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Application of radiation protection principles to the cleanup of contaminated areas

Interim report for comment

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FOREWORD

Recognizing that there was a general lack of guidance on protection from ionizing radiation in the case of protracted or chronic exposures and prompted by the clear need for such guidance for aiding decision making in the particular case of the rehabilitation of areas affected by residual deposits of radioactive materials from past activities, the IAEA started a project in 1993 to address the problem. A small working group was established and met on several occasions over a three year period. The working group used, as its starting point, the Recommendations of the International Commission on Radiological Protection (ICRP) (Publication 60) and the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (IAEA Safety Series No. 115). These documents set out systems of radiation protection for 'practices' (beneficial human activities that add radiation exposure to that which people normally incur due to background radiation) and for 'interventions' (human activities that seek to reduce extant radiation exposures). It became obvious that environmental cleanup (or rehabilitation) situations could be categorized as either practices or interventions depending upon the circumstances in which the environment had been contaminated. However, in many cases it could be argued that the distinction made between these categories is arbitrary and that some situations could be considered as being either practices or interventions. Since the criteria for aiding decision making on cleanup derived from considering contamination situations involving residual radioactivity to be practices could be very different from when they are considered to be interventions, it was clear to the working group that there are problems in applying the basic approach. Subsequently, the working group devised an approach which seeks to remove the explicit 'practice/intervention' distinction and to develop a unified approach for considering all types of potential cleanup situation. The approach emphasizes the use of risk to individuals from existing contamination and from the residual contamination after cleanup actions as a basis for decision making. Nevertheless, links are maintained with the basic ICRP radiation protection system by recognising that, in many situations, cleanup actions may be influenced by more than only individual risk considerations; there will be radiological and non-radiological constraints which will differ depending on whether the situation is more 'intervention like' or 'practice like'. The framework for decision making being proposed by the working group is being published in this report to allow for a period of review and comment by experts and decision makers in Member States.

In the period during which the working group has developed its framework for decision making, the problems in applying the existing ICRP radiation protection systems to chronic radiation exposure situations, such as environmental cleanup, have come to be recognized more widely in the radiation protection community. Preliminary proposals are now being made for the coherent and consistent application of the existing system of radiation protection to the control of chronic radiation exposure situations.

ICRP guidance has mainly been required by users, operators and regulators for the control of radiation doses delivered by particular sources (*source related* guidance). In the case of chronic exposure to radiation, for instance, from residual radioactivity on land surfaces, it is the total radiation exposure to an individual which is likely to be of principal concern for the individual and for public authorities alike and so the guidance needs to be further developed towards *individual related* approaches. It seems that some complementary criteria, derived from the application of the existing system of radiation protection for practice and intervention situations may be needed. These ideas are still under development within the ICRP and it is likely to be some time before they have been properly elaborated and applied to chronic exposure situations. When the time comes to review and possibly revise the preliminary guidance given in this report, on the basis of comments received, account will also have to be taken of the developments made by the ICRP.

This report was developed with the help of consultants (notably P. Hedemann Jensen, Denmark, I. Barraclough, UK, R. Meck, USA, and B. Yatsalo, Russian Federation), and through an Advisory Group meeting held in 1994 and a Technical Committee meeting held in 1996. G. Linsley, M. Crick, P. Stegnar and G. Gnugnoli of the Division of Radiation and Waste Safety were the responsible officers at the IAEA.

CONTENTS

1. INTRODUCTION

BACKGROUND

101. In the past, radiation protection has been concerned primarily with establishing the conditions that should be applied to the introduction of new practices and the management of continuing practices. This has led to a well developed system of principles for deriving numerical criteria [1, 2], including limits on releases from normally operating facilities and levels for initiating protective actions to reduce doses and protect populations in the event of an accident. These principles and, in some cases, the associated numerical values have been documented, for example in International Atomic Energy Agency (IAEA) Safety Series Nos 77 [3] and 109 [4].

102. This report addresses another major category of situations, which have to date received less attention. These are commonly known as 'cleanup' situations and include, for example, when a practice is discontinued at a particular site, when contamination from a previously discontinued practice is discovered, or when an accident occurs that leads to chronic exposures due to contamination. The term 'cleanup' is used in this report in a very general sense, and has essentially the same meaning as the words such as 'rehabilitation', 'reclamation', 'remediation', 'restoration', etc., used elsewhere. Examples of cleanup situations are given in the shaded area on the following page, and more specific examples are described in Appendix I.

OBJECTIVES

103. The purpose of this report is to set out radiological principles for use in decisions related to the cleanup of contaminated areas. More specifically, it aims to establish an approach to developing radiological criteria for cleanup and to recommend ranges of generally applicable numerical values (cleanup levels). It is also intended that the report should provide outline guidance on how the radiological criteria can be applied to the cleanup of contaminated areas. In developing this guidance, existing recommendations of the ICRP and of the IAEA are taken into account.

104. While the proposed cleanup criteria have been developed by taking account of the need to optimize radiation protection and of relevant international guidance, the analysis has been necessarily generic and, therefore, the values may not be appropriate in all situations. Site specific analysis could lead to criteria which are higher or lower than those given here.

SCOPE

105. This report is intended to apply to situations in which environmental media have been contaminated as a result of human actions. The definition of contamination therefore includes concentrations of naturally occurring radionuclides enhanced by humans, as well as anthropogenic nuclides. The sources considered as potential candidates for cleanup include contaminated land areas, ground waters, and sediments in rivers, lakes, and sea areas.

106. This report addresses those measures that might be carried out to reduce the exposure from existing contamination through actions applied to the contamination itself (e.g. removal of contaminated soil or sediments, decontamination of surfaces) — i.e. actions that would be

CONTAMINATION SITUATIONS

Cleanup may be needed when environmental media have been contaminated as a result of a variety of human activities involving radionuclides. The activities, past and present, that may lead to contaminated areas and eventually to cleanup include:

(a) *various phases of the nuclear fuel cycle (mining and milling of uranium ore, enrichment and fuel fabrication, energy production and reprocessing)*
(b) *radioactive waste disposal, either on land or in the marine environment*
(c) *nuclear weapons production*
(d) *nuclear tests and other detonations of fissile materials*
(e) *use of radionuclides in medicine and research*
(f) *use of sealed and unsealed sources in industry*
(g) *the extraction and processing of materials containing natural radionuclides, and other activities that may generate enhanced levels of natural radionuclides (radium, thorium, rare earths, phosphates, oil and gas production)*
(h) *misuse of natural or man-made materials containing natural radionuclides (e.g. uranium mill tailings used in landfills or in residential construction)*
(i) *accidents involving radionuclides*

The type and extent of the contamination will depend on the scale of the operation, the amount and and kind of radioactive materials, the chemical nature of the contaminant, and the environmental media involved. The contamination may be confined to the site of the operation or extend to off-site areas. In the latter case the contamination may result, for example, from inadequately controlled discharges from either current or past operations, transportation accidents (including satellites and weapons), and major accidents at nuclear installations. Apart from terrestrial contamination, such releases may also contaminate off-site groundwater, aquifers and river, lake and estuarine sediments.

generally understood as 'cleanup'. However, in this report 'cleanup' is broadly taken to include dose reduction measures applied to the exposure pathways to humans (e.g. covering the contaminated material to reduce external exposure or radon exhalation, planting vegetation to reduce resuspension, incorporating contaminated material into structures to prevent dispersion, or restricting particular uses of an area). Measures applied directly to people, such as relocation, are excluded from the scope of 'cleanup' in this report; these measures are associated with cleanup, but appropriate criteria are given elsewhere (e.g. Safety Series No. 109 [4]).

107. The report focusses on the radiological part of decisions on cleanup. Other equally important parts of the decision making process, such as political, economic and social factors, are discussed, but detailed analysis of such factors is beyond the scope of this report.

STRUCTURE

108. Following this introduction, Section 2 reviews the conceptual framework of radiation protection and gives guidelines on how the basic principles should be applied in cleanup of contaminated sites. Section 3 presents the basis for criteria to be used in implementation of cleanup actions, and Section 4 provides a summary of the proposed cleanup levels. Appendix I provides a variety of examples of contamination situations. Appendix II provides an illustration of how the various factors could be considered in the justification and optimization of cleanup actions. Appendix III contains discussion of the factors that affect the derivation of operational quantities, and Appendix IV addresses the considerations affecting the definition of conditions for a 'return to normality'.

2. CONCEPTUAL FRAMEWORK FOR PROTECTION

GENERAL FRAMEWORK

201. According to the ICRP, *"...the primary aim of radiological protection is to provide an appropriate standard of protection for man without unduly limiting the beneficial practices giving rise to radiation exposure"* (ICRP 60, paragraph 100 [2]). More specifically, the ICRP states that:

> *"A system of radiological protection should aim to do more good than harm, should call for protection arrangements to maximize the net benefit, and should aim to limit the inequity that may arise from a conflict of interest between individuals and society as a whole."* (paragraph S14 [2])

202. This statement of objectives can be expressed in terms of the following general principles for radiological protection:

(a) Justification: *The overall effect of activities involving risks from radiological hazards should be to do more good than harm.*
(b) Optimization: *Radiological risks should be managed so that they are as low as can reasonably be achieved.*
(c) Protection of the individual: *Measures to protect people from radiological risks should aim to limit the inequity that may arise from a conflict of interest between individuals and society as a whole.*

203. These general principles have been further elaborated by the ICRP for two classes of situations — those in which protection measures can be planned prospectively, before sources of exposure are introduced, and other situations, where the source of exposure is already present and protection measures have to be considered retrospectively. These are characterized respectively as the principles for protection for *practices* and for *intervention*, and between them encompass most situations involving radiation exposure.

204. The following sections lay out the relevant radiation protection principles for practices and for intervention, then discuss the similarities and differences in the three basic elements of each of the approaches, and finally set forth the features required for a comprehensive,

unified approach to decisions on the control and remediation of exposure from contaminated sites.

PRACTICES AND INTERVENTION

205. A practice is defined as:

> *"any human activity that introduces additional sources of exposure or exposure pathways or extends exposure to additional people or modifies the network of exposure pathways from existing sources, so as to increase the exposure or the likelihood of exposure of people or the number of people exposed"* [1].

Intervention is defined by the ICRP in general terms as *"an activity that decreases overall exposure by removing existing sources, modifying pathways, or reducing the number of exposed individuals"* [2], and has been more particularly specified as:

> *"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"* [1].

206. The radiation protection principles for practices [2] are:

(a) Justification of the practice: *"No practice involving exposures to radiation should be adopted unless it produces sufficient benefit to the exposed individuals or to society to offset the radiation detriment it causes."*

(b) Optimization of protection: *"In relation to any particular source within a practice, the magnitude of individual doses, the number of people exposed, and the likelihood of incurring exposures where these are not certain to be received should be kept as low as reasonably achievable, economic and social factors being taken into account. The optimization should be constrained by restrictions on the doses to individuals (dose constraints), or the risks to individuals in the case of potential exposures (risk constraints), so as to limit the inequity likely to result from the inherent economic and social judgements."*

(c) Individual limits: *"The exposure of individuals resulting from the combination of all the relevant practices should be subject to dose limits, or to some control of risk in the case of potential exposures. These are aimed at ensuring that no individual is exposed to radiation risks that are judged to be unacceptable from these practices in any normal circumstances. Not all sources are susceptible to control by action at the source and it is necessary to specify the sources to be included as relevant before selecting a dose limit."*

207. The radiation protection principles for intervention [2] are:

(a) Justification: *"The proposed intervention should do more good than harm, i.e. the reduction in detriment resulting from the reduction, in dose should be sufficient to justify the harm and costs, including social costs, of the intervention."*

(b) Optimization: *"The form, scale, and duration of the intervention should be optimized so that the net benefit of the reduction of dose, i.e. the benefit of the reduction in radiation detriment, less the detriment associated with the intervention, is maximized."*

(c) Individual limits: *"Dose limits do not apply in the case of intervention."*

Application of principles for practices and intervention to cleanup

208. For a practice, justification is based on the entire practice which gave rise to the contamination (e.g. the generation of electricity, beneficiation of mineral ores, etc.). The need for cleanup operations when the practice is discontinued should be assumed to have been taken into account in the original justification of the activity. Justification of the cleanup of a practice is thus to be considered in the context of the entire practice, and not for cleanup alone. In contrast, in the case of intervention, where the benefit associated with the conduct of the practice that gave rise to the source of exposure cannot be considered relevant (e.g. because it was not regulated and/or occurred in the distant past, or because it resulted from a major accident), justification will have to be considered in the context of the benefits and costs of cleanup alone.

209. Although the formulations of the optimization principle differ, the practical implementation of optimization of cleanup is essentially the same process, whether it is considered in the context of the continuing operation of a practice, as part of decommissioning of a practice, or for intervention. In all cases, it consists of looking at the different options available and how exposures might be reduced, and choosing the course of action which results in the greatest net benefit, considering all of the relevant factors that influence costs and benefits. These benefits and costs may accrue to directly affected populations, both now and in the future, as well as to other parts of society. The impact on availability of natural resources may also be a factor. In the case of practices, the optimization process will always be subject to constraints on the *residual dose* (or risk), i.e. the projected doses or risks to people using the site as a result of contamination left behind after cleanup. In the case of intervention the use of such constraints is not required, with the result that residual exposures may receive inadequate attention in the optimization process. This is an important consideration, because residual doses or risks are clearly a matter of major public concern for the return to normality in all cleanup situations. This is addressed below.

210. In practice situations, constrained optimization would be used to derive authorized release levels (in terms of residual dose, or corresponding measurable units such as activity concentrations *after* the implementation of cleanup decisions), below which the residual contamination could be "released" into the environment[1] (clearance is a special case of authorized release where the risks are so low that detailed optimization is not necessary). In intervention situations, optimization would be used to derive intervention levels (in terms of averted dose) for possible countermeasures, and action levels (in terms of projected dose, or corresponding measurable units such as activity concentrations *before* any cleanup). If action levels are exceeded, then some form of action will be necessary to reduce doses, whereas for

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[1] This 'release' would actually take the form of removing controls that separate the contaminated area from the public domain, e.g. removing fences around a licensed site, and removing some or all legal restrictions on use.

situations below action levels cleanup measures are unlikely to be justified. In general terms, therefore, levels of residual dose below action levels should be suitable to allow "release" of the area. However, when the optimization used to derive action levels is not constrained, residual doses below action levels may need further consideration, particularly in the context of 'return to normality' (see below).

211. The dose limits for members of the public apply to exposures from radiation sources, excluding any occupational or medical exposure and the normal local natural background radiation. Therefore, the dose limits for members of the public are not directly applicable to cleanup decisions. In the case of practices they are replaced by dose constraints applied to the optimization of protection, and dose limits act only as the upper bound on the choice of constraints. In the case of intervention the dose limits are not applicable, in principle, because their use could, in some cases, invoke the use of action that causes more harm than good, i.e. the action is not justified[2]. Obvious examples include relocation of a population in the later phases following a nuclear accident and the remediation of indoor radon in large numbers of existing homes to the level of control of exposure required of practices. In the former case the risk from the action is potentially greater than the risk avoided and in the latter the costs are not societally acceptable in relation to the risks avoided.

212. In this context, therefore, the most important difference between application of the principles to practices and interventions is the greater role played in the system for practices by constraints. It is noteworthy, however, that the system for intervention does not preclude the use of constraints, provided that their application does not lead to unjustified actions.

A GENERAL FRAMEWORK FOR CLEANUP

213. Some cleanup situations will clearly fall into one or other of the categories — practice or intervention — but for others it will not be so obvious. For example, the decommissioning of a recently authorized practice and measures taken to provide protection from the consequences of a serious accident are clearly cases of management of a practice and of intervention, respectively. However, the transfer of an uninhabited historically contaminated site to use for residential development may be considered under either approach, depending upon the jurisdiction and practice of the relevant national authorities. In other cases, although the distinction and choice is clear, it may not be acceptable to society to reach different conclusions for the level of protection that depend on the origin of the source of exposure. For example, if an ore milling operation is decommissioned, and a nearby historical operation that is radiologically identical is remediated through intervention, it will be difficult to justify different endpoints.

214. For the above reasons, it will often be desirable (although not always possible) to seek to achieve cleanup criteria that do not differ depending on whether the situation is deemed to fall within the category of practices or of intervention. Instead, it is useful to consider the more general objectives outlined in paragraphs 201 and 202 as the basis for a framework in which the whole range of situations can be accommodated.

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[2] Dose levels high enough to cause deterministic effects will normally be avoided through application of the justification principle.

215. Such a general framework should include the principles of practices and intervention, but place them in a wider context in which they continue to provide guidance for situations that fit well into one category or the other. For situations that do not fit well into either category, it should provide useful guidance that is independent of such a categorization. Such application of the general principles to control and remediation of contaminated sites is described in more detail below.

Justification

216. Justification decisions in the context of cleanup (as in many areas of radiation protection) will often be very complex, and will usually involve consideration of factors such as non-radiological risks and environmental effects, economic costs and benefits, and a wide range of social and political factors, as well as the direct radiological risks. The proper consideration of many of these factors may require expertise far beyond radiological protection. Nevertheless, simplified consideration of justification in terms only of monetary costs of cleanup and monetary values of doses or risks avoided can provide useful guidance.

217. The social and political value of limiting inequity needs to be identified and included when justification decisions are made in situations involving the use of a constraint to limit inequity, and the perceived benefit from imposing a constraint should be sufficient to justify any measures that might otherwise appear unjustified. Otherwise, when a constraint on residual dose or risk is applied, it is possible that the cleanup might incorrectly appear to be not justified.

Optimization

218. Optimization requires that the radiological risks be as low as can reasonably be achieved, economic and social factors being taken into account. As has already been noted, the general process for conducting optimization, whether or not it is constrained, is essentially identical in any application, including control and remediation of contaminated sites.

219. The word *reasonably* is clearly a key consideration. For example, it is not reasonable to expect significant resources to be devoted to reduce risks that are already negligible, or that could only be reduced further by means that are clearly not cost-effective or simply not feasible. Such cases are the basis for the established concepts of exemption and exclusion [1].

220. One particular issue that may be relevant in implementation of the optimization principle is whether options involving restrictions on use of the land should be treated on an equal basis to those that would allow unrestricted use. In this context, sustainability may be an important additional factor to be considered in carrying out the optimization — short term restrictions on the use of small areas are unlikely to be of major concern, but a situation in which large areas are subject to long term restrictions may not be sustainable, and the expected value of assumed benefits will therefore be reduced. There may also be social and equity considerations associated with passing uncertainty in the level of protection to future generations. This issue may also interact with the concept of 'return to normality' (see below), in the sense that only options with no ongoing controls can be considered to represent 'normal' conditions.

Protection of the individual and the use of dose constraints

221. The key to individual protection at contaminated sites is the concept of limiting *inequity*[3]. The ICRP introduced the use of dose constraints to provide a means to deal with individual equity issues associated with the distribution of detriment from radiation exposure. As they have expressed the problem and its solution:

> *"In radiological protection...attention has to be paid, not only to the advantages and disadvantages for society as a whole, but also to the protection of individuals. When the benefits and detriments do not have the same distribution through the population, there is bound to be some inequity. Serious inequity can be avoided by the attention paid to protection of individuals"* ([2] para. 101).
>
> *"Most of the methods used in the optimization of protection tend to emphasize the benefits and detriments to society and the whole exposed population. The benefits and detriments are unlikely to be distributed through society in the same way. Optimization of protection may thus introduce a substantial inequity between one individual and another. This inequity can be limited by incorporating source related restrictions on dose into the process of optimization. The Commission calls these source related restrictions dose constraints..."* ([2] para. 121).

Equity does not, as the ICRP makes clear, require that everyone be treated equally; it means that individuals should be treated fairly – that is, *in*equities should be *limited*, not eliminated.

222. There are many circumstances under which the use of dose constraints is either necessary or appropriate for cleanup situations. Although they were originally intended for use on a prospective basis (i.e. for specific practices), their basic function, limiting individual inequity, is also more generally useful to facilitate socially optimal choices of the levels of cleanup in situations handled as interventions, as well as in cases where distinctions based on the origin of sources are either not relevant or cannot clearly be made. In considering these applications, the difference between dose limits and dose constraints is of fundamental importance: limits are *mandatory* requirements that must be satisfied, whereas dose constraints are *discretionary* requirements that may be overruled by regulatory authorities if there is good cause — i.e. the existence of a situation in which more harm than good would result from satisfying a dose constraint. This difference makes it reasonable for national authorities to adopt, on a non-binding basis, objectives for limiting individual inequity that will normally apply, but which do not require action be taken in those situations where it is not justified.

223. There are two counteracting factors that will most commonly influence the choice of dose constraints; these are the desire to limit inequity in the exposed population and the need to place reasonable bounds on the monetary cost to society as a whole. These are matters for

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[3] In fact, it is arguable whether a separate principle is needed — limiting inequity is, for example, explicitly considered as part of the optimization process through the use of constraints. As another example, although limiting inequity would require that particular efforts be made in all circumstances to avoid individuals receiving doses high enough to cause serious deterministic health effects, the same conclusion will be reached by observing that this is almost always achieved under the justification principle. However, for clarity, concepts related to protecting the interests of individuals, and hence to limiting inequity, are discussed together in this section.

national decision, and the result will depend in large part on the origin and nature of the source of the inequity involved, the extent of national economic resources, and the priorities of competing demands for use of these national resources, including but not limited to other forms of risk management. Other factors that could play a role under some circumstances include protection of natural resources, reduction of individual risk (independently of equity concerns), and management of intergenerational risks.

224. The following examples may be used in the context of cleanup situations in which dose constraints may be used:

(i) In the case of an authorized practice, the site will already have been subject to an overall dose constraint during operations. Cleanup as part of continuing operation (e.g. cleaning up contamination on site from past operations or an accident) will be subject to optimization within that same constraint, as would any other routine activity, and cleanup wastes would be treated on the same basis as any other radioactive wastes. Any contamination remaining after cleanup would remain within the authorized practice.

(ii) Decommissioning an authorized practice and transfer of the site out of the practice for unrestricted future public use involves other constraints. Under the provisions of the Basic Safety Standards, sources within an authorized practice can only leave that practice by satisfying criteria for clearance or authorized release to the environment [1].

(iii) In cases where cleanup of one site is managed as part of a practice and cleanup of another is managed through intervention, but each involves otherwise comparable sources, it will normally not be acceptable to reach different conclusions for the level of protection. For example, if a current mining operation is decommissioned, and a nearby historical operation that is comparable is remediated through intervention, it will be difficult to justify different endpoints. In such situations the use of a common dose constraint is indicated, unless it is not justified on economic or social grounds.

(iv) National authorities may, for hazardous chemical, biological, or radiological sites, adopt general risk limitation objectives based on individual equity considerations, to supplement the results of unconstrained optimization. To the extent that these objectives do not lead to unjustified actions (in the sense that they do more harm than good), dose constraints may be utilized to assist in implementing these objectives.

(v) In many cases, the greatest benefits and risks from a particular site are experienced by the generation alive at the time. However, some sites will impose risks on future generations who are unlikely to receive a direct, compensating benefit, whereas remedial actions might reduce the risks to future generations at the expense of cost or disruption to the current generation. The aim of limiting inequity indicates that future generations should be given no less consideration than the current generation. This can be assured by applying an appropriate dose constraint to exposure of future generations. However, such decisions need also to take account of the uncertainty — which increases with time — that exposures will actually occur as predicted. Hence, the terms 'no less consideration',. and 'an appropriate dose constraint' do not necessarily imply the use of identical criteria to those applied for the current generation.

(vi) In some cases, important economic and/or social benefits may result from cleanup beyond that indicated on radiological grounds alone. Examples include enhancement of the marketability of agricultural produce or the value of land. In such cases, use of a dose constraint may be useful to assure the desired endpoint.

(vii) To facilitate 'return to normality'; this is discussed below.

Return to normality

225. Return to normality does not necessarily imply a return to conditions before the contamination occurred — there will usually be an increased level of radiological risk, but this must be low enough to be acceptable without any restrictions on people's behaviour. 'Normality' or 'normal conditions' in the context of this report means that members of the public can live and/or work in the area under consideration without any restrictions associated with residual contamination[4]. This means that no restrictions on behaviour or use of the area to control exposure, such as limiting access, preventing use of local foods, water, building materials or other resources, are necessary. When normality is redefined, the area can and should be treated as if the residual contamination is part of normal background radioactivity. Criteria for determining when return to normality is possible are discussed in Section 3, and may require action beyond that indicated by application of the above principles. Situations which do not meet these conditions, i.e. where institutional restrictions are maintained, may still be acceptable endpoints, but do not constitute return to normality.

226. Application of the principles of protection to contaminated sites is illustrated schematically in Fig. 1. If cleanup measures are justified, then optimization (constrained or not, as fits the situation) should be used to determine an appropriate cleanup strategy. If cleanup is not justified, or if the optimization is unconstrained, and the result is high residual doses, then the regulatory authority will need to decide whether the exposures will be acceptable without further control, i.e. whether return to normality has been achieved, or whether restrictions on the use of the area will need to be maintained, based on the residual dose.

3. BASES FOR CLEANUP CRITERIA

INTRODUCTION

301. The principles discussed in Section 2 can be applied to determine whether cleanup is justified, and to optimize any cleanup actions, subject to any constraints that may be considered appropriate for the given situation. This process would determine the 'end point' for cleanup, which may be expressed in terms of the residual dose — the projected dose from use of the cleaned-up area, taking account of an appropriate range of uses. The definition of 'an appropriate range of uses' will need to reflect whether or not there will be continuing regulatory control over the area after cleanup (see Section 2 and Appendix II).

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[4] The situation can alternatively be defined as *redefinition of normality* to avoid the perception that the situation is the same as before the area was contaminated, in view of the increased risk of radiation induced cancer.

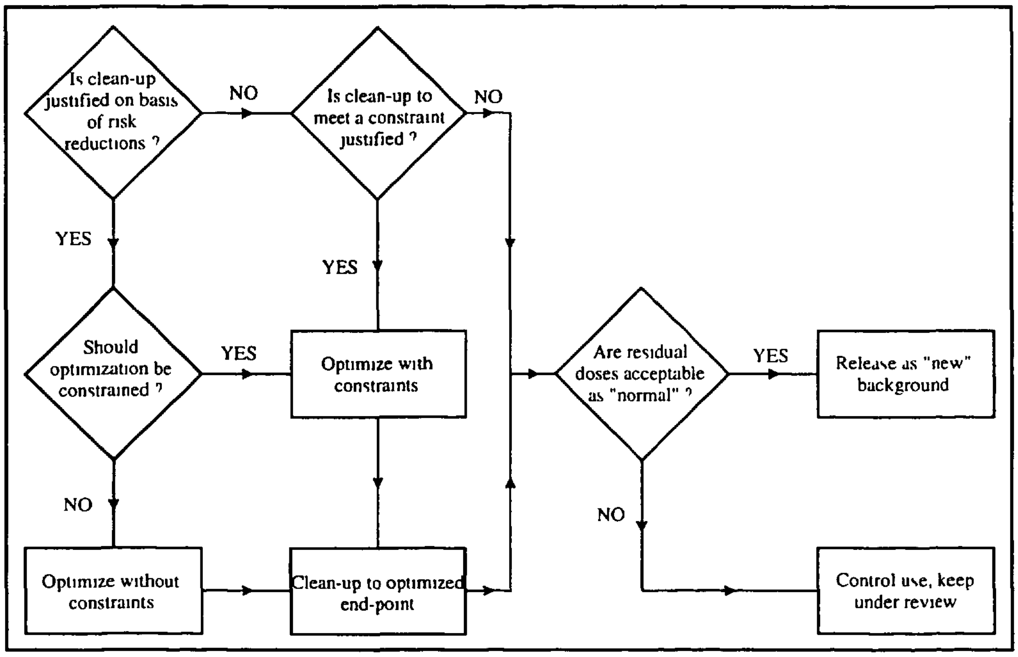


FIG. 1. Schematic diagram of cleanup decisions (justification takes into account all significant and relevant radiological and non-radiological factors, e.g., chemical risks, industrial and transportation risks, physical risks, and socio-economic factors. In the case of decommissioning of a practice, cleanup is normally assumed to have been previously justified).

302. To provide some indication of the range of likely results of such detailed analyses, a set of generic criteria — referred to as *cleanup levels* — are proposed, based on general consideration of the justification/optimization principles of protection, the need to protect individuals, and the acceptability of different levels of risk.

RANGE OF CLEANUP SITUATIONS

303. Figure 2 shows the range of possible cleanup situations, divided into six sections or 'bands', each covering approximately an order of magnitude in dose or risk. For easy reference, these are numbered from 1 (very low doses) to 6 (very high doses); each band covers approximately one order of magnitude of exposure.

304. Band 1, annual doses less than 10 μSv above background, represents risks that would be regarded as trivial in the vast majority of situations. Criteria for triviality of risks have been published in the context of exemption of practices and sources and clearance of materials from practices [5]. The Basic Safety Standards [1] specify a criterion for exemption and clearance of the order of 10 μSv/a for the average member of the critical group.

305. Band 2 represents annual doses (typically tens of μSv/a above background) in the range that would be considered acceptable as additional exposures imposed on members of the public as a result of a set of planned actions with an overall net benefit to society, i.e. a justified practice.

Band	Need for cleanup actions if this is initial level	Acceptability of this level for release	Additional annual dose projected, mSv/a	Additional annual mortality risk, a^{-1}
6	Cleanup or prevent use			$\sim 10^{-2}$
		Not suitable for release. (restrict use)	~ 100	
5	Cleanup or restrict use			$\sim 10^{-3}$
	(Cleanup likely)		~ 10	
4		Release may be possible subject to regular review of situation		$\sim 10^{-4}$
	Cleanup decisions based on justification/optimization		~ 1	
3		Release possible — situation may need occasional review		$\sim 10^{-5}$
	(Cleanup unlikely unless constrained)		~ 0.1	
2	Cleanup unlikely to be necessary on the basis of radiological risks	Release likely — review only if a problem becomes apparent		$\sim 10^{-6}$
			~ 0.01	
1	No cleanup necessary	Can be released without controls		$\sim 10^{-7}$

NOTES

1. Doses and risks are those to an average member of the critical group, based on appropriate assumptions about use of the area, and exclude background.
2. Exposures are assumed to be chronic, i.e. approximately constant over a period of at least a significant fraction of a lifetime.
3. When doses are essentially due to radon exposures, cleanup and subsequent release would normally fall above the three lower bands.
4. The incremental lifetime risk can be found as the product of the annual risk and the number of years of exposure.

FIG. 2. Proposed criteria for cleanup of contaminated areas.

306. Band 3 represents risks that might be considered tolerable as additional risks from a justified practice, provided that they were as low as reasonably achievable; the upper bound of Band 3 corresponds approximately to the ICRP dose limit for members of the public. Also, many national authorities have adopted dose constraints, typically between a hundred and some hundreds of μSv/a to apply to new and/or existing practices, and international recommendations have been made about rationales for choosing constraints [6, 7]. These

levels of risk are low enough that they are considered acceptable in many other situations, e.g. occupational exposure, doses incurred over a year by 'frequent fliers' from air travel.

307. Band 4 represents risks corresponding to doses of the order of a few mSv/a. These would *not* normally be considered acceptable if they were deliberately imposed on the public, but are low enough that they would be acceptable in a range of other situations, such as:

(a) If the individuals are exposed voluntarily and receive a direct compensating benefit, e.g. radiation workers, then risks of this magnitude would be acceptable if they were as low as reasonably achievable;

(b) Radiation risks of this magnitude are routinely accepted from natural sources, and variations of this magnitude in levels of background radiation do not appear to influence people's behaviour.

308. Band 5 (doses of tens of mSv/a) represents risks that would generally be regarded as unacceptable from any source (with the exception of necessary medical treatment) because the stochastic risks associated with exposures in this band are too high to be tolerated under normal circumstances [1].

309. Band 6, doses of hundreds of mSv/a or more, represents risks (whether in terms of serious deterministic effects or a high probability of stochastic effects) that are clearly intolerable in all but the most exceptional circumstances (e.g. radiation therapy). Both the risk of serious deterministic effects and stochastic risks would always be so high as not to be tolerated under any circumstances.

CONSIDERATIONS IN SETTING CRITERIA

310. In principle, consideration of situations in all bands would be based on the basic principles outlined in Section 2. Methods such as cost–benefit analysis can be used to assist in seeking solutions that comply with the justification and optimization principles. However, justification/optimization studies based on cost–benefit analysis methods may omit certain factors that are of potentially great relevance to cleanup decisions, but are difficult to quantify in monetary terms, such as the social and political aspects of cleanup decisions (see Appendix II). Therefore other methods, such as multiattribute analyses (see Ref. [8]), may be needed.

311. Furthermore, considerations based on the protection of the individual may constrain optimization (and perhaps even justification). Factors such as these tend to be of particular importance towards the extremes of the range shown in Fig. 2. Examples of particular relevance are discussed below.

Radiological constraints

312. As discussed in Section 2, optimization largely deals with the interests of society as a whole. Constraints can be imposed to prevent consideration of options that would lead to outcomes (in this case, residual dose levels) that are determined in advance to be unacceptable for individuals in particular categories of situation. Two particular cases are effectively constrained within existing radiological protection recommendations:

(i) In all situations, every effort should be made to prevent serious deterministic health effects [1, 12]. This in effect imposes a constraint on residual dose at the lower bound of doses that could cause such effects; and

(ii) Where additional risks are being imposed as a result of controlled practices (other than those involving indoor radon), additional annual residual risks from a source to individual members of the public much above about 10^{-5} a^{-1} are not considered to be acceptable. Constraints for practices are set on this basis.

As discussed in Section 2, constraints could be considered necessary in other situations on equity grounds, for example on the basis of comparisons between similar situations, or protection of individuals remote in space and/or time from the contaminating practice.

Non-radiological factors

313. Taking non-radiological benefits into account may result in dose criteria being either less restrictive (higher) or more restrictive (lower). In extreme cases of very widespread contamination, non-radiological constraints may become more important. For example if contamination affects a significant fraction of the area of a country, or if cleanup costs are significant compared to the Gross National Product, or if particular cleanup options would generate unmanageable quantities of waste, the options available may be limited by such factors.

314. In other cases non-radiological considerations may lower the residual dose level. For example, in any contamination situation, there may be a significant potential 'socio-political' benefit that could be obtained if it were possible to remove all traces of contamination from an area, making it radiologically indistinguishable from the surrounding area. This benefit is largely independent of the scale of the contamination, whereas the conventional radiological protection factors cost and dose reduction are strongly dependent on the area and level of contamination. As a result, when relatively small areas are contaminated to a moderate degree (and hence where the costs and dose reduction are not very large), this political factor may dominate, driving the decision towards a complete cleanup, irrespective of strict cost-effectiveness. Where large areas are heavily contaminated, on the other hand, the costs and potential dose reductions are much larger, and the potential 'socio-political' benefit may be too small to significantly affect the decision. Other aspects to be considered are hazardous chemical, biological, or other non-radiological risks that could override the radiological considereations.

315. Some cleanup methods, in addition to their monetary costs, necessarily involve other, less quantifiable, 'costs' that can be substantial. A particular example is disruption to the lives of the individuals whose exposures are to be reduced (e.g. if the measures would necessitate removing people from their homes or work for more than a few days, or would have a significant effect on their lifestyle, such as by making land unsuitable for farming). This additional 'cost' of cleanup measures could significantly raise the levels of contamination that would need to be present to justify action, relative to the levels at which less disruptive measures of similar effectiveness would be justified. On the other hand, the costs of cleanup measures like decontamination of urban environments from which people have been relocated might reduce the disruptive costs by bringing about an accelerated return of people from a temporary relocation.

316. Another aspect in which the disruption associated with cleanup measures could be a significant factor is in the timing of cleanup. For example, cleanup at the time of a change of use or ownership of an area might be considerably less disruptive than applying the same measures while the area is in use. Hence, cleanup at the time of a change of use or ownership might be justified at a significantly lower level of projected risk than would be the case at other times. This could be a particularly relevant consideration in the case of contamination with very long lived radionuclides (e.g. enhanced concentrations of naturally occurring nuclides), where the risk accumulates over such a long period of time that relatively small delays in the timing of cleanup will not significantly reduce the overall reduction in radiation detriment achieved.

Return to normality

317. Decisions may also be influenced by a desire to achieve conditions where return to normality can be achieved, i.e. where no restrictions are placed on people's behaviour (see Section 2).

318. Clearly return to normality will depend on local circumstances, and need to be addressed on a case-by-case basis. Some further guidance on how such factors may be included in the decision making process is given in Appendix II.

DEVELOPMENT OF CRITERIA

319. It is possible to suggest, in a generic way, how situations in each of the bands in Fig. 2 might be treated. It should be remembered, however, that situation specific factors could sometimes lead to different conclusions (i.e. higher or lower criteria) from those implied by such generic guidance.

320. Each band in Fig. 2 is categorized in two aspects — the need (or not) for cleanup if this level of exposure would result from the *initial* level of contamination, and the post-cleanup measures that would be implied if the situation were to be used as the end point, indicating its possible suitability as a release level for 'return to normality'. The doses quoted are assumed to be chronic (i.e. persisting at a similar level over at least a significant fraction of a lifetime); where shorter term exposures are involved, it might be considered appropriate to use higher annual dose/risk criteria such that the lifetime risks are similar. The dose and risk levels refer to the dose/risk to an average member of the critical group, that is received additional to the level of doses from the regional natural background radiation. The risks relate to the probability of premature death resulting from exposure (as a result either of fatal cancer or, in the case of very high dose rates, deterministic effects).

321. In principle, the doses quoted should include any doses from indoor radon that are attributable to the contamination. However, it is recognized that radon concentrations in buildings depend on many site specific factors and are often only weakly correlated with the concentration of radium in materials close to the ground surface. Thus it may be extremely difficult to distinguish radon attributable to the contamination from background radon levels. It may therefore be more sensible, or even necessary, to exclude doses from indoor radon from comparisons with these criteria.

322. For contamination situations initially in Bands 1 and 2, it is very unlikely that cleanup measures involving any significant cost or disruption would be warranted by the risk reductions that might be obtained. Similarly, if the residual situation after a justified and optimized cleanup were in Band 1 or 2, the area could normally be released as a 'new background' without any need for further control. There would in principle be a need to optimize by considering possible cleanup options, but the risk reductions available are so small that they would be unlikely to warrant radiologically any but the most simple and inexpensive measures.

323. At the other extreme, situations in Band 6 would require cleanup or, in the absence of feasible cleanup options, access restrictions or access prevention to avoid very high exposures that could cause serious deterministic health effects. Clearly, therefore, a situation in Band 6 would not be acceptable as an 'end point' for cleanup.

324. Situations initially in Band 5 would also normally be expected to require some form of cleanup or severe restriction on use to avoid what would normally be regarded as unacceptable exposures (lifetime excess mortality risks on the order of one in 10). However, it is possible to envisage particularly severe situations in which the only options available (either cleanup methods or restrictions on the population) might be so costly and/or disruptive that they normally cannot be justified. In these extreme cases, the end point for cleanup could conceivably be in Band 5, but such a situation could not be considered 'normality'; the situation would need to be kept under regular review, and populations should not remain under such exposure conditions for many years.

325. For contamination situations in Bands 3 and 4, justification/optimization arguments of the type reflected in the type of calculations outlined in Appendix II are likely to be of greater relevance than for the extreme cases. Hence, the likelihood of cleanup being warranted will tend to increase as the level of risk increases, as will the possibility that more costly and/or disruptive countermeasures might be appropriate. Thus, situations initially in Band 4 are likely to require cleanup at least to Band 3, whereas situations at the lower part of Band 3 are unlikely to require cleanup in the absence of constraints on individual dose. Similar considerations would apply to the potential suitability of Band 3 or 4 situations as end points for cleanup, and hence as new background levels for a return to normality, e.g. situations in Band 4 would be much less likely to be considered 'normal' than those in Band 3.

326. Consideration of the radiological constraints and non-radiological factors discussed above suggests three main situations likely to be exceptions in the treatment of Band 3 and 4 situations, as follows:

(i) When allowance is made for the extra 'disruption cost' discussed above, it is unlikely that, even near the top of Band 4 (i.e. doses of several mSv/a), the risks would be sufficient to warrant the most expensive and/or disruptive measures, such as large scale soil removal or those necessitating relocation of large numbers of people;

(ii) Constraints based on equity arguments could lead to areas in Bands 3 and 4 being more likely to be cleaned up, and cleaned up more thoroughly (e.g. to Band 2), than unconstrained cost–benefit analyses might indicate; and

(iii) For small areas initially in Bands 3 and 4 (or even Band 2) it might be considered beneficial to clean up 'completely', i.e. to Band 1, irrespective of strict cost-effectiveness considerations.

327. Although release of cleaned up areas would essentially define a new 'background', decisions to release areas in Band 4, may need to be kept under review. Justification/optimization studies are generally valid only for the time at which they are carried out; subsequent changes in economic or social conditions, advances in technology or new information on radiation risks might all affect the decision, and it would therefore be wise to reconsider periodically whether further cleanup might be justified in the new circumstances.

Upper bound of annual dose for return to normality

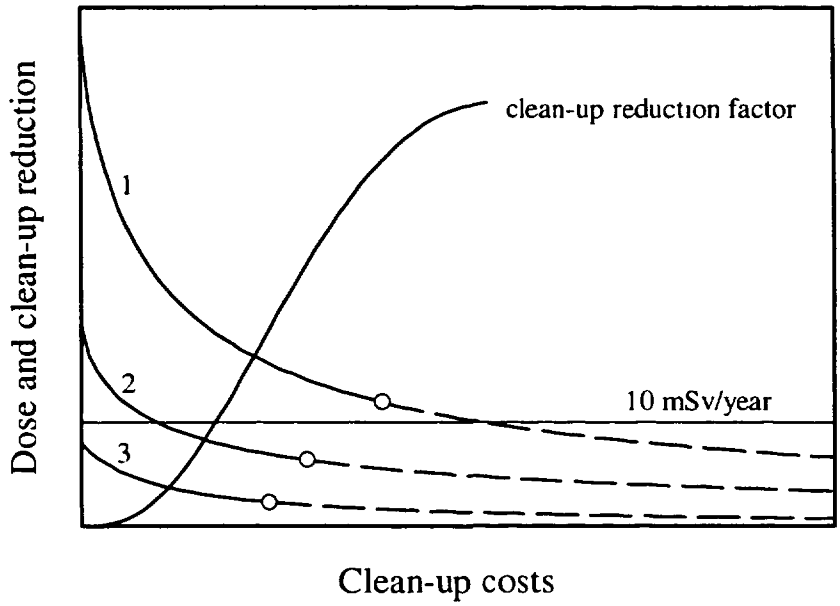
328. The boundaries between the bands in Fig. 2 are, to a large extent, arbitrary. In many cases existing criteria offer convenient points at which to set these boundaries, and in other cases (e.g. between Bands 1 and 2), the precise position of the boundary is not of great importance. However, the boundary between Bands 4 and 5 defines an important upper bound in two regards, namely that above this point:

(i) some form of cleanup action or prohibitation of use would almost certainly be required; and
(ii) the situation could never really be regarded as 'normal'.

There is no obvious existing criterion with which to link this boundary, and therefore it is necessary to form a judgement about an appropriate level.

329. The *average* annual individual effective doses from natural sources, including radon, are of the order of 2.4–10 mSv when areas with elevated exposures are included (Table 28, Annex A in [9]). The action level for radon in dwellings as recommended by the ICRP to be 3–10 mSv/a for simple remedial measures [10]. For more severe measures (i.e., permanent removal of people from their homes) the ICRP states that the action level should be at least one order of magnitude higher. The exemption levels for activity in foodstuffs moving in international trade recommended by the World Health Organization/Food and Agriculture Organization Codex Alimentarius Commission (CAC) [11] corresponds to an annual committed effective individual dose of around 10 mSv/a if the annual food basket contains activity at the levels recommended by the CAC. However, it is not realistic to anticipate that contamination of food would result in chronic exposure at such levels, because this level is the upper bound derived from an assumption that all food is contaminated to the maximum level. The intervention level for permanent resettlement due to exposure from deposited activity in the environment from a nuclear accident has been recommended by the IAEA [1] and the ICRP [12] to be 1 Sv in a lifetime corresponding to an annual average dose level of about 10–15 mSv. Further details are given in Appendix IV.

330. From the above discussion it appears that an effective dose of about 10 mSv/a (3% additional lifetime risk of fatal cancer) represents an upper bound on levels that might be used as a generic maximum residual annual dose dividing contamination situations into two 'classes'. Situations with annual individual doses above this level would never be considered as normal, whereas some situations with annual doses below this level could, depending on the situation, be considered as normal. In cases where the residual dose is characterized as 'normal' it would henceforth be considered 'background'.



In all three situations cleanup is justified and optimized based on dose reduction and costs of the cleanup The optimum endpoint is indicated by ○. Since the residual dose for situation 1 is greater than 10 mSv/a, the acceptance of such an endpoint is unlikely

FIG. 3. Cleanup of an area with three hypothetical situations of surface contamination.

331. Cleanup should almost always result in an annual residual dose less than the generic upper bound of 10 mSv/a. If measures leading to lower residual doses are justified, cleanup should be undertaken and the scale of the cleanup be determined by optimization (see Fig. 3).

332. It is conceivable that there may be rare situations, where cleanup is justified, but where the residual individual doses after cleanup are greater than 10 mSv/a. Such situations necessarily would be very severe, e.g. necessitating relocation of a large city or removal of all top soil (arable soil), thus stopping agricultural production. The rationale for exceeding the generic upper bound must be explicitly stated, thoroughly investigated and clearly defensible.

4. PROPOSED CLEANUP CRITERIA

401. The approaches for implementation of the cleanup criteria in Section 3 are summarized in the form of the cleanup levels shown in Table I. The cleanup levels relate to the annual individual doses, to an average member of the critical group, additional to the regional level of background. For Bands 5 and 6 (and possibly 4), however, the additional dose is usually large compared to this background, and so the criteria might reasonably be applied to the total dose including background if this is more convenient.

402. The cleanup levels would, in the first instance, be compared to the doses estimated on the basis of the initial level of contamination. This comparison will give an indication of whether cleanup is likely to be justified radiologically. The end point for cleanup would then, in principle, be determined by optimization, but the cleanup levels can also be used to give an indication of the likely acceptability of different end points as a new 'background' level

(i.e. for a return to normality). With the possible exception of situations initially in the upper end of Band 4 (where a justified and optimized cleanup might conceivably leave a situation towards the lower end of Band 4), any cleanup would normally need to produce an end point at least one band lower, and no higher than Band 4.

TABLE I. PROPOSED CLEANUP LEVELS

Band No.	**Range of annual doses** (to average member of critical group)	**Is cleanup needed ?**	
		With constraint	Without constraint
Band 6	> 100 mSv/a	always	always
Band 5	10–100 mSv/a	always	almost always
Band 4	1–10 mSv/a	almost always	usually
Band 3	0.1–1 mSv/a	usually	sometimes
Band 2	10–100 μSv/a	sometimes	rarely
Band 1	< 10 μSv/a	almost never	almost never

403. As stated in the discussion in Section 3, the annual doses dividing the bands can only be approximations in view of the uncertainties involved. Nevertheless it is convenient to have single numbers to represent criteria, and considerable presentational problems may be expected if slightly different numbers are quoted in different situations.

404. In this case, the most significant criterion that cannot readily be linked to existing criteria is probably that dividing Bands 4 and 5. This represents a point above which cleanup would normally be expected to be undertaken in unconstrained situations, and therefore also represents the maximum level of residual dose that (apart from exceptional circumstances) might be considered acceptable as a new 'background' level. Therefore, situations with annual individual doses above this level would never be considered as normal whereas situations with annual doses below this level could, depending on the situation, be considered as normal.

405. The choice of 10 mSv/a for this boundary is necessarily a judgement, but is felt to be robust in the face of a number of considerations, including:

(i) Worldwide variation in annual natural background dose;
(ii) Action levels recommended by ICRP and the Basic Safety Standards for radon in dwellings;
(iii) Doses implied by interdiction levels of activity in foodstuffs; and
(iv) IAEA recommendations on criteria for resettlement of populations.

These issues have been discussed in more detail in Section 3 and Appendix IV, but all are consistent with a generic criterion in the region of 10 mSv/a as a level above which some form of cleanup would normally be expected.

406. The generic criteria in Table I may not be appropriate in all situations. However, any perceived inconsistency in criteria may have negative effects in terms of public acceptance

that could well outweigh the economic or radiological benefits to be gained by using situation specific rather than generic criteria. Therefore, where local factors do support the use of situation specific criteria that differ significantly from the generic ones, these factors, and the effect they have been considered to have on the criteria (including any judgements or assumptions made), should be clearly stated. Such factors would include the distribution of individual doses and risks within the population.

Appendix I
EXAMPLES OF CONTAMINATION SITUATIONS

I.1. Many contamination situations are reported in the literature. Appendix I contains a number of such contamination situations which have been selected and grouped together, for illustrative purposes, under the categories of:

existing practices: situations where contamination has resulted from operations which continue to operate,

past practices: situations where contamination has resulted from discontinued operations, and

accidents: situations where contamination has resulted from inadvertent or unforeseen releases to the environment.

EXISTING PRACTICES

Cleanup of areas and decommissioning of installations in the nuclear industry

I.2. The decision to cleanup and the level of decontamination in the nuclear industry is dependent on the circumstances. In small scale applications it might be a reasonable decision to remove all the radioactivity to background levels. Examples of this have been presented at recent international conferences (Ref. [13], p. 693, Ref. [14]). One of these is the cleanup of a small shallow land burial site (40 m x 20 m) for low level radioactive waste which was in use at a research institute in the Netherlands. Because the waste site was very close to a densely populated area, the site was cleaned up by removing all the radioactive waste.

I.3. If the scale of the contamination is large, such decisions may not be practicable. For instance, there are many contaminated sites, ranging from uranium tailings piles to nuclear weapons facilities, that cover many square miles of land. The contamination may extend to all environmental media, as well as to on-site buildings and equipment. In these situations the decision to cleanup, and to what level, depends on a comprehensive analysis of all the impacts of the cleanup operation in order to arrive at an optimal solution [15].

Contamination resulting from the phosphate industry

I.4. Phosphate rock contains naturally occurring radionuclides. After extraction of the phosphate from this rock for use in fertilizers, the phosphogypsum tailings containing most of the radioactivity are either discharged to rivers, or are deposited on ground surfaces (Ref. [13], p. 645). Cost–benefit analyses on radiological protection considerations of the cleanup operation may be part of the decision making process but other considerations, such as conventional ecological (i.e. non-radiological) consequences of the phosphogypsum itself, may also enter the decision making process.

I.5. When phosphogypsum in tailings or in river sediments is used as landfill for housing, elevated radium concentrations may result. Houses built on these areas may as a consequence have higher radon concentrations (Ref. [13], p. 207). In this example, remedial actions which are outside the direct control of the operation might be required.

Contamination resulting from the oil and gas wells

I.6. Naturally occurring radioactive materials may be dissolved in water accompanying the hydrocarbons in oil and gas fields. Recovery of these hydrocarbons can result in contamination of piping and the local environment if the water is discharged without adequate treatment. Comprehensive analyses should be performed to arrive at an optimal solution for reuse, recycling or disposal of the contaminated piping as well as for cleanup of the areas contaminated by water discharges.

Contamination resulting from historic controlled discharges at current practices

I.7. There are examples of nuclear facilities currently operating where effluents discharged many years ago, at concentrations acceptable at the time, caused contamination sufficient to cause some concern in relation to current standards. Current discharges are lower and therefore such situations will require analysis to determine optimal cleanup solutions if required.

PAST PRACTICES

Contamination resulting from past uranium mining and milling operations

I.8. Mining and milling of uranium ore have generated waste rock and tailings with an increased content of natural radioactivity. Radiation exposures can be associated with the use of such materials for fill or construction purposes. The presence of populations, industry and agriculture close to or actually on such areas can result in protection problems. The optimization process for remedial actions can be more complex because of the combination of above average natural and man-made radioactivity.

Contamination resulting from former radium plants

I.9. Radium has been used as a luminizing agent and for medical purposes. There are several examples in the literature on radium contamination incidents on and off-site (Ref. [13], p.263, p.281, p. 672). Most of these situations are in urban areas and consequently, require special considerations in the optimization process for remediation.

Contamination resulting from past mining, milling and processing of metal ores

I.10. Mining and smelting of ores containing ferrous and non-ferrous metals goes back to the Middle Ages. Waste rock and slag piles can be found at numerous places. In many cases, like the Mansfeld region in Germany (Ref. [13], p. 295), the ores contain high uranium concentrations. The consequences of these activities are comparable to those of the uranium mining industry. Optimization decisions in such situations are complex and depend not only on the magnitude of the contamination but also on available resources and other considerations.

Contamination due to nuclear weapons testing

I.11. About 450 atmospheric explosions have occurred, corresponding to an explosive yield of 545 Mt TNT. In addition, some underground weapons tests have caused environmental contamination.

I.12. In the former Soviet Union (FSU) atmospheric test explosions have been carried out at Novaya Zemlya, the most important test site of the FSU (87 explosions corresponding to 235 Mt TNT) and at Semipalatinsk (124 explosions corresponding to 6.4 Mt TNT). The majority of the radioactive substances released by these explosions became global fallout, but some tests have produced high levels of local fallout. Investigations have been undertaken to characterize the environmental contamination. Details on these contaminated sites have been presented at the International Symposium on Remediation and Restoration of Radioactive-contaminated Sites in Europe [13].

I.13. Similar tests have been carried out in the US, mainly at the Nevada Test Site. This site occupies an area of 1350 square miles (3500 km^2). The tests have released large quantities of radioactive material to surface and sub-surface soil, both on and off-site. Besides weapon testing, the site has also been used for radioactive waste disposal [15, 16].

I.14. The inhabitants of Bikini Atoll in the Marshall Islands were relocated in 1946 prior to twenty-three nuclear tests. In 1954, a nuclear weapon test caused heavy fallout at Bikini Island. In 1969 a general cleanup of debris and buildings as well as the planting of trees began at Bikini Atoll. After a preliminary survey in 1970, Bikini families moved back to Bikini Island. In 1978, whole body counting revealed that ^{137}Cs body burdens in the people who had returned to Bikini were found to be well above the U.S. recommended level. Consequently, in August 1978 the people were relocated to Kili Island. Countermeasures are currently being designed to reduce the potential doses to people, which are mainly due to consumption of terrestrial foods (Ref. [17], p. 11), in order to allow their return to Bikini.

Contamination resulting from peaceful nuclear detonations

I.15. 115 nuclear detonations[5] designed to explore their use for civil purposes, such as artificial reservoirs and canals, took place in the former Soviet Union from 1971 to 1988. (Ref. [13], p.383). In some cases substantial environmental contamination has been observed which may require remediation.

ACCIDENTS

Contamination due to accidents in the nuclear industry

I.16. Several accidents have occurred with releases having off-site consequences. Three of these accidents resulted in the release of large quantities of radioactivity into the environment, namely the accident in the Mayak plant in 1957 (the Kyshtym accident), the Windscale accident also in 1957 and the Chernobyl accident in 1986. The areas around two of these sites, Kyshtym and Chernobyl, are presently still heavily contaminated and large areas are evacuated. Complete cleanup of these two sites, if undertaken, would require enormous resources.

I.17. The Chernobyl accident contaminated the Pripyat River and its flood plains with large amounts of ^{137}Cs and ^{90}Sr. Several countermeasures have been considered to reduce the

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[5] More recent data indicate that this number may be an underestimate.

effects of the contamination. As a result of an optimization process, the decision was made to build levees along river banks to prevent the release of radionuclides during flooding [18].

I.18. The Chernobyl accident has led to various remedial actions far from the source. Examples of these are the administration of Prussian Blue to sheep in Scotland and Norway, in order to decrease the uptake of ^{137}Cs [19], liming of lakes in Sweden [19] and the restricted use of contaminated peat ash in building materials in Finland (Ref. [13], p. 223).

Contamination due to accidents in the nuclear weapons industry

I.19. There have been several accidents in which nuclear weapons were involved. Four of these accidents are mentioned here, because of their different environmental impacts.

I.20. In 1960 an explosion and fire occurred in the Boeing Michigan Aeronautical Research Center (BOMARC) Missile Shelter 204 in the USA. A substantial amount of plutonium was released from the Shelter, contaminating approximately 218 acres (88 ha). The facility was de-activated in 1972, but is still under Government control [15].

I.21. A mid-air collision of two US Air Force planes in 1966 over the town of Palomares in south-eastern Spain was followed by an explosion. Two of the four thermonuclear weapons detonated their conventional explosives and contaminated approximately 226 hectares of uncultivated farm land and urban areas. Remedial actions were undertaken. The resulting waste was collected in drums and sent to the USA. After the intervention was completed a radiological surveillance program was established for the public in the area (Ref. [13], p. 727).

I.22. In 1989 a fire broke out on board the *Komsomolets* nuclear submarine. The submarine sank to a depth of 1685 meters southwest of Bear Island (300 nautical miles (560 km) from the Norwegian coast). The wreck still contains one nuclear reactor and two nuclear missile warheads, one of which was fractured. Reports by several Russian research institutes have stated that, by 1995 or 1996, the two nuclear warheads in the submarine would have been completely corroded by sea water. As a result, about 42 Ci (1.6 TBq) of ^{90}Sr, 55 Ci (2 TBq) of ^{137}Cs and 430 Ci (16 TBq) of plutonium would be released into the marine environment. The openings in the ship have been sealed to reduce the dispersion of radioactivity.

I.23. In 1968, a US B-52 bomber carrying four unarmed thermonuclear weapons crashed off the shore of Thule, Greenland (Ref. [13], p. 754). The conventional explosive components detonated and dispersed radioactive material, mainly ^{239}Pu and tritium, on the wreck, the surrounding ice crust and into the burning fuel. Part of the radioactive material was carried away in the plume. It was decided to cleanup the ice crust, and a total of 3.1 kg Pu-oxide and 1337 Ci (about 50 TBq) of tritium were recovered. After the summer-melt of the sea-ice, a survey showed that on the bottom of the bay a residual contamination of 0.5 kg Pu-oxide existed.

Contamination due to accidents with medical sources

I.24. In September 1987, a shielded strongly radioactive ^{137}Cs source (51 TBq) was removed from its protective housing in a teletherapy machine in an abandoned clinic in Goiânia, Brazil, and subsequently ruptured [20]. Consequently, many people incurred large doses of radiation, due to both external and internal exposure. Four of the casualties ultimately died and 28 people suffered radiation burns. The environment was severely contaminated in the accident. The cleanup actions were divided into two phases. The first phase included the actions needed to bring all potential sources of contamination under control. The second phase, which can be regarded as the remedial phase to restore normal living conditions, included the demolition of seven residences and other buildings, and the removal of topsoil from the contaminated areas.

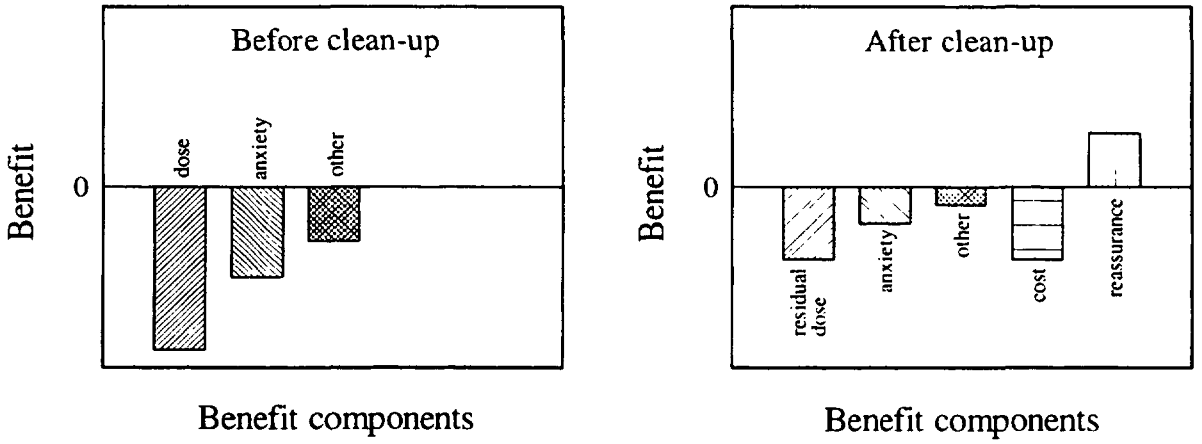
I.25. All the above examples demonstrate the wide variety of contamination situations and the challenge for the application of general radiation protection principles. Decisions on cleanup have to be taken on a case-by-case basis taking into account the specific features of the contamination and all other relevant local circumstances. For example, contamination in an area with almost no inhabitants will lead to different cleanup decisions than the same contamination in a densely populated area.

Appendix II
GENERAL METHODS FOR JUSTIFICATION AND OPTIMIZATION OF CLEANUP

II.1. According to the ICRP, radiological protection should aim to do more good than harm, should call for protection arrangements to maximize the net benefit, and should aim to limit the inequity that may arise from a conflict of interest between individuals and society as a whole. The purpose of Appendix II is to describe the general methods and approaches for justification and optimization of cleanup that are discussed in the main text.

JUSTIFICATION

II.2. Cleanup of contaminated land will introduce some benefit to the affected populations. The components of benefit will include, e.g. averted dose and decrease in anxiety. Without any cleanup the benefit components will all be negative as shown in the left picture of Fig. 4. After a cleanup has been implemented some of these negative benefits have been reduced or even removed but other negative benefits and positive benefits will be introduced as shown in the right picture of Fig. 4.



The left picture shows that the benefit components are all negative. The right picture shows that cleanup will reduce (or remove) some of the negative benefits, introduce new negative benefits (e.g. costs) and positive benefits (e.g. reassurance). The component 'other' includes negative benefit components such as social disruption.

FIG. 4. Components of benefit, B, *of cleanup operations.*

II.3. Cleanup is justified when the net benefit, ΔB, is positive:

$$\Delta B = \sum_i b_i \text{ (after clean-up) } - \sum_i b_i \text{ (before clean-up) } = \sum_i \Delta b_i > 0$$

The application of the justification principle to cleanup situations requires prior consideration of the benefit that would be achieved by the cleanup and also of the harm, in its broadest sense, that would result from it. It is emphasized that justification must consider non-radiological risks as well as radiological risks, e.g., chemical risks, and risks from industrial and transportation operations. Each of the benefit components, b_i, has to be expressed in the same units. These units must be in like quantities or values. For example, since costs are expressed in monetary terms, equivalent monetary values may be assigned to other parameters. Alternatively, other units of value must be used, for example, equivalent years of lost life.

II.4. Some 'decision aiding' techniques available for use in carrying out decision analysis have been described in detail in ICRP Publication No. 55 [8]. The primary objectives of these techniques are to identify the various factors influencing the decision, to quantify them if this is reasonable and desirable, and to systematically examine the tradeoffs between them, so that the process can be made open to the people responsible for the decision and to public scrutiny.

II.5. One decision aiding technique that is capable of accepting input data of both a quantitative and a qualitative nature, and which can be used in a wide variety of situations, is multiattribute utility analysis. Some of the factors to be used in such analyses are more or less quantifiable; these are the averted individual and collective risks from exposure to radiation for the members of the public, the individual and collective physical risks to the public caused by the cleanup, the individual and collective risks to the workers carrying out the cleanup, and the monetary cost of the cleanup. The less quantifiable factors, including the reassurance provided by the cleanup but also the anxiety it causes, and the individual and social disruption resulting, are also factors relevant to the decision.

II.6. In analyzing the inputs to the decision, it is necessary to decide on the relative importance or weight of each factor. These judgements have to be made irrespective of the decision aiding technique used. The resultant decision will be the same provided that the database is the same and the judgements are consistent. If multiattribute utility analysis is the technique used, then all the relevant factors can be directly included in the analysis by deriving or assigning utility functions to them [21], but weights still need to be assigned.

II.7. The net benefit, ΔB, of a cleanup operation will depend on several factors (attributes), e.g. avertable collective dose, ΔS, monetary costs of a cleanup operation, C, anxiety of the contamination, A, reassurance by the cleanup, R, etc. Thus the net benefit, ΔB, is a function of of all the relevant parameters:

$$\Delta B = \Delta B\ (\Delta S,\ C,\ A,\ R,\ ....)$$

II.8. The individual dose, E, is often taken as the dose to the average member of the critical group. It is a point value in a distribution, and it does not take the variance of the distribution into account. While the dose to the average member of the critical group may serve as a constraint, variation of doses in the entire distribution are accounted for by summing up all the individual doses to arrive at the collective dose, S. Depending on the cleanup option, collective dose may be reduced with or without changing the specified individual dose, E. Also, the critical group may change depending on the cleanup option. Thus, when establishing a constraint for a specific cleanup situation, it may be useful first to examine the effects of various levels of individual dose within a single option and among all options.

OPTIMIZATION

II.9. Normally, there would be a range of justified cleanup options for which the net benefit would be positive. The optimum cleanup option would be the one for which the net benefit is maximized, as shown in the left picture of Fig. 5. There might be justified options with a lower residual dose than at the optimum. This is due to the fact that some of the negative benefit components entering the optimization process would have a higher weighting than averted dose. This is illustrated in Fig. 5 where both options 7 and 8 are justified but give a smaller net benefit that the optimized option 6. The optimum cleanup option is the one among all the *justified* options which has the largest net benefit as shown in Fig. 5. Therefore, cleanup is optimized when:

$$\textbf{Maximum}\left[\sum \Delta b_i\right]$$

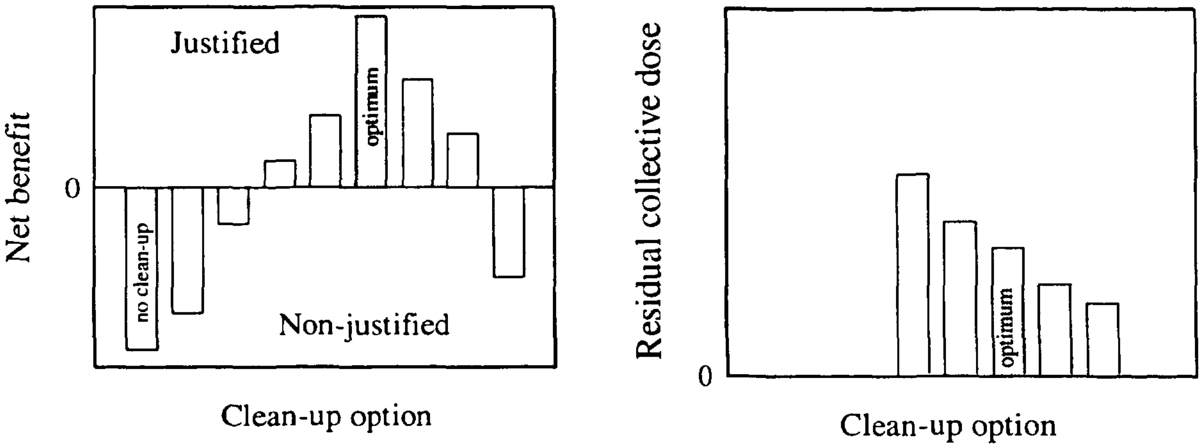
II.10. Most of the methods used in optimization of protection tend to emphasize the benefits and detriments to society and the whole exposed population. Optimization of cleanup, whether it is considered in the context of a practice or for intervention, is essentially an identical process: choosing the course of action which results in the maximum net benefit, considering all the relevant factors that influence the advantages and disadvantages of the cleanup operation.

II.11. For cleanup of contaminated land, society usually requires that the same level of protection be provided regardless of the source of exposure. Therefore, cleanup criteria that do not differ depending on whether the situation is deemed to fall within the category of practices or intervention are desirable, but may not always be possible. As described below, constraints imposed on the optimization process tend to limit inequities that can arise from different situations.

LIMITING INEQUITY

II.12. Neither justification nor optimization necessarily protect all members of a population from radiation equally. Therefore, another general process is required to limit some members from being exposed inequitably. As described above, optimization is simply the process of selecting among justified cleanup approaches for the maximum net benefit, i.e., a comparison of options. The avertable collective dose is only one component of the net benefit or justification equation. Furthermore, collective dose is not necessarily linearly related to the other terms of the equation. Also, the collective dose is calculated from the distribution of all the exposures for the entire population. Therefore, collective dose, alone, cannot be a general indicator of justification, nor does justification or collective dose, *per se*, provide information on the exposure of the critical group. The critical group is the group who, because of similar circumstances or behaviors, reasonably could be expected to receive the highest exposures [1, 2].

II.13. Limiting inequities is targeted at protecting the average member of the critical group. The critical group may or may not be different for various justified cleanup approaches. Thus, limiting inequities is accomplished by constraining the individual dose of the average member of the critical group for the option under consideration. A dose constraint can be applied to both practices and intervention situations.



The left picture shows that there is a range of options, both justified and non-justified. The right picture shows the residual collective dose, S, after cleanup. The optimum solution is not necessarily the one with the lowest residual collective dose, because there are additional considerations for determining net benefit.

FIG. 5. Net benefit of different cleanup options and the corresponding residual collective dose, S, *after the cleanup.*

II.14. Dose constraints for practices are numerically less than the dose limit. For justified cleanup of intervention situations, dose levels high enough to cause deterministic effects will normally be avoided through application of the justification principle. An upper bound for the outcome of an unconstrained optimization would probably be of the order of 10 mSv/a (see Appendix IV) indicating that a generic upper cleanup level would be of that order. This does not imply that below such a cleanup level it is never worthwhile to undertake cleanup. If it is justified it should be done and the scale of cleanup be determined by optimization.

II.15. The relationship of a dose constraint to avertable collective dose and, in turn, to justification is a complex one that is potentially different for various cleanup options and for different situations. If a dose constraint is set without examining its effects on justification of the options, the dose constraint could lead to doing more harm than good. In some circumstances, dose constraints may already be set by authories. In such cases, where cleanup could result in more harm than good, efforts should be taken to identify alternative solutions, including relaxing the constraint.

II.16. Potentially, a dose constraint that conserves justification of a cleanup option could have one of four effects when compared to another justified option, i.e., when optimized:

(i) decreased risk for the average member of the critical group and increased net benefit to the population;

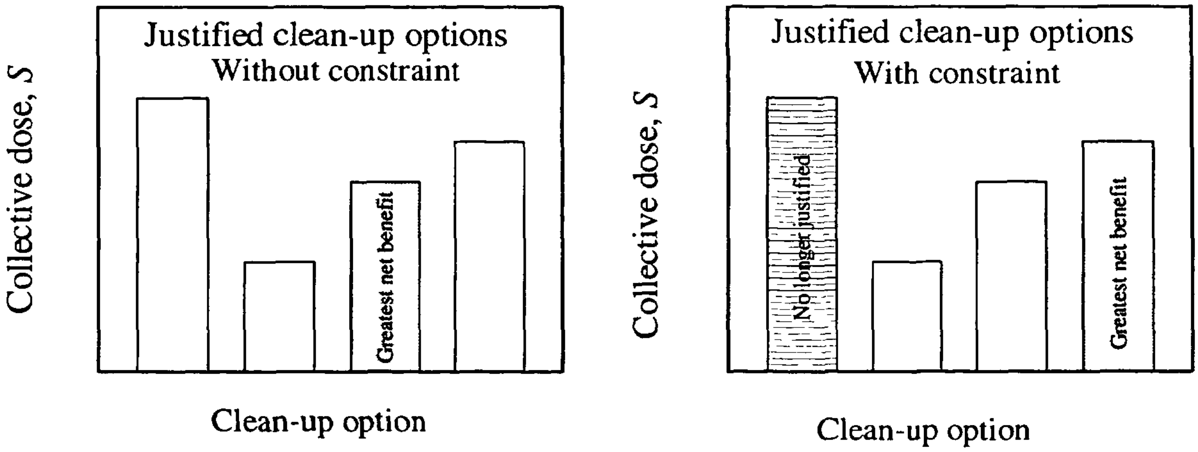
(ii) increased risk for the average member of the critical group and decreased net benefit to the population;

(iii) decreased risk for the average member of the critical group and decreased net benefit to the population;

(iv) increased risk for the average member of the critical group and increased net benefit to the population.

II.17. Clearly, the effect (i) above is always acceptable, and effect (ii) is always unacceptable. Effects (iii) and (iv) summarize the trade-offs that must be balanced with the other components of the net benefit evaluation. The selection of trade-offs is the job of authorities.

II.18. Constraints can be imposed to prevent options with a residual risk deemed to be unacceptable in advance. This would include all situations where serious deterministic health effects would occur, situations where dose levels would exceed criteria for resettlement of the affected population or practices where the additional residual risk to individual members of the public would be much above about 10^{-5} a^{-1}. The application of dose constraints in the process of optimization of protection is illustrated in Fig. 6.



The left picture illustrates an unconstrained optimization for which the optimum residual collective dose is the direct outcome. The right picture illustrates a constrained optimization process where the residual individual doses after cleanup all are less than the dose constraint. The residual collective dose in the constrained optimization turns out to be larger than for the unconstrained optimization.

FIG. 6. Optimization of protection without dose constraints and through the use of dose constraints.

ENVIRONMENTS

II.19. The term cleanup includes processes that will reduce doses to people. Cleanup will be different in nature depending on the environment being contaminated with radioactive materials. There are several environments to be considered for cleanup of which the most important are the following:

(i) urban environment
(ii) agricultural environment
(iii) forest environment
(iv) natural areas and resources.

Remediation operations in these environments would include decontamination, stabilization or isolation of contamination along with the transport and disposal of the wastes arising from the cleanup as well as agricultural countermeasures.

Appendix III
DERIVATION OF OPERATIONAL QUANTITIES

OPERATIONAL QUANTITIES

III.1. Operational quantities are the quantities actually measured to evaluate or to demonstrate compliance with a particular cleanup criterion. The cleanup criteria, as discussed in Section 3, would generally be expressed in individual dose in excess of background to the average member of the critical group. However, for many practices and for some interventions, these criteria may not be readily or directly measurable because of the presence of background radiation, because the levels are often too low to be measured directly by radiation detection instruments typically used in the field, and because of the difficulties in directly measuring dose to humans, especially as a result of internal exposure. Therefore, cleanup criteria must generally be converted into more readily measurable quantities, operational quantities, such as mass activity concentration (Bq/kg or Bq/l), dose rate (μSv/h) and surface contamination density (Bq/m^2) in the contaminated media. Both generic and specific operational quantities are calculated as follows:

$$\text{operational quantity} = \frac{\sum\limits_{\text{all pathways}} \text{annual dose before or after clean-up}}{\sum\limits_{\text{all pathways}} \text{annual dose per unit operational quantity}}$$

III.2. Operational quantities correspond to dose[6] levels and are derived by mathematical modelling of all the significant pathways of exposure and the projected relevant behavior of the average member of the critical group. To make such calculations requires a detailed understanding of the nature and extent of the contaminated area, environmental factors for the area like transfer factors to food and location factors, the reasonably possible pathways by which humans may be exposed to radiation from this area, and the scenarios that describe how the site will be used after cleanup.

MODELLING APPROACHES AND PATHWAYS

III.3. The calculation of projected doses requires the modelling of the various pathways involved in the transfer of radiation from an environmental contaminant to man. Details on these pathways can be found in other relevant IAEA publications [22, 23]. The models adopted may be of varying complexity depending upon the processes involved in this transfer. Some models may be only suitable and useful for screening, while others may be suitable for site specific application. In general, the models used should be as realistic as is appropriate for screening or realistic projections of dose. Incorporation of too much pessimism can result in operational quantities that are impractical or impossible to measure, or result in cleanup that is more costly than necessary. The models should readily be able to address all relevant exposure pathways. They should be able to readily use site specific data, and they should have been validated. Particular attention should be given to matching the assumptions of the model to the circumstances under consideration.

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[6] Unless otherwise stated, the term 'dose' refers to the sum of the effective dose from external exposure in a given period and the committed effective dose from radionuclides taken into the body in the same period

III.4. Some of the parameters, such as the extent of the contamination, may not become fully known until after cleanup is in progress. Therefore, new information may require an adjustment of the calculated operational quantities as part of the iterative nature of the decision making process. In those cases where the contamination comprises both radioactive and non-radioactive materials, planning for and confirmation of cleanup should take both kinds of contaminants into account.

GENERIC AND SITE SPECIFIC METHODS OF DERIVING CLEANUP LEVELS

III.5. Generic operational quantities may be used as a screening tool for a generic optimization or as a basis for planning cleanup. Generic operational quantities (e.g. Bq/kg) should be derived based on generic values of environmental conditions, and typical values of efficiency. The generic operational quantities correspond to the generic optimized cleanup level.

III.6. In a real situation, specific information on the nature of the contamination would be expected to be available. This would involve characteristics of the source as well as environmental and demographic data. In this case, a more accurate and specific optimization analysis may be carried out on the basis of actual data and the actual efficiency of the cleanup. This should result in specific operational quantities for the cleanup.

III.7. Allowance could be made to adjust or modify the generic operational quantities based on site-specific information or considerations. In some cases, site specific considerations may show the generic quantities to be too conservative, and in other cases, site specific considerations may preclude using the generically operational quantities. For example, if generic quantities were derived using models that calculate contaminant migration to groundwater based on pore water concentration and transport retardation based on distribution coefficients, a site specific situation with fractured topography may result in a very different contaminant transport to the groundwater.

UNCERTAINTIES IN CALCULATIONS

III.8. Uncertainties are inherent in dose calculations and the uncertainty bands should be quantified. In most cases uncertainties will increase with the time frame used in the modelling. Reduction of the uncertainties may be warranted, for example, by more detailed site investigations, more precise modelling, etc., in those cases where the outcome of the assessment and decision process is particularly sensitive to them. Uncertainties can also arise in projecting future use, human behavior, the total quantity and distribution of the contamination, and environmental factors.

III.9. When dealing with situations where the contamination is due to natural radionuclides, the same uncertainties arise when background levels are established. If an operational quantity is derived to be small compared to the existing background only the total response from background plus contaminant can be measured. Under such circumstances it could be very difficult to separate background and contaminant from each other. In such cases a certain percentile of the distribution of these background levels above the mean value may be chosen as a cleanup level.

III.10. Cleanup decisions regarding the release of a site or its restrictions almost always will be based on historical information, both oral and written, and on radiation measurements. The decision process can be considered as four iterative and interactive phases[7], namely:

(1) planning,
(2) implementation,
(3) assessment, and
(4) decision.

III.11. The planning phase includes defining the problem, using the available information to estimate the kind and scope of the problem, and determining the kind, quality and quantity of measurements needed to make a decision. Several types of surveys may be necessary and have different objectives, e.g. historical site assessment, scoping measurements survey, detailed site characterization surveys, surveys during cleanup operations, and surveys to confirm that the cleanup reached the final levels as planned.

III.12. Implementation of the measurements requires proper instrument selection, calibration, measurement techniques, and the recording of data. The sensitivity of instruments directly affect the number of measurements needed.

III.13. Assessment means certifying that the quality and quantity of the data are sufficient to make the decision. The appropriateness of the particular data for the is statistical tests must be affirmed. Management of elevated measurements in relatively small areas should be in the context of exposure to the average member of the critical group. It is important to verify that the data taken actually meet the design criteria for data, so that interpretations are valid.

III.14. Decisions with respect to the measurements depend on verification that the data were interpretable as planned, that records document the findings, and the basis for decisions is explicitly stated. As discussed above, the overall decision on the release and use of a site, either with or without restrictions, depends on the final radiological status of the site as well as other factors, such as socio-economic factors.

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Appendix IV
FACTORS FOR CONSIDERATION OF AN UPPER BOUND OF ANNUAL DOSE FOR REDEFINING NORMALITY

NATURAL BACKGROUND RADIATION

IV.1. The worldwide average annual dose from natural sources is estimated to be 2.4 mSv [9], of which about 1.1 mSv is due to terrestrial, cosmic, and internal sources of background radiation and 1.3 mSv is due to exposure to radon and its decay products. The cosmic ray dose rate depends on height above sea level and on latitude. Excluding doses from radon, annual doses in areas of high exposure (locations at higher elevations) are about 5 times the average. Annual doses to a few communities living near some types of mineral sand may be much higher than the average. Radiation doses from radon decay products depends on the local geology and housing construction and use, with the dose in some regions being much higher than the average. In unusual cases, local geology and the type and ventilation of some houses may combine to give dose rates from radon decay products of several hundred times the average. A representative range of the worldwide annual dose from natural sources would be 1–10 mSv/a with values in some regions an order of magnitude higher.

RADON IN DWELLINGS

IV.2. According to ICRP [10] some remedial measures against radon in dwellings are almost always justified above a continued annual effective dose level of 10 mSv. For simple remedial measures, a somewhat lower figure could be considered. Because of the uncertainty inherent in any measurement of indoor radon level, ICRP recommends some flexibility in cases marginally above or below the action level, which is given as a range of 3–10 mSv/a.

IV.3. The action level recommended by ICRP relates only to normal remedial measures. Severe measures, such as relocation, would according to ICRP not be appropriate unless irreducible concentrations were an order of magnitude or more higher than the action level.

NON-ACTION LEVELS FOR ACTIVITY IN FOODSTUFFS

IV.4. When a foodstuff leaves a country, it must meet certain standards in order that it may be exempted from any further monitoring or control by the receiving country and any subsequent receiving countries. Thus, the internationally agreed standards for minimum food quality established by the Codex Alimentarius Commission (CAC) [11] are essential in order that international trading in food is not severely disrupted by excessive monitoring, administrative and legal requirements.

IV.5. The generic action levels for control of foodstuffs contaminated as a result of a nuclear or radiological accident as recommended in the BSS [1] are identical to the values recommended by the Codex Alimentarius Commission [11]. These levels are recommended for use by national authorities as generic action levels in their emergency plans unless there are strong reasons for adopting very different values. In so doing, considerable advantages will accrue in terms of maintaining confidence and trust in the authorities by accepting internationally recognized values. Moreover, the use of such values will help to prevent anomalies that otherwise might occur between neighboring countries.

IV.6. The Codex Alimentarius Commission's levels in terms of activity concentration in foodstuffs are conceptually exemption levels for foodstuffs moving in international trade. This means that residual individual doses from consumption of foodstuffs containing such levels would be acceptable without any actions to be taken to reduce the levels. Depending on the annual 'food basket' [24] the consumption of food all of which is contaminated at the CAC levels would result in a individual annual dose in the range of 7–11 mSv. With the FAO figure for total food consumption of 550 kg per year (not including drinking water) the annual dose would be about 10 mSv. These dose figures are likely overestimates of any real case of chronic exposure, because they have been calculated with the assumption that the entire annual food basket is permanently contaminated to the full CAC values.

INTERVENTION LEVEL FOR PERMANENT RESETTLEMENT

IV.7. Temporary relocation and/or permanent resettlement elsewhere are two of the more extreme protective measures available to reduce exposures to the public in the event of a nuclear accident. Temporary relocation is used to mean the organized and deliberate removal of people from the area affected by an accident for an extended but limited period of time (typically several months but no longer than a few years) to avert exposures principally from radioactive material deposited on the ground surface and from inhalation of any resuspended radioactive material on ground. During the period of a relocation, people would typically be housed in temporary accommodation.

IV.8. Permanent resettlement is the term used for the deliberate complete removal of people from the area with no expectation of return. Permanent resettlement should — according to the BSS, IAEA, ICRP and EU — be considered if the lifetime dose over 70 years is irreducible and projected to exceed 1 Sv [1, 4, 12, 25], corresponding to an average annual dose of about 10–15 mSv. Situations where assessed individual doses are in the region of 10 mSv per year or greater would almost always call for cleanup if the source is reducible.

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GLOSSARY

The following definitions clarify those terms that have particular meanings in this report. Terms not defined here may be assumed to have the same definition as that given in the IAEA Basic Safety Standards, Safety Series No. 115.

background radiation. The natural radiation in the region in question plus that part of artificial environmental radiation which can be regarded as a normal part of the living environment in this region.

chronic exposure. Radiation exposure persisting in time. In this report it is assumed to persist at least for a significant fraction of a lifetime, i.e. decades.

cleanup. Any measures which may be carried out to reduce the radiation exposure from existing contamination through actions applied to the contamination itself (the source) or to the exposure pathways to humans. As used in this report 'cleanup' has essentially the same meaning as 'rehabilitation', 'reclamation', 'remediation', restoration", etc.

cleanup level. A general term for a criterion used to determine whether cleanup should be undertaken and/or whether the residual dose after cleanup (or a decision not to undertake cleanup) is likely to be acceptable.

dose. Unless otherwise stated, effective dose.

dose constraint. A prospective and source related restriction on the individual dose delivered by the source which serves as a bound in the optimization of protection and aims to limit inequity.

equity. The concept that individuals are treated fairly, but not necessary equally, as far as the detriment and/or benefit due to radiation exposure is concerned, i.e. the limitation of inequity.

inequity. The uneven distribution of risks and benefits between different members of society.

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

justification. A succinct term to express the principle that no practice resulting in human exposure to radiation should be authorized by the relevant competent authority unless its introduction produces a positive net benefit.

normality/normal conditions. A concept implying that people's life and/or work conditions are not subject to any restrictions associated with contamination of the area.

optimization. A procedure used to determine the most effective protection of the public by the cleanup of contaminated land, economic and social factors being taken into consideration.

past practice. A practice no longer operating.

practice. Any human activity that increases the radiation exposure or the likelihood of exposure of people or number of people exposed.

residual dose. The dose resulting from the contamination remaining after cleanup (or after a decision not to undertake cleanup).

residual risk. The risk associated with a residual dose, including the probability of exposure if it is not certain to occur.

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3–7 April 1995, 9–13 October 1995, 4–8 December 1995,
24–28 June 1996, 4–8 November 1996,
27–31 January 1997

Advisory Group Meeting

Vienna, Austria, 13–17 June 1994

Technical Committee Meeting

Vienna, Austria, 4–8 November 1996