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Protection of the public in situations of prolonged radiation exposure

The application of the Commission's system of radiological protection to controllable radiation exposure due to natural sources and long-lived radioactive residues

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Abstract-This report provides guidance on the application of the ICRP system of radiological protection to prolonged exposure situations affecting members of the public. It addresses the general application of the Commission's system to the control of prolonged exposures resulting from practices and to the undertaking of interventions in prolonged exposure situations. Additionally, it provides recommendations on generic reference levels for such interventions.

The report also considers some specific situations and discusses a number of issues that have been of concern, namely: natural radiation sources that may give rise to high doses; the restoration and rehabilitation of sites where human activities involving radioactive substances have been carried out; the return to 'normality' following an accident that has released radioactive substances to the environment; and the global marketing of commodities for public consumption that contain radioactive substances. Annexes provide some examples of prolonged exposure situations and discuss the radiological protection quantities, radiation-induced health effects and aspects of the Commission's system of radiological protection relevant to prolonged exposure.

Quantitative recommendations for prolonged exposures are provided in the report. They must be interpreted with extreme caution; Chapters 4 and 5 stress the upper bound nature of the following values: Generic reference levels for intervention, in terms of existing total annual doses, are given as $<\sim$100 mSv, above which intervention is almost always justifiable (situations for which the annual dose threshold for deterministic effects in relevant organs is exceeded will almost always require intervention), and $<\sim$10 mSv, below which intervention is not likely to be justifiable (and above which it may be necessary). Intervention exemption levels for commodities, especially building materials, are expressed as an additional annual dose of $\sim$1 mSv. The dose limit for exposures of the public from practices is expressed as aggregated (prolonged and transitory) additional annual doses from all relevant practices of 1 mSv. Dose constraints for sources within practices are expressed as an additional annual dose lower than 1 mSv (e.g. of $\sim$0.3 mSv), which could be $\sim$0.1 mSv for the prolonged exposure component. An exemption level for practices is expressed as an additional annual dose of $\sim$0.01 mSv.

Keywords: Radiation protection; Public exposure; Prolonged exposure; Chronic exposure; Intervention

EXECUTIVE SUMMARY

(a) This report provides guidance on the application of the Commission's system of radiological protection to *prolonged exposure* to radiation. Prolonged exposures are adventitiously and persistently incurred by the public over long periods of time. They are incidental to situations in which members of the public may find themselves. The average annual dose associated with prolonged exposures is more or less constant or decreases slowly over the years. Public exposures of a temporary nature are not covered by the report; nor are occupational and medical exposures, which are not considered to be prolonged exposures.

(b) Typical prolonged exposures are those delivered by the so-called 'natural' sources such as cosmic radiation and radionuclides in primordial in decay chains. Some 'artificial' sources may also deliver prolonged exposures; for example, long-lived radioactive residues from human activities are a common cause of prolonged exposure. It is to be noted that radioactive residues may contain both natural and artificial radionuclides. In situations of prolonged exposures, it may be difficult to separate the exposure attributed to the artificial component from that due to the natural component; moreover, protective measures against the artificial component can affect the exposure due to the natural component and vice versa.

(c) Radioactive residues may remain after the termination of regulated activities that increase the overall exposure of people to radiation; these activities are termed *practices*. Also, they may have been produced by past unregulated activities and events. Exposure to natural sources and to radioactive residues already existing — de facto — in human habitats can be subject to protective actions through a process termed *intervention,* which is intended to decrease the overall exposure of people. Many prolonged exposures to natural sources and almost all prolonged exposures to radioactive residues are *controllable*, i.e., can be restricted by protective measures. Prolonged exposures that are essentially uncontrollable (for instance the exposure to natural radionuclides with metabolic roles in the human body), or unamenable to control (for instance exposure to cosmic radiation), are generally *excluded* from the scope of regulations on radiological protection.

(d) Sources of controllable prolonged exposure, therefore, include most primordial radionuclides in nature and long-lived radioactive residues. These residues may remain in human habitats after the operation and decommissioning of regulated practices and other activities that were conducted either outside any control or under regulatory requirements less stringent than those applying today. They can also result from events — such as accidents — that release long-lived radionuclides into the environment. Commodities for public consumption containing radioactive substances may also be a cause of prolonged exposure.

(e) The recommendations in this report are based on objective assessments of the health risks associated with prolonged exposure levels and on radiological protection attributes of various exposure situations. However, members of the public (and sometimes their political representatives) may have personal and distinct views on the radiation risks attributable to artificial sources of prolonged exposure in relation to those due to natural sources. This usually results in differently perceived needs for

response and a different scale of protection, depending on the origin of the exposure. The public claim for protection is generally stronger when the source of exposure is a technological by-product rather than when it is considered to be of natural origin. Typically elevated prolonged exposures due to natural radiation sources are usually ignored by society, while relatively minor prolonged exposures to artificial long-lived radioactive residues are a cause of concern and sometimes prompt actions that are unnecessary in a radiological protection sense. This reality of social and political attributes, generally unrelated to radiological protection, usually influences the final decision on the level of protection against prolonged exposure. Therefore, while this report should be seen as a provider of *decision-aiding* recommendations mainly based on scientific considerations on radiological protection, the outcome of its advice will be expected to serve as an input to a final (usually wider) *decision-making* process, which may include other societal concerns and considerations. The decision-making process may include the participation of relevant stakeholders rather than radiological protection specialists alone.

(f) The relevant quantity to be used in the assessment of prolonged exposure situations is the *annual* [effective] *dose* attributable to the exposure. A subsidiary quantity used in the context of this report is the summation of the annual doses caused by all the persisting sources of prolonged exposure in a given human habitat; this quantity is termed the ***existing*** *annual dose*. The annual dose that is added to the existing annual dose as a result of a practice is termed the ***additional*** *annual dose*. The annual dose that is removed from the existing annual dose by intervention is termed the ***averted*** *annual dose*. (If the intended meaning is an annual dose that can potentially be prevented from being delivered, as a result of a prospective intervention, the term ***avertable*** *annual dose* is used.)

(g) The principles of the system of radiological protection for practices are the *justification of the practice,* the *optimisation of radiological protection,* with regard to any source within the practice, and the *limitation of individual doses* attributable to the practice. These principles should be applied prospectively at the planning stage of any practice, including those practices expected to deliver prolonged exposures. They are applicable to the design, operation and decommissioning of the practice and its radiation sources. Under certain conditions, sources used in justified practices can be exempted from regulatory requirements if the individual additional annual doses attributable to the source are below around 0.01 mSv in a year.

(h) The justification of a practice delivering prolonged exposure requires that all relevant long-term factors be considered prior to the adoption of the practice. Pertinent factors are those related to the long-lived radioactive substances that are expected to be discharged to the environment or to remain as radioactive residues in human habitats after the decommissioning of the practice. The factors will include the prolonged components of the anticipated additional annual doses, both individual and collective, that are attributable to the discharges and residues.

(i) The optimisation of protection requires the selection of the best radiological protection option for any source, under the prevailing social and economic circumstances. This optimum option will be expected to deliver doses 'as low as reasonably achievable', taking into account economic and social factors. In a justified practice

delivering prolonged exposure, all pertinent long-term factors should be taken into account in the optimisation process. The process may be carried out using the optimisation techniques recommended by the Commission.

(j) The application of the justification and optimisation principles to practices may introduce individual inequities that may be important when prolonged exposures are involved. Inequities are caused by the possibly wide spatial distribution of prolonged exposures, which may involve people who are not direct beneficiaries of the practice. They can also be attributed to the potentially long-term temporal distribution of prolonged exposure, which may affect future generations. It should be noted, however, that inequity between different generations is a more elusive concept than inequity between different individuals at a given time. In order to limit these inequities and to allow for prolonged and transitory exposures to multiple sources, stringent individual dose restrictions should be applied to the prolonged exposure expected to be delivered by individual sources and to the prolonged exposures predicted to be aggregated by all regulated practices. The exposure restrictions to sources are termed *dose constraints;* the exposure restrictions to all regulated practices are termed *dose limits*.

(k) In relation to dose constraints, the Commission continues to recommend that the maximum value of the dose constraint to be used in the optimisation of radiological protection for a single source should be less than 1 mSv in a year, and that a value of no more than about 0.3 mSv in a year would be appropriate. Consideration should be given to exposure situations where combinations of transitory and prolonged exposures or a build-up over time of prolonged exposures from a source could occur. In these situations it should be verified that appropriate dose assessment methods are used for ensuring compliance with the established dose constraint. The assessment should take account of any reasonably conceivable combination and build-up of exposures. If, in a particular situation, such verification of compliance is not feasible, it will be prudent to restrict the prolonged component of the individual dose from the source with a dose constraint of the order of 0.1 mSv in any given year during the operational lifetime of the source.

(l) In relation to dose limits, the Commission continues to recommend that the sum of the prolonged and transitory exposures from all regulated practices should be restricted to a dose limit of 1 mSv in a year. It also emphasises that concerned national authorities and, as appropriate, relevant international organisations should consider situations where there could be a build-up of the prolonged components of the exposures attributable to all regulated practices as a result of the accumulation of radioactive residues from continuing practices. The aim should be to prevent that the aggregated individual additional annual doses attributable to all current practices and to predictable future practices exceed the dose limit of 1 mSv in a year.

(m) The principles of the system of radiological protection for interventions are the *justification of intervention* and the *optimisation of the protective actions*. These principles should be applied to any de facto exposure situations involving controllable prolonged exposure.

(n) The justification of intervention in prolonged exposure situations should be assessed by means of a *decision-aiding process* requiring a positive balance of all

relevant long-term attributes related to radiological protection. (In addition to the avertable annual doses, both individual and collective, other attributes include the following: the expected reduction in the anxiety caused by the situation, the reassurance to be provided by the intervention, and the social cost, harm, and disruption that may be caused by the implementation of the protective actions.) The results of such a decision-aiding process should be used as an input into a *decision-making process* which may encompass other considerations and may involve relevant stakeholders.

(o) The optimisation of protective actions can be performed following the general approach to optimisation of protection recommended by the Commission in the context of practices. The optimum form, scale and duration of the protective actions should be selected from the justified options of intervention. For some prolonged exposure situations, a restricted use of human habitats can be the outcome of the optimisation process.

(p) National authorities and, as appropriate, relevant international organisations should predetermine *specific reference levels* (such as *intervention levels, action levels* and *intervention exemption levels)* for particular prolonged exposure situations amenable to intervention. They can be conveniently expressed in terms of the avertable annual dose, or some related subsidiary quantity. The use of predetermined specific reference levels can facilitate timely decisions on interventions and the effective deployment of resources; however, an improper use may lead to inconsistencies with the principles of justification and optimisation.

(q) The use of *generic reference levels* for interventions is also recommended. These levels can conveniently be expressed in terms of the existing annual dose. They are particularly useful when intervention is being considered in some situations, such as exposures to high natural background radiation and to those radioactive residues that are a legacy from the distant past. Generic reference levels, however, should be used with great caution, as discussed in Chapters 4 and 5. If some controllable components of the existing annual dose are clearly dominant, the use of generic reference levels should not prevent protective actions from being taken to reduce these dominant components. These actions can be triggered by either specific reference levels or case-by-case decisions following the requirements of the system of radiological protection for interventions. Nor should the use of the generic reference levels encourage a 'trade-off' of protective actions among the various components of the existing annual dose. A low level of existing annual dose does not necessarily imply that protective actions should not be applied to any of its components; conversely, a high level of existing annual dose does not necessarily require intervention.

(r) With these provisos, it is considered that an existing annual dose approaching about 10 mSv may be used as a generic reference level below which intervention is not likely to be justifiable for some prolonged exposure situations. Below this level, protective actions to reduce a dominant component of the existing annual dose are still optional and might be justifiable. In such cases, action levels specific to particular components can be established on the basis of appropriate fractions of the recommended generic reference level. Above the level below which intervention is

not likely to be justifiable, intervention may possibly be necessary and should be justified on a case-by-case basis. Situations in which the annual (equivalent) dose thresholds for deterministic effects in relevant organs could be exceeded should require intervention. An existing annual dose rising towards 100 mSv will almost always justify intervention, and this may be used as a generic reference level for establishing protective actions under nearly any conceivable circumstance.

(s) Challenging situations of prolonged exposure include those where high levels of natural background radiation are present and where the exposure is controllable. One such situation is the presence of elevated ambient indoor levels of the noble gas isotope radon-222. The Commission's recommendations on '*Protection against Radon-222 at Home and at Work*' (ICRP, l993b) remain valid and are fully applicable for controlling prolonged exposure to radon-222 in dwellings. Another case is the presence of natural gamma-emitting radionuclides in building materials and in the ground. Concerned national authorities and, as appropriate, relevant international organisations should derive standardised intervention exemption levels for activity concentrations of specific radionuclides in building materials, taking into account the recommendations for commodities containing radioactive substances presented in this report (see paragraph x). For areas experiencing controllable exposures to high levels of natural gamma radiation emitters in the ground, the use of appropriate fractions of the recommended generic reference levels of existing annual dose should provide guidance for the solution of practical problems.

(t) Other difficult prolonged exposure situations are caused by the presence of radioactive residues in human habitats. These residues may result from the discontinuation and decommissioning of a regulated practice or from other past human activities and events, including accidents. For regulated practices, the recommended dose constraints and dose limits should be applied prospectively to the prolonged exposure expected to remain after the discontinuation of the practice — for instance, at the site of a decommissioned installation. (In principle, the applicable dose constraint may be expected to be no higher than the dose constraint used during the operational phase of the practice. However, there is not necessarily a common basis on which to presume equality between the dose constraint applied before the discontinuation of a practice and that applied afterwards. If the operational dose constraint was very low, maintaining it in the post-decommissioning phase could introduce an unreasonable restriction.)

(u) For radioactive residues from other past human activities and events that were not regulated as practices, the need, form, scale, and duration of protective actions should be determined on a case-by-case basis. This should be done following the recommended principles of justification of intervention and optimisation of the protective actions, rather than through pre-selected individual dose restrictions. If necessary, the recommended generic reference levels of existing annual dose may be used as guidance. However, in cases where the origins of the situation are traceable and where those who produced the residues can still be made retrospectively liable for the protective actions, national authorities may consider applying a specific ad hoc restriction to the individual doses attributable to these

residues, constraining the resulting doses to levels below those resulting from the optimisation process. For this purpose, additional protective actions may be required from those who created the situation. Such specific dose restrictions, however, may still be higher than the dose constraints and dose limits applied to practices. Residues that are deemed not to require protective actions should not be subject to further restrictions.

(v) In some circumstances, radioactive residues can be very sparsely distributed in the environment, usually as 'hot particles', giving rise to situations of prolonged *potential* exposure. These are situations where there is the potential but not the certainty that the exposure will actually occur. For these situations, action levels should be derived on the basis of the unconditional probability that members of the public would develop fatal stochastic health effects attributable to the exposure situation. That probability should be assessed by combining the following probabilities: the probability of being exposed to the hot particles; the probability of incorporating a hot particle into the body as a result of such exposure; the probability of incurring a dose as a result of such incorporation; and, the probability of developing a fatal stochastic effect from that dose. (These probabilities should be integrated over the full range of situations and possible doses.) In establishing such action levels, consideration should be given to the possibility that localised deterministic effects may also occur as a result of the incorporation of hot particles.

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

(x) One cause of prolonged exposure is the presence of long-lived radionuclides in commodities for public use. When the radionuclides are attributable to a practice, their levels in the commodities should be controlled through the principles of the Commission's system of radiological protection for practices. In other cases, they should conceptually be subject to intervention. Mainly due to the globalisation of markets, *intervention exemption levels* of radionuclides in commodities cannot be established on a case-by-case basis; rather, they need to be standardised.

(y) It is not likely that several types of commodities would be simultaneous sources of high prolonged exposure to any given individual. On the basis of this presumption, a generic intervention exemption level of around 1 mSv is recommended for the individual annual dose expected from a dominant type of commodity, such as some building materials which may in some circumstances be a significant cause of prolonged exposure.

(z) On the basis of this recommendation, concerned national authorities and, as appropriate, relevant international organisations should derive radionuclide-specific intervention exemption levels for individual commodities, in particular for specific building materials. It should be noted that intervention exemption levels should not be used, either explicitly or implicitly, for relaxing the limits imposed on the activity of radionuclides that may be released from practices. In particular, they should not be used for clearing the recycling of materials resulting from the decommissioning of practices (these situations are better handled with the criteria of exemption for practices).

(aa) An exceptionally difficult situation is presented by commodities produced in an area affected by radioactive releases from an accident and containing radioactive substances attributable to the releases. If the corresponding activity levels are higher than those in produce from neighbouring areas, issues of market acceptance could arise — particularly if there are transboundary movements of the commodities. (The Codex Alimentarius Commission of WHO/FAO (1991) adopted generic intervention exemption levels for radionuclides in foodstuffs following an accident. These levels have been incorporated into international radiological protection standards. They would lead to individual doses of up to a few millisieverts per annum to those who consume the foodstuffs.)

(ab) If the annual doses in the area affected by the accident are acceptable because the intervention strategy has been optimised, the situation outside the affected area should also be acceptable because the individual annual doses elsewhere from the use of commodities produced in the affected area would normally not be higher than those in the affected area. If the restrictions on commodities produced in the area affected by the accident have not been lifted, production of the restricted commodities should not be restarted; conversely, if the restrictions have been lifted, production can be restarted. If an increase in production is proposed, it could proceed subject to appropriate justification. In circumstances where restrictions have been lifted as part of a decision to return to 'normal' living, the resumption and potential increase of production in the affected area should have been considered as part of that decision and should not require further consideration.

(ac) The quantitative recommendations provided in the report are summarised in the following Table. The information is presented in an extremely simplified form and is not amenable to comparison. In its upper part, the Table shows quantitative recommendations in terms of individual *existing* annual dose; the lower part presents quantitative recommendations in terms of individual *additional* annual dose. Therefore, in these two parts, the dose ranges are expressed in different quantities and cannot be compared. Furthermore, the Table does not include any reference to

specific intervention and action levels of averted annual dose nor of collective doses. It is important to refer to the discussion in Chapters 4 and 5 before applying the numerical values in this Table.

Concept	Quantity	Value (mS)
Generic reference level for interventions almost always justifiable	Existing annual dose	$<\sim$100
Generic reference level for interventions not likely to be justifiable	Existing annual dose	$<\sim$10
Exemption from intervention in commodities	Additional annual dose	$\sim$1
Dose limit for practices	[Aggregated] Additional annual dose	1
Dose constraint for practices	Additional annual dose (for the prolonged component)[a]	$<\sim$1 & $\sim$0.3 ($\sim$0.1)
Exemption for practices	Additional annual dose	$\sim$0.01

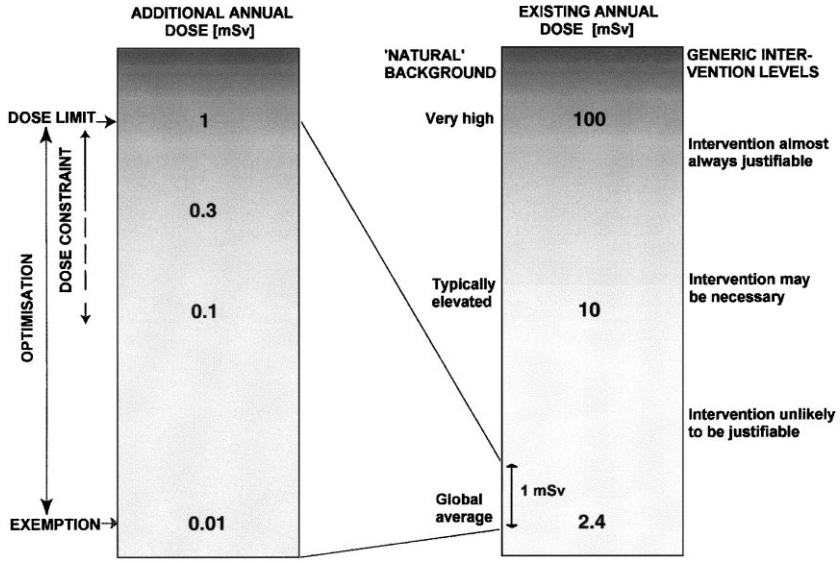
[a] To be considered if dose assessment methodologies to ensure compliance under any conceivable situation of combination of doses is not available.

(ad) In order to gain some perspective it is illustrative to present the values in the above table, both the dose restrictions in terms of additional annual dose and the upper bound of the generic intervention levels of existing annual dose, vis à vis reported levels of 'natural' background dose. This is schematically represented in the figure below.

(ae) The quantitative recommendations in this report will be difficult to implement unless a number of issues in the estimation of the exposures are carefully taken into account. Prolonged exposures are generally expected to be assessed on the basis of the mean annual dose in the *critical group*. However, it is to be noted that occasionally it may be more difficult to estimate this dose than the dose to an identifiable 'maximally' exposed individual. Long term scenarios must be defined to characterise the individuals exposed and the ways in which they are exposed.

(af) Quantification of uncertainty should be an integral part of the estimation of the annual doses. Whenever possible and appropriate, annual doses should be reported as a distribution of possible values rather than as single point values. It should be kept in mind that radioactive residues are usually unevenly distributed, creating situations of heterogeneous prolonged exposure. These need to be addressed on a case-by-case basis by making realistic assumptions about the pattern of people's exposure.

(ag) The selection of methods for evaluating heterogeneous exposure will depend on the situation and the objectives of the evaluation. The evaluation of annual doses in prolonged exposure situations should generally be based on the assumption of unrestricted use of the site or commodity affected. This assumption implies that all exposure pathways that could realistically be in operation at any time in the future should be accounted for.


ADDITIONAL ANNUAL DOSE [mSv]
EXISTING ANNUAL DOSE [mSv]
'NATURAL' BACKGROUND
GENERIC INTER-VENTION LEVELS
DOSE LIMIT
1
Very high
100
Intervention almost always justifiable
DOSE CONSTRAINT
0.3
OPTIMISATION
Typically elevated
Intervention may be necessary
0.1
10
Intervention unlikely to be justifiable
1 mSv
Global average
EXEMPTION
0.01
2.4

1. INTRODUCTION

1.1. Background information

(1) This report provides guidance on the application of the Commission's system of radiological protection to situations of *prolonged exposure*[1] to ionising radiation (or *radiation* for short). Prolonged exposures are adventitiously and persistently incurred by the public over long periods. Their distinguishing characteristics are that they are incidental to situations in which members of the public may find themselves, and that the consequent average annual dose is usually more or less constant or decreases slowly over the years. A situation of prolonged exposure is expected to affect at least one generation of people, i.e., to last around a decade or more. (For example, the rate of decrease in the annual dose due to a prolonged exposure is no more than a few per cent per year.)

(2) Typical *sources*[2] of prolonged exposure are the so-called '*natural*'[3] sources such as cosmic radiation and radionuclides in primordial decay chains. Some *'artificial*'[3] sources may also deliver prolonged exposure; for example, long-lived *radioactive residues*[4] from human activities. It is to be noted that radioactive residues may contain both natural and artificial radionuclides. In situations of prolonged exposure, it may be difficult to separate the exposure attributed to the artificial component from that due to the natural component; moreover, protective measures against the artificial component can affect the exposure due to the natural component and vice versa.

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[1] The Commission uses the term *exposure* in a generic sense to mean the process of being exposed to radiation or radionuclides, the significance of exposure being determined by the resulting radiation *dose* (ICRP 1991 a, paragraph S4). The adjective *prolonged* is used in this report to indicate persistence over time. The adjective *chronic* has been used in international radiation safety standards (IAEA 1996) and in technical literature to describe exposures to radiation that persists over time; however, because *chronic* is sometimes misinterpreted to indicate severity rather than persistence, it is not used in this report.

[2] The Commission uses the term *source* to indicate sources of radiation, such as radiation generators and radionuclides (e.g. as sealed radioactive materials), and also, more generally, to indicate the cause of exposure to radiation or to radionuclides in radioactive substances, and not necessarily an individual physical source of radiation. For instance: if radioactive materials are released from an installation to the environment, the installation as a whole may be regarded as a source; if they are already dispersed in the environment, the portion of them to which people are exposed may be considered a source.

[3] Because of the ubiquity of radiation, it is useful to deal separately with the primordial and the human made radiation and radioactive materials. Two fundamental properties of matter, radiation and radioactivity, have been traditionally qualified as '*natural*' and '*artificial*', respectively; but the distinction is peculiar and certainly not precise. For instance, some radionuclides which are primordial, and are therefore considered 'natural', can also be produced 'artificially' (such as technologically enhanced concentrations of radionuclides in naturally occurring radioactive materials — usually termed NORMs). Others which are produced by humans, and are therefore considered 'artificial', can also be produced by natural phenomena (such as the natural fission process which took place at Oklo, Africa). More controversial is the application of these qualifiers to radiation sources and even more so to exposures.

[4] The Commission uses the term *radioactive residues* to mean radioactive materials that have remained in the environment from early operations (including past practices) and from accidents (ICRP 1991a, paragraph 219). The Commission uses the term *radioactive waste* to mean any [radioactive] material that will be or has been discarded, being of no further use (ICRP 1997c, paragraph 3); therefore, radioactive residues are a part of radioactive wastes in general.

(3) Radiation exposure may be detrimental to health regardless of its origin, whether natural or artificial. For this reason, the Commission's estimates of radiation risks do not depend on the source of exposure but on the exposure level regardless of its origins. Therefore, the recommended degrees of protection are based on the circumstances giving rise to the exposure, and not on whether the exposure originates from a natural or an artificial source. However, the Commission notes that members of the public (and sometimes its political representatives) may have personal and distinct views on the radiation risks attributable to artificial sources of prolonged exposure in relation to those due to natural sources. This usually results in differently perceived needs for response and a different scale of protection, depending on the origin of the exposure. The public claim for protection is generally stronger when the source of exposure is a technological by-product rather than when it is considered to be of natural origin. Typically elevated prolonged exposures due to natural radiation sources are usually ignored by society, while relatively minor prolonged exposures to artificial long-lived radioactive residues may be a cause of concern and sometimes prompt unnecessary actions.

(4) The Commission provides recommendations on radiological protection on the basis of objective assessments of the health risks associated with exposure levels and relevant attributes of various exposure situations. However, it also recognises (and, in this report, addresses) the reality of social and political attributes, generally unrelated to radiological protection, which usually influence the final decision on the level of protection to be provided against prolonged exposure. Therefore, while this report should be seen as a provider of *decision-aiding* recommendations mainly based on scientific considerations on radiological protection, the outcome of its advice could also serve as an input to the final (usually wider) *decision-making* process which may include other societal concerns and considerations. Many situations of prolonged exposure are integrated into the human habitat and the Commission anticipates that the decision-making process will include the participation of relevant *stakeholders*,[5] rather than radiological protection specialists alone. This process may take account of attributes other than those directly related to radiological protection.

(5) One important issue arising from this wider decision-making approach lies in the quantification of prolonged exposure. The Commission has traditionally recommended restrictions on the expected additional exposure attributable to a particular source or group of sources and also criteria for averting exposure in de facto situations (such as those remaining after an accident that released radionuclides to the environment). It has not, however, provided recommendations for judging the total, '*existing*', environmental exposure prevailing in a given human habitat. The quantification of the Commission's recommendations in terms of marginal rather than total exposures is based on the fact that only the marginal exposures are controllable through regulation by the competent authorities, who cannot influence the total existing exposure as a whole. For situations of prolonged

[5] The term *stakeholder* is used in the report to mean those parties who have interests in and concern on the prolonged exposure situation.

exposure, however, there is perceived to be a need for not only controlling the relevant marginal components of exposure, but also gaining a feeling for how safe the existing exposure is in the environment of concern. The Commission has therefore decided to provide in this report *generic reference levels* quantified in terms of the existing exposure in the human habitat. They are aimed at facilitating judgements by decision-makers in relation to decisions on actions for radiological protection in prolonged exposure situations.

1.2. Prolonged exposure

(6) The presence of primordial radionuclides in human habitats, together with the cosmic radiation permeating the Earth and the cosmogenic radionuclides continuously generated by this radiation, have always been a source of prolonged exposure. This exposure eventually came to be loosely described as 'natural'. Over the course of time, some aspects of human behaviour, such as living in enclosed dwellings, have generally enhanced the levels of 'natural' prolonged exposure mainly due to an increase in the exposure to some radionuclides in the progeny of the primordial chains. For example, exposure to isotopes of radon in indoor air has increased due to improved insulation in dwellings and exposure to isotopes of radium has increased owing to their presence in building materials. In recent years, industrial development has further increased the 'natural' exposure of people by technologically enhancing the concentrations of radionuclides in *n*aturally *o*ccurring *r*adioactive *m*aterials *(NORMs)*. Typical activities in which this occurs include the mining and milling of ores and sands containing natural radionuclides, extractive industries for energy production and the use of phosphate rock.

(7) Following the discovery of radiation and radioactivity, society introduced a number of human activities that make specific use of radiation sources and their properties. These sources and the exposure they deliver are usually described as 'artificial'. The exposure due to artificial sources is additional to prolonged exposure due to natural sources, Usually this additional exposure does not persist over long periods of time, being of a *transitory*[6] nature (sometimes even of an *acute* nature). Some artificial sources, however, may cause prolonged exposure as well, because radioactive residues remaining in the environment after the use of the source may contain long-lived radionuclides.

[6] The term *transitory exposure* is used in the report to mean all exposures that do not persist over long periods of time, i.e. that are not *prolonged exposure*. It encompasses the relatively longer term exposures caused by the potential build-up of transitory exposures over time. It is to be noted that the distinction between transitory and prolonged exposures is not precise. While acute exposures due to radiation generators are clearly *transitory* and permanent exposures caused by most natural sources are clearly *prolonged*, between these extremes the distinction becomes a matter of definition. In this report, exposures caused by radionuclides with a half-life shorter than around a decade (and which are not progeny of a long-lived radionuclide) are considered transitory and are excluded from the scope of the report. There are no absolutely permanent exposures: background exposure changes over time; other exposures decrease owing to radioactive decay and to natural processes such as erosion.

(8) While many prolonged exposures to natural sources and almost all prolonged exposures to radioactive residues are *controllable*,[7] a number of prolonged exposures are either *uncontrollable* (for example exposure to natural radionuclides with metabolic roles in the human body), or essentially *unamenable to control* (for example exposure to cosmic radiation at ground level). Prolonged exposures that are uncontrollable, or unamenable to control, are generally subject to *exclusion*[8] from the scope of regulations on radiological protection.

(9) Situations of controllable prolonged exposure, therefore, mainly result from the presence of natural and artificial long-lived radionuclides (and their short-lived progeny) in the human habitat. They can be the anticipated result of radioactive residues expected to remain after the termination of regulated human activities that are termed *practices*[9] by the Commission. They may also already exist — de facto — in human habitats, because of the presence of those long-lived radionuclides not only in nature but also in radioactive residues from unregulated past activities and events. The existing prolonged exposures may be amenable to reduction by *protective actions*,[10] through a process that is termed *intervention*[9] by the Commission.

(10) Long-lived radionuclides may also be incorporated (and even concentrated) into *commodities*[11] for public consumption, particularly into building materials, thereby becoming a source of prolonged exposure. They may also be attached to finely divided microparticles (termed *hot particles)* which, if sparsely distributed in the environment, may become a source of prolonged *potential* exposure.[12]

(11) Fig. 1 presents a schematic illustration of various sources of prolonged exposure. With the exception of cosmic radiation, all the sources presented are generally controllable. They include a number of natural and artificial sources. The sum of exposures to the sources present in a human habitat result in an *existing* exposure to the individuals living there. Annex A provides brief descriptions of some relevant situations involving prolonged exposure and of the consequent radiation doses. The

[7] The term *controllable* is used in the report to denote exposures that can be restricted by protective measures.

[8] The term *exclusion* as used in this report refers to [exposures] not being regulated because they are either uncontrollable or unamenable to control. Its paronym *exemption* as used here refers to exempting [sources] from compliance with some specific regulatory requirement, such as the requirement to notify, register, or license a source. The Commission has recommended criteria for implementing both concepts (see paragraphs D12–Dl8).

[9] The concepts of *practices* and *interventions* were introduced by the Commission in *Publication 60* (ICRP 1991a, paragraph 106), as 'human activities [that] increase the overall exposure to radiation...' and 'human activities [that] can decrease the overall exposure...', respectively. The concepts are further discussed in Section 1.4 and Annex D of this report.

[10] The term *protective actions* is used in this report to mean suitable steps taken to avert doses through intervention. In the literature, the terms *remedial actions, protective measures, remedial measures* and *countermeasures* have also been used.

[11] The term *commodity* is used in this report to mean produce that can generally be used or consumed by the public, e.g., building materials, foodstuffs, as well as other consumer products.

[12] The concept of *potential exposure* was introduced by the Commission in *Publication 60* (ICRP 1991a, paragraph 111), as an exposure having the potential 'but not the certainty that it will occur'. The concept was further elaborated in *Publication 64* (ICRP 1993a) and *Publication 76* (ICRP 1997b).

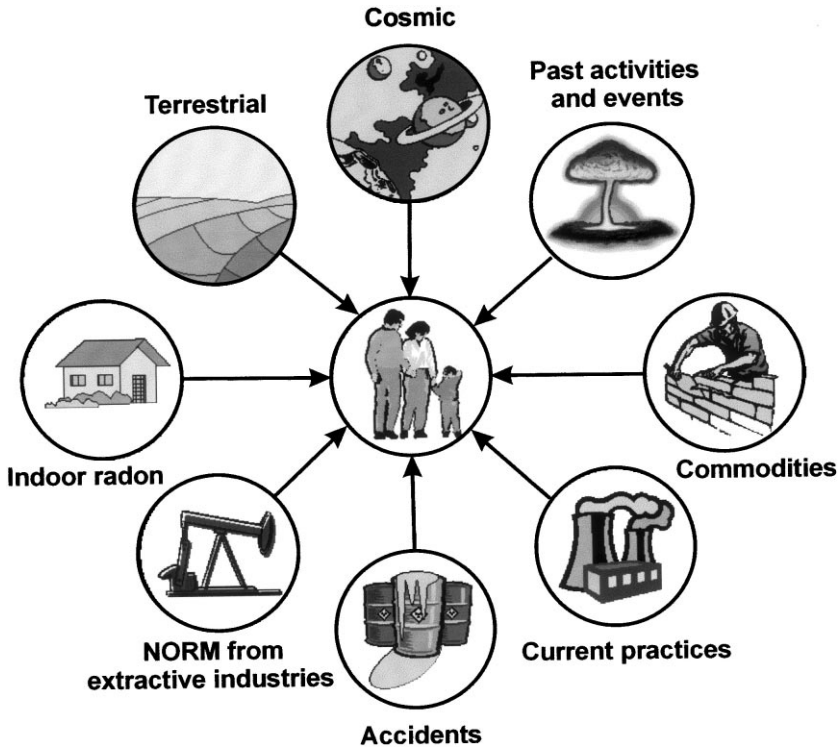

Fig. 1. Schematic presentation of various sources of prolonged exposure.

descriptions are based on information provided by the United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR.[13]

1.3. Objective

(12) ***Basis***: This report is based on the Commission's latest comprehensive set of radiological protection recommendations, *Publication 60* (ICRP 199la).[14] After issuing these general recommendations, the Commission became increasingly interested in prolonged exposure situations involving the radionuclide radon-222 and issued specific recommendations on '*Protection against Radon-222 at Home and at*

[13] The information from UNSCEAR is mainly taken from the latest comprehensive report published by UNSCEAR (1993). However some data were updated taking into account information from drafts of the forthcoming report of the Committee (UNSCEAR 2000) kindly supplied by the UNSCEAR Secretariat.

[14] Before 1959, the Commission's recommendations were published as papers in various scientific journals. In the Commission's present series of publications, earlier radiological protection recommendations, now superseded by *Publication 60* (ICRP 1991a), were given in *Publication 1* (ICRP 1959), *Publication 6* (ICRP 1964), *Publication 9* (ICRP 1966), *Publication 26* (ICRP 1977), and a series of statements amending *Publication 26* (ICRP 1978, 1980, 1984, 1985a, 1987a, 1987b).

Work' (ICRP 1993b). However, the Commission has not provided guidance for the application of its latest recommendations to prolonged exposure situations in general. Furthermore, it has noted that there seems to be some confusion in the use of its recommendations in a number of these situations.

(13) ***Aim***: The Commission has therefore decided to issue this report with the main aim of providing consistent guidance for applying its system of radiological protection to situations in which members of the public are subject to controllable prolonged exposure. Exposures occurring during or relatively soon after the cessation of a regulated practice or of an unregulated past activity or event are evidently controllable by the Commission's system of radiological protection. However, in cases in which the exposures have been tolerated as a feature of the habitat, or the link to the initiating cause of the exposure situation is vague, the application of the system of radiological protection is not straightforward. Therefore, a complementary objective of the report is to provide generic guidance for dealing with exposure situations for which the application of the system of radiological protection is not evident, for instance situations of exposure to natural sources and other situations where the exposure is weakly linked to an original cause. The report also provides further advice for dealing with some particular sources of prolonged exposure.

(14) ***Audience***: As is customary, the Commission intends this report to be of help to responsible administrations and regulatory and advisory agencies with competence in radiological protection, at regional, national, and international levels. The report provides guidance to these bodies on the fundamental principles on which appropriate radiological protection of the public against prolonged exposure may be based. Different regulatory conditions apply in different countries and the Commission, therefore, wishes to emphasise that the report should not be viewed as a universal regulatory text on the control of prolonged exposures. The Commission considers that the report may also be of interest to professionals not necessarily specialised in radiological protection, who sometimes are involved in decision-making processes relating to prolonged exposure situations. For this reason, the report is exceptionally supplemented with a number of Annexes and several footnotes, which are intended to facilitate the understanding of the Commission's terminology and policies in the context of prolonged exposure.

1.4. Scope

(15) ***Extent***: This report addresses only the controllable prolonged exposure component of the *public exposure*.[15] Its scope excludes all transitory exposures, which are expected to cease soon after the cause of the exposure ends. Therefore, for instance, practices that do not generate prolonged exposures are not included in the scope of the report. Types of exposure other than public exposure, such as *medical*

[15] The Commission uses a division into three types of exposure: *occupational exposure,* which is the exposure incurred at work, and principally as a result of work; *medical exposure,* which is principally the exposure of patients as part of their diagnosis or treatment; and *public exposure,* which comprises all other exposures (ICRP 1991a, paragraph 109).

exposure[15] (and exposures of users of spas) and *occupational exposure*[15] are also excluded from the scope as they are not adventitious, nor are they generally of a persisting nature. Moreover, the report does not address prolonged exposure situations that may be expected to arise as a result of *radioactive waste disposal*[16] from practices. The long-term potential exposures and other issues associated with the disposal of radioactive waste are more elusive than the problems presented by actual exposure situations such as those involving prolonged exposure. The Commission, therefore, has decided to publish separate recommendations on radioactive waste disposal: *Publication* 46 (ICRP 1985b), *Publication 77* (ICRP 1997c), and *Publication 81* (1998). Nevertheless, the content of this report is fully coherent and consistent with the Commission's recommendations on radioactive waste disposal.

(16) ***Content***: Following this introductory Chapter, Chapter 2 addresses the general application of the Commission's system of radiological protection to the control of prolonged exposure situations attributable to practices. Chapter 3 addresses the general application of the system of radiological protection to interventions in prolonged exposure situations. Chapter 4 provides recommendations on generic reference levels, qualified in terms of the existing annual dose, for interventions in prolonged exposure situations. Chapter 5 addresses the application of the recommendations to some specific prolonged exposure situations and discusses a number of particular issues that have caused concern, namely: natural radiation sources that may give rise to high annual doses; the restoration and rehabilitation of sites where there have been human activities involving radioactive substances; the return to 'normality' following an accident which has caused the release of radioactive substances to the environment; and the global marketing of commodities for public consumption which may contain relatively high levels of radioactive substances. Chapter 6 provides a summary of the quantitative recommendations and briefly discusses issues in the estimation of prolonged exposure. Four Annexes complete the content of the report. Annex A has already been mentioned. Annex B summarises the Commission's recommendations on radiological protection quantities that are relevant for prolonged exposure situations. Annex C reviews radiation-induced health effects taking account of the characteristics of prolonged exposure. Annex D discusses concepts of the Commission's system of radiological protection, as they are used in this report in the context of prolonged exposure.[17]

[16] The Commission uses the term *radioactive waste disposal* to mean disposal of radioactive waste with no intention of retrieval (ICRP 1997c, paragraph 3).

[17] The Annexes refer to the relevant Commission recommendations, bringing out the aspects that are of direct importance for prolonged exposure. These references are intended only as a reminder of the detailed recommendations in *Publication 60* (ICRP 1991a). For some aspects, reference is also made to *Publication 63* on protection of the public in a radiological emergency (ICRP 1991b); *Publication* 64 on protection from potential exposure (ICRP 1993a); *Publication 65* on protection against radon-222 (ICRP 1993b); *Publication 76* on protection from potential exposures as applied to selected radiation sources (ICRP 1997b); and *Publication 77* on protection policy for the disposal of radioactive waste (ICRP 1997c).

1.5. Basic framework

(17) ***Radiation quantities***: In the light of the considerations outlined in Annex B, the Commission considers that the relevant dosimetric *quantity*[18] for controlling prolonged exposures is the *annual effective dose*. This is the sum of the time integral, over a year, of the effective dose rate due to external irradiation caused by the prolonged exposure situation and the committed effective dose due to internal contamination caused by all intakes, during that year, of the long-lived radionuclides (and their short-lived progeny) involved in the situation (see paragraph B.11). The annual effective dose, unless otherwise indicated, will be simply termed *annual dose* in this report. The unit used in this report for the quantity *'annual dose'* is a thousandth of a sievert (Sv), or millisievert (mSv). A subsidiary quantity used within the context of prolonged exposure is the *existing annual dose* caused by all persisting sources of prolonged exposure in a given situation (see paragraph B.14).[19] Other subsidiary quantities that will be used in this report are: the *additional annual dose*[20] caused by practices (see paragraph B.15) and the *averted annual dose*[21] precluded by an intervention. If the intended meaning is of an annual dose that can potentially be precluded, as a result of a prospective intervention, the term *avertable annual dose* is used (see paragraph B.16).

(18) *Radiation induced health effects:* In the light of the information outlined in Annexes A and C, the Commission considers that, in common prolonged exposure situations, the annual dose is usually well below the threshold for *deterministic effects*[22] (see paragraph C.4) and that, therefore, *stochastic*

[18] The term *quantity* is used in this report to mean radiation-related properties that can be measured, assessed, or estimated, such as the *activity* and the *dose*, rather than the amount of these.

[19] The term *existing annual dose* is used to mean all of the existing and persisting whole annual doses incurred by individuals in a given location. The adjectives *total, environmental, ambient,* and *background* are also sometimes used to describe this concept, but will not be used for that purpose in this report. The adjective *total* could be misunderstood to describe the sum of transitory and prolonged doses; *environmental* and *ambient* could be confused to describe a dose in the environment rather than in people (moreover, *ambient* has been used by the International Commission on Radiological Units and Measurements to denote an operational quantity); and, *background* has been commonly understood as describing exposures caused by natural radiation sources only, although a fraction of such exposure may be artificial (such as the exposure to fallout from historical nuclear weapons testing). Therefore, in order to avoid confusion, the qualifier *existing* will be used in this report. It should be noted that there is always an *existing annual dose* before the introduction of a practice or the undertaking of an intervention, and a *residual* existing annual dose after the cessation of the practice or the completion of the intervention.

[20] The term *additional annual dose* is used to mean the prolonged annual dose that is added to the existing annual dose as a result of the implementation of a practice.

[21] The term *averted annual dose* is used to retrospectively refer to the reduction in the existing annual dose brought about by an intervention, i.e., the prolonged annual dose that has been precluded by a protective action.

[22] *Deterministic effects* are health effects resulting from the killing of cells by radiation, 'which, if the dose is large enough, causes sufficient cell loss to impair the function of the tissue. The probability of causing such harm will be zero at small doses, but above some level of dose (the threshold for clinical effects) the probability will increase steeply to unity. Above the threshold, the severity of the harm will increase with increasing dose' (ICRP 1991a, paragraph S6).

effects[23] are the only radiation-induced health effects of concern (see paragraphs C.5–C.7). Moreover, the Commission also considers that, in common prolonged exposure situations, the *effects of antenatal* [prolonged] *exposure*[24] should not be a cause of additional concern. (This is because, in these situations, the exposure period for antenatal exposure should be much shorter than that for the exposure after birth, which is expected to be of several years at least; see paragraph C.8 and paragraph C.9).

(19) ***The Commission's system of radiological protection***: The Commission recommends that all types of radiation exposure, i.e. transitory and prolonged exposure, should be controlled through its system of radiological protection. Annex D presents aspects of the system that are of relevance for prolonged exposure situations. A brief summary of important issues follows:

- *Scope of the system of radiological protection:* Because its recommendations are advisory, the Commission does not need to provide a formal statement of the scope of its system of radiological protection. Broadly, however, it intends that its system should apply to controllable exposures. As indicated before, a number of prolonged exposure situations are essentially uncontrollable, or unamenable to control. These exposures are subject to exclusion from the system's scope (see paragraphs D.12–D.14).
- *Aim of the system of radiological protection:* The primary aim of the system of radiological protection is to provide an appropriate standard of protection for human beings without unduly limiting the beneficial practices giving rise to exposure, including prolonged exposure. To achieve this aim, the system is intended to prevent the occurrence of deterministic effects, by keeping doses below the relevant thresholds, and also to ensure that all reasonable steps are taken to reduce the induction of stochastic effects, by keeping doses as low as is reasonably achievable, economic and social factors being taken into account. These statements of policy imply the protection both of individuals and of populations, and have particular impact on the control of prolonged exposures owing to the wide spatial and temporal distribution that these types of exposures may have (see paragraphs D. 1–D.2).[25]

[23] *Stochastic effects* are health effects that may occur as a result of modifications to cells caused by radiation exposure. 'Modified somatic cells may subsequently, after a prolonged delay, develop into a cancer... If the damage occurs in a cell whose function is to transmit genetic information to later generations, any resulting "hereditary" effects are expressed in the progeny of the exposed person' (ICRP 1991a, paragraph S8).

[24] *Effects of antenatal exposure* are radiation health effects of exposure incurred before birth that will express either before birth, on the conceptus, embryo, or foetus, or after birth, in the child or the adult, or in his or her descendants.

[25] As doses from prolonged exposures are in the range for which the most likely relationship between an increment in dose and the resulting increment in the probability of stochastic effects is a proportional one, i.e., linear, non-threshold, it follows that the radiation detriment expected from an additional annual dose attributable to one source of prolonged exposure is unaffected by additional annual doses from other sources. Consequently, the additional annual doses (and the associated radiation detriments) from different sources can be dealt with separately and, if necessary, summed to give an existing annual dose, i.e., total dose, and therefore total detriment. It should be emphasised that a relevant policy implication of

- *Source-related and individual-related considerations:* The processes causing prolonged exposures can be modelled as a network of events and situations. Radiation and radioactive material passes continuously through environmental pathways, some pathways being common to many sources, and individuals — possibly many individuals — are exposed owing to a single original source. In dealing with the network of prolonged exposure pathways, a distinction is drawn between *source-related* considerations and *individual-related* considerations. Source-related considerations apply to the protection of individuals and populations against the prolonged exposure component arising from a given source. Individual-related considerations apply to the protection of individuals against the overall prolonged exposure from several sources that give rise to the existing dose. In a number of prolonged exposure situations, members of the public may be exposed to more than one significative source (see paragraphs D.4–D.8).
- *Practices and interventions:* A relevant aspect of the system of radiological protection is its categorisation of radiation exposure situations into *practices* and *interventions*. An unambiguous understanding of this categorisation is essential for applying the Commission's recommendations to prolonged exposure situations. On the one hand, a decision can be made to introduce a new activity involving radiation sources with the aim of gaining some benefit and despite the fact that its introduction will cause some additional dose to people (i.e., additional doses to the existing doses that people are already receiving). Such new activities, which are a matter of deliberate choice, are categorised as *practices* by the Commission. On the other hand, existing doses may need to be averted by, for instance, modifying the pathways between the sources of exposure and people or by moving people away from the sources. Such actions, which respond to de facto exposure situations that are not a matter of choice but are already present, are those categorised as *interventions* by the Commission.[26]
- *Applying the categorisation between practices and interventions:* The system of radiological protection is devised to deal separately with practices and intervention. However, the separate categorisation of some prolonged exposure

the linear non-threshold dose–effect relationship is that some finite radiation risk must be accepted at any level of protection; i.e., zero risk is not a protection option. This is a particularly important consideration in protection against prolonged exposure, among other reasons because of the ubiquitous presence of natural radiation sources. The simple proportional relationship also has some other important practical implications: it allows annual doses within an organ or tissue of the body to be averaged over that organ or tissue; and it allows doses received at different times to be summed.

[26] The Commission's concepts of practices and interventions have evolved over recent years. In *Publication 60, practices* were defined as the human activities that 'increase the overall exposure to radiation' and *interventions* were defined as 'other human activities [that] decrease the overall exposure by influencing the existing [causes of exposure]' (ICRP 1991a, paragraph 106). In *Publication 73,* the Commission further explained its intentions, indicating that while in *practices* 'the radiation sources are deliberately used and are under control', in *interventions* 'the existence of the sources is not a matter of choice [as they already exist' (ICRP 1996b, paragraph 32). (In practices, natural sources may be used but these sources are under control.)

situations seems to have been a cause of misunderstanding. One problem appears to be the difficulty of applying the categorisation to natural radiation sources. For some natural exposure situations, the Commission's system of radiological protection for current practices is applicable because the exposures are the result of the introduction of human activities which are a matter of deliberate choice. Conversely, for most natural exposure situations, it is the system of radiological protection for interventions which is applicable because the exposure exists de facto, i.e. it is not a matter of choice and can only be reduced through protective actions. Another problem relates to situations involving long-lived radioactive residues. Prolonged exposure caused by residues from practices would be controlled as a part of the practice; conversely, prolonged exposure caused by residues from past activities which were not controlled as a practice, and from accidents, would be addressed as an intervention. Since some confusion has been created by these problems, the Commission has decided to describe in detail its intentions in categorising situations as practices and interventions; this description is provided in Annex D, paragraphs D.19–D.24.

2. APPLICATION OF THE SYSTEM OF RADIOLOGICAL PROTECTION TO PRACTICES RESULTING IN PROLONGED EXPOSURE

(20) The operation of practices may leave long-lived radioactive residues in the environment, resulting in situations of prolonged exposure. Practices may also generate prolonged exposure situations due to the disposal of radioactive wastes and, as indicated before, the Commission provides recommendations elsewhere on radioactive waste disposal (ICRP 1985; ICRP 1997c; ICRP 1998). Radioactive residues from practices can either result from normal discharges to the environment or remain on and around the site of a practice after the cessation of the practice and decommissioning of its installations. The control of the prolonged exposures caused by these residues should have been taken into account prospectively at the planning stage of the practice.[27] Radioactive residues from other past human activities and from events that were not controlled within the Commission's system of radiological protection for practices may require the application of the system of radiological protection for intervention (see Chapter 3).

(21) The Commission does not intend ordinary human actions, such as choosing a place to live or a type of dwelling, to be regarded as falling within the system of radiological protection for practices. For example, in its recommendations on protection against radon, the Commission has not treated occupancy of a dwelling as a practice (ICRP 1993b, paragraph 166). Although ordinary human actions may increase the levels of prolonged exposure to people, the exposure they will cause is not a decisive factor when they are planned. In practices, conversely, activities causing exposure to radiation and radioactive materials are deliberately planned, introduced, continued, and eventually terminated, with the object of yielding a benefit for individuals and society, and with account taken of the expected exposure. This benefit should be sufficient to offset not only the costs and other inconveniences caused by the implementation of the practice, but also the radiation detriment expected from the exposure that it entails.

(22) The principles of the system of radiological protection for practices are: the *justification of the practice;* the *optimisation of radiological protection,* with regard to any source within the practice; and the *limitation of individual doses* attributable to the practice (see paragraph D.25 for further details on the principles). These principles should be applied prospectively at the planning stage of any practice expected to deliver prolonged exposures. In cases of practices involving prolonged exposure, the principles generally operate as follows. Before a justified practice is introduced, people will already be incurring a pre-practice existing annual dose, usually, but not necessarily, of mostly natural origin. The practice is expected to add to this existing annual dose both transitory additional annual doses, which will cease soon after the practice is terminated, and prolonged additional annual doses, which will persist over time. The Commission's system of radiological protection calls for

[27] It is to be noted, however, that prolonged exposures due to long-lived radioactive residues from current practices are generally insignificant in comparison with prolonged exposures caused by past human activities and natural sources (UNSCEAR 1993).

the optimisation of protection and the restriction of all additional annual doses attributable to the practice, including those due to prolonged exposure. After the practice is terminated, the post-practice existing annual dose will be higher than the pre-practice existing annual dose, because the residual prolonged additional annual dose, ΔE, attributable to the practice, will be added to the pre-practice existing annual dose.[28] If this additional annual dose has been restricted according to the principles of the system of radiological protection, the post-practice existing annual dose does not require further restrictions (see a simplified schematic presentation in Fig. 2 below; refer to Fig. D.2, Annex D, for a more detailed description).

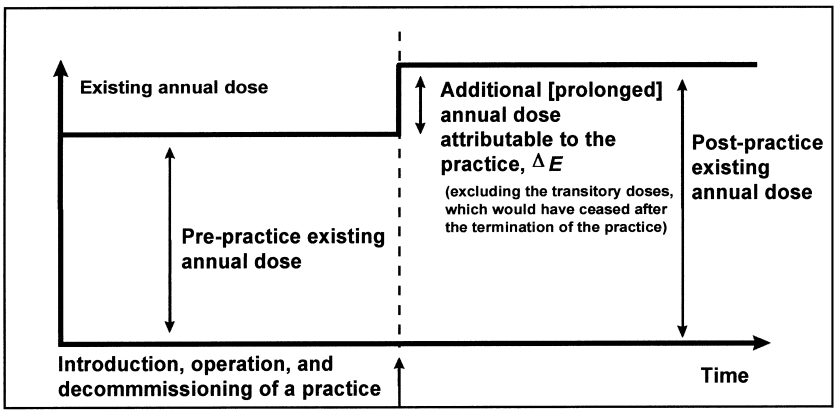

Fig. 2. Simplified schematic presentation of the existing annual dose over tune when a beneficial practice is introduced, operated, and decommissioned (for more detail, see Fig. D.2 in Annex D).

(23) *Exemptions of practices:* The Commission has recommended criteria for exemption of practices from regulatory provisions (see paragraphs D. 15–D.17). The general principles for exemptions adopted in international standards are as follows: (i) the radiation risks to individuals caused by the exempted practice or source should be sufficiently low as to be of no regulatory concern; (ii) the collective radiological impact of the exempted practice or source should be sufficiently low as not to warrant regulatory control under the prevailing circumstances; and, (iii) the exempted practices and sources should be inherently safe, with no appreciable likelihood of scenarios that could lead to a failure to meet the previous criteria (IAEA 1996, Schedule I; see also IAEA 1988). Within the context of prolonged exposures, therefore, exemptions may be granted if the attributable additional annual doses, both individual and collective, are trivial. It is to be noted, however, that generic assessments have shown that the individual doses are the dominant factor for granting exemptions. The level of a trivial individual annual dose has been derived on the basis of risk-based considerations and also on considerations of natural background radiation (IAEA 1988). The level of annual risk which is held to be of

[28] Even in the case of very long-lived radionuclides, the post-practice existing annual dose will not usually be completely invariant with time. Radioactive decay, erosion and environmental dispersion will tend to reduce the level of the additional annual dose with time.

no concern to individuals is taken to be around 10^{-6} to 10^{-7} and a trivial change in the natural background radiation is considered to be in the order of few per cent of its average value of ≅2.4 mSv per annum (see paragraph A.8). Both considerations lead to an annual dose of the order of few hundredths of a millisievert. The Commission therefore considers that:

- Under certain conditions, sources used in justified practices can be exempted from regulatory requirements if the individual additional annual doses attributable to the source are below around 0.01 mSv in a year.

2.1. Justifying practices involving prolonged exposure

(24) The Commission has already provided advice on the general implementation of the principle of justification of practices (see paragraph D.26). Within the context of prolonged exposure, justification must take into account the factors associated with long-term conditions, such as those related to the discharge of long-lived radionuclides to the environment and related to the radioactive residues remaining after the discontinuation of the practice, and the release of its site for other uses. It should be noted, however, that these factors may represent only a small fraction of the many factors involved in the justification of the practice.

(25) In summary, the Commission considers that:

- The justification of a practice delivering prolonged exposure requires that all relevant long-term factors be considered prior to the adoption of the practice. Pertinent factors are those related to the long-lived radioactive substances that are expected to be discharged to the environment or to remain as radioactive residues in human habitats after the decommissioning of the practice. The factors will include the prolonged components of the anticipated additional annual doses, both individual and collective, that are attributable to the discharges and residues.

2.2. Optimising protection for sources delivering prolonged exposure

(26) The Commission has provided advice on the implementation of the principle of optimisation of protection (see paragraph D.28) and issued a number of relevant publications.[29] The recommendations in these publications are still valid and should

[29] The general application of the Commission's recommendations on optimisation of protection was presented in *Publication 22* (ICRP 1973). Then, in *Publication 37* (ICRP 1983), the Commission issued specific recommendations for the use of techniques of cost-benefit analysis in the optimisation of radiological protection. Finally, in *Publication 55* (ICRP 1989), the Commission addressed the general issue of optimisation and decision-making in radiological protection. The optimisation techniques recommended by the Commission have been widely applied (IAEA 1986b). It should be noted, however, that the Commission's intentions on optimisation have sometimes been misinterpreted as a wish to optimise the entire practice. This is a much wider process that involves the entire organisation of the practice. Optimisation of protection often improves the overall quality of the practice, but this is incidental.

be followed in the optimisation of protection with regard to sources delivering prolonged exposures.

(27) In summary, the Commission considers that:

- The optimisation of protection requires the selection of the best radiological protection option for any source, under the prevailing social and economic circumstances. This optimum option will be expected to deliver 'as low as reasonably achievable' doses, taking into account economic and social factors. In a justified practice delivering prolonged exposure, all pertinent long-term factors should be taken into account in the optimisation process. The process may be carried out using the optimisation techniques recommended by the Commission.

(28) It is legitimate to deal separately with prolonged exposures in the optimisation of protection, provided that the control of prolonged exposure can be accomplished independently of the control of transitory exposures from the same source. If this is not the case, the Commission's recommended approaches for optimisation of complex systems should be applied.[30]

2.3. Limiting individual doses attributable to prolonged exposure

(29) Prolonged exposures from a practice will extend beyond the life of the practice and may still be occurring when other practices are introduced. Individual doses attributable to this predicted prolonged exposure should be restricted so that future individuals will not exceed certain dose levels even when other sources are utilised.

(30) With the exception of medical practices involving exposure of patients,[31] the Commission's implicit assumption has generally been that decisions on the justification of practices and optimisation of protection are made largely on societal rather than individual bases. Thus, many of the techniques recommended for the justification and optimisation processes tend to emphasise societal rather than individual aspects and may introduce inequity among individuals. Transitory exposures caused by a practice are usually incurred by the generation of people who experience benefits from the practice, eliminating one possible source of inequity among individuals. However, this is not always the case for prolonged exposure situations. Owing to the widespread environmental distribution of some of the long-lived radionuclides that can be released from practices, some exposed individuals can be spatially distant from those receiving benefit. Moreover, people who experience prolonged exposure from a practice can also be temporally distant from those that benefit directly from the practice, e.g. they may not belong to the same generation. The Commission has already addressed the elusive concept of inequity over time recognising that many current practices give rise to doses that will be received in the

[30] In *Publication 37* the Commission provided recommendations on the optimisation of complex systems with interrelated subsystems (ICRP 1983, paragraphs 114–116).

[31] In medical exposures, unlike most radiation exposure, the same individual patient enjoys the benefit of the procedure and sustains the detriment of the exposure.

future, sometimes the far future. In the Commission's view, these future doses should be taken into account in the protection of both populations and individuals, although not necessarily on the same basis as is used for current doses (see paragraph D.27).

(31) In summary, the Commission considers that:

- The application of the justification and optimisation principles to practices may introduce individual inequities that may be important when prolonged exposures are involved. Inequities are caused by the possibly wide spatial distribution of prolonged exposures, which may involve people who are not direct beneficiaries of the practice. They can also be attributed to the potentially long-term temporal distribution of prolonged exposure, which may affect future generations. (However, inequity between different generations is a more elusive concept than inequity between different individuals at a given time).
- In order to limit these inequities and to allow for prolonged and transitory exposures to multiple sources, stringent individual dose restrictions should be applied to the prolonged exposure expected to be delivered by individual sources and to the prolonged exposures predicted to be aggregated by all regulated practices.

(32) The Commission recommends two types of individual dose restrictions, which are termed *dose constraints* and *dose limits*. The dose constraints apply to doses expected to be delivered by a specific source within a practice. The dose limits apply to doses that are predicted to be aggregated by all *relevant* practices, i.e. by all the practices regulated following the principles of the Commission's system of radiological protection for practices. Both restrictions apply to the sum of prolonged and transitory exposures and refer to individuals. Therefore, doses to be compared with these dose restrictions are individual doses estimated from individual-related assessments.

(33) ***Dose constraints***: When optimising the protection of a source within a justified practice, the system of radiological protection requires that the individual additional annual dose, ΔE, be restricted by dose constraints. The optimisation process excludes any protection options that would involve individual annual doses above the selected dose constraint. The Commission uses the term 'constraint' only for this prospective purpose. The dose constraints are used as an integral part of the process of optimising prospectively radiological protection at the source and not as a form of retrospective dose limitation.

(34) Dose constraints are specific to the practice involved and to sources within the practice. In principle, they should be established on a case-by-case basis, with due consideration of the maximum annual dose that would be acceptable from a new source at a single location, taking into account exposures from other sources subject to control and equity considerations. Sometimes, however, they can be set on the basis of simple generic optimisation.

(35) In its main recommendations, the Commission did not suggest any numerical values for dose constraints. Recently, however, it has provided some quantitative recommendations within the context of radioactive waste disposal (ICRP 1997c,

paragraph 48): the Commission recommended that the dose constraint should be less than 1 mSv and that a value of no more than about 0.3 mSv would be appropriate. These recommendations are in principle applicable to prolonged exposure.

(36) Within the context of prolonged exposure, however, it should be recalled that if the *prolonged component* of the individual dose from a source could — in any given year during its operation — approach the dose constraint recommended for the overall exposure from the source, no margin would remain for the *transitory component* of the individual dose. Moreover, should the source continue to operate over years, the level of prolonged exposure could build up over time (the situation is illustrated in Fig. 3). It is important that these situations be taken into account for the selection of the dose constraint. The objective is that any conceivable combination of annual doses, including combinations resulting from the build-up of annual doses from the continuing operation of a source, should not cause the dose constraint for that source to be exceeded at any time during its lifetime. A source or a practice operating for a year at a given output, and discharging long-lived radionuclides to the environment, will deliver a prolonged annual dose, A, to a critical group during the year of operation, which will be slightly lower (B, C, D, E,... etc.) over future years [see (a)]. If the source or the practice continues operating for a second year, the annual dose to the same critical group during that year will be $A+B$, and over the future years $B+C$. $C+D$, $D+E$, ... etc. [see (b)]. In the long term, the per caput prolonged annual dose attributable to the continuing operation of a source or a practice and incurred by a hypothetically constant critical group becomes equal to $A+B+C+D+E$... etc. [see (c)], which is equal to the summation of the annual doses caused by one year of operation of the source or by 'one year of practice', respectively. (This summation is usually termed the *committed dose* from one year of operation of the source, or one year of practice).

(37) In order to cope with these problems, national authorities should envisage the use of appropriate methods for dose estimates. The methods should allow for the environmental build-up of the radioactive residues of a given source and should also take account of the transient exposures delivered by the source, thus providing an estimate of the maximum dose from the operation of the source. Several modelling techniques have been available to achieve this objective. For instance, some national authorities assume that sources will continue to discharge radioactive residues during their lifetime and they assess the dose in the Nth year for the purpose of assessing compliance with dose constraints (see, for instance, NRPB 1993). If, in a particular situation, such verification of compliance is not feasible, it will obviously be prudent to impose additional restrictions on the *prolonged component* of the annual individual dose attributable to the source. The intention should be to ensure that the dose constraints recommended by the Commission are respected at any time during and after the operation of the source.

(38) In summary, therefore, in relation to dose constraints for sources delivering prolonged exposure, the Commission considers that:

- The maximum value of the annual dose constraint to be used in the optimisation of radiological protection for a single source should be less than 1

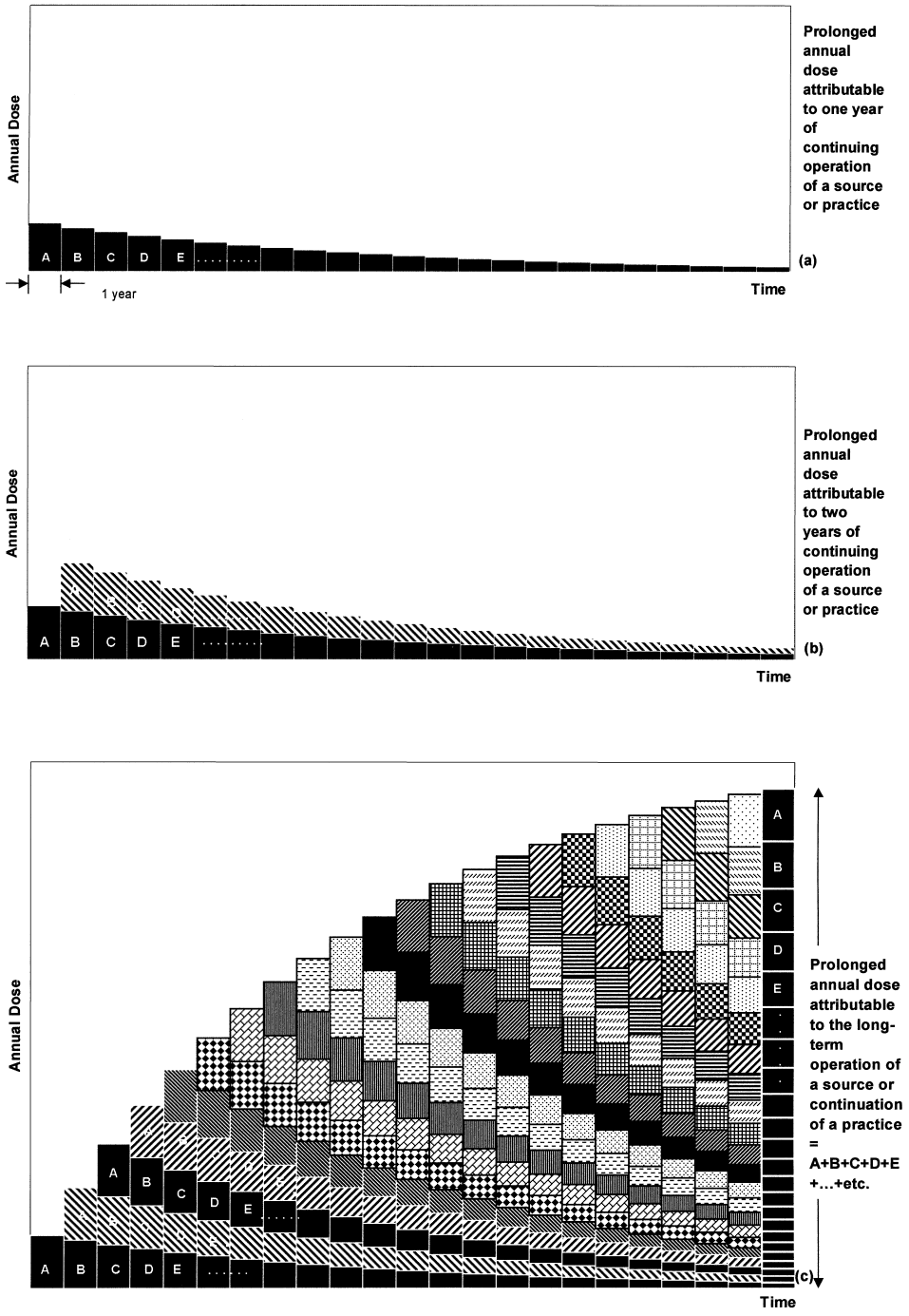

Fig. 3. The accumulation of prolonged exposures caused by the continuing operation of a source or a practice.

mSv in a year and a value of no more than about 0.3 mSv in a year would be appropriate.

- Consideration should be given to exposure situations where combinations of transitory and prolonged exposure or a build-up over time of prolonged exposures from a source could occur. In these situations, it should be verified that appropriate dose assessment methods are used for ensuring compliance with the established dose constraint. The assessment should take account of any reasonably conceivable combination and build-up of exposures.
- If, in a particular situation, such verification of compliance is not feasible, it would be prudent to restrict the prolonged component of the individual dose from the source with a dose constraint of the order of 0.1 mSv in any given year during the operational lifetime of the source.

(39) In order not to bias the optimisation of protection, these recommendations should be applied with extreme care and flexibility:

- It should be recalled that the build-up of long-lived radionuclides released from a source will be more significant in some situation than in others. For example, the aggregation of exposure may be less significant in the marine environment than in lakes and rivers or in the terrestrial environment.
- The application of dose constraints in some specific cases involving NORMs requires special consideration. A difficult case is presented by the use of constraints for doses from radioactive residues in tailings from mining and milling of ores that contain radioactive substances, and from other extractive industries. In many parts of the world, these operations last for many decades usually without specific restrictions. The imposition of low dose constraints could, in many of these cases, be too restrictive because it is not feasible to achieve the necessary degree of environmental isolation for very large amounts of material containing relatively high concentrations of very long-lived natural radionuclides (see UNSCEAR 1993). Tailing sites have accumulated radioactive residues from the past, and in many situations new residues are being (and are expected to continue to be) deposited.
- Prolonged exposure situations due to tailings from past activities should be treated as intervention, within the framework provided in Chapter 4. The additional individual doses resulting from depositing new tailings, as a result of current and future operations, should preferably be restricted within the recommended dose constraints.
- For proposed new facilities, the principles of optimisation of protection and restriction of individual doses recommended in this Chapter should be fully applied, bearing in mind that tailings also contain radioactive waste which may give rise to exposure in the future. As indicated before, the Commission is addressing the general problem of disposal of long-lived radioactive waste, including waste in tailings, in a separate report, *Publication 81* (ICRP 1998).

(40) ***Dose Limits:*** In addition to the use of dose constraints, the Commission recommends that the sum of all individual additional annual doses from transitory

and prolonged exposures that are attributable to all relevant practices should comply with a specified dose limit, E_{limit}. Thus, the sum of contributions of all additional annual doses, ΔE_i, including transitory and prolonged doses, from all sources, i, within the relevant practices, should be no higher than the dose limit; i.e., $\Sigma_i \Delta E_i \leq E_{\text{limit}}$. The dose limit applies to the sum of both transitory and prolonged exposure from practices.

(41) The Commission has provided extensive advice on the application of the principle of individual dose limitation (see paragraphs D.29–D.30). It recommends that the dose limit, E_{limit}, for public exposure should be expressed as an annual dose of 1 mSv. In special circumstances, a higher annual dose could be allowed provided that the average over 5 years does not exceed 1 mSv (ICRP 1991a, paragraph S40). In situations of prolonged exposures it is difficult to envisage special circumstances that permit continually exceeding the principal dose limit.

(42) As in the case of dose constraints, there is a practical problem in the application of dose limits because of the prolonged component of the exposure. It lies with the expected build-up of exposures due to the potential accumulations of long-lived radioactive residues resulting from the continuation over time of current practices (see again Fig. 3). The Commission has addressed this in the context of waste disposal (ICRP 1997c, paragraph 44). As for dose constraints, the objective is that the build-up of annual doses from continuing practices should not cause dose limits to be exceeded in the future. Some years ago, a simple approach was suggested (Lindell 1973) for ensuring the limitation of future *per caput* doses attributable to continuing practices. The approach requires the limitation of doses delivered over time (sometimes termed the *dose commitment,* see paragraph B.7) by a given unit practice. The doses are assessed to hypothetical individuals belonging to an idealised *critical group* that retains its characteristics indefinitely. The approach has been recommended in international guidance (IAEA 1986a) and by some national agencies (e.g. Nordic Countries 1976).

(43) In summary, therefore, in relation to dose limits for practices delivering prolonged exposure, the Commission continues to recommend that:

- The sum of the prolonged and transitory exposures from all regulated practices should be restricted to a dose limit of 1 mSv in a year.
- Concerned national authorities and, as appropriate, relevant international organisations should consider situations where there can be a build-up of the prolonged component of the exposure attributable to all regulated as a result of the accumulation of radioactive residues from continuing practices. The aim should be to prevent that the aggregated individual additional annual doses attributable to all current practices and to predictable future practices exceed the dose limit of 1 mSv in a year.

(44) There continues to be some confusion over the meaning and application of the Commission's recommendations regarding individual dose limits. Clarification of the use of dose limits is particularly relevant to prolonged exposure situations. In *Publication 60,* the Commission had already noted a number of misunderstandings (ICRP 1991a, paragraph 124). Dose limits were being widely, but erroneously,

regarded as a line of demarcation between safe and dangerous situations. They were also widely, and also erroneously, seen as the most simple and effective way of keeping exposures low and forcing improvements. Furthermore, they were commonly seen, again erroneously, as the sole measure of stringency of a system of protection. The Commission noted that these misconceptions were, to some extent, strengthened by the incorporation of dose limits into regulatory instruments. Against this background, it was not surprising that management, regulatory agencies, and governments have at times improperly set out to apply dose limits whenever possible, even when the sources in question are partly, or even totally, beyond their control.

(45) Unfortunately, in spite of the Commission's advice, some confusion on the application of dose limits still seems to remain and the Commission feels that it is necessary to provide further clarifications. These are particularly important for prolonged exposure situations:

- First, dose limits are not operative levels to determine the degree of radiological protection for a practice. In normal circumstances, additional annual doses from practices close to the limits should be considered unacceptable. Compliance with dose limits is a necessary, but not a sufficient, condition for satisfying the Commission's system of radiological protection for practices.

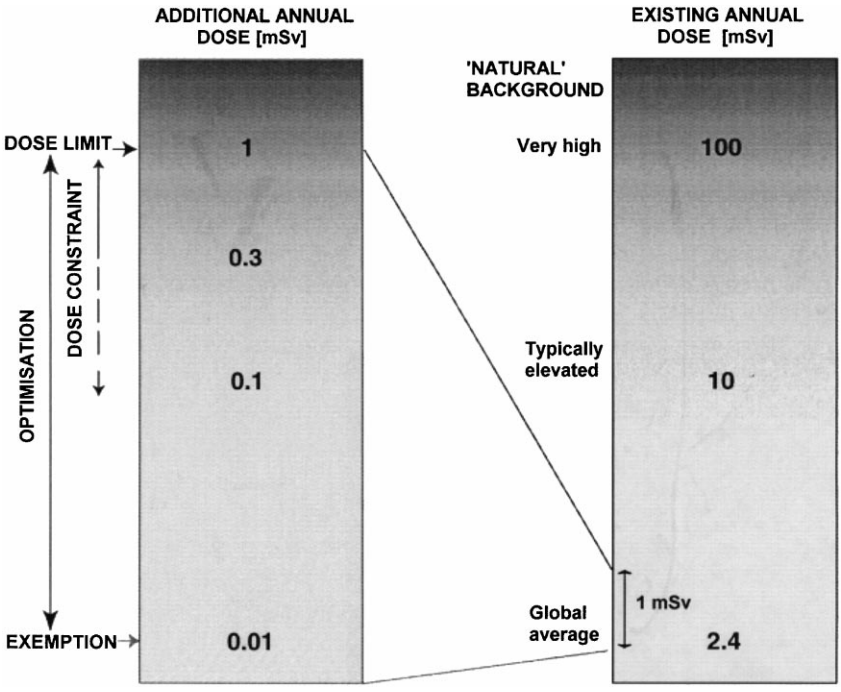

Fig. 4. Schematic representation of the individual dose restrictions in terms of additional annual dose vis à vis the reported levels of 'natural' background exposure in terms of existing annual dose.

The degree of rigour implied by the recommendations should be judged by the overall impact of the system, of which the optimisation of protection at the source (within dose constraints) is the most stringent and effective component.

- Second, and conversely, virtually everywhere in human habitats, the existing annual doses are higher than the numerical value of the dose limits for practices. This, however, does not imply that the situation is unacceptable or that intervention to reduce the doses is justified or necessary. It should again be recalled that dose limits apply to additional annual doses from practices and not to existing annual doses. The value selected for the limit is less than the existing annual dose caused by environmental sources, many of which are natural sources and some of which arc not amenable to control. This position is not easily explicable. Existing annual doses caused by natural sources and by radioactive residues do not justify additional annual doses attributable to practices, and it is proper to control practices, even if the annual doses expected from them are much lower than the existing annual doses. Levels of existing annual doses in the human environment are useful indicators for comparisons of situations and policy decisions in radiological protection.

(46) A perspective on the recommended levels for the individual dose restrictions in terms of additional annual dose can be gained by presenting them vis à vis values of existing annual doses due to natural background radiation, as shown in Fig. 4.

3. APPLICATION OF THE SYSTEM OF RADIOLOGICAL PROTECTION TO INTERVENTION IN PROLONGED EXPOSURE SITUATIONS

(47) *Intervention* is required for reducing the existing annual dose if a de facto exposure situation is judged to be unsatisfactory from the point of view of radiological protection. Prolonged exposure usually is a significant part of the existing exposures. Intervention may take the form of a single set of protective actions that achieve a permanent reduction of components of the existing annual dose: for instance, the cleaning up of some radioactive residues. It may also reduce the whole existing annual dose but require continuing protective action to be effective (where, at some point, it may be possible to discontinue the intervention): for instance, relocating people.

(48) The principles of the Commission's system of radiological protection for intervention are the *justification of intervention* and the *optimisation of the protective actions* (see paragraph D.31 for further details on the principles). In prolonged exposure situations, the principles generally operate as follows. The system of radiological protection calls for the consideration of intervention to reduce components of the pre-intervention existing annual dose. (Usually, but not necessarily always, there is just one significant component attributable to one source.) The intervention will achieve an averted annual dose, $-\Delta E$. A residual post-intervention existing annual dose will remain; this will equate to the pre-intervention existing annual dose minus the averted annual dose (see Fig. 5 and, for more detail, Figs. 8, 9, D.3, and D.4). If the protective actions to avert annual doses have been optimised, the post-intervention existing annual dose is not subject to further reductions.

(49) Intervention situations involving prolonged exposure are of various types. In all cases, decisions have to be taken on whether and how to intervene in order to reduce these exposures and, eventually, on whether and when to discontinue the protective actions. The classical intervention situation is where people are already

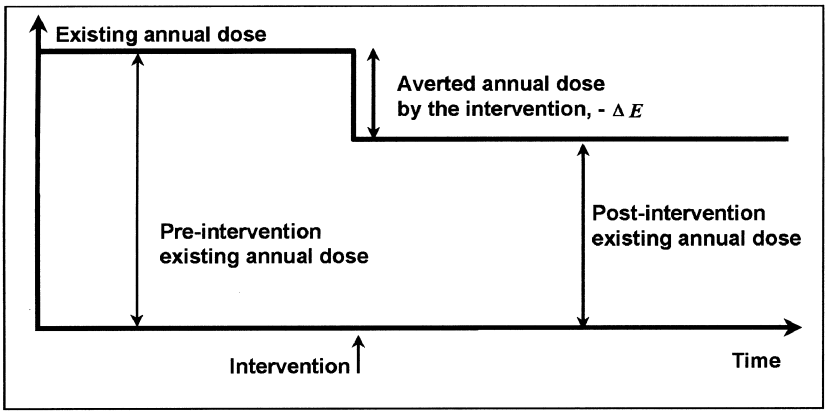

Fig. 5. Simplified schematic presentation of the existing annual dose over time when intervention is undertaken.

incurring exposures attributable to an identifiable cause relatively close in time; for example, a nuclear accident. Another type is situations that have became an integrated part of the human habitat; for example, exposures to natural sources and to radioactive residues that cannot be linked to any particular originating cause or where the link to the cause has weakened over time. A particular type is where, although there is a prolonged exposure situation, people are not yet subject to the exposure; for instance, an uninhabited contaminated area which might be inhabited in the future. (A decision to inhabit the area can create a situation that is conceptually similar to the suspension of intervention in the first type of situation). It appears that there are considerable differences in the perception of these situations, with society appearing to expect different standards of protection to be applied. Societal preferences can be reflected in regulatory policies or considered during the decision-making process leading to intervention. Decisions on whether to intervene (and if so, how) can be made easier by the use of predetermined *reference levels*[32] (see Section 3.3).

(50) Intervention in prolonged exposure situations can also be considered in relation to two extremes. One extreme is where the existing annual dose caused by the prolonged exposure is low enough to make intervention unexpected and not likely to be justifiable; the other is where the existing annual dose is so high as to justify intervention under almost any circumstances. Although the system of radiological protection for intervention should be applied on a case-by-case basis, justification of intervention and optimisation of protective actions will become crucial somewhere between these extremes. At the extremes, generic rather than case-by-case approaches are more suitable. Recommendations on quantifying these extremes, by means of relevant *generic reference levels*[32] expressed in terms of existing annual doses, are provided in Chapter 4.

(51) ***Exemptions from Intervention***: Exemptions from even considering intervention can be set up in regulatory instruments. The Commission recommends the establishment of *intervention exemption levels,* particularly in relation to commodities containing radioactive substances (see Sections 3.3 and 5.4).

3.1. Justifying intervention in prolonged exposure situations

(52) The immediate advantage of intervening in a prolonged exposure situation is the expectation of obtaining averted (individual and collective) doses, i.e. of reduction in the existing annual doses, with the consequent reduction in the risk of radiation health effects to individuals and of radiation detriment to the exposed population. Other advantages are the consequent reassurance gained by the population and the decrease in the anxiety created by the situation. The disadvantages introduced by the intervention include the costs, harm and social disruption

[32] The term *reference level* is used by the Commission to mean values of measurable quantities above which some specified action [such as intervention] or decision should be considered (ICRP 1991a, paragraph 257). *Generic reference levels* relate to an entire class of situations (here, prolonged exposure) rather than any particular case.

associated with it. If the advantages of intervening offset the disadvantages, the net benefit of intervening will be positive and the intervention is said to be justified.

(53) In the particular case of prolonged exposure situations, intervention decisions involve a large number of *attributes*.[33] These attributes quantify relative partial benefits, which can be numerically 'positive' (for advantages) or 'negative' (for disadvantages). Without intervention, most attributes quantify disadvantages, for instance:

- *the existing individual and collective annual doses;*
- *the anxieties they cause;* and
- *the consequent political pressures to remedy the situation.*

The advantage of intervention is that it may reduce the disadvantageous attributes, for instance averting individual and collective doses, or even get rid of them, for example eliminating anxieties and political pressures. Intervention may also introduce advantageous attributes, such as:

- *the reassurance produced by the intervention.*

But intervention will in addition introduce new disadvantageous attributes, for instance:

- *the costs, harm, and inconveniences introduced by the protective actions;*
- *the social disruption they may cause;* and
- *the occupational doses incurred by those implementing the intervention.*

(54) Intervention is justified when its net benefit, or balance between attributes before and after intervention, is positive. In quantitative terms this is achieved when the summation of attributes with intervention minus the summation of attributes without intervention is higher than zero. It is the difference between the values of the attributes before and after intervention, rather than the absolute values, which is relevant for justifying intervention. For instance, the avertable annual dose, rather than the existing annual dose, is the relevant quantity to be used in the justification process.

(55) Justification should be objectively assessed through a *decision-aiding process*. This process could be qualitative or quantitative, simple or sophisticated. If a simple quantitative decision aiding technique is used (such as *cost-benefit analysis,* addressed by the Commission in *Publication 37,* ICRP 1983), all of the attributes have to be expressed in the same unit. Since costs are expressed in monetary units, equivalent monetary values may be assigned to other attributes or, alternatively, other common units of value may also be considered. Some attributes are amenable to quantification; e.g., the avertable annual doses in the exposed population and the occupational doses incurred by those implementing the intervention, and the costs and inconveniences caused by the protective actions. However, there may be many

[33] The term *attribute* is used in this report to mean quantifiable characteristics associated with or resulting from intervention.

attributes that are less readily quantifiable, e.g. reassurance, anxiety, social disruption, and political pressure. *Multi-attribute utility analysis,* addressed by the Commission in *Publication 55* (ICRP 1989, paragraphs 105–122) is a more sophisticated quantitative technique that can also be used in the decision-aiding process. This technique is capable of accepting input data on attributes with various degrees of quantification. Therefore, it can be used for assessing the justification of intervention in a wide variety of prolonged exposure situations.

(56) In analysing the inputs to any decision aiding technique, it is necessary to decide on the relative importance or weight of each attribute. If multi-attribute utility analysis is the technique used, then all of the relevant factors can be directly included in the analysis by deriving or assigning utility functions to them, but weights still need to be assigned. These judgements have to be made irrespective of the decision-aiding technique used. Indeed, they are made implicitly even if a decision aiding technique is not used. (The technique does not create the need for judgements; rather it makes them explicit!) The resulting decision should be the same whether the decision aiding technique is used or not-provided that the database is the same and the judgements are consistent.

(57) In many prolonged exposure situations, there are also other considerations, which may not be objectively related to radiological protection, that may also need to be taken into account in making decisions about intervention. The Commission considers that these other considerations, which are mainly of a socio-political and cultural nature, may be taken into account in a *decision-making process* which should be wider than the decision-aiding process for the justification of intervention. The relative weighting assigned to these considerations may be very different depending on the type of situation, and it may be difficult to achieve a broad consensus on them, thus making it hard to generalise. As indicated by recent studies, considerations other than those usually taken into account in a decision-aiding process based on radiological protection attributes could even dominate decisions on intervention (NEA 2000).

(58) In the wider decision-making process, the role of stakeholders should be recognised. The objective is that those concerned with the situation should be involved and be given the opportunity to participate in the decision-making process. The extent of stakeholder involvement will vary from one situation to another. An important example of stakeholders' participation is in long term intervention after an accident and, in particular, in the definition of 'normality' of the situation. Another example where stakeholders may play an important role is in the case of habitats that were contaminated many decades ago, with insufficient consideration having been given at the time of contamination to the eventual rehabilitation of the habitats. In such cases, the decision maker usually faces a dilemma: on the one hand, some stakeholders may want to return the site to its original state regardless of radiological protection considerations; on the other hand, some stakeholders may be more concerned with immediately occupying the contaminated habitats without any remedial measures. The weight given to these interests could be an important factor in the acceptability of the ultimate decision.

(59) In summary, the Commission considers that:

- The justification of intervention in prolonged exposure situations should be assessed by means of a *decision-aiding process* requiring a positive balance of all relevant long-term attributes related to radiological protection. (In addition to the avertable annual doses, both individual and collective, other attributes include the following: the expected reduction in the anxiety caused by the situation, the reassurance to be provided by the intervention, and the social cost, harm, and disruption that may be caused by the implementation of the protective actions).
- The results of such decision-aiding process should be used as an input into a *decision-making process* which may encompass other considerations and may involve relevant stakeholders.

(60) It is important to ensure that the various considerations influencing the decision are each taken into account only once. For instance, in a number of justification processes, it has been a common practice to introduce (and count) 'political' factors twice. Political factors are sometimes taken into account by technical experts during the decision-aiding process for justifying intervention, and they are subsequently introduced again by politicians participating in the wider decision-making process. Decision aiding techniques can assist in avoiding such 'double-counting' of factors, by making it clear what considerations have been included in a given recommendation or decision. In any case, the overall decision-making process for intervention should be as integrated as possible.

3.2. Optimising protective actions in prolonged exposure situations

(61) Optimisation of the protective actions is the process of deciding on the form, scale, and duration of the protective actions of the already justified intervention. The aim is to obtain not only a positive net benefit, but also a maximised net benefit. The procedure is no different conceptually from optimising protection for sources within practices,[34] and the types of decision-aiding techniques discussed in Sections 2.2 and 3.1 are applicable to the optimisation of protective actions. The techniques are independent of the nature of the situation causing the prolonged exposure, provided that there is no significant interaction between the protective actions for reducing prolonged exposure and those concerned with other types of exposure. If such interactions are significant, as indicated before, the recommended approaches for optimisation of complex systems with interrelated subsystems should be applied (see ICRP 1983, paragraphs 114–116).

(62) Normally, there would be a range of justified intervention options for which the net benefit is positive. Other options will not be justified because the net benefit is zero or negative. These unjustified options should not be considered in the

[34] Techniques for optimising radiological protection were introduced in *Publication 22* (ICRP 1973) and addressed in detail in *Publications 37* and *55* (ICRP 1983, 1989). Although all of these publications were aimed at the optimisation of protection in practices, their underlying recommendations also apply to optimisation of protective actions in interventions.

optimisation process. Among the justified options, the optimum protection option would be the combination of form, scale, and duration of a protective action for which such net benefit is maximised. The optimum protection option is not necessarily the option that results in the lowest residual annual doses, either individual or collective dose. Some options could result in a lower residual annual dose but give a smaller net benefit than the optimum option.

(63) Some intervention options could involve restrictions of use of the human habitat as a means of reducing doses. These options may be considered in the optimisation process provided that the institutional control required to implement the restrictions is feasible. They should be compared on an equal basis with options in which dose reductions are achieved by other means. However options which do not require restrictions on the use of the human habitat may be favoured in the decision-making process, mainly due to socio-political considerations.

(64) In summary, the Commission considers that:

- The optimisation of protective actions can be performed following the general approach to optimisation of protection recommended by the Commission in the context of practices. The optimum form, scale, and duration of the protective actions should be selected from the justified options of intervention. For some prolonged exposure situations, restricted use of human habitats can be the outcome of the optimisation process.

3.3. Specific reference levels for interventions in prolonged exposure situations

(65) The Commission considers that:

- National authorities and, as appropriate, relevant international organisations should pre-determine *specific reference levels* (such as *intervention levels, action levels* and *intervention exemption levels)* for particular prolonged exposure situations amenable to intervention. They can be conveniently expressed in terms of the avertable annual dose, or a related subsidiary quantity.
- The use of predetermined specific reference levels can facilitate timely decisions on interventions and the effective deployment of resources; however, an improper use may lead to inconsistencies with the principles of justification and optimisation.

Specific reference levels for intervention are applicable only to particular prolonged exposure situations. They can be conveniently quantified in terms of either the avertable annual dose due to the intervention or a related subsidiary quantity.

(66) ***Intervention levels***: In the context of prolonged exposures, an *intervention level* is the minimum level of annual dose that must be averted if an intervention is to be justified. Intervention levels are expressed as an avertable annual dose that can be achieved by a specific protective action. If the annual dose expected to be averted by the protective action, $|-\Delta E|$, is greater than the intervention level, $|-\Delta E| > IL$, the protective action should be considered a candidate for application. The

intervention level concept has been adopted in international standards in relation to transitory exposures (IAEA 1996).

(67) ***Action levels***: An *action level* is the value of some measurable quantity, such as an activity per unit area in a contaminated land, above which it is likely that a given protective action will achieve an averted annual dose which is large enough to justify the intervention. Action levels refer to a whole class of different protective actions, such as restrictions in food consumption or radon reduction measures in houses. Action levels have also been adopted in international standards (IAEA 1996), where they have been defined as the level of dose rate or activity concentration above which protective actions should be carried out in specific exposure situations.

(68) ***Intervention exemption levels***: The Commission has considered the concept of *exemption* in the context of interventions, particularly in order to avoid unnecessary restrictions in international trade of commodities. It has recommended the use of *intervention exemption levels* to indicate a line of demarcation between freely permitted exports or imports and those that should be the subject of special decisions. Any restrictions applied to goods below the intervention exemption levels should be regarded as artificial barriers to trade (ICRP l991a, paragraph 284; see also paragraph D. 18). Intervention exemption levels are therefore applicable to commodities for public use involving prolonged exposure (see Section 5.4).

(69) ***Quantitative specific reference levels***: Specific reference levels for intervention are influenced by many attributes that depend on the circumstances of the particular situation. The Commission, therefore, has recommended just a few specific reference levels, which have in turn been adopted by international standards (IAEA 1996). In an example of generic optimisation, the Commission showed that relocation after an accident was optimised at an averted monthly dose of about 10 mSv (ICRP 1991b, paragraph C8). A number of generic studies had shown similar values for returning populations to a contaminated area (IAEA 1986b). Therefore, the Commission recommended a range of optimised values for relocation, ranging between 5 and 15 mSv of averted monthly dose of prolonged exposure (ICRP 199lb. paragraph 119). The Commission also recommended permanent resettlement following a nuclear accident at an averted dose of 1000 mSv in a lifetime, which would correspond to an average annual dose of about 15–20 mSv (ICRP l991b, paragraph 119). It also stated that intervention for restriction of a single foodstuff will almost always be justified at an averted annual dose of 10 mSv, and suggested ranges of optimised values of 1000–10 000 Bq kg^{-1} for beta/gamma emitters, and 10–100 Bq kg^{-1} for alpha emitters (ICRP l991b, paragraph 119). In relation to radon concentration in dwellings, the source-related action levels for radon recommended by the Commission correspond to a range of annual effective dose of 3–10 mSv (ICRP 1993b, paraqraph 72), which, in turn, corresponds to a radon concentration of 200–600 Bq m (ICRP 1993b, paragraph 73). The Commission indicated that these action levels relate only to simple measures and that for more severe measures, such as the permanent removal of people from their homes, it considered that the action level should be an order of magnitude or more higher (ICRP 1993b, paragraph 74).

4. GENERIC REFERENCE LEVELS OF EXISTING ANNUAL DOSE FOR INTERVENTION IN PROLONGED EXPOSURE SITUATIONS

(70) The existing annual dose can conceptually be used to establish generic reference levels for intervention. However, such quantity should be used with caution. It is made up of all the existing and persisting annual doses incurred by individuals and, therefore, it is constituted by many different components of prolonged exposure. These include external exposure to long-lived radionuclides (and their progeny) in soils, strata, and building materials (including exposure to radon and other radionucides in the ambient), internal exposure due to the incorporation of those radionuclides into the body as a result of inhalation of resuspended materials, and ingestion of contaminated foodstuff. There is not a single measure that can be used to determine the value of the existing annual dose, as any of its components may require different assessment methodologies. Likewise, there is no evident common regulation for all components. Some components are 'natural' and have always been a feature of the habitat being considered. Others are considered 'artificial'. Among these, some may have been part of the habitat for many years; others may be the cause of recent human activities and events. Although the health effects attributable to each component depend on its dose level and not on its origins, the public perception on the need to reduce a particular component is some times associated with its origins rather than with its dose level. The public and the authorities representing them do not usually regard and treat these components in a similar manner. Moreover, there usually are different levels of responsibility on the control of these different components. (In many prolonged exposure situations, however, there is only one dominant component of the existing annual dose and the difficulties described become simplified.) Thus, there may be practical problems in implementing regulatory standards expressed in terms of the existing annual dose. Because of these difficulties, the Commission has given preference to *specific reference levels* based on avertable doses of given components, rather than to *generic reference levels* based on existing doses.

(71) However, in spite of their imperfections, generic reference levels expressed in terms of the existing annual dose can still be very useful. They can assist in the recognition of extreme cases of prolonged exposure situations and, as indicated before, they may be an important factor in intervention decisions. They may facilitate the identification of situations where the annual doses involved in a given prolonged exposure situation are low enough to make intervention usually not to be expected and not likely to be justifiable. Conversely, they can identify situations where the existing annual dose is so high as to justify intervention under almost any circumstances. Hence, they can also identify the intermediate situations where the justification for intervention should be determined on a case-by-case basis. They may be useful in situations where averting doses from one component may increase the dose from another component. (For instance, when changes in the diet are the best protective action for reducing one component but the new diet increase another component; or in relocation situations where the receiving area may experience a higher existing annual dose than the evacuated area, albeit from a different

component.) They may help local authorities to deal with situations that are integrated in the current habitats, such as situations of controllable exposure to background radiation that has been enhanced by natural processes and situations of exposure to radioactive residues that are a legacy from the distant past. They may also be helpful for providing perspectives on the exposure situation remaining after the application of the Commission's system of radiological protection for intervention.

(72) Therefore, while the Commission recommends the full use of the system of radiological protection for interventions, including the setting-up of *specific intervention levels* expressed in terms of avertable annual dose,

- the use of *generic reference levels* for interventions, expressed in terms of the *existing annual dose,* is also recommended. They are particularly useful when intervention is being considered in some situations, such as exposures to high natural background radiation and to those radioactive residues that are a legacy from the distant past.

(73) However, the Commission wishes to underline that:

- Generic reference levels should be used with extreme caution. If some controllable components of the existing annual dose are clearly dominant, the use of the generic reference levels should not prevent that protective actions are taken to reduce these dominant components. (These actions can be triggered by either specific reference levels or case-by-case decisions following the requirements of the system of radiological protection for interventions.) Nor should the use of the generic reference levels encourage a 'trade-off' of protective actions among the various components of the existing annual dose.

(74) In this regard, the Commission considers that:

- A low level of existing annual dose does not necessarily imply that protective actions should not be applied to any of its components. And, conversely,
- A high level of existing annual dose does not necessarily require intervention.

(Neither should a high level of existing annual dose preclude the introduction of a new practice: a practice is controlled through the additional annual dose attributable to the practice rather than through the existing annual dose.)

(75) It is re-emphasised that the generic reference levels of existing annual dose should be viewed as a consequential derivation from the principles of the Commission's system of radiological protection for intervention and as complementary, rather than alternative, to those principles. Their use should not preclude the application of these principles to any dose component of the existing annual dose that is controllable, particularly if it is a dominant component.

(76) The identification of existing annual doses low enough to make intervention usually not to be expected, and not likely to be justifiable, is not simple and certainly not straightforward. For perspective purposes, it is helpful to use the 'natural' existing annual doses experienced in many parts of the world. The global average 'natural' dose is $\cong$2.4 mSv per annum (see paragraph A.8) and the majority of the world's population incur doses below or at about this level. However, many large

populations have lived for years in areas of the world experiencing typically elevated doses of up to around ~10 mSv per annum (see paragraph A.9), with some populations even incurring doses above ~100 mSv per annum (see paragraph A.10). In many of the places experiencing high levels of background radiation, the dominant component of exposure is due to radon gas in dwellings; in other situations, the exposure is mainly caused by other gamma-emitting radionuclides, such as radium in soil and water. With some exception, intervention has rarely, if ever, been undertaken to reduce the typically elevated 'natural' background doses of −10 mSv per annum. Moreover, only occasionally have protective actions been implemented to reduce higher 'natural' background doses, even when these doses were controllable. This might suggest that competent authorities have considered these levels as being unlikely to trigger any intervention in those situations. It should be noted, however, that the reasons why typically elevated levels of existing annual doses due to 'natural' sources have been generally tolerated, not only by the competent authorities but also by those exposed, are probably diverse. They may be based more in political, legal, and economic considerations (even in ignorance) than upon a conscious objective decision. In many countries, chief among these reasons may have been the lack of legal authority to control a natural radiation source. It seems, therefore, that the lack of intervention by public health authorities in these cases may not be a sufficient reason to infer that they will automatically accept doses of similar values from other sources. Moreover, as indicated before, the Commission considers that a high level of existing annual dose — e.g., due to high natural background levels — should not per se justify a particular component of annual dose — e.g., a high level of annual dose attributable to long-lived radioactive residues. This should always be restricted following the principles of the system of radiological protection for intervention. However, as the expected radiation health effects depend on the dose received and not on the source origin, the Commission also considers that the typically elevated levels of existing annual doses from 'natural' sources, which have not triggered any protective action, may provide an useful insight into decisions related to intervention.

(77) Further insight on sufficiently low levels of existing annual doses can be obtained from earlier recommendations of the Commission, for instance, in *Publication 63* (ICRP 1991b) and in *Publication 65* (ICRP 1993b), where it addressed a number of intervention situations including some involving prolonged exposure. In these publications the Commission recommended specific reference levels below which any intervention or action is unlikely to be taken in various situations, suggesting levels ranging from a few to a few tens of mSv for a dominant single component of the existing annual dose; see paragraph (69). Such intervention and action levels have been generally incorporated into international standards (IAEA 1996) and some national regulations. Again, this suggests — in this case without provisos — that governmental authorities have considered the recommended levels (of around 10 mSv per annum) as being unlikely to trigger intervention, although they refer to exposures due to just a component of the existing annual dose.

(78) At the other extreme of the spectrum, it is convenient to identify generic situations where intervention will almost always be necessary. This will be the case if the existing annual dose approaches the thresholds for deterministic effects, or if it

entails a high risk of stochastic effects. If such annual dose levels were to be incurred, some intervention would need to be undertaken under almost any circumstances[35]. Prolonged exposure situations resulting in existing annual dose levels below around 100 mSv are not likely to result in serious deterministic effects, provided that the relevant dose thresholds in relevant organs are not exceeded (see paragraph C.3). However, at this level of existing annual dose, the risk of stochastic effects would be too high to be considered generally acceptable. On this basis, it is concluded that some intervention would almost always be justifiable in prolonged exposure situations resulting in existing annual doses rising towards 100 mSv.

4.1. Recommended generic reference levels for intervention

(79) From the preceding discussion, the Commission concludes that:

- An existing annual dose approaching about 10 mSv may be used as a generic reference level below which intervention is not likely to be justifiable for some prolonged exposure situations.

(80) The Commission wishes to stress that this type of generic reference level is more useful in situations where there are no dominant components among the many constituting the existing annual dose. There might be situations where intervention to reduce one or more of these components might be justified at existing annual doses much lower than about 10 mSv. This will be the case if the protective action to reduce such components is fairly simple or is the result of optimisation, depending on the levels of the avertable individual and collective dose associated with the components and on decisions by local and national authorities after taking account of all relevant factors. As concern will usually be focused on one component, national authorities will find it useful to establish specific reference levels-such as an action level specific to that particular component-which could be based on appropriate fractions of the generic reference levels.

(81) In summary, the Commission concludes that:

- Below the level of existing annual dose for which intervention is not likely to be justifiable, protective actions to reduce a dominant component of the existing annual dose are still optional and might be justifiable. In such cases, action levels specific to particular components can be established on the basis of appropriate fractions of the recommended generic reference level.
- Moreover, above the level of existing annual dose for which intervention is not likely to be justifiable, intervention may possibly be necessary and its justification should be considered on a case-by-case basis as appropriate.

[35] The Commission has already stated that, although it recommends against the application of dose limits for deciding on the need for intervention, at a dose level approaching one which would cause serious deterministic effects, some kind of intervention will become almost mandatory (ICRP 1991a, paragraph 131).

(82) Should intervention be considered justifiable, the form, scale, and duration of the protective actions should be optimised taking into account all factors involved, including the avertable individual and collective annual doses.

(83) Finally, the Commission concludes that:

- Situations in which the annual (equivalent) dose thresholds for deterministic effects in relevant organs could be exceeded should require intervention. (In establishing this requirement, uncertainties in the current estimates of deterministic effects from prolonged exposures should prudently be taken into account.)
- An existing annual dose rising towards 100 mSv will almost always justify intervention and may be used as a generic reference level for establishing protective actions under nearly any conceivable circumstance.

(84) The Commission wishes to stress that, as explained in paragraphs 80–81 and exemplified in Section 5.2.2, the levels recommended in the previous paragraphs are *upper bounds* of generic reference levels. That is to say, they are values that refer to non-specific situations and provide broad boundaries to ranges of existing annual doses for which decisions on intervention may be considered. The Commission does not intend that the recommended values of generic reference levels acquire the status of 'restrictions' or 'limiting' levels, nor conversely as 'acceptable' levels, of any kind and expect that they will not be used in this way.

4.2. Perspectives on the recommended generic reference levels for intervention

(85) A perspective on the recommended levels for the generic intervention levels of existing annual dose can be gained by presenting them vis à vis dose values of natural background radiation, as shown in Fig. 6.

(86) It is also useful to gain some perspective on the risks implied by prolonged annual doses at levels around the upper bound of the recommended generic intervention levels. This can be done by comparing the risks with the total conditional probability of death from all causes for an average person. (This comparison was already used in the Commission's main recommendations, ICRP 1991a, paragraph C8). That probability is given by the *Gompertz–Makeham curve,* which describes the age-specific mortality rate in a population as a function of age. The mortality described by the Gompertz–Makeham curve refers to all causes of risk, natural and artificial risks, including the risk due to the radiation exposure incurred by the population under study. Fig. 7 presents, as a continuous line, the Gompertz–Makeham curve of age-specific mortality rate for a reference population, usually termed the *standard population,* of a given gender and living in a relatively developed country. Fig. 7 also presents the extrapolated influence of additional annual doses of around 10 mSv and 100 mSv, respectively, on the mortality rate of the standard population. The calculated values are presented as a dotted-line curve for 10 mSv and a dashed-line curve for 100 mSv. The resulting curves show the increased mortality rates for the exposed population over the normal values for the standard

population. It should be noted that these curves are theoretical constructions and not the result of any epidemiological study. They have been calculated using the Commission's nominal probability coefficients for stochastic effects (see paragraph C.7). Although the curves relate to the average probability over the whole standard population rather than to individual probabilities, they provide a useful insight into the change in the probability of death attributable to the individual dose. For a continuous prolonged exposure of ~10 mSv per annum, the lifetime shift in the mortality rate is ~5% of the total conditional probability of death. The shift is ~50% for a continuous prolonged exposure of ~100 mSv per annum. (The larger shifts occur at the age of ~40; they are: ~10% of the total conditional probability of death for a continuous prolonged exposure of ~10 mSv per annum; and, ~100% for

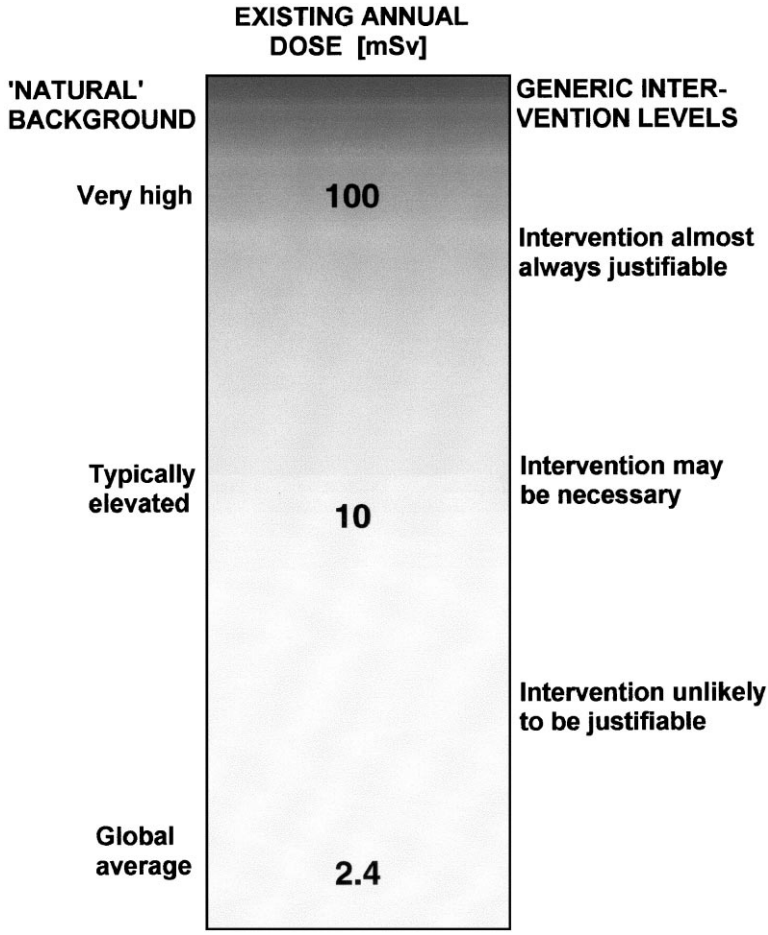

Fig. 6. Schematic representation of the upper bound of the generic intervention levels of existing annual dose vis a vis the reported levels of 'natural' background dose.

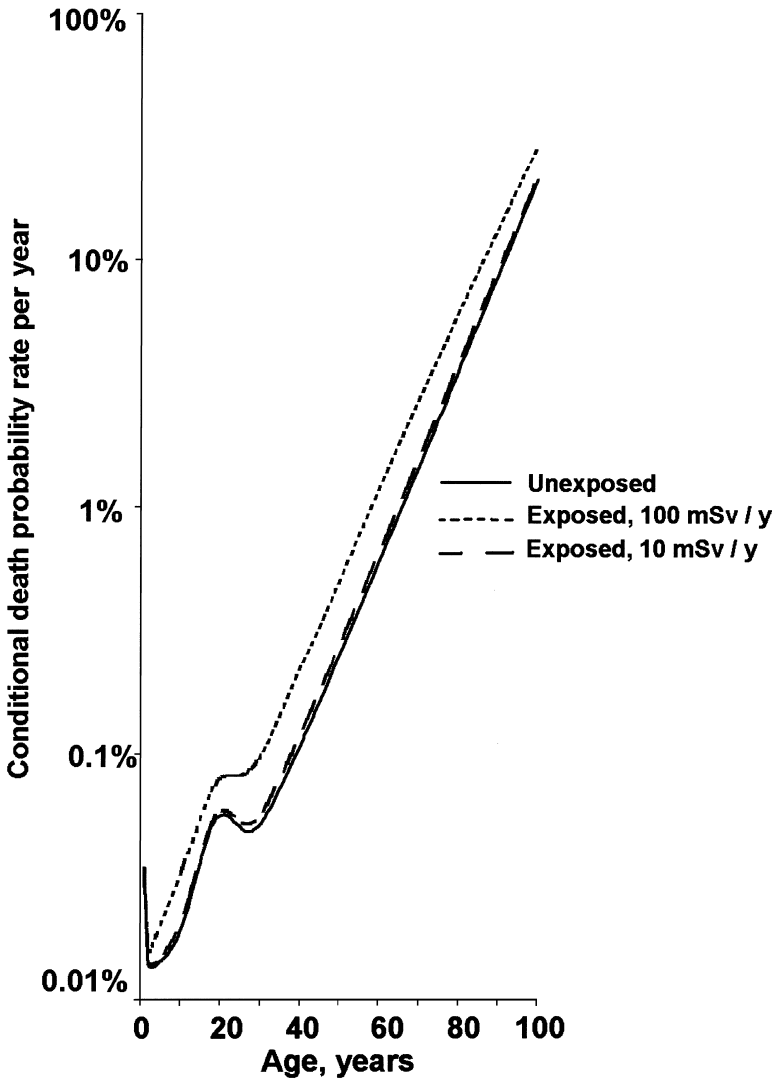

Fig. 7. Conditional death probability per year with age for a standard population and for that population exposed to additional prolonged annual doses of ~10 mSv and of ~100 mSv.

a continuous prolonged exposure of ~100 mSv per annum). Higher shifts occur between the mortality rate of standard populations of males and females, and among the mortality rates of standard populations of countries of different degrees of development (see ICRP 1991a, Figs. C-6 and C-7).

5. APPLICATION OF THE RECOMMENDATIONS TO SPECIFIC PROLONGED EXPOSURE SITUATIONS

(87) This chapter presents examples of specific prolonged exposure situations and explains how they can be dealt with in the context of the recommendations given in previous chapters. The examples include some cases of high levels of natural background radiation; long-lived radioactive residues from practices and from other previous activities and events; discontinuation of intervention after accidents; and commodities for public use containing radioactive substances.

5.1. Consideration of high levels of prolonged exposure to natural background radiation

(88) Relatively high individual annual doses are incurred by some populations around the world as a result of exposure to natural radiation sources. Although the sources are sometimes controllable, these high doses generally do not seem to have been a cause of public intolerance, and many public health authorities have been unsure about whether and, if so, how to intervene to reduce the doses. As noted before, however, in many countries competent authorities lack legal authority or jurisdiction for controlling natural background radiation. Nevertheless, some situations have been a cause of professional concern: they include high concentrations of the gas radon in the air in dwellings and of natural gamma-emitting radionuclides in building materials and in the ground. The main issues are whether there are annual dose levels from controllable natural radiation sources that should almost always call for protective measures, however disruptive and intrusive these measures might be, and, conversely, whether there are levels below which there should rarely be any intervention. For addressing these issues, national authorities may wish to use the generic intervention levels recommended in Chapter 4 as general guidance. More specific recommendations for each particular case follow.

(89) ***Radon in dwellings***: The presence of elevated ambient levels of the noble gas radon-222 in dwellings constitutes a difficult situation of prolonged exposure (see paragraph A.12). As indicated before, the Commission has previously issued *Publication 65* (ICRP 1993b) containing recommendations on *'Protection against Radon-222 at Home and at Work'*, which includes guidance for dealing with situations in existing and new buildings.

(90) For existing buildings, the Commission emphasises that intervention should take place to protect the more highly exposed individuals among the inhabitants. The cost and effectiveness of the protective actions are likely to vary locally and national authorities are best placed to adapt their policies to their particular circumstances (ICRP 1993b, paragraph *65*). As noted before, the Commission recommends a range of annual doses attributable to radon-222 of 3 to 10 mSv from which an action level for intervention should be selected (ICRP 1993b, paragraph 72). Assuming an annual occupancy of 7000 hours and an equilibrium factor of 0.4, the corresponding rounded values of radon concentration are about 200–600 Bq m^3 (ICRP 1993b, paragraph 73). The actions needed to reduce concentrations are

usually fairly simple and only moderately expensive. The Commission has indicated that the recommended range of action levels relates only to simple measures, while more severe measures, such as relocation, would not be appropriate unless the irreducible concentrations were an order of magnitude or more higher than those for the action levels adopted (ICRP 1993b, paragraph 74).

(91) For new buildings, the Commission recommends to impose restrictions on construction in radon prone areas. The aims are twofold: first, to keep the radon concentrations in the finished buildings as low as can reasonably be achieved and, second, to provide for the easy introduction of further protective actions if the initial construction fails to achieve concentrations below the action level for existing buildings. These aims are best achieved by issuing guidance on construction practices. When new buildings are to be erected in a radon prone area, it will be advisable to modify the design of the foundations so as to prevent elevated radon levels. In some circumstances, elevated radon concentrations could be caused by the use of ground fill or building materials with elevated radium-226 content. As such materials can be readily detected by the gamma ray emission, consideration should be given to identifying them and preventing or restricting their use (ICRP 1993b, paragraphs 77–81).

(92) The Commission re-emphasises that proven protective actions against radon in indoor air are readily available. The remedial procedure that is most likely to maintain the radon level to a value well below the action level should be adopted from the outset. Intervention should take place soon after the discovery of elevated levels, especially if the concentrations are substantially above the action levels adopted by the competent authority. For preventive work, construction codes and building guides should be devised that consistently achieve low concentrations of radon in the completed buildings (ICRP 1993b, paragraph 105).

(93) The Commission therefore wishes to recall that:

- The Commission's previously issued recommendations for protection against radon-222 remain valid and are fully applicable for controlling prolonged exposure to this radionuclide in dwellings.

(94) ***Natural gamma radiation emitters in building materials***: Intervention is applicable to existing buildings with high annual dose levels caused by gamma radiation emitters in the construction materials (see paragraph A. 13). However, the feasible protective actions are not as easy to implement or as numerous as in the case of radon. A possible, but extreme, intervention is demolition of the building and relocation of the occupants. This countermeasure carries serious economic and social penalties and is not likely to be applied without careful consideration. As indicated before, the generic reference levels recommended in Chapter 4 can provide some guidance for the solution of practical problems.

(95) For new buildings to be constructed with materials having high concentrations of gamma-emitting radionuclides, some of the principles set forth in the Commission's recommendations for radon-222 in new buildings could be applied with appropriate adaptations. It will usually be feasible to avoid highly contaminated building materials. The establishment of standardised intervention

exemption levels for activity concentrations in building materials should help to solve many practical problems (see Section 5.4).

(96) Therefore, the Commission considers that:

- National and, as appropriate, relevant international organisations concerned should derive standardised intervention exemption levels for activity concentration of specific radionuclides in building materials, taking into account the recommendations for commodities containing radioactive substances presented in this report.

(97) ***Natural gamma radiation emitters in the ground***: Throughout the world, there are areas of markedly high natural background annual doses which are caused mainly by external exposure to gamma radiation emitters in the ground. In these areas, the soil is unusually rich in thorium bearing and uranium bearing minerals, such as monazite sands (see paragraph A. 14). Properly constructed buildings can reduce indoor doses. Outdoor doses are less amenable to control unless the population is relocated. Intervention carries serious economic and social penalties and should not be applied without careful consideration.

(98) The Commission considers that:

- For areas having controllable exposures to high levels of natural gamma radiation emitters in the ground, the use of appropriate fractions of the recommended generic reference levels of existing annual dose should provide guidance for the solution of practical problems.

(99) While this recommendation applies to members of the public who are living in these areas, groups of people living in more 'normal' background areas may come to work in the high background area. This may present a particularly difficult problem for regulatory organisations. Before deciding on the feasibility and extent of possible protective actions, the exposure of such persons may need to be assessed on a case-by-case basis. The extension of the assessment will depend on the place, duration and nature of their work in the high background areas. The Commission's *General Principles for the Radiation Protection of Workers* (ICRP 1997a) can be used as general guidance in these cases.

5.2. Long-lived radioactive residues in human habitats

(100) After the use of radioactive substances, radioactive residues may remain in human habitats, usually as 'contaminated' land, and give rise to prolonged exposure of either a 'normal' or 'potential' nature. The radioactive residues can originate from several causes. Occasionally, they may have been caused by the accumulation of radionuclides from normal discharges of radioactive effluents from practices to the environment. They may also be radioactive remnants following the termination and decommissioning of a practice. Most commonly, they are the result of human activities that have been carried out in the past. Some of these activities were simply not regulated with regard to radiological protection. Others were regulated but without following the requirements of the current system of radiological protection

for practices, which was not available at that time. Radioactive residues can also be the consequence of unregulated events, such as unforseeable accidents and nuclear weapons tests, that have released radioactive materials to the environment (see Section 5.3).

(101) If the radioactive residues are the result of a practice, the system of radiological protection requires that the residual prolonged exposures attributed to the practice should be restricted by, among other things, application of individual dose constraints and limits. If the activity has not been controlled according to these requirements, intervention should be considered and, if necessary, implemented. There are differences of perception between the residual doses remaining after the application of the system of radiological protection to practices and interventions, respectively. Moreover, as the system of radiological protection is applied on a case-by-case basis, with the prevailing conditions being taken into account, the final residual prolonged annual dose can be different in different cases. In addition, the exposures can be heterogeneous and even uncertain to occur. All these situations create practical problems, including those of public acceptance of different levels, types, and even degrees of certainty of residual annual doses.

5.2.1. Radioactive residues from practices

(102) In cases of radioactive residues that are attributable to current practices, the recommended dose constraints are applicable to the residues remaining after the discontinuation of operation of the sources within the practice. Therefore, the Commission considers that:

- The recommended dose constraints should be applied prospectively to the prolonged exposure from the radioactive residues expected to remain in human habitats after the discontinuation of a practice — for instance, at the site of a decommissioned installation.

(103) In principle, the applicable dose constraint may be expected to be no higher than that applied to the operational phase of the practice. In fact, it might appear unreasonable to allow the practice to pose a greater individual risk after it has ceased operation than before. However, the two phases do not necessarily share a common set of circumstances on the basis of which to prescribe equality between the dose constraint applied before the discontinuation of a practice and that applied afterwards. If the operational dose constraint was very low, maintaining it in the post-decommissioning phase could introduce an unreasonable restriction.

(104) Should the site of a former practice be shown to satisfy the dose constraint for all its future plausible uses, the site may be released for *unrestricted use*[36] and the decommissioning phase of the practice terminated. However, if this is not feasible, the site may still be released but only for *restricted use*. The restriction can be considered a type of intervention because some form of institutional control will be required. However, the dose constraint should still play a role: the restrictions on the

[36] The term *[un]restricted use* is used in this report to mean the [un]limited utilisation of the human habitat under radiological protection conditions regulated by a competent authority.

use of the site should be such that they provide reasonable assurance that the dose constraint will be satisfied. If there is a proposal in the future to change the use of a habitat that had been released for restricted use, annual doses will have to be re-assessed and compared with the appropriate dose constraint in order to evaluate the acceptability of the proposal.

5.2.2. Radioactive residues from past human activities and events

(105) In the case of human activities which have been carried out in the past without following the current system of radiological protection for practices, the termination of the activity and the handling of the remaining residues would most probably not have been adequately considered when the activity was initiated.[37] Common long-lived radioactive residues from these early operations are those from activities such as luminising with radium compounds and ancient mining and milling of ores containing radioactive materials (see paragraph A.15 et seq). (The application of individual dose restrictions to tailings from mining and milling is addressed in section 2.3. The use of mining spoil as a land fill material, followed by the construction of dwellings, has caused substantial problems). A different case of radioactive residues from the past are those remaining from an unforeseeable event, such as an accident, that has released long-lived radioactive materials to the environment (see paragraph A.19). However, the most significant residues from the past are those remaining from operations at military facilities. Sometimes military operations, such as nuclear weapons tests, have resulted in large amounts of radioactive materials being dispersed over vast areas (see paragraphs A.17–A.18).

(106) National authorities should consider options for dealing with radioactive residues remaining from uncontrolled early operations and events. In principle, decisions on the need for intervention and on the scale and extent of any required protective action should be made on a case-by-case basis, as no general solutions are available. The necessary actions may vary greatly in complexity and scale. They may involve site rehabilitation through in situ treatment of residues (covering of residues, deep ploughing, soil treatment to prevent uptake by plants, etc.), or scrapping and removal of residues for storage and ultimate disposal. The methods recommended for justifying intervention and for optimising protective actions in prolonged exposure situations should be applied in each individual situation. The generic reference levels recommended in Chapter 4 may also provide guidance for the solution of difficult problems.

(107) An interesting issue is whether the individual annual doses attributable to radioactive residues from earlier human activities and events should be subject to any restriction criterion. In principle, there are no impediments in these situations to restricting the attributable individual doses to arbitrary levels. But, in many situations, the origins (and originators) of some of these activities and events are not even traceable. Thus, it may not be reasonable or even feasible to impose on society today

[37] The Commission has already recognised the difficulties of handling this problem in *Publication 60* (ICRP 1991a, paragraph 219).

the costs and other disadvantages of the protective actions needed for restricting individual doses, a posteriori, to levels that were not considered, a priori, by those who decided to carry out the original activity or event at the time.

(108) However, there are many cases of existing radioactive residues that are traceable to a precise original activity or event that sometimes occurred not long ago. Moreover, in many of these cases, those who caused the situation can still be made retrospectively liable for the required protective actions. For example, the radioactive residues remaining from a recent accident[38] have traceable origins and the liabilities of the originators are sometimes (although not always) straightforward. The existing annual doses before the event are usually well known. The existing annual doses after the optimised protective actions have been undertaken could be much higher that the existing annual doses existing before the event. In these cases the imposition of additional protective actions to those responsible for the situation, in order to achieve some pre-selected individual dose restriction, could be considered by the competent authorities a reasonable and justifiable measure. This type of a posteriori individual dose restriction, however, should not necessarily conform to the individual dose restrictions recommended for practices. Fig. 8 illustrates the situation.

(109) Once all required protective actions have been undertaken, the situation should be considered 'normal' again. No further restriction should be imposed on the basis of radiological protection considerations.

(110) In summary, the Commission considers that:

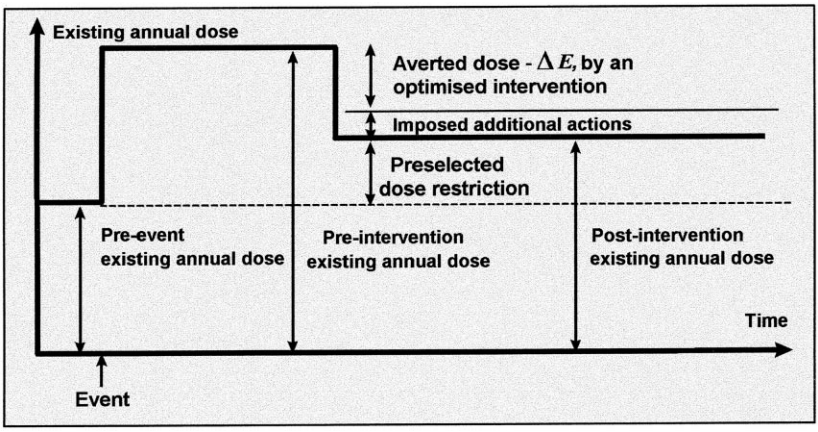

Fig. 8. Simplified schematic presentation of the existing annual dose over time when the intervention is caused by a traceable event and those who produced the radioactive residues can still be made retrospectively liable for the protective actions. In these cases, national authorities may consider applying a specific restriction to the individual doses attributable to the residues and, therefore, imposing protective actions additional to those considered being optimised.

[38] See next section for the discontinuation of protective actions after an accident.

- For radioactive residues from other past human activities and events that were not regulated as practices, the need, form, scale, and duration of protective actions should be determined on a case-by-case basis. This should be done following the recommended principles of justification of intervention and optimisation of the protective actions, rather than through pre-selected individual dose restrictions. If necessary, the recommended generic reference levels of existing annual dose may be used as guidance.
- However, in cases where the origins of the situation are traceable and those who produced the residues can still be made retrospectively liable for the protective actions, national authorities may consider applying a specific restriction to the individual doses attributable to the residues, constraining the resulting doses to levels below those resulting from the optimisation process. For this purpose, additional protective actions may be required from those who created the situation. Such specific dose restriction, however, may be higher than the dose constraints and dose limits applied to practices.
- Residues that are deemed not to require protective actions should not be the subject of further restrictions.

5.2.3. Situations of potential exposure

(111) All of the preceding recommendations relate to prolonged *normal exposure* to radioactive residues in a human habitat. In normal exposure situations annual doses are either being delivered or will certainly occur in the future. There may also be situations in which the exposure is not certain to occur and the attributable dose may have only a small probability of being incurred. These are termed situations of *potential exposure*.[39] Potential exposure situations cover a wide range of circumstances, including normal uses of radiation sources and situations of potential exposure to radioactive residues. An example of these situations is presented by areas contaminated with sparsely distributed hot particles.[40]. In this case, the most direct exposure pathway would be deposition of a particle in a wound, uptake of the radionuclides from the wound into the body, and consequent internal exposure. The possibility of this scenario exists although it is remote: the particles are usually scarce and it may be unlikely that people will come into contact with them; moreover, if this happened, the chance that a particle would enter a wound would be small. Nevertheless, should people be exposed to the contaminated area and a hot particle be actually incorporated through a wound, the resulting local dose might be

[39] See paragraph D.9 for a description of *normal* and *potential exposure*. The concept of *potential exposure* was introduced by the Commission in *Publication 60* (ICRP 1991a, paragraphs 127–129). In *Publication 64* (ICRP 1993a), the Commission provided tools for judging the acceptability of potential exposures. The Commission addressed the protection from potential exposure for selected radiation sources in *Publication* 76 (ICRP 1997b).

[40] An example of potential exposure to hot particles has been illustrated in the assessment of the radiological situation created by plutonium hot particles present on the motus (islets) of Colette, Ariel and Vesta, in the Atoll of Mururoa, French Polynesia (IAEA 1998b).

relatively large (see paragraph A. 18) and may even be a cause of localised deterministic effects such as micro-necroses around the incorporated hot particles. The potential for this exposure would remain for as long as the hot particles were present in the environment. This is a prolonged *potential* exposure situation, i.e., it is the exposure potential which is prolonged rather than the exposure itself.[41]

(112) According to the Commission's recommendations, a potential exposure situation should be evaluated on the basis of the combination of the probabilities that a radiation dose will be incurred and that such a dose will cause the development of lethal stochastic health effects (ICRP 1993a). In many cases, the product of these probabilities, which is the unconditional probability of incurring the health effect, provides a suitable basis for decisions. Thus, the concepts of individual and collective detriment resulting from any normal exposure need to be extended because the event that leads to the exposure may or may not occur.

(113) Therefore, the simplest way of dealing with *prolonged potential exposure* situations is to consider the overall probability that individual members of the public will develop lethal stochastic health effects attributable to the situation, rather than just the annual dose that such an individual would incur, should the exposure actually take place. This probability will result from the combination of the probabilities of a number of random events, namely: the exposure to the hot particles, the incorporation of a particle, the incurring of a dose as a result, and the development of lethal stochastic health effects attributable to that dose. An action level can then be expressed in terms of this combined probability and used as guidance for remediation of areas with hot particles.

(114) In summary, the Commission considers that:

- In situations of prolonged potential exposure caused by sparsely distributed hot particles in the environment, action levels for intervention should be derived on the basis of the unconditional probability that members of the public would develop fatal stochastic health effects attributable to the exposure situation. That probability should be assessed by combining the following probabilities: the probability of being exposed to the hot particles; the probability of incorporating a hot particle into the body as a result of such exposure; the probability of incurring a dose as a result of such incorporation; and, the probability of developing a fatal stochastic effect as a result of that dose. (These probabilities should be integrated over all the range of situations and possible doses).

[41] It could be said that this is a situation of *prolonged potential exposure* (i.e. where there is prolonged 'exposure' to the possibility of receiving a dose from an intake of a hot particle which, if it occurred, could itself be acute), rather than a situation of *potential prolonged exposure* (i.e. where there is a potential event, such as an accident, that could create a prolonged 'normal' exposure situation). In this report, prolonged potential exposure situations do not include cases in which a low probability event has widespread radiation consequences The techniques for evaluating these cases have been broadly considered by the Commission in the context of solid waste disposal in *Publications 46* and *77* (ICRP 1985b; ICRP 1997c). Some such cases are complex and are still being discussed (IAEA 1990; INSAG 1995; NEA 1995).

- In establishing action levels for prolonged potential exposure, consideration should be given to the possibility that localised deterministic effects may also occur as a result of the incorporation of hot particles.

5.3. Discontinuation of intervention after an accident

(115) Disruptive protective actions, such as evacuation or other restrictions in the 'normal' living conditions of people, may be required after accidents that have released radioactive substances into the environment. Eventually, in order to return to 'normality', such actions may need to be discontinued at some stage in spite of the continuous presence of a residual prolonged exposure. The discontinuation of protective action after an accident is a complicated problem in the context of prolonged exposure. If significant amounts of radioactive materials are released to the environment as a consequence of the accident, the Commission's system of radiological protection requires the consideration and, if justified, implementation of intervention. Two distinct phases are usually recognised, namely: the *emergency situation,* which the Commission has dealt with in *Publication 63* (ICRP 199lb); and, the *long-term prolonged situation,* which is treated in this document. The latter involves longer-term protective actions, such as resettlement of people and restrictions on food and other commodities.

(116) It is emphasised that this report does not include recommendations for intervention in emergency situations after an accident. In *Publication 63* (ICRP 1991b), the Commission issued recommendations for dealing with measures to protect the affected population at the early and intermediate stages of intervention after an accident. These stages may involve immediate protective actions such as sheltering, evacuation and iodine prophylaxis, and more protracted measures such as relocation. As indicated in Chapter 3, the intervention level for averted dose at which relocation is regarded as 'almost always justified' is 1000 mSv in a lifetime, with an optimised action level in the range 5–15 mSv per month (the dose rate at which relocation was generically optimised is about 10 mSv per month). Following these recommendations, generic optimised actions levels for emergency preparedness for accidents have been established in international standards (IAEA 1996) as follows: for initiating temporary relocation, 30 mSv in a month, and for terminating the temporary relocation, 10 mSv in a month (with the proviso that if the dose is not expected to fall below this level within a year or two, or the lifetime projected dose is expected to exceed 1000 mSv, permanent resettlement should be considered).

(117) If the protective actions undertaken in the emergency situation have been successful, a significant amount of both the transitory and prolonged exposures attributable to the accident will have been averted. For instance, if the affected population is evacuated, the radioactive residues from the accident will not deliver doses to the people. However, they will remain in the protected areas as a latent cause of residual prolonged exposure, which could persist for a relatively long time. The exposure will become evident when the protective actions are discontinued. The issues are when, given this residual exposure, the long-term situation may be treated

as 'normal' again as regards those affected and, therefore, when the intervention can terminated.

(118) Fig. 9 presents a relatively comprehensive picture of the evolution of the annual dose after an accident, which enlarges upon the schematic presentation of Fig. 5. The annual doses are caused by both prolonged and transitory exposures. In the best of circumstances, both prolonged and transitory doses are fully averted by the intervention and the annual dose is reduced to the pre-event existing annual dose level. The annual dose that would be incurred if intervention had not been undertaken would usually decrease with time. After some time, therefore, it may be appropriate to discontinue some or all of the protective actions. As a result, the residual existing annual dose after the discontinuation of protective actions will be higher than the pre-event existing annual dose because of the remaining annual dose attributable to the event. At this stage, the radionuclides giving rise to the transitory doses will probably have decayed and the remaining doses will be mainly of a prolonged nature. Following the discontinuation of protective actions, the long-term residual prolonged annual dose should not be subject to further control and the situation could conceptually be considered 'normal' again.

(119) If a given action level has been used to trigger intervention, the corresponding protective actions can be discontinued when the value of the relevant quantity falls below such action level. It is important to recall, however, that the protective actions taken would have been intended to produce substantial reduction in the exposure remaining after the accident: it is not necessarily sufficient to make marginal improvements aimed at reducing the exposures to values just below the

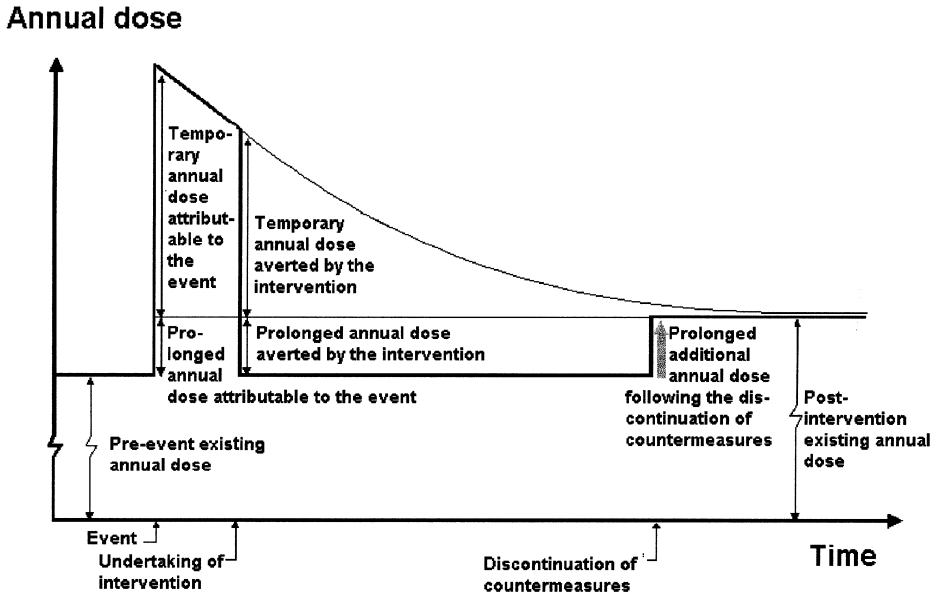

Fig. 9. Evolution of the existing annual dose after an accident, followed by intervention and, eventually, the discontinuation of protective actions.

action level. The situation after discontinuation will then be much the same as that in areas where intervention had been considered, but not taken.

(120) A practice being introduced into an area with a prolonged exposure situation remaining after the discontinuation of intervention should be subject to the requirements of the Commission's system of radiological protection for practices in just the same manner as outside that area. This is because all decisions about a new practice should be related only to the additional annual doses attributable to that practice which would be measured from the new baseline of existing annual dose (see paragraph D.16 and Fig. D.4). Similarly, although it may not be a practice in its own right, the building of new houses for the population moving into such an area should not be subjected to any restrictions additional to those imposed on existing houses; conversely, if any restrictions are still in force, incoming groups should be subject to them.

(121) If the only available protective action is the relocation of residents, it will usually be appropriate to accept higher exposures rather than to impose the social costs and disadvantages of relocation. It will then usually be impractical to prevent people from outside the affected area from moving in to take up residence.

(122) In summary, the Commission considers that:

- The simplest basis for justifying the discontinuation of intervention after an accident is to confirm that the exposures have decreased to the action levels that would have prompted the intervention. If such a reduction in exposure is not feasible, the generic reference level of existing annual dose below which intervention is not likely to be justifiable could provide a basis for discontinuing intervention.
- However, it may be difficult to discontinue protective actions that have been in force for many years: the decision may not be acceptable to the exposed population and the social pressures may override the benefit of discontinuing the intervention. In these cases, the participation of the stakeholders in the decision-making process becomes essential.
- After intervention has been discontinued, the remaining existing annual dose should not influence the normal living conditions in the affected area (including decisions about the introduction of new practices), even if such a dose is higher than that prevailing in the area before the accident.

5.4. Radioactive substances in commodities

(123) Radioactive substances may be present in commodities, thus representing a source of prolonged exposure. Some of the radionuclides in these substances may be natural in origin, and others may be artificial. Usually, natural radionuclides are present in commodities as a result of natural processes and deliver prolonged exposures that are essentially unamenable to control. On the other hand, natural and artificial radionuclides may also be present in commodities as a direct result of human activities. They may be incorporated as a result of the operation of practices: for instance, as result of radioactive residues from the operation and decommission-

ing of the practice or, from exempted materials, that were used in the practice and are cleared for recycling and release into the market. (Recycled materials may still contain small amounts of radionuclides.) The levels in the commodities of radionuclides attributable to the normal operation of practices should be controlled through the principles of the system of radiological protection for practices, including the criteria for exemption of practices.

(124) Natural and artificial radionuclides may also be incorporated into commodities from an environment contaminated with radioactive residues from past activities or events, or from accidents. This is the more pervasive process of contamination of commodities and the method of control is through the system of radiological protection for intervention. However, mainly due to the globalisation of markets, *intervention exemption levels* of radionuclides in commodities cannot be established on a case-by-case basis; rather, they need to be standardised. As recalled in Chapter 3 and further expanded in Annex D, the Commission has previously stated (ICRP 1991a: paragraph 284) that in order to avoid unnecessary restrictions on international trade, it may be necessary to establish intervention exemption levels that would indicate a line of demarcation between freely permitted exports or imports and those that should be the subject of special decisions.

(125) As discussed in Chapter 4, intervention is not likely to be justifiable in situations where the existing annual dose incurred by a member of the public is below about 10 mSv. It would be illogical to allow the annual dose components attributable to commodities and amenable to intervention even to approach this level. Natural background exposure causes annual doses of at least a few millisieverts per annum and, taking account of possible annual doses from authorised practices, this leaves an upper bound of the order of a few millisieverts per annum for the annual doses from all commodities to be exempted from intervention. It is not likely that several types of commodities would be simultaneous sources of high prolonged exposure to any given individual.

(126) On the basis of the above presumptions, the Commission considers that:

- A generic intervention exemption level of around 1 mSv is recommended for the individual annual dose expected from a dominant type of commodity amenable to intervention, such as some building materials, which may in some circumstances be a significant cause of prolonged exposure.
- On the basis of this recommendation, concerned national and, as appropriate, relevant international organisations should derive generic, and radionuclide-specific, *intervention exemption levels* for individual commodities, in particular for specific building materials.

(127) The recommended generic intervention exemption level should be used with care. For instance, there are commodities that are, in given situations, irreplaceable and essential for normal living, such as some basic building materials and foodstuffs. Other commodities, such as a number of consumer products, may be considered superfluous. It is not appropriate to use the same criteria for these different situations. In addition, it should be recalled that international and national guidance exists on exemption for individual consumer products, usually expressed in terms of

an annual dose of a few hundredths of a millisievert (NEA 1985). The Commission wishes to underline that:

- Intervention exemption levels should not be used, either explicitly or implicitly, for relaxing the limits imposed on the activity of radionuclides that may be released from practices. In particular, they should not be used for clearing the recycling of materials resulting from the decommissioning of practices (these situations are better handled with the criteria of exemption for practices).

(128) ***The control of commodities after an accident***: A particularly difficult situation is presented by commodities that are produced in an area affected by radioactive releases from an accident, and which contain radioactive substances attributable to the releases. Fig. 10 presents the evolution of the annual dose caused by a change in the activity concentrations of radionuclides in commodities produced in such an area (the analysis of the graph is similar to that for Fig. 9). A nuclear power plant accident with widespread effects can create such a situation. Application of the Commission's system of radiological protection for intervention should result in a radiologically acceptable situation in the area affected by the accident. However, if long-lived radionuclides are involved, some radioactive residues may remain in the environment. Following a subsequent return to normal living, these radionuclides could be present in commodities produced in the affected area. If the corresponding activity levels are higher than those in produce from neighbouring areas, issues of market acceptance could arise, particularly if there are transboundary movements of the commodities.

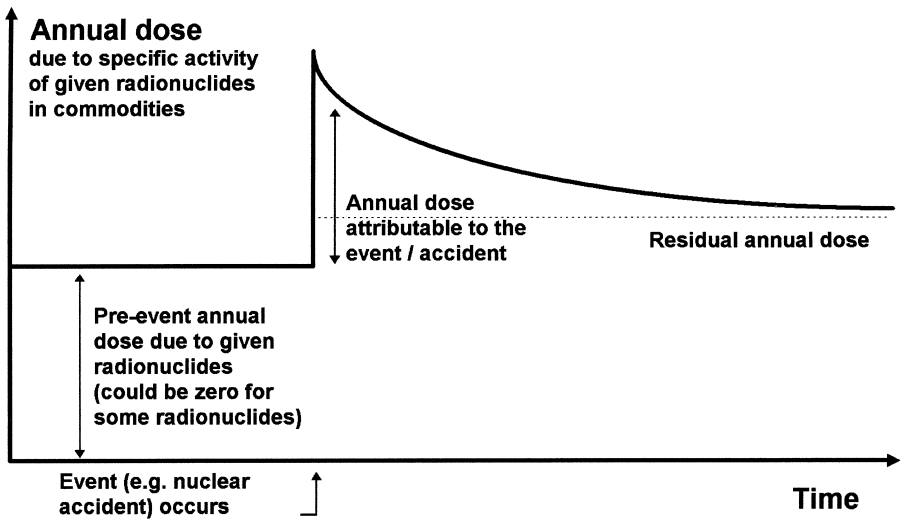

Fig. 10. Evolution of the annual dose caused by radionuclides in contaminated commodities in the aftermath of an accident.

(129) The WHO/FAO Codex Alimentarius Commission adopted de facto generic intervention exemption levels for radionuclides in foodstuffs following an accident (Codex Alimentarius 1991). Identical levels have been established in international standards (IAEA 1996). These levels would lead to individual doses of around a few millisieverts per annum to those who consume the food.

(130) If the annual doses in the area affected by the accident are acceptable because the intervention strategy has been optimised, the situation outside the affected area will also be acceptable because the individual annual doses elsewhere from the use of commodities produced in the affected area would normally not be higher than those in the affected area. However, the production of commodities in areas affected by an accident could commence some years after the accident; this possibility should be considered in any intervention strategy applied after the accident.

(131) The Commission considers that:

- If the restrictions on commodities produced in the area affected by an accident have not been lifted, production of the restricted commodities should not be restarted; conversely, if the restrictions have been lifted, production can be restarted. If an increase in production is proposed, it could proceed subject to appropriate justification.
- In circumstances where restrictions have been lifted as part of a decision to return to 'normal' living, the resumption and potential increase of production in the affected area should have been considered as part of that decision and should not require further consideration.

6. OUTLOOK

6.1. Summary of the quantitative recommendations

(132) A condensed view of the quantitative recommendations in this report is provided in Table 1. The information is presented in an extremely simplified form

Table 1. Quantitative recommendations
It is important to refer to the discussion in Chapters 4 and 5 before applying the numerical values in this Table.

Concept	Quantity	Value (mSv)
Generic reference level for interventions almost always justifiable *(above which intervention should be considered almost always justifiable)*	Existing annual dose *(summation of all [prolonged] annual doses attributable to all sources of prolonged exposure in a given location)*	$<\sim$100
Generic reference level for interventions not likely to be justifiable *(below which intervention is optional but not likely to be justifiable, and above which intervention may be necessary)*	Existing annual dose *(summation of all [prolonged] annual doses attributable to all sources of prolonged exposure in a given location)*	$<\sim$10
Exemption from intervention in commodities *(criterion for deriving intervention exemption levels for dominant commodities, such as some building materials)*	Additional annual dose *(annual dose attributable to the dominant type of commodity)*	$\sim$1
Dose limit for practices *(applicable to the indivdual dose contributed by all relevant practices)*	Aggregated additional annual dose *(summation of all annual doses [transitory and prolonged] attributable to all relevant practices)*	1
Dose constraint for practices *(applicable to the individual dose from a source within a practice; to be used for the optimisation of protection of the source)*	Additional annual dose *(summation of all annual doses [transitory and prolonged] attributable to a source within a practice)*	$<\sim$1 & $\sim$0.3
	(for the prolonged component)[a]	($\sim$0.1)
Exemption for practices *(criterion for deriving exemption levels for sources within practices; protection at the sources should be optimised and the sources should be part of a justified practice)*[b]	Additional annual dose *(summation of all annual doses [transitory and prolonged] attributable to a source within a practice)*	$\sim$0.01

[a] *To be considered if dose assessment methodologies to ensure compliance under any conceivable situation of combination of doses is not available.*

[b] *Also generally applicable to clear the release of materials containing radioactive substances from practices and which may subsequently be recycled as commodities for public use with no restrictions.*

and its parts are not amenable to comparison. The upper part of the Table shows recommendations in terms of individual *existing* annual dose; the lower part presents recommendations in terms of individual *additional* annual dose. Therefore the dose ranges in these two parts are expressed in different quantities and cannot be compared. Furthermore, the Table does not include any reference to specific intervention and action levels of averted annual dose nor of collective doses in general.

6.2. Demonstration of compliance

(133) The quantitative recommendations in this report will be difficult to implement unless there are agreed approaches to the estimation of exposures with the purpose of demonstration of compliance with the recommendations. A number of problems related to exposure assessment need clarification and the Commission may choose to return to these issues in the future. A summary of some relevant topics related to the estimation of prolonged exposures follows:

(134) As general guidance, the Commission considers that its recommendations on the estimation of exposures in *Publication 43* (ICRP 1985c) apply to prolonged exposure situations. Therefore, in applying the recommendations in this report, prolonged exposures are generally expected to be assessed on the basis of the mean annual dose in the *critical group*. However, in some situations it may be more difficult to estimate this dose than the dose to an identifiable 'maximally' exposed individual.

(135) Long-term scenarios must be defined to characterise the individuals exposed and the ways in which they are exposed.

(136) Quantification of uncertainty should be an integral part of the estimation of the annual doses. Methods for estimating uncertainties have been documented and are being applied in a wide range of applications in environmental dosimetry (NCRP 1984; IAEA 1989; NCRP 1996). These methods vary significantly, ranging from qualitative judgements about variability to more rigorous approaches that include a statistical analysis of distributions for a range of input values that influence the dose estimate. Uncertainty analysis is evolving rapidly, and techniques for estimating dosimetric uncertainties are also still being developed. Whenever possible and appropriate, annual doses should be reported as a distribution of possible values rather than as single point values.

(137) Radioactive residues are usually unevenly distributed in space, creating heterogeneous prolonged exposure situations. These need to be addressed on a case-by-case basis by making realistic assumptions about the pattern of people's exposure. The selection of methods for evaluating heterogeneous exposure will depend on the situation and the objectives of the evaluation.

(138) The evaluation of annual doses in prolonged exposure situations should be based on the assumption of unrestricted use of the site or commodity affected. This assumption implies that all exposure pathways that could realistically be in operation at any time in the future should be accounted for. However, restrictions on use may be the outcome of optimisation. Restrictions will preclude certain pathways and thus may reduce exposures, thereby achieving some advantages while

introducing the disadvantages imposed by the restriction. Scenarios describing restricted use following remediation will be case-specific. Furthermore, decisions about possible restricted uses may vary significantly within and between different countries. Restricted use will usually involve some form of ongoing institutional control such as land use registry. The possibility of failure of this institutional control may need to be taken into account in the estimation of exposure.

(139) For areas where there is more than one site with exposure at high levels, the necessary degree of remediation should be determined by taking account of the annual doses from all the high exposure areas as well as those from the region as a whole.[42] This evaluation should be made using realistic assumptions about diet and lifestyle, using realistic habitability data and accounting for all possible pathways. It is recognised that, when sites with high exposure levels exist within a larger area of prolonged exposure, remediation of these high exposure sites may be governed by local regulations for decontamination. It is important that the strategy be realistic. Intervention involves considerable costs and social inconvenience, and the line between caution and overreaction may be fine.

[42] An illustration is provided by the common policy for dealing with radon in dwellings. A large radon prone area can be defined and used to concentrate resources. The decision to intervene is taken house by house on the basis of direct monitoring in individual dwellings. Another illustration is provided by contaminated areas in the countryside. If the necessary monitoring is feasible, intervention can be applied to individual farms or even individual fields.

A. ANNEX A: SOME PROLONGED EXPOSURE SITUATIONS

(A1) Prolonged exposure situations involve exposure to the following sources: primaeval cosmic rays and the cosmogenic radionuclides produced by their interaction with nuclides in the upper atmosphere; primordial radionuclide chains in the earth's crust; and long-lived 'artificial' radionuclides in radioactive residues. More than 2,000 radionuclides have been identified, but only around 100 have long enough half-lives (of more than about ten years)[43] to have the potential for becoming a cause of prolonged exposure. Many short-lived radionuclides are decay products of long-lived radionuclides and are constantly generated by their long-lived precursors. The exposure they cause, therefore, should also be considered prolonged. Many of these belong to the long-life decay chains of primordial radionucides.

(A2) Cosmogenic radionuclides causing prolonged exposure are hydrogen-3 (tritium), carbon-14, and sodium-22. They are isotopes of elements with metabolic roles in the human body. However, their contribution to the existing annual dose is insignificant.

(A3) The primordial radionuclide decay chains are:

- The *thorium series,* headed by thorium-232, the most abundant of all naturally occurring radionuclides, with a half-life of 1.41 10^{10} years, and constituted by 228Ra(5.75 a), ^{228}Ac (6.15 h), ^{228}Th (1.913a), ^{224}Ra (3.66 d), ^{220}Rn (55.6 s), ^{216}Po (0.145 s), ^{212}Pb (10.6 h), ^{212}Bi (60.6 m), ^{212}Po (0.299 μs), ^{208}Tl (3.05 m), and ^{208}Pb (stable).
- The *uranium series,* headed by uranium-238, with a half-life of 4.47 10^9 years, and constituted by ^{234}Th (24.1 d), ^{234m}Pa (1.17 m), ^{234}U (2.45 10^5 a), ^{230}Th (7.54 10^4 a), ^{226}Ra (1600 a), ^{222}Rn (3.82 d), ^{218}Po (3.10 m), ^{214}Pb (26.8 m), ^{214}Bi (19.9 m), ^{214}Po (164 μs), ^{210}Pb (22.3 a), ^{210}Bi (5.01 d), ^{210}Po (138 d), and ^{206}Pb (stable).
- Less important, the *actinium series,* headed by uranium-235, with a half-life of 7.04 10^8 years, and constituted by ^{231}Th (25.5 h), ^{231}Pa (32,800 a), ^{227}Ac (21.8 a), ^{227}Th (18.7 d), ^{223}Fr (22.0 m), ^{223}Ra (11.4 d), ^{219}Rn (3.96 s), ^{215}Po (1.78 ms), ^{211}Pb (36.1 m), ^{211}Bi (2.14 m), ^{207}Tl (4.77 m), and ^{207}Pb (stable).

(A4) Another decay chain to mention is the *neptunium series,* headed by plutonium-241, which includes the long-lived neptunium-237 (2.2 10^6 a) and uranium-233 (1.62 10^5 a) and is considered to be artificial (i.e., created by human activities), although there has been natural generation of these radionuclides in so-called natural nuclear reactors. Of the radionuclides in the primordial chains, those of particular importance for prolonged exposure situations are radioisotopes of radium, of

[43] Radionuclides with half-lives of more than about 10 years include: ^{3}H, ^{10}Be, ^{14}C, ^{26}Al, ^{32}Si, ^{36}Cl, ^{39}Ar, ^{42}Ar, ^{40}K, ^{41}Ca, ^{44}Ti, ^{53}Mn, ^{60}Fe, ^{59}Ni, ^{63}Ni, ^{79}Se, ^{81}Kr, ^{85}Kr, ^{87}Ru, ^{90}Sr, ^{93}Zr, ^{91}Nb, ^{92}Nb, ^{93m}Nb, ^{94}Nb, ^{93}Mo, ^{97}Tc, ^{98}Tc ^{99}Tc ^{107}Pd, ^{108m}Ag, ^{113m}Cd, ^{121m}Sn, ^{126}Sn, ^{129}I, ^{135}Cs, ^{137}Cs, ^{133}Ba, ^{138}La, ^{145}Pm, ^{146}Sm, ^{151}Sm, ^{150}Eu, ^{152}Eu, ^{148}Gd, ^{150}Gd, ^{157}Tb, ^{158}Tb, ^{154}Dy, ^{163}Ho, ^{166m}Ho, ^{176}Lu, ^{178m}Hf, ^{182}Hf, $^{187+186m}$Re, ^{192m}Ir, ^{193}Pt, ^{194}Hg, ^{202}Pb, ^{205}Pb, ^{210}Pb, ^{207}Bi, ^{210m}Bi, ^{208}Po, ^{209}Po, ^{226}Ra, ^{227}Ac, ^{229}Th, ^{230}Th, ^{232}Th, ^{231}Pa, ^{232}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U, ^{236}Np, ^{237}Np, ^{241}Pu, ^{238}Pu, ^{250}Cm, ^{247}Bk, ^{249}Cf, ^{250}Cf and ^{251}Cf.

the noble gas *radon,* i.e., radon-219 (or *actinon*), radon-220 (or *thoron)* and, particularly, radon-222. Radon-222 has a half-life of only few days, but it has two longer-lived decay products (lead-210 and polonium-210).

(A5) Several other natural radionuclides are very long-lived and may deliver prolonged exposure. ^{40}K (1.28 10^{10} a) is a generalised contributor to prolonged exposure by virtue of its widespread distribution in nature and because it is an important constituent of the human body. ^{87}Rb (4.75 10^{10} a), ^{138}La (1.05 10^{11} a), ^{147}Sm (1.06 10^{11} a) and ^{176}Lu (3.78 10^{10} a) are widespread in nature but at such low levels that their contribution to human exposure is negligible.

(A6) Of the radionuclides in radioactive residues, those of importance for prolonged exposure are: carbon-14 (with a half-life of 5600 a); hydrogen-3, or tritium (12.3 a) (these are also cosmogenic, produced naturally in the atmosphere); krypton-85 (10.7 a); iodine-129 (1.6 10^{7} a); and the fission products caesium-137 (30 a) and strontium-90 (28.8 a) as well as the transuranic radionuclides (significantly, plutonium-239, 2.41 10^{4} a). All these are present in many radioactive residues around the world, particularly in those from nuclear accidents and military nuclear operations.

A.1. Natural radiation sources

(A7) Prolonged exposure to what is loosely termed '*natural background radiation*' is continuously incurred by everyone from conception to death. The levels of annual dose vary not only with relatively permanent environmental features, such as geographical and geological characteristics, but also as a consequence of environmental changes. Variations in annual doses due to natural background radiation are caused by natural processes (such as volcanic eruptions) and also by features associated with human development (such as settlement and dwelling). Some exposures to natural background radiation are essentially not amenable to control and therefore excluded from radiological protection standards. (This is the case, for instance, with exposure to cosmic radiation.) Conversely, other background exposures are controllable and radiological protection measures are possible and sometimes desirable.

(A8) The development of human society has changed — and usually increased the prolonged exposure to primordial radionuclides. Siting of dwellings in high background areas, house construction materials rich in some radionuclides in the primordial chains, developments in eating and drinking habits that include the use of artificial fertilisers and water from mineral sources, have all typically increased the prolonged exposure of people. The radioactive progeny of radon-222 cause widespread exposure in many dwellings, where they are often the predominant source of prolonged exposure. In recent years, industrial development has further increased natural exposures to radionuclides in the primordial chains. Some industries have modified human habitats, making available Naturally Occurring Radioactive Materials (usually termed *NORMs)*. Industries producing *NORMs* include: extractive industries for energy production; use of phosphate rock; and mining and milling of mineral sands.

(A9) ***Annual doses from natural sources***: A summary of the average annual doses from natural sources is presented in Table A.1. The left column in the Table presents

average annual doses caused by the global natural background. The right column presents average annual doses in areas of *typically elevated* natural background exposures. The table is based on estimates of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 1993, 2000).

(A10) As can be seen in Table A.1, the average typically elevated annual doses, which occur in relatively common situations, are much higher than the average annual dose due to global exposure. Fig. A.1 presents a map of Western Europe indicating many areas with typically elevated annual doses higher than 10 mSv (CEC 1993). Living in areas with high concentrations of primordial radionuclides is a common cause of typically elevated exposures. Many situations of typically elevated exposure are created by the presence of high concentrations of the gas radon in dwellings. Others, however, are caused by elevated concentrations of other natural radionuclides in the environment. It should also be noted that levels up to 10 mSv per annum are relatively rare in global terms. (The vast majority of the world population incur doses around the average global exposure of 2.2 to 2.4 mSv per annum; more than about 98% of the population incur doses lower than about 5 mSv per annum, and about 99% doses lower than 7 mSv per annum.) However, there are many inhabited areas of the world where the annual doses from natural sources are much higher than 10 mSv.

(A11) Annual doses much higher than the typically elevated average annual doses occur locally in many parts of the world. Table A.2 presents a number of situations of high natural background radiation (UNSCEAR 2000). In the populous city of Ramsar, in Iran, some annual doses are reported to be higher than 100 mSv.

(A12) On the basis of UNSCEAR estimates, some specific prolonged exposure situations to natural background radiation are described below.

(A13) ***Radon in dwellings***: Some confined spaces selected by humans as dwellings, especially those bound by radon emitting materials and/or located on radon emitting ground, are prone to having enhanced concentrations of radon in the air; examples are caves used by primitive man and stone and brick dwellings of modem man. The use of natural gas for cooking has also enhanced exposure to radon in homes. More recently, the insulation of houses to improve the efficiency of heating has exacerbated the problem. Extreme concentrations of radon and its progeny in

Table A.1. Annual doses from natural sources.

Source of exposure	Average annual effective dose (mSv)	
	Global exposure	Areas of typically elevated exposures
Cosmic rays	0.39	2.0
Terrestrial gamma rays	0.46	4.3
Radionuclides in the body (except radon)	0.23	0.6
Radon and its decay products	1.3	10
Total (rounded)	2.4	~

buildings have been reported as locally occurring maximum values in several countries, e.g. Ca. 4000 Bq/m^3 in Belgium and Sweden, Ca. 10,000 Bq/m^3 in the United Kingdom, Ca. 20,000 Bq/m^3 in the Czech Republic and up to 100,000 Bq/m^3 in Germany. These levels are up to two orders of magnitude higher than those in areas with typically elevated exposures, leading to annual doses of up to several hundred millisieverts. However, these extreme radon concentrations are in most cases being reduced by remediation.

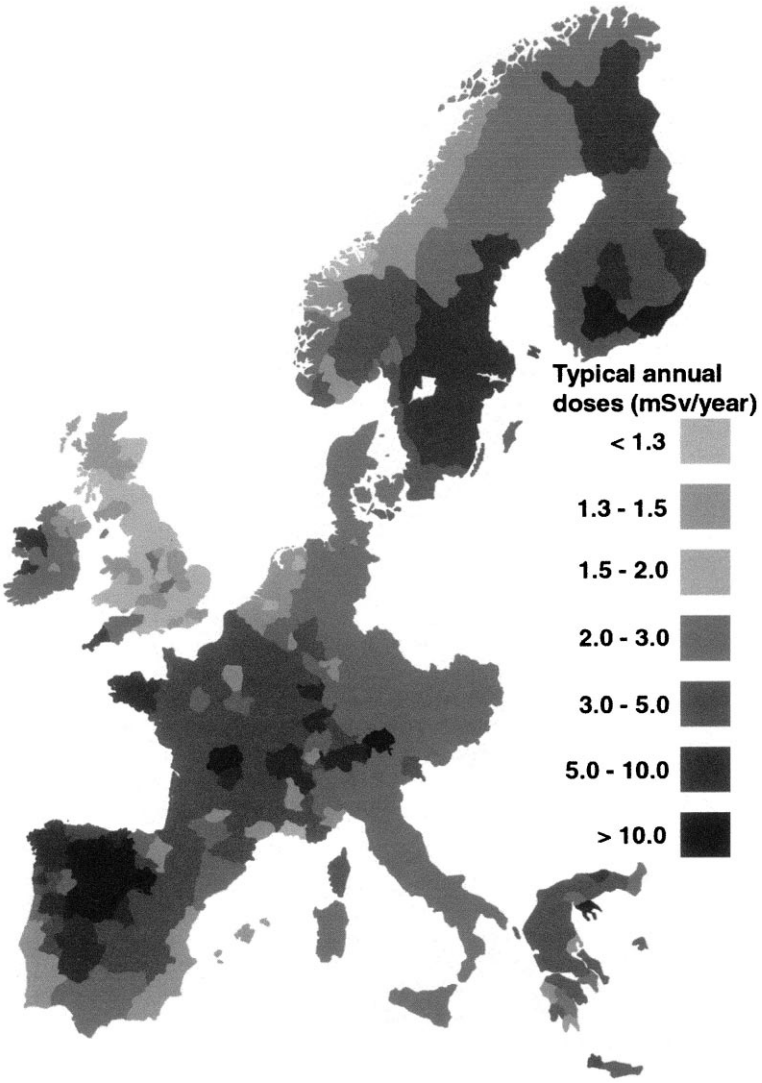

Fig. A.1. Existing annual doses from natural background radiation in Western Europe. Adapted with kind permission from CEC (EUR report 14470, 1993).

Table A.2. Some areas of high natural background radiation.

Area	Characteristics of area	Existing annual dose [mSv per annum]
States of Rio de Janeiro and Espírito Santo, Brazil	Monazite sand; coastal	up to ~30 (3.6 average)
Mineas Gerais and Goias, Brazil	Volcanic intrusions in 6 km^2 scattered inland areas	up to ~80 (13.3 average)
Kerala and Tamil nadu, India	Monazite sand; coastal area, 200 km long and 0.5 km wide	up to ~30 (9 average)
Central region of France	Granitic, schistous and sandstone	up to ~6
Niue Island	Volcanic soil	up to ~5
Mombasa, Kenya	Thorium bearing carbonalyte	up to ~30
Ramsar, Iran	Areas of radium-226 deposition from spring water	up to ~200
Mahallat, Iran	Areas of radium-226 deposition from spring water	up to ~20

(A14) ***Natural gamma radiation emitters in building materials***: Another cause of high levels of prolonged exposure is the use of building materials, including water, rich in gamma-emitting primordial radionuclides. In a few parts of world, building materials containing these radionuclides have been used over generations. Annual doses approaching 10 mSv have been reported in houses in Europe with outside walls containing uraniferous alum shale and also coal slag. As indicated before, in at least one major city, Ramsar, the prolonged exposure due to the use in house construction of shine-bottom deposits is reported to deliver annual doses up to well above 100 mSv. The deposits are collected from areas through which underground water from hot springs in travertine is flowing.

(A15) ***Natural gamma radiation emitters in the ground***: A number of areas in the world with high levels of exposure to natural background radiation from the soil have been identified. The exposure can be an order of magnitude above the world average exposure to natural background radiation. Mineral sands containing monazite in Kei'ala and Tamil Nadu, India, and in Espírito Santo, Brazil, thorium bearing carbonalite in Mombasa, Kenya, volcanic intrusions with mixed thorium and uranium mineralisation in Minas Gerais, Brazil, as well as other minerals in vast areas of China, deliver annual doses of around 30 mSv.

A.2. Long-lived radioactive residues in human habitats

(A16) Of the many past human activities and events involving deposits of residual radioactive materials in human habitats, it is useful to review three that cause particular problems: extractive industries involving *NORMs;* military operations, including nuclear weapon testing; and some nuclear accidents. On the basis of UNSCEAR estimates, they are described below.

(A17) ***Extractive industries, NORMs***: The extraction of earth materials has brought *NORMs* into closer contact with humans. Although the main concerns have been with occupational exposures, tailings from mining and other associated industrial processes cause contamination of air, soil, and water and therefore also direct local prolonged exposures. The industrial products or by-products arising from these activities may contain above-average concentrations of natural radionuclides.

(A18) The main industries involved include: elementary phosphorus production; phosphoric acid production; fertiliser production; primary iron and steel production, coal tar processing; coke production; coal- and gas-fired power plants; extraction of coal, peat, oil and gas; cement production; the ceramics industry; mineral sand; and titanium pigment production. A large variety of *NORMs* are produced from the extraction of coal, oil, peat, and natural gas for energy production, and also from the production and use of phosphate products, including fertilisers. Waste and by-products containing high concentrations of uranium and thorium and their daughter products are produced during the mining and processing of heavy mineral sands such as ihnenite, leucoxene, rutile, zircon and, particularly, monazite, and xenotime. Some mining processes have been recognised from the start as calling for the control of radiation exposures of the public. With others, the problems have only recently become apparent. Comprehensive information on public annual radiation doses due to *NORMs* is yet not available; UNSCEAR is preparing new estimates (UNSCEAR 2000).

(A19) ***Military operations***: The production of nuclear weapon materials has left several areas of the world contaminated with radioactive residues that cause prolonged exposure situations. Relatively high releases of radioactive materials to the environment occurred during the early years of operation of these facilities. In addition, a series of accidents occurred in initial periods of intense military activity. Examples are the major weapon materials production facilities located in the Chelyabinsk, Krasnoyarsk, and Tomsk regions of the former Soviet Union. A main source of radioactive contamination was the 'Mayak' facility near Kyshtym in the Chelyabinsk region of the Southern Urals, where there occurred: discharges of about 110 PBq of liquid waste including long-lived radionuclides of caesium-137 and of strontium-90 into the Techa River during the period 1949–56; the dispersion of about 74 PBq into the atmosphere, including 5.4 PBq of strontium-90 following an explosion in a radioactive waste storage facility in 1957; and the resuspension of more than 20 TBq in dry silt from the shores of Lake Karachay during a heavy storm in 1967 (UNSCEAR, 2000). The present radioactive contamination caused by the industrial activities of the 'Mayak' facility covers more than 1600 square kilometres, with residual radioactive materials that could result in individual annual doses higher than 10 mSv. There is also a potential for prolonged exposures from radioactive residues dumped into the seas (IAEA 1999a).

(A20) Other examples can be found in other nuclear weapon States. Nuclear weapon plants in the United States included Femald in Ohio (materials processing), Oak Ridge in Tennessee (enrichment, separation, laboratories), Rocky Flats in Colorado (manufacturing of weapon parts), Hanford in Washington (plutonium production) and Savannah River in South Carolina (plutonium production). The

programme for cleaning up sites in the United States where contamination with radioactive materials has occurred (not all of them associated with weapon materials production) currently represents one of the largest radiological protection operations in the world.

(A21) In the United Kingdom there are plants in Springfields (uranium processing and fuel fabrication), Capenhurst (enrichment), Sellafield (production reactors and reprocessing), Aldermaston (weapons fabrication) and Harwell (research). Plutonium production reactors were operated at Sellafield (two graphite moderated, gas cooled reactors known as the Windscale piles) and later at Calder Hall on the Sellafield site and Chapelcross in Scotland. A fire occurred in one of the Windscale reactors in 1957, resulting in the discharges of long-lived radionuclides.

(A22) In France, the first experimental reactor, named EL1 or Zoé, went critical in 1948, and a pilot reprocessing plant began operation in 1954. A second experimental reactor, EL2, was constructed at the Saclay centre. From 1956 to 1959, three larger production reactors began operation at the Marcoule complex on the Rhône River. These gas cooled, graphite moderated reactors, operated until 1968, 1980 and 1984 respectively. A full scale reprocessing plant was also built and operated at the Marcoule site from 1958. Two further reprocessing plants were constructed at La Hague in the north of France.

(A23) In China, the first experimental reactor was constructed in Beijing, and a uranium enrichment plant was built in Lanzhou in Gansu Province in western China. The production reactor began operation in 1967, and the reprocessing plant in 1968. Plutonium production and reprocessing were carried out at the Jinquan complex, also in Gansu Province, where weapons were assembled. Production and reprocessing also took place at Guangyuan in Sichun Province, where larger installations were constructed.

(A24) Activities related to peaceful nuclear power programmes were incorporated at some of these global sites. Current activities at some production sites also involve the dismantling of weapons (UNSCEAR 2000).

(A25) ***Weapons testing***: The practice of nuclear weapons testing has released radioactive materials to the environment and contaminated areas which are now sources of prolonged exposure. Major test sites included: Nevada in the United States; Bikini and Enewetak Atolls in the Republic of the Marshall Islands; Semipalatinsk in Kazakhstan; Novaya Zemlya in the Russian Arctic; Maralinga and Emu in Australia; Mururoa and Fangataufa Atolls in French Polynesia; and Lop Nor in China. At the evacuated Bikini Atoll, the current level of prolonged annual dose to a hypothetical inhabitant wishing to return and settle there has been estimated to be up to 17 mSv (IAEA 1998a). At Maralinga, although the average annual dose is only a few millisieverts, there is a prolonged potential exposure situation involving a small probability of an individual receiving an annual dose approaching 500 mSv (NRPB 1990). The annual doses to a hypothetical inhabitant wishing to settle in some areas at the Semipalatinsk test site have been estimated to be above 140 mSv (IAEA 1999b).

(A26) ***Accidents***: The accident on 26 April 1986 at the Chernobyl nuclear power plant caused the largest accidental release of radioactive materials to the environment

in the history of the nuclear industry. The release of ^{137}Cs was estimated to be 85 PBq (UNSCEAR, 2000). In the former Soviet Union there is an area of more than 10,000 km^2 of land with a contamination level exceeding 0.56 MBq m^{-2} where about 150,000 people continue to live. The current annual doses due to fallout from the accident rarely exceed 10 mSv. However, in the now uninhabited areas in the vicinity of the Chernobyl nuclear power plant (within the '30-km-zone' of about 4,000 km^2) the maximum annual doses have been estimated to be about 25 mSv in the Ukrainian sector and up to 120 mSv in Belarusian sector. The rate of annual dose reduction with time has been estimated to be 3–7% per year.

A.3. Commodities containing radioactive substances

(A27) Commodities containing radioactive substances become a source of prolonged exposure. As such commodities may be distributed widely and sometimes stored, the original prolonged exposure situation can extend geographically and in time. The consumption and use of such commodities may be considered beneficial, but it will increase the radiation exposure of the consumers. Some examples follow.

(A28) Throughout the world, the use of phosphate fertiliser in agriculture has increased and become essential to food production. However, many phosphate rocks contain relatively high concentrations of uranium and, hence, of its decay products. It is estimated that the use of phosphate fertiliser has at least doubled the prolonged exposure of humans from the ingestion of food, with variations of more than an order of magnitude in the activity levels in foodstuffs. Elevated specific activity levels in foods may reach up to tens of Bq kg^{-1}, e.g. in some cereals, roots, and fruits.

(A29) The drinking of mineral water rich in primordial radionuclides is also a cause of additional prolonged exposure. The activity of these radionuclides in potable water may deliver annual doses up to a few millisieverts. UNSCEAR (1993) reported variations of more than an order of magnitude in the ^{226}Ra, ^{238}U, ^{232}Th, ^{210}Pb, and ^{210}PO concentrations in mineral water sold in bottles and drunk at fountains fed by aquifers.

(A30) Coal ash is slightly radioactive because of the presence of primordial radionuclides in the coal. Owing to the use of coal ash from coal-fired power stations in the production of bricks and cement, many people are being exposed to these sources. More than about 280 million tonnes of coal ash (fly ash and bottom ash combined) are produced annually. About 40 million tonnes are used in the production of bricks and cement, and a great deal as road stabiliser, road fill, asphalt mix, and fertiliser Some large users of coal ash as filling materials are not included in the figures: for instance, it is reported that in China, in 1996, when the raw coal output was about 1400 million tonnes, the production of coal ashes amounted 329.6 million tonnes of which 141 million tonnes are used in the production of building materials including cement (Pan 1999). Residents of buildings constructed with these materials can incur annual doses of up to several mSv.

(A31) Commodities made available under the umbrella of exempted practices contain radionuclides. In some cases, the radiation source performs a specific function in

the commodity. Use of an ^{241}Am source in smoke detectors is an example. In others, the radioactivity is an unavoidable result of producing the commodity. Radioactivity in gemstones as a result of their irradiation to enhance their attractiveness is an example.

(A32) Some commodities may contain small amounts of radioactive substances as a consequence of the free release from controlled practices of contaminated materials, which are subsequently recycled. The benefit resides in recycling or further use of the materials. The radioactivity is simply a contaminating by-product as similar commodities could be produced from non-contaminated materials.

(A33) Accidents involving the release of radioactive materials to the environment have produced wide contamination of foodstuff and other commodities. The prolonged annual doses attributable to this contamination have been extremely variable, sometimes exceeding tens of millisieverts.

B. ANNEX B: RADIOLOGICAL PROTECTION QUANTITIES IN THE CONTEXT OF PROLONGED EXPOSURES

(B1) The principal physical quantities used by the Commission are the *activity* of an amount of radionuclide and the *absorbed dose* from radiation in matter. The absorbed dose is weighted for radiological protection purposes, resulting in a number of relevant dosimetric quantities.

(B2) ***Activity***: The *activity, A,* of an amount of a radionuclide is defined as (ICRP 1991a, paragraph 37):

'The average number of spontaneous nuclear transformations taking place per unit time. Its unit is the reciprocal second, s^{-1}, given, for this purpose, the special name becquerel (Bq).'

(B3) *Dosimetric Quantities*: The Commission has indicated that (ICRP 1991a, paragraph S4):

*'It uses "**dose**" as a generic term that can apply to any of the relevant dosimetric quantities. The Commission also uses the term "**exposure**" in a generic sense to mean the process of being exposed to radiation or radioactive material. The significance of an exposure in this sense is determined by the resulting doses.'*

(B4) The dosimetric quantities have been summarised by the Commission as follows (ICRP 1991a, paragraph S2):

*'The principal dosimetric quantities in radiological protection are the mean **absorbed dose** in a tissue or organ, D_T, the energy absorbed per unit mass; the **equivalent dose** in a tissue or organ, H_T, formed by weighting the absorbed dose by the radiation weighting factor, w_R; and the **effective dose**, E, formed by weighting the equivalent dose by the tissue weighting factor, w_T, and summing over the tissues. ...The unit of absorbed dose is the gray (Gy), and the unit of both equivalent and effective dose is the sievert (Sv).'*

The links between the fundamental quantities are illustrated in Fig. B.1.

(B5) The dosimetric quantities relate to individuals and are often supplemented by their collective analogues, which are given by the product of the mean relevant dose in a group of individuals and the number of individuals in the group. Both individual and collective doses may be qualified by adjectives such as *annual, additional, averted, projected, residual, committed,* and *lifetime.*

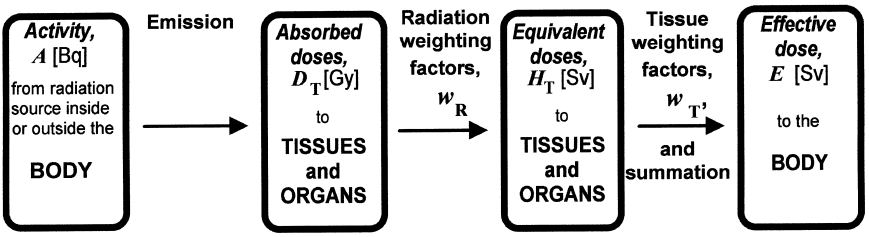

Fig. B.1. The relationship between activity, A, absorbed dose, D_T equivalent dose, H_T, and effective dose, E.

(B6) ***Committed dose***: The Commission has indicated that (ICRP 1991a, paragraph 33):

'Following an intake to the body of a radioactive material, there is a period during which the material gives rise to equivalent doses in the tissues of the body at varying rates. The time integral of the equivalent-dose rate is called the ***committed equivalent dose****. $H_T(\tau)$, where τ is the integration time (in years) following the intake. If τ is not specified, it is implied that the value is 50 years for adults and from intake to age 70 years for children. By extension, the* ***committed effective dose****, $E(\tau)$, is similarly defined. When the Commission refers to an equivalent or effective dose accumulated in a given period of time, it is implicit that any committed doses from intakes occurring in that same period are included.'*

(B7) ***Dose commitment***: The Commission also indicated that (ICRP 1991a, paragraph 33):

'The ***dose commitment*** *is a calculational tool. It can be assessed for a critical group as well as for the whole world population. It is defined as the infinite time integral of the* ***per caput dose rate*** *due to a specified event, such as a unit of practice (e.g. a year of practice).'*

(B8) ***Collective dose***: The Commission has referred to dosimetric collective quantities as follows (ICRP 1991a, paragraphs 34 and 35):

'The dosimetric quantities referred to above all relate to the exposure of an individual. The Commission uses further quantities related to exposed groups or populations. These quantities take account of the number of people exposed to a source by multiplying the average dose to the exposed group from the source by the number of individuals in the group. The relevant quantities are the ***collective equivalent dose****, S_T, which relates to a specified tissue or organ, and the collective effective dose, S. If several groups are involved, the total collective quantity is the sum of the collective quantities for each group. The unit of these collective quantities is the man-sievert. The collective quantities can be thought of as representing the total consequences of the exposure of a population or group... If the ranges of individual dose or time are large, it may be useful to subdivide the collective quantities into blocks covering more limited ranges of dose and time...'*

(B9) In *Publication 77,* the Commission has further clarified its intentions regarding the use of collective dose as follows (ICRP 1997c, paragraph 20):

'The unlimited aggregation of collective dose over time and space into a single value is unhelpful because it deprives the decision maker of much necessary information. The levels of individual dose and the time distribution of collective dose may be significant factors in making decisions.'

(B10) In addition, in relation to the estimation of collective dose over time, the Commission has indicated that (ICRP 1997c, paragraph 58):

'The problems of estimating collective dose over long periods of time are those of uncertainty. Both the individual doses and the size of the exposed population

become increasingly uncertain as the time increases. Furthermore, the current judgements about the relationship between dose and detriment may not be valid for future populations. No detailed guidance can be given, because some situations can be forecast with confidence further into the future than can others. Decisions must be made on a case-by-case basis. In general, however, forecasts of collective dose over times longer than several thousand years and forecasts of health detriment over times longer than several hundred years should be examined critically.'

B.1. Quantities used for prolonged exposures

(B11) ***Annual dose***: As prolonged exposures persist over time, the relevant dosimetric quantity for dealing with prolonged exposures is the committed effective dose in a specified period; for practical reasons, a period of one year is chosen. The annual effective dose is, unless otherwise indicated, simply termed *annual dose* in this report. The annual dose is thus defined as the sum of (i) the time integral, over a year, of the effective dose rate due to *external irradiation* caused by a prolonged exposure situation, and (ii) the committed effective dose due to *internal contamination* from any intakes, during the year, of the long-lived radionuclides (and their short-lived progeny) involved in the situation. The unit used in this report for the annual dose is a thousandth of a sievert, i.e. millisievert (mSv), per annum.

(B12) Again, as prolonged exposures persist over time, it would be practical to use, as a collective quantity, the collective dose committed by a population in a given year of exposure. This *collective annual dose* is the summation of the products of the mean annual dose and the number of individuals exposed. As indicated before, although the collective dose can be used for comparing some radiological protection options, if the distribution of individual annual doses covers several orders of magnitude, the simple aggregation of individual annual doses is less useful because it combines too much diverse information. For some decisions, different importance may be attached to different levels of individual annual dose, and it would then be better to present partially disaggregated data in the form of collective dose blocks, each covering a narrower range of individual annual doses. A simplistic application of the collective dose when dealing with radiological protection options in prolonged exposure situations may be inadequate and may lead to misinterpretations or to a misallocation of resources.

(B13) ***Operational quantities for prolonged exposures***:[44] For *external prolonged exposures,* the relevant operational quantity is the (prolonged) *annual ambient dose equivalent*. For *internal prolonged exposures,* the relevant operational quantity is the

[44] The dosimetric quantities relating to the human body can be estimated from directly measurable quantities of external exposure that are termed *operational quantities*. The operational quantities are recommended by the International Commission on Radiation Units and Measurements (ICRU) and have been introduced by the Commission as follows (ICRP 1991a, paragraph 138): '*There are also four operational quantities of particular interest in the measurement of radiation fields for protection purposes. These ICRU quantities, the ambient dose equivalent, H*(d), the directional dose equivalent, H'(d), the individual dose equivalent, penetrating, $H_p(d)$, and the individual dose equivalent, superficial, $H_s(d)$ are based on the concept of the dose equivalent at a point and not on the concept of equivalent dose'*

activity of intake of the relevant radionuclides over the year. In operational practice with prolonged exposures, therefore, the *annual dose* is taken to be the sum of (i) the time integral, over the year, of the *ambient dose equivalent rate* and (ii) the summation of the *activity of intakes during the year,* each multiplied by the *dose per unit intake coefficients* recommended by the Commission in *Publications 67, 69, 71,* and *72*. (ICRP 1993c; ICRP 1995a; ICRP 1995b; ICRP 1996a).

B.2. Subsidiary quantities for prolonged exposures

(B14) ***The existing annual dose***: In this report, all persisting sources of prolonged exposures in a given situation are said to result in an *existing annual dose,* which is the sum of all significant components of annual doses incurred by a typical individual in an exposed group of people, from all relevant sources and via all pathways, of a human habitat subject to a prolonged exposure situation. The existing annual dose therefore includes: the annual dose from natural radiation sources; the annual doses caused by the accumulation of long-lived radionuclides released from practices under control; and the annual doses caused by long-lived radioactive residues from previous human activities and from long standing accidental contamination of the environment. Any decision concerning the introduction, operation, and decommissioning of a practice or the undertaking of intervention takes place in the context of an existing annual dose. It is important, therefore, to distinguish between this existing annual dose and the marginal doses that are attributable to the decision to introduce a practice or undertake an intervention.

(B15) ***The additional annual dose from practices***: The additional annual dose is the long-term annual dose attributable to the practice and which is added to the existing annual dose. The existing annual dose can marginally change (increase) as a result of the practice, because a practice may result in prolonged exposure causing additional annual dose over and above the existing annual dose. The additional annual dose is amenable to restrictions during the operation of the practice.

(B16) ***The annual dose averted by intervention***: Similarly, the existing annual dose can marginally change (decrease) as a result of undertaking intervention. An intervention is expected to result in components of the annual dose being averted. This has led to a number of special concepts for intervention that the Commission formulated as follows in *Publication 63* (ICRP 1991b, paragraphs 9–12):

> *'... doses to the population, ... estimated for each exposure pathway without taking into account possible protective actions, ... are called* ***projected doses****. The key concept for an intervention is the* ***averted dose*** *for each pathway, which is the dose saved by implementing a protective action. ... It may be expressed in any of the relevant dosimetric quantities ... If the interventions are fully effective, the averted dose is numerically equal to the projected dose, but these are conceptually different quantities ... However, it may be appropriate to express the intervention level in terms of a projected dose for that pathway rather than an averted dose. Intervention may not be fully effective, either because the dose has already been received, or because the intervention itself may only partly reduce the total*

projected dose. The remaining dose from each pathway (projected dose minus averted dose) is called ***residual dose****. ... the sum of residual doses from all pathways after implementation of protective actions should be kept under review because of the possibility of serious deterministic health effects.'*

(B17) Thus, within the context of prolonged exposure situations, the *existing annual dose* before intervention is equivalent to the *projected annual dose* in a year. The reduction of this annual dose by the intervention is the *averted annual dose*. A dose is said to be 'averted' if it has been averted by a protective action; it is said to be 'avertable' if it can be averted by a protective action.

C. ANNEX C: RADIATION HEALTH EFFECTS IN THE CONTEXT OF PROLONGED EXPOSURE

(C1) The Commission's current policy regarding the health effects attributable to radiation exposure is summarised as follows (ICRP 1991a, paragraphs 44–46):

> *'The process of ionisation necessarily changes atoms, at least transiently, and may thus alter the structure of the molecules containing them. If the affected molecules are in a living cell, the cell itself may sometimes be damaged, either directly if the molecule is critical to the cell's function, or indirectly by causing chemical changes in adjacent molecules, e.g. the production of free radicals. Of the various forms of damage that radiation can cause in cells, the most important is that in the DNA. Damage in the DNA may prevent the survival or reproduction of the cell, but frequently the damage is repaired by the cell. If that repair is not perfect, it may result in a viable but modified cell. The occurrence and proliferation of a modified cell may well be influenced by other changes in the cell caused either before or after the exposure to radiation. Such influences are common and may include exposure to other carcinogens or mutagens. If enough cells in an organ or tissue are killed or prevented from reproducing and functioning normally, there will be a loss of organ function — an effect that the Commission ... calls "**deterministic**". The loss of function will become more serious as the number of affected cells is increased. A modified somatic cell may still retain its reproductive capacity and may give rise to a clone of modified cells that may eventually result in a cancer. A modified germ cell in the gonads, with the function of transmitting genetic information to the descendants of an exposed individual, may transmit incorrect hereditary information and may cause severe harm to some of those descendants. These somatic and hereditary effects, which may start from a single modified cell, are called stochastic effects. Because of the complex processes involved in the development of the conceptus to an embryo and a foetus, it is convenient to discuss* [separately] *both deterministic and stochastic* [prenatal] *effects of radiation on the unborn child... There is some experimental evidence that radiation can act to stimulate a variety of cellular functions, including proliferation and repair. Such stimulation is not necessarily beneficial. Most of the experimental data on such effects, currently termed "hormesis", have been inconclusive, mainly because of statistical difficulties at low doses. Furthermore, many relate to biological endpoints other than cancer or hereditary effects. The available data on hormesis are not sufficient to take them into account in radiological protection.'*

In *Publication 73,* the Commission has provided an annotated bibliography of authoritative reviews of the biological effects of ionising radiation (ICRP 1996b, Annex B).

(C2) Thus, the development of the Commission's recommendations has been closely linked to the two kinds of health effects that radiation may cause: *deterministic effects* and *stochastic effects*. *Deterministic effects* are expressed in individuals only if the radiation dose is above a dose threshold, the severity of the effect increasing with dose; they can be clinically attributed to the exposure incurred by the affected

individual. *Stochastic effects* can only be detected epidemiologically, in large populations; they may be found as a change in the normal incidence of somatic and hereditary effects in the exposed population and in their descendants, only if the collective dose is sufficiently large to make them statistically discernible. In addition, health effects may occur as a result of the so called *antenatal exposures;* these are those incurred before birth that can be expressed as follows: before birth, in the live born person, and in his/her descendants. The Commission recommends that the considerations in this Annex should be used with caution, mainly because of the limited scientific information on radiation health effects attributable to prolonged exposure — particularly with regard to deterministic effects and to effects of antenatal exposure.

C.1. Deterministic effects of prolonged exposures

(C3) Although there is a great deal of experience and information relating to *deterministic effects* caused by short term *acute* exposures, there is little direct human data on deterministic effects caused by transitory exposures of longer duration, and even less on those caused by prolonged exposures. The available information on prolonged doses at which deterministic effects may start to occur has been extrapolated from experience with patients who have incurred protracted doses in the course of radiotherapeutic procedures, and it has been supplemented by data from animal experiments. In this context, the Commission has concluded that (ICRP 1991a, paragraphs 58–61):

> *'For doses spread out over a period of years, severe effects are not likely in most tissues at annual* [absorbed] *doses of less than about 0.5 Gy. However, the gonads, the lens of the eye, and the bone marrow show higher sensitivities. ... for temporary sterility in the male ... under conditions of prolonged exposure the dose rate threshold is about 0.4 Gy^{-1}. The corresponding value for permanent sterility* [is] *about ... 2 Gy^{-1}. The threshold for permanent sterility in women is ...a protracted dose rate over many years of more than 0.2 Gy^{-1}* [older women being more sensitive]. *The dose rate threshold* [for opacities sufficient to cause impairment of vision] *... is thought to be somewhat above 0.15 Gy^{-1} ... Clinically significant depression of the blood-forming process has a ... dose rate threshold ... of more than 0.4 Gy^{-1}.'*

(C4) Therefore, the Commission has to conclude that, in relatively homogeneous prolonged exposure situations, with radiation weighting factors of unity, the threshold for deterministic effects should be above an annual effective dose of around 100 mSv, provided that no organ receives an annual absorbed dose exceeding its threshold for deterministic effects.

C.2. Stochastic effects of prolonged exposure

(C5) For *stochastic effects*, the Commission has indicated that (ICRP 1991a, paragraph 33):

'*The most characteristic form of the relationship between the equivalent dose in an organ and the probability of a resultant cancer is that of an initial proportional response at low values of equivalent dose, followed by a steeper rate of increase (slope) that can be represented by a quadratic term, followed finally by a decreasing slope due to cell killing. There are no adequate grounds for assuming a real threshold in the relationship. This form of response, while typical, is not necessarily the definitive form for all human cancers. Taken together with the linear approximation for increments over the dose due to natural background, it provides a suitable basis for the Commission's use of a simple proportional relationship at all levels of equivalent dose and effective dose below the dose limits recommended.*'

(C6) Furthermore, the Commission has stated that (ICRP 1991a, paragraphs 78 and 79):

'*Because of the uncertainties of recording cancer incidence rather than mortality, most of the data on exposed human populations are expressed in terms of excess cancer mortality attributable to the exposures. However, the incidence of cancer is also important and the Commission lakes it into account on the basis of currently observed cure rate for the main types of cancer. More generally, the Commission needs a broader basis for expressing the harm expected in an exposed population and has therefore made use of the concept of detriment... All these difficulties introduce uncertainties into the estimation of the cancer risks from exposure to radiation. For this reason, and because the Commission estimates the risks for representative populations with defined exposure patterns, the Commission calls the estimated probability of a fatal cancer per unit effective dose the nominal fatality probability coefficient. This applies to low doses at all dose rates and to high doses at low dose rates. ... It is very desirable for protection purposes to use the same nominal coefficients for both men and women and for a representative population of a wide range of ages. Although there are differences between the sexes and between populations of different age-specific mortality rates, these are not so large as to necessitate the use by the Commission of different nominal probability coefficients.*'

(C7) For purposes of public protection, the Commission estimates that the nominal fatality probability coefficient is around 5 10^{-5} mSv^{-1}. The Commission has also estimated nominal probability coefficients for other components of the detriment, namely non-fatal cancer and severe hereditary effects. The Commission's recommended nominal probability coefficients for stochastic effects for the whole population are shown in Table C.1. The Commission now reconfirms that all of these coefficients are applicable to prolonged exposures.

C.3. Effects of antenatal prolonged exposure

(C8) The Commission's estimates of risks of health effects from antenatal exposure have been presented in *Publication 73* as follows (ICRP 1996b, paragraphs 28–30):

'The effects on the conceptus of exposure to radiation depend on when the exposure occurs relative to conception. Exposure of the embryo in the first three weeks following conception is not likely to result in deterministic or stochastic effects after birth. During the period of major organogenesis (4–14 weeks after conception), animal data suggest that malformations may be caused in the organ under development at the time of exposure. These effects are deterministic in character with a threshold in man, estimated from animal experiments to be in the range 0.1–0.5 Gy. Throughout the period from 3 weeks after conception until the end of pregnancy, it is likely that radiation exposure can cause stochastic effects, such as an increased probability of cancer. The available data are not consistent. However, the Commission assumes that the nominal fatality probability coefficient is about the same as for children. Values of intelligence quotient (IQ) lower than expected have been reported in some children exposed in utero at Hiroshima and Nagasaki. The data are consistent with a general downward shift in the distribution of IQ with increasing dose. The Commission assumes that this shift is proportional to dose. A coefficient of about 30 IQ points per sievert relates to the dose to the foetus in the period from 8 weeks to 15 weeks after conception. On this basis, the change in the IQ of an individual that can be caused by a dose of about 100 mSv will be no more than 3 IQ points. Small shifts in IQ cannot be clinically identified. The effects on IQ are less marked following exposure in the period

Table C.1. Recommended nominal probability coefficients for stochastic effects for the whole population (ICRP 1991a)

Nominal probability coefficients (probability per unit effective dose per 100 000 per mSv)[45]			
Fatal cancer[46]	Non-fatal cancer	Severe hereditary effects	Total detriment
5.0	1.0	1.3	7.3

[45] Rounded values. The Commission's risk estimates are called 'nominal' because they relate to the continuous exposure of a nominal population of males and females with a typical age distribution. As with all estimates derived from epidemiology, the nominal risk coefficients are based on extrapolations from effects seen at higher doses and further do not apply to specific individuals, unless it can be assumed that the individual is typical of the nominal population. For populations with an age distribution very different from the nominal populations, it may be desirable to use adjusted risk coefficients, but not to seek different sets of radiation and tissue weighting factors because these would confuse the use of effective dose. The estimates of fatality and detriment coefficients are adequate both for planning purposes and for general prediction of the consequences of exposures. For the estimation of the likely consequences of an exposure of an individual or a known population, it will occasionally be better to use absorbed dose and specific data relating to the relative biological effectiveness of the radiations concerned and estimates of the probability coefficients relating specifically to the exposed population or individual.

[46] For the sum of fatal cancers, the detriment coefficient is equal to the probability coefficient.

from 16 weeks to 25 weeks after conception and have not been observed for other periods. All the observations on IQ relate to high doses and high dose rates.'[47]

(C9) In the absence of other evidence, and even recognising the data available on antenatal exposure is scarce (particularly with regard to in utero irradiation of the developing brain), the Commission provisorily notes that antenatal exposure should not be a specific protection case in common prolonged exposure situations where the prolonged annual dose is well below about 100 mSv because:

- for prolonged annual doses below 100 mSv, there is a very low probability of excess childhood leukaemia or cancer (in the liveborn) as a result of in utero radiation in the first three weeks after conception;
- no organ malformations should be expected at foetal doses lower than 100 mSv, i.e., for prolonged annual doses below about 100 mSv;
- a practical threshold should be assumed for mental retardation effects at a prolonged annual dose of several hundred millisieverts, because the threshold of detectability of these effects is 100 mSv and the period of sensitivity during gestation is just a fraction of a year; and,
- for similar reasons, the individual lifetime risk of stochastic effects should be lower in antenatally exposed children than in the general population, because the nominal fatality probability coefficients are within a small range and the period of prenatal exposure is lower than the continuous time of exposure expected for the general population.

[47] During the period of neuronal and synapse development there is the potential for radiation effects in the developing brain. There has been scarce but significant epidemiological evidence of an increase in the frequency of serious mental retardation in children irradiated in utero. The number of cases in the epidemiological studies are small and relate to acute exposures only, but results of intelligence quotient (IQ) tests indicate a general downward shift in the distribution of IQ with increasing doses in children who were exposed in utero between the eighth and fifteenth weeks after conception, by a coefficient of about thirty IQ points per thousand millisieverts of dose. The resulting excess probability is about 0.4 for doses of around 1000 millisievert. At doses of the order of 100 millisievert, no effects would be detectable in the general distribution of IQ as the increase, if any, will be lower than the sensitivity of the test.

D. ANNEX D: THE SYSTEM OF PROTECTION IN THE CONTEXT OF PROLONGED EXPOSURE

D.1. Aims of the Commission's system of radiological protection

(D1) Although the Commission's policy for radiological protection has evolved over the years, its main objective has remained basically unchanged. It was formulated as follows in the Commission's latest recommendations (ICRP 1991a, paragraph 15):

> *'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.'*

(D2) This aim of providing an appropriate standard of protection, rather than the best possible standard regardless of costs and benefits, cannot be achieved on the basis of scientific concepts alone. The Commission's policy is to supplement the available scientific knowledge with value judgements about the relative importance of different kinds of risk and about the balancing of risks and benefits. The Commission has indicated that (ICRP 1991a, paragraph 100):

> [the system of radiological protection] *'is intended to prevent the occurrence of deterministic effects, by keeping doses below the relevant thresholds, and to ensure that all reasonable steps are taken to reduce the induction of stochastic effects.'*

The aims of the Commission's system of radiological protection encompass prolonged exposure situations.

(D3) Many prolonged exposure situations have given rise to societal problems (NEA 2000) and to discussions about the ethical principles on which the radiological protection approach should be based. Although no specific philosophical doctrine has been explicitly referenced by the Commission in the formulation of its recommendations, the principles on which the system of radiological protection is based are an example of two commonly accepted ethical principles. On the one hand, the system requires that adequate radiological protection of identified individuals be ensured; for instance, it is required that deterministic effects on individuals must be prevented and the individual risk of stochastic effects must be restricted. This could be construed to be linked to the principles of *deontological ethics*. On the other hand, the system requires that an overall guiding principle of radiological protection should be to obtain a positive health benefit for the greatest number of people in society under the prevailing social and economic circumstances of the exposure situation: for instance, it is required that all doses be kept as low as reasonably achievable, social and economic considerations being taken into account. This could be construed to be linked to the principles of the *utilitarian ethics*. Consideration of both these types of ethical principles is critical for the societal acceptability of the radiological protection approach in many prolonged exposure situations.

D.2. Source-related and individual-related protection approaches

(D4) The Commission has indicated that (ICRP 1991a, paragraphs 102–103):

'To clarify the way in which the Commission has developed its recommendations, it is convenient to think of the processes causing human exposures as a network of events and situations. Each part of the network starts from a source. This term is used by the Commission to indicate the source of an exposure, not necessarily a physical source of radiation. Thus ... when radioactive materials are released to the environment as waste, the installation as a whole might be regarded as the source. Radiation or radioactive material then passes through environmental pathways, which may be ... very complex in the natural environment, with some pathways being common to many sources. Eventually. individuals, possibly many individuals, are exposed as a result of a single original source. Since there can be many sources, some individuals will be exposed to radiation from more than one of them. If natural sources are included, all individuals are exposed to radiation from at least a few sources. Fortunately, it is rarely necessary to treat this network as a single entity. Provided that the individual doses are well below the threshold for deterministic effects, the contribution to an individual dose from a single source has an effect that is independent of the doses from other sources. For many purposes, each source, or group of sources, can then be treated on its own. Each individual, however, is exposed as a result of several sources. It follows that assessments of the effectiveness of protection can be related to the source giving rise to the individual doses (source-related) or related to the individual dose received by a person from all the relevant sources (individual-related).'

(D5) In reality, therefore, a distinction is made between *source-related protection* — which is concerned with all the exposures resulting from a single source — and *individual-related protection* — which is concerned with the exposure of a single individual from many sources (see Fig. D.1). This distinction is essential in many prolonged exposure situations.

(D6) The Commission's system of radiological protection is similar in this regard to other risk based health protection systems that are focused either on controlling the source of a hazard to individuals or on restricting the exposure of individuals to the hazard. It is often necessary to use both approaches. The system of radiological protection emphasises the case-by-case control of exposures delivered by a source, because the most effective and the least intrusive point of control is usually at the source. Source-related assessments make it possible to judge whether a practice or intervention is likely to bring benefits sufficient to outweigh any disadvantages and whether all reasonable steps have been taken to reduce the radiation exposures that a source will cause. They thus facilitate the *justification of practices* and *interventions* and the *optimisation of protection* at the source level. Source-related assessments take account of the magnitude (increase or decrease) of the annual doses attributable to the assessed source, and of the number of individuals exposed, but not of the influence on individuals of other exposure sources.

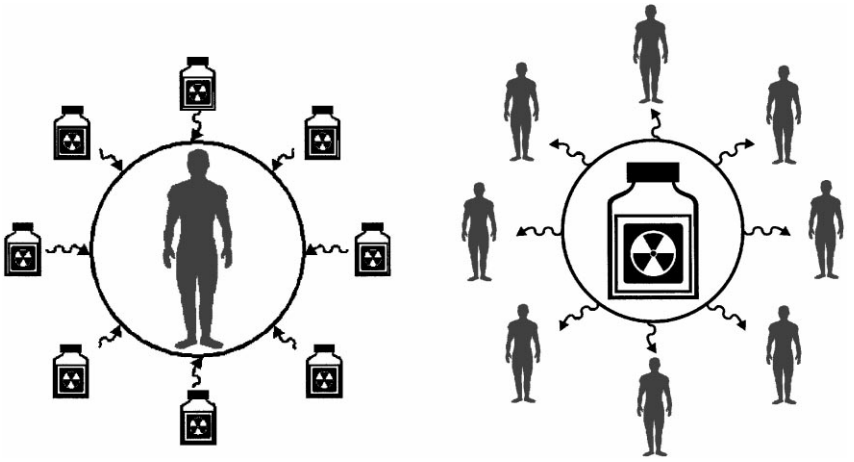

Fig. D.1. Illustration of the concepts of individual-related protection of a single individual exposed to a number of sources (left-hand picture) and source-related protection of a number of individuals exposed to a single source (right-hand picture).

(D7) Practical application of the system of radiological protection calls for a pragmatic combination of both source-related and individual-related assessments. For example, in the system of radiological protection for practices, the optimisation of protection involves the use of collective dose — a source-related concept, which requires a source-related assessment-supplemented by the use of annual dose constraints, an individual-related concept, linked to a defined source, which requires individual-related assessments of the annual dose attributable to the source under consideration. To ensure compliance with individual annual dose limits, the system also requires individual-related assessments of the sum of annual doses from all the *relevant* practices. Within the context of regulatory requirements formulated by regulatory agencies, the Commission has stated that (ICRP 199lb. paragraph 242):

> *'The agency will have to consider both the source-related approach, to ensure the proper optimisation of protection, including the selection of source-related dose constraints, and the individual-related approach to ensure the adequate protection of individuals in relation to all the relevant sources. If the primary source is not under the jurisdiction of the agency, e.g. when radioactive material is released to a river upstream of the agency's area, it may be useful to consider assessments and controls to be related to a particular sector of the environment. Control cannot then be applied at the source, so that doses can be limited, if at all, only by some form of intervention. It will usually be better to achieve control of the source by inter-state, or inter-agency, collaboration.'*

(D8) The Commission has not specifically recommended individual-related assessments of the existing annual dose incurred by an individual in a habitat subject to a prolonged exposure situation, irrespective of the source. This is because the system of radiological protection concentrates on marginal annual doses, which are

either added by practices to, or averted by interventions from, the existing annual doses. In fact, the system requires case-by-case consideration of the more effective ways to control marginal annual doses in specific situations. The case-by-case, situation related solution is a logical outcome of the ideal process of optimising protection. In practice, however, there may be a need for generic solutions to radiological protection problems created by existing annual doses, even if they are not optimum solutions. The Commission has always recognised the benefits of standardisation, which is an example of the use of generic solutions. As described in Chapter 4, individual-related assessments of the existing annual doses may have a significant role in providing generic guidance for some prolonged exposure situations.

D.3. Classification of exposures

(D9) ***Occupational, medical, and public exposures***: In relation to the classification of exposures the Commission has stated that (ICRP 1991a, paragraph 109):

> *'The Commission uses a division into three types of exposure:* ***occupational exposure****, which is the exposure incurred at work, and principally as a result of work;* ***medical exposure****, which is principally the exposure of persons as part of their diagnosis or treatment; and* ***public exposure****, which comprises all other exposures.'*

Prolonged exposures are part *of public exposures*. It should be noted, however, that workers and patients are also members of the public and that it is the type of prolonged exposure (i.e. the source and circumstances of prolonged exposure) that is of importance for this classification, not the recipient of the exposure.

(D10) ***Normal exposure and potential exposures***: The Commission has also divided radiation exposure into two broad categories: *normal exposure* and *potential exposure*. In the Commission's terms (ICRP 1993a, paragraph 2; ICRP 1997b, paragraph 6):

> *'****Normal exposure*** *is that exposure which can be reasonably expected to occur, i.e. the exposure is predicted to occur with the probability of one or near one.'*

and

> '[**Potential exposures** are those exposures for which] *'there is a potential, but not a certainty, of occurrence. They may be foreseeable and their probability of occurrence estimated, but they cannot be predicted in detail.'*

A conceptual framework for protection from potential exposure is presented in *Publication 64* (ICRP 1993a), while some applications to selected radiation sources are presented in *Publication 76* (ICRP 1997b).

(D11) Prolonged exposures can be generally regarded as being *normal exposures*. However, there may be situations of *prolonged potential exposure,* i.e. persistent situations in which there is the potential but not the certainty of incurring the exposure. In Chapter 5, an example of a prolonged potential exposure situation is discussed: this is the contamination of land with sparsely dispersed hot particles.

D.4. Scope of the system of radiological protection

(D12) ***Exclusion***: The Commission, recognising the necessary limitations in the scope of its system of radiological protection, has indicated that (ICRP 1991a, paragraph 99):

> [as] *'everyone in the world is exposed to radiation from natural and artificial sources..., any realistic system of radiological protection must therefore have a clearly defined scope if it is not to apply to the whole of mankind's activities. It also has to cover, in a consistent way, a very wide range of circumstances.'*

(D13) Therefore, although it is not wrong per se to extend the system to the whole of humankind's activities, its scope should be limited for practical reasons. The system can only deal with situations in which actions that influence the level of exposure of people are feasible, or at least worth considering, i.e. with situations where the exposure is *controllable,* or amenable to control. Some prolonged exposures are simply not controllable and others are essentially unamenable to control. The Commission has recommended that (ICRP 1991a, paragraph 291):

> *'Sources that are essentially uncontrollable, such as cosmic radiation at ground level and potassium-40 in the body, can best be dealt with by the process of exclusion from the scope of the regulatory instruments...'*

(D14) The *exclusion* of some prolonged exposures from formal regulations is ultimately a matter of a regulatory decision on the amenability to control of the exposure.[48] Such a decision must be made by competent authorities.

(D15) ***Exemption***: The Commission has also provided recommendations on the *exemption* of sources from regulatory control as follows (ICRP 1991a, paragraphs 285–288):

> *'In order to avoid excessive regulatory procedures, most regulatory systems include provisions for granting* ***exemptions*** *... The Commission believes that the exemption of sources is an important component of the regulatory functions. It notes that the International Atomic Energy Agency and the Nuclear Energy Agency of OECD issue advice on this subject to their Member States. There are two grounds for exempting a source or an environmental situation from regulatory control. One is that the source gives rise to small individual doses and small collective doses in both normal and accident conditions. The other is that no reasonable control procedures can achieve significant reductions in individual and collective doses. The basis for exemption on the grounds of trivial dose is much sought after, but very difficult to establish. Apart from the difficulty of deciding when an individual or a collective dose is small enough to be disregarded for*

[48] Some exposures are obviously uncontrollable, such as the exposure caused by the homeostatically regulated levels of potassium-40 in the body; for others, the amenability to control depends on a regulatory definition. Many prolonged exposures caused by natural sources, such as exposure to cosmic radiation, are not amenable to control and are usually excluded from regulations.

regulatory purposes, there is a considerable difficulty in defining the source... The underlying problem is that exemption is necessarily a source-related process, while the triviality of the dose is primarily individual-related.'

(D16) The Commission has also indicated that (ICRP 1991a, paragraph 290):

'The second basis for exemption calls for a study similar to that needed in the optimisation of protection. It provides a logical basis for exemption of sources that cannot be exempted solely on the grounds of trivial doses, but for which regulation on any reasonable scale will produce little or no improvement.'

(D17) ***Exemption levels for practices***: In *Publication 64,* the Commission summarised the current criteria for exemption levels for practices as follows (ICRP 1993a, paragraph 86):

'In the case of normal exposure, most regulatory systems include provisions for granting exemptions from the regulatory system where it is clear that a practice is justified but regulatory provisions are unnecessary. The grounds for exemption are that the source gives rise to small individual doses (of the order of 10 microsievert per year) and the protection is optimised, i.e. regulatory provisions will produce little or no improvement in dose reduction. (If the collective dose is small, e.g. on the order of one man-sievert per year, protection is often assumed to be optimised).'

(D18) ***Exemption levels for interventions***: The Commission has considered the concept of exemption levels also within the context of interventions as follows (ICRP 1991a, paragraph 284):

'To avoid unnecessary restrictions in international trade, especially in foodstuffs, it may be necessary, in this context, to apply derived intervention levels [that] indicate a line of demarcation between freely permitted exports or imports and those that should be the subject of special decisions. Any restrictions applied to goods below the intervention levels, better called intervention exemption levels for this purpose, should be regarded as artificial barriers to trade. Trade in materials above an intervention exemption level should not automatically be prohibited, but such materials might be subject to temporary controls. Intervention exemption levels used in this way in international trade should not necessarily have the same quantitative values as the intervention levels used for initiating action in other circumstances.'

This important recommendation is applicable to prolonged exposure situations involving commodities for public use.

D.5. Practices and interventions

(D19) ***Characterising practices***: During its period of operation, a practice may add annual doses to the *existing annual dose* that people are incurring at the time of the introduction of the practice. On the one hand, the practice may add *transitory*

exposures due to direct irradiation and short-lived radionuclides; on the other hand, the practice may add *prolonged exposures* due to long-lived radionuclides that accumulate year after year during its operation. The upper graph in Fig. D.2 presents both the transitory annual doses, which are delivered during the operation of a practice, and the prolonged annual doses, which are delivered during *and long after* the operation of the practice, as additions to the pre-existing existing annual dose.

(D20) If the intensity of the practice is more or less constant over the years, the transitory annual doses (i.e. the transitory doses delivered or committed in a given year) should usually be constant; they will become effectively zero when the operation of the practice is terminated or soon after. The prolonged annual doses, however, will accumulate year after year during the operation of the practice, and the resulting sum of prolonged annual doses will remain approximately constant after the termination of the practice for a long period, depending on the lifetime and migration time of the radionuclides involved. This sum represents the *prolonged additional annual dose* attributable to the practice.

(D21) If the period of operation of the practice is collapsed into a point in time, the diagram will show just the sum of the prolonged additional annual dose attributable to the practice added to the existing annual dose that people are incurring at the time of the practice's introduction, which results in the post-practice existing annual dose. This is illustrated more simply in the lower graph of Fig. D.2, which provides the basis for Fig. 2 in Chapter 2.

(D22) The Commission's system of radiological protection for practices is concerned with the additional annual dose attributable to practice, ΔE, and not with the existing annual dose — either that existing before the practice or that remaining after the practice. The system requires that the additional annual dose attributable to justified practices, ΔE, be restricted, preferably at the source, to levels which result from the process of *optimisation of protection* under *annual dose constraints*. In addition, it requires that the sum of annual doses attributable to all *relevant* practices, $\Sigma(\Delta E)$, not exceed *individual annual dose limits*. The word 'relevant' deserves to be emphasised: relevant practices are those — and only those — practices that are within the scope of the system of radiological protection for practices. The existing annual dose (either the pre-practice existing annual dose or the post-practice existing annual dose) is not subject to any annual dose restrictions other than the restrictions on those of its components that are attributable to the relevant contributing practices. In other words, the system for practices does not impose restrictions on the existing annual dose stripped of all the ΔEs.

(D23) ***Characterising interventions***: In prolonged exposure situations, interventions are intended to reduce the existing annual dose by removing existing sources, modifying pathways or reducing the number of exposed individuals, thereby averting annual dose components of the existing annual dose. Once the intervention has been fully and successfully undertaken, the remaining annual dose, i.e. the post-intervention existing annual dose, is not subject to further consideration. The process is as follows: first, an assessment should be made of whether the existing annual dose and the annual doses avertable by the intervention, $-\Delta E$, are sufficiently large to justify intervention; second, if intervention is justified, the protective actions should be

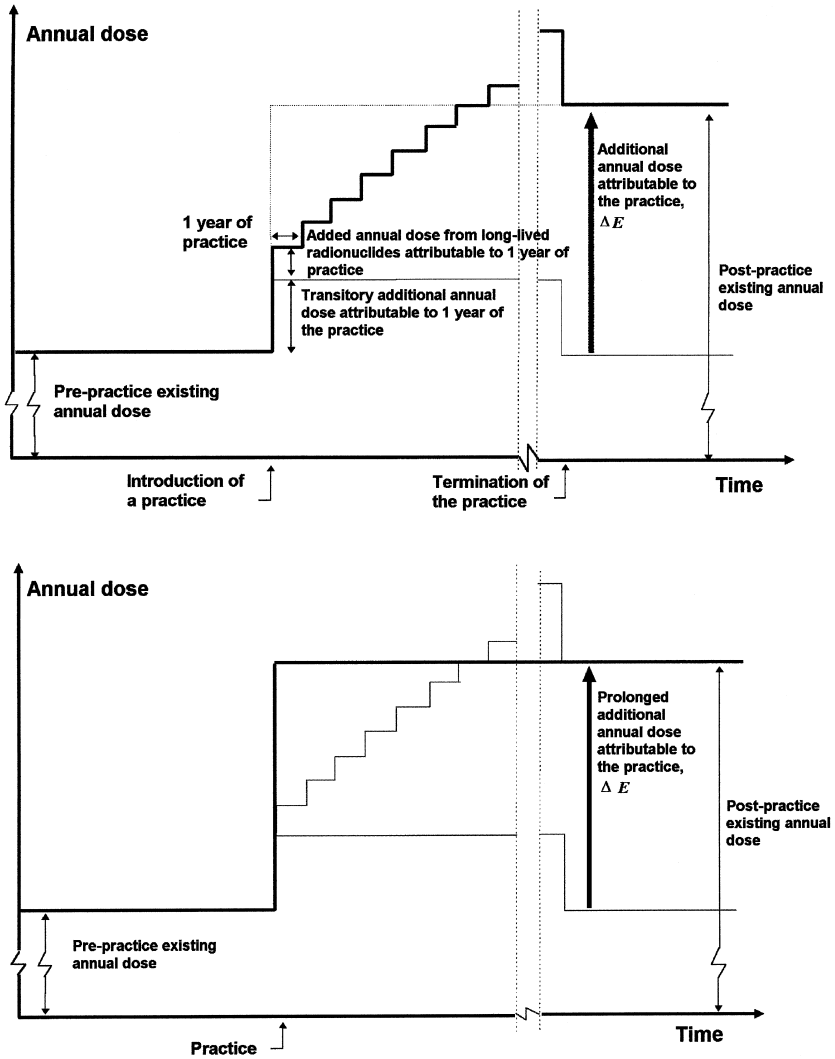

Fig. D.2. During the period of operation of a practice, the existing annual dose should be expected to increase due to two main sources. One is the relatively brief transitory exposures due to direct irradiation and to the release to the environment of short-lived radionuclides; the other is the prolonged exposure caused by the release of long-lived radionuclides. If the practice intensity is relatively constant, the annual doses due to transitory exposures should be more or less constant over the period of operation of the practice and will be effectively zero after the termination of the practice. The annual doses due to prolonged exposures will accumulate year after year and remain practically constant after termination of the practice (slightly reduced by the small decay in the activity of the radionuclides released). This process is shown in the upper diagram. The lower diagram shows the simplification that occurs in the presentation if the time of operation of the practice is reduced to a point in the abscissa; this leads to the simplified Fig. 2 in Chapter 2. Note that a further simplification is to show the post-practice existing annual dose as a level constant; it should in fact be a function decreasing with time.

optimised with the averted annual dose as a relevant quantity. After intervention is terminated, the residual post-intervention existing annual dose is not subject to any control. This is illustrated in Fig. D.3.

(D24) ***Moving from an intervention to a practice***: There has been some uncertainty about the introduction and management of a practice in an area previously subject to intervention. It should be emphasised that decisions on whether or not to undertake an intervention, as well as on the suspension of an existing intervention, should consider the expected exposure from all existing or realistically foreseen uses of the area. As the existing annual doses remaining after the intervention has been completed are not subject to restrictions, this existing annual dose becomes the new baseline for considering any further practices. Fig. D.4 clarifies the position.

(D25) ***Distinguishing between practices, interventions, and other human activities***: In most situations there is no difficulty in distinguishing practices from interventions. However, there have been some misunderstandings over this distinction and the Commission now wishes to re-emphasise some important issues relating to the distinction between practices, interventions, and other human activities which may change the exposure of people, such as modification of living habits:

- Practices are adopted as a *matter of a planned choice* in order to gain some *individual* or *societal benefit*. There is a conscious decision to adopt a beneficial practice in spite of the doses that it will add to existing annual doses.
- An intervention is intended to reduce existing annual doses caused by a de facto situation whose existence *is not a matter of choice,* although it *may be a matter of health concern*. In an intervention situation, the source (and/or the

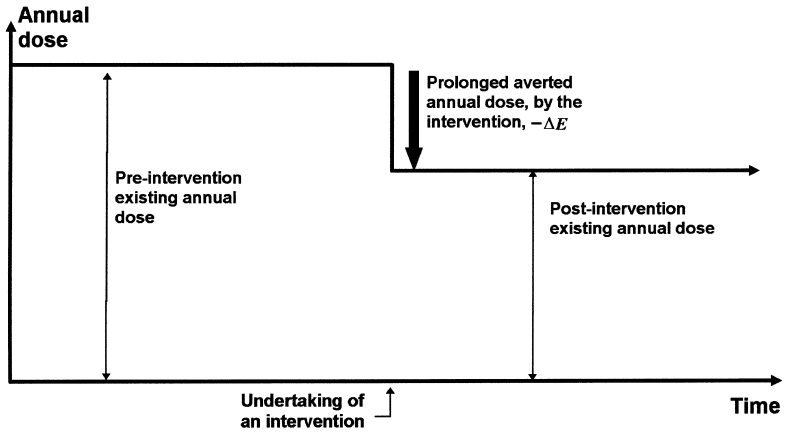

Fig. D.3. Undertaking an intervention will reduce the existing annual dose obtaining at the time of the intervention. The intervention is therefore expected to *avert* part of the preintervention existing annual dose. The existing annual dose will therefore be lower after the intervention than before it. The expected averted annual dose is found by subtraction of the post-intervention existing annual dose from the pre-intervention existing annual dose (it is represented in this case as a negative value of ΔL). The averted dose is clearly not subject to annual dose limits or constraints. The residual post-intervention existing annual dose is also not subject to restrictions.

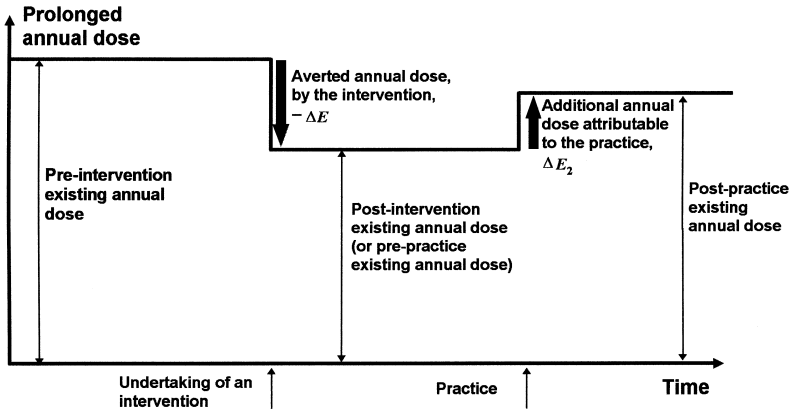

Fig. D.4. The case where a practice is introduced after intervention has been undertaken. The Commission's system of radiological protection restricts the additional annual doses attributable to the practice, ΔE, regardless of the level of the post-intervention existing annual dose.

dose) already exist at the time when the situation is being considered and is usually *not tied to any particular societal benefit* specifically related to the source.

- The clearest distinction between practices and interventions is the *ability to choose* a priori *whether to accept beneficial sources and the consequent exposures*. If a choice is still available, the exposure can usually be said to be due to a practice. The control of annual doses attributable to the practice should be planned in advance. Subsequent steps to reduce the annual doses attributable to the practice are improvements in the practice and not necessarily an intervention. If there is no choice, because the sources already exist, any action taken to reduce exposures is an intervention. (However, the occupational activities involved in the intervention should be controlled as is done in a practice; the exposure of those conducting the intervention should be restricted, even under emergency).
- When introducing the concepts of *practice* and *intervention,* the Commission did not intend to imply that any human activity that might cause increases in an individual's exposure is a *practice,* nor that any human activity that might reduce an individual's exposure is an *intervention*. For instance, normal modifications of living habits which may increase or reduce the individuals' background exposure (for example, a move to another part of the country or a change in the type of home) should not be treated either as a practice or as an intervention and should not be subject to the Commission's system of radiological protection. (However, intervention may still be called for if people have moved into an area where the exposure is sufficiently high to justify intervention).

(D26) ***Difficult cases for categorisation***: There are, however, some situations that are difficult to categorise as practices or interventions. One particular case relates to

the categorisation of the use of radioactive materials remaining from authorised discharges from a practice to the environment. The Commission advises that any environmental radioactive materials from authorised discharges should not be subject to further controls unless the environmental pathways to humans change. However, if a new use of environmental materials, for example, the harvesting and consumption of a type of shellfish not previously considered in the assessment of the discharges, is proposed, it may be possible to include it in the control of the current practices by re-optimising the discharge limits; if that is not practicable, or not effective, it may be necessary to deal with the environmental accumulation by intervention. A notable difficulty for categorisation arises from the incorporation of radionuclides into commodities; this case is treated separately in Chapter *5* of the main text.

D.6. Principles of the system of radiological protection for practices

(D27) The basic principles of its system of radiological protection for practices have been summarised by the Commission as follows (ICRP 1991a, paragraph S 18):

'The system of radiological protection recommended by the Commission for proposed and continuing practices is based on the following general principles:

- *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 justification of a practice).*
- *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 all be kept as low as reasonably achievable, economic and social factors being taken into account. This procedure 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 optimisation of protection).*
- *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. (Individual dose and risk limitation).'*

(D28) ***Justification***: The Commission has provided the following recommendations on justification of practices (ICRP 1991a, paragraph 115):

'Decisions concerning the adoption and continuation of a practice involve a choice between possible options and are often carried out in two stages. The first stage is the examination of each option separately in order to identify those options which can be expected to do more good than harm. This provides a ''short list'' from

which the preferred option can then be selected. The second stage, the final selection, will often involve the replacement of one existing practice by another. The net benefit of the change will then be the relevant feature rather than the net benefit of each option separately. The Commission recommends that, when practices involving exposure, or potential exposure, to radiation are being considered, the radiation detriment should be explicitly included in the process of choice. The detriment to be considered is not confined to that associated with the radiation; it includes other detriments and the costs of the practice. Often, the radiation detriment will be a small part of the total. The justification of a practice thus goes far beyond the scope of radiological protection. It is for these reasons that the Commission limits its use of the term justification to the first of the above stages, i.e., it requires only that the net benefit be positive. To search for the best of all the available options is usually a task beyond the responsibility of radiological protection agencies.'

(D29) In this regard, the Commission had stated its basic conceptual framework as follows (ICRP 1991a, paragraph 101):

'Most decisions about human activities are based on an implicit form of balancing benefits against costs and their disadvantages, leading to the conclusion that a particular course of action or practice either is or is not worthwhile. Less commonly, it is also recognised that the conduct of a practice should be adjusted to maximise the net benefit to the individual or to society. This is not a simple process because the objectives of the individual and society may not coincide. In radiological protection, as in other areas, it is becoming possible to formalise and quantify procedures that help in reaching these decisions. In doing so, attention has to be paid not only to the advantages and disadvantages for society as a whole, but also to the protection of individuals. When the benefits and detriments do not have the same distribution through the population, there is bound to be some inequity. Serious inequity can be avoided by the attention paid to the protection of individuals. It must also be recognised that many current practices give rise to doses that will be received in the future, sometimes the far future. These future doses should be taken into account in the protection of both populations and individuals, although not necessarily on the same basis as is used for current doses.'

(D30) ***Optimisation***: The basic framework for the optimisation of protection has been given by the Commission as follows (ICRP 199la, paragraph 117):

'Once a practice has been justified and adopted, it is necessary to consider how best to use resources in reducing the radiation risks to individuals and the population. The broad aim should be to ensure that the magnitude of the individual doses, the number of people exposed, and the likelihood of incurring exposures where these are not certain to be received, are all kept as low as reasonably achievable, economic and social factors being taken into account. Consideration has to be given to any interaction between these various quantities. If the next step of reducing the detriment can be achieved only with a deployment of resources that is seriously out of line with the consequent reduction, it is not in society's interest

to take that step, provided that individuals have been adequately protected. The protection can then be said to be optimised and the exposures to be as low as reasonably achievable, economic and social factors having been taken into account. The procedure should also be applied when an existing practice is being reviewed.'

Furthermore, the Commission has indicated that (ICRP 1991a, paragraph 119:

'The judgements involved in optimising protection are not purely quantitative — they involve preferences between detriments of different kinds and between the deployment of resources and health effects.'

(D31) ***Limitation***: The Commission has indicated that (ICRP 1991 a, paragraphs 122–123):

[if] *'the procedures of justification of practices and of optimisation of protection have been conducted effectively, there will be few cases where limits on individual dose will have to be applied. However, such limits provide a clearly defined boundary for these more subjective procedures and prevent excessive individual detriment, which might result from a combination of practices. The Commission's dose limits should be applied only in the control of practices. It is the Commission's intention to choose the values of dose limits so that any continued exposure just above the dose limits would result in additional risks from the defined practices that could reasonably be described as ''unacceptable'' in normal circumstances.'*

(D32) The Commission further considered that (ICRP 1991a, paragraph 188):

'With the widespread use of source-related dose constraints and practical restrictions on the sources of public exposure, generally applicable dose limits are rarely limiting in practice. However, because the [dose] *constraints are source-related they might, at least in principle, fail to take adequate account of the exposures from other sources. Although the Commission does not believe that this occurs to a significant extent, it continues to recommend dose limits for public exposure, if only to provide a limit on the choice of constraints.'*

D.7. Principles of the system of radiological protection for interventions

(D33) The basic principles of its system of radiological protection for interventions have been summarised by the Commission as follows (ICRP 1991a, paragraph 113):

'The system of radiological protection recommended by the Commission for intervention is based on the following general principles:

- *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 the costs, including social costs, of the intervention. (Justification of interventions).*

- *The form, scale, and duration of the intervention should be optimised 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, should be maximised (Optimisation of Protection in interventions).'*

(D34) In addressing these principles, the Commission indicated that (ICRP 1991a, paragraphs 130–131):

'In some situations, the sources, the pathways, and the exposed individuals are already in place when the decisions about control measures are being considered. Sometimes, the new control procedures can be achieved as part of a review of the original practice, but, more commonly, they will constitute intervention. An important group of such situations is that involving exposure to natural sources of radiation. Accidents and emergencies will have been considered as sources of potential exposure when dealing with practices, but if they occur, they may call for intervention. ... In most situations, intervention cannot be applied at the source and has to be applied by modifying the environment or by restricting individuals' freedom of action. The countermeasures forming a programme of intervention, which always have some disadvantages, should be justified in the sense that they should do more good than harm. Their form, scale, and duration should then be optimised so as to maximise the net benefit. The dose limits recommended by the commission are intended for use in the control of practices. The use of these dose limits, or of any other pre determined dose limits, as the basis for deciding on intervention might involve measures that would be out of all proportion to the benefit obtained and would then conflict with the principle of justification. The commission therefore recommends against the application of dose limits for deciding on the need for, or scope of intervention. Nevertheless, at some level of dose, approaching that which would cause serious deterministic effects, some kind of intervention will become almost mandatory.'

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PERGAMON

ICRP Publication 82

Annals of the ICRP

Editorial

TOGETHER, WE CAN MAKE IT!

This report on protection of the public against prolonged (or, in common parlance, chronic) exposures and the companion report, *Publication 81* on disposal of long-lived solid radioactive waste, are likely to become stepping-stones in the discussion of these important, interrelated, and difficult topics.

The reports do not aspire to solve all problems. They certainly do not prescribe all-embracing numbers to replace painstaking evaluation of specific circumstances. On the contrary, the reports provide the radiological protection philosophy for these topics, which is exactly what ICRP aims to do. Thus, the reports are intended to help readers achieve the analytical frame of mind required in order to work on these complicated problems.

In fact, *Publication 81* contains no new numbers and not a single table! Its importance lies in the manner of thinking it advises. *Publication 82*, the present report, does provide a table of generic reference levels, exemption levels, and intervention exemption levels, some of which are not immediately evident in earlier ICRP reports. However, as explained in the report, this does not mean that the numerical advice is 'new'. Instead, it is derived from existing ICRP recommendations, taking into account the experience of how situations of existing exposures have actually been handled. In addition, the report goes to great pains to clarify that its numerical values are just starting points, usually of an upper bound nature, for the discussions leading up to the decisions needed. Thus, again the primary importance lies in the philosophy rather than in specific numbers.

These two reports also represent the latest examples of the Commission's new policy of seeking much wider participation in a public consultation process before its advice is finally completed. Draft versions of both reports were sent to a considerable number of experts in many countries, and in addition, they were both posted on our web site (www.icrp.org) for anyone in the entire world to see and comment on.

The consultation process was doubly advantageous in that it generated numerous helpful suggestions for improvement of the drafts, and at the same time permitted a huge number of people to participate in the process. Such participation ensures that ICRP recommendations and advice do not come as a surprise to the intended readership.

Of course, the concept of consultation is not entirely new to ICRP. The members of Task Groups preparing new reports have always informally circulated draft versions of their reports to colleagues before submitting them for final approval by the

Commission. The 1990 Recommendations of ICRP had been subjected to quite extensive consultations before they were finally adopted. However, the present consultation policy includes some new features. Perhaps the most important aspect is that the Commission provides advance information to and solicits comments from all persons who are interested, rather than handpicking its peers for these purposes.

It seems safe to predict that this new policy of openness is here to stay. There are a few draft reports in the system that are already being finally prepared for printing and therefore will not now be circulated for world-wide consultation; there may be instances where for some reason or other a particular report bypasses the process; but by and large, widespread consultation is expected to become the future norm.

This change from a top-down to a bottom-up consultation procedure would not have been conceivable without the advent of electronic communication. Even with narrowly limited target groups, the costs in money and in time of circulating drafts to thousands upon thousands of people would have been prohibitive. Admittedly, electronic mail is not always reliable; admittedly, the abundance of e-mail messages that tend to fill the in-tray whenever one turns one's back can be devastating – but electronic information systems do provide possibilities that were never before available.

JACK VALENTIN

PREFACE

At its meeting in Paris, France, in November 1996 the International Commission on Radiological Protection (ICRP), hereinafter referred to as 'the Commission', on the recommendation of ICRP Committee 4, established a Task Group to develop protection criteria for prolonged exposure of the public to ionising radiation. The criteria were to cover application and withdrawal of countermeasures, including situations where countermeasures were considered but never applied; decontamination and reclamation of land contaminated by past practices or accidents; and high exposures due to natural sources of radiation.

The membership of the Task Group was as follows:

A.J. González (Chairman)	J. Cooper	P. Hedemann-Jensen
S. Przyborowski	M. Savkin	J.E. Till

The membership of Committee 4 during the period of preparation of this report was:

(1993–1997)

D. Beninson (Chairman)	D. Cool	R.M. Duncan
A.J. González	R. Hock	C.J. Huyskens
T. Kosako	K.H. Lokan	F. Luykx
Z. Pan	K.C. Pillai	A.C.B. Richardson
A. Sugier	K. Ulbak	J. Valentin
B.C. Winkler (Vice-Chairman)	A.D. Wrixon (Secretary)	

(1997–2001)

B.C. Winkler (Chairman)	R.M. Alexakhin	E. d'Amato
D. Cancio	T. Godås	A.J. González
K.R. Kase	T. Kosako	W. Kraus
J. Lochard	A.G. McEwan	R.V. Osborne (Vice-Chairman)
K.C. Pillai	A. Sugier	J.E. Till
A.D. Wrixon (Secretary)	Y. Xia	C. Zuur

The Task Group benefited from the work of a previous ICRP Task Group on the subject. It wishes to express its appreciation for the support received from those members of the previous Task Group who were not part of it — B.C. Winkler, A. Richardson, and D. Robeau, and the corresponding member, K. Lokan — as well as from members of ICRP Committee 4 and the ICRP Main Commission.

The Commission's Chairman, R.H. Clarke and its emeritus members, H.J. Dunster and B. Lindell, supported the Task Group with invaluable advice and assistance and Commission member D.J. Beninson attended one Task Group meeting. The Task Group also benefited from the work of the *IAEA Advisory Group on the Application of Radiation Protection Principles to the Clean-up of Contaminated Areas* (IAEA 1997), chaired by P. Hedemann-Jensen.

An advanced draft of this report was widely circulated among professional colleagues in specialised organisations and committees and also via the ICRP site on the Internet. The Commission is extremely grateful for the detailed review carried out by many colleagues and for the comments and suggestions received.

The Commission is very grateful for the editorial help that the Task Group received from I. Barraclough, D. Delves, and S. Francis, and for the administrative assistance provided by P. Clavera Ortiz, J. Heap, S. Ratheiser and C. Vilaplana in the preparation of the various manuscripts.

For the preparation of the report, the Task Group met at the Headquarters of the International Atomic Energy Agency in Vienna in 1997 and in 1999; by courtesy of the Spanish Consejo de Seguridad Nuclear in Seville in 1997; and at the Headquarters of the Spanish Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas in Madrid in 1998. The Commission wishes to express its appreciation for the support received from those who hosted those meetings.

The report was adopted for publication by the Commission at its meeting in St. Petersburg, Russian Federation, in September 1999.