Friday, 28 June 1996

INTERNATIONAL ATOMIC ENERGY AGENCY

Division of Radiation and Waste Safety

CRITERIA FOR CLEAN-UP OF CONTAMINATED AREAS

Produced at the Consultants Meeting

24 to 28 June 1996

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Vienna, Austria

Friday, 28 June 1996

Attachment

CONTENT

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 values including limits on releases from normally-operating facilities; levels for initiating protective actions to reduce doses; and levels to protect populations in the event of an accident. These principles and, in some cases, the resulting numerical values have been documented, for example in IAEA Safety Series 77 and 109.

102. There are other situations which may need to be considered, 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. In these cases it is necessary to evaluate the adequacy of current and future protection of public health and the environment. Based on the evaluation, some remedial actions may be necessary, such as removal, cover and/or mixing of radioactive materials in soil, treatment of ground and surface waters, and the decontamination of structures. In order to accomplish the evaluation or remedial actions, one may specify generic criteria or treat each situation on a site specific basis using risk assessment.

IN GENERAL, WE DISAGREE W/ THIS APPROACH

103. In the context of the present report the term "clean-up" has a wider meaning than in its normal usage. Clean-up is taken to mean the measures which are carried out to reduce the exposure from existing contamination; these can be related to the contamination itself (the source) and to the exposure pathways to humans. For example, clean-up includes stabilization of a source at a site. Measures applied to people, such as relocation of persons and access limitation are associated with clean-up but appropriate criteria are given elsewhere (eg. SS109). The sources considered for clean-up include contaminated land areas, structures, rivers, lakes and sea areas.

Examples of clean-up measures applied to the sources include:

- decontamination of confined areas, e.g. floors
- removal of the contaminated medium, e.g. exchange of the upper layer of soil, transport the material of a mining pile to another site, removal of sediments

Examples of clean-up measures to avoid or reduce particular exposure pathways include:

- covering the contaminated area with inactive material, e.g. in the case of mining piles to reduce radon emanation rates
- modifying the contaminated area, e.g. planting vegetation or use of synthetic covers to reduce resuspension of contaminated material.

Contamination situations considered in this report are summarized in the Box.

CONTAMINATION SITUATIONS

Clean-up 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 clean-up include amongst others:

(a) *nuclear energy production*
(b) *mining, milling and processing of uranium ores*
(c) *enrichment and fuel fabrication*
(d) *reprocessing*
(e) *radioactive waste disposal, either on land or in the marine environment*
(f) *nuclear weapons production*
(g) *nuclear weapons detonations*
(h) *use of radionuclides in medicine and research*
(i) *use of sealed and unsealed sources in industry*
(j) *ore processing and mineral extraction of materials containing natural radionuclides (radium, thorium, rare earths, phosphates, oil and gas production)*
(k) *accidents*

The type and extent of the contamination situation will depend on the scale of the operation, the source term, the nature of the radionuclides and the contaminated environmental media involved. This will lead to different contamination situations. They may be confined to the site of the operation or extended to the off-site area. In the latter case, the contamination situation may be caused for instance by inadequately controlled discharges, either by current operations, or by operations in the past, transportation accidents (including satellites and weapons) and major accidents with nuclear installations, causing large scale off-site contamination. Apart from the terrestrial contamination, such releases may also contaminate off-site groundwater, aquifers and river, lake and estuarine sediments.

Another differentiation in contamination situations can be made by distinguishing situations resulting from ongoing and previous operations. In the latter case, the contamination can even be detected long after the operation has been ceased. Specific examples of contamination situations are given in Annex A.

OBJECTIVES

104. The purpose of this document is to set out radiological principles for use in decisions related to the clean-up of contaminated areas. More specifically, it aims to establish an approach to developing radiological criteria for clean-up and to recommend generally applicable numeric values. It is also intended that the document should provide outline guidance on how the radiological criteria can be applied to the clean-up of contaminated areas. In developing this guidance the recommendations of the ICRP and of the IAEA BSS are taken into account.

105. While the reference values for clean-up criteria have been developed by taking account of the need to optimize radiation protection and, as appropriate, of international dose limits and constraints, the analysis has been necessarily generic and, therefore, the values may not be appropriate in all situations. Site specific analysis could lead to criteria, implemented in terms of concentrations of specific radionuclides, which are higher or lower than those given here.

106. The document focusses on the radiological part of decisions on clean-up. Other equally important parts of the decision making process, for example, political and social factors, are discussed but not analyzed in a detailed way.

SCOPE

107. This document is intended to apply to situations in which environmental media have been contaminated as a result of human actions. This includes such situations as accidental releases of radionuclides, previous discharge practices, uranium and other types of mining activities, and operations of nuclear sites and of industrial premises where radionuclides (or materials containing enhanced levels of naturally occurring radionuclides) have been employed. It is intended to apply to situations in which previously controlled areas are intended to be released for various uses. It is not concerned with levels of contamination within controlled areas. In relation to areas contaminated as a result of accidental releases, the guidance does not apply to the early phases of accidents where concern is with avoiding acute risks to health (the emergency phase) but rather to the later phases where the risks presented are of a chronic nature (the chronic phase or recovery phase).

STRUCTURE

Following this introduction, Section 2 reviews existing radiation protection principles and their implications for approaches and outcomes. Section 3 presents an alternative conceptual framework for approaches to clean-up decisions and compares the outcomes to those from the established approach. Appendix A provides examples of a variety of contamination situations. Appendix B illustrates the calculation of generically justified of clean-up levels (Action Levels). Appendix C covers the factors that affect the derivation of operational quantities from modelling.

2. APPLICATION OF THE RADIATION PROTECTION PRINCIPLES IN THE BASIC SAFETY STANDARDS

2.1 Introduction

201. Within the international framework for radiation protection, human activities that involve or could involve exposure to radiation can be dealt with either as practices or as intervention. (ref. ICRP-60, BSS). 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" (ref. BSS). In contrast, intervention assumes the introduction of exposures to radiation has already occurred or is presently occurring and is defined 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".

202. Situations involving contaminated areas may fall into either of these categories, and in some cases it may not be clear which is more appropriate. For example, the clean-up of a licensed nuclear site as part of decommissioning is clearly a part of that practice, and the clean-up of contaminated areas from a major nuclear accident would clearly be intervention. However, clean-up of contamination left behind from a previously discontinued practice may be controllable by the generator and would be a practice. But, if the generator is unknown, or unable to control the clean-up, the situation is not so clear.

203. In the BSS, the technical distinction between practices and intervention is fairly explicit, and can be summarized as follows (see also Figure 2.1). Any contaminated area would constitute a source. If this source, at the time when a decision on clean-up is being taken, is within an authorized practice, then any clean-up activities would be part of that authorized practice, and the radiological protection principles for practices would apply. If the source (ie the contaminated area) is not within an authorized practice, then any clean-up action will be classified as intervention, and the corresponding principles apply.

204. With these definitions, the situations described in Appendix A can readily be categorized: situations of type (a) would be part of the relevant practice, whereas those of types (b) and © (residues from past practices and accidents) would be intervention situations. However, for the latter cases, the status of the remaining contaminated area *after* any clean-up (given that clean-up will rarely remove all of the contamination) is an important consideration. This is discussed later in this section.

2.2 Principles for practices

205. These principles will apply to clean-up situations in which the contaminated area is within an authorized practice. This will include the clean-up of sites as part of the decommissioning of part or all of the practice.

206. The radiation protection principles for practices (ref. ICRP 60) 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 dose and risk 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.

DOES THIS SENTENCE HAVE ANY REAL SIGNIFICANCE? IF SO, NEED TO EXPAND DISCUSSION

Justification of the practice

207. In the context of clean-up, the relevant practice is that which gave rise to the contamination, eg the generation of electricity, the production of nuclear weapons, the use of radium for luminescing dials. The need for clean-up operations at the end of the practice should have been taken into account in the original justification of that practice. The justification requirement cannot be applied to clean-up in isolation from the practice.

IN REALITY, THIS IS OFTEN NOT THE CASE

Optimization of protection within a practice

208. Clean-up as part of the continuing operation of the practice, eg cleaning up contamination on-site resulting from past operation of the practice or an accident, would simply be part of the operation of the practice, and would be subject to the principle of optimization, as for any other routine activity. Wastes generated during such clean-up operations would be treated on the same basis as any other radioactive wastes. Any contamination remaining after clean-up would remain within the authorized practice.

209. However, if clean-up of a contaminated area is intended to lead to the area being transferred out of the authorized practice, eg clean-up during decommissioning, leading to release of the land for public use, then further considerations apply. Sources within an authorized practice can, under the provisions of the BSS, only leave that practice by clearance or by authorized release to the environment. Therefore, if the cleaned up area is to be released for public use, it must meet criteria for clearance or authorized release[1] (see Figure 2.2).

NO FIGURE 2.2 FOUND IN TEXT

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210. Criteria for *clearance* are based on the idea of trivial risk, and are derived on the basis of the criteria for exemption, eg if clearance would lead to individual doses of the order of 10 $\mu Sv\ y^{-1}$ or less, and collective dose commitment from one year of operation below 1 man Sv, then it may be granted automatically. Criteria for *authorized release* to the environment are derived on the basis of optimization, ie the additional exposures introduced as a result of the releases should be ALARA. In order to ensure that dose limits will not be exceeded, and to limit the inequity that might result from the judgements inherent in optimization, the optimization process is subject to constraints on the maximum exposure of individuals from a particular source. In clean-up situations, authorized release

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[1] Authorized releases to the environment are commonly thought of in the context of gaseous discharges to atmosphere or liquid releases to water bodies. However, removing access restrictions to a contaminated area has the same effect of putting radioactivity that had been controlled into the public domain, and therefore might similarly be regarded as a release to the environment.

THERE ARE OFTEN CASES OF LIQ + AIRBORNE DISCHARGES THAT RESULT IN CONTAM > CLEARANCE LEVELS + IT UNACCEPTABLE TO LEAVE THIS CONTAM IN PLACE

is more likely to be a generally useful concept than is clearance. However, once material is in the environment from an authorized release, it becomes exempt from further requirements of the BSS--in effect, it becomes part of "background."

Individual Dose and risk limits

211. Dose constraints are commonly derived on the basis of the maximum dose that would be tolerable on an ongoing basis from a single new practice. In the case of clean-up, however, the residual doses after clean-up are a subset of the doses associated with an existing practice. There may be situations in which compliance with a dose constraint could only be achieved at unreasonable cost (in terms of money, resources, or benefit foregone). In such situations, regulatory authorities may consider it appropriate to use the dose limit rather than the dose constraint as an upper bound on optimization (see also para 355).

Equity and Inequity

212. The concept of inequity was highlighted by ICRP, in Publication 60, where dose and risk constraints for practices were proposed as a way '...to limit the inequity likely to result from the inherent economic and social judgements in optimization'. In explanation of this concept of inequity, ICRP state that:

> '*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.*' (paragraph 121)
>
> '*Serious inequity can be avoided by the attention paid to the protection of individuals*' (paragraph 101).

213. Inequity, therefore, is a ~~slightly vague and~~ relative concept related to the fact that actions that are, overall, beneficial from society's point of view will often have 'gainers'- individuals who benefit more and 'losers' - individuals who bear greater costs or risks. An overall net benefit to society does not imply necessarily a net benefit for every individual. A measure of inequity could be, for example, the difference between the net benefit to the greatest 'losers' (which is likely to be negative) and the average net benefit (which must be positive for a justified set of actions). Conversely, equity implies an expected and reasonable distribution of the net positive benefits. An equitable distribution would minimize the fraction with negative net benefits and the increment of benefit between those with the least benefit and the most probable or average positive net benefit.

214. The definition of inequity implied in the optimization principle concerns only the uneven distribution of the risks and benefits associated with a particular source or practice. If inequity is more generally defined in terms of unequal distribution of risks and benefits in society, then there would seem to be other situations in which it could arise in the context of clean-up. In particular under the Basic Safety Standards:

(i) If clean-up situations can be classified either as practices or as intervention, then optimization may or may not be constrained. As a result, a constraint applied at one site to limit the inequity between different individuals associated with that site could lead to inequity between individuals at that site and individuals at another similar site where the constraint was not applied.

(ii) In many cases, the greatest benefits and the greatest risks from a particular set of actions are

both felt by the generation alive at the time. However, some actions will impose risks on future generations who are unlikely to receive a compensating benefit, whereas others might reduce the risks to future generations at the expense of cost or disruption to the current generation. Some clean-up situations might be expected to fall into the latter category. Equity arguments would suggest that future generations should be given at least as much consideration as the current generation. However, it is difficult to be precise about how such an idea might be implemented, as projections of risks to future generations are always subject to considerable uncertainty.

In cases inequities are unavoidable, ethical considerations indicate that compensation for the inequities should be provided.

215. When the exposure results from the decommissioning of an authorized practice, an operational level for clean-up is readily derived. The action level should correspond to a level no greater than, and preferably below, the value of the dose constraint under which the practice operated during the period it provided direct benefits to society. Clearly, it would be inappropriate to allow a practice to pose a greater risk after it has ceased operation than before it does so, since benefits would not continue to accrue.

2.3 Principles for intervention

216. These principles apply to clean-up situations where the contaminated area is, for whatever reason, not within an authorized practice. This includes a very wide range of situations, ranging from small areas contaminated by unregulated or poorly regulated practices which were subsequently discontinued (eg processing of radium and thorium compounds) to the contamination of very large areas as a result of practices such as uranium mining, and due to nuclear weapons testing, or major reactor accidents. (It could also include areas that are not contaminated by human activity, but where remedial action might be considered necessary, such as areas of high natural background radiation).

ARE NATIONS ACTUALLY DOING THIS?

217. The radiation protection principles for intervention (ref. ICRP 60) 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.

The dose limits which are set for the control of exposures from practices cannot be used as a basis for deciding on the reduction of doses by intervention since they might invoke measures with economic and social costs that could be out of proportion to the reduction of the radiation detriment obtained, which would conflict with the principle of justification.

DOES THIS MEAN DOSE LEVELS ABOVE THE SAFETY LIMITS COULD BE JUSTIFIED? I DON'T THINK WE WOULD AGREE WITH THIS

218. Justification and optimization of intervention are based upon maximizing the individual and collective doses averted or avertable by the intervention (ref. SS 109). This contrasts with justification and optimization for practices, which are based upon minimizing the additional exposures resulting from the practice. However, it is worth noting that the practical implementation of the optimization principle in the two cases may be very similar, as it will normally involve examining the

cost-effectiveness of possible measures for reducing exposures.

219. For intervention situations, there are fundamental differences between the protection of members of the public and the protection of workers engaged in interventions. Members of the public will receive the doses unless some action is taken to reduce them. Workers would only receive doses when they are involved in justified remedial actions with the aim of reducing public exposure (except during the initial course of the accident). For workers involved in the implementation of clean-up operations the system of radiological protection for practices would normally apply.

Intervention levels and action levels

220. Intervention levels are levels of avertable dose above which specific protective actions should normally be taken and below which, depending on justification, they may or may not. They are expressed in terms of the dose that is expected to be avoided (avertable dose) by a specific countermeasure over the period it is in effect. The intervention level is defined in the Basic Safety Standards (BSS) as:

> *The level of avertable dose at which a specific protective action or remedial action should be taken in an emergency exposure situation or a chronic exposure situation.*

If an intervention level is exceeded, *ie*, if the expected avertable individual dose is greater than the intervention level, then implementation of the specific protective action is indicated. Intervention levels are used for *specific protective actions*, normally for emergency exposure situations e.g., population relocation or food impoundment.

221. The action level has been defined in the (BSS) as the level of dose *rate* or activity *concentration* above which remedial actions or protective actions should be carried out in chronic or emergency exposure situations. Justified action levels begin at the minimum value of the avertable individual dose at which remedial action does more good than harm. Action levels are generally derived for specific exposure situations rather than generically determined for the particular form of protective or remedial action.

222. The BSS action level definition had its first practical use in relation to remedial actions for radon in dwellings. There is, however, no reason for limiting the definition of an action level to include only dose rate and activity concentration, and for purposes of clean-up the action level is used here in a more general sense:

> *An action level is the level of dose, dose rate, activity concentration or any other operational or measurable quantity above which remedial actions or protective actions should be carried out.*

223. The action level thus is the measurable quantity that corresponds to the lowest dose level at which remedial actions to reduce doses are justified. If an action level is exceeded, some form of remedial action specific to the situation considered is appropriate.

Treatment of post-intervention situations

224. An optimized intervention (or a decision that intervention is not justified) will normally result in at least some of the contaminated material remaining in place, and this will still constitute a source. From a strict interpretation of the BSS, any subsequent action that exposes people to that source who

would otherwise not be exposed , would apparently be a practice, if it were a controlled release[2]. Unless such post-intervention practices can be freed from the requirements of notification and authorization, they will be required to comply with these requirements each time the land with the source is used for a different purpose. However, if it is intended to allow unrestricted release for public use of the area, it would be uncontrolled, and thus, by definition, it would not be a practice. The term 'release' is used here to cover all general situations, and the term 'area' is meant to include soil, structures, and associated water pathways.

I DISAGREE WITH THE PREMISE THAT CONTAMINATION ABOVE THE UNRESTRICTED USE LIMITS FOR A "PRACTICE" WOULD BE ALLOWED FOR UNRESTRICTED USE FOR AN INTERVENTION

225. In concept, there are a number of possible ways in which contaminated areas might be released from further regulatory control after intervention. The BSS allow for practices and sources to be exempted or excluded from the requirements of notification and authorization, and also for the clearance or authorized release of material from a practice. However, in reality the most likely mechanism is authorized release.

An *authorized release includes both unrestricted release and restricted release. Unrestricted release is appropriate when the remediation results in dose levels predicted to adequately protect public health, safety, and the environment in consideration of all exposure pathways and a reasonable spectrum of uses. Restricted release limits one or more exposure pathways and* would, imply an ongoing requirement to monitor the situation. However, if restricted release is considered as an option, the costs of such monitoring (which could be substantial) should be taken into account and weighed against the benefits in terms of reducing the risk of higher doses resulting from undetected changes in the situation.

226. Irrespective of the precise mechanism by which the cleaned up area is 'released', it is clear that the *residual exposures* must be considered by the regulatory authority to be acceptable (or at least tolerable) in the circumstances. Furthermore, if control over the contaminated area is to be given up after clean-up, i.e., unrestricted release, then it should be envisaged that the exposures will continue to be acceptable in any reasonably foreseeable circumstances, because the residual exposure will become part of the new "background."

227. When a remedial action is considered in the context of intervention, it is the (residual) individual lifetime risk (or annual individual risk) *without any action taken* that is the basis for comparison of averted dose. A remedial action to reduce the dose (or risk) level should be justified *and* optimized. The goal of the remedial action should be clearly identified during the planning stage. If the assumption is simply to return the area to the activity that was present before the need for intervention was determined, then justification and optimization may lead to different results compared to a remediation goal that allows unrestricted use. In any case, the avertable doses resulting from the remedial action should be a net positive benefit compared to the costs and any other disadvantages by that action, *and* the type and scale should be determined in such a way that further clean-up beyond that scale is no longer worthwhile.

If the action levels for unrestricted use are reached, no further control is required. However, if only return to the previous activity is justified, then changes from that activity need to be considered as a practice on a case-by-case basis. In other situations, unrestricted release may not be feasible; in these cases, the authority may establish and maintain controls to limit doses by restricting exposures to

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The position is somewhat less clear if the previous use of the area continues throughout, or resumes after, the intervention. However, it would seem reasonable that similar considerations should apply to such cases, even if their application might be more flexible.

specific pathways, e.g., restrictions on farming or water use.

Intervention situations where special considerations may apply

There might be contamination situations where equity or other arguments could support the imposition of constraints on the residual doses following clean-up. In particular, the following situations could be envisaged:

(a) Contamination confined to a relatively small area that is currently not accessible to the public, but will be made accessible following the intervention (eg redevelopment of an old radium or thorium processing site from industrial use to housing). This situation is very similar to the decommissioning of an authorized practice (*eg* a licensed nuclear site). In these circumstances, equity arguments might suggest that the residual exposures in the former case should be constrained to the same level as would be applied to the latter. Hence the 'release levels' applied after the intervention would need to be consistent with levels for clearance or authorized release from practices. Indeed, general considerations (as opposed to the strict interpretation of the BSS) might lead one simply to regard clean-up in such situations as a continuation of the original practice.

THE CONSTRAINED UNRESTRICTED USE DOSE LIMITS SHOULD APPLY, IN FACT EFFLUENT RELEASE PATHWAYS SHOULD BE CONSIDERED IN ALL DECOM PLANS

(b) Contamination clearly attributable to past controlled releases to the environment from an authorized practice that is still in existence (eg if re-concentration of activity occurs in ways unforeseen at the time of the release). In this case, there may be strong arguments that the exposures from the contamination should comply with (for example) at least the dose limit for members of the public. (The BSS also permit regulatory authorities to impose new requirements for notification and authorization in these situations if they consider it to be necessary - the effect of this would be similar to constraining the intervention as already discussed).

UNRESTRICTED DOSE OBJECTIVES APPLY UNLESS SOME INSTITUTIONAL CONTROL PROGRAM IS APPLIED TO RESTRICTED USES

(c) Contamination with very long-lived radionuclides, where existing exposures are relatively low (eg dwellings constructed on areas contaminated with enhanced concentrations of naturally-occurring nuclides). In these situations, the current exposures might not themselves warrant disruptive and/or expensive clean-up operations but, in the absence of intervention, will continue for generations into the future. In these circumstances, particular consideration might need to be given to equity arguments. (Alternatively, similar conclusions might result logically from the relatively high avertable doses associated with exposure to very long-lived nuclides for very long time periods).

(d) Contamination of limited areas, remote from the practice using the sources, resulting from accidents (eg accidents during land transport of radioactive materials). In such cases there may be strong pressure to clean up to very low levels, because the exposed population have received little or no benefit from the practice for which the materials are being transported.

UNRESTRICTED USE LEVELS APPLY IN ALMOST ALL CASES

228. With reference to the categories of situation in Appendix A, and their status as practice or intervention situations, it may be that particular cases within categories (b) and © might form a further sub-group of [redacted] for which criteria similar to those for practices might be employed.

TABLE 2.1 Classification of contamination situations

Situation		Examples from Appendix A	BSS System of Protection
(a) Existing practices	(I) contamination still within practice	A2-A3	Practices
	(ii) contamination in public domain	A4-A6	Constrained intervention or practices
(b) Discontinued practices	(I) change of use giving new public access to limited area of contamination	A10-A12	Constrained intervention
	(ii) very long-lived nuclides	A7-A9, A13-A14	Intervention, may need constraining
	(iii) otherwise	A15-A19	Intervention
© Accidents	(I) accident affecting limited area remote from practice	A22-A24	Constrained intervention
	(ii) very long-lived nuclides		Intervention, may need constraining
	(iii) otherwise	A20-A21	Intervention

229. As discussed in Appendix A different contamination situations can be categorized as (a) existing practices, (b) past or discontinued practices and © accidents. Examples on such situations are given in Appendix A. Table 2.1 gives a summary of these situations with reference to the paragraphs where they can be found in Appendix A.

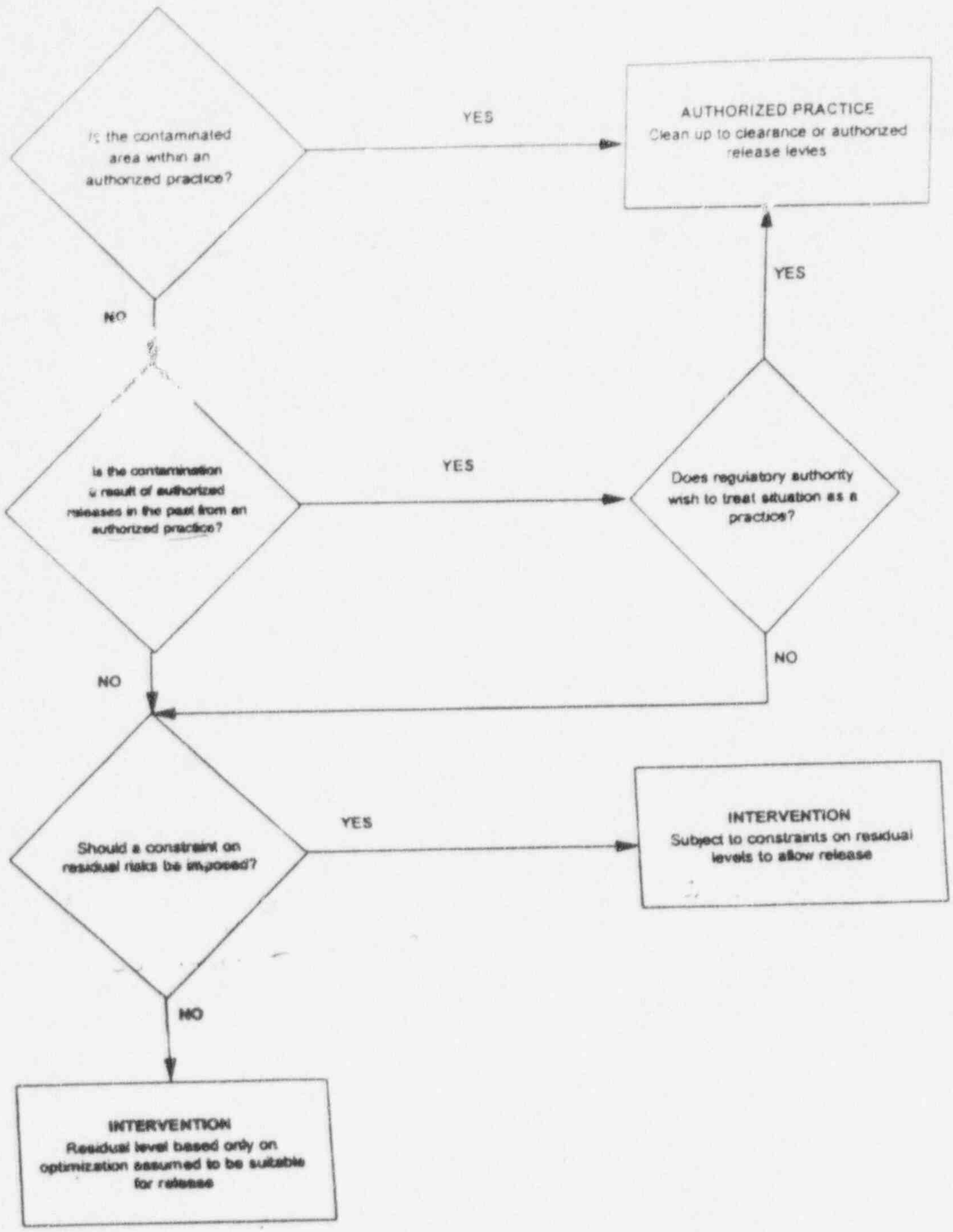

Figure 2.1 Interpretation of the BSS to contamination situations.

3. AN ALTERNATIVE CONCEPTUAL FRAMEWORK FOR CLEAN-UP SITUATIONS

3.1. The need for an alternative framework

301 It is apparent from the discussion in Section 2 that clean-up situations can be fitted within the framework of practices and intervention described in the BSS, although this is not always entirely straightforward. A slightly more general approach based on the broader conceptual definitions of practices and intervention provided by ICRP (rather than the stricter 'regulatory' definitions in the BSS) can also be used to simplify the advice. For example, the redevelopment for public use of a site where contamination from a discontinued practice is currently within a defined and relatively inaccessible area would arguably, following the BSS definitions, require intervention that is constrained on equity grounds to meet criteria similar to those for practices. The same outcome could be obtained simply by designating the redevelopment to be a practice.

302. However, both of these approaches still imply the existence of two fundamentally different categories of situation - practices and interventions - into which every situation is required to fit, even if it does not obviously fit in either. It may be useful, at least for presentational reasons, to investigate a broader system in which the whole range of situations can more readily be accommodated, without requiring every situation to be classified as *either* a practice *or* an intervention.

303 This possibility is hinted at in the 'basic framework' of radiological protection given in ICRP 60, but only the systems of protection for practices and intervention are then developed in detail.

3.2. A general system of radiological protection

304. According to 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). More specifically, 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)

305. The principles of protection for practices and for intervention therefore appear to be based on more fundamental, common principles for dealing with radiological hazards. Thus the principles for a general system are as follows:

(a) *Justification* - The overall sum of all actions affecting the risks from radiological hazards should do more good than harm. To ensure this, any concerted set of such actions should be expected to produce an overall net benefit;

(b) *Optimization* - All radiological risks should be as low as can reasonably be achieved;

(c) *Protection of the individual* - Aim to limit the inequity that may arise from a conflict of interest between individuals and society as a whole.

Table 3.1 provides a straightforward comparison between this general system and the systems for practices and intervention.

306. Such a general system does not invalidate the concepts of practices and intervention, but rather places them in a wider context in which they provide interpretations of the way in which the overall system applies to particular types of situation. Where situations fit well into one category or the other, this provides a valuable 'short-cut' in the form of a simpler ready-made system of protection. Where some situations do not fit well, it may be better not to persevere with the categorization.

IS THIS DISCUSSION OF CRITERIA ?

Justification

307. It is clearly not practicable for every single action to produce a net benefit or even be expected to - waste disposal, for example, would almost invariably fail in this regard - but groups of actions with a common aim should, overall, do so. A corollary of this is that an action that is a planned part of a justified set of actions can be *assumed* to be justified. For example, decommissioning of reactors is justified because it is a planned part of the operation of nuclear power generation.

308. Justification decisions in the context of clean-up will often be very complex, and could involve 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 radiological risks. The proper consideration of many of these factors may require expertise far beyond radiological protection. Nevertheless, consideration of justification in terms only of monetary costs of clean-up and monetary values of doses saved (as, for example, in the calculations in Appendix B) can provide useful information.

309. In particular circumstances discussed below, a constraint on residual risks might be considered to be appropriate for reasons of equity, and clean-up to at least meet the constraint would than be required. In such cases, it is possible that the clean-up might otherwise appear not to be justified. This needs to be considered carefully when decisions are made on whether to impose constraints - the perceived benefit from imposing a constraint may need to be sufficient to justify otherwise unjustified measures.

Optimization

310. The word *reasonably* is clearly the key to the optimization principle, and in a general system of protection needs to have a very broad definition (arguably even broader than in the optimization principle of the system for practices). 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 are simply not feasible. This example is the basis for exemption and exclusion concepts.

311. One particular issue that might be relevant in the 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 factor - 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.

THIS IS A FAR BETTER APPROACH THAN RELEASING CONTAMINATED AREAS FOR "UNRESTRICTED USE" AT DOSE OBJECTIVES" HIGHER THAN THE "CONSTRAINED LIMITS"

Protection of the individual

312. The key word in the individual protection principle is *inequity*, a concept that was discussed in Section 2. In fact, it is arguable whether a separate principle is needed - the concept of equity (or limiting *inequity*) might be regarded simply as a further extension of the definition of *reasonably* in the optimization principle. For example, *equity* requires that particular efforts be made in all circumstances to avoid individuals receiving doses high enough to cause serious deterministic health effects, but the same conclusion could be reached by saying that this is simply a *reasonable* thing to expect. However, for clarity, concepts related to protecting the interests of individuals, and hence to equity and inequity, are discussed together in this section. DC

313. Actions can comply with the justification and optimization principles whether they increase or decrease radiation risks. However, the protection of the individual principle would place particular emphasis on the responsibilities of people knowingly taking actions that are likely to *increase* radiological risks from sources under their control (eg by introducing new sources or modifying exposure to existing sources) in return for other benefits, such as economic profit or reduction in non-radiological risks. This emphasis is especially relevant in respect of additional risks that are imposed on individuals who are not necessarily receiving a corresponding benefit. In such cases, the additional imposed risks are controllable, and therefore it is reasonable to expect them to be controlled so that they do not substantially affect such individuals' overall risk. This argument leads to the concepts of constraining optimization to limit inequity, and of limits on the overall imposed risks to any individual.

314. As discussed in paragraphs 230, 232, considerations of equity lead one to expect that similar situations will be handled in a similar way, so that the imposed risks do not differ greatly between different situations which have most important features in common (again, this conclusion could equally well be reached from consideration of 'reasonable-ness'). Whereas inequity in the risk and benefit distribution associated with a particular source tends to arise from the optimization process and may need to be limited by constraints, the potential inequity between individuals at different, but similar, sites might be expected to be reduced by optimization, and it is the inconsistent use of constraints on optimization that might create it. For example, if unconstrained optimization were applied to determine clean-up levels for two similar sites, one would expect to get similar answers, but if one optimization were to be constrained the answers could be significantly different.

3.3. Application of the general system

315. The general system is illustrated schematically in Figure 3.1. If clean-up measures are justified on the basis of the radiological factors[3] then optimization (subject to any constraints on residual risk) should be used to determine an appropriate clean-up strategy. The residual risk after such a justified and optimized clean-up would then normally be expected to be acceptable for release, ie the situation after clean-up would become the new 'background'.

316. If clean-up is justified by a requirement to comply with an imposed constraint (bearing in mind the caveats noted in paragraph 309), the process of constrained optimization should be followed to determine an appropriate clean-up strategy as above.

Examples

317. It is not expected that the general system would provide different solutions to those proposed under the system described in Section 2. Nor does it remove the need for judgements to be made when considering a particular clean-up situation. It is rather intended to improve the presentation of the solutions by eliminating the need for what otherwise appear to be exceptions or special cases.

318. In particular, the cases listed in paragraph 230, 232 would simply be further examples of constrained optimization, where the values of any constraints would be determined by the regulatory authority on the basis of the principles described above:

(a) Redevelopment for public use of a limited area contaminated by a discontinued practice. The redevelopment would be an action taken in the knowledge that it would be likely to increase

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[3] Including cases where clean-up is assumed to be justified because it is the final part of a justified programme of actions (ie a justified practice).

the number of people exposed, and therefore the risks imposed on those individuals may need to be constrained. Equity arguments would suggest that the constraints imposed on other such deliberate actions, *ie*, operating practices, might be appropriate for this situation.

(b) Past discharges from an operating practice. The decision to release the material was taken in the knowledge that it was likely to increase exposure. If there is perceived to be a problem, this implies either that the predictions of future exposures were incorrect, or that something - conditions, human behavior or the level of imposed risk considered tolerable - has changed. There might, therefore (depending on the reason) be equity arguments for applying a constraint and thereby possibly requiring some clean-up. However, the net benefit or otherwise of imposing such a constraint might need to be considered.

(c) Very long-lived contamination. The equity arguments concerning distribution of benefits and risks from a particular source can be applied to intergenerational equity - hence it might be considered necessary to constrain risks to a level that would be acceptable for all future generations. However, as noted in Section 2, optimization might automatically imply low individual dose rates because the long timescales imply a great reduction in the total overall risk, if a large enough integration time is used.

(d) Accidents remote from the practice. Again the arguments would focus on inequity, but in this case the issue would be whether the population at the accident site receive significantly less benefit from the practice than do the people close to it.

[Need to review examples, and maybe add a few more from Appendix A to illustrate how the system could be used]

TABLE 3.1 Comparison of systems of protection

Principle	Practices	Intervention	General
Justification	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.	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.	The overall sum of all actions affecting the risks from radiological hazards should do more good than harm
Optimisation	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.	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	All radiological risks should be as low as can reasonably be achieved
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.	When faced with a need for intervention, every possible effort should be made to prevent anyone receiving doses above the thresholds for serious deterministic effects	Aim to limit the inequity that may arise from a conflict of interest between individuals and society as a whole

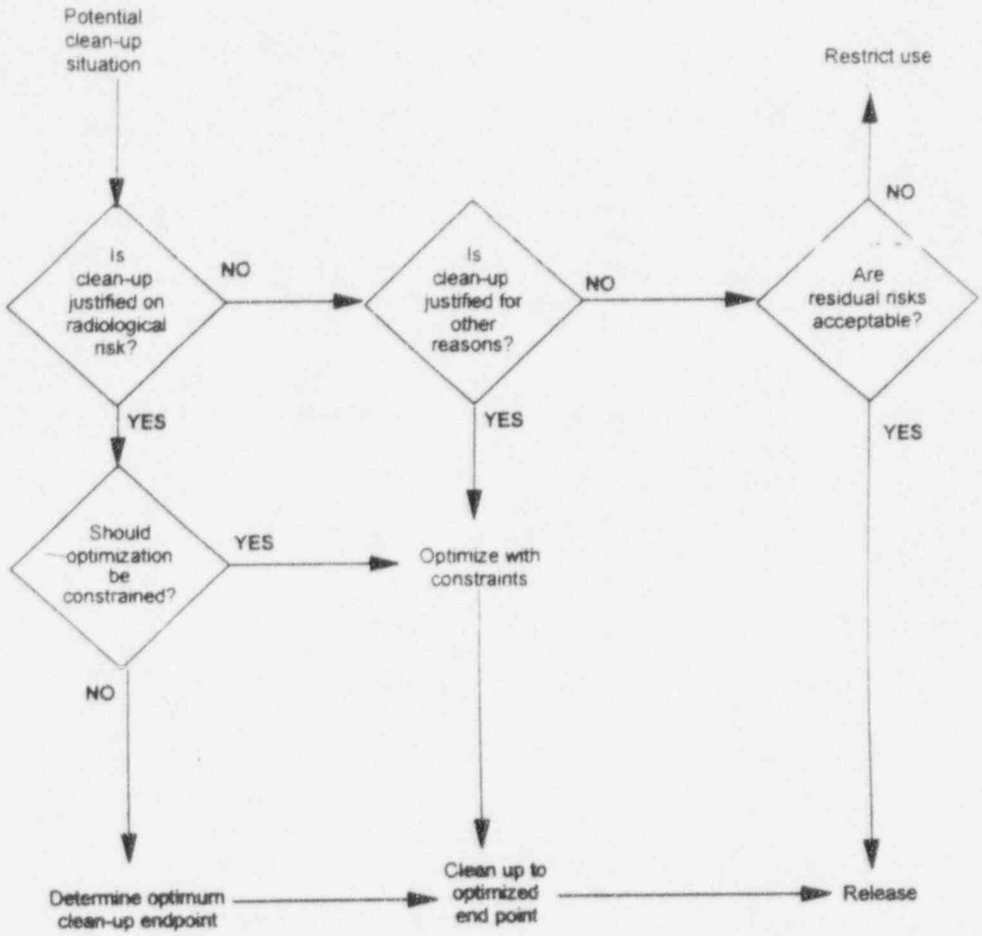

FIGURE 3.1 **Schematic diagram of clean-up decisions.**

NOTE: **Constraints could be imposed in order to protect the interests of individuals, ie to limit inequity. Examples are discussed in paragraph 318.**

[redacted]

4. CLEAN-UP CRITERIA

4.1. Characterization of contamination situations

401. Clean-up situations can be characterized initially on the basis of the risk to a critical group selected from people using the area (or, in the absence of such a group, the projected risk to a notional critical group) if unrestricted use of the area were allowed without any clean-up[4]. The principles discussed in Section 3 can then be applied to determine whether any clean-up is warranted, and to optimize any clean-up actions, subject to any constraints that may be considered appropriate. This process will then determine the 'end-point' for clean-up, which may be expressed in terms of the residual risk, ie the projected risk from unrestricted use of the cleaned-up area[5], taking account of reasonably plausible uses of the area.

402. Figure 4.1 shows the range of possible clean-up 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 (annual doses of order 10 μSv or less above background) to 6 (dose rates with the potential to cause serious deterministic effects in less than a year). Each band is categorized in two aspects - the need or otherwise for clean-up if this is the *initial* level of contamination, and the post-clean-up measures that would be implied if the situation were the end-point, indicating its possible suitability as a release level.

403. Band 1, equivalent to dose rates of the order of μSv y^{-1} 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. The BSS specifies criteria for exemption and clearance of the order of 10 μSv y^{-1} for individual doses (provided that the collective dose is as low as reasonably achievable).

404. Band 2 represents dose rates (typically tens of μSv y^{-1} 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 (ie a justified practice).

405. 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 (1 mSv y^{-1} above background). Also, many national authorities have adopted dose constraints, typically between 100 μSv and 800 μSv y^{-1} to apply to new and/or existing practices, and international recommendations have been made about rationales for choosing constraints [IAEA Safety Series 92, IAEA TECDOC 664]. However, these levels of risk are low enough that they would be considered acceptable in many other situations. For example, additional doses of this magnitude from activities such as air travel seem not to be of sufficient concern to affect people's behaviour.

406. Band 4 represents risks corresponding to doses of the order of mSv y^{-1} (up to a few times

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Related factors, such as the projected doses to 'average' individuals and the number of people potentially exposed, will also be relevant in clean-up decisions, but are less convenient as a basis for characterising situations.

If clean-up is justified neither radiologically nor because of the need to comply with an imposed constraint, then the area should be released or its use restricted, depending on the acceptability of the residual risks.

average background) that would not normally be considered acceptable if they were deliberately imposed on the public, but which are low enough that they would be acceptable in other situations, such as:

a. If the individuals are exposed voluntarily and receive a direct compensating benefit, eg radiation workers or people receiving medical x-rays, 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.

407. Band 5 (doses of tens of mSv y^{-1}) represents risks that would generally be regarded as unacceptable from any source (with the exception of necessary medical treatment). Although serious deterministic effects would only be a possibility if the lifetime dose were received within a short period of time, the stochastic risks associated with exposures in this band are too high to be tolerated under normal circumstances [ref ?].

408. Band 6 represents risks (whether in terms of serious deterministic effects or stochastic risk) that are clearly intolerable in all but the most exceptional circumstances (eg radiation therapy to treat cancer).[ref ?]

4.2. Considerations in setting criteria

409. In principle, consideration of situations in all bands would be based on the basic principles outlined in Section 3. 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 such as those in Appendix B, based on cost-benefit analysis methods, inevitably omit certain factors that are of potentially great relevance to clean-up decisions, but are difficult to quantify in monetary terms, such as the social and political aspects of clean-up decisions. Furthermore, considerations based on the protection of the individual principle 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 Figure 4.1. Examples of particular relevance are discussed below.

Radiological constraints

410. As discussed in Section 3, 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 risk levels) that are determined in advance to be unacceptable for individuals in particular categories of situation. The two cases in which constraints are already established are:

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

ii. Where additional risks are being imposed as a result of planned actions, additional residual risks from a source to individual members of the public much above about 10^{-5} y^{-1} are not considered to be acceptable. Constraints for practices are set on this basis.

As discussed in Section 3, 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 constraints

411. In extreme cases of very widespread contamination, non-radiological constraints may become important. For example if contamination affects a significant fraction of the area of a country, or if clean-up costs represent a significant fraction of GNP, or if particular clean-up options would generate unmanageable quantities of waste, the options available may be limited by such factors.

Non-radiological benefits

412. In any contamination situation, there is clearly a significant potential '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 small), this 'political' factor may dominate, driving the decision towards a complete clean-up, 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 'political' benefit ~~is~~ MAY BE too small to significantly affect the decision.

Non-monetary costs

413. Some clean-up 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 (eg 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 clean-up 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.

414. Another aspect in which the disruption associated with clean-up measures could be a significant factor is in the timing of clean-up. For example, clean-up 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, clean-up at the time of a change of use or ownership might be indicated 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. Clearly, however, such judgements may need to be tempered in certain situations by consideration of social factors.

4.3. Proposed criteria

415. Taking into account the calculations described in Appendix B and the discussion above, it is possible to suggest, in a generic way, how situations in each of the bands might be expected to be treated. It should be remembered, however, that situation-specific factors could sometimes lead to different conclusions (ie higher or lower criteria) from those implied by this generic guidance.

416. For contamination situations initially in Bands 1 and 2, it is very unlikely that clean-up 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 clean-up were in Band 1 or 2, the area could normally be released without the need for ongoing monitoring. In situations where constraints on the individual risk are applicable (usually such constraints would be expected to lie in Band 3), there would in principle be a need to optimize below the constraint by considering possible clean-up options. However, the risk reductions available in Bands 1 and 2 are

so small that they would be unlikely radiologically to warrant any but the most simple and inexpensive measures.

417. At the other extreme, situations in Band 6 would require clean-up or, in the absence of feasible clean-up options, access restrictions to prevent exposures that could cause serious deterministic health effects. Clearly, therefore, a situation in Band 6 would not be acceptable as an 'end-point' for clean-up.

418. Situations initially in Band 5 would also be expected to require some form of clean-up or restriction on use to avoid what would normally be regarded as unacceptable exposures. However, it is possible to envisage particularly severe situations in which the only options available (either clean-up methods or restrictions on the population) might be so costly and/or disruptive that they would be difficult to justify.

419. For contamination situations in Bands 3 and 4, justification/optimization arguments of the type reflected in the calculations in Appendix B are likely to be of greater relevance than for the extreme cases. Hence, the likelihood of clean-up 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.

420. The calculations described in Appendix B provide generic action levels for a variety of countermeasures for urban, semi-urban and agricultural areas, as shown in the table below. These levels range from about 100 μSv y^{-1} to several mSv y^{-1}, placing them within Bands 3-4, and indicating that situations in Band 4 are likely to require clean-up at least to Band 3, and that situations at the lower part of Band 3 are unlikely to require clean-up. Similar considerations would apply to the potential suitability of Band 3 or 4 situations as end-points for clean-up.

Type of area	Generically justified clean-up levels
Urban	0.1 - 2 mSv y^{-1}
Semi-urban	0.4 - 8 mSv y^{-1}
Agricultural	0.1 - 2 mSv y^{-1}

[The ranges for urban and semi-urban areas represent uncertainty, but the range for agricultural areas is minimum justified to maximum justifed. This may be misleading - can we get consistent types of result for all cases?]

421. However, consideration of the factors discussed in Section 4.2 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 in Section 4.2, it is unlikely that, even near the top of Band 4 (ie doses of several mSv y^{-1}), 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 significant 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 (eg 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', ie to Band 1, irrespective of strict cost-effectiveness considerations.**

422. Although release of cleaned up areas would essentially define a new 'background', decisions to release areas in Bands 3 and 4, particularly in Band 4, would 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 clean-up might be justified in the new circumstances.

4.4. Summary of recommended criteria

423. Figure 4.1 and the above discussion can be summarised in the following table. The doses quoted are additions to background. For Bands 5 and 6, however, the additional dose is large compared to average background, and so the criteria might reasonably be applied to the total dose if this is more convenient.

	Range of annual doses	Clean-up?
Band 1	< 10 μSv y^{-1}	Never
Band 2	10 - 100 μSv y^{-1}	Very rarely
Band 3	100 μSv y^{-1} - 1 mSv y^{-1}	Rarely unless constrained
Band 4	1 - 10 mSv y^{-1}	Usually for simple measures Rarely for disruptive measures
Band 5	10 - 100 mSv y^{-1}	Almost always
Band 6	> 100 mSv y^{-1}	Always

424. As will be apparent from the foregoing discussion, the dose rates 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.

425. 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 clean-up would normally be expected to be undertaken in unconstrained situations, and therefore also represents the maximum level of residual risk that (apart from exceptional circumstances) might be considered acceptable as a 'new background' level. The choice of 10 mSv y^{-1} 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 natural background dose rates;
ii. Action levels recommended by ICRP for radon in dwellings;
iii. Doses implied by acceptable levels of activity in foodstuffs; and
iv. IAEA recommendations on criteria for resettlement of populations.

These issues are discussed in more detail in Appendix D, but all are consistent with a generic criterion in the region of 10 mSv y^{-1} as a level above which some form of clean-up would normally be expected.

426. As noted above, generic criteria such as those in the table will 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.

Band	Risk index	Actions if this is initial level	Acceptability of this level for release as "new background"	Additional annual dose projected, mSv y^{-1}	Additional annual risk, y^{-1}
6	Intolerable	Clean-up or prevent use	Not suitable for release. Restrict use	~ 100	
					~ 10^{-3}
5	Unacceptable	Clean-up or restrict use			
				~ 10	
4		(Clean-up likely)	Release may be possible subject to regular review of situation		~ 10^{-4}
	Tolerable (if ALARA)	Clean-up decisions based on justification/optimization		~ 1	
3			Release possible - situation may need occasional review		~ 10^{-5}
		(Clean-up unlikely unless constrained)		~ 0.1	
2	Acceptable	Clean-up unlikely to be necessary on the basis of radiological risks	Release likely - review only if a problem becomes apparent		~ 10^{-6}
				~ 0.01	
1	Trivial	No clean-up necessary	Can be released without controls		~ 10^{-7}

Figure 4.1. Standard on environmental quality for clean-up of contaminated areas.

APPENDICES

A. EXAMPLES ON CONTAMINATION SITUATIONS

A1. Different contamination situations can be classified into three major categories depending on the origin of the contamination:

(a) existing practices

(b) past practices

(c) accidents

In the following paragraphs examples are given for situations in each of these major categories.

A. EXISTING PRACTICES

Decommissioning of contaminated areas and installations from the nuclear industry

A2. Decommissioning is to be considered as part of the normal operation. In fact it is the last part of an operation, before ceasing the activity and releasing the buildings and/or the area for other use. In the last decades, many nuclear facilities, both for civil and defence purposes, have been used and some of them have been decommissioned. The decision to clean-up and the level of decontamination is dependent on the circumstances. In small scale applications it might be a reasonable decision to remove all the radioactivity up to background levels. Examples of this have been presented at recent international conferences [ref. Antwerp Proceedings, page 693; IRPA Symp. Portsmouth].

A3. If the scale becomes larger such decisions are much more difficult. In the United States for instance, there are many contaminated sites, ranging in size from corners of laboratories to nuclear weapons facilities covering many square miles of land. The contamination extends to all environmental media, as well as to on-site buildings and equipment. In these situations the decision to clean-up, and to what level, depends amongst others on a comprehensive analysis of the impacts of the clean-up operation (radiological health impacts, volumes of soil to be remediated, etc.) in order to prioritize the contamination situations [ref. EPA-document].

Contamination resulting from the phosphate industry

A4. Phosphate rock contains naturally occurring radionuclides from the uranium decay series to typical levels of 1500 $Bq \cdot kg^{-1}$ U-238 [ref. UNSCEAR 1988; ref. EUR 13262 EN 1991]. Most of the daughter Ra-226 is concentrated in the phosphogypsum, the main waste product in the fertilizer production process. The phosphogypsum is either discharged as a slurry in rivers, or it is deposited in certain disposal areas as a solid. Such areas can contain millions of tons of phosphogypsum, with surfaces of hundreds of hectares [ref. Antwerp Proceedings, p.645]. Here also, a cost-benefit analysis on radiological considerations of the clean-up operation may be part of the decision making process but also other considerations, such as ecological consequences of the phosphogypsum itself, may enter the process.

A5. When phosphogypsum is discharged as a slurry in rivers, it will deposit in the river sediments. River sludges have been used as a landfill for housing areas and thus give rise to elevated radium concentrations in the ground [ref. Antwerp Proceedings p.207]. Houses built on these areas may have as a consequence higher radon concentrations. In this example, remedial actions which are outside the direct control of the operation might be considered.

Add example on past controlled discharges

A6. Text to be added

B. PAST PRACTICES

Contamination resulting from past uranium mining and milling operations

A7. Mining and milling of uranium ore have generated waste rock and tailings with an increased content of natural radioactivity. After World War II intensive uranium mining has been started throughout the world, occupying much land and changing the landscape. In some countries, such as Germany [ref. Antwerp Proceedings, p.119; ref. SSK report], these tailings have strongly influenced the infrastructure and the environment, as they were carried out in densely populated regions, which had already a long tradition in ore mining. In the last decades many of these sites and facilities have been abandoned by the uranium industry and passed over to other enterprises and communities.

A8. Problems of radiation exposure can be associated with the relics of uranium as well as traditional mining in particular if they have been used as building sites or building material. Dumped material had also been used for land filling, road construction and other purposes. The density of population and the intensive industrial and agricultural utilization of the mining areas create special features with regard to radiological protection. In addition, the situation is much more complex and requires differentiated considerations since both above-average natural and man-made radioactivity contribute to the level of radiation exposure in the areas concerned.

A9. The obvious consequences of the traditional mining and of the uranium industry, public concern and the need for decisions on restoration and remediation of radioactive-contaminated sites require systematic investigation and objective evaluation of the existing radiological situation in the mining areas.

Contaminations resulting from former radium plants

A10. Radium has been used extensively as a luminizing agent and for medical purposes. There are several examples in the literature giving information on radium contaminations due to spills in radium plants. [ref. Antwerp Proceedings, p.263, p.281; p.672]. These contaminations can be inside the workshops where the work took place or outside, for instance on-site burial sites.

A11. These contaminations are generally of a much smaller scale than in the former example. Clean-up decisions will be made on an inventarisation of the level of contamination of the sites, taking into account that most of them are in urban areas.

A12. Situations as mentioned under a) are mainly related to activities that have been carried out in the past. They invariably deal with enhanced levels of natural radioactivity. An example is given below.

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

A13. 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 regions which are known for their mining activities. In many cases, like the Mansfeld-region in Germany [ref. Antwerp Proceedings, p.295], the ores were accompanied by uranium. The consequences of the activities are more or less comparable to those of the uranium mining industry.

A14. It is obvious that accidental releases can give rise to contamination situations that need to be cleaned up. Decisions on such operations depend very much on the magnitude of the contamination

and the available resources and on a great number of other considerations.

Conta[illegible]inations due to nuclear weapons testing

A15. The first nuclear weapons test explosion in the atmosphere took place in the USA and int[illegible]nsive testing occurred subsequently in the years 1952-1954, 1957-1958 and 1961-1962. Since in 1963 in Moscow the Treaty on Restricting Nuclear Weapons Tests was signed most subsequent explosions were carried out underground. The last atmospheric explosion took place in October 1980 and in total about 450 atmospheric explosions have occurred corresponding to an explosive yield of 545 Mt TNT equivalent.

A16. 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 major part of the radioactive substances released by these explosions became global fallout, but some tests have produced higher 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 [ref. Antwerp Proceedings].

A17. Similar test have been carried out in the US, mainly at the Nevada Test Site. This site occupies an area of 1350 square miles. 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 [ref. EPA doc].

A18. Another test site in use by the US was Bikini Atoll, one of the Marshall Islands. Twenty-three nuclear tests were concluded there from 1946 to 1958. In 1954, a nuclear weapon test, code named BRAVO, had an explosive yield that greatly exceeded expectations, with the result that heavy fallout was experienced at Bikini Island and atolls east of Bikini Atoll. The Bikini people, since their initial relocation to Rongerik Island in 1946, have had a continuing desire to return to their homeland. In 1969 a general cleanup of debris and buildings as well as the planting of coconut, breadfruit, *Pandanus*, papaya, and banana trees began at Bikini Atoll. After a preliminary survey in 1970 Bikini families moved back to Bikini Island. A radiological survey was conducted in 1975, but few samples of locally grown food crops were available to confidently establish the radionuclide concentrations on Bikini Island to reliably estimate the dose; predictions based on the preliminary data indicated that when food crops matured, the body burden of ^{137}Cs and resulting doses would exceed federal guidelines. In 1978, when the coconuts started producing fruits, whole body counting revealed that ^{137}Cs body burdens in the people on Bikini were well above the U.S. recommended level. Consequently, in August 1978 Trust Territory officials arrived at Bikini Island and relocated the people to Kili Island. Countermeasures are designed to reduce the dose to people, which is mainly due to consumption of terrestrial foods, that are resettling Bikini Island [ref. IAEA-TECDOC-755, p.11].

Contaminations resulting from peaceful nuclear detonations

A.19 In the former Soviet Union from 1971 to 1988, 115 nuclear detonations have taken place in order to explore the possibilities of such explosions for civil purposes. The aim of these detonations was to use the nuclear explosive technology for artificial water reservoirs and french excavation for canal construction [ref. Antwerp Proceedings p.383]. Such explosions have also been conducted for research on the deep underground structure of the earth's crust [ref. Antwerp Proceedings, p.473]. Apparently, in some cases substantial environmental contamination has been observed.

C. ACCIDENTS

Contaminations due to accidents in the nuclear industry

A20. Since the beginning of the nuclear age, several accidents have occurred with releases having off-site consequences. Three of these accidents resulted in the release of large quantities of radioactive substances 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, Kystym and Chernobyl, are presently still heavily contaminated and large areas are evacuated. Restoration of these sites, if undertaken, will take many years and ask enormous financial efforts.

A21. The Chernobyl accident has led to various remedial actions far away from the release point. Examples of these are for instance the administration of Prussian Blue to sheep in Scotland and Norway, in order to decrease the uptake of ^{137}Cs in the animals [Technical Rep. Series 363], lining of lakes in Sweden [Technical Rep. Series 363] and the restricted use of contaminated peat ash in building materials in Finland [ref. Antwerp Proceedings, p.223].

Contaminations due to accidents in the nuclear weapons industry

A22. There have been several accidents in which nuclear weapons were involved. Four of these accidents are mentioned here, because of their different environmental impacts.

(a) In 1960 an explosion and fire occurred in the Boeing Michigan Aeronautical Research Center (BOMARC) Missile Shelter 204 in the US. The BOMARC site has a surface of approximately 218 acres. A substantial amount of plutonium was released from the Shelter during the accident. The facility has been deactivated in 1972, but is still under Defence jurisdiction [ref. EPA doc.]

(b) An accident involving two US Air Force planes engaged in a refueling operation occurred in 1966 over the town of Palomares in Southeastern Spain, close to the Mediterranean coast. The mid-air collision was followed by an explosion and pieces of the aircraft fell onto Palomares and neighboring Villaricos. The four thermonuclear weapons transported by one of the planes fell with the aircraft wreckage. Three of the bombs, one intact, were found on land, in or near Palomares, within 24 hours of the accident. Following an extensive search, the fourth was removed intact from the Mediterranean Sea. The parachutes of two of the bombs did not deploy resulting in the detonation of their conventional explosives and release of fissile material upon impact. Partial burning of the fissile material formed an aerosol that contaminated approximately 226 hectares of uncultivated, farmed and urban land. In order to return the area to a normal situation intervention was decided and some remedial actions undertaken depending on the contamination levels. The resulting wastes were collected in drums and sent to the USA. After the intervention was completed a radiological surveillance program was established to control the achievement of the radiation protection objectives for the public in the area. The program has shown that the situation is acceptable from the radiological point of view [ref. Antwerp Proceedings, p.727].

(c) In 1989 a fire broke out in the stern section of the "Komsomolets" nuclear submarine. The vessel surfaced, but after seven hours, in spite of the efforts of the crew, sank with the loss of 42 of the 70 crew members. The submarine sank to a depth of 1685m near the southwest of Bear Island. The site is about 300 nautical miles from the Norwegian coast. The wreck still contains one nuclear reactor and two nuclear warhead missiles, one of which was fractured. Reports of several Russian research institutes have stated that, by 1995 or 1996, the two nuclear warheads on the submarine could be completely corroded by sea water. As

a result, about 42 kCi of ^{90}Sr, 55 kCi of ^{137}Cs and 430 Ci of plutonium could be released from the damaged "Komsomolets" wreck into the marine environment. Attempts are undertaken to seal the openings in the ship, in order to reduce the possibilities of dispersion of radioactivity in the marine environment.

(d) In 1968, a US B-52 bomber carrying four unarmed thermonuclear weapons crashed in the Polar region, off the shore of Thule, Greenland [ref. Antwerp Proceedings, p.754]. The high explosive components of the weapons detonated and dispersed the radioactive material, mainly Pu-239 and tritium, on the wreck, the surrounding ice crust and into the splashing, burning fuel. Part of the radioactive material was carried away in the plume. It was decided to clean-up the ice crust, and a total of 3.1 kg. Pu-oxide and 1337 Ci 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.

Contaminations due to accidents with medical sources

A23. In September 1987, a shielded strongly radioactive caesium-137 source (50.9 TBq, or 1375 Ci, at the time) was removed from its protective housing in a teletherapy machine in an abandoned clinic in Goiânia, Brazil, and subsequently ruptured. 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 actions taken to clean up the contamination can be divided into two phases. The first phase corresponds to the urgent actions needed to bring all potential sources of contamination under control, and was in the main completed by October, but elements of this phase persisted until Christmas 1987, when all the main contamination sites had been dealt with. The second phase, which can be regarded as the remedial phase aiming to restore normal living conditions, lasted until March 1988. The decontamination necessitated the demolition of seven residences and various other buildings, and the removal of the topsoil from large areas. In total about 3500 m^3 of waste were generated.

A.24 The above examples show that there exists a wide variety of contamination situations. It will be clear that decisions on clean-up have to be taken on a case-by-case basis and that each case consideration should be given to the specific features of the contamination and the circumstances that influence the decision. For instance, a contamination in an area with almost no inhabitants may lead to another clean-up decision than the same contamination in a densely populated area. On the other hand, a local contamination on the ice cover in the Arctic may be removed just on the basis of good housekeeping.

B. GENERICALLY JUSTIFIED CLEAN-UP LEVELS

B1. URBAN AND SEMI-URBAN AREAS

B1. This Section provides a simple example of how a generic dose level for justified clean-up of contaminated areas might be determined.

B2. The optimum intervention criteria for clean-up operations would depend on many factors. The most important factors are the avertable individual doses to the population, ΔE_{ind}, the efficiency of the decontamination (fraction of activity remaining), η, and the monetary costs of the cleaning operation, c_{clean}. The clean-up costs, c_{clean}, can be expressed as:

$$c_{clean} = c_{waste}\, w + c_{lab}\, \varepsilon + c_{equip}\, \delta \qquad (1)$$

where c_{waste} is the cost per unit mass of produced waste, w is the waste produced per unit area, c_{lab} is the labour cost per unit time, ε is the working time spent per unit area, c_{equip} is the equipment cost per unit time, and δ is the time of equipment use per unit area. The parameters w, ε, and δ, would all depend on the clean-up efficiency, η.

B3. The clean-up costs would depend on the type of area contaminated as the clean-up procedures would be different for the different areas. Clean-up of *urban areas* would include street sweeping, firehosing, asphalt planing, removal of vegetation and removal of soil. Clean-up of *agricultural areas* would include removal of soil and removal of vegetation. Clean-up of *forest areas* would include removal of trees, removal of undervegetation and removal of soil.

B4. The clean-up costs would involve the disposal of waste which could be the dominating cost in the clean-up of large areas. Removal of the upper 1 centimeter of soil in an area of 1 km^2 would create 10,000 m^3 of soil waste with a cost of disposal of the order of \$ 10^6 per km^2. For an urban area with the same characteristics as the city of Copenhagen the costs of clean-up, c_{clean}, have been estimated to the values shown in Table B1, based on the Nordic research program on waste and decommissioning (KAN-Programme)[6].

Table B1. Costs for different clean-up methods in an area of 250 km^2 of a city with the characteristics of Copenhagen.

Clean-up method	Clean-up costs ($\$\cdot km^{-2}$)		
	Clean-up	Transport a)	Wages c)
Soil removal	400,000-800,000 b)	-	100,000-200,000
Grass cutting	5,000-10,000	2,000-5,000	5,000-10,000
Firehosing	5,000-15,000	1,000-4,000	5,000-10,000
Asphalt planing	600,000-1,000,000	40,000-80,000	70,000-150,000

a) Transport of waste
b) Includes transport of waste
c) Based on Western countries with a salary of \$ 15 per hour

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Cleanup of Large Radioactive Contaminated Areas and Disposal of Generated Waste, Final Report of the KAN2 Project, TemaNord 1994:567, February 1994.

B5. Taking into consideration only the avertable dose to the population, the doses to the workers engaged in the clean-up and the monetary costs of the cleaning operation the following factors would enter the optimization process for determining the intervention level for the clean-up:

- the number of people living in the contaminated area, N_{pop}
- the size of the contaminated area, A
- the monetary cost of the clean-up per unit area, c_{clean}
- the number of workers carrying out the clean-up, N_{work}
- the collective dose to the clean-up personel, $S_{work} = E_{work} N_{work}$
- the efficiency o the clean-up operation (fraction of activity removed), η
- the reduction factor of dose rate, $f\,(= 1/(1 - \eta))$
- the monetary cost of relocation per person and unit time, c_{rel}
- the equivalent monetary cost of the unit collective dose, α

B6. In the optimisation of intervention levels for clean-up two different situations will be considered. Firstly, a contaminated residential area from which people have not been relocated, and, secondly, a contaminated residental area from which people have been relocated because the avertable doses by relocation exceed the intervention level.

AREAS FROM WHICH PEOPLE ARE NOT RELOCATED

B7. The condition for a clean-up operation to be justified is that the monetary value of the avertable collective dose, ΔS, from the clean-up is larger than the sum of the monetary value of the collective dose to the clean-up workers and the cost of the clean-up operation:

$$\alpha \ \Delta S \geq \alpha \ E_{work} \ N_{work} + c_{clean} \ A \approx c_{clean} \ A \qquad (2)$$

The cost of the collective dose to the clean-up workers will normally be marginal compared to the other clean-up costs and therefore the first term in the above equation can be disregarded.

B8. The annual dose, E_{an}, from activity deposited in urbam and semi-urban environments will, as an approximation, be proportional to the surface contamination density at each surface type. The annual dose would thus be:

$$E_{an} \approx x_{soil} \ v_{soil} + x_{grass} \ v_{grass} + x_{house} \ v_{house} + x_{asphalt} \ v_{asphalt} \qquad (3)$$

where:

- x is the fraction of the given surface type, and
- v is the relative deposition velocity for that surface type.

When the clean-up efficiency for the different surfaces is ϵ_i, which defines the reduction factor, f_i, as $1/(1 - \eta_i)$, the annual dose after clean-up, $E_{an,clean}$, can be described as:

$$E_{an,clean} \approx (1 - \eta_{soil}) \ x_{soil} \ v_{soil} + (1 - \eta_{grass}) \ x_{grass} \ v_{grass} + (1 - \eta_{house}) \ x_{house} \ v_{house} + (1 - \eta_{asphalt}) \ x_{asphalt} \ v_{asphalt} \qquad (4)$$

The effective dose reduction factor, f, by clean-up of the different surfaces can then be described as:

$$f = \frac{E_{an}}{E_{an,clean}} = \frac{\sum_i x_i v_i}{\sum_i (1 - \eta_i)\, x_i v_i} \tag{5}$$

B9. If T is the time period over which the collective dose is accumulated, the avertable collective dose, ΔS, over the time, T, is related to the (fairly constant) annual individual effective dose, E_{an}, as:

$$\Delta S = N_{pop} \left[\int_0^T E_{an}(t)\, dt - \frac{1}{f} \int_0^T E_{an}(t)\, dt \right]$$

$$= N_{pop} \frac{f - 1}{f} E_{an}\, T \tag{6}$$

B10. The justified annual individual effective dose, E_{an}, before clean-up can be found from the following considerations. The avertable collective dose over time, T, with clean-up will determine the justified value of the annual individual dose before clean-up, E_{an}, as:

$$\alpha\ \Delta S = \alpha\ N_{pop} \frac{f - 1}{f} E_{an}\, T \ge c_{clean}\, A \tag{7}$$

With a population density $P_{pop} = N_{pop}/A$, a dose reduction factor, f, equal to $1/(1 - \eta)$, the justified value of the annual effective dose before clean-up, E_{an}, can then be found from Eq. (7) to be

$$\boxed{(E_{an})_{just} = \left(\frac{f}{f - 1} \right) \frac{c_{clean}}{\alpha\ P_{pop}\ T}}$$

Figure B1 illustrates the effect of a clean-up operation which results in a reduction of the collective dose by a factor, f.

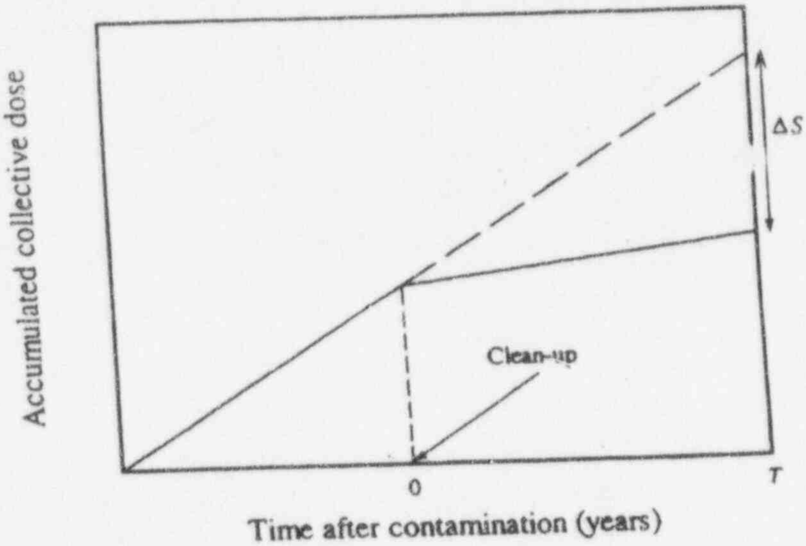

Figure B1. Avertable collective dose from clean-up with efficiency of the clean-up, η, which expresses the fraction of the radioactive material removed after clean-up.

B11. Calculations of the justified annual effective dose, E_{an}, before clean-up of urban and semi-urban areas have been made with the program Crystal Ball. For an assumed clean-up efficiency, η, of *soil removal*, *grass cutting*, *firehosing* of houses and *asphalt planing* the total clean-up costs per unit area were calculated as:

$$c_{clean} = x_{soil}\, c_{clean,soil} + x_{asphalt}\, c_{clean,asphalt} + x_{house}\, c_{clean,house} + x_{grass}\, c_{clean,grass} \quad (8)$$

Assigning distributions to all parameters, a range of justified values of the annual individual dose before clean-up has been calculated. The values of the parameters and the parameter distributions used in the calculations are shown in Table B2.

Table B2. Parameter values and their distributions used in the optimization calculations.

Parameter		Uniform distribution	Log-normal distribution	
			Central value	Standard deviation
Soil removal cost, \$ km^{-2}		400,000-800,000	600,000	200,000
Wages, \$ km^{-2}		100,000-200,000	150,000	50,000
Grass cutting cost, \$ km^{-2}		5,000-10,000	7,500	2,200
Transport, \$ km^{-2}		2,000-5,000	3,500	1,000
Wages, \$ km^{-2}		5,000-10,000	7,500	2,500
Firehosing cost, \$ km^{-2}		5,000-15,000	10,000	3,000
Transport, \$ km^{-2}		1,000-4,000	2,500	800
Wages, \$ km^{-2}		5,000-10,000	7,500	2,500
Asphalt planing, \$ km^{-2}		600,000-1,000,000	800,000	300,000
Transport, \$ km^{-2}		40,000-80,000	60,000	20,000
Wages, \$ km^{-2}		70,000-150,000	110,000	35,000
Population density, km^{-2} (urban)		300-600	450	200
Population density, km^{-2} (semi-urban)		100-200	150	60
Relative deposition on roads, ν_{road}		0.2-0.5	0.30	0.08
Relative deposition on houses, ν_{house}		0.05-0.2	0.12	0.03
Relative deposition on grass, ν_{grass}		0.8-1.2	1.0	0.20
Relative deposition on soil, ν_{soil}		0.8-1.2	1.0	0.20
Fr[illegible] on houses, x_{house}	Urban	0.50	0.50	-
	Semi-urban	0.30	0.30	-
Fraction roads, x_{road}	Urban	0.25	0.25	-
	Semi-urban	0.25	0.25	-
Fraction soil, x_{soil}	Urban	0.20	0.20	-
	Semi-urban	0.30	0.30	-
Fraction grass, x_{grass}	Urban	0.05	0.05	-
	Semi-urban	0.15	0.15	-
Soil removal efficiency, η_{soil}		0.5-0.8	0.7	0.14
Grass cutting efficiency, η_{grass}		0.2-0.6	0.4	0.06
Firehosing efficiency, η_{house}		0.1-0.5	0.3	0.03
Asphalt planing efficiency, $\eta_{asphalt}$		0.6-0.9	0.8	0.12
Cost of a unit dose, α, \$ Sv^{-1}		10,000-40,000	25,000	8,000
Integration time, T, years		30-300	200	50
Relocation costs, \$ month^{-1}		200-500	200	70

B12. The results of the Crystal Ball calculations with the above values and distributions are shown in Table B3. The reason why the results for semi-urban areas are approximately four times higher than for urban areas is mainly due to the difference in population density. For more dense populated areas the avertable dose by the clean-up operation per unit reduction in dose rate will result in a correspondingly higher avertable collective dose over the period considered.

Table B3. Annual dose levels, E_{an} in mSv/year above which clean-up is justified based on avertable dose and monetary costs of the clean-up of urban and semi-urban areas.

Area type	Distribution	Percentiles			Mean	Median
		2.5%	50%	97.5%		
Urban	uniform	0.14	0.43	2.30	0.60	0.40
	log-normal	0.10	0.34	1.20	0.40	0.30
Semi-urban	uniform	0.49	1.50	7.80	2.20	1.50
	log-normal	0.36	1.20	3.90	1.40	1.20

The justified annual dose level, E_{an}, before clean-up can be considered as the *action level, AL* for introducing clean-up. If the actual dose level, E_{act} (from all relevant exposure pathways) is greater than the *AL*, clean-up would normally be justified.

B13. The residual dose *after* an optimized clean-up operation can be either lower or greater than the *AL*. This will depend on the ratio E_{act}/AL. If the ratio is significantly higher than the effective dose reduction factor, *f*, the residual dose after an optimized clean-up would still be higher than the *AL*. If the ratio is of the same order of magnitude or lower than, *f*, the residual dose would most likely be lower than the *AL*.

B14. If the actual dose level is much higher than a few millisieverts per year this would invoke the temporary countermeasures appropriate for the later phases of a nuclear or radiological emergency. Where assessed individual doses are in the region of 10 mSv/y or greater, remediation will almost always be justified. Doses of that magnitude, corresponding to a lifetime dose of about 1 Sv, would, in any case, invoke permanent relocation if the exposure rate is chronic or semi-chronic. However, the generic justification calculations performed in this Appendix - although of a rather simple nature - seem to indicate that an *AL* for clean-up in terms of annual dose before clean-up would fall in the range from a fraction of a millisievert to a few millisievert per year.

B15. Operational quantities are the parameters actually measured to evaluate or to demonstrate compliance with a particular cleanup criterion. The action level, *AL*, would generally be expressed in dose, *eg* annual dose. However, for many practices and for some interventions, these criteria can generally be converted into more readily measurable operational quantities. Such quantities are derived by mathematical models where all significant exposure pathways and the projected relevant behavior of the exposed population group. Some models may only be suitable and useful for screening, while other models may be suitable for site specific application. The methodology for deriving operational quantities is discussed in Appendix C.

AREAS FROM WHICH PEOPLE HAVE BEEN RELOCATED

B16 The condition for a clean-up operation to be justified in areas from which people have been relocated is that the saved relocation costs by the accelerated return time, $\Delta\tau$, is larger than the sum of the monetary value of the collective dose to the clean-up workers and the cost of the clean-up operation itself:

$$c_{rel}\, N_{pop}\, \Delta\tau \geq \alpha\, E_{work}\, N_{work} + c_{clean}\, A \tag{9}$$

where c_{rel} is the relocation cost per person and unit time. The dose rate at the return time is here assumed to be equal in the situations with and without clean-up. The accelerated return time can be found from the above equation as:

$$\Delta\tau = \frac{c_{clean}}{c_{rel}} \frac{A}{N_{pop}} = \frac{c_{clean}}{c_{rel}} \frac{1}{P_{pop}} \tag{10}$$

as the equivalent cost of the doses the workers is only marginal compared to the clean-up costs, c_{clean}. The value of $\Delta\tau$ can be expressed by the half-life of the deposited radionuclides as:

$$\Delta\tau = \frac{T_{1/2}}{\ln 2} \ln f \tag{11}$$

The justified value of $\Delta\tau$ can then be expressed by the half-life of the deposited radionuclides as:

$$T_{1/2} = \frac{\ln 2}{\ln f} \frac{c_{clean}}{P_{pop}\, c_{rel}}$$

B17. The half-life, $T_{1/2}$, corresponding to the justified accelerated return time has been calculated from Crystal Ball, and the results are shown in Table B4. It is not justified to clean areas for half-lives less than the values shown as the costs from the clean-up will be greater than the saved relocation costs. It is therefore better to wait for the decay of activity before the area is reinhabited.

Table B4. Half-life of contaminant, $T_{1/2}$, in months above which clean-up is justified based on the break-even between clean-up costs and saved relocation costs.

Area type	Distribution	Percentiles			Mean	Median
		2.5%	50%	97.5%		
Urban	uniform	1.1	2.1	4.3	2.3	2.1
	log-normal	1.1	3.8	12.0	4.5	3.8
Semi-urban	uniform	3.8	7.4	15.5	8.0	7.4
	log-normal	3.9	13.0	41.0	15.4	13.0

B2. AGRICULTURAL AREAS

B17 The different methods and appropriate data for the derivation of Action Levels (ALs) for

countermeasures in agricultural production are first of all based on the experience of liquidating the consequences of nuclear accidents as described in detail in [1]. Generic recommendation on the implementation of agricultural countermeasures are also considered in [1,2].

B18 In emergency exposure situations, agricultural countermeasures are based mainly on measures of a more administrative/organizational character [1]. The methodology for setting action levels for agricultural countermeasures are described below. Generic ALs have been estimated based on appropriate economical, radiological and agro-ecological parameters. Such ALs are recommended mainly for the longer term period after a nuclear accident or radiological emergency.

B19 The methodology used here is based on cost-benefit analysis (CBA) [4]. Cost-benefit theory takes an objective view that alternative strategies should be selected according to a systematic comparison of the advantages (benefits) and disadvantages (costs) that result from the consequences of the choice. A balance in terms of a net benefit can be expressed as:

$$B = Y - Y_c - X + B_a = \Delta Y - X + B_a \qquad \text{(B2.1)}$$

where:

- B is the net benefit associated with any course of action;
- Y is an expression of the detrimental effects due to radiation without any action taken;
- Y_c is an expression of the residual detrimental effects due to radiation when the action is taken;
- X is an expression of the resources and effort needed to implement the protective measure;
- B_a is an expression of the additional benefit from the protective measure (*eg*, due to an increase of crop productivity or its quality).

Each of the terms in Eq. (B2.1) have to be expressed in the same units. Conventionally in cost-benefit approaches values are expressed in monetary units. However, it is the *relative* values placed on the components and their weighting one to another that is important, rather than the absolute unit in which they are quoted. Factors of the physical risk of the countermeasures itself, individual anxiety and social disruption are not considered as they are not significant in case of implementation of agricultural countermeasures.

B20 The expression (B2.1) can be elaborated as follows:

$$B = \alpha\ \Delta S - X + B_a \qquad \text{(B2.2)}$$

where ΔS is averted/avertable collective dose by the countermeasure, and α is the cost equivalent of averting a unit collective dose ($\Delta Y = \alpha\ \Delta S$). If it is assumed:

$$e = \frac{X}{\Delta S} \quad \text{and} \quad r = \frac{B_a}{X} \qquad \text{(B2.3)}$$

a countermeasure is justified if $B > 0$, *ie*, if:

$$e_r = e\ (1-r) < \alpha \qquad \text{(B2.4)}$$

where e is the cost-effectiveness, and e_r is the modified effectiveness of the agricultural countermeasure [5].

B21 Let C and C_1 be the concentration of a given radionuclide in a given agricultural product before and after the countermeasure, respectively:

$$C_1 = \frac{C}{f} \tag{B2.5}$$

f is here the reduction factor of activity concentration in a foodstuff by the countermeasure. M and M_1 is the amount of a product without/before and after the countermeasure with the ratio $m=M_1/M$; k is the remaining activity fraction after technological processing and culinary treatment of a given product (see remark concerning a conservative approach in [3, App. II]); and b is the cost of a given product. With these definitions the following relations can be found:

$$\Delta S = k\, e(50)\, M\, C\, (1 - \frac{m}{f}) \tag{B2.6}$$

$$B_a = M(m - 1)B$$

[If there is a post-effect of the countermeasure it is necessary to consider its time characteristics ans dynamics of contamination due to radioactive decay and self-cleaning, expressed as:

$$\Delta S = k\, e(50)\, M \int C(t)\, (1 - \frac{m}{f(t)})\, dt$$

see paras B27, B30].

A countermeasure is justified if $B > 0$, *ie*, according to the above equations, if $C > C_{min}$:

$$C_{min} = \frac{X - M\,(m-1)\,b}{\alpha\, k\, e(50)\, M}\ \frac{f}{f - m} \tag{B2.7}$$

B22 The definition of an AL as a minimum level above which an action may/should be implemented defines a minimum justified level. Evaluation of an *optimized* AL using any optimization procedure leads inevitably to a contraction of the set of countermeasures (CMs) {CM_i, $i = 1, 2, ..., n$} under consideration (or to an admission, that not any positive benefit is justified). Therefore, for the set of co[illegible]ntermeasures being considered, the definition of a generic Action Level can be expressed as:

$$AL = \min_i\, (C_i :\ B(C_i\, , CM_i) \geq 0) \tag{B2.8}$$

which is equivalent to:

$$AL = \min_i\, \min_\theta\, (C_i(\theta) : B(C_i(\theta)\, , CM_i(\theta)) \geq 0) \tag{B2.9}$$

where $\theta = \theta_i$ is a parameter of the countermeasure i, CM_i.

B23 In principle, an *optimized Action Level*, AL^*, may be defined by the expression:

$$AL^* = \min_i\, (C_i(\theta_i^*) : B(C_i(\theta_i^*)) \geq 0) \tag{B2.10}$$

θ_i^* is here an "optimized" (*eg*, in an agro-ecological/radioecological sense) parameter of CM_i. In practice Eq. (B2.10) would be identical to Eq. (B2.8), as the use of CM_i just means the choice of an optimal parameter $\theta=\theta_i^*$. In practice, however, it is impossible to get a functional dependence between

values θ, f, X, M due to significant parameter variabilities and uncertainties. It leads to the use of Eq. (B2.8) when evaluating justified ALs.

B24 When assessing ALs for agricultural countermeasures the following types of ALs may be considered:

- AL for contaminated animal products (first of all milk contamination as the most critical product), C_o (Bq/kg);
- AL for contaminated plant-growing products, eg, grass/hay contamination), C_i (Bq/kg);
- AL for surface contamination density, q (kBq/m^2).

When considering the "tropical chain" (natural lands)-(grass/hay)-(milk/meat) it is possible to use all three types of ALs: C_o, C_i, q. For arable lands, ALs of C_i and q are more convenient, but also C_o is useful taking into account the annual production of grasses/hay. Due to crop rotation it is adequately to consider surface contamination q only, whereas the C_o and C_i types are useful when assessing ALs and Operational Intervention Levels (OILs) for specific/local conditions.

B25 The evaluation of ALs in agriculture has been considered for ^{137}Cs as an example. The following main agricultural countermeasures were taken into account for assessment of the ALs:

- countermeasures for natural lands: radical and surface improvement of pastures and hayfields;
- use of Cs-binders with feed (ferrocene, befege);
- countermeasures for arable lands: the use of organic and mineral fertilizers, liming, combined countermeasures.

Specific countermeasures like processing of products, *eg*, processing of milk to cheese and butter, were not considered and will be useful when evaluating OILs.

B26 For intensive agriculture it can be assumed that additional yield after the implementation of a countermeasures will be practically insignificant (see para B21). In addition, an increase of productivity of grass/hay after radical or surface improvement of pastures or hayfields does not automatically lead to an increase of the milk/meat production. Therefore, when assessing justified ALs it should be considered that the parameter m (ratio of production after to that before the countermeasure) should have a value of one in Eq. (B2.7) which would give a modified value of the justified AL as:

$$C_{min} = \frac{X}{\alpha\ k\ e(50)\ M}\ \frac{f}{f - 1} \tag{B2.11}$$

B27 With the use of Eq. (B2.11) the following types of Action Levels C_o, C_i and q can be derived based on the estimation of minimum justified OILs. Countermeasure i for reduction of milk contamination is justified, if $C > C_{o,i}$, where:

$$C_{0,i} = \frac{P_{c,i}\ R_i}{\alpha\ k\ e(50)\ M}\ \frac{f_i}{f_i - 1} \tag{B2.12}$$

C_o is the contamination of milk, M is the production of milk per day per cow, $P_{c,i}$ is the cost and f_i

the efficiency of the countermeasure CM_i. The parameter, R_i, takes into account the post-effect of the countermeasure i (see paras B21, B30). Milk contamination C_0 in Bq/kg can be estimated by the relation:

$$C_0 = K_m (C_1 V) \qquad \text{(B2.13)}$$

where C_1 is the grass/hay contamination, V is the rate of grass/hay consumption (kg per day per cow) and K_m is transfer factor from daily ration to milk (Bq/kg)/(Bq/ration). Countermeasure i for reduction of milk or grass/hay contamination is justified, if the contamination of grass/hay $C > C_{1,i}$, given as:

$$C_{1,i} = \frac{P_{c,i} \, R_i}{\alpha \; k \; e(50) \; M \; K_m \; V} \; \frac{f_i}{f_i - 1} \qquad \text{(B2.14)}$$

B28 The activity concentration in crop/grass/hay C_1 can be assessed as:

$$C_1 = K_T \, q \qquad \text{(B2.15)}$$

where q is the surface contamination density and K_T is transfer factor from soil to crop, *eg*, in (Bq/kg)/(Bq/m^2). Countermeasure i for reduction of milk concentration is justified, if the surface contamination density of pasture/hayfield $q > q_{0,i}$, where:

$$q_{0,i} = \frac{P_{c,i} \, R_i}{\alpha \; k \; e(50) \; M \; K_m \; V \; K_T} \; \frac{f_i}{f_i - 1} \qquad \text{(B2.16)}$$

B29 For countermeasures like radical/surface the cost of improvement of pastures or hayfields, $P_{c,i}$, can be estimated as follows:

$$P_{c,i} = \frac{P \, V}{y} \qquad \text{(B2.17)}$$

where P is the cost of the CM per 1 ha, and y is the production yield of grass/hay, say in kg/ha. It can be assumed that countermeasure, i, CM_i for arable land is justified, if the surface contamination density $q > q_{a,i,j}$:

$$q_{a,i,j} = \frac{P_{i,j} \, R_i}{\alpha \; k \; e(50) \; y_j \; K_{T,j}} \; \frac{f_{i,j}}{f_{i,j} - 1} \qquad \text{(B2.18)}$$

where j is the crop, i is the countermeasure considered, $P_{i,j}$ is the cost of countermeasure i for crop j, $f_{i,j}$ is the reduction factor of countermeasure i, y_j is the production yield of crop j, and $K_{T,j}$ is the transfer factor from the given soil to crop j. The generic Action Levels C_0, C_1 and q types can be derived from Eqs. (B2.12), (B2.14), and (B2.16) based on the approach in Eq. (B2.8).

B30 The list of main parameters for assessing ALs for agricultural countermeasures is given partly in Table B2.T1. Cost parameters are given, according to [3], in fractions of the annual GNP per capita.

[As the costs of the agricultural countermeasures were based on Russian and former USSR data, the influence of specific cost values can be evaluated (first of all, when considering mineral fertilizers and radical/surface improvement). However, taking into account the expression of cost in fractions of the GNP and the wide range of all parameters considered, this influence is negligible when estimating generic ALs.]

The parameter k (see para B21) has been assumed to have the value 1 for milk and 0.5 for potato/grain. The parameter R_i (see para B27 Eqs. (B2.12), (B2.14), (B2.16), (B2.18)) for countermeasures like the use of Cs-binders equals 1, as well as for countermeasures for arable lands: for radical and surface improvement of pastures and hayfields the parameter R_i is assumed to have a value of approximately 0.5. The result of post-effect of the countermeasure - the avertable dose and the additional costs of the countermeasure for the following 6-8 years and the dynamics of the transfer factor K_T (see Eq. (B2.15)) were taken into account [6-9].

B31 In the assessment of ALs the ranges of parameter *mean values* observed have been used as central estimates (Table B2.T1). Uniform (U), Normal (N) and logNormal (logN) distributions of the parameter values have been used. The ranges for the U-distribution are indicated in the Table B2.T1. These intervals correspond to a 98-99% confidence interval when using N-distribution and a 95% confidence interval for the logN-distributions.

B32 When evaluating ALs/OILs of the q-type (surface contamination density) it is necessary to take into account the dynamics of transfer factors from soil to plant $K_T(t)$ [6-9]. Such time dynamics have been used for the assessment of ALs (Table B2.T1) corresponding to the range of average values of K_T for the first 1-3 years after the Chernobyl accident (1987-1989) for the main types of soil indicated. The dynamics of transfer factors can be approximately estimated by the formula $K_T(t)=K_T(t_0)p(t)$, where the function $p(t)$ can be expressed by one or two exponential terms with reduction half periods of 3-15 years for natural lands and 2-8 years for arable lands [6-9]. The q-type ALs/OILs should be corrected correspondingly.

B33 For the estimation of the ranges of values (Eqs. (B2.11)-(B2.18)) the following variants of distributions were considered:

1) U-distribution for the all parameters;
2) N-distribution for the all parameters;
3) U-distribution for a part of parameters and logN-distribution ($K_{i,p}$, see Table B2.T1) for the remaining part.

The following characteristics of output values were computed: mathematical expectation (mean), mode, median, standard deviation, 90 and 95%-confidence intervals and the observed range of values. The examples of characteristics indicated for minimum justified OILs of the C_o, C_i and q-types are presented in Tables B2.T2-B2.T5.

B34 The choice of ALs with the use of Eqs. (B2.8) and (B2.11)-(B2.18) is not a simple task due to the wide range of values being assessed (see 95%-confidence intervals and other characteristics of values C_o, C_i and q in Table B2.T4-B2.T5). For example, the 97.5% percentile may not be recommended as a *generic* (minimal justified) AL, because there exists a *considerable probability* to implement a justified countermeasure for values which are less than the $AL_{97.5\%}$ indicated and:

a) contamination of products after the implementation of countermeasures may be above the Intervention Levels for withdrawal and substitution of foodstuffs ([3, Annex I]) and /or implementation of administrative countermeasures (*eg*, withdrawal and substitution of foodstuffs) may be more effective according to cost-benefit analusis (see para B35);

b) surface contamination density may be above established OILs for permanent resettlement and/or prohibitation of the use of lands for agricultural purposes (*eg*, q_{max} = 40 Ci/km^2 = 1480 kBq/m^2, [5]). Therefore, when choosing ALs based on the range of values and main characteristics the interval [X_{min}, E] may be considered (X_{min} is the 2.5% percentile of the value being estimated,

and E is the mean value).

Therefore, when $x = C_0, C_i$ or q, then:

if $x < x_{min}$ no action/countermeasure should be recommended ($x = C_0, C_i, q$) as the probability of getting a net benefit after countermeasure implementation will be very small;

if $x_i \leq x \leq E$ an action/countermeasure may be implemented; however, local radiological, agro-ecological and agricultural/economic conditions should be taken into account;

if $x > E$ an action/countermeasure is recommended to be implemented, taking into account local radiological, agro-ecological and agricultural/economic conditions.

B35 The statement 'if $x > E$ an action/countermeasure is recommended to be implemented' does not mean that just an agricultural countermeasure must be implemented as have been mentioned above, para B34 a-b). Agricultural countermeasures may be implemented if the level of contamination $x \in [X_{min}, X_{max}]$, where X_{min} was defined in para B34, and the approach to the evaluation of X_{max} is considered below.

The countermeasure CM_1 is preferable to countermeasure CM_2 if the total detriment:

$$(X + Y)CM_1 < (X + Y)CM_2 \quad \text{(B2.19)}$$

(the case when additional benefit B_a=0 is considered, see paras B19, B21, B26). Then, an agricultural countermeasure is preferable to withdrawal and substitution of foodstuffs (or to substitution of contaminated with uncontaminated fodder) if:

$$P_{c,i} + \frac{k\ \alpha\ e(50)\ C}{f_i} \leq b \quad \text{(B2.20)}$$

(b is the cost of product (*eg*, milk) being considered, $P_{c,i}$ is the cost of countermeasure 'per unit product', f_i is the reduction factor of countermeasure and C is the product contamination). Furthermore:

$$C \leq C_{max,i}$$

where:

$$C_{max,i} = \frac{f_i\ (b - P_{c,i})}{k\ \alpha\ e(50)} \quad \text{(B2.21)}$$

The level $X_{max,i}$ (C_i and q-type, see para B24) may be evaluated using $C_{max,i}$ and Eqs. (B2.13) and (B2,15). Then the upper level X_{max} is defined by the expression:

$$X_{max} = \max_i \max_b X_{max,i} \quad \text{(B2.22)}$$

and it can be stated that if $x > X_{max}$, the implementation of agricultural countermeasures is not "justified" as the use of administrative countermeasures is more preferable. The value X_{max} may be called a "*maximum justified Action Level*" *for the class of agricultural countermeasures*.

B36 The inhomogeneous character of contamination of agricultural products may lead to the use of *Separation Intervention Levels* (SILs) in agricultural practice on contaminated lands which

differentiates the production obtained as "clean" (with contamination below SIL) and "dirty" (above SIL correspondingly). It should be stressed, however, that SILs may be different from ILs for withdrawing and substitution of foodstuffs, as well as from DILs/OILs [3,5] or ALs considered. It depends on the strategy of using "clean" and "dirty" production. Below the approach for deriving *optimized* SILs based on the use of (modified) cost-benefit analysis is considered.

B37 When the strategy ST_1 is implemented, ST_1 = {all the local "clean" production is consumed; the "dirty" production obtained is not consumed but replaced by non-contaminated one}, the ILs for withdrawing and substitution of foodstuffs [3] are used. But if the strategy ST_2 is implemented, ST_2 = {all the local "clean" production is consumed; the "dirty" fraction of production is consumed only after appropriate treatment or processing}, the specific SILs may be considered. It was indicated [10], that the implementation of agricultural countermeasures within strategies ST_1 and ST_2 may lead to an increase in population dose. Let:

b_1 and b_2 be the cost per unit of "clean" and "dirty" production, respectively (or benefit from realization of a unit production indicated);

k_1 and k_2 the remaining activity fraction after technological processing and culinary treatment of the "clean" and "dirty" production, respectively;

A_1 and A_2 the activity in "clean" and "dirty" production, respectively, normalized per unit of total production under consideration;

P_0 the expenses for production;

θ = SIL is the level of contamination, Bq/kg, for separation "clean" and "dirty" production under consideration;

$d(\theta)$ is the fraction of "clean" production.

Then, the net benefit B when strategy ST_2 is used may be presented as follows:

$$B = B(\theta;ST_2) = b_1\, d(\theta) + b_2(1 - d(\theta)) - P_0 - k_1\, \alpha\, e(50)\, A_1(\theta) - k_2\, \alpha\, e(50)\, A_2(\theta) \qquad \text{(B2.23)}$$

Considering the extremum of net benefit $B(\theta,ST_2)$ the following is obtained [11]:

$$\frac{dB}{d\theta} = \varphi(\theta)(k_1 - k_2)\, \alpha\, e(50)(\theta_{opt} - \theta) \qquad \text{(B2.24)}$$

where $\varphi(x)$ is density function of the distribution of production contamination, and

$$\theta_{opt} = \frac{b_1 - b_2}{(k_1 - k_2)\alpha\, e(50)} \qquad \text{(B2.25)}$$

It can be proved from Eq. (B2.24), that $\max_\theta B(\theta;ST_2) = B(\theta_{opt};ST_2)$. Evidently, the optimized Separation Intervention Level, θ_{opt}, is not dependent on the distribution of the production contamination (and concrete characteristics of the countermeasure that may be implemented [11]). Formula (B2.25) is a generalization of a formula for evaluation of IL for withdrawing and substitution of foodstuffs ([3], p.83, (I-21)).

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Table B2.T1. The main Parameters used for determination of ACTION LEVELS in agriculture.

Parameter	Definition	Range of value	Type of distribution (U-uniform, N-normal, logN-logNormal)
α	Cost equivalent of 1 manSv	0.5-1.5 (in fraction of GNP per head)	U,N
M	Amount of milk produced per day per cow	12-18 [l/(day·head)]	U,N
V	Amount of grass per day per cow, d.w.	7.5-12.5 [kg/(day·head)]	U,N
y_1	Grass productivity,d.w. (natural lands)	10-30 [hkg/ha]	U,N
y_2	Productivity of potato	100-300 [hkg/ha]	U,N
y_3	Productivity of grain	20-50 [hkg/ha]	U,N
P_1	Cost of Cs-binders application	$(0.1\text{-}0.2)\cdot10^{-4}$ (in fraction of GNP, per head per day	U,N
P_2	Cost of Radical Improvement of pastures/hayfields	$(4\text{-}8)\cdot10^{-2}$ (in fraction of GNP/ha)	U,N
P_3	Cost of Liming application (arable lands)	$(4\text{-}6)\cdot10^{-3}$ (in fraction of GNP/ha)	U,N
P_4	Cost of Combined CM (arable lands)	$(2\text{-}3)\cdot10^{-4}$ (in fraction of GNP/ha)	U,N
P_5	Cost of Organic Fertilizers application	$(1\text{-}2)\cdot10^{-2}$ (in fraction of GNP/ha)	U,N
f_1	Reduction factor of Cs-binders	4-8	U,N
f_2	Reduction factor of Radical Improvement	2-8	U,N
f_3	Reduction factor of Liming	1.4-2.2	U,N
f_4	Reduction factor of Combined CM	2-3.6	U,N
f_5	Reduction factor of organic fertilizers	1.2-2	U,N
K_m	Transfer factor from daily ration to milk	0.005-0.015 (95%) 0.004-0.023 [(Bq/kg)/(Bq/rat)]	U,N, logN
$K_{1,1}$	Transfer factor from soil to grass (sandy,sandy loam soil)	8-20 (95%) 7-23 [(Bq/kg)/(kBq/m^2)]	U,N, logN
$K_{1,2}$	Transfer factor from soil to grass (light/middle loam)	5-15 (95%) 4.8-20 [(Bq/kg)/(kBq/m^2)]	U,N, logN
$K_{1,3}$	Transfer factor from soil to grass (heavy loam,clay)	0.4-0.8 (95%) 0.25-1.2 [(Bq/kg)/(kBq/m^2)]	U,N, logN
$K_{1,4}$	Transfer factor from soil to grass (peat)	20-80 (95%) 25-85 [(Bq/kg)/(kBq/m^2)]	U,N, logN
$K_{2,1}$	Transfer factor from soil to potato/grain (sandy/sandy loam)	0.2-0.5 [(Bq/kg)/(kBq/m^2)]	U,N
$K_{2,2}$	Transfer factor from soil to potato/grain (light/middle loam)	0.08-0.2 [(Bq/kg)/(kBq/m^2)]	U,N
$K_{2,3}$	Transfer factor from soil to potato/grain (heavy loam,clay)	0.05-0.1 [(Bq/kg)/(kBq/m^2)]	U,N
$K_{2,4}$	Transfer factor from soil to potato/grain (peat)	0.3-1 [(Bq/kg)/(kBq/m^2)]	U,N

Table B2.T2. Characteristics of minimum justified OILs, C_0 for milk (Bq/l) (according to Eq. (B2.7)).

Type of distribution: U - uniform, N - normal.

Countermeasure	Type of distribution	Mean	Mode	Median	95%-confidence interval
Cs-binders	U N	105 95	75 90	95 93	50-210 65-140
Radical improvement of pastures/hayfields	U N	1,250 1,010	700 900	1,050 1,000	450-3,150 650-1,550

Table B2.T3. Characteristics of minimum justified OILs, C_i for grass (d.w.) (kBq/kg) (according to Eq. (B2.14)).

Type of distribution: U - uniform, N - normal.

Countermeasure	Type of distribution	Mean	Mode	Median	95%-confidence interval
Cs-binders	U N	1.2 1	0.7 0.8	1 0.9	0.4-3 0.6-1.6
Radical improvement of pastures/hayfields	U N	13 10	7 8	11 9	4-35 6-17

Table B2.T4. Characteristics of minimum justified OILs, q_i (kBq/m^2), i=1-4.

Type of soil: 1 - sandy/sandy loam, 2 - light/middle loam, 3 - heavy loam/clay, 4 -peat.
Type of distribution: U - uniform, N - normal, logN - logNormal.

Countermeasure	Type of soil	Type of distribution	Mean	Mode	Median	95% -confidence interval
Use of Cs-binders	1	U	90	50	75	25 - 240
		N	75	60	70	40 - 125
		logN	100	45	80	20 - 300
	2	U	125	65	105	35 - 300
		N	100	80	95	55 - 190
		logN	150	60	120	30 - 450
	3	U	2,015	1,125	1,710	630-5,200
		N	1,650	1,400	1,600	950-2,750
		logN	2,500	800	2,000	450-8,300
	4	U	25	10	20	10 - 80
		N	20	15	19	10 - 40
		logN	30	10	25	7 - 90
Radical improvement of pastures/hayfields	1	U	950	450	800	300 2,450
		N	750	600	720	400 - 1,350
	2	U	1,340	610	1,100	400 - 3,600
		N	1,100	850	1,000	540 - 2,050
	3	U	21,500	10,900	18,300	6,700-55,500
		N	17,400	14,000	16,500	9,800-29,800
	4	U	250	120	220	80 - 700
		N	210	170	200	110 - 400

Table B2.T5. Characteristics of minimum justified OILs q_i (kBq/m^2), i=1-4, for liming (arable lands, potato/grain).

Type of soil: 1 - sandy/sandy loam, 2 - light/middle loam, 3 - heavy loam/clay, 4 -peat
Type of distribution: U - uniform, N - normal, logN - logNormal.

Countermeasure	Type of soil	Type of distribution	Mean	Mode	Median	95% - confidence interval
Liming	1	U N	385 315	220 260	330 295	130-970 170-565
	2	U N	850 685	465 545	715 640	265-2,225 355-1,260
	3	U N	1,635 1,350	945 1,100	1,400 1,275	555-4,065 730-2,415
	4	U N	190 185	100 150	155 180	55-530 100-350

Table B2.T6. Justified ACTION LEVELS for agricultural countermeasures.

Type of soil: 1- sandy/sandy loam, 2- light/middle loam, 3- heavy loam/clay, 4-peat.

Type of ACTION LEVEL		ACTION LEVEL: minimal	ACTION LEVEL: mean
C_p: **Bq/kg** milk contamination		60	100
C_l: **Bq/kg** contamination of grass/hay of natural pastures, hayfields		500	1,000
q: kBq/m²	**Type of soil**		
Surface contamination of natural pastures/hayfield	1 2 3 4	30 40 500 10	90 120 1,600 30
Surface contamination on arable lands	1 2 3 4	150 300 650 100	350 750 1,500 200

B3. FOREST AREAS

B4. NATURAL AREAS AND RESOURCES

C. DERIVATION OF OPERATIONAL QUANTITIES

C.1 Operational quantities

C1 Operational quantities are the parameters actually measured to evaluate or to demonstrate compliance with a particular cleanup criterion. The cleanup criteria, as discussed in Chapter 3, would generally be expressed in dose. 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, the 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:

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

C2. Operational quantities correspond to avertable or residual dose levels and are derived by mathematically modelling all the significant pathways of exposure and the projected relevant behavior of the critical group. Making these calculations requires a detailed understanding of the nature and extent of the contaminated area, environmental factors for the area, the reasonably possible routes by which humans may be exposed to radiation from this area, and the scenarios that describe how the site will be used after cleanup.

C.2 Modelling approaches and pathways

C3. The calculation of projected doses[7] requires the modelling of the various processes involved in the transfer of radiation from an environmental contaminant to man. 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 other models 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 clean-up that is more costly than necessary. The models should be readily able to address all relevant exposure pathways. They should be readily able to use of 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.

C4. 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 clean-up should take both kinds of contaminates into account.

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

C5. Radiation doses to an individual may be delivered by a combination of pathways, namely, external radiation, inhalation and ingestion (including incidental ingestion of dust), and these pathways should be considered in modelling. Sources of radionuclides that could contribute to these pathways include: contamination in soil, buildings, or aquifers, buildings, equipment, vegetation, sediments, and materials suspended in air or in gaseous form. Details on these pathways can be found in other relevant IAEA documents (Safety Series No. 57, "Generic Models and Parameters for Assessing the Environmental Transfer of Radionuclides from Routine Releases: Exposures of Critical Groups" 1982, and ? a technical report update to this reference ?).

C.3 Generic and site specific methods of deriving clean-up levels

C6. If **generic** operational quantities are derived using slightly pessimistic assumptions, then the results of modelling (eg in units of $Sv \cdot Bq^{-1} \cdot kg$) may be used as a screening tool for a generic optimization or as a basis for planning clean-up. **Generic** operational quantities (eg 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 clean-up level.

C7. 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 clean-up. This should result in **specific** operational quantities for the clean-up.

C8. 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.

C.4 Uncertainties in calculations

C9. There can be a great deal of uncertainty in the calculated doses. Uncertainties limit the resolution of the dose projections and should be quantified so that decisions can be made with the knowledge of the limits of the technical basis. In most cases this uncertainty will increase with the time in the future that the dose projections are made. 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 arise in projecting future use, human behavior, the total quantity and distribution of the contamination, and environmental factors such as transport, among others.

D. GENERIC MAXIMUM ACCEPTABLE ANNUAL DOSE LEVEL

D1 Dose limits for the population is used to control dose increments as the result of practices. For protection of the population in chronic exposure situations where clean-up operations or remedial actions might be needed, these dose limits do not apply. The approach suggested here defines a generic maximum acceptable annual dose level to constrain the residual dose following clean-up operations or remedial actions. This approach does not imply that below such a level remedial actions should not be undertaken. Only in situations where the foreseen remedial actions are very severe or where the dose levels are irreducible, would further dose reductions below the maximum acceptable annual dose level not be necessary.

D1. Dose levels from natural sources and for long-term intervention situations

Natural background radiation

D2 The worldwide average annual dose from natural sources is estimated to be 2.4 mSv (UNSCEAR 1993), of which about 1.1 mSv is due to the basic background radiation and 1.3 mSv is due to exposure to radon. The cosmic ray dose rate depends on height above sea and on latitude. Annual doses in areas of high exposure (locations at higher elevations) are about 5 times the average. The terrestrial gamma-ray dose rate depends on local geology, with a high level typically being about 10 times the average. The dose to a few communities living near some types of mineral sand may be up to about 100 times the average. The dose from radon decay products depends on the local geology and housing construction and use, with the dose in some regions being about 10 times the average. 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 2-20 **[check]** mSv/y with values in some regions of the order of 30-50 mSv/y **[check] [a distribution of world population on annual background dose preferable]**.

Radon levels in dwellings

D3 According to the ICRP (ICRP Publication 65) some remedial measures against radon in dwellings are almost always justified above a continued annual effective dose 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/y.

D4 The action level recommended by ICRP relates only to simple measures. More severe measures, such as relocation, would according to the ICRP not be appropriate unless irreducible concentrations were an order of magnitude or more higher than the action level adopted, *ie* at a dose level of 30-100 mSv/y.

Acceptable activity levels in foodstuffs

D5 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 are essential in order that international trading in food is not severely disrupted by excessive monitoring, administrative and legal requirements.

D6 The recommended generic action levels recommended in the BSS are identical to the values agreed by the Codex Alimentarius Commission (CAC). These levels are recommended for use by national authorities as the 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 neighbouring countries.

D7 The Codex Alimentarius Commission's action levels for activity concentration in foodstuffs are conceptually non-action levels. This means that the residual individual doses from consumption of foodstuffs containing such levels were to be acceptable without any actions to be taken to reduce the levels. Depending on the annual 'food basket' (WHO, 1988) the consumption of food containing activity concentrations 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 10 mSv. These dose figures assumes that the food basket is contaminated to the full CAC values for the whole year.

Intervention level for permanent resettlement

D8 Temporary relocation and/or permanent resettlement are two of the more extreme protective measures available to control 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) to avert exposures principally from radioactive material deposited on the ground and from inhalation of any resuspended radioactive particulate material. During this period, people would typically be housed in temporary accommodation.

D9 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 - be considered if the lifetime dose over 70 years is irreducible and projected to exceed 1 Sv, corresponding to an average annual dose of about 10-15 mSv. Where assessed individual doses are in the region of 10 mSv per year or greater, this would almost always call for clean-up if the source is not irreducible. Is that the case the only alternative left is a permanent resettlement.

D2. Basis for a generic maximum acceptable annual dose level

D10 Protection of individuals in chronic exposure situations is based on the common principles for dealing with radiological hazards, namely *justification* of the remedial actions, *optimization* of the level of protection of individual achieved by that action, and *protection of the individual* by limiting inequities as discussed in details in Chapter 3. Justification and optimization of clean-up situations in which dose reductions and monetary costs of the remedial actions are the major components, the residual individual dose after clean-up is not adequately addressed.

D11 In an unconstrained optimization process with dose reduction and costs as the only components, the residual dose level is considered to be acceptable whatever the dose level is reduced from, *eg* 10 to 2 mSv/y or from 200 to 40 mSv/y. There is therefore a need to constrain the optimization process in such a way that the residual dose and thus the "new" background level is not deemed to be unacceptable. A pragmatic approach would be to select a dose level that is considered not to be intolerable and use such a dose level to constrain the outcome of the optimization of any clean-up operation or other remedial actions in chronic exposure situations.

D12 The annual individual effective doses from natural sources are of the order of 2-20 mSv and in many places higher than *10 mSv*. The action level for radon in dwellings as recommended by the ICRP to be *3-10 mSv/y* for simple remedial measures. For more severe measures the ICRP states that

the action level should be *at least* one order of magnitude higher. The non-action level for radioactivity in foodstuffs moving in international trade recommended by the WHO/FAO Codex Alimentarius Commission (CAC) corresponds to an annual committed effective individual dose of around *10 mSv/y* if the annual food basket contains activity at the levels recommended by the CAC. The intervention level for permanent resettlement due to exposure from deposited activity in the environment from a nuclear accident has been recommended by the BSS and the ICRP to be 1 Sv in a lifetime corresponding to an annual average dose level of about *10-15 mSv*.

D13 From the recommendations stated in para D12 it appears that an effective dose of *10 mSv/y* is a very robust number which can be used as a *generic maximum* acceptable annual dose below which it is not worthwhile to clean the area if the conditions are such that it is no longer justified on the grounds of dose reduction and remediation costs. In other words, such a dose level could be used as a constraint to the optimization process for clean-up of areas and thus act as the maximum acceptable dose level ("new" background) either after a continued clean-up is no longer justified or when a clean-up is considered but not found to be justified on radiological grounds.

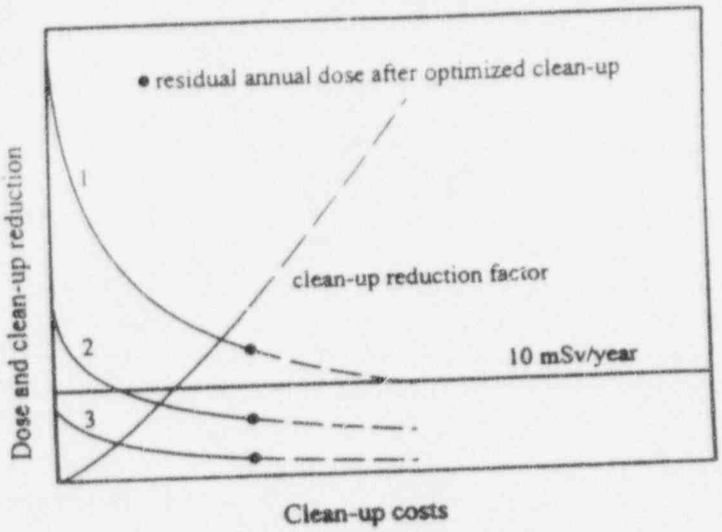

Figure D1. Clean-up of an area with three hypothetical situations of surface contamination. In all three situations clean-up is justified and optimized based on dose reduction and costs of the clean-up. As the residual dose for situation 1 is greater than 10 mSv/y, clean-up may not be justified on an overall consideration.

D14 The approach of a generically acceptable annual dose level does *not* imply that below such a level it is never worthwhile to clean the area. If it is justified on radiological grounds it should always be done and the scale of clean-up be determined by optimization. This is illustrated in Fig. 1 for three hypothetical situations contamination situations.

D15 In addition to the approach of a maximum acceptable annual dose it would be beneficial also to define a dose level at which intervention would *always* be justified on radiological grounds. The basis for selecting numerical dose values would here be the threshold doses for deterministic effects. BSS defines such dose levels for both acute and chronic exposure. For clean-up operations the values for chronic exposure will be relevant. The dose levels at which deterministic effects will occur in a chronic exposure situation will be organ dependent and for the purpose of this document the lowest

number has been used (lens of the eye) [**need to consider if exposure of the foetus is more sensitive than the lens of the eye (although only effective for a nine month period)**]. The two sets of action levels are summarized in the Table 4.1 below.

Table 4.1. Generic action levels for clean-up and for general intervention.

Type of action level	Annual dose
Clean-up above this level almost always justified	10 mSv/y
Any intervention above this level always justified	100 mGy/y

D16 In chronic exposure situations where the total annual individual doses from artificial sources are above 10 mSv clean-up should be undertaken to bring the doses below 10 mSv/y. The goal is here the *residual dose* which should be limited to 10 mSv or less. In chronic exposure situations where the total annual individual doses from artificial sources already are below 10 mSv, the objective is to avert as much of the doses by clean-up as reasonable achievable. The goal is here the *avertable dose* and the residual dose *after* clean-up has no longer a role to play. The residual dose is now the "new" background level which automatically is acceptable.

D17 There may be situations where clean-up is justified on the grounds of dose reduction and remediation costs alone but where the residual individual doses after clean-up are greater than 10 mSv/y. Whether this is acceptable or not will depend on alternative options of intervention or further implementation of options tried. Such situations necessarily would be very severe, *eg* relocation of a large city or removal of all top soil (arable soil) for agricultural production. The rationale for exceeding the generic criteria must be explicitly stated, thouroughly investigated and clearly defensible. Similar considerations should be given to situations where clean-up was not justified on radiological grounds but the individual doses were above 10 mSv/y. In both situations, however, if the annual residual doses were above 100 mSv/y intervention would always be justified, even the most disruptive actions.

GLOSSARY

Accident:

Any unintended event, including an operating error, equipment failure or other mishap, the consequences or potential consequences of which cannot be ignored from the point of view of *protection* or *safety*, and which could lead to *potential exposure* or to abnormal *exposure* conditions

Action level:

The level of *dose* rate or *activity* concentration above which *remedial* or *protective actions* should be carried out in *chronic* or *emergency exposure* situations.

Agricultural countermeasures:

Actions taken to reduce contamination of food or agricultural or forestry products before they reach consumers.

Authorized:

Granted an *authorization* by the *Regulatory Authority*.

Authorized practice:

Authorized release:

Automatic clearance/exemption:

Averted (avertable) dose:

The *dose* (to be) saved by a *protective action*; that is, the difference between the *doses* expected with and without the protective action.

Chronic exposure:

Exposure persisting in time.

Clearance:

Removal of radioactive materials or objects within *authorized practices* from any further control from the *Regulatory Authority*.[8]

Clearance dose:

Clearance levels:

Values, established by the *Regulatory Authority* and expressed in terms of *activity* concentrations and/or total *activity*, at or below which sources of radiation can be released from regulatory control.

Conditional clearance/exemption:

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[8] Authorized radioactive discharges are not covered by clearance.

Contamination:
The presence of radioactive substances in or on a material or the human body or other place where they are undesirable or could be harmful.

Criteria:
Conditions on which a decision or judgement can be based. They may be qualitative or quantitative and should result from established principles and standards.

Critical group:
A group of *members of the public* whose *exposure* for a given *radiation source* and given *exposure pathway* is reasonably homogeneous and is typical of individuals receiving the highest *effective dose* or *equivalent dose* (as relevant) by the given *exposure pathway* from the given *source*.

Countermeasure:
An action aimed at alleviating the consequences of an *accident*.

Decontamination:
The removal of radioactive substances causing *contamination* with the objective of reducing the residual amount of radioactive substances in or on materials, persons or the environment.

Defence in depth:
The application of more than a single protective measure for a given *safety* objective such that the objective is achieved even if one of the protective measures fails.

Dose constraint: one source
A prospective upper bound on the individual dose which is used in the optimization of protection and safety for *sources*. For *public exposure*, the *dose constraint* is an upper bound on the annual *committed doses* that *members of the public* should receive from the planned operation of any controlled *source*, ensuring that the sum of *doses* to the *critical group* from all controlled *sources* remains within the *dose limit*.

Emergency:
An accident requiring immediate *protective actions*.

Discussion s.sec 2.14, p. 7 s.sec 4.10, p. 20

Equity: in time + space
Even distribution of detriments and benefits from a practice between individual members of the general public or between members of the general public and workers.

Exemption:
Automatic or conditional permission to carry out some practice or use sources within practices without obligation to comply with the requirements of the Regulatory Authorities.

Guidance level:
A level of a specified quantity "above which appropriate actions should" be considered. In some circumstances, actions may need to be considered when the specified quantity is substantially below the guidance level.

Institutional control:
Control of a *site* (e.g. *decommissioning* site, etc.) by an authority or institution designated under the laws of a country or state. This control may be active (*monitoring*, *surveillance*,

remedial work) or passive (land use control).

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

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

Investigation level:
The value of a quantity such as *equivalent dose*, *intake*, or *contamination* per unit area or volume at and above which an investigation should be conducted.

Member of the public:
In a general sense, any individual in the whole population, excluding those occupationally or medically exposed. For the purpose of verifying compliance with the annual *dose limit* for *public exposure*, the average individual in the relevant *critical group*.

Natural exposures:
Exposures delivered by *natural sources*.

Natural sources:
Naturally occurring *sources* of *radiation*, including cosmic radiation which affects people in high altitude flight and terrestrial *radiation sources* in dwellings, mines, spas, etc.

Occupational exposure:
All *exposures* of *workers* incurred in the course of their work with the exception of *exposures* not subject to the requirements of the Regulatory Authorities or *exposures* from *exempted practices* or *sources*.

Permanent Resettlement:
Deliberate complete removal of people from a contaminated area with no expectation of return.

Practice:
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.

Protective action:
An *intervention* intended to avoid or reduce doses to members of the public in *chronic* or *emergency exposure* situations.

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

Radiological Risk:
Product of the probability of an individual being exposed to a particular radiation dose and the probability of a health effect arising from that dose.

Recovery measures:
Remedial measures (see Remedial Actions)

Reference level:
Generic term for *action, intervention, investigation* and *recording levels*. Such levels may be established for any of the quantities determined in the practice of *radiation protection*.

Remedial action:
Action taken when a specified *action level* is exceeded to reduce *radiation doses* that might otherwise be received, in an *intervention* situation involving *chronic exposure*.

Regulatory Authority:
An authority or authorities designated or otherwise recognized by a government for regulatory purposes in connection with *protection* and *safety*.

Residual dose:

Source:
Anything that may cause *radiation exposure*, such as by emitting ionizing *radiation* or releasing radioactive substances or materials.

Temporary relocation:
Organized and deliberate removal of people from a contaminated area for an extended but limited period of time.

Unconditional clearance/exemption:

Unrestricted release or use:
A designation, by the *regulatory body* in a country or state, that enables the release or use of equip ent, materials, buildings or the site without radiological restriction.

Worker:
Any person who works, whether full time, part time or temporarily, for an employer and who has recognized rights and duties in relation to occupational *radiation protection*.

Unconstrained optimization — See Appendix D, ¶D11, page 53

Appendix B:

The results of the example calculations for generic action levels described in Appendix B are not applicable to the USA since most of the concepts and parameters used in the analysis are quite different for the USA. For example, the costs of remediation, which are considered most significant for the cost/benefit analyses in Appendix B, may not be perceived by the American public as the most important factor in optimization. While in the USA the value cost per person-rem averted is currently $1000, the values listed in Appendix B range from around $80 to $400 per person-rem. The use of fixed costs of remediation to justify the derivation of generic criteria may also not be appropriate because these costs depend on variety of factors that depend on the technology and economics which vary for each site-specific clean-up situation.

We believe that the cost-benefit analyses in appendix B did not properly address long-term, future use of decommissioned land. The analysis was based on parameters that apply only to the present situation rather than on potential future use of the land assuming no institutional controls. An analysis of potential land use and potential migration of contamination should also be performed to establish the criteria.

Appendix D:

The use of 10 mSv/y (1000 mrem/y) as the upper bound of the tolerable exposure for individual members of the public is inconsistent with current international and national value of 1 mSv/y (100 mrem/y).

Attachment: As stated

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