, including that from the natural background. This is an existing annual dose that is recommended by [4, 5] that may be used as a GRLs below which intervention is not likely to be justifiable (from a radiation protection perspective) for prolonged exposure situations. However, intervention may be justified at existing annual doses lower than this level if the protective action to reduce such components is not disruptive (will interfere with return to normal living). This should not be considered as a limit, but only as input into decision making and should be used along with an understanding of the range of 'natural' existing annual doses and other considerations discussed above.
H_{Foetus}: < 0.1 Sv in months	This GRL applies to the dose to pregnant women (and, consequently, foetus) individuals residing in the area after the disruptive protective actions have been discontinued and normal living conditions have been established within the area. Every effort should be taken to avoid this level because it approaches the level at which there are detectable deterministic health effects as discussed in Table I-5.
$H_{Thyroid}$: < 50 mSv	This GRL applies to a typical person residing in the area after the disruptive protective actions have been discontinued and normal living conditions have been established. At doses above this level there is a substantial risk of stochastic health effects as discussed in Table I-5.
$H_{Any\ other\ organ}$: < 0.1 Sv per annum	This GRL applies to a typical person residing in the area after the disruptive protective actions have been discontinued and normal living conditions have been established. Refs. [4] and [6] indicate that an existing annual dose rising towards 100 mSv will almost always justify intervention and may be used as a GRL for establishing protective actions under nearly any (most) conceivable circumstances. In addition, if doses approach the levels in Table I-5, there is a substantial risk of detectable stochastic health effects.

Appendix II

DOSIMETRIC BASIS FOR CRITERIA RELATED TO DETERMINISTIC HEALTH EFFECTS

This appendix provides a description of the dosimetric basis for the GRLs in Table 2, Section A.

Material of the Appendix includes:

- Definition of dosimetry quantities related to assessment of deterministic health effects;
- Risk models for development severe deterministic health effects;
- Full set of parameters of risk functions for the effects concerned;
- Threshold RBE-weighted absorbed dose ($AD_{T,05}$) for severe deterministic health effects from external exposure;
- List of target specific GRLs for taking actions to prevent severe deterministic health effects due to external and internal exposure;
- GRLs for protective actions to prevent severe deterministic health effects in cases of acute intake of radioactive material in terms of a 30 day committed RBE-weighted absorbed dose;
- Threshold doses for developing selected non-fatal severe deterministic health effects that are assumed to result in decrease of quality of life;
- Verification of compliance for an estimated risk with a threshold value in case of combined internal and external exposure.

II.1. Dosimetric quantities for evaluation of deterministic health effects

For evaluating deterministic health effects developing due to exposure of an organ, the averaged absorbed dose in the organ or tissue (RBE-weighted absorbed dose) is used. This quantity (AD_T) is defined as a product of averaged absorbed dose in organ or tissue and the relative biological effectiveness (RBE):

$$AD_T = \sum_R D_{R,T} \times RBE_{R,T} \qquad \text{(II-1)}$$

For a particular organ or tissue (T), the $RBE_{R,T}$ is the ratio of the absorbed dose of a reference radiation that produces a specified biological effect relative to the absorbed dose of the radiation of interest (R) producing the same biological effect. The $RBE_{R,T}$ value is dependent on the organ and tissue, the biological condition under consideration and the quality of the radiation producing the absorbed dose. The quality of the radiation depends upon many factors, the most important being the linear energy transfer (LET), and the penetrating capability of the radiation. Due to microdistribution of radionuclides emitting weakly penetrating radiation, the $RBE_{R,T}$ value may be different for internal and external exposure from radiation with the same value of LET. Therefore, external irradiation by photons with an energy in the range of 1.0–0.5 MeV is used as a reference radiation and a route of exposure. How to adjust doses, taking into account radiation quality with regard to deterministic health effects, is discussed in NUREG Report 4214 [14] and in ICRP Publication 92 [13].

II.2. Risk model for deterministic health effects

In 1980, B. Scott first proposed the biophysical models used in this document for characterization of severe deterministic health effects [30, 31]. The mathematical formulation

of these models is similar to the probability function used in reliability theory and is described in the NUREG/CR-4214 report [32]. These models will be referred to as risk models.

Risk models and associated parameters were developed using the available data on animal experiments and analysis of human exposures as described in detail in Refs. [14, 33]. As an example, Figure II-1 shows the estimated median lethal absorbed dose (LD_{50}) to the human relative to the absorbed dose rate for humans, based on data collected in NUREG-4214 to confirm the risk models. This data also illustrates the strong dependence of risk on dose rate.

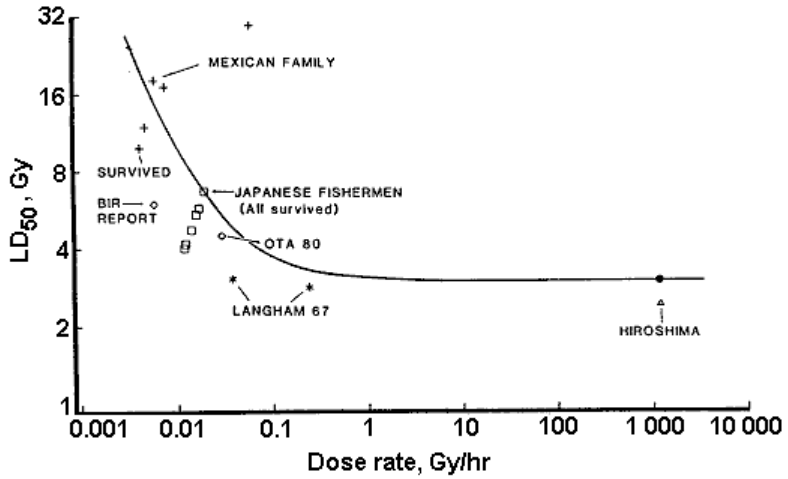

FIG. II-1. Estimated AD_{50} vs. dose rate for humans [32].[17]

According to the NUREG/CR-4214 risk models, the probability (risk) R_T of developing deterministic health effects is a function of $H_T\{\tau, \dot{AD}_T(t)\}$:

$$R_T = 1 - \exp\left(-H_T\{\tau, \dot{AD}_T(t)\}\right), \qquad \text{(II-2)}$$

where:

$H_T\{\tau, \dot{AD}_T(t)\}$ = a hazard function in the form of the Weibull-type function that depends upon the history of the exposure as quantitatively characterized by:

[17] Sources of data and judgmental values. See Ref: [32] for full cites: LANGHAM 67 two estimates based on linear probit model for exposure for 0–1 day and 1–7 days. HIROSHIMA: estimate for Hiroshima with LD_{50} dose at 892 meters from hypocentre; dose estimate modified based on DS86 dosimetry and new transmission factors. MEXICAN FAMILY: Mexican family unknowingly exposed intermittently in their home to ^{60}Co gamma radiation; 4 out of the 5 died. A factor of 0.0073 was used to convert R to Gy. Values plotted represent midrange of estimated individual doses rather than values for median lethal dose. JAPANESE FISHERMEN: Seven of the 23 fishermen exposed to fallout gamma radiation had estimated total-body doses greater than 4 Gy; none died from marrow-syndrome mode. Values plotted represented midrange of estimated individual total-body external dose rather than median lethal doses. Sixteen other fishermen with lower doses also survived acute radiation syndrome. OTA 80: Judgment of LD_{50} provided by the Office of Technology Assessment for a one week exposure period. BIR REPORT: Judgment of LD_{50} provided by the British Institute of Radiology for a one month exposure period (1982).

- period of exposure, $(0, \tau)$, presented by its duration time τ;
- exposure history, presented by RBE-weighted absorbed dose rate in organ or tissue as a function of time: $\dot{AD}_T(t), \quad t \in (0, \tau)$.

The general equation for $H_T\{\tau, \dot{AD}_T(t)\}$ [34] is:

$$H_T\{\tau, \dot{AD}_T(t)\} = [\ln(2)]\left(\int_0^{\tau} \frac{\dot{AD}_T(t)}{\theta_{T\infty} + \theta_{T1} / \dot{AD}_T(t)} dt\right)^{V_T}, \qquad \text{(II-3)}$$

where:

$\dot{AD}_T(t)$ = the instantaneous RBE-weighted absorbed dose rate in the organ or tissue *T* at a time *t* after the start of exposure, Gy-Eq h^{-1}.

$\theta_{T\infty}$ = the asymptotic value of RBE-weighted absorbed dose that theoretically results in the condition affecting 50% of those exposed for a very high dose rate exposure (brief exposure), Gy-Eq. A high dose rate is much greater than $\theta_{T1} / \theta_{T\infty}$.

θ_{T1} = when divided by $\dot{AD}_T$ accounts for the increase in the $AD_{T,50}$ above $\theta_{T\infty}$ when $\dot{AD}_T$ decreases, $(Gy\text{-}Eq)^2\ h^{-1}$.

V_T = a parameter that determines the shape (steepness) of the dose-response curve for deterministic health effects in organ *T*. The shape of dose-effect curve reflects a variability of human radiosensitivity and ability to compensate for radiation induced injury in the organ or tissue.

It should be noted that as a rule, the actual health effect being considered does not occur at the same time as irradiation. For instance, for total body external exposure, early symptoms of acute radiation sickness may be manifested hours after irradiation and the development of haematopoetic syndrome may lead to death months later.

Parameters needed for the NUREG/CR-4214 risk models [14, 32, 33, 35] for selected organs are listed in Table II-1 and Table II-2.

TABLE II-1. PARAMETERS NEEDED FOR THE RISK MODELS TO ESTIMATE THE RISK OF DEVELOPING SELECTED FATAL DETERMINISTIC HEALTH EFFECTS

Health effect	Target organ or entity	Type of exposure	Parameter[a]				Source
			$RBE_{R,T}$	$\theta_{T\infty}$, Gy-Eq	θ_{T1}, (Gy-Eq)^2/h	V_T	
Haematopoetic syndrome[b]	Red marrow	External γ	1	4.5	0.1	6	[32, Table 2.8]
		External n^0	3	4.5	0.1	6	[36]
		Internal β, γ	1	4.5	0.1	6	[32, Table 2.8]
		Internal α	2	4.5	0.1	6	[33
Pneumonitis	Lung[c], [d]	External γ	1	10[c]	30	12	[32, Table 2.14]
		External n^0	3	10[c]	30	12	[36, 36]
		Internal β, γ	1	10[c]	30	5	[32]
		Internal α	7	10[c]	30	5	[33]
GI Syndrome	Small intestine	External γ	1	15	4	10	[32, Table 2.11]
		External n^0	3	15	4	10	36
	Colon	Internal β, γ	1	15	4	10	[32, Table 2.11]
		Internal α	0[e]	NE	NE	NE	[35]
Embryo/foetal death	Embryo/foetus 0-18 days gestation	External γ	1	1	0.02	2	[32, Table 2.27]; [37, para. 409]
		External n^0	3				
	Embryo/foetus 18-150 days	External γ	1	1.5	0.03	3	[32, Table 2.27];
		External n^0	3				
	Embryo/foetus 150 - term	External γ	1	3	0.07	6	[32, Table 2.27; Table 2.7]
		External n^0	3				
Moist desquamation	Skin[f]	External β[g], γ	1	20	NE	5	[32, Table 2.19]

[a] Presented the central estimates of the values; *NE* = not estimated.

[b] For the supportive medical treatment, with only minimal treatment $\theta_{T\infty}$ is 3 Gy-Eq and θ_{T1} - 0.07 (Gy-Eq)^2 h^{-1} [32].

[c] Presented values of $\theta_{T\infty}$ in case of irradiation of the lung are evaluated for children, and for adults of 40 years old and younger; for older individuals these values need to be divided by 2 [32], [33, Table 2.4].

[d] Gas exchange alveolar interstitial region of the respiratory tract.

[e] For alpha-emitters uniformly distributed in content of Colon assumed that irradiation of walls of intestine is negligible.

[f] For a skin area of 600 cm^2 (1/3 of the skin area of a reference adult) which is considered life threatening. As recommended by ICRP, skin dose needs to be calculated for a nominal depth of 0.5 mm (See paras. (305), (306), and (310) in [18] and subsection 3.4.1 in [19]).

[g] Includes the dose from bremsstrahlung in the material of the source.

TABLE II-2. PARAMETERS NEEDED FOR THE RISK MODELS TO ESTIMATE THE RISK OF DEVELOPING SELECTED NON-FATAL SEVERE DETERMINISTIC HEALTH EFFECTS THAT RESULT IN A LOWER QUALITY OF LIFE

Health effect	Target organ or entity	Type of exposure	Parameter[a]				Source
			$RBE_{R,T}$	$\chi_{T\leftarrow}$, Gy-Eq	χ_{T1}, $(Gy\text{-}Eq)^2/h$	V_T	
Cataract	Lens of the eye	External η[b], ν	1	3.1	NE	2	[32, Table 2.29]
Permanently suppressed ovulation	Ovum	External ν	1	3.5	NE	3	[32, Table 2.21]
Sperm counts suppressed for a long time	Testes	External ν	1	2.5	NE	10	[32, Table 2.21]
Acute radiation thyroiditis	Thyroid	Internal[c] (intake of ^{131}I)	0.20	240	NE	1.9	[32], Table 2.16]
		Internal (others[d])	1	240	NE	1.9	

[a] The central estimates of the values; *NE* = not estimated.

[b] Includes the dose from bremsstrahlung in the material of the source.

[c] Uniform irradiation the critical tissues of thyroid gland is 5 times more likely to produce deterministic health effects than internal exposure to I-131 (Ref.[32]). Thyroid seeking radionuclides has a heterogeneous distribution in thyroid tissues. ^{131}I emits low energy beta-particles that leads to reduced effectiveness of irradiation of critical thyroid tissues due to dissipation of their energy in other tissues. Listed value for $\chi_{T\leftarrow}$ corresponds to committed absorbed dose in thyroid of 1200 Gy due to internal exposure after intake of ^{131}I.

[d] For intake of thyroid seeking radionuclides other than ^{131}I

The analysis of exposure includes two stages:

(i) the characterization of the basic physical parameters of an interaction between radiation human body, such as fluence and energy of particles and photons, absorbed dose in the point of radiation field, and concentration of radioactive aerosols in the air. Values of these parameters may be directly measured or derived from results of direct measurements with any reasonable accuracy characterized by (standard) error.

(ii) the characterization of the biological consequences of an interaction between radiation human body. Examples of such parameters are the probability of developing a particular health effect or an 'equivalent' dose in an organ or tissue. These are intended to account for differences in biological effectiveness in producing effects of radiation in organs or tissues due to the quality of radiation. Their values cannot be measured principally and may be only evaluated from measurable parameters of an interaction by means of a set of radiobiological or dosimetry models. The principal feature of these models is that they need to rely on analogy and/or to be based on the agreement of qualified experts. Examples relying on analogy are models of radiation health effects based on the results of the exposure of laboratory animals or specific groups of people. Uncertainties associated with such models depend upon the adequacy of analogy that very often cannot be estimated and confirmed. An example based on the agreement of qualified experts is a definition of an ambient dose equivalent and its relationship with the parameters of the radiation field and effective dose as a radiation protection quantity.

In radiation protection, a framework has been developed for operation with errors of measurement and uncertainties of models accompanying the analysis of consequences of human exposure. The framework is based on the concept of *reference man*. According to this concept, the consequences of exposure involve health effects in an abstract reference man in the same irradiation conditions as the individual in question. So possible differences in individual responses to irradiation relating to discrepancies between the characteristics of an abstract reference man and the personal biological characteristics of the individual are ignored. This approach requires radiobiological models used for radiation protection to be described in terms of the properties of reference man. The most commonly used convention employs central estimates for parameters of such models. Addressing uncertainties of the model parameters is beyond the scope of the current effort. The material of this section is based mainly on risk models described in NUREG reports [14, 32, 33]. These reports document dose–response models recommended for estimating the health effects of ionizing radiation. The reports focused on estimating uncertainties associated with the evaluation the parameters of the risk models. According to the radiation protection framework, the central estimates of model parameters were used to estimate generic intervention levels. It was assumed that models with parameters so estimated characterized the health effects in reference man. Analysis of the credibility of the NUREG risk models is outside the scope of this document, so model uncertainties have not been taken into account.

II.3. Irradiation with a constant dose rate

Duration of irradiation (τ) and an RBE-weighted absorbed dose rate ($\dot{AD}_T$) are the measurable parameters characterizing the exposure. For exposure with a constant dose rate, e.g. from exposure to an external source, the RBE-weighted absorbed dose delivered in the organ or tissue in a period (0, τ) is:

$$AD_T = \dot{AD}_T \times \tau, \qquad \text{(II-4)}$$

where:

$\dot{AD}_T$ = the constant RBE-weighted absorbed dose rate in the organ or tissue T (Gy-Eq h^{-1}).

The expression for the hazard function given in Eq. (II-3) for irradiation with a constant dose rate is:

$$H_T(AD_T) = [\ln(2)]\left(\frac{AD_T}{AD_{T,50}}\right)^{V_T}, \quad \text{(II-5)}$$

where:

$AD_{T,50}$ = the value of RBE-weighted absorbed dose that theoretically results in the condition affecting 50% of those exposed. It is a function of dose rate:

$$AD_{T,50} = \theta_{T\infty} + \theta_{T1}\left(\dot{AD}_T\right)^{-1}, \quad \text{(II-6)}$$

where:

$\theta_{T\infty}$ = the asymptotic value of RBE-weighted absorbed dose that theoretically results in the condition affecting 50% of those exposed for a very high dose rate exposure (brief exposure), Gy-Eq. A high dose rate is much greater than $\theta_{T1} / \theta_{T\infty}$.

θ_{T1} = when divided by $\dot{AD}_T$ accounts for the increase in the $AD_{T,50}$ above $\theta_{T\infty}$ when $\dot{AD}_T$ decreases, $(\text{Gy-Eq})^2\ h^{-1}$.

$\dot{AD}_T$ - = the constant RBE-weighted absorbed dose rate in the organ or tissue T (Gy-Eq h^{-1}).

Dependence of $AD_{T,50}$ upon $\dot{AD}_T$ is illustrated by Figure II-1, which corresponds to the development of haematopoetic syndrome after external exposure to photons, assuming that minimal medical treatment is provided to those exposed (See remarks to Table II-1).

The threshold dose for an effect could not be determined experimentally with certainty, so the value for $AD_{T,05}$ is used instead as the threshold dose. By definition, $AD_{T,05}$ is the RBE-weighted absorbed dose that theoretically affects 5% of exposed people. Another important quantitative parameter is the 'killing' dose which is the minimal level of exposure that leads to death of 100% of those exposed. The 'killing' dose for specific health effects could not be determined experimentally with certainty, so the value for $AD_{T,95}$ is used instead. By definition, $AD_{T,95}$ is the RBE-weighted absorbed dose that theoretically results in the effect in 95% of exposed people.

The probability of development of a severe deterministic effect in an organ or tissue T will exceed a level of R_T only if an RBE-weighted absorbed dose AD_T exceeds $AD_{T,R}$. The value of $AD_{T,R}$ is related to $AD_{T,50}$ and V_T by equation:

$$AD_{T,R} = AD_{T,50} \times \exp\left(\frac{1}{V_T}\ln\left(\frac{-\ln(1-R_T)}{\ln(2)}\right)\right) \quad \text{(II-7)}$$

The values of threshold dose ($AD_{T,05}$) and killing dose ($AD_{T,95}$) have the same dependence upon dose rate as the $AD_{T,50}$ has:

$$AD_{T,05} = \left(\theta_{T\infty} + \theta_{T1}\left(\dot{AD}_T\right)^{-1}\right) \times \exp\left(-\frac{2.6}{V_T}\right) \quad \text{(II-8)}$$

$$AD_{T,95} = \left(\theta_{T\infty} + \theta_{T1}\left(\dot{AD}_T\right)^{-1}\right) \times \exp\left(\frac{1.5}{V_T}\right) \quad \text{(II-9)}$$

The ratio of $AD_{T,05}$ to $AD_{T,95}$ is a 'steepness' of risk function:

$$S_T = \frac{AD_{T,05}}{AD_{T,95}} = \exp\left(-\frac{4.1}{V_T}\right). \qquad \text{(II-10)}$$

For a step function, 'steepness' is equal to unity and reflects the absolute uniformity of all humans in developing the deterministic effect of concern. If human radiosensitivity and ability to compensate for radiation induced injury in the organ or tissue concerned are very variable, steepness of the corresponding risk function approaches zero, e.g. steepness of risk function of foetal death after exposure at 0–18 days of gestation is equal to 0.13.

Taking into account Eqs. (II-4) and (II-6), equation (II-7) may be rewritten:

$$\tau_{T,R} = \left(\theta_{T\infty}\left(\dot{AD}_T\right)^{-1} + \theta_{T1}\left(\dot{AD}_T\right)^{-2}\right) \times \exp\left(\frac{1}{V_T}\ln\left(\frac{-\ln(1-R_T)}{\ln(2)}\right)\right) \qquad \text{(II-11)}$$

If $R_T = 0.05$, the value $\tau_{T,05}$ is a theoretical threshold value for the duration of exposure with an RBE-weighted absorbed dose rate of $\dot{AD}_T$ that leads to development of the severe deterministic effect in organ or tissue T in 5% of those exposed.

The relationship between duration of irradiation ($\tau_{T,05}$) and RBE-weighted absorbed dose rate ($\dot{AD}_T$) may be important for the medical prognosis of the consequences of emergency exposure when individual dose is not measured, e.g. in a radiological terrorist attack. Figure II-2 shows values $\tau_{T,5}$ as a function of $\overline{\dot{AD}_T}$ for local external irradiation of different organs or tissues of humans. If more than one critical organ is irradiated, the threshold value for the duration of exposure may be found by:

$$0.05 = 1 - \exp\left(-\sum_T H_T(\tau, \overline{\dot{AD}_T})\right). \qquad \text{(II-12)}$$

The threshold value should be lower than the minimal value of $\tau_{T,05}$ as predicted by (II-11) for exposure of the separate organs exposed under the same conditions.

An important task during a response is the control of the exposure to emergency workers such that they do not receive a dose sufficient to result in severe deterministic health effects. In some situations, this may involve determining the time that can be spent in a high radiation environment. Figure II-3 could be useful for such a purpose. This figure illustrates the dependence of the threshold ($AD_{T,05}$) dose upon duration of irradiation (τ) for a constant dose rate. The curves divide the graph into two areas: above the curve, the probability of developing deterministic health effects is more than 5% (above the threshold dose) and below the curve, it is less than 5% (below the threshold).

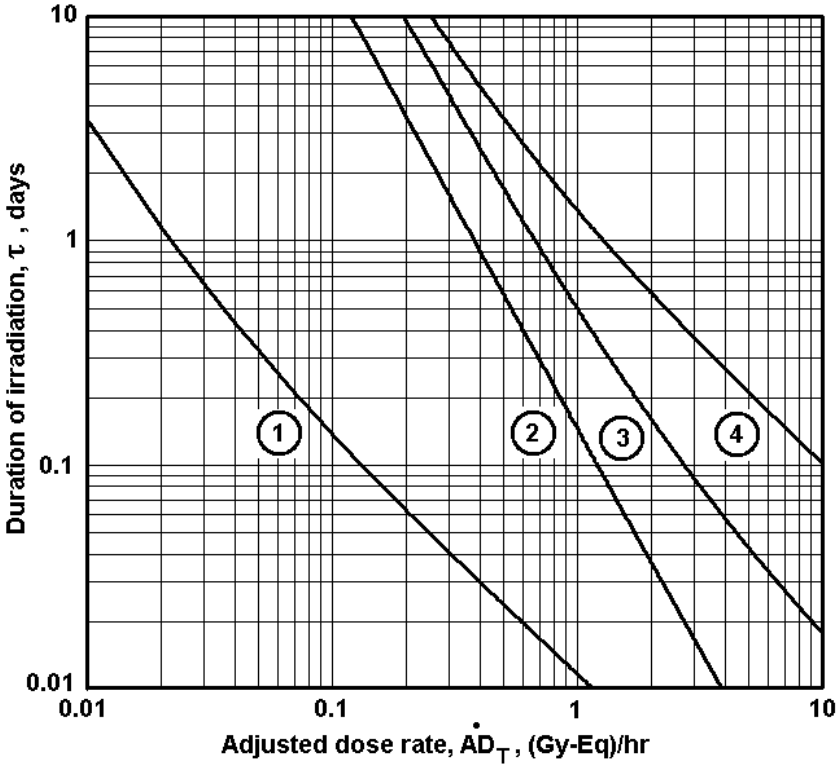

FIG. II-2. Theoretical RBE-weighted absorbed dose rate $\dot{AD}_T$ relative to the exposure duration (τ) that leads to severe deterministic health effects in organ or tissue T in 5% those exposed: 1). foetal death; 2). haematopoetic syndrome; 3). GI syndrome; and 4). pneumonitis.

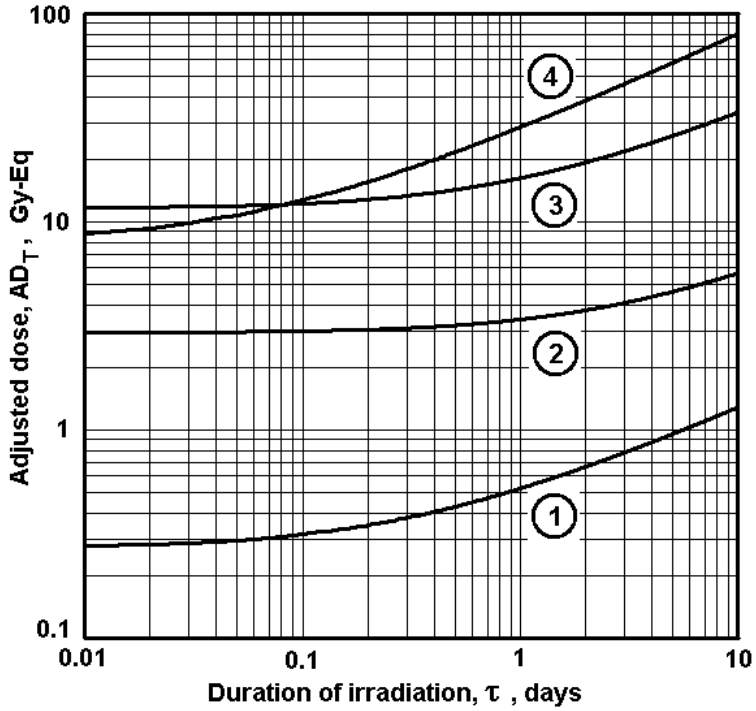

FIG. II-3. Theoretical exposure duration (τ) relative to the RBE-weighted absorbed dose AD_T that leads to severe deterministic health effects in organ or tissue T *in 5% those exposed: 1). foetal death; 2). haematopoetic syndrome; 3). GI syndrome; and 4). pneumonitis.*

II.4. Irradiation with variable dose rate

For internal exposure due to intake of a radionuclide, the RBE-weighted absorbed dose rate in any organ or tissue of a body is a function of time:

$$\dot{AD}_T(t) = I_{RN} \times \dot{Ad}_T(t), \tag{II-13}$$

where:

I_{RN} = the intake of radionuclide *RN*,

$\dot{Ad}_T(t)$ = the RBE-weighted absorbed dose rate in organ *T* at time *t* after intake 1 Bq of radionuclide concerned.

Taking into account Eq. (II-13), the equation (II-3) may be rewritten:

$$H_T(\tau, I_{RN}) = [\ln(2)] \times (I_{RN})^{2 \times V_T} \times \left\{ \int_0^{\tau} \frac{\dot{Ad}_T(t)}{I_{RN} \times \theta_{T\infty} + \circledR\circledC\overset{\text{TM}}{}\dot{Ad}_T(t) \rceil^{-1} \theta_{T1}} dt \right\}^{V_T}, \tag{II-14}$$

where parameters $\theta_{T\infty}$ (Gy-Eq), θ_{T1} ((Gy-Eq)^2 h^{-1}), and V_T were defined above.

I_{RN} and τ in Eq. (II-14) are the only measurable characteristics for intake of a radionuclide. So for internal exposure, they play the same role as $\dot{AD}_T$ and τ for external irradiation with a constant dose rate. Intake is characterized not only by the amount of activity, but also by the route of intake and chemical-physical properties of the radioactive material. These characteristics determine the behaviour of the radioactive material in the human body and the irradiation history of separate organs and tissues.

While calculating an RBE-weighted absorbed dose for internal exposure, one needs to take into account two types of radiation emitted by radionuclides: radiation with low LET (electrons and photons) and radiation with high LET (α-particles):

$$\dot{Ad}_T(t) = RBE_{L,T} \times \dot{d}_{L,T}(t) + RBE_{H,T} \times \dot{d}_{H,T}(t). \tag{II-15}$$

Here the indexes *L* and *H* correspond to low and high LET radiation respectively: $\dot{d}_{R,T}(t)$ is the absorbed dose rate of radiation *R* in the organ or tissue at time *t* after intake of 1 Bq of the radionuclide; $RBE_{R,T}$ is the relative biological effectiveness of radiation *R* for generating the severe deterministic health effects in *T*.

In general, the dependence of $\dot{Ad}_T(t)$ upon time may be described by the radiation decay characteristics of the radionuclide and its behaviour in the human body. For instance, retention of aerosol particles in the gas-exchange alveolar interstitial (AI) region of the respiratory tract, leaching of the radionuclide and its radiation decay, and ingrowth and radiation decay of progenies describe the time dependence of the dose rate in the lung. Figure II-4 and Figure II-5 show the effect of different types of retention functions on $\dot{Ad}_T(t)$, assuming no significant decay.

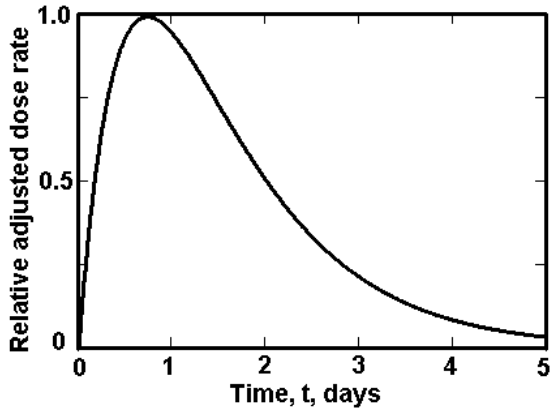

FIG. II-4. Dose rate in the colon after ingestion intake, assuming no reduction due to decay.

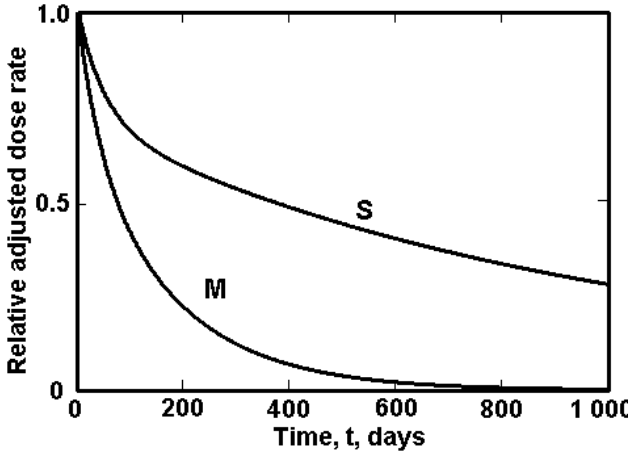

FIG. II-5. Dose rate in the AI region of the respiratory system, assuming no reduction due to decay after inhalation of aerosol particles: Type S and M respectively.

The models used here for biokinetic behaviour of radioactive material in the human body were developed by ICRP and are described in:

- dosimetry models for radioactive material passing through barrier organs:
  - model for gastro-intestinal (GI) tract – in ICRP Publication 30 [38];
  - model for respiratory system – in ICRP Publication 66 [17];
- dosimetry models for radioactive material passed through barrier organs and its retention in inner organs and excretion from the body:

  models for systemic activity – in ICRP Publications No 30, 67, 69, and 71 [38, 39, 40, 41, 42].

These ICRP publications include all the model parameters essential for modelling biokinetic behaviour of radioactive material in the body.

As a rule, time dependence of $\dot{Ad}_T(t)$ for the exposed organ or tissue (T) is mostly defined by the biokinetic behaviour of the radioactive material in the organ. An exception is for the dose to red marrow when for some bone-seeking elements, the dose rate in this organ is defined by the biokinetic behaviour of the elements in other bone tissues (e.g. bone surface). So there is no need to model the behaviour of a radionuclide in all organs of the body when one needs to know the dose rate in the organs or tissues from Table II-1 and Table II-2. In order to calculate the dose rate one needs to know only the number of radionuclide disintegrations per unit time in the organ of tissue T as a function of time after intake 1 Bq of radionuclide, $\dot{n}_T(t)$.

To calculate $\dot{n}_T(t)$:

- a biokinetic model for the alveolar interstitial (AI) region of the respiratory system ought to be used for dose assessment in the lung;
- a biokinetic model for the GI tract ought to be used for dose assessment in the colon,
- a biokinetic model for the whole body or skeleton ought to be used for dose assessment in the red marrow, and
- a biokinetic model for the thyroid ought to be used for dose assessment in this gland.

The ICRP dosimetry models are used as the basis for the data used here for internal dose assessment. The data used here is from:

- the CD Supplement to EPA Federal Guidance Report 13 [43]; and
- the ICRP database of dose coefficients [44].

The CD contains files of the age-dependent absorbed dose rate $\dot{d}_{L,T}(t)$ and $\dot{d}_{H,T}(t)$ for low LET and high LET radiation respectively. Data is listed for 29 organs or tissues as a function of time after an acute ingestion and inhalation intake by members of the public (reference individuals in six age groups). For inhalation only, the data for aerosols with an AMAD of 1 μm are presented. Data from this CD may be directly used for calculation of RBE-weighted absorbed dose rate in organs or tissues of interest as defined by Eq.(II-15).

The ICRP database covers a wider spectrum of intake conditions than the EPA report does but does not contain values of $\dot{d}_{L,T}(t)$ and $\dot{d}_{H,T}(t)$. Nevertheless, this database may be used for RBE-weighted absorbed dose assessment as described below. The CD with the ICRP database of dose coefficients contains age-dependent committed radiation weighted doses for 35 organs or tissues as a function of time (Δ) after an acute ingestion or inhalation intake of 1 Bq of a radionuclide by members of the public (reference individuals in six age groups) and workers. The quantity of committed radiation weighted dose is:

$$h_T(\Delta) = \int_0^{\Delta} \dot{h}_T(t)dt \approx \int_0^{\Delta} \left\{ \dot{n}_T(t) \times \eta_T(t) \right\} dt \,, \tag{II-16}$$

where:

$\eta_T(t)$ = a radiation weighted dose in organ *T* due to one disintegration in the decay chain produced by disintegration of the parental radionuclide;

$\dot{h}_T(t)$ = the radiation weighted dose rate in organ or tissue *T* at a time t after intake of 1 Bq of radionuclide:

$$\dot{h}_T(t) = w_L \times \dot{d}_{L,T}(t) + w_H \times \dot{d}_{H,T}(t) \,. \tag{II-17}$$

and w_R – radiation weighted factor of radiation *R* as defined by the ICRP [8].

Time dependence of $\eta_T(t)$ in Eq. (II-16) is defined by possible change upon a time of the contribution of progenies to the combined radiation spectrum of the decay chain. Usually the difference in half-lives of parental and progenies is large and this dependence is very weak. If so, one may use η_T instead of $\eta_T(t)$ in Eq. (II-16) and $\dot{h}_T(t)$ in Eq. (II-17) has to be estimated taking into account $h_T(\Delta)$ from ICRP database [44]:

$$\dot{h}_T(t) = \eta_T \times \dot{n}_T(t) = \frac{h_T(\Delta)}{\int_0^{\Delta} \dot{n}_T(t)dt} \dot{n}_T(t) \,. \tag{II-18}$$

For most alpha-emitting radionuclides, the alpha radiation is the main contributor to absorbed dose when the tissue is irradiated due to decay of the radionuclide deposited in it (self-exposure). So, one may rewrite Eq. (II-15) as follows

$$\begin{aligned} \dot{Ad}_T(t) &= \frac{RBE_{L,T}}{w_L} \dot{h}_T(t) \text{ for non } \alpha\text{-emitting radionuclides; and} \\ \dot{Ad}_T(t) &\approx \frac{RBE_{H,T}}{w_H} \dot{h}_T(t) \text{ for } \alpha\text{-emitting radionuclides,} \end{aligned} \tag{II-19}$$

The value of τ in Eq. (II-14) is the time after intake needed for developing an irreversible injury in a biological structure that results in severe deterministic health effects in an organ or tissue. Following intake of the radioactive material, irradiation of organs and tissues lasts as long as a radionuclide is present in the human body. Consequently, $\dot{A}d_T(t)$ generally decreases as a function of time and approaches zero due to radioactive decay and excretion of radionuclides from the body. Obviously, the time of exposure is limited by the lifespan of those exposed. That is why $H_T(\tau, I_{RN})$ is a bounded function as shown by:

$$H_T(\tau, I_{RN}) \le H_T(I_{RN}), \tag{II-20}$$

where:

$H_T(I_{RN})$ = an asymptotic value for a defined intake of the radionuclide, I_{RN}:

$$H_T(I_{RN}) = \lim_{\tau \to lifespan} \{H_T(\tau, I_{RN})\}. \tag{II-21}$$

The risk of developing severe deterministic health effects after intake of the radionuclide is a function of intake and time after intake as shown by:

$$R_T(\tau, I_{RN}) = 1 - \exp[-H_T(\tau, I_{RN})]. \tag{II-22}$$

Taking into account Eqs. (II-20) and (II-21), one can write:

$$R_T(\tau, I_{RN}) \le R_T(I_{RN}) = \lim_{\tau \to lifespan} \{R_T(\tau, I_{RN})\}, \tag{II-23}$$

where:

$R_T(I_{RN})$ = the lifespan risk of developing severe deterministic health effects after intake of the radionuclide.

An important difference between the risk functions for deterministic health effects due to external and internal exposure is that for external exposure (See Eq (II-5), the corresponding hazard function is proportional to RBE-weighted absorbed dose:

$$H_T(AD_T) \sim [AD_T]^{V_T}, \tag{II-24}$$

but for internal exposure (See Eq. (II-14)), the corresponding hazard function is proportional to the square of the intake (and also to the square of the committed RBE-weighted absorbed dose):

$$H_T(I_{RN}) = [\ln(2)] \times \left(\frac{I_{RN}}{I_{RN,50}} \right)^{2 \times V_T}, \tag{II-25}$$

where:

$I_{RN,50}$ = the intake of the amount of the radioactive aerosol that ultimately leads to death of 50% those exposed. Proximate formula for $I_{RN,50}$ may be derived from Eqs (II-14) and (II-25):

$$I_{RN,50} \approx \left\{ \int_0^{lifespan} \frac{\theta_{T1}}{\left[\dot{A}d_T(t) \right]^2} dt \right\}^{\frac{1}{2}}. \tag{II-26}$$

So the probability of developing severe deterministic health effects in an organ or tissue T will exceed a level of R_T only if an RBE-weighted absorbed dose I_{RN} exceeds $I_{RN,R}$. The value of $I_{RN,R}$ is related to $I_{RN,50}$ and V_T by equation:

$$I_{RN,R} \approx I_{RN,50} \times \exp\left\{\frac{1}{2V_T} \ln\left(\frac{-\ln(1-R_T)}{\ln(2)}\right)\right\}. \quad \text{(II-27)}$$

The steepness of risk function for internal exposure:

$$S_T = \frac{I_{RN,05}}{I_{RN,95}} \approx \exp\left\{\frac{4.1}{2V_T}\right\}. \quad \text{(II-28)}$$

Values of $I_{RN,R}$ for fatal risk equal to 5%, 50%, and 95% are solutions of the equation:

$$\frac{R}{100\%} = 1 - \exp\left[-H_T(\tau, I_{RN,R})\right] \text{ for } \tau \to \infty, \quad \text{(II-29)}$$

where the hazard function is defined by Eq. (II-14). In this calculation, the RBE-weighted absorbed dose rate was estimated on the basis of the ICRP dosimetry models and database [38–42, 44] as described above (See Eqs. (II-13) – (II-18)).

$R_T(\tau, I_{RN})$ forms a crescent shaped curve as a function time after intake as shown in Figure II-6 and Figure II-7. Curve 1 presents the estimated risk of developing radiation pneumonitis as a function of time after inhalation of the amount of the radioactive aerosol that ultimately leads to a maximum risk of death of 5% (I_{05}) more than 400 days after an acute inhalation. The maximum risk is, therefore, the level of probability of developing radiation pneumonitis that will not be exceeded during the expected lifespan. Curves 2 and 3 present the estimated risk of developing radiation pneumonitis as a function of the time after intake of the amount of the radioactive aerosol that ultimately leads to the death of 50% and 95% of those exposed (I_{50} and I_{95}). Death is very probable if intake exceeds a value of I_{95}. The value for I_{05} is assumed to be the threshold value of intake that leads, in this case, to mortality due to severe deterministic health effects in the lung.

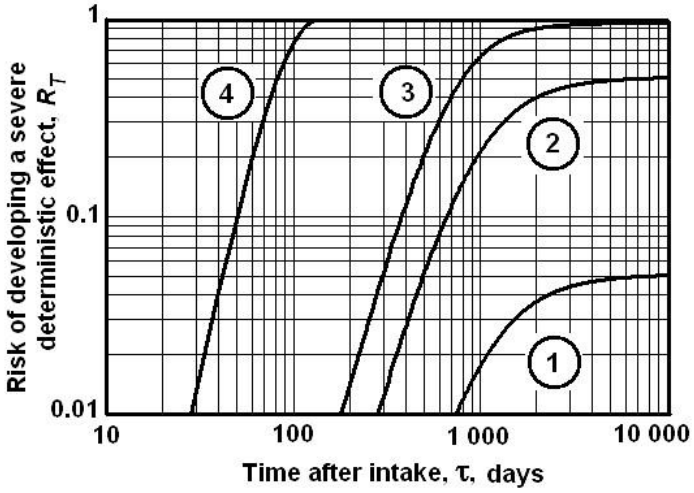

FIG. II-6. Risk of pneumonitis due to inhalation of Type S aerosol of ^{239}Pu with an AMAD of 1μm for intake of: 1). 22 MBq; 2). 29 MBq; 3). 33 MBq; 4). 67 MBq.

The time for the development of an irreversible injury of lung tissue decreases as intake increases. As an irreversible injury needs time to develop, it may be possible to decrease the risk of developing severe deterministic health effects by means of medical treatment to decrease the body burden of the radionuclide. For example, theoretically it takes some tens of days of exposure following intake to develop significant irreversible lung tissue damage after inhalation of 67 MBq of Type S aerosol of ^{239}Pu (See curve 4 in Figure II-6) and some hundreds of days after intake of 33 MBq of Type S aerosol of ^{239}Pu (See curve 3) to develop

sufficient lung damage to lead to 100% risk of death. In the latter case, decorporation during the first 30 days after intake may decrease this probability of death to a negligible level if that treatment leads to a decrease of the lung burden by a factor of 10. The time interval for effective decorporation depends upon the characteristics of the dose rate after intake. Figure II-7 shows that for inhalation of the aerosol of the relatively soluble plutonium compounds (Type M), the time for effective decorporation decreases by a factor of 10. For instance, decorporation performed 20 days after intake of 84 MBq of Type M aerosol of ^{239}Pu is useless (See curve 3 in Figure II-7).

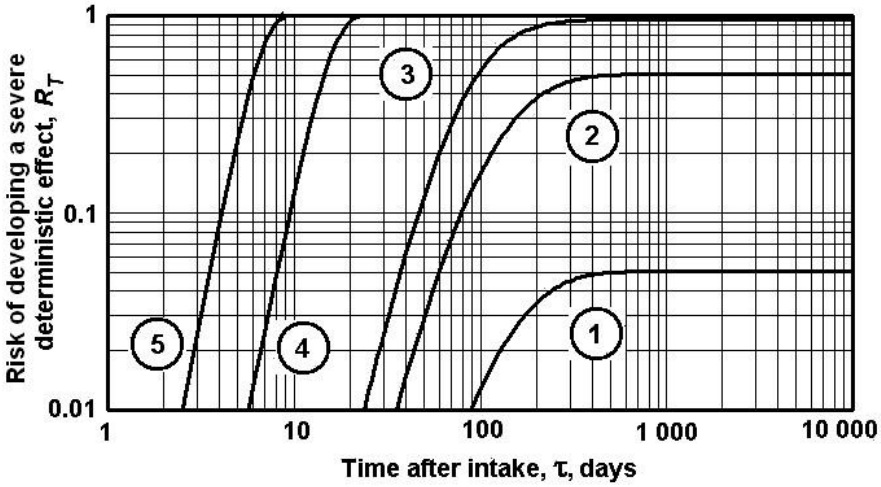

FIG. II-7. Risk of pneumonitis due to inhalation of Type M aerosol of ^{239}Pu with an AMAD of 5 μm for intake of: 1). 55 MBq; 2). 72 MBq; 3). 84 MBq; 4). 170 MBq; 5). 250 MBq.

For a given route of intake and effect, the values of I_{05}, I_{50} and I_{95} depend on the chemical and physical properties of the radionuclide and aerosol as well as on the time dependent RBE-weighted absorbed dose rate.

Table II-3 lists the estimated I_{05}, I_{50} and I_{95} for inhalation by an adult of selected radioactive aerosols, which illustrates that these values range over a number of orders of magnitude.

Intake thresholds (e.g. I_{05}) can be an objective characteristic of internal exposure. However, it does not provide a basis for a uniform approach to establishing emergency response criteria due to the wide and radionuclide specific variation in these threshold values, as illustrated above.

A practical solution to this difficulty is to use a committed RBE-weighted absorbed dose instead of intake as the basis for emergency response criteria. Committed RBE-weighted absorbed dose is defined as the time integral of RBE-weighted absorbed dose in an organ or tissue and is proportional to intake:

$$AD_T(\Delta) = \int_0^{\Delta} \dot{AD}_T(t)dt = I_{RN} \times \int_0^{\Delta} \dot{Ad}_T(t)dt = I_{RN} \times Ad_T(\Delta), \qquad \text{(II-30)}$$

where:

I_{RN}, and $\dot{Ad}_T(t)$ are defined in Eq. (II-13),

$Ad_T(\Delta)$ = a committed RBE-weighted absorbed dose for intake of 1 Bq of radionuclide, and time Δ is a free parameter and has no biological significance.

TABLE II-3. ESTIMATED VALUES FOR I_{05}, I_{50} AND I_{95} NEEDED TO CAUSE PNEUMONITIS IN AN ADULT WITH THE ASSOCIATED RISK DUE TO INHALATION OF AEROSOLS OF SELECTED RADIONUCLIDES

Radio-nuclide, $T_{1/2}$	AMAD, μm	Type S aerosol			Type M aerosol		
		I_{05}, MBq	I_{50}, MBq	I_{95}, MBq	I_{05}, MBq	I_{50}, MBq	I_{95}, MBq
^{239}Pu	1	2.2E+1	2.8E+1	3.3E+1	5.5E+1	7.1E+1	8.3E+1
2.41×10^4 a	5	3.9E+1	5.1E+1	5.9E+1	9.6E+1	1.3E+2	1.4E+2
	10	8.2E+1	1.1E+2	1.2E+2	1.9E+2	2.5E+2	2.9E+2
^{90}Sr	1	8.5E+2	1.1E+3	1.3E+3	2.1E+3	2.8E+3	3.2E+3
29.1 a	5	1.6E+3	2.0E+3	2.3E+3	3.7E+3	4.8E+3	5.6E+3
	10	3.1E+3	4.0E+3	4.7E+3	7.3E+3	9.4E+3	1.1E+4
^{144}Ce	1	1.2E+3	1.5E+3	1.7E+3	1.9E+3	2.4E+3	2.8E+3
284 d	5	2.1E+3	2.7E+3	3.1E+3	3.3E+3	4.3E+3	4.9E+3
	10	1.6E+3	2.1E+3	2.4E+3	6.6E+3	7.7E+3	1.0E+4
^{91}Y	1	4.4E+3	5.8E+3	6.7E+3	5.6E+3	7.3E+3	8.5E+3
58.2 d	5	8.1E+3	1.0E+4	1.2E+4	9.9E+3	1.3E+4	1.5E+4
	10	1.7E+4	2.2E+4	2.5E+4	2.1E+4	2.7E+4	3.1E+4
^{90}Y	1	1.2E+4	1.5E+4	1.8E+4	1.2E+4	1.6E+4	1.8E+4
2.67 d	5	2.0E+4	2.7E+4	3.1E+4	2.3E+4	3.1E+4	3.6E+4
	10	4.5E+4	5.9E+4	6.9E+4	4.9E+4	6.4E+4	7.5E+4

For evaluation of severe deterministic health effects, the committed dose is used only as a mathematically calculated value that can be reasonably related (mapped) to the risk from intake as calculated by the hazard function given by Eq. (II-14). Value of $Ad_T(\Delta)$ may be directly calculated by means of Eq. (II-15) and data listed in Ref. [43].

Table II-4 shows the estimated committed RBE-weighted absorbed dose $AD_{Lung,05}(\Delta)$ to the gas-exchange alveolar interstitial region of the respiratory tract from intake of the threshold amount of radionuclides, I_{05} for the cases listed in Table II-3.

Data from the ICRP database [44] was used for this estimation. Listed values were calculated by means of Eqs. (II-19) and (II-30) as follows:

$$Ad_T(\Delta) = \frac{RBE_{L,T}}{w_L} h_T(\Delta) \text{ for non } \alpha\text{-emitting radionuclides; and}$$
$$Ad_T(\Delta) \approx \frac{RBE_{H,T}}{w_H} h_T(\Delta) \text{ for } \alpha\text{-emitting radionuclides.} \quad \text{(II-31)}$$

For the effect concerned, the committed RBE-weighted absorbed dose does not depend on the aerosol size but on Δ. The variation in $AD_{Lung,05}(\Delta)$ is much smaller than the variation of I_{05}. This type of analysis was conducted for the radionuclides of concern and found (as illustrated by Table II-4) that:

- the value of $AD_{Lung,05}(\Delta = 30\,d)$ shows the lowest variation for a wide spectrum of exposure conditions; and
- the value of $AD_{Lung,05}(\Delta = 30\,d)$ ranges between about 30 and 100 Gy-Eq.

Consequently, 30 Gy-Eq delivered to the gas-exchange alveolar interstitial region of the respiratory tract in the first 30 days after acute inhalation can be used as a reasonable basis for

GRLs that corresponds to intake threshold for development of the severe deterministic health effect of pneumonitis in the lung due to inhalation.

TABLE II-4. COMMITTED RBE-WEIGHTED ABSORBED DOSE $AD_{Lung,05}(\Delta)$, FROM INTAKE OF THE I_{05} AMOUNT NEEDED TO DEVELOP PNEUMONITIS IN AN ADULT DUE TO INHALATION OF AEROSOLS OF SELECTED RADIONUCLIDES

Radio-nuclide	$T_{1/2}$	Type	Δ			
			7 d	30 d	1 a	50 a
Pu-239	2.41×10^4 a	S	8	30	300	1200
		M	20	70	300	400
Sr-90	29.1 a	S	9	30	300	1300
		M	13	70	400	400
Ce-144	284.3 d	S	15	60	400	500
		M	20	80	300	300
Y-91	58.2 d	S	30	90	200	300
		M	30	100	200	200
Y-90	2.67 d	S	50	60	60	60
		M	50	60	60	60

Figure II-8 and Figure II-9 present comparisons between threshold levels obtained by means of the methodology described above and experimental data.

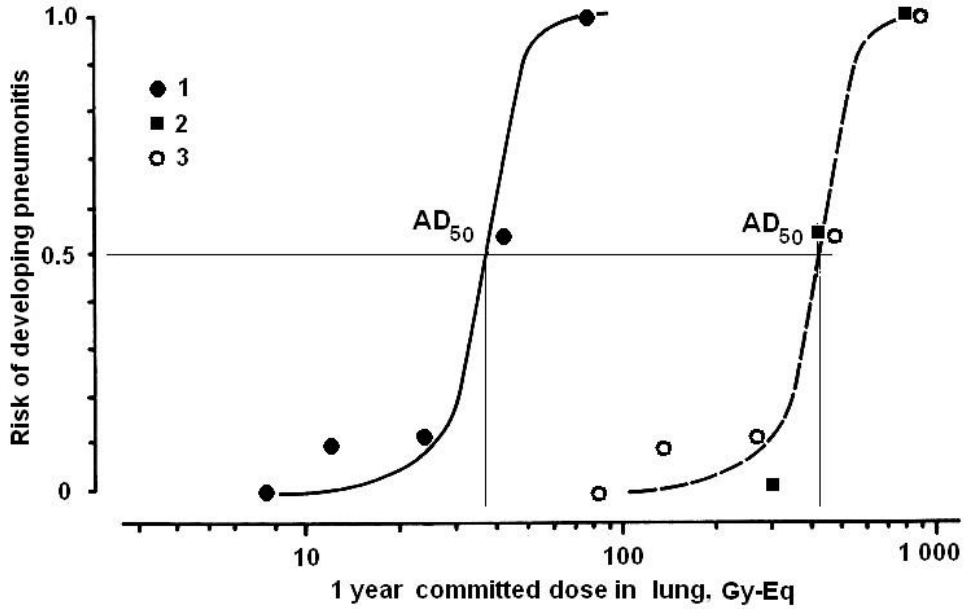

FIG. II-8. Relationship between one-year committed absorbed dose to the lung and mortality from radiation pneumonitis and pulmonary fibrosis (cited from [36]): 1). absorbed dose from inhalation of ^{239}Pu Type S aerosol ; 2). RBE-weighted absorbed dose from inhalation of ^{90}Sr Type S aerosol; 3). RBE-weighted absorbed dose from inhalation of ^{239}Pu Type S aerosol based on curve (1) assuming an RBE of about 12.

It must be noted that for ^{239}Pu, the dose shown for curve (1) in Figure II-8 is the absorbed dose (D_T) and must be multiplied by the RBE for alphas in order arrive at the RBE-weighted

absorbed dose (AD_T). As can be seen this experimental data leads to use of an $RBE_{Lung,H}$ of about 12 for alphas. As was shown in [33,34] estimations of $RBE_{Lung,H}$, values for alphas range from 5 to 12 with a central estimate of 7 as presented in Table II-1. There is reasonably good agreement between the one year committed RBE-weighted absorbed doses adequate to I_{05} from Table II-4 and those that can be interpolated from the graphs in Figure II-9.

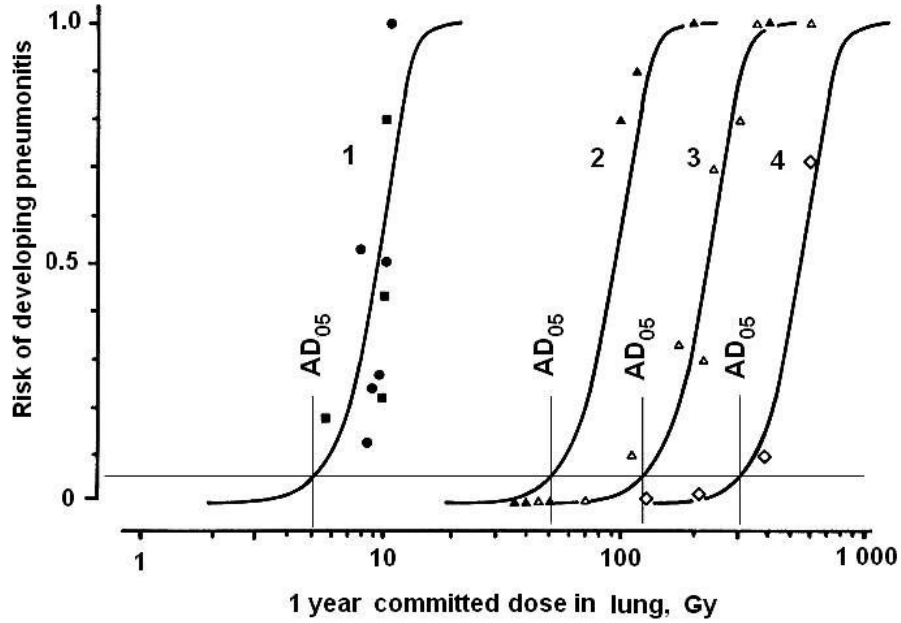

FIG. II-9. Relationship between one-year committed absorbed dose to the lung and mortality from radiation pneumonitis and pulmonary fibrosis (cited from [36]): 1. brief exposure; 2. inhalation of ^{90}Y Type S aerosol; 3. inhalation of ^{91}Y Type S aerosol; 4. inhalation of ^{144}Ce Type S aerosol.

Figure II-9 shows that the risk functions for different exposure conditions have the same shape. It shows that experimental estimates for risk function for cases of external and internal exposure are in good agreement.

The same type of analysis, as described above for the lung, was conducted for the bone marrow. Biokinetic behaviour of radionuclides in organs and tissues that may be a source of internal irradiation of red marrow is very diversified. Table II-5 shows that the 30 day committed RBE-weighted absorbed dose, $AD_{Red\ marrow,\ 05}(\Delta = 30\ d)$ for haematopoetic syndrome ranges between 0.2 and 8 Gy-Eq for the radionuclides of concern. Thereby, one value of an $AD_{Red\ marrow,\ 05}(\Delta = 30\ d)$ cannot represent that diversity. Consequently, if 0.2 Gy-Eq delivered by actinides to the bone marrow over 30 days, or 2 Gy-Eq delivered to it by other radionuclides, following intake can be used as a reasonable basis for GRLs that correspond to intake threshold for developing the severe deterministic health effect of haematopoetic syndrome. It is also important to note the ratio of I_{05} to the annual limit of intake (ALI) for workers if ^{90}Sr from ingestion is only about 60.

Similar evaluations showed that an $AD_{Colon,\ 05}(\Delta = 30\ d)$ equal to 20 Gy-Eq is a reasonable basis for GRLs for the intake threshold for developing severe deterministic health effects to the colon and GI tract.

The RBE-weighted absorbed dose rate in the colon is mainly determined by the kinetics of radioactive material. Radioactive decay plays a negligible role in that process, so $AD_{Colon,05}(\Delta=30\ d)$ varies from 20 to 24 Gy-Eq for wide list of radionuclides.

TABLE II-5. COMMITTED RBE-WEIGHTED ABSORBED DOSE $AD_{Red\ marrow,\ 05}(\Delta)$, FROM INTAKE OF THE I05 AMOUNT NEEDED TO DEVELOP HAEMATOPOETIC SYNDROME AS A RESULT OF INTERNAL EXPOSURE OF RED MARROW

Radionuclide	**$T_{1/2}$**	**I_{05}, MBq**	$AD_{Red\ marrow,\ 05}(\Delta=30\ d)$ **Gy-Eq**	**Pathway**
C-14	5.73E+3 a	2.7E+4	6.2	Ingestion
P-32	14.3 d	1.2E+3	7.7	Ingestion
S-35	87.4 d	2.3E+4	5.6	Ingestion
Zn-65	244 d	5.6E+6	4.1	Ingestion
Se-75	120 d	1.0E+4	5.9	Ingestion
Sr-90	29.1 a	4.4E+2	1.7	Ingestion
Mo-99	2.75 d	9.3E+3	5.7	Ingestion
Cs-137	30.0 a	1.8E+3	4.2	Ingestion
Hg-203	46.6 d	9.3E+3	6.8	Ingestion
Po-210	138 d	2.8E+2	6.4	Ingestion
U-232	72.0 a	1.3E+2	1.5	Inhalation
Pu-238	87.7 a	2.0E+1	0.27	Inhalation
Am-241	4.32E+2 a	2.3E+1	0.17	Inhalation
Cm-244	18.1 a	2.8E+1	0.22	Inhalation

II.5. Combined irradiation

In general, one should expect a combined character of exposure in an emergency situation. Combined exposure includes external exposure with a constant dose rate and intake of radionuclides that leads to internal exposure with a variable dose rate. The RBE-weighted absorbed dose rate of combined exposure in organ *T* is:

$$\dot{AD}_T(t) = \begin{cases} \dfrac{AD_T}{t_C} + I_{RN} \times \dot{Ad}_T(t), & t \in (0, t_C) \\ I_{RN} \times \dot{Ad}_T(t), & t > t_C \end{cases}, \qquad \text{(II-32)}$$

where:

AD_T = RBE-weighted absorbed dose of external exposure during time interval $t \in (0, t_C)$;

t_C = duration of combined exposure;

I_{RN} = intake of radionuclide *RN,* and

$\dot{Ad}_T(t)$ = the RBE-weighted absorbed dose rate in organ *T* at time *t* after intake 1 Bq of radionuclide concerned.

Mostly, the dose rate of external exposure is higher than the dose rate of internal exposure in an emergency:

$$\frac{AD_T}{t_C} >> I_{RN} \times \dot{Ad}_T(t), \quad t \in (0, t_C). \qquad \text{(II-33)}$$

Taking into account Eqs. (II-3), (II-5), (II-25), and (II-33), one can write a hazardous function for combined exposure for this particular, but very probable case:

$$H_T\{\tau = lifespan, \dot{AD}_T(t)\} \approx [\ln(2)]\left(\frac{AD_T}{AD_{T,50}} + \int_0^{lifespan} \frac{\dot{AD}_T(t)}{\theta_{T\infty} + \theta_{T1} / \dot{AD}_T(t)} dt\right)^{V_T}$$

$$= [\ln(2)]\left(\frac{AD_T}{AD_{T,50}} + \frac{I_{RN}}{I_{T,RN,50}}\right)^{V_T} \qquad \text{(II-34)}$$

$$= [\ln(2)]\left(\frac{AD_T}{AD_{T,50}} + \frac{AD_T(\Delta = 30\ d)}{AD_{T,50}(\Delta = 30\ d)}\right)^{V_T},$$

where:

$AD_T(\Delta = 30\ d)$ = an actual 30-days committed RBE-weighted absorbed dose in organ *T*;

$AD_{T,50}(\Delta = 30\ d)$ = a median 30-days committed RBE-weighted absorbed dose for producing the severe deterministic effect in organ concerned.

Risk function of combined exposure is a function of two variables: RBE-weighted absorbed dose of external exposure and intake of radioactive material. The last variable may be represented by the committed RBE-weighted absorbed dose of internal exposure. For this case Eq. (II-2) has the form of the equation of a curve:

$$\ln(1 - R) = -H_T\{I_{RN}, AD_T\}, \qquad \text{(II-35)}$$

which may be rewritten taking into account Eq. (II-34):

$$\frac{AD_T}{AD_{T,50}} + \frac{AD_T(\Delta = 30\ d)}{AD_{T,50}(\Delta = 30\ d)}\Bigg)^2 = \left(\frac{-\ln(1 - R)}{\ln(2)}\right)^{\frac{1}{V_T}}, \qquad \text{(II-36)}$$

or, using notations of Eqs. (II-7) and (II-26):

$$\frac{AD_T}{AD_{T,R}} + \frac{AD_T(\Delta = 30\ d)}{AD_{T,R}(\Delta = 30\ d)}\Bigg)^2 = 1, \qquad \text{(II-37)}$$

where

$AD_{T,R}(\Delta = 30\ d)$ = 30-days committed RBE-weighted absorbed dose in organ *T* corresponded to $I_{RN,R}$.

Therefore, in a case of combined exposure, the probability of developing severe deterministic effects in organ *T* is less than 5% if the following inequality is true:

$$P_T^{ext} + \left(P_T^{\text{int}}\right)^2 < 1, \qquad \text{(II-38)}$$

where P_T^{ext} and P_T^{int} are indexes of external and internal exposure of organ concerned:

$$P_T^{ext} = \frac{AD_T}{AD_{T,05}}, \qquad \text{(II-39)}$$

$$P_T^{\text{int}} = \frac{AD_T(\Delta = 30\ d)}{AD_{T,05}(\Delta = 30\ d)}. \qquad \text{(II-40)}$$

Therefore, for combined internal and external exposure, the sum of the indexes of RBE-weighted absorbed doses for intake of radioactive material and for external exposure may be used as a basis for calculation of OILs for decision making. Keeping the sum of the index of external exposure and the square of the index of internal below 1 will prevent severe deterministic health effects in the organ concerned in combined internal and external exposure.

II.6. Threshold doses for severe deterministic health effects

Table II-6 and Table II-7 summarize the results of using the NUREG/CR-4214 risk models which were the basis GRLs for intervention to prevent severe deterministic health effects in cases of brief external irradiation and acute intake of radioactive material. The organs listed in these tables are those that accident analysis and experience indicate would be most critical during an emergency, i.e. controlling the dose to these organs prevents all severe deterministic health effects.

Data listed in Table II-6 and Table II-7 were estimated for exposure of adults (except the data for embryo and foetus). Parameters of most NUREG/CR-4214 risk models were estimated only for this group of exposed members of the public. Only the parameters for the model of severe deterministic health effects in the lung were estimated for two age groups (See comments to Table II-1). Difference in these parameters does not influence threshold values of intake and committed RBE-weighted absorbed dose for exposure of individuals over 15 years old. For internal exposure, the criteria are expressed in terms of 30 day committed RBE-weighted absorbed dose of internal exposure in a critical organ or tissue. The Table II-7 criteria for intervention to prevent embryo/foetal death in a case of the intake of radioactive material by a pregnant woman are based on the criteria in Table II-6, which are for external exposure. It was assumed that committed adjusted exposure of embryo and foetus *in utero* from intake should not exceed numerically the value of $AD_{T,05}$ for embryo/foetal death in cases of brief external exposure.

TABLE II-6. THRESHOLD RBE-WEIGHTED ABSORBED DOSE ($AD_{T,05}$) FOR SEVERE DETERMINISTIC HEALTH EFFECTS FROM EXTERNAL EXPOSURE

Symptom	Organ or entity	$AD_{T,05}$[(a)], Gy-Eq
Haematopoetic syndrome[(e)]	Red Marrow	3[(b)]
Gastrointestinal syndrome[(e)]	Small Intestine	12
Pneumonitis[(e)]	Lung	8[(c)]
Cataract[(f)]	Lens of the eye	0.8
Permanently suppressed ovulation[(f)]	Ovum	1.5
Embryo/foetal death[(e)]	Embryo/foetus 0–18 days gestation	0.3
	Embryo/foetus 18–150 days	0.6
	Embryo/foetus 150–term	2.0
Moist desquamation[(e)]	Skin	12[(d)]

(a) Central estimates of the values.

(b) For supportive medical treatment, with only minimal treatment the $AD_{T,05}$ is 2 Gy-Eq.

(c) The $AD_{T,05}$ value is for children, and for adults of 40 and younger; for older individuals the value for $AD_{T,05}$ is 4 Gy-Eq.

(d) For 600 cm^2 that is considered life threatening, calculated for a skin structure lining at a depth of 50 mg/cm^2 (or 0.5 mm) under the surface.

(e) Assumed to be fatal.

(f) Non-fatal effect assumed to result in a lower quality of life and is thus a severe deterministic health effect.

TABLE II-7. GRLs FOR INTERVENTION TO PREVENT SEVERE DETERMINISTIC HEALTH EFFECTS IN CASES OF ACUTE INTAKE OF RADIOACTIVE MATERIAL IN TERMS OF A 30 DAY COMMITTED RBE-WEIGHTED ABSORBED DOSE

Symptom	**Target organ**	**Type of exposure**	**RBE**	$AD_{T,05}(\Delta = 30d)$**, Gy-Eq**	
				Range[a]	**GRL**
Haematopoetic syndrome[b]	Red marrow	Internal[c] α	2	0.5–8[b, c]	- 0.2 Gy-Eq for intake of actinides - 2 Gy-Eq for intake of radionuclides other than actinides
		Internal[c] β, γ	1		
Pneumonitis	Lung[d]	Inhalation, α	7	30 - 100[e]	30
		Inhalation β, γ	1		
Gastrointestinal syndrome	Colon	Internal[c] α	0	NE	NE
		Internal[c] β, γ	1	20 - 24	20
Embryo/foetal death	Embryo and foetus	Internal[c] α	10	NE	0.1[f]
		Internal[c] β, γ	1		

[a] Range presents a variance of value of $AD_{T,05}(\Delta = 30d)$ for different radionuclides and chemical forms.

[b] For cases of supportive medical care.

[c] For inhalation or ingestion.

[d] Gas exchange alveolar interstitial region of the respiratory tract.

[e] Values are applicable for inhalation by individuals of any age; radioactive material of inhalation type S or M, provided the radionuclide has a half-life greater than 1 d.

[f] Estimated value for $AD_{T,05}(\Delta)$ where Δ is the time of embryo and foetus development *in utero* as defined in ICRP Publication 88 [27]. The value is based on brief external exposure. For prolonged exposure (from intake), the value may be higher.

Table II-8 lists the estimates of the threshold dose, $AD_{T,05}$, from the literature, for those severe deterministic health effects for which there were insufficient data to make estimates based on the models.

Material of Appendix II elaborates a dosimetric basis and a system of levels to prevent severe deterministic health effects in case of emergency previously introduced by the IAEA [1, 2] and as required by Ref. [3]. It forms the basis for numerical values of GRLs in Section A of Table 2 and in Tables II-6–II-8.

TABLE II-8. THRESHOLD DOSES ($AD_{T,05}$) FOR DEVELOPING SELECTED NON-FATAL SEVERE DETERMINISTIC HEALTH EFFECTS THAT ARE ASSUMED TO RESULT IN A LOWER QUALITY OF LIFE

Health effect	Target organ or entity	Type of exposure	$RBE_{R,T}$	Threshold dose, ($AD_{T,05}$) Gy-Eq	Source
Necrosis	Soft tissue[a]	External β[b], γ	1	25	[32,Table 2.17;] [11, 20,21 45]
Permanently suppressed sperm counts	Testes in males	External γ	1	1[c]	
Malformation	Embryo/foetus 8-25 weeks	External γ	1	0.1	[37, para. 417]
Growth retardation	Embryo/foetus 8-25 weeks	External γ	1	0.25	[37], para. 420
Possible verifiable reduction in IQ	Embryo/foetus 8-25 weeks	External γ	1	0.1	[32, Table 2.26;] [22, para. 27-29;] [37, para. 441]
Severe mental retardation	Embryo/foetus 8-15 weeks	External γ	1	0.6	[37, para. 437]
	Embryo/foetus 16-25 weeks	External γ	1	0.9	
Hypothyroidism	Thyroid	External γ	1	2	[32, Appendix A]
		Internal (intake of ^{131}I)	0.20[d]	2[e]	
		Internal (others[d])	1	2[e]	

[a] Delivered to a depth of 0.5 cm in the tissue. Based on clinical experience in treating injuries resulting from accident exposures.

[b] Includes the dose from bremsstrahlung in source material.

[c] Data for threshold dose for permanently suppressed sperm counts in case of acute external irradiation are not available. Listed value is estimated from Table 2.21 and Table 2.22 of reference [32], that presents data for long term suppressed sperm counts in case of brief exposure and for permanently suppressed sperm counts in case of fractioned exposure. The most complete human experimental data are found in [46].

[d] External irradiation of thyroid gland is as five times as effective in producing deterministic health effects than internal exposure to ^{131}I. For other thyroid seeking radionuclides, the RBE value is assumed equal to 1. For more detail see footnote [c] to Table II-2.

[e] The value of the lifespan committed RBE-weighted absorbed dose in the thyroid is assumed in case of internal exposure.

Appendix III

EPIDEMIOLOGICAL AND STATISTICAL CONSIDERATIONS FOR GENERIC REFERENCE LEVELS IN TABLE 2 SECTIONS B AND C

III.1. Introduction

A number of factors need to be taken into account in considering decisions as to whether to take some specific action following radiation exposure from a nuclear accident. One of the more important factors is clearly the expected health consequences of such exposure upon the affected population. The induction of cancer is recognized as the most important long-term stochastic health effect from such radiation [12]. The only way to predict future cancer risks from such exposures is to use statistical models that quantitatively relate radiation dose to the risk of the particular cancers which are under consideration.

This Appendix describes the methods and results of applying such models to various scenarios of radiation exposure from future nuclear accidents. Standard life table techniques are used to estimate various parameters that are of direct interest to those who have to make decisions over possible actions such as registration for long term medical follow-up to be applied to an affected population.

III.2. Methods

The basic scenario considers a general population of 100,000 persons exposed to a specified equivalent dose of ionizing radiation from a nuclear accident. Two types of exposure are considered:

- Internal exposure of the thyroid gland from radioactive iodines, predominantly ^{131}I.
- External and internal whole-body exposure from gamma emitters such as ^{137}Cs.

These two types of exposure were, by far, the most important source of doses to the general population from the Chernobyl nuclear power plant accident and by analogy are likely to be of considerable importance in any future nuclear accidents. However, the calculations presented would apply equally whatever the source of exposure both to the thyroid gland and to whole-body exposures.

Doses to the thyroid gland would be expected to lead to an increase in risk of thyroid cancer. For whole-body radiation two categories of cancer are usually considered in predicting the long-term effects of such exposure, namely, leukemia and all other cancers combined [12]. Leukemia is considered separately since it appears to follow a different dose-response relationship (i.e., linear quadratic) than other cancers (i.e., linear) from acute exposures such as that of the atomic bomb survivors [12]. Leukemia also appears to follow a different temporal pattern with a very short minimal latent period (two years or less) and a peak in its effect followed by a subsequent decline in radiation risk, in contrast to other cancers [47]. It should also be noted that internal doses to organs are essentially uniform from water-soluble compounds of such elements as cesium.

The doses in question are assumed to be received as acute doses during a very short time period. This is true for doses arising from radioactive iodines with a physical half-life of ^{131}I of about eight days and any nuclear accident is likely to result in the emission of radioactive iodines over a relatively short period. For whole-body radiation, in reality, doses may be protracted over a number of years from environmental contamination. In this sense, the following calculations are conservative, i.e., predict greater risks than if doses are protracted,

both because individuals will have shorter time at risk for some of their dose and the possibility of a dose and dose-rate effect that may reduce the cancer risk per unit of dose [12].

The procedure for applying life table techniques to the above general scenario is as follows:

A. The procedure starts with a population of 100,000 individuals with a specified gender and age composition.

B. Two follow-up scenarios are considered:

- Follow-up until the end of the 90th year of life (i.e., the end of the year in which one achieves the age of 89 years). This is labeled "lifetime risk." The cut off at age 90 is applied because in a typical population more than 99% of the person-years at risk is accumulated by age 90, and cancer rates are notoriously unreliable in those above this age because of diagnostic difficulties.
- Fifty years of follow-up where people are followed for 50 years from the date of exposure or until they achieve the age of 90 (as above), whichever comes first. This is subsequently referred to as "the 50-year risk."

C. The number of cancers of the specified type (thyroid cancer, leukemia or cancers excluding leukemia) is estimated for this population in the absence of radiation, using standard life table techniques. For each year of follow-up the background cancer rate is applied to the population of a particular gender and age using gender- and age-specific background cancer rates. The all-cause mortality rate is also applied to this particular population group and the number of cancers and deaths subtracted from that group before the next year of follow-up is carried out. The all-cause mortality rate is assumed not to be affected by radiation exposure since such changes will be negligible in reducing the population at risk.

D. An equivalent dose of D Sv is then applied to the same population and the follow-up procedure repeated with the cancer risk being modified by an appropriate dose-response model for that particular cancer (see below for details). Thus, the number of cancers occurring at the end of a specified follow-up period under the radiation scenario is estimated.

E. If C_0 cases of cancer are expected in the absence of radiation, and C cases are expected following such exposure, the following parameters are then calculated:

- Absolute excess of cases = $C - C_0$.
- The relative excess of cases = $(C - C_0)/C_0$ (expressed as a percentage).
- The power of the study which compares two cohorts, each of 100,000 people, one with no exposure and the other with a specified exposure, to detect a statistically significant difference in the number of observed cases between the two cohorts.
- The size of two equal size cohorts which are needed to provide a power of 50% for the above test.

The first two are the most important parameters for assessing potential effects of a nuclear accident. The last two refer to the issue of "detectability," i.e., as to whether the level of the dose is adequate to produce a statistically detectible effect in a cohort of a specified size. This criterion is sometimes used, but, in fact, is more appropriate for the consideration of epidemiologic studies empirically assessing future effects in an exposed population. Power can also be calculated using an "infinite" sized comparison population, which would result in

increased power, but introduces difficulties of the comparability of the two groups under consideration.

Power is calculated using the statistical test for comparing two Poisson distributed counts. This test is given by:

$$z = (C - C_0)/(C_0)^{1/2} \qquad \text{(III-1)}$$

This z value may be converted to a power by subtracting the standardized normal deviate for the α level of the test (1.645 for a one-sided 95% test) and converting the resulting z to a probability value using the inverse of the standardized normal distribution. Thus, if the initial value of z provided by the equation is equal to 1.645, the power of the test will be 50%.

III.3. Sources of data

Two countries were selected to provide the basic data for the above calculations. Canada was chosen as a country to represent populations representative of North America and Western European types of populations, and Belarus was selected to represent a country from Eastern Europe. These two countries both have national cancer registries, which are recognized to be of high standard and which have contributed to the publication "Cancer Incidence in Five Continents" published by the International Agency for Research on Cancer and recognized to be the standard for cancer registries [48]. The populations considered, i.e., North America, Western Europe and Eastern Europe, represent areas where the majority of nuclear reactors are presently located. However, in the future, it will be necessary to extend consideration of geographic areas to reflect any increase in the spread of nuclear reactors.

The basic data used for each country were the current population classified by gender and five-year age grouping and the current all-cause mortality and the cancer incidence rate for the specified cancers, again, by gender and age. For Belarus, the thyroid cancer incidence rates were taken from the period immediately before the Chernobyl accident in 1986, in view of the large increase in thyroid cancer seen in Belarus after the accident. The distribution of each of these parameters by gender and five-year age group was obtained using World Health Organization sources [49].

It was assumed that the population in a specified five-year age group was distributed uniformly across the five years of age and, similarly, that rates by five-year age group apply uniformly to each year in that group. Life-table calculations were carried out by individual year.

III.4. Dose-response models for radiation and cancer risk

The following models were considered for the three cancers under consideration:

A. Thyroid cancer:

The model used was a modification of the model presented by Ron et al. [50], from the combined analysis of seven studies of those exposed to gamma rays (the atomic bomb survivors study) and x-rays (several medically-treated cohorts). The model is a linear excess relative risk model with the excess relative risk per sievert (ERR) modified by age at exposure.

Risks are highest in those aged under five years at the time of exposure and drop off noticeably by increasing age at exposure. For the present application, the model was extended so that the estimated excess relative risk, which applies to those age 10 years or more at exposure, continues to apply through life. The sensitivity of the adult thyroid gland to ^{131}I (the

main source of exposure in any future nuclear accident) is still a matter of debate so this assumption may be regarded as conservative. The form of the model is:

$$R = R_{Background}(1.0 + \beta \cdot D \cdot A) \qquad \text{(III-2)}$$

*

where:

R = risk of radiation-induced incidence;

$R_{Background}$ = risk of background incidence;

D = dose;

β = the Excess relative risk (ERR); and

A = the modifying effect of age at exposure.

The values of the parameters are given in [50].

B. Leukemia:

The model for leukemia is taken from Preston, et al. [47] from the analysis of the latest incidence data from the atomic bomb survivors study. The model is an excess absolute risk model, which is linear quadratic in dose with modifying effects by age at exposure, time since exposure and gender. The form of the model is:

$$R = R_{Background} + (\beta_1 D + \beta_2 D^2) \exp(\gamma_1 (T - 20)) \qquad \text{(III-3)}$$

where:

R = risk of radiation-induced incidence;

$R_{Background}$ = risk of background incidence;

D = dose;

β_1 = the excess risk per unit of dose;

β_2 = the coefficient for dose^2, and

γ_1 = the coefficient for T, time since exposure.

All three parameters, β_1, β_2 and γ_1 are functions of age at exposure and gender.

C. All causes of cancer, except leukemia:

It has been argued [51] that the best approach for modeling radiation risk for the non-leukemia cancers is to treat them as a single entity with a single dose-response relationship. This was done by Pierce, et al. [52] for the atomic bomb survivors' mortality data. Since this is a relative risk model, it may be applied to incidence data since the survival rates for radiation-induced cancers are likely to be very similar to that for non-radiation-induced cancers.

The form of the model is:

$$R = R_{Background}\ (1.0 + (\beta_M D + \beta_F D) \exp(-0.038\,(A - 30)) \qquad \text{(III-4)}$$

where:

R = risk of radiation-induced incidence;

$R_{Background}$ = risk of background incidence;

β_M = the ERR for males;

β_F = the ERR for females;

A = age at exposure.

The values for β (0.375 for males and 0.774 for females) and the negative coefficient for age at exposure means that relative risks are greater for women than for men, and risks for those exposed at early ages are greater than risks for those exposed at later ages.

Some further points are worth noting with regard to the above models. Minimal latent periods of five years for thyroid cancer, two years for leukemia and 10 years for other cancers were assumed. At the moment there is some controversy over the relative biological effectiveness of ^{131}I as compared to gamma or x-rays. The above model assumes a RBE of 1.0, though, others have suggested that a lower value should be used, e.g., a value of 0.67 proposed by the BEIR V Committee [53]. Thus, the present approach is, again, conservative in predicting greater risks than if the true RBE is less than 1.0. A dose and dose-rate effectiveness factor could be applied to the all other cancers for protracted exposure, but, there is considerable uncertainty as to the magnitude of this factor so, for present consideration, none has been applied.

Finally, it should be pointed out that a number of models are available for the above cancers. The above models have been selected on the basis of their fairly common usage and, also, because most postulated models would lead to similar numerical conclusions.

III.5. Results

The results of applying the above procedures are shown in Tables III-1 – III-5. Table III-1 shows the results for all cancer incidence for Belarus and Canada. Tables III-2 and III-3 show results for thyroid cancer, again, with Belarussian and Canadian results alternating, and finally, Tables III-4 and III-5 give the leukemia results for the two countries. For thyroid cancer and leukemia, results are shown in separate tables for a cohort age 0-19 at exposure (Tables III-2 and III-4) and for cohort age 0-89 years at exposure (Tables III-3 and III-5).

With each table results are shown for three levels of doses, namely, 50, 100 and 1,000 mSv. Again, within each table two sets of results are given, the first corresponding to “lifetime” follow-up, i.e., 90 years, and the second corresponding to 50 years of follow-up.

TABLE III-1. EXPECTED EXCESS OF ALL CANCER INCIDENCE FOLLOWING ACUTE EXPOSURE TO VARIOUS LEVELS OF RADIATION WEIGHTED DOSE FROM EXTERNAL PENETRATING RADIATION[18] TO COHORT OF 100 000 PERSONS AGE 0-89 YEARS

Dose, mSv	Follow-up years	Expected background cases	All expected cases after exposure	Absolute excess of cases	Relative excess (%)	Power (%)	Number required for power of 50%
Using Belarusian Baseline Data							
50	90	18 985	19 451	466	3	77	48 028
100	90	18 985	19 909	924	5	100	12 342
1000	90	18 985	27 125	8140	43	100	189
50	50	14 896	15 182	286	2	50	99 793
100	50	14 896	15 467	571	4	95	25 292
1000	50	14 896	20 324	5428	37	100	324
Using Canadian Baseline Data							
50	90	31 508	32 220	712	3	88	34 104
100	90	31 508	32 914	1406	5	100	8794
1000	90	31 508	43 046	11 538	37	100	152
50	50	23 557	23 968	411	2	59	76 219
100	50	23 557	24 376	819	4	98	19 303
1000	50	23 557	31 163	5428	33	100	255

[18] Since the weighting factor for external penetrating radiation excluding for neutrons, is 1, the level of radiation weighted dose from external penetrating radiation is equal to the level of effective dose.

TABLE III-2. EXPECTED EXCESS OF THYROID CANCER INCIDENCE FOLLOWING ACUTE EXPOSURE TO VARIOUS LEVELS OF RADIATION WEIGHTED DOSE TO THYROID TO COHORT OF 100 000 PERSONS AGE 0-19 YEARS

Dose, mSv	Follow-up years	Expected background cases	All expected cases after exposure	Absolute excess of cases	Relative excess (%)	Power (%)	Number required for power of 50%
Using Belarusian Baseline Data							
50	90	126	158	32	26	61	73 014
100	90	126	190	64	51	98	20 333
1000	90	126	769	643	511	100	585
50	50	69	85	16	24	35	169 679
100	50	69	101	32	47	78	47 608
1000	50	69	384	315	457	100	1250
Using Canadian Baseline Data							
50	90	334	432	98	30	97	21 230
100	90	334	531	197	59	100	6000
1000	90	334	2276	1942	582	100	187
50	50	206	260	54	27	81	42 192
100	50	206	315	109	53	100	11 788
1000	50	206	1288	1082	526	100	345

TABLE III-3. EXPECTED EXCESS OF THYROID CANCER INCIDENCE FOLLOWING ACUTE EXPOSURE TO VARIOUS LEVELS OF RADIATION WEIGHTED DOSE TO THYROID TO COHORT OF 100 000 PERSONS AGE 0-89 YEARS

Dose, mSv	Follow-up years	Expected background cases	All expected cases after exposure	Absolute excess of cases	Relative excess (%)	Power (%)	Number required for power of 50%
Using Belarusian Baseline Data							
50	90	103	119	16	16	29	228 425
100	90	103	135	32	32	68	61 189
1000	90	103	426	323	314	100	1298
50	50	83	95	12	15	21	383 912
100	50	83	106	23	28	49	102 082
1000	50	83	307	224	270	100	2116
Using Canadian Baseline Data							
50	90	245	287	42	18	58	79 499
100	90	245	330	85	35	97	21 440
1000	90	245	1086	841	344	100	510
50	50	204	234	30	15	42	129 701
100	50	204	264	60	30	87	34 486
1000	50	204	805	601	295	100	756

TABLE III-4. EXPECTED EXCESS OF LEUKEMIA INCIDENCE FOLLOWING ACUTE EXPOSURE TO VARIOUS LEVELS OF RADIATION WEIGHTED DOSE TO RED MARROW TO COHORT OF 100 000 PERSONS AGE 0-19 YEARS

Dose, mSv	Follow-up years	Expected background cases	All expected cases after exposure	Absolute excess of cases	Relative excess (%)	Power (%)	Number required for power of 50%
Using Belarusian Baseline Data							
50	90	1334	1355	21	2	11	1 635 743
100	90	1334	1380	46	4	22	347 901
1000	90	1334	2444	1110	84	100	826
50	50	528	549	21	4	16	649 415
100	50	528	573	45	9	40	144 044
1000	50	528	1639	1111	211	100	475
Using Canadian Baseline Data							
50	90	2172	2193	21	1	9	2 651 368
100	90	2172	2218	46	3	17	565 186
1000	90	2172	3281	1109	52	100	1199
50	50	511	532	21	5	16	623 170
100	50	511	557	46	10	41	135 041
1000	50	511	1631	1120	220	100	462

TABLE III-5. EXPECTED EXCESS OF LEUKEMIA INCIDENCE FOLLOWING ACUTE EXPOSURE TO VARIOUS LEVELS OF RADIATION WEIGHTED DOSE TO RED MARROW TO COHORT OF 100 000 PERSONS AGE 0-89 YEARS

Dose, mSv	Follow-up years	Expected background cases	All expected cases after exposure	Absolute excess of cases	Relative excess (%)	Power (%)	Number required for power of 50%
Using Belarusian Baseline Data							
50	90	1206	1230	24	2	12	1 230 470
100	90	1206	1255	49	5	25	279 847
1000	90	1206	2072	866	72	100	1164
50	50	933	956	23	3	13	949 708
100	50	933	982	49	6	30	220 643
1000	50	933	1795	862	93	100	994
Using Canadian Baseline Data							
50	90	1982	2005	23	2	10	2 011 720
100	90	1982	2030	48	3	19	454 103
1000	90	1982	2851	869	44	100	1730
50	50	1386	1409	23	2	11	1 403 810
100	50	1386	1434	48	4	23	322 877
1000	50	1386	2256	870	63	100	1300

The statistically determined sample size of the irradiated and controlled cohorts needed to detect a significant increase in cancer risk from whole body exposure of 100 mSv is about 100 000 (of each the cohort). Long-lasting investigation (50-90 years after exposure) of such cohorts are needed to produce a study with more than 80% power, which would be acceptable from an epidemiological point of view. In general, a power of less than 80% is regarded as unacceptable, however for the purpose of public health care policy to address public concern and in consideration of the number of people that could be followed as a practical matter, cohorts of 10 000 each could be followed up with power of 50%.

Whole body exposure of 100 mSv effective dose was chosen as the GRL for long-term medical follow-up on the basis of the following:

- current data of UNSCEAR for risk of radiation-induced cancer [12];
- data on thresholds for deterministic effects (100 mSv is well below threshold doses for deterministic effects);
- practicality of having one value for criteria used for long-tem monitoring and for protection of foetus; and
- results of simulation presented in Appendix III.

As has been mentioned several times, the results of simulation are quite conservative, however it provides an opportunity to apply the GRL to emergencies involving different numbers of people.

The level of 50 mSv radiation weighed dose for exposure of thyroid was chosen as the GRL for long-term medical follow-up on the basis of the following considerations:

- results of thyroid cancer studies after the Chernobyl accident [26];
- results of simulation presented in Appendix III.

The chosen values are based on the currently available scientific data and may be subjects of revision in the future.

Appendix IV

PLAIN LANGUAGE EXPLANATION OF RISKS

In the event of a real or perceived radiation emergency, there will be considerable demand for information both from the public and media. The ref. [3] requires that "All practicable steps shall be taken to provide the public with useful, timely, truthful, consistent and appropriate information throughout a nuclear or radiological emergency". Counties need to have national programmes on communicating nuclear, radiation., transport and waste safety to different audiences, such as to decision makers, the media, the public, the nuclear community and non-governmental organisations [54].

IV.1. Communication

Communication experts and psychologists suggest that many of the sources of conflict and problems observed following the Chernobyl accident arose because of a lack of information and the resultant misunderstandings [55, 56, 57]. Recent publications on radiation protection seem to be in broad agreement on one main issue: that successful policy requires committed public information and communication[19]. In addition, both the scientific community and concerned officials have an ethical obligation to provide information to the public to enable informed decision making.

Risk communication is the two-way exchange of information about the nature, significance or control of risk. Its purpose is to inform, but ultimately influence behaviour about a specific risk. The tasks in risk communication are usually defined as:

- presenting and explaining information on risk;
- identifying controversial aspects of perceived risks;
- influencing the behaviour of individuals to better control risk;
- developing information strategies for emergency cases, evolving co-operative resolution of conflict when such appear;
- producing an informed public that is involved, interested, reasonable, thoughtful, solution-oriented and collaborative; and
- providing people with information that enables them to make their best decisions on risk and gives them the feeling of control over their own life [58].

Effective risk communications involves two parts: the exchange process and the actual information about the risk. The two-way exchange process fosters a dialogue between those who may be affected by the risk and those who are charged with controlling it. Both the circumstances of the emergency and public perceptions of the risks involved should drive this exchange process. Risk perception considers the difference between how risk is perceived by the public (a psychometric approach) versus how the risk is actually assessed and measured by experts (a technical approach) [59]. All too often, an assumption is made that public perception is wrong and the public must be persuaded that the technical assessment is in fact the right without first taking into account the different “common sense” factors on which the public’s perception and assessment of risk is based. In fact, the goal of risk communications is not to force a change between the divergent views of the expert and the public, but rather to

[19] Public information is a one-way communication process where information is provided to the public; communication is a two-way process of information exchange with the public where information is both sent and received.

develop an understanding of these factors so that they may be considered and addressed. This requires an understanding of the underlying factors on which public perception of risk is based.

Significant research has been undertaken to understand the nature of these factors. Generally the predominant factors relate to concerns about the nature of the hazard and the social context. Key factors related to the nature of the hazard include [59]:

- voluntariness—the public perceives less risk in hazards that are voluntary rather than imposed;
- controllability—the public perceives less risk in hazards over which they have direct control;
- familiarity—the public perceives less risk from hazards with which they are familiar;
- scientific certainty—the public perceives less risk from hazards where there is scientific consensus;
- dread—the public perceives more risk from hazards whose consequences evoke strong fears;
- history—the public perceives more risk from hazards where accidents or problems have already occurred;
- onset of effects—the public perceives more risk from hazards which occur with little warning or that have large and immediate effects; and
- reversibility—the public perceives more risks from hazards whose effects are not reversible.

Key factors relating to the social context of the hazard include [59]:

- fairness—the public perceives less risk in hazards with a fair distribution of both risks and benefits;
- trust—the public perceives less risk in hazards handled or assessed by experts they believe are trustworthy and credible;
- availability of information—the public perceives less risk in hazards for which they have sufficient and authoritative information;
- children—the public perceives more risk in hazards that affect children; and
- future generations—the public perceives more risk in hazards that may affect future generations.

In considering the nature of radiation as a hazard and its social context, the influence of these factors towards the generally negative public perception of nuclear technology becomes evident. To address this general negative perception, since the nature of the hazard is somewhat fixed, trust and availability of information become the key elements for risk communication. In order to establish this trust, particularly during emergencies where the public may be asked to comply with countermeasures, information provided to the public must not only satisfy their needs, but must also be provided in plain language so that it can be easily understood and facilitate their decision making.

IV.2. Ethical considerations

The following ethical elements are assumed to be essential for an individual or group to make informed decisions [60]:

- **Transparency:** the authorities' obligation to provide information. This should contain factual data and information on the uncertainties, assumptions and priorities (e.g. social, economic, ethical) involved in the selection and implementation of a countermeasure.
- **Clarity:** the obligation to provide information that is understandable and relevant.
- **Awareness:** comprehension of the public's ability to understand and use the information. Authorities need to recognize that the public and stakeholders (e.g. farmers, food producers) can represent a valuable and important source of knowledge about countermeasures. The authorities have an obligation to find out what the public knows and wishes to know.
- **Alternatives:** that the public should be able in some way to act (or make a decision) based on that information. Knowledge of possible alternatives is necessary if personal choice and control are to be respected. Where possible, the information should increase the ability of individuals to make personal choices and take control of their own lives.

This process requires the ethical standards of fairness, openness, honesty and non-bias. Transparency and public/stakeholder involvement are necessary for societal decisions. To address these ethical considerations, the scientifically based criteria concerning protective and other actions should be described in an understandable way to the public and to decision makers.

IV.4. Public information

The UN Åarhus convention, described by Kofi Annan as "the most ambitious venture in the area of environmental democracy so far undertaken under the auspices of the United Nations", aims to ensure that the public has access to information on the environment and a voice in any decision making that affects the environment [61].

The negative effects of the Chernobyl accident were not limited to radiation-induced cancer [62]. Psychological stress (feelings of helplessness and confusion, lack of control and personal autonomy) associated with living within contaminated areas of the former Soviet Union, and also the consequences of some of the remedial measures have been shown to be sometimes more detrimental to health than the radiation risk itself. Consequences of the emergency not related to radiation exposure, such as unnecessary abortions after the Chernobyl emergency reported in Italy, Denmark, and other countries, provide an example of action taken because of lack of understanding by the public and insufficient information provided by officials [63, 64].

IV.5. Plain language explanation

Effective risk communication can help the public to make informed choices to protect their health and safety. Unplanned and poorly thought-out risk messages can confuse the public, undermine response activities and cause unnecessary public alarm and psychological stress during an emergency. A plain language explanation of the radiation risks and any measures being taken is a vital part of an effective risk communications process—presenting clear and understandable explanation of the risk. Using plain language explanations not only facilitates public understanding, it satisfies their need for information and fosters trust with those who are in charge. Effective risk communications may not be able to change strongly held perceptions, but it can improve understanding of and compliance with response measures.

The public tends to consider deterministic health effects from a variety of hazards (e.g. heat, toxic substances, starvation, etc.) in very finite terms—either as safe or dangerous. Stochastic effects from radiation are much more difficult for the public to understand since there is assumed to be no dose that is absolutely safe, even though the probability of harm at very low doses is correspondingly very low. The layman, who wants assurance that a situation is 'safe', fails to understand the expert's aversion to the unconditional use of that word. And the expert, who tries to simplify such complexities and calls a low-risk situation 'safe', may immediately be reproached by those who know that there will still be some risk. This absence of a clear 'black-or-white' situation may be the major reason for communication problems with regard to low-risk situations. [65]

To be able to cope with uncertainties sometimes means to admit that some questions have no answer. "When the risks associated with exposures to low doses of harmful substances are under consideration by scientists, the limitations of science need to be made clear. Some aspects of estimating risk are hard science, others are scientific speculation involving sensible extensions of data, and still others are beyond the ability of science to provide reliable answers." [66].

Experience to date indicates that most participants in the general debate over nuclear technology are concerned with societal, rather than individual, risks, largely due to the involuntary nature of the risk (such as siting a nuclear power plant) that has been imposed by industry or governments. In a radiation emergency, the situation completely changes as people become much more concerned about the individual risk to themselves and their loved ones. However, the rule of voluntarily chosen action still applies: if people understand the actions undertaken taken by government/community or themselves, they feel as if they are participating in the decision making, hence feel a sense of control, which somewhat decreases the psychological stress and negative perceptions. Therefore, the explanation of actions being undertaken in an emergency becomes crucial at the stage of preparedness, as well as at the stage of response, because people will then have more trust in the emergency procedures, protective actions, and criteria that are presented and approved before the radiation emergency.

The zero risk view is both factually and ethically flawed. It is factually flawed because no situation has zero risk options. All alternatives involve some kind of risk. Indeed, virtually anything increases one's risk of cancer if the level of analysis is sophisticated enough. The zero risk proposition ignores the fact that, through technological progress, smaller and smaller levels of risk will become measurable, and more complex causes of risk will be discovered. Yet everything measurable is not obviously ethically significant; pragmatists would say that not all measurable risk causes negative consequences. All alleged risk reductions are actually risk tradeoffs, and one cannot diminish one risk without increasing another. Indeed, throughout life, we exchange risks rather than remove them, and we increase our risks to gain something more valuable. During an emergency such tradeoffs are made between risks posed by potential exposure to radiation against the broader societal risks imposed by any protective actions.

Ref. [11, Appendix 18] provides plain language statements of the risks to the public and emergency responders due to lost or stolen radioactive sources or material. These statements can be used in alerting the public to the possible risks in the event that a radioactive source or radioactive material is uncontrolled and in the public domain.

Table III-1 below provides plain language explanation of the Generic Reference Levels for decision making on protective or other actions in case of radiation emergency.

TABLE IV-1. PLAIN LANGUAGE EXPLANATION OF THE GENERIC REFERENCE LEVELS FOR DECISION MAKING ON PROTECTIVE OR OTHER ACTIONS IN CASE OF RADIATION EMERGENCY

<table>
<tr><th>GENERIC REFERENCE LEVELS</th><th>PROTECTIVE OR OTHER ACTIONS</th></tr>
<tr><td colspan="2">(Section A)
Projected (substantial risk of) or received dose approaches the Section A GRLs: Take precautionary urgent protective action to prevent or medical action to treat severe deterministic health effects[20].</td></tr>
<tr><td rowspan="2">External exposure
AD_{Torso} : 1 Gy-Eq (brief exposure)
AD_{Foetus}: 0.1 Gy-Eq (brief exposure)
AD_{Tissue}: 25 Gy-Eq at 0.5 cm depth (contact - brief exposure)
AD_{Skin}: 10 Gy-Eq to 600 cm^2 (brief exposure)
Internal exposure
$AD(\Delta)_{Red\ marrow}$: 0.2 Gy-Eq for intake of actinides (Δ = 30 days)
$AD(\Delta)_{Red\ marrow}$: 2 Gy-Eq for intake of radionuclides other than actinides (Δ = 30 days)
$AD(\Delta)_{Thyroid}$: 2 Gy-Eq (Δ = 30 days)
$AD(\Delta)_{Lung}$: 30 Gy-Eq (Δ = 30 days)
$AD(\Delta)_{Colon}$: 20 Gy-Eq (Δ = 30 days)
$AD(\Delta)_{Foetus}$: 0.1 Gy-Eq (Δ = period of in utero development)</td><td>If dose is projected or substantial risk exists:
-Immediately take precautionary urgent protective actions, even under difficult conditions, to keep dose below the reference level
-Provide public information and warning</td></tr>
<tr><td>If dose is received:
-Immediate medical examination, consultation and indicated treatment
-Contamination control
-Immediate decontamination (if applicable)
-Immediate decorporation (if applicable)
-Prescription of stable iodine (if applicable)
-Registration for long term medical follow-up
-Comprehensive psychological counselling</td></tr>
<tr><td colspan="2">Plain language explanation:</td></tr>
<tr><td colspan="2">Through medical research, criteria for intervention have been established at or just below the threshold dose for which health effects due to radiation are known to occur. These health effects are called deterministic and their severity increases according to the dose of radiation received above this threshold. During an emergency, if a dose of radiation above the intervention criteria is projected to occur or if a substantial risk of deterministic health effects exists, it is necessary to take protective action in advance—before such criteria are actually reached. While there is no danger to health from radiation at this stage, the action should be taken as a precaution, in order to reduce the chance of severe deterministic health effects occurring at a later stage during the emergency or in the future.</td></tr>
<tr><td colspan="2">If, as the emergency develops, precautionary protective action has not been taken in time, it is possible that persons could be exposed to radiation. Should a dose above the criteria be received, it means that the person has been exposed to a radiation dose close to the threshold for severe deterministic health effects. Such exposure may result in health effects that occur shortly following exposure and could lead to serious health problems. In order to evaluate the health status and to provide prompt medical assistance (very often life saving), such persons should have immediate medical examination and consultation and receive any indicated medical treatment without delay.</td></tr>
<tr><td colspan="2">(Section B)
Projected dose (substantial risk of dose) that exceeds the Section B GRLs: Take precautionary urgent protective action to reasonably reduce the risk of detectable increase of stochastic health effects[21].</td></tr>
</table>

[20] Radiation health effects are divided into two groups. One group is called deterministic because the damage that results is determined by the specific dose absorbed by the organ or tissue exposed to the radiation. Deterministic effects occur soon after exposure to high doses of radiation and their severity increases according to the dose of radiation received above the specific threshold. Examples of these effects are: acute radiation syndrome (syndrome which represents the collection of bodily effects resulting from exposure to large amounts of radiation) and radiation skin burns.

GENERIC REFERENCE LEVELS	PROTECTIVE OR OTHER ACTIONS
$H_{Thyroid}$: 50 mSv	-Precautionary food, milk and water restrictions -Public information and warning
Plain language explanation:	
Exposure to radioactive contamination may increase the long term chance of developing some diseases, such as thyroid cancer. Simple precautionary measures provide protection against contamination by radioiodine—a radioactive contaminant that affects the thyroid and can be spread throughout the environment and can be consumed in milk, water and foods. While there is no danger to health from radiation at this stage, precautionary actions should be taken in order to reduce the potential exposure to radioiodine or other radioactive contaminants that may increase the future likelihood of developing cancer.	
(Section C) **Received dose that exceeds the Section C GRLs:** Take longer term medical action to treat a detectable increased incidence of cancer and other health effects.	
E_T: 0.1 Sv in weeks - months $H_{Thyroid}$: 50 mSv	-Screening, based on individual dose, to determine if registration is necessary for long term medical follow-up -Advice and basic counselling
Plain language explanation:	

[21] The second group of radiation health effects is called stochastic: these effects are not immediate or certain to occur, but the likelihood that they will occur increases as the dose increases. Unlike deterministic effects, the timing and severity of any stochastic effects does not depend on the dose absorbed by the body. Examples of these effects include cancer and hereditary effects.

GENERIC REFERENCE LEVELS	PROTECTIVE OR OTHER ACTIONS
If a dose of radiation above the criteria is received during an emergency, it means that the person may have a slightly increased risk of developing cancer as a result of the exposure. Because this risk is only slightly higher than the normal (spontaneous or background) cancer risk for the population in that area, such exposures may only result in a few hundred extra cases of cancer, which depending on the population size and duration of observation period may not be easy to detect. In order to determine cancers due to radiation as opposed to other causes (i.e. cases induced by radiation additional to spontaneous or background cases) a careful long-lasting study of tens of thousands of cancers occurring in the population within dozens of years may be needed. These Generic Reference Levels have been established to provide a basis for: (i) decisions concerning long term medical monitoring in order to detect this slight increase in cancers due to exposure to radiation and thus be able to treat these effects at an early stage; and (ii) identifying those who should receive individual consultation concerning the health risks based on their estimated individual dose. An additional aim of the GRLs is to establish levels below which people can be reassured that their health risks are not different from those of people not exposed during the emergency. Therefore, these GRLs should be used to establish screening levels to determine the necessity for individual assessment based on an estimate of individual dose. To meet this, a very conservative approach has been taken by establishing the GRLs at levels at which radiation effects will be detectable only through very careful study, in most cases, of very large groups of people. Consequently, the vast majority of the health effects following an emergency among those who received doses above these GRLs will not be the result of their emergency exposure. This approach is used in part because the GRLs should be established in advance and thus a reasonable upper bound was selected. Clearly the use of much higher GRLs would be reasonable for individual exposures or if the number of people in the exposed group is much smaller than the size that must be monitored to detect a significant increase in cancers. However, since GRLs should be established in advance, the use of higher GRLs at the time of the emergency may be difficult to explain to the public.	
H_{Foetus}: 0.1 Sv in months	-Basic counselling to allow informed decisions to be made in individual circumstances
Plain language explanation:	
If a dose above the criteria is received, it means that there are some risks to an unborn foetus related to nervous system abnormalities, malformations, growth retardation, and foetal death. The magnitude of these risks differs quite considerably depending on the stage of pregnancy; however, a woman should be provided with appropriate information and counselling in order to make informed decisions according to her individual circumstances (e.g. stage of pregnancy when exposure occurred, dose, health status, etc.). Her physician should address all these questions and explain the advice given in each specific case.	
(Section D) **Avertable dose that exceeds the Section D GRLs:** Take urgent protective action to reasonably reduce the risk of stochastic health effects.	

GENERIC REFERENCE LEVELS	PROTECTIVE OR OTHER ACTIONS
E_T: 10 mSv in 2 days	-Sheltering
E_T: 50 mSv in 1 week	-Evacuation, urgent decontamination, restriction of food, milk and water consumption
$H_{Thyroid}$: 50 mSv	-Iodine prophylaxis and urgent decontamination
H_{Skin}: 0.1 Sv in days	-Contamination control -Urgent decontamination
(Section E) **Avertable dose that exceeds the Section E GRLs:** Take longer term protective action to reasonably reduce the risk of stochastic health effects.	
E_T: ≈ 5 mSv per annum	-Replacement of food, milk and water
E_T: 30 mSv in 1st month	-Temporary relocation -Discretionary decontamination
E_T: 1 Sv in a lifetime	-Permanent resettlement
H_{Skin}: 10 mSv in days	-Discretionary decontamination
Plain language explanation:	
Sometimes, protective actions are taken to avert doses of radiation that may contribute towards a general risk of future disease, rather than to prevent immediate health effects in individuals. Such protective actions may include: evacuation, sheltering, monitoring and decontamination, and/or restriction of food/water. Taking such actions does not necessarily mean there is a risk of specific health effects for individuals, but is rather a prudent measure to reduce the possibility of increased incidence of disease for the population affected by the emergency. The actual risk of adverse health effects for individuals can only be assessed based on their actual exposure during the emergency. However, such protective actions are taken at radiation doses well below those at which such health effects would be expected to occur and so will reduce individual as well as general risk.	
(Section F) **Projected or received dose that is less than the Section F GRLs:** Discontinue disruptive protective and other actions.	
E_T: 10 mSv per annum H_{Foetus}: 0.1 Sv in months $H_{Thyroid}$: 50 mSv $H_{Any\ other\ organ}$: 0.1 Sv per annum	No protective action except those without undue hardship such as: -Limited area/object decontamination -Limited restriction of food, milk and water consumption -Public information
Plain language explanation:	
Should the radiation dose level to a population already be above 'normal' for the area before the emergency situation, the risks and benefits of continuing protective action in the area of concern must be considered. Continuing with protective action may not be justified if the increase in radiation risk to health is negligible and lower than the economic, social or other risks that result from the protective actions. The area of concern would be considered to be safe. Nonetheless, officials may continue to take some protective actions there (e.g. monitoring, sampling, restricting certain activities, etc.) to ensure that the risk remains negligible over time.	

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DEFINITIONS

absorbed dose, D

The fundamental dosimetric quantity *D*, defined as:

$$D = \frac{d\bar{\varepsilon}}{dm}$$

where $d\bar{\varepsilon}$ is the mean energy imparted by *ionizing radiation* to matter in a volume element and *dm* is the mass of matter in the volume element. The unit of absorbed dose is J/kg, termed the *gray* (*Gy*).

action level

The level of dose rate or activity concentration above which remedial actions or protective actions should be carried out in chronic exposure or emergency exposure situations. An action level can also be expressed in terms of any other measurable quantity as a level above which intervention should be undertaken.

acute exposure

Exposure received within a short period of time.

- Normally used to refer to *exposure* of sufficiently short duration that the resulting *doses* can be treated as instantaneous (e.g. less than an hour).

acute intake

An *intake* occurring within a time period short enough that it can be treated as instantaneous for the purposes of assessing the resulting *committed dose*.

annual dose

The *dose* due to *external exposure* in a year plus the *committed dose* from intakes of radionuclides in that year.

- This is not, in general, the same as the dose actually delivered during the year in question, which could include doses from radionuclides remaining in the body from intakes in previous years, and could exclude doses delivered in future years from intakes during the year in question.

avertable dose

The *dose* that could be averted if a countermeasure or set of countermeasures were to be applied.

chronic exposure

Exposure persisting in time.

- Normally used to refer to *exposures* persisting for many years as a result of long lived radionuclides in the environment. *Exposure* that is too protracted to be described as *acute exposure*, but does not persist for many years, is sometimes described as *transitory exposure***.**

committed effective dose, E(τ)

The quantity $E(\tau)$, used as characteristic of internal exposure and defined as:

$$E(\tau) = \sum_T w_T \times H_T(\tau)$$

where $H_T(\tau)$ is the *committed radiation weighted dose* to tissue T over the integration time τ and w_T is the tissue weighting factor for tissue T. When τ is not specified, it will be taken to be 50 years for adults and up to the age of 70 years for *intakes* by children.

committed absorbed dose, $D_T(\tau)$

The quantity $D_T(\tau)$, used as characteristic of internal exposure and defined as:

$$D_T(\tau) = \int_{t_0}^{t_0+\tau} \dot{D}_T(t)\, dt$$

where t_0 is the time of *intake*, $\dot{D}_T(t)$ is the *organ dose rate* at time t in organ or tissue T and τ is the time elapsed after an *intake* of radioactive substances.

- For intake of radioactive material, a committed absorbed dose characterizes internal irradiation of organs and tissues of an individual according to its distribution in the body of *reference man* which would occur after the same intake.

committed RBE-weighted absorbed dose, $AD_T(\tau)$

The quantity $AD_T(\tau)$, used as characteristic of internal exposure and defined as:

$$AD_T(\tau) = \int_{t_0}^{t_0+\tau} \dot{AD}_T(t)\, dt$$

where t_0 is the time of *intake*, $\dot{AD}_T(t)$ is the *RBE-weighted absorbed dose rate* at time t in organ or tissue T and τ is the time elapsed after an *intake* of radioactive substances.

- For intake of radioactive material, a committed RBE-weighted absorbed dose characterizes internal irradiation of organs and tissues of an individual according to quality of radiation and to its distribution in the body of *reference man* which would occur after the same intake.

committed radiation weighted dose, $H_T(\tau)$

The quantity $H_T(\tau)$, used as characteristic of internal exposure and defined as:

$$H_T(\tau) = \int_{t_0}^{t_0+\tau} \dot{H}_T(t)\, dt$$

where t_0 is the time of *intake*, $\dot{H}_T(t)$ is the *radiation weighted dose rate* at time t in organ or tissue T and τ is the time elapsed after an *intake* of radioactive substances. When τ is not specified, it will be taken to be 50 years for adults and up to the age of 70 years for *intakes* by children.

- For intake of radioactive material, a committed radiation weighted dose characterizes internal irradiation of organs and tissues of an individual according to quality of

radiation and to its distribution in the body of *reference man* which would occur after the same intake.

contamination

Radioactive substances on surfaces, or within solids, liquids or gases (including the human body), where their presence, or the process giving rise to their presence, is unintended or undesirable.

dangerous source

A source that could, if not under control, give rise to exposure sufficient to cause severe deterministic effects. The categorization is used for determining the need for emergency response arrangements and is not to be confused with categorization of sources for other purposes.

decontamination

The complete or partial removal of *contamination* by a deliberate physical, chemical or biological process.

- This definition is intended to include a wide range of processes, but to exclude the removal of radionuclides from within the human body, which is not considered to be *decontamination*.

deterministic effect

A health effect of radiation for which, generally, a threshold level of dose exists above which the severity of the effect is greater for a higher dose. Such an effect is described as a 'severe deterministic effect' if it is fatal or life threatening or results in a permanent injury that reduces the quality of life.

dose

A measure of the energy deposited by *radiation* in a target.

dose assessment

Assessment of the *dose(s)* to an individual or group of people.

effective dose, *E*

The quantity E, defined as a summation of the tissue *radiation weighted doses*, each multiplied by the appropriate tissue weighting factor:

$$E = \sum_T w_T \times H_T$$

where H_T is the *weighted dose* in tissue T and w_T is the *tissue weighting factor* for tissue T. From the definition of *radiation weighted dose*, it follows that:

$$E = \sum_T w_T \times \sum_R w_R \times D_{R,T}$$

where w_R is the radiation weighting factor for *radiation R* and $D_{T,R}$ is the average *absorbed dose* in the organ or tissue *T*.

- The unit of effective dose is J/kg, termed the *sievert* (*Sv*).
- *Effective dose* is a measure of *dose* designed to reflect the amount of radiation detriment likely to result from the *dose*.
- Values of *effective dose* from any type(s) of *radiation* and mode(s) of *exposure* can be compared directly.
- Effective dose is intended to account for differences in biological effectiveness in producing harm, due to the quality of radiation and its distribution in the body of *reference man*.
- Effective dose is intended for use as a radiation protection quantity and therefore should not be used for epidemiological evaluations, nor should it be used for any specific investigation of human exposure.

emergency

A non-routine situation or event that necessitates prompt action, primarily to mitigate a hazard or adverse consequences for human health and safety, quality of life, property or the environment. This includes nuclear and radiological emergencies and conventional emergencies such as fires, release of hazardous chemicals, storms or earthquakes. It includes situations for which prompt action is warranted to mitigate the effects of a perceived hazard.

emergency action level (EAL)

A specific, predetermined, observable criterion used to detect, recognize and determine the emergency class.

emergency class

A set of conditions that warrant a similar immediate emergency response. This is the term used for communicating to the response organizations and the public the level of response needed. The events that belong to a given emergency class are defined by criteria specific to the installation, source or practice, which if exceeded indicate classification at the prescribed level. For each emergency class, the initial actions of the response organizations are predefined.

emergency classification

The process whereby an authorized official classifies an emergency in order to declare the applicable emergency class. Upon declaration of the emergency class, the response organizations initiate the predefined response actions for that emergency class.

emergency preparedness

The capability to take actions that will effectively mitigate the consequences of an emergency for human health and safety, quality of life, property and the environment.

emergency response

The performance of actions to mitigate the consequences of an emergency for human health and safety, quality of life, property and the environment. It may also provide a basis for the resumption of normal social and economic activity.

emergency worker

A worker who may be exposed in excess of occupational dose limits while performing actions to mitigate the consequences of an emergency for human health and safety, quality of life, property and the environment.

equivalent dose

Superseded by *radiation weighted dose*.

exposure

The act or condition of being subject to irradiation. *Exposure* can be either external exposure (due to a source outside the body), or internal exposure (due to a source within the body).

exposure pathway

A route by which *radiation* or *radionuclides* can reach humans and cause *exposure*.

- An *exposure pathway* may be very simple, e.g. *external exposure* from airborne radionuclides, or a more complex chain, e.g. *internal exposure* from drinking milk from cows that ate grass contaminated with deposited radionuclides.

first responders

The first members of an emergency service to respond at the scene of an emergency.

general emergency

An emergency involving an actual, or substantial risk of, release of radioactive material or radiation exposure that warrants taking urgent protective actions off the site (Ref. [3]).

generic reference level

Reference levels for protective and other actions in radiation emergency expressed in dose.

gray-equivalent (Gy-Eq)

Name for the unit of *RBE-weighted absorbed dose*.

index of RBE-weighted absorbed dose of external exposure P_T^{ext}

Index of external exposure of organ or tissue T equal to a ratio of RBE-weighted absorbed dose of external exposure of organ to the threshold RBE-weighted absorbed dose of external exposure of organ concerned:

$$P_T^{ext} = \frac{AD_T}{AD_{T,05}}$$

index of RBE-weighted absorbed dose of internal exposure P_T^{int}

Index of RBE-weighted absorbed dose of internal exposure of organ *T* equal to a ratio of 30-day committed RBE-weighted absorbed dose in the organ to the value of 30-day committed RBE-weighted absorbed dose in organ concerned what is relevant to threshold value of intake of radioactive material:

$$P_T^{\text{int}} = \frac{AD_T(\Delta = 30\ d)}{AD_{T,05}(\Delta = 30\ d)}$$

individual dose

The *dose* incurred by an individual.

individual (personal) monitoring

Monitoring using measurements by equipment worn by individual workers, or measurements of quantities of radioactive material in or on their bodies.

intake

The activity of a radionuclide taken into the body by inhalation or ingestion or through the skin in a given time period or as a result of a given event. Intake could be *acute* or *chronic*.

internal exposure

Exposure due to a source within the body.

intervention

Any action intended to reduce or avert exposure or the likelihood of exposure to sources which are not part of a controlled practice or which are out of control as a consequence of an accident.

intervention level

The level of avertable dose at which a specific protective action is taken in an emergency or a situation of chronic exposure.

iodine prophylaxis

The administration of a compound of stable iodine (usually potassium iodide) to prevent or reduce the uptake of radioactive isotopes of iodine by the thyroid in the event of an emergency involving radioactive iodine.

- The terms *thyroid blocking* or *iodine blockade* are sometimes used.

lifetime dose

The total *dose* received by an individual during his/her lifetime.

- In practice, often approximated as the sum of the *annual doses* incurred. Because *annual doses* include *committed doses*, some parts of some of the *annual doses* may not actually be delivered within the lifetime of the individual, and therefore this may overestimate the true *lifetime dose*.
- For prospective assessments of *lifetime dose*, a lifetime is normally interpreted as 70 years.

longer term protective action

A protective action that is not an urgent protective action. Such protective actions are likely to be prolonged over weeks, months or years. These include measures such as relocation, agricultural countermeasures and remedial actions.

non-radiological consequences

Effects on humans or the environment that are not deterministic or stochastic health effects. These include effects on health or quality of life resulting from psychological, social, or economic consequences of the emergency or the response to the emergency.

nuclear or radiological emergency

An emergency in which there is, or is perceived to be, a hazard due to:

the energy resulting from a nuclear chain reaction or from the decay of the products of a chain reaction; or

radiation exposure.

operational intervention level (OIL)

A calculated level, measured by instruments or determined by laboratory analysis, that corresponds to an intervention level or action level. OILs are typically expressed in terms of dose rates or of activity of radioactive material released, time integrated air concentrations, ground or surface concentrations, or activity concentrations of radionuclides in environmental, food or water samples. An OIL is a type of action level that is used immediately and directly (without further assessment) to determine the appropriate protective actions on the basis of an environmental measurement.

organ dose, D_T

The mean *absorbed dose* in a specified tissue or organ *T* of the human body, given by:

$$D_T = \frac{1}{m_T} \int_{m_T} D \, dm$$

where m_T is the mass of the tissue or organ and *D* is the *absorbed dose* in the mass element dm.

precautionary action zone

An area around a facility for which arrangements have been made to take urgent protective actions in the event of a nuclear or radiological emergency to reduce the risk of severe deterministic health effects off the site. Protective actions within this area are to be taken

before or shortly after a release of radioactive material or an exposure on the basis of the prevailing conditions at the facility.

projected dose

The dose that would be expected to be incurred if a specified countermeasure or set of countermeasures ─ or, in particular, no countermeasures ─ were to be taken.

protective action

An intervention intended to avoid or reduce doses to members of the public in emergencies or situations of chronic exposure.

public exposure

Exposure incurred by members of the public from radiation sources, excluding any *occupational* or *medical exposure* and the normal local natural background radiation but including *exposure* from authorized sources and *practices* and from *intervention* situations.

radiation weighted dose in organ or tissue, H_T

The quantity H_T, defined as:

$$H_T = \sum_R w_R \times D_{R,T}$$

where $D_{T,R}$ is the *organ dose* delivered by *radiation* type R to organ or tissue T and w_R is the *radiation weighting factor* for *radiation* type R. The unit of radiation weighted dose is J/kg, termed the *sievert* (*Sv*).

It is a measure of the *dose* to a tissue or organ designed to reflect the amount of harm caused.

- The values of a *radiation weighted dose* to a specified tissue from any type of radiation can therefore be compared directly.
- The radiation weighted dose is intended to account for differences in biological effectiveness in producing stochastic health effects in organs or tissues of *reference man* due to the quality of radiation.

RBE-weighted absorbed dose

A product of the absorbed dose in an organ or tissue and the RBE of radiation:

$$AD_T = \sum_R D_{R,T} \times RBE_{R,T} \ ,$$

where $D_{R,T}$ is the *organ dose* from radiation R in tissue T and $RBE_{R,T}$ is the relative biological effectiveness of radiation R in producing a specific effect in a particular organ or tissue (T). The unit of RBE-weighted absorbed dose is $J \times kg^{-1}$, termed the *gray-equivalent* (*Gy-Eq*).

- The RBE-weighted absorbed dose is intended to account for differences in biological effectiveness in producing deterministic health effects in organs or tissues of *reference man* due to the quality of radiation.

reference man

An adult human with the anatomical and physiological characteristics defined in the report of the ICRP Task Group on Reference Man [67].

reference worker

An adult worker with the anatomical and physiological characteristics defined in the report of the ICRP Task Group on Reference Man [67].

relative biological effectiveness (RBE)

For a particular organ or tissue (T), the $RBE_{R,T}$ is the ratio of the absorbed dose of reference radiation that produces a specified biological effect relative to the absorbed dose of the radiation of interest (R) that produces the same biological effect.

In general, the RBE for biological effects of radiation depends on such factors as the quality of radiation, irradiated organ or tissue, committed effect, and a dose rate. Values of the RBE of radiation for severe deterministic health effects used in this manual are the listed below**.**

Relative Biological Effectiveness of Radiation for Severe Deterministic Health Effects

Radiation	Lungs	Red marrow
Photons (gamma- and X-rays)	1	1
Electrons and positrons, including β^- and β^+ particles	1	1
Neutrons	3	3
Alpha particles	7	2

site area emergency

An emergency involving a major decrease in the level of protection for those on the site and near the facility (Ref. [3]).

stochastic effect (of radiation)

A radiation induced health effect, the probability of occurrence of which is greater for a higher radiation dose and the severity of which (if it occurs) is independent of dose. Stochastic effects may be somatic effects or hereditary effects, and generally occur without a threshold level of dose. Examples include thyroid cancer and leukaemia.

total effective dose

The *effective dose* due to *external exposure* in a certain period of time plus the *committed dose* from *intakes* of radionuclides in that period of time.

torso RBE-weighted absorbed dose

The mean RBE-weighted absorbed dose in a torso of *reference man* irradiated in uniform field of penetrating radiation, given by:

$$AD_{Torso} = \frac{1}{m_{Torso}} \int_{m_{Torso}} AD \, dm$$

where m_{Torso} is the mass of the body of *reference man* and AD is the *RBE-weighted absorbed dose* in the mass element dm.

Torso RBE-weighted absorbed dose is used to address external exposure to the lung, red marrow, small intestine, gonads, thyroid and lens of eye when body of *reference man* is in a uniform field of strongly penetrating radiation. This would also be the dose of strongly penetrating radiation typically monitored by a personal dosimeter**.**

urgent protective action.

A protective action in the event of an emergency which must be taken promptly (normally within hours) in order to be effective, and the effectiveness of which will be markedly reduced if it is delayed. The most commonly considered urgent protective actions in a nuclear or radiological emergency are evacuation, decontamination of individuals, sheltering, respiratory protection, iodine prophylaxis, and restriction of the consumption of potentially contaminated foodstuffs.

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