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Protection of the Environment under Different Exposure Situations

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Protection of the Environment under Different Exposure Situations

ICRP Publication XXX

Approved by the Commission in 20YY

Abstract- In this report the Commission provides further recommendations with regard to the protection of the environment that have been drawn up within its existing overall framework of protection. The report explains how the recommendations with regard to environmental protection are integrated into the Commission's aims to manage radiation under all exposure situations, by way of the introduction of an additional category of exposure, that of environmental exposures. It also examines how these recommendations relate to the Commission's three key principles of justification, optimization of protection, and the application of dose limits. The report describes the logic behind the need to apply a set of Derived Consideration Reference Levels for managing the exposures of animals and plants in existing exposure situations, plus Environmental Reference Levels for individual sources in planned exposure situations, and the use of a pattern of dose rate bands selected to represent severe radiation effects for evaluating environmental consequences in emergency exposure situations.

The Annex to this report reviews the types of environmental protection legislation currently in place in relation to large industrial sites and practices, and the various forms in which wildlife are protected from various threats arising from such sites. The Commission's own approach to protection of the environment, based on various points of reference, is then discussed in the context of different categories of environmental exposure situations (normal, existing, and emergency) and how this approach may be interfaced with the actual situations being assessed by way of the selection of Representative Organisms. Because the assessment process will also, by necessity, involve an engagement with relevant stakeholder bodies, some outline guidance and advice is given with regard to how this engagement should be handled.

Keywords: Radiation, exposure situations, environmental protection, biota.

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PREFACE

At its meeting in Suzhou, China, in 2010, the Main Commission approved the formation of a new Task Group reporting to Committees 4 and 5 on the ICRP's approach to protection of the environment. This was done because, although ICRP 103 had introduced a new 'environmental protection' requirement into its Recommendations (following on from ICRP 91), the subsequent publication of ICRP 108 had now made it necessary to demonstrate, explicitly, how the expanded ICRP framework collectively held together in a coherent way. This was essential in order to articulate how more practical advice, in the future, could be accommodated within existing and anticipated regulatory frameworks.

It was also recognized that although ICRP 91 and 108 had collectively set out the ethics, values, and the current science base underlying the Commission's environmental objectives, it was still necessary to explain how these new areas resided within the long-standing context of the Commission's principles of justification, optimization, and the application of limits.

The membership of the Task Group was as follows:

R.J. Pentreath, Chairman	D. Cool	D. Copplestone
J. Lochard, Vice-Chairman	P. Strand	M. Watanabe
C-M. Larsson	J. Simmonds	

The following persons were corresponding members:

A. Janssens	D. Oughton	E. Lazo
I. Outola	G. Pröhl	

The Task Group met twice, 12-13 June 2010, at STUK, Finland, and 28-29 June 2011, at CEPN, Fontenay-aux-Roses, France, but worked mainly by correspondence. The explanation of how the Commission's approach to environmental protection relates to that of human radiation protection, and how the principles of justification, optimisation of protection, and application of limits apply to different exposure situations received the full endorsement of Committees 4 and 5 in Washington, October 2011

In parallel to the Task Group's work, ICRP Committee 5 continued to consider the more practical aspects of applying the Commission's approach to protection of the environment, and this information and advice is provided in Annex A.

The membership of Committee 5 during the preparation of Annex A was as follows:

R.J. Pentreath, Chairman	D. Copplestone	A. Real
C-M. Larsson, Vice-Chairman	K.A. Higley	K. Sakai
F. Brechignac	G. Pröhl	P. Strand

EXECUTIVE SUMMARY

(a) The Commission's acknowledgement of the importance of protecting the environment has called for a number of issues to be examined and clarified, particularly with regard to how such objectives can be met in the context of the ICRP's existing framework of protection. Effectively, this new objective expands the Commission's set of (human) exposure situations by adding a new situation. It is not additional to those relating to humans, but is one that runs in parallel to them, which is here referred to as that of environmental exposures – those of the animals and plants (the biota, or non-human organisms) that inhabit the natural environment.

(b) The Commission's framework is centered on the principles of justification, optimization of protection, and the application of dose limits. With regard to justification, the responsibility for judging it usually falls on governments, or national authorities, to ensure an overall benefit in the broadest sense to society. The benefits are deemed to apply to humans and society as a whole, whereas the term 'harm' might encompass any effects, or increased risks of effects, from radiation exposure, and the Commission believes that this should apply not only to humans but also to biota. Because the principal of justification also includes the need to take account of future harm and benefits, the Commission considers that the potential risk of radiation harm to the environment should also be considered within the overall evaluation of whether or not an activity or action does more harm than good.

(c) For the protection of non-human biota, *Derived Consideration Reference Levels* (DCRLs) have been defined that are specific to each of the Commission's 12 different types of Reference Animals and Plants. A DCRL can be considered as a band of dose rate, spanning one order of magnitude, within which there is some chance of deleterious effect from ionizing radiation occurring to individuals of that type of Reference Animal or Plant. Thus, when considered together with other relevant information, DCRLs can be used as points of reference to optimize the level of effort expended on environmental protection, dependent on the overall management objectives, the exposure situation, the actual fauna and flora present, and the numbers of individuals thus exposed.

(d) The Commission therefore recommends that DCRLs be used under circumstances where there is an environmental exposure of significance in order to assist, further inform, and guide efforts to optimize protection of the environment. In planned exposure situations, the lower boundary of the relevant DCRL band should be used as the appropriate starting point for optimization of environmental exposures to different types of animals and plants during the planning of controls to be applied to discharges into a specific environmental area. The DCRL bands therefore apply to animals and plants within a given location. Because of the possibility of multiple sources affecting the same animals or plants, or for any residual exposures arising from previous sources affecting the same animals and plants, consideration also needs to be given to possible cumulative impacts, as is the case for human exposures. The Commission therefore recommends that a value, termed the Environmental Reference Level (ERL), be established for a specific source at a level below the relevant DCRL for the relevant RAP or RAPs.

(e) For emergency exposure situations, it is necessary to consider the environmental consequences of possible accidents at a site, as well as the planning for emergency preparedness, communications with stakeholders in relation to such situations, and the intended response should an event occur. There may also be a need to consider different siting options for a specific source with regard to the potential impact on a defined environmental area; or a need to consider the potential impact on different environmental areas in relation to the defined siting of a specific source. Optimization at the planning stage will therefore involve examination of different protective strategies and, in order to facilitate this optimization, the Commission recommends that an appropriate band of dose rates related to severe effects (at least one or more orders of magnitude above the relevant DCRL) be identified for the relevant RAPs, depending on the specific features of the biota exposed and the spatial and temporal aspects of the expected situation. With regard to responding to an actual event, consideration of environmental protection is unlikely to be an immediate priority if human exposures are involved. Nevertheless, if human exposures are involved, consideration should also be given to the environmental consequences of the possible options available for maximizing human protection, and the values used in emergency planning, generally one or more orders of magnitude above the DCRL, will thus again be useful in communicating the implications of the situation to stakeholders, particularly in relation to environmental conditions where humans have been removed from the area, and food chains leading to human exposure have been severed. Indeed, in some cases, the only considerations may be impact on the natural environment, and options for minimizing such impact need to be considered in advance in relation to different environmental impact scenarios.

(f) For existing exposure situations, if the dose rates are above the relevant DCRL bands, the Commission recommends that the level of ambition for optimization would be to reduce exposures to levels that are within the relevant DCRL bands, fully considering the radiological and non-radiological costs and benefits of so doing. If dose rates are within the bands, the Commission considers that the optimization principle should nevertheless continue to be applied, assuming that the costs and benefits are such that further efforts are warranted.

(g) The Commission does not recommend any generally applied form of dose limitation for biota. This is because the necessity for dose limits to ensure equity in the application of optimization for human exposures does not clearly exist in the optimization of protection of the environment; plus the fact that the objectives of such protection, and the highly variable nature of the exposure situations, make it difficult to establish limits that would be scientifically defensible. The Commission nevertheless recognizes that some regional or national legislation may direct the development of some type of limitation, and therefore recommends that the derivation of any relationship of such values to the Commission's set of RAPs, and their data bases, should be explicitly set out. The Commission intends to keep reviewing this situation in the light of national developments.

(h) The Annex A describes many of the legislative frameworks in existence relating to protection of the environment from industrial practices, and notes that risks arising from ionising radiation may often need to be considered within such larger frameworks of legislative control. This legislation usually relates to permitted releases into the environment, or relates to the direct protection of the environment from different threats. Thus there are already various intsdcavernational agreements relating to larger industries under the general heading of what one might term pollution control, and these are briefly reviewed. The general thrust of such legislation is to ensure that the environment is not generally harmed or contaminated because this, in turn, could affect its future use and value. And recognising that some elements of the environment are already used as a resource for human food supply, some forms of environmental protection legislation are directly drawn up to safeguard them. But the most challenging existing frameworks may well be those that have been drawn up to protect wildlife in its own right, both in relation to particular species, or to the habitats that different types of biota inhabit. These can often be in close proximity to industrial sites.

(i) It is thus against this existing background of environmental protection requirements that the Commission's approach needs to be considered in a practical way. The Commission has recommended that certain biological effects of radiation (early mortality, some forms of morbidity, impairment of reproductive capacity, or the induction of chromosomal damage) are the appropriate ones to focus on, and it has previously reviewed the relationships between such effects and radiation dose for a set of Reference Animals and Plants (RAPs), together with other data relevant to estimating their potential for exposure by way relevant transfer factor data and dosimetric models.

(j) Because the RAPs are, by definition, points of reference, it is also necessary to identify Representative Organisms relevant to each evaluation. These may well be extremely similar to RAPs, or different. In some cases there will be little choice in selecting them, because this may already have been done by way of other existing legislation. Nevertheless, differences between such biota and the RAPs should be quantifiable, in relation to their basic biology, dosimetry, or radiation effects, and such differences need to be noted and taken into account. The extent to which such factors then need to be applied, and their relevant impact on the final decision, will depend on the nature of the implementation and application of the planning process relevant to protection of the environment. Because other regulatory bodies are likely to be involved, such as those responsible for wildlife management, it is essential to have a clearly set out logical link between any radioactive releases and potential risk of biological effects (for which the RAP framework should be a starting point) and a clearly laid out strategy by which the relevant stakeholders can be engaged in the decision making process.

GLOSSARY

Concentration Ratio (CR)

Activity concentration within an organism relative to that in its surrounding habitat (as represented by a particular media such as air, sediment, soil or water).

Derived Consideration Reference Level (DCRL)

A band of dose rate within which there is likely to be some chance of deleterious effects of ionising radiation occurring to individuals of that type of reference animal or plant (derived from a knowledge of defined expected biological effects for that type of organism) that, when considered together with other relevant information, can be used as a point of reference to optimise the level of effort expended on environmental protection, dependent upon the overall management objectives and the relevant exposure situation.

Dose conversion factor

A value that enables the dose to an organism to be calculated on the assumption of a uniform distribution of a radionuclide within or external to an organism, assuming simplified dosimetry, in terms of (μGy/day)/(Bq/kg).

Emergency exposure situation

An unexpected situation that occurs during the operation of a practice, requiring urgent action. Emergency exposure situations may arise from practices.

Environmental exposures

All additional radiation exposures of biota in the natural environment as a result of human activities.

Environmental radiation protection

Measures taken to prevent or reduce the frequency of deleterious radiation effects in animals and plants (biota) in their natural environmental setting to a level where they would have a negligible impact on the maintenance of biological diversity, the conservation of species, or the health and status of natural habitats, communities, and ecosystems.

Existing exposure situation

A situation that already exists when a decision on control has to be taken, including natural background radiation and residues from past practicesthat were operated outside the Commission's recommendations.

Gray (Gy)

The special name for the SI unit of absorbed dose: $1\ Gy = 1\ J\ kg^{-1}$.

Justification

The process of determining whether either (1) a planned activity involving radiation is, overall, beneficial, i.e. whether the benefits to individuals and to society from introducing or continuing the activity outweigh the harm (including radiation detriment) resulting from the activity; or (2) a proposed remedial action in an emergency or existing exposure situation is likely, overall, to be beneficial, i.e., whether the benefits to individuals and to society (including the reduction in radiation detriment) from introducing or continuing the remedial action outweigh the cost and any harm or damage it causes.

Natural environment

A collective term for all of the physical, chemical, and biological conditions within which wild animals and plants normally live.

Optimisation of protection (and safety)

The process of determining what level of protection and safety makes exposures, and the probability and magnitude of potential exposures, as low as reasonably achievable, economic and societal factors being taken into account.

Planned exposure situations

Everyday situations involving the planned operation of sources including decommissioning, disposal of radioactive waste and rehabilitation of the previously occupied land. Practices in operation are planned exposure situations.

Radioactive material

Material designated in national law or by a regulatory body as being subject to regulatory control because of its radioactivity, often taking account of both activity and activity concentration.

Reference Animal or Plant (RAP)

A hypothetical entity, with the assumed basic biological characteristics of a particular type of animal or plant, as described to the generality of the taxonomic level of family, with defined anatomical, physiological, and lifehistory properties, that can be used for the purposes of relating exposure to dose, and dose to effects, for that type of living organism.

Representative organism (RO)

A particular species or group of organisms selected during a site specific assessment. In many cases the representative organisms chosen for this purpose may be the same as, or very similar to, the Reference Animals and Plants; but in some cases they may be very different.

Source

An entity for which radiological protection can be optimised as an integral whole, such as the x-ray equipment in a hospital, or the releases of radioactive materials from an installation. Sources of radiation, such as radiation generators and sealed radioactive materials and, more generally, the cause of exposure to radiation or radionuclides.

1. INTRODUCTION

1.1. Background

(1) All of the Commission's Recommendations are based within a framework of aims, fundamental principles, and scope, the last of which has, since 1977 (ICRP, 1977), recognized different categories of human exposure, namely: occupational, public, and the medical exposure of patients. But in its recent revision of its general Recommendations (ICRP, 2007), the Commission introduced a new requirement - that of protecting the environment. This decision logically followed on from a previous ICRP document that had discussed the basis for assessing the impact of ionizing radiation on non-human species, the basic principles and approaches to environmental protection, and how they could be applied to environmental radiation protection (ICRP, 2003).

(2) In relation to animals and plants in their natural environmental setting, the Commission's environmental protection aims (ICRP, 2007) are those of "*….preventing or reducing the frequency of deleterious radiation effects to a level where they would have a negligible impact on the maintenance of biological diversity, the conservation of species, or the health and status of natural habitats, communities and ecosystems*". In achieving this aim, the Commission also recognized that exposure to radiation is but one factor to consider, and that it is often likely to be a minor one.

(3) The Commission's additional requirement therefore introduced a new category, that of environmental exposures, where non-human biota are the targets for radiation exposure and where radiation effects in such organisms, as well as the environment as a whole, may need to be assessed. Such an expansion naturally also raised the question of how protection of the environment fitted within the Commission's overall, and well-established, radiation protection framework for human protection.

(4) The Commission stated in its Publication *103* (ICRP, 2007), based on the advice given in Publication *91* (ICRP, 2003), that it intended to base the concept of 'protection of the environment' within a scientific framework similar to that which had been developed for the protection of humans, by employing a set of 'reference' models and data bases. This proposed framework was then further developed in Publication *108* (ICRP, 2008) by explaining the concept and use of a small set of Reference Animals and Plants (RAPs) to explore the issues of relating exposure to dose, and dose to effects, for different types of animals and plants. This document also included biological descriptions of RAPs, relevant radiation effects data, and a number of new terms and numerical values, such as RAP-specific dose conversion factors for a variety of radionuclides, and Derived Consideration Reference Levels as starting points for optimizing the level of their protection. The overall dataset for these RAPs has recently been extended by the compilation of relevant transfer factors (Concentration Ratios), describing the relationship between environmental levels of a number of radionuclides and the corresponding levels in such animals and plants (ICRP, 2011).

(5) The present report therefore provides further advice on how the framework recently developed for protection of the environment relates to the general system of protection that has been developed in the past by the Commission for the protection of human beings. This is to ensure that comprehensive and coherent decisions are made in relation to providing protection from any source of exposure, in any specified exposure situation, including non-human species – referred to in this report simply as 'biota'.

(6) An Annex to this document provides more practical information and advice on the application of the Commission's recommendations to different exposure situations with respect to the animals and plants living in different types of natural environments, particularly with regard to relating the actual objects of protection to those used for reference purposes, and in the context of the need explicitly to demonstrate environmental protection in the context of different legal and sociological obligations, including those specifically relating to the environment as set out in the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (IAEA, 1997).

2. TYPES OF EXPOSURE SITUATIONS AND CATEGORIES OF EXPOSURE

2.1. Types of exposure situations

(7) The Commission intends that its Recommendations be applied to all sources of radiation in the following three types of exposure situations.

(8) *Planned exposure situations*, which are defined as *everyday situations involving the planned operation of sources including decommissioning, disposal of radioactive waste and rehabilitation of the previously occupied land. Practices in operation are planned exposure situations*. They therefore include those situations that involve the deliberate introduction and operation of sources. Planned exposure situations may give rise both to exposures that are anticipated to occur (normal exposures) and to exposures that are not anticipated to occur (potential exposures).

(9) *Emergency exposure situations*, which are defined as *unexpected situations that occur during the operation of a practice, requiring urgent action. Emergency exposure situations may arise from practices*. They may therefore occur during the operation of a planned situation, or from a malicious act, or from any other unexpected situation, and require urgent action in order to avoid or reduce undesirable consequences.

(10) *Existing exposure situations*, which are defined as *situations that already exist when a decision on control has to be taken, including natural background radiation and residues from past practices that were operated outside the Commission's recommendations*. They therefore include prolonged exposure situations after emergencies.

2.2. Categories of exposure

(11) The Commission continues to distinguish amongst three categories of human exposure. These are as follows.

(12) *Occupational exposures*, which are exposures incurred (with certain exceptions) by workers in the course of their work. But because radiation is ubiquitous, the direct application of this definition would mean that all workers should be subject to a regime of radiological protection. The Commission therefore limits its use of 'occupational exposures' to radiation exposures incurred at work as a result of situations that can reasonably be regarded as being the responsibility of the operating management.

(13) *Medical exposures*, which are exposures incurred by patients as part of their own medical or dental diagnosis or treatment; by persons, other than those occupationally exposed, knowingly, while voluntarily helping in the support and comfort of patients; and by volunteers in a programme of biomedical research involving their exposure.

(14) *Public exposures*, which are incurred by members of the public from radiation sources, excluding any occupational exposure or medical exposure and the

normal local background radiation. Exposures of the embryo and foetus of pregnant workers are considered and regulated as public exposures.

(15) The introduction of the Commission's aims of protecting the environment thus introduces a different category of exposure that is defined as follows:

Environmental exposures, which are all additional radiation exposures of biota in the natural environment as a result of human activities.

(16) The Commission expects this category of exposure to be considered in the context of all three exposure situations, i.e., planned, existing, and emergency.

2.3. Environmental media and natural resources

(17) The term *environmental protection* is sometimes taken to include the prevention of the contamination of environmental media that are considered to constitute environmental resources (such as soil, water, sediment, and air) of human value with the objective of 'protecting' such natural resources for the future. A typical example is that of guarding against the risk of contaminating ground water that could be of use to humans with radionuclides from waste disposal. In such cases the 'object' of protection (for example, groundwater) is not itself 'harmed' by exposure to ionizing radiation, and the concern is essentially that of the future use of the resource by humans. It thus forms part of the framework of human protection. In the same manner, however, these resources also form part of the network of exposure media for non-human biota. As such, protection of such resources is also a mechanism for limiting exposures for both humans and biota. Environmental media are therefore considered by the Commission as *pathways* of exposure, whereas the recommendations relating to protection are derived from an understanding of effects in, and the sensitivity of, the organisms living in the environment. Thus although the protection of resources is an aspect (and often a legal requirement with regard to the principles of sustainable development) that should not be overlooked, it is not the object of this report.

3. THE PRINCIPLES OF RADIOLOGICAL PROTECTION

(18) The three key principles of radiological protection are those of justification, optimization of protection, and the application of dose limits. These principles have been defined as follows for human radiation protection.

(19) *The Principle of Justification* is that any decision that alters the radiation exposure situation should do more good than harm.

(20) *The Principle of Optimization of Protection* is that the likelihood of incurring exposure, the number of people exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable, taking into account economic and societal factors.

(21) *The Principle of the Application of Dose Limits* is that the total dose to any individual from regulated sources in planned exposure situations, other than medical exposure of patients, should not exceed the appropriate limits recommended by the Commission.

(22) The principles of justification and optimization apply in all three exposure situations and for the exposure of workers, patients, and the public, whereas the principle of dose limits applies only to doses to workers and the public that are expected to be incurred as a result of planned exposure situations. It is thus necessary to examine first how the introduction of another exposure category, that of environmental exposures in relation to the protection of the natural environment, relates to these fundamental principles.

3.1. Justification

(23) Justification is the process of determining whether (a) a planned activity involving radiation is, overall, beneficial (i.e. whether the benefits to individuals and to society from introducing or continuing the activity outweigh the harm, including radiation detriment, resulting from the activity); or whether (b) a proposed protection strategy in an emergency or existing exposure situation is likely, overall, to be beneficial (i.e., whether the benefits to individuals and to society, including the reduction in radiation detriment, from introducing or continuing the strategy, outweigh its cost and any harm or damage it causes).

(24) There are two different approaches to applying the principle of justification, which depend upon whether or not the source can be directly controlled. The first approach is used in the introduction of new activities, where radiological protection is planned in advance and the necessary protective actions can be taken on the source. Application of the justification principle to these situations requires that no planned exposure situation should be introduced unless it produces sufficient net benefit to the exposed individuals, or to society, to offset any radiation detriment it causes. Judgments on whether it would be justifiable to introduce or continue particular types of planned situation involving exposure to ionizing radiation are important, and the justification may need to be re-examined as new information or technology becomes available.

(25) The second approach is used where exposures can be controlled mainly by action to modify the pathways of exposure, and not by acting directly on the source – such as existing exposure situations and emergency exposure situations. In these circumstances, the principle of justification is applied when making decisions as to whether to take action to avert exposure. The decision taken to reduce exposures, which always has some disadvantages, should therefore be justified, in the sense that it should do more good than harm.

(26) In both approaches, the responsibility for judging the justification usually falls on governments, or national authorities, to ensure an overall benefit in the broadest sense to society. However, input to the justification decision may include many aspects that could be informed by users or other organizations, or persons, outside of such bodies. As such, justification decisions will often be informed by a process of public consultation, typically during the environmental impact assessment stage, dependent upon, amongst other things, the size of the source concerned. There are many aspects of justification, and different organizations may be involved and responsible for providing different forms of advice. In this context, human radiological protection considerations will serve as but one input to the broader decision process.

(27) The benefits are deemed to apply to humans and society as a whole, whereas the term ‘harm’ encompasses any increased risk from radiation exposure, and this will apply to both humans and biota. Because the principle of justification also includes the need to take account of future harm and benefits, the Commission considers that the potential risk of radiation harm to the environment should also be considered within the overall evaluation of whether or not an activity or action does more harm than good. Such evaluations - that will ultimately be made by governments, or regulatory bodies - are likely to be part of more inclusive and holistic assessments relating to all of the impacts of introducing activities where control is exercised over the source.

(28) With regard to remedial actions, in the context of emergency and existing exposure situations, consideration should also be given to the likely consequences for radiation exposure of biota (as, for example, by way of relocating contaminated material) so that the overall outcome does more good than harm. These decisions must be made in the more inclusive and holistic context of benefits and impacts, and again the Commission notes that radiation exposure is often not the dominant impact to biota from proposed actions.

3.2. Application of dose limits

(29) The Commission has recommended the use of dose limits for protection against occupational and public exposures of people in planned exposure situations, other than medical exposure of patients. (The use of dose limits is also not recommended for protection against occupational and public exposures in emergency or existing exposure situations.) The Commission does not, however, recommend any generally applied form of dose limitation for biota. This is because the necessity for dose limits to ensure equity for human exposures does not clearly exist in protection of the environment; plus the fact that the objectives of such protection, and the highly variable nature of the exposure situations, make it difficult to establish limits that would be scientifically defensible.

3.3. Optimization of protection

(30) The process of optimization of protection is intended for application to those situations that have been deemed to be justified in the first place. The principle of optimization of protection is central to the system of protection and applies to all exposure situations; it considers all exposures, and thus includes environmental exposures. It is a source-related process, aimed at achieving the best level of protection under the prevailing circumstances through an ongoing, iterative, process. The Commission has drawn attention to the fact that it is always necessary to consider the inter-relationships amongst the different categories of exposure (ICRP, *101*, 2006). Thus, for example, in optimizing the level of protection in the case of occupational exposure, it is necessary also to consider the potential effect on public exposure (for example as a result of releasing more radioactive material into the environment). If the scale of release is significant, it is also necessary to consider any impact on biota.

(31) To assist in the optimization process for human exposures, the Commission has defined *Dose Constraints* for restricting, during the planning process, the range of acceptable outcomes for occupational and public individual exposures in planned exposure situations in relation to a source. In emergency and existing exposure situations, the Commission has also recommended that *Reference Levels* be used in conjunction with the optimization of protection to restrict occupational and public exposures. The Commission believes that steps taken to protect the environment should fall within the concept of optimization, and thus it is worth first reviewing very briefly how it is applied to human protection before discussing how it should be applied to environmental protection.

3.3.1 Dose constraints and reference levels for human exposures

(32) The *dose constraint* is a source-specific value of individual dose used for the optimization process for planned exposure situations. It is almost always a fraction of the dose limit. In the Commission's view it would be unacceptable to plan activities so that resulting doses are above the predefined constraint level; although, should this occur, it should not be formally regarded as a regulatory infraction. Similarly, *reference levels* may be defined for existing and emergency exposure situations, indicating, for planning purposes, a desired outcome of protective actions; although it is also recognized that the reference level may not always be possible to reach. For selecting dose constraints and reference levels, the Commission has set its advice in terms of bands of dose, as shown in Fig. 1.

(33) Dose constraints provide a desired upper bound for the optimization process. Some sources and technologies are able to satisfy dose constraints that are set at a low level, while others are only able to meet dose constraints set at a higher level. This is normal and should be reflected in the freedom of operators, regulatory authorities, and others as appropriate, to select such values for particular circumstances. The role of experience and good practice should play an important role in the setting of dose constraints, as well as the need to allow for the presence of multiple sources, or the legacy from previous sources, that may affect the same exposed population.

(34) Emphasis on optimization using reference levels in emergency and existing exposure situations focuses attention on the residual level of dose remaining after implementation of protection strategies. This residual dose should be below the reference level, which represents the total residual dose as a result of an emergency, or in an existing situation, that the regulator has planned not to exceed. These exposure situations often involve multiple exposure pathways, so that protection strategies involving a number of different protective actions will have to be considered (ICRP *103*, 2007).

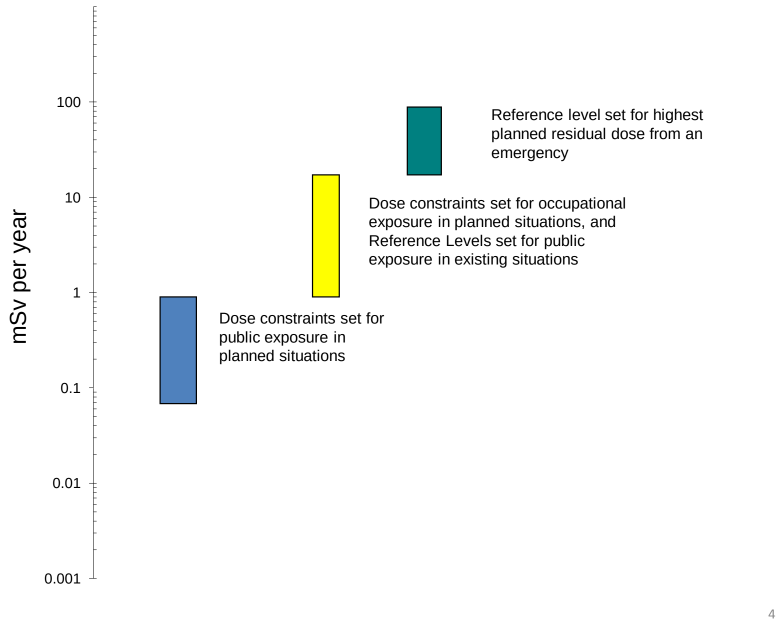

Fig. 1. Range of Reference Levels and Dose Constraints for human radiological protection [Note that in emergency situations the dose may need to be considered as an acute dose rather than an annual dose.]

(35) Emergency exposure situations include consideration of emergency preparedness and emergency response. Emergency preparedness should include planning for the implementation of optimized protection strategies which have the purpose of preventing or reducing exposures, should the emergency occur, to below the selected value of the reference level. During emergency response, the reference level would act as a benchmark for evaluating the effectiveness of protective actions, and as one input into the need for establishing further actions.

3.3.2 Points of reference for environmental exposures

(36) For the protection of non-human biota, *Derived Consideration Reference Levels* (DCRLs) have been defined that are specific to each of the 12 different types of Reference Animals and Plants in Publication 108 (ICRP, 2008). A DCRL can be considered as a band of dose rate within which there is some chance of deleterious effect from ionising radiation occurring to individuals of that type of Reference Animal or Plant. When considered together with other relevant information, DCRLs can be used as points of reference to optimise the level of effort expended on environmental protection, dependent on the overall management objectives, the

exposure situation, the actual fauna and flora present, and the numbers of individuals thus exposed. The DCRLs have been defined in terms of bands of dose rates spanning one order of magnitude (Fig. 2) relevant to each RAP.

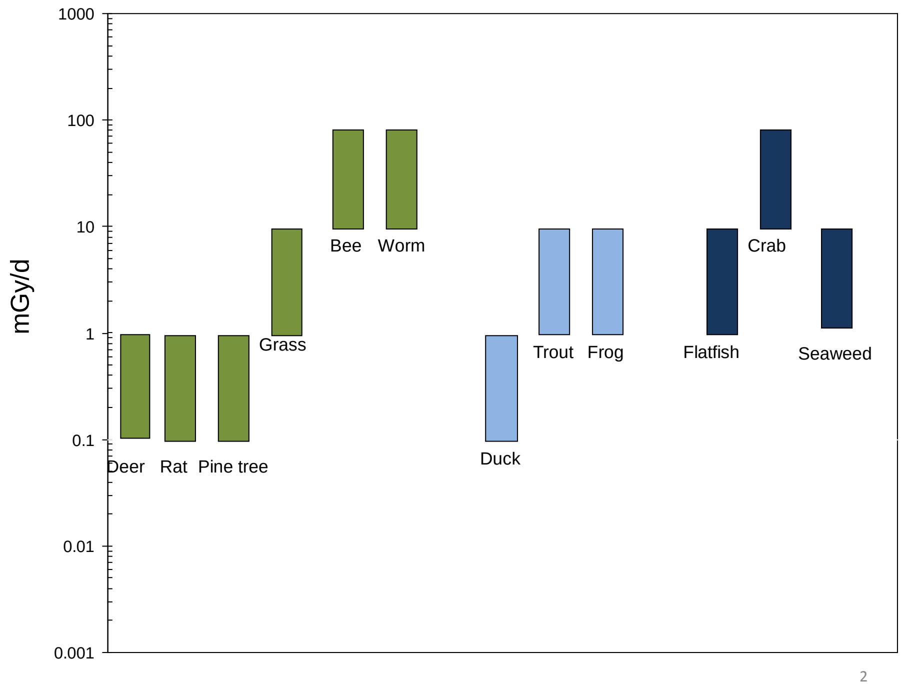

Fig. 2. Derived Consideration Reference Levels (DCRLs) for environmental protection for each RAP, the RAPs being grouped according to their terrestrial, freshwater, or marine habitat.

(37) Protection of the environment is a requirement of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (IAEA, 1997) in relation to the safety of the management of spent fuel and radioactive waste, including the siting of facilities, their design and operation, and dealing with unplanned releases and the implementation of intervention measures. The Convention has a requirement to "…*provide for effective protection of individuals, society and the environment, by applying at the national level suitable protective methods as approved by the regulatory body, in the framework of its national legislation which has due regard to internationally endorsed criteria and standards*". The Commission recommends that DCRLs be used under all circumstances where there is an environmental exposure of significance from any major nuclear facility in order to assist, further inform, and to guide efforts to optimize protection of the environment. The use of the DCRLs in each exposure situation is elaborated as follows.

(38) In *planned exposure situations*, the lower boundary of the relevant DCRL band should be used as the appropriate starting point for optimization of environmental exposures to different types of animals and plants within a given area during the planning of controls to be applied to a source. Because the DCRL bands apply to animals and plants within a given location, the extent of such an area needs to be determined in advance relative to the overall conservation objectives. And because there may be the possibility of multiple sources affecting the same animals or plants, or for any residual exposures arising

from previous sources affecting the same animals and plants, consideration also needs to be given to possible cumulative impacts, as is the case for human exposures. The Commission therefore recommends that a value, termed the Environmental Reference Level (ERL), be established for a *specific* source at a level below the relevant DCRL for the relevant RAP or RAPs for use in the optimization of protection. This is illustrated in Fig. 3.

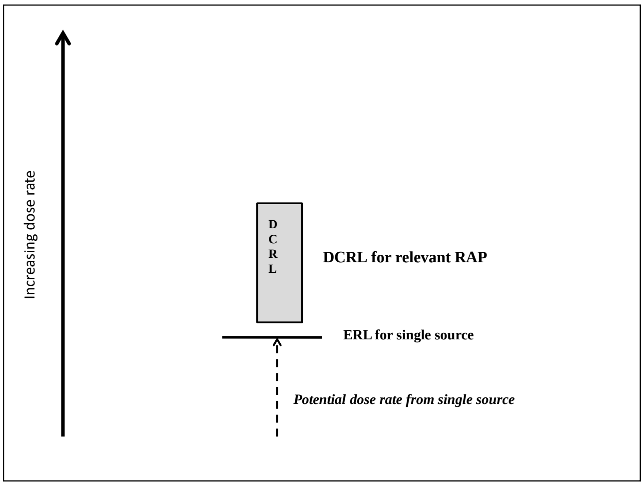

Fig. 3. Relationship between DCRLs and Environment Reference Levels (ERLs) for single sources, under planned exposure situations, when other sources, or historic sources, are present in the same location.

(39) For *emergency exposure situations*, it is necessary both to consider the environmental consequences of possible accidents at a site, as well as the planning for emergency preparedness, communications with stakeholders in relation to such situations, and the intended response, should an event actually occur. Thus there may be a need to consider different siting options for a specific source with regard to the potential impact on a defined environmental area; or a need to consider the potential impact on different environmental areas in relation to the defined siting of a specific source. Optimization at the planning stage will therefore involve examination of different protective strategies. In such circumstances, concern will be focused on the expectation of severe effects on the local biological community, and thus a scale of effects that are not reflected in the DCRL bands. In order to facilitate this optimization, the Commission therefore recommends that an appropriate band of dose rates related to the probability of severe effects occurring (and thus at least one or more orders of magnitude above the relevant DCRL) be identified for the relevant RAPs, depending on the specific features of the biota exposed and the spatial and temporal aspects of the expected situation. The Commission notes that, in the chemical hazard analysis situation, such values are sometimes termed ‘severe effect levels’.

(40) The appropriate levels of effects should be selected from the dose-effect tables for the Reference Animal and Plants as in ICRP (2008) and discussed further in Annex A. Such levels are the most appropriate benchmarks for emergency situations, and will form a pattern of information for differentiating amongst various protective strategies for emergency scenarios. They may also be particularly useful in communicating with

stakeholders on the possible effects and implications of releases of large quantities of radionuclides into the environment as events unfold.

(41) With regard to responding to an actual event, consideration of environmental protection may not be an immediate priority, depending on the actual or potential implications for human exposure. In fact, the options for mitigation may be very limited with respect to non-human biota, but there is usually something that could be done, as discussed in Annex A. And even where human exposures are of primary concern, consideration should nevertheless be given to the environmental consequences of the possible options available for maximizing human protection. The values used for emergency planning will also be useful in communicating the implications of the situation to stakeholders, particularly in relation to environmental conditions where humans have been removed from the area, and food chains leading to human exposure have been severed. In doing so, reference should be made to the relevant biota: either the relevant Reference Animal or Plant, or to the Representative Organism, as appropriate (Fig. 4). Once the decision has been made that the *emergency exposure situation* is over, the Commission recommends that the approach for protection of the environment for *existing exposure situations* should then be applied.

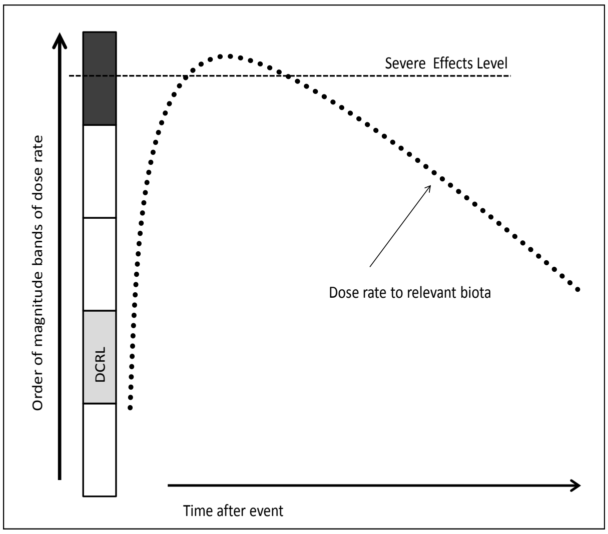

Fig. 4. Potential use of severe effects bands, relative to DCRLs, to relate exposure of relevant biota following an accidental or emergency release of radionuclides into the environment.

(42) For *existing exposure situations*, if the dose rates are above the relevant DCRL band, the Commission recommends that the level of ambition for optimization would be to reduce exposures to levels that are within the DCRL band, fully considering the radiological and non-radiological costs and benefits of so doing (Fig. 5). If dose rates are within the band, the Commission considers that the optimization principle should nevertheless continue to be applied, assuming that the costs and benefits are such that further efforts are warranted. Thus, in the case of existing exposure situations, the DCRL levels are to be used as the criteria for mitigating environmental exposures, in the implementation of optimization, just as reference levels are used for mitigating individual exposures for human protection in such situations.

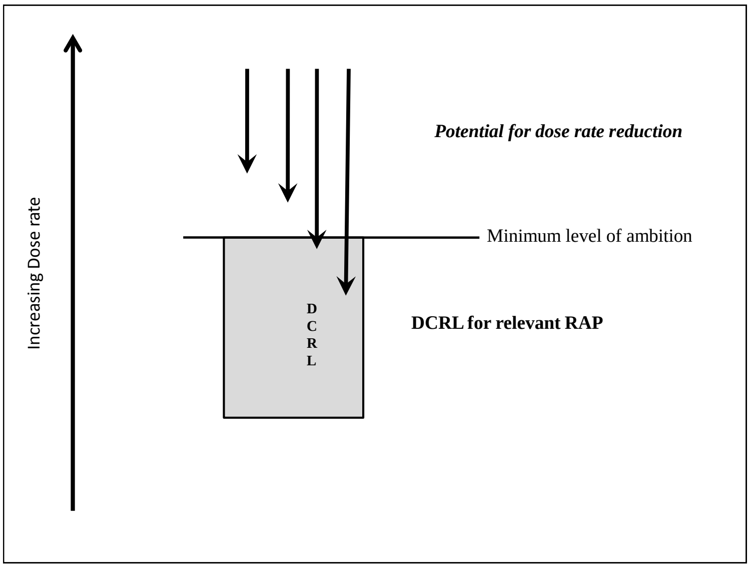

Fig. 5. Relationship between DCRLs and ambition to reduce exposures in existing exposure situations.

4. IMPLEMENTATION AND APPLICATION

4.1. Representative organisms

(43) For the protection of the public, the Commission recommends the use of the dose to the '*Representative Person*' to verify compliance with dose limits, dose constraints, and reference levels, and to select options in implementing the optimization principle. The dose to the Representative Person is defined as the dose that is representative of the more highly exposed individuals in the relevant population. This *Representative Person* may be hypothetical or real (ICRP, 2006).

(44) For the purposes of protecting the environment, the Commission similarly recommends the use of *Representative Organisms* to represent the actual objects of protection in the specific circumstance under consideration. Such organisms will be the actual animals and plants identified for evaluation in each circumstance and these, too, may be hypothetical or real, depending on the specific objectives of the evaluation. Their identification will arise either from specific legal requirements aimed at protecting them for one reason or another, or from more general requirements to protect the local habitats or ecosystems. They may be very similar to, or even congruent with, one or more RAPs. Where this is not the case (and it should be noted that it is not currently possible for the present range of RAP types to be increased appreciably) then attempts should be made to consider to what extent the Representative Organisms differ from the nearest RAP, in terms of known radiation effects upon it, basic biology, radiation dosimetry, and pathways of exposure. Some advice on these issues has already been provided (ICRP, 2008; 2009) and they are discussed further in Annex A.

4.2. Evaluations

(45) The principal components of the system of radiological protection with regard to any evaluation relating to the management of radiation in the environment, can be summarized as follows.

- A characterization of the possible situations where radiation exposure may occur (planned, emergency, and existing exposure situations).
- A precise formulation of the principles of protection: justification, optimization of protection, and application of dose limits to humans in planned exposure situations.
- An identification of the exposed environments, and of the pathways leading to the exposure of biota of interest or concern.
- A description of the levels of doses that require protective action or assessment during optimization (DC and RL for humans; ERL and DCRL, for biota).
- Engagement with the relevant stakeholders.

(46) The objectives for making evaluations of the impact of radiation in the environment with regard to human exposures under different exposure situations are

well established. With regard to exposures to biota, however, the needs may arise for reasons that stem from a wide range of environmental management requirements. These may be of a very general nature, or specifically defined in order to meet national or international legal requirements including, in some cases, a specific need in relation to specific types of habitat or to specific types of fauna or flora. The practical consequence, however, is that this need may include any of the following *objectives***,** each of which would need to be expressed, and deemed 'acceptable' or otherwise, in different ways:

- compliance with the spirit or the letter of trans-national general pollution or wildlife-protection obligations;
- compliance with national pollution control licensing requirements relating to particular industrial practices or to specific sites or areas;
- compliance with the requirements of specific national wildlife and habitat protection legislation;
- compliance with specific environment-based industry needs, such as those relating to fisheries, forestry, farming, and so on; or
- general assurance of the public or their representatives, at national or international level, of the likely environmental impact of any actual or proposed specific practices, and demonstration of the ability to deal with any consequences should accidents occur.

(47) In the application of the principle of optimization of protection of the natural environment, it is important to approach it in an integrated manner, as one would the optimization of protection of workers, patients, or the public. Optimization is always implemented through a procedure aimed at achieving the best level of protection under the prevailing circumstances through an ongoing, iterative process that involves:

- evaluation of the exposure situation (the framing of the process);
- selection of appropriate values for constraining the optimization of protection(dose constraint or reference level or environmental reference level);
- identification of the possible protection options;
- selection of the best option under the prevailing circumstances; and
- implementation of the selected option.

(48) Many problems may well arise, particularly with regard to planned exposure situations, because of the lack of relevant data upon which to make an assessment of environmental impact. The Commission intends to produce further information with regard to data bases for its set of Reference Animals and Plants, and further guidance on their application in relation to different exposure situations.

5. REGULATORY FRAMEWORK AND COMPLIANCE

(49) The Commission has clearly stated (ICRP, 2007) that there are two distinct concepts that delineate the extent of radiological protection control: (i) the exclusion of certain exposure situations from radiological protection legislation, usually on the basis that they are not amenable to control with regulatory instruments (cannot be regulated); and (ii) the exemption of a source from some or all radiological protection regulatory requirements for situations where such controls are regarded as unwarranted, often on the basis that the effort to control is judged to be excessive compared with the associated risk (need not be regulated). A legislative system for radiological protection should first establish (a) what should be within the legal system and (b) what should be outside it and therefore excluded from the law and its regulations. Secondly, the system should also establish what could be exempted from some or all regulatory requirements because regulatory action is unwarranted, or is the optimized approach to protection.

(50) For human exposures, there is considerable experience in applying these concepts, although there is also considerable variation in their application, particularly with regard to naturally occurring radionuclides. More important is the fact that the distinction between exclusion and exemption is not absolute; regulatory authorities in different countries may take different decisions about whether to exempt or exclude a specific source or situation.

(51) With regard to environmental exposures, however, the Commission would expect that consideration of the use of Environmental Reference Levels would apply mainly to major nuclear installations; to major industrial or other activities generating waste or discharges with significant concentrations of radionuclides, even if volumes are small; to major activities generating large volumes of waste, such as the mining and milling of radioactive ores; or to small environmental areas that were subject to the input of radionuclides from several sources. The precise details of where a reasonable line should be drawn, however, will vary considerably from one country to another, particularly in relation to the general environmental legislation obtaining to the areas into which any radioactive materials may be released.

(52) Another issue is the manner by which compliance with any ERL might need to be demonstrated on a regular basis. The Commission believes that protection of the environment from a source should complement controls to protect the public and not add unnecessarily to its complexity. It therefore believes that, having essentially clarified the basis upon which decisions relating to protection of the environment can be made, by way of a framework relating exposure to dose, and dose to effect, for different types of organisms (the set of RAPs), the demonstration of protection of both humans and non-human species as a result of planned (normal) exposure situations might well in the furure be integrated in a relatively simple way, based solely on concentrations of radionuclides in the environment, as suggested when the concept of reference animals and plants was first raised (Pentreath, 1999) and further elaborated since then (Pentreath, 2012).

(53) This should be possible by back-calculating from the relevant site specific sets of dose constraints (for humans) and environmental reference levels (for biota) to derive a rate of discharge of both individual and total radionuclides that would not

lead to a breach of either level within a given area distal to the point of discharge. For existing and emergency situations, each case would need to be examined in its own way. Indeed, the methodology by which such back-calculation from predefined environmental dose rates for biota has already been developed (Larsson, 2008; Howard et al, 2010).

6. CONCLUSIONS

(54) The Commission has developed a comprehensive and systematic framework for human radiological protection. The advantage of such a framework approach has been that, as the needs for change to any component of the system has arisen (as in the acquisition of new scientific data, or changes in societal attitudes, or simply from experienced gained in its practical application) it has then been possible to consider what the consequences of such a change would have elsewhere within the system, and thus upon the system as a whole. Such a system would not have worked unless it was based upon a numerical framework that contained some key points of reference, particularly with respect to how best to relate exposure to dose, dose to the risks of radiation effects, and the consequences of such effects. The need now to consider, explicitly, the actual or potential consequences of radiation effects upon the natural environment, independent of any effects on human beings, under all exposure situations, has been just such a change. And in order to meet this need, the Commission has proceeded in a manner similar to that developed for human radiological protection, in that it has examined the broader sociological context in Publication 91 (ICRP, 2003), the science base in Publications 108 and 114 (ICRP, 2008; 2009), and now how it might be applied to different exposure situations.

(55) A key step in the development of the scientific framework for human protection was the development of a model then known as Reference Man, the subsequent development of which has served as a conceptual and analytical tool for many of the Commission's numeric analyses and resulting conclusions. And for humans, a substantial body of epidemiological information exists with regard to exposures and risk that, together with the Linear No Threshold (LNT) model, plus experimental animal data, allow what are generally agreed levels of 'risk' (that can serve as starting points for the optimisation of protection under different exposure situations), to be translated to dose. It is also possible to relate concentrations of radionuclides in the environment into internal and external dose rates, using radiation and tissue weighting factors. Hence, for a given set of radionuclides in the environment, regardless of their origin or quantity, one can relate that to dose, and thus to risk, and thus to the optimisation of protection of workers, patients, and the public.

(56) For other species the situation is different. Notwithstanding the fact that it is necessary to address directly the issue as to what extent the environment itself is protected for the satisfaction of many international and national legislative requirements, one also has to consider the present state of scientific knowledge, and how this can be interpreted and used, in a pragmatic and simple way, for the purposes of environmental protection. Nevertheless, notwithstanding the need for more scientific information, the Commission believes that it has been sensible and timely to draw together, in a consistent manner, existing data for a limited set of different types of organisms (the Reference Animals and Plants) to serve as a basis for an environmental protection framework. With regard to radiation effects for this set, all that can be concluded is that it is possible to discern bands of dose rates within which it is known, or suspected, that something adverse may happen to

individuals of that type of organism. These bands, or DCRLs, have therefore been identified as being rates of dose within which, if experienced or expected, one should stop and consider further what best to do. These values are not limits, and are not intended to be used in that manner.

(57) The Commission therefore believes that, given the present state of knowledge, and of ignorance, it would be prudent to use the DCRLs in the way indicated in this document for different exposure situations. In doing so, the Commission has thus extended its overall system of radiation protection, but has attempted to do so in a manner that is consistent with, and sits within, the overall framework of protection that has previously evolved for the protection of humans and which now extends to the natural environment.

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ANNEX A: PRACTICAL ASPECTS

A.1. Environmental protection legislation

(A1) Requirements in relation to environmental protection have been rapidly developing at international and regional level, and legally binding requirements flow from them to inform and influence national legislation and regulation. Of particular relevance, however, is the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (IAEA, 1997) which makes very specific reference to the environment in relation to general safety provisions, and to the safety of the management of spent fuel and radioactive waste. It is worth looking at these points in a little more detail. There is a general requirement "….*to ensure that at all stages of spent fuel management, individuals, society and the environment are adequately protected against radiological hazards*", and to "…*provide for effective protection of individuals, society and the environment, by applying at the national level suitable protective methods as approved by the regulatory body, in the framework of its national legislation which has due regard to internationally endorsed criteria and standards*".

(A2) With regard to spent fuel management, there is a requirement to "…*evaluate the likely safety impact of such a facility on individuals, society and the environment*"; and in relation to the siting of radioactive waste management facilities there is a requirement to "… *evaluate the likely safety impact of such a facility on individuals, society and the environment, taking into account possible evolution of the site conditions of disposal facilities after closure*". With regard to design and construction there are requirements to provide for "….*suitable measures to limit possible radiological impacts on individuals, society and the environment, including those from discharges or uncontrolled releases*". Reference is also made with regard to the need for environmental assessments. Thus, in relation to waste management facilities, it is necessary to ensure that: "…*before construction of a radioactive waste management facility, a systematic safety assessment and an environmental assessment appropriate to the hazard presented by the facility and covering its operating lifetime shall be carried out; in addition, before construction of a disposal facility, a systematic safety assessment and an environmental assessment for the period following closure shall be carried out and the results evaluated against the criteria established by the regulatory body*" and "… *before the operation of a radioactive waste management facility, updated and detailed versions of the safety assessment and of the environmental assessment shall be prepared when deemed necessary to complement the assessments…*".

(A3) Requirements also relate to operational matters. Thus, it is necessary to "…*take appropriate steps to ensure that during the operating lifetime of a regulated nuclear facility, in the event that an unplanned or uncontrolled release of radioactive materials into the environment occurs, appropriate corrective measures are implemented to control the release and mitigate its effects*". Communications with the public are also a necessity including the need to "…*make information on the safety of such a facility available to members of the public*" and to "… *consult*

Contracting Parties in the vicinity of such a facility, insofar as they are likely to be affected by that facility, and provide them, upon their request, with general data relating to the facility to enable them to evaluate the likely safety impact of the facility upon their territory"

(A4) More recent is the requirement for the development of environmental protection criteria, and methodology for their use and implementation, when deemed necessary by the national authorities, included in the revised Basic Safety Standards, or GSR Part 3 (IAEA, 2011). There also many other significant and relevant pieces of legislation, and these have been summarized by Copplestone (2012); some examples are given in Annex A. The NEA has also provided a more detailed overview of some relevant legislation (OECD NEA, 2007). There are also a number of European Council Directives that relate in some detail to environmental protection. Examples are the Directive on Integrated Pollution Prevention and Control (CEC, 1996), the Directive of the Conservation of Natural Habitats and of Wild Fauna and Flora (CEC, 1992), the Water Framework Directive (CEC, 2000), and the Directive 85/337/EEC on the Impact of Certain Projects on the Environment (CEC, 1985). The last of these is designed to ensure that, before consent for the development of a project is given, any project likely to have a significant effect on the environment (because of its nature, size or location) is made subject to an assessment with regard to its expected effects. Environmental impact assessments must consider humans, fauna and flora, the abiotic environment (soil, water, air), material assets, and cultural heritage, as well as the interactions amongst these factors. A study on the scope and application of 85/337/EEC, specifically in relation to geological disposal of radioactive waste, was presented at the IAEA's Conference on the Safety of Radioactive Waste Management, Córdoba, Spain, 2000 (Webster, 2000). By insisting on an environmental impact assessment for substantial projects, 'best practice' is demonstrated and enables consideration of the benefits of harmonisation of approaches in different countries.

(A5) It should also be noted that regulatory requirements for protection of the environment have often been written in terms of "*no significant adverse effect on the environment*", or have stated that substances should not enter the environment in quantities, concentrations, or under conditions, that have or may have an immediate or long-term "*harmful*" effect on the environment itself or its biological diversity. But there are also other ways in which environmental protection has been addressed (Pentreath, 2003), which may usefully be considered under the following headings.

A.1.1 Pollution control

(A6) Pollution control is usually concerned with protecting the environment *generally* from *specific* pollutants or categories of pollutants. The requirements - to take some European examples - are often couched in terms of having to take steps or measures in order to prevent *pollution of the environment* (that is to say, something that is *harmful* to the *quality of the environment* (EC 1996)) or, more explicitly, by referring to pollution as being the causing of " *... harm to man or any other living organism…*" where *harm* means "*... harm to the health of living organisms or other interference with the ecological systems of which they form a part*" (UK, 1990). Elsewhere, as for example in Canada, industrial activities may be constrained to ensure that they do not present '*unreasonable risks to the environment*' (Thompson and Chamney, 2001). Pollution control can be taken to include control over sources of chemicals from a specific practice, from a specific location, or from a specific area – such as contaminated land. Control is usually exercised by way of requiring specific and auditable actions to be undertaken, and by the setting of numerical values in relation to emissions and one or more components of the environment that are not to be exceeded (Environmental Quality Standards).

(A7) Regulations in relation to pollution control may include the need to take steps to avoid the creation of any unnecessary waste, to render any such waste as harmless as possible, and to minimise the need to dispose of, or release, any waste into the environment. They may also relate to situations where the environment has already been unacceptably contaminated and requires remediation. Management controls are therefore exercised in relation to the point of release, or to the manner in which a contaminated area is to be cleaned up. For environmental protection, various safeguarding measures or evaluations may be undertaken - often by way of the use of one or more "standards", as is already the case for radionuclides at certain sites in the USA (US DOE, 1993,1996). Such standards may be set in terms of generalised 'dose standards' for organisms, and for which methods for compliance then need to be developed and applied (Domotor et al, 2001; Higley et al, 2001). Or they could be set in terms of concentrations of radionuclides that could give rise to such dose rates.

(A8) Different numerical values may be relevant to different situations. Other approaches might be favoured for specific practices, circumstances, or locations. Much thought has been given to the development of what have become known as '*ecotoxicological*' type assessments for many chemicals. Such assessments, using models for characterising the distribution and fate of chemicals in the environment, may focus on what is considered to be the most exposed or the most 'sensitive' individuals, species, or life stages of fauna or flora in a particular environment or ecosystem (Barnthouse, 1997).

A.1.2. Safeguarding specific environmental resources

(A9) Exploitation of the environment, as in such practices as fisheries, forestry, and agriculture, takes for granted the fact that the environment will be 'damaged' in that individual animals or plants will die. Its relevance to environmental protection, however, is that the objective is usually to ensure that the practice can be carried out in a sustainable way, and although it is essentially concerned with effects on the environment at the 'population' level, it may also be concerned about the genetic 'integrity' or 'stability' of those populations. Very specific requirements may however emerge, such as the need to ensure that there is no damage done to particular areas, such as nursery/spawning grounds of fish in estuaries, shellfish rearing beds, and so on.

A.1.3. Nature conservation

(A10) In contrast, the objectives for nature conservation are usually to protect specific species, habitats, or areas from threats (including pollution) in a general sense, and are thus framed in other forms of legislation. This "nature conservation" legislation is often necessarily less precise, but has essentially stemmed from the following three, broad, requirements:

- the *conservation* needs of particular species (which may have populations in more than one habitat) or areas, where the term 'conservation' usually implies active management of a situation to achieve a particular objective and includes the term *preservation*, which usually implies the need to maintain the *status quo* absolutely, and is therefore usually applied to inanimate components of the environment;
- the *maintenance of biological diversity* ('biodiversity') which is usually construed to include biodiversity *within* species (i.e. the morphological and physiological variations to be found within a particular species), biodiversity *amongst* species (i.e. the overall number and variety of species), and the biodiversity of habitats (i.e. the number and variety of species present *in a* particular habitat and *amongst* different habitats);
- the protection of *specific habitats*, such as wetlands, heath lands, marshes, woods, and coastal areas, because of their particular importance to one or more groups of animals and plants, possibly in relation to their seasonal importance in the life history or annual cycle of that species, such as estuaries as staging posts for migratory wildfowl or other birds.

(A11) Both conservation and the maintenance of biodiversity take note of the necessity to protect the abiotic as well as the biotic components of the environment, but the concept behind habitat protection recognises the fact that *habitats* (both abiotic and biotic components) need to be protected from direct and indirect pressures, even though their specific faunal and floral assemblages may continually vary and be primarily affected by events outside the habitat. Similarly, biological diversity is not a static entity, but the aim is to ensure that it is allowed to develop without avoidable and undue human interference.

(A12) An example of the implications of all of the above is again provided by some European Directives. Two of them, in relation to particular species and habitats, collectively require that steps be taken to ensure that designated areas are maintained in, or restored to, "*favourable conservation status*" (EC, 1979, 1992). This 'status' may be differently, and explicitly, defined for each and every site in a numerical way – such as percentage changes in the numbers of certain species, ratios of different species to each other, age structures of populations of species, and so on. Similarly, a third Directive requires action to be taken to ensure "*good ecological status*" of aquatic ecosystems (EC, 2000). It will probably therefore be necessary to demonstrate in all of these cases that controllable activities would not have a detrimental effect on such factors, as variously defined for specific locations.

(A13) The more recent trend is to apply what is sometimes termed an *'ecosytem approach'* to protection of the environment. This requires that one looks at the environment (or a specific and identified part of it) as a whole and considers all of the factors that might adversely affect it, such as abstractions of materials from it; discharges of materials into it; deliberate or accidental changes to its fauna or flora; and the collective synergistic or antagonistic effects of all of these different types of pressures.

(A14) The responsibility for such collective management usually resides within a government department, which must then ensure that the individual steps taken to control individual activities (such as abstracting water, or permitting the discharge of certain chemicals) collectively achieve the overall goal. In the context of radionuclides, therefore, their presence in the environment, at sufficient concentrations, may be considered as one factor (or pressure) amongst many that need to be controlled because of their potential to frustrate the overall aims of the ecosystem approach.

(A15) Environmental assessment methods (e.g. ecological risk assessment) must therefore be capable of demonstrating whether or not such environmental objectives will be met by the proposed control over all relevant industrial activities, and of describing the level of environmental harm when effects are predicted to occur. This has usually required the development of environmental protection benchmarks (e.g. limits, criteria, standards) that are representative of trivial or "no-expected" effects on the environment against which predicted or observed environmental pressures can be compared. When actual or potential environmental values exceed these benchmarks, a quantification (with an indication of the level of uncertainty) of potential effects is needed.

(A16) It is obviously difficult, in an ecosystem approach (because of the current lack of suitable tools and assessment methodologies capable of coping with the inherent complexity of ecosystem functions and interactions) to demonstrate that the objectives are being met. Whilst accepting that such characterisation is valuable, it is thus common practice in ecological management that, in order to assess the status of a particular area, or ecosystem type, studies are made of population structures and numbers of those species that are regarded as 'typical' members of it (EC, 2005). If these are changing beyond an expected or desired range, then further studies are made to examine the underlying causes. These studies usually relate either to physical (or chemical) changes to the habitat, or to biological factors that could affect the population, such as changes in food supply or to predator/prey relationships, the consequences of which are likely to lead to early mortality, reduced reproductive success, and so on.

A.1.4. Summary of various environmental protection requirements in existing legislation

(A17) It is immediately apparent from this brief summary of the different approaches to environmental management that there are clear – and often contradictory – aspects about them. But it is also important to note that the specific requirements relating to any of them will also differ considerably. And all of these subject areas are continuing to develop at an international level. Thus the need to make evaluations of the impact of radiation on the environment, now or in the future, might arise for reasons that stem from any or all of the above environmental management requirements, but particularly in relation to pollution control and nature conservation. The practical consequence, however, is that this need may now include any of the following *objectives*, each of which would need to be expressed, and deemed 'acceptable' or otherwise, in different ways:

- *compliance* with the spirit or the letter of *trans-national* general *pollution* or *wildlife-protection obligations*;
- *compliance* with *national pollution control licensing requirements* relating to particular industrial practices or to specific sites or areas;
- *compliance* with the requirements of specific *national wildlife and habitat protection legislation; or*
- *general assurance* of the public and decision makers, whether corporate, local, regional, national, or international, of the likely environmental impact

of any actual or proposed specific practices, and demonstration of the ability to deal with any consequences of potential accidents.

(A18) For the purpose of *pollution control*, the above protection *objectives* may, in turn, require that, in addition to protection of the public, the explicit demonstration of:

- the general avoidance or minimisation of harm to the environment; or
- the ability to deal with the environment that is already harmed.

(A19) And, for the purpose of *nature conservation*, the above protection *objectives* may, in turn, require assessments to be made of:

- the likelihood of harm to individuals of particular species;
- potential or actual effects on populations of one or more species, in terms of population integrity and viability (this would also apply to environmental exploitation);
- potential or actual effects on the principal (or majority) components of a specific habitat, or at a specific place; or
- potential or actual effects at ecosystem level, within a local area or more generally, but without specific reference or preference to any particular faunal or floral type.

(A20) Common to all of them, however, is the process of having to *assess* the situation, to analyse its component parts and then, if necessary, consider the various options for *managing* whatever situations may arise. This is particularly important when attempting to understand the purpose of the environmental evaluation, because each component may need to make use of completely different approaches and interpretations. But what should also be common to both assessment and management is the basic scientific understanding, plus the means of expressing and using the relevant scientific information. This has been the basis of success for the radiological protection of humans, and therefore needs to be carefully considered with respect to protection of the environment generally. The Commission believes that, if its advice and recommendations as set out in this document are followed, then this should provide sufficient evidence with regard to protection of the environment from radiation with regard to currently known environmental legislative requirements.

A.2. The Commission's approach to protection of the environment

A.2.1. Objectives

(A21) With respect to the protection of human beings under different exposure situations, not only are the objectives clear, but they are applied to the reduction of risks to individuals, or to particular groups of individuals, rather than to the population as a whole. For environmental protection, however, the biological endpoints of most relevance are those that could lead to changes in population size or structure. Nevertheless, radiation affects individuals, and thus among the biological endpoints of interest to individuals that could have a consequence at a population level are those of:

- early mortality (leading to changes in age distribution, death rate, and population density);
- some forms of morbidity (that could reduce "fitness" of the individuals, making it more difficult for them to survive in a natural environment);

- impairment of reproductive capacity by either reduced fertility or fecundity (affecting birth rate, age distribution, number, and density); and
- the induction of chromosomal damage.

(A22) While some of these endpoints, such as mortality or reduced reproductive capacity, could directly affect the population growth rate or structure, the consequences at the population level of other endpoints, such as morbidity and some forms of chromosomal damage, are either not fully understood or are simply unknown. The grouping of effects into those that are stochastic, or not (as in the case of human radiation protection) is therefore of little value; it is the broader biological consequence that is of interest, particularly at the population level. And there cannot be any effect at the population level if no effects occur in any of the individuals of that population. (But the inverse is not always the case, because detectable effects in some members of a population would not necessarily have a consequence for the population as a whole.)

(A23) In order to meet the Commission's overall objective, therefore, it is necessary to have a framework that would ideally include the following elements:

- clearly stated local environmental protection objectives that relate to a specific environmental exposure situation;
- a knowledge of the effects of radiation, at different dose rates, to different tissues, organs and life stages of the relevant biota relating to such objectives;
- estimates of the dose likely to be received by the relevant biota, under those environmental exposure situations, in terms of the tissues, organs, and life stages most likely to be at risk with regard to the relevant biological endpoints;
- the number of individuals, or fraction of the relevant population, that would be likely to receive such dose rates, and when; and
- the actions, or choice of actions, that could be taken to optimize the level of protection of the relevant biota relating to radiation exposure, bearing in mind other possible threats to the same population.

(A24) Quite clearly, apart from the first, this is collectively a daunting and virtually impossible task. The range of biota is immense, and the effects of radiation on them, at different stages in their life cycles, are not only unknown but unknowable. Nevertheless the Commission believes that there is sufficient information to provide basic guidance and advice on this issue, providing that it is well structured, and logically and scientifically linked to the framework, and system, that has been developed for the protection of human beings.

(A25) Because of the immense variety of biota, and their presumed response to radiation, any credible system needs to have some key points of reference which provide some form of auditable trail that links the basic elements of the framework together – or at least could do so if further data were forthcoming, and it is feasible to obtain such data. The advantage of such a systematic approach is that, as the needs for change to any component of the system arise (as in the acquisition of new scientific data, or changes in societal attitudes, or simply from experience gained in its practical application) it is then possible to consider what the consequences of such a change may be elsewhere within the system, and upon the system as a whole. Such an approach would not work unless it was based on a numerical framework that contained some key points of reference.

A.2.2. Reference Animals and Plants

(A26) In the case of human radiological protection, the Commission's approach to such issues has been greatly assisted by the development of anatomical and physiological reference models (ICRP, 2002). It therefore concluded that a similar approach would be of value as a basis for developing further advice and guidance for the protection of other species. The Commission therefore developed a small set of *Reference Animals and Plants* (Pentreath, 2005), plus their relevant databases, for a few types of organisms that are typical of the major environments. The Reference Animals and Plants can therefore be considered as hypothetical entities, with certain assumed basic biological characteristics of a particular type of animal or plant, as described to the generality of the taxonomic level of Family - the highest taxonomic level at which the biological features of an animal or plant of relevance to the effects of radiation can be assumed to be relatively constant. They are essentially reference models and not, therefore, *necessarily*, the direct objects of protection themselves (although they could be) but, by serving as points of reference, they provide a basis upon which some management decisions could be made.

(A27) A Reference Animal and Plant (RAP) is therefore defined as "…*a hypothetical entity, with the assumed basic characteristics of a specific type of animal or plant, as described to the generality of the taxonomic level of Family, with defined anatomical, physiological, and life-history properties, that can be used for the purposes of relating exposure to dose, and dose to effects, for that type of living organism*".

(A28) The set of RAPs, and the criteria for their selection, were set out in ICRP *108* (ICRP, 2008). Essentially, the following points were considered, including the fact that there was a reasonable amount of radiobiological information already available on them, and that they were amenable to future research, in order to obtain the necessary missing or imprecise data. All of them were considered to be typical representative fauna or flora of particular ecosystems, with a wide geographic variation. It was also considered that they were likely to be exposed to radiation from a range of radionuclides in a given situation, both as a result of bioaccumulation and the nature of their surroundings, and because of their overall lifespan, lifecycle and general biology. A further consideration was that their life-cycles were likely to be of some relevance for evaluating total dose or dose-rate, and of producing different types of dose-effect responses; plus the fact that there was a reasonable chance of being able to identify any effects at the level of the individual organism that could be related to radiation exposure (bacteria and unicellular organisms were excluded because of their high resistance to radiation). It was also considered that their taxonomic Family names had some form of public or political resonance, so that both decision makers and the general public at large were likely to know what these organisms actually are, in common language.

(A29) A 'set' of Reference Animals and Plants was therefore identified, but there is nothing sacrosanct about the set. They were all considered to be organisms that are 'typical' of different environments, in the sense that one might expect to find them there: *earthworms* in soil, *ducks* in estuaries, *flatfish*, *crabs* and *brown seaweed* in coastal waters, *trout* in rivers and lakes, *frogs* in marshland, *deer*, *pine trees*, *wild grass* and *bees* across much of the temperate part of the globe, and small mammals such as the *rat* being virtually ubiquitous. The set is also essentially one of 'wild' animals and plants rather than domesticated ones, although many of them are 'farmed' in some countries in one way or another. With regard to typical farm animals - primarily large mammals that live essentially in a human environment - it was considered that the use of the human animal itself was probably sufficient for such managed environmental or ecological situations.

(A30) This publication also included reference data sets (*Dose Conversion Factors*) by which concentrations of radionuclides inside or outside the RAPs could be converted into dose rates at an approximate whole body level, and a further publication (ICRP *114*, 2011) has provided reference data sets (*Concentration Ratios*) by which concentrations in the ambient media, under equilibrium conditions, can be related to whole body concentrations for the relevant RAPs.

A.2.3. Derived Consideration Reference Levels

(A31) A review of all of the known data on the effects of radiation relevant to the RAPs has also been made, and the information summarised (Appendix 1) in terms of increasing orders of magnitude of dose (ICRP *108*, 2008). From these compilations, a band of dose rate for each RAP, spanning one order of magnitude, was selected for the purposes of providing a starting point for considering what action, if any, should be carried out. These bands are called *Derived Consideration Reference Levels* (DCRLs). A DCRL is "*......a band of dose rate within which there is some chance of deleterious effect from ionising radiation occurring to individuals of that type of Reference Animal or Plant*". The values themselves are very similar to those which have recently been derived by other reviews and analyses of radiation effects data from a wider range of biota (Larsson, 2012).

(A32) When considered together with other relevant information, particularly the number of individuals likely to be exposed to such dose rates, and thus over what area, DCRLs can be used as points of reference to optimise the level of effort expended on environmental protection, dependent on the overall management objectives, the exposure situation, the actual fauna and flora present, and the fraction of the population thus exposed. The DCRLs have been defined in terms of bands of dose rates relevant to each RAP. Before discussing how these values should be applied, however, there is one further aspect of the framework that needs to be explained.

A.2.4. Representative Organisms

(A33) The development and use of Reference Animals and Plants can be considered as being similar to the approach that has been developed over many years as the basis for protecting human beings. It is therefore useful first to explain this approach with regard to human beings. For human protection, Reference Males and Females have been used to establish equivalent doses, and a Reference Person to establish effective doses, from which dose constraints, dose limits, and reference levels are derived for application to the different types of exposure situations. And as is the case for human protection, where the Reference Male and Female and the sex-averaged Reference Person could be used in hypothetical exposure situations, compliance with the ICRP's advice and Recommendations is usually achieved by way of a Representative Person. The Representative Person more accurately reflects the exposure situation of members of the public in actual or anticipated exposure situations - even though many of the numerical values derived from the Reference individuals are used to calculate the exposure of the Representative Person.

(A34) With regard to radionuclides in the environment, the relevant exposure category is that of the public – a rather varied and heterogeneous mixture of people who could be of any age, build, state of health, and so on. For radiological protection purposes, a member of the public is defined as any individual who receives an exposure that is neither occupational nor medical. In general, each source will result in a distribution of doses over many individuals. In the past, the ICRP has used the 'critical group' concept to characterize individuals receiving a dose that is representative of the more highly exposed persons in the population, and dose restrictions have been applied to the mean dose in the appropriate critical group. A considerable body of experience has been gained in the application of the critical group concept, and there have also been developments in the techniques used to assess doses to members of the public, particularly in the use of probabilistic techniques. The ICRP therefore now recommends the use of the 'Representative Person' for the purpose of radiological protection of the public (ICRP *101*, 2006). The Representative Person, of course, is not the same as the Reference Males and Females or Reference Person used to derive the quantities used for radiation protection.

(A35) The Representative Person may be real (as in actual exposure situations) or hypothetical (for the purpose of modelling or the making of estimations), but the habits used (e.g., consumption of foodstuffs, location, use of local resources) needs to be typical of those of a small number of individuals who are most highly exposed. Calculations based on Representative Persons are therefore made to demonstrate compliance or otherwise with the various dose constraints, dose limits, and reference levels appropriate to the relevant exposure situation. The same applies to the environment, and thus more precisely defined animals or plants should be used to serve as *Representative Organisms* with respect to specific sites and specific circumstances. But in view of the fact that the RAPs are defined as being generalised to the taxonomic level of Family, it should be possible for thousands of species to be used as examples that would generally be compliant with the assumptions made for the twelve RAPs.

(A36) With respect to the protection of the biota, however, it should be noted that it may not be the most exposed organisms that are relevant; these may be more resistant to the effects of radiation than others less exposed. The objects of protection are therefore more likely to be identified by the underlying need to protect some specific aspect of the environment. So, for the purposes of protecting the environment, the Commission recommends the use of Representative Organisms to represent "*...the actual objects of protection in the specific circumstance under consideration*". Such organisms will be the actual animals and plants identified for evaluation in each circumstance and these, too, may be hypothetical or real, depending on the specific objectives of the evaluation. Their identification will arise either from specific legal requirements aimed at protecting them for one reason or another, or from more general requirements to protect the local habitats or ecosystems. They may be very similar to, or even congruent with, one or more RAPs. Where this is not the case, then attempts should be made to consider to what extent the Representative Organisms differ from the nearest RAP, in terms of known radiation effects upon it, basic biology, radiation dosimetry, and pathways of exposure. Some advice on these issues has already been provided in ICRP 108 (ICRP, 2008).

(A37) The choice of Representative Organism(s) will obviously depend on the environmental protection framework within which the potential impact of radionuclides is being evaluated. Thus the legislation may require an assessment of the impact of radiation with respect to a particular (defined) species, a mixture of such species, or simply to different types of animals and plants. Examples of such types of legislation are the protection of particular species of animals (particularly of birds); the protection of particular habitats that are important for the feeding/resting/breeding of specific types of birds (typically ducks and geese) in their ‘transnational boundary’ annual life cycle; and the protection of habitats because of their mixtures of species, where the species are not themselves identified (such as wetlands).

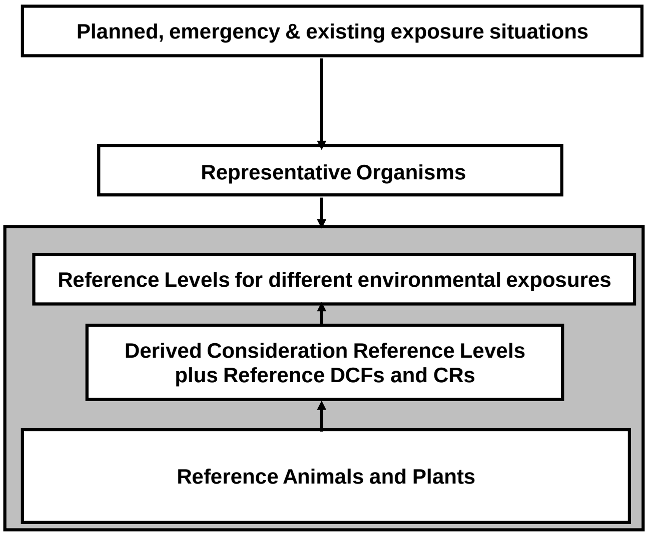

Fig A.1. Overall framework for relating different sets of information with respect to different exposure situations (DCFs are Dose Conversion Factors; CRs are Concentration Ratios).

(A38) The overall relationship amongst these components of the ICRP’s framework for protection of the environment is set out in Fig. A.1. Before discussing in more detail how the Representative Organisms may be chosen, however, it is first necessary to consider the different types of exposure situations to which they would be applied.

A.3. Application to the different types of exposure situations

A.3.1. Basic assumptions

(A39) The Commission now considers that it is useful to consider three different types of exposure situations: planned, emergency, and existing. The set of DCRLs is thus intended to be used in relation to any exposure situation. In this respect, a ‘banded’ approach (as opposed to simply using a single value, or ‘line’) was deliberately adopted for the DCRLs because it is possible to use an order of magnitude difference in what one might be trying to achieve, depending on whether one is trying to avoid being in that situation, as with planned exposures, as opposed to finding oneself in that situation, as with possible existing or emergency situations.

Dose rates observed or estimated as falling within the dose range for a particular type of animal or plant (RAP), across a population of that type of RAP (and for which population sizes are given in ICRP 108) are considered worthy of further consideration in terms of what 'management' action might be taken.

A.3.2. Planned exposure situations

(A40) Interest in the potential environmental impact of radionuclides released into the environment is only likely to be of concern in relation to large nuclear facilities, and for such facilities an evaluation of any potential impact may be required in order to meet legislation with regard to the protection of species, habitats, or ecosystems. With regard to planned exposure situations, such as routine discharges from nuclear power stations, waste facilities, and so on, one might therefore need to:

- demonstrate compliance with international obligations;
- demonstrate compliance with particular environmentally-specific obligations;
- or satisfy the needs of pollution control;
- or satisfy particular interest groups (eg commercial or leisure fisheries);
- or demonstrate how this would fit into the needs of the 'ecosystem' approach;
- or just demonstrate to the local community that such discharges are 'safe' for the environment.

(A41) And with regard to future normal planned exposure situations, one might need to demonstrate compliance with what would be required via an Environmental Impact Assessment (EIA), or required via various international and international obligations or legislation.

(A42) In selecting the Representative Organisms in relation to that particular source, a number of questions will therefore arise, such as the following. What is the principal reason for the assessment being made, (such as the need to comply with some form of existing legislation)? Does the assessment relate to actual species, or simply to generalised animal or plant types? Are the discharges already taking place, or are these planned future discharges? What is the area or zone within which such dose rates do (or are expected) to occur? Are there biological aspects that need to be especially considered, such as seasonality (for example breeding), stages in the life cycle? Over what time period are such dose rates expected to last? What degree of precaution is considered necessary, for various purposes? (For example in relation to the importance of the necessity of the assessment being made and in relation to the amount of information that exists in order to derive the DCRL for that type of organism.)

(A43) In considering the actual or potential impacts of releases from a single source, one would obviously need to have regard to other sources of radionuclides into the same area, or of discharges in the past, or of potential discharges in the future. The Commission therefore recommends that *an Environmental Reference Level* (ERL) be established for a specific source, at a level below the relevant DCRL for the relevant RAP or RAPs, for use in the optimization of protection. It may also be necessary to allow for the fact that exposure of the same biota may occur at other stages in their life cycle, or on migration, or when using other feeding ground and so on, in other areas where radionuclides are present.

(A44) One issue that is likely to arise more than any other is the extent to which one should be 'precautionary', for one reason or another. The reasons could be because of the current lack of data at lower dose rates for many of the RAP types, or because of other uncertainties in the data or their derivation. As yet, the DCRLs make no allowance for RBE, a subject still being considered by the Commission (Higley et al 2012). Equally, a degree of precaution may be considered necessary because of the importance of the site or habitat, or the importance of the actual species present or likely to be present. Such precautionary-based decisions are expected. But if such precautionary measures are to be included in the decision making process (with regard to what the actual dose rate bandings should be, in comparison with the DCL levels), then they should also be separately specified.

(A45) Care should also be taken in using ERL values to make decisions with regard to populations of animals or plants, as opposed to small groups of individuals. It is often not possible to say with any confidence that measures to protect individual organisms would also, necessarily, protect the population. Population modelling approaches demonstrate that the linkage between radiation effects in the individuals and in the population is very complex, and may be dependent on factors other than the radiation doses and the dose-response relationships. Some rough guidance may nevertheless be helpful, as in attempting to relate the bands of DCRLs to a spatial area over which they are considered to apply. The data in Table 1 of Chapter 2 in ICRP 108 (Annex 4) could be used for this purpose.

A.3.3. Existing exposure situations

(A46) Exposure situations that already exist are those situations upon which a decision on what to do about them may need to be made. In an environmental context, such situations will usually involve areas that have been contaminated either by actions (possibly deliberate) in the distant past; or as a result of accidents. People will usually have been removed from the site; or the site may be one that is not normally occupied by people. The question may then arise: what about the 'health' or 'well-being' of the biota within the contaminated zone?

(A47) Having established the objectives of any action, the initial assessment in such a situation will clearly be that of characterising the 'boundary conditions' as discussed by Pentreath (2012). These will include the sources of exposure within the site; its actual fauna and flora; the levels of dose rate estimated to be received by the biota (the Representative Organisms); and a comparison of these with the relevant DCRLs. A clear view then needs to be reached as to what management actions may be required, and why, together with an assurance that the actions will do more good than harm, and that social and economic factors have been taken into account.

(A48) The principal reasons for any action being considered may be varied. In the aftermath of an accident, public concern may well centre on animal welfare, particularly where domestic or farmed animals are concerned. Animal welfare may suffer simply because of the sudden withdrawal of human care, but it will be important to differentiate between these factors and other factors which could result directly from exposure to radiation. Differentiating between these two aspects may be important in communicating with the public. There may also be reasonable pressure to investigate the need, or feasibility, of restoring long-standing contaminated areas from a biodiversity or ecosystem restoration point of view.

(A49) In all of these cases it is necessary to have a clear starting point. In the first instance, it will not be necessary to postulate what the ecosystem might be, its dominant biota, characteristics, and so on. The ecosystem exists and can be examined directly. Assuming that the dose rates received by the Representative Organisms are in excess of the relevant DCRLs, the Commission recommends that the level of ambition for optimization would be to reduce exposures to levels that are within the DCRL band, fully considering the radiological and non-radiological costs and benefits of so doing. If dose rates are within the band, the Commission considers that the optimization principle should nevertheless continue to be applied, assuming that the costs and benefits are such that further efforts are warranted. Thus, in the case of existing exposure situations, the DCRL levels are to be used as the criteria for restricting environmental exposures, in the implementation of optimization, just as reference levels are used for restricting individual exposures for human protection in such situations.

A.3.4. Emergency exposure situations

(A50) Emergency exposure situations include consideration of emergency preparedness and emergency response. Emergency preparedness should include planning for the implementation of optimized protection strategies which have the purpose of preventing or reducing exposures, should the emergency occur. Emergency exposure situations can be taken to include exposure situations resulting from a variety of causes including planned exposures going wrong and deliberately malicious acts (such as dirty bombs). With regard to the former, an Environmental Impact Assessment (EIA) will usually require some form of evaluation of what environmental impact a major accident could have. But all emergency situations are likely to have various characteristics in common:

- they will require immediate action and may also require longer term action;
- they will almost always involve some form of environmental contamination; and
- they will also likely involve other chemicals/hazards and thus there will be a need to prioritise which of these to deal with first.

(A51) For emergency exposure situations, it is therefore necessary to consider the environmental consequences of possible accidents at a site, as well as the planning for emergency preparedness, communications with stakeholders in relation to such situations, and the intended response, should an event occur, as indicated in A1 to A3. There may be a need to consider the environmental impact of a severe accident depending upon where a specific source was to be located; for example comparing the siting of a reactor on a river bank, on an estuary, or on the nearby coast. Alternatively there may be a need to consider independently the impact of accidental releases (such as to the atmosphere, or into a river or estuary) from a defined site on different surrounding environmental areas such as woodlands, agricultural land, nearby fishery breeding grounds in an estuary and so on. Optimization at the planning stage will therefore involve examination of different protective strategies. In such circumstances concern will be focused on the potential for severe effects on the local biological community, and thus a scale of effects that are not reflected in the DCRL bands. Thus to facilitate this optimization, the Commission recommends that an appropriate band of dose rates related to severe effects (at least one or more orders of magnitude above the relevant DCRL) be identified for the relevant RAPs, depending on the specific features of the biota exposed and the spatial and temporal aspects of the expected situation. These might typically be dose rates likely to result in total reproductive failure.

(A52) Dose-effect tables for the Reference Animal and Plants, across a wide range of dose rates, are presented in Annex 4, and these should be used for selecting the appropriate levels. Such levels are more appropriate benchmarks for emergency situations, and will form a pattern of information for differentiating amongst various protective strategies for emergency scenarios. They may also be particularly useful in communicating with stakeholders on the possible effects and implications of releases of large quantities of radionuclides into the environment as events unfold. The Commission notes that, in the chemical hazard analysis situation, such values are sometimes termed 'severe effect levels'.

(A53) With regard to responding to an actual event, consideration of environmental protection is unlikely to be an immediate priority. Nevertheless, consideration should be given to the environmental consequences of the possible options available for maximizing human protection. But human exposures may be minimal, or readily controlled. The options available for mitigation are usually very limited with respect to non-human biota, but are not zero. Consideration should be given to the different environmental radiological consequences of either dispersing the contaminated medium further by physical means, or of restricting its dispersion (such as by using chemicals to precipitate radionuclides from a water column). The values used in emergency planning, generally one or more orders of magnitude above the DCRL, will also be useful in communicating the implications of the situation to stakeholders, particularly in relation to environmental conditions where humans have been removed from the area, and food chains leading to human exposure have been severed. Once the decision has been made that the *emergency exposure situation* is over, the Commission recommends that the approach for protection of the environment for *existing exposure situations* be applied.

A.3.5 Pathways of exposure of biota in relation to the different types of exposure situations

(A54) One feature common to all three types of exposure situations is the necessity to consider the pathways by which the local biota may be exposed. For existing exposure situations this may well be easy to determine, as will be the mixture of different radionuclides at the site. For planning purposes, however, and particularly in relation to planning for emergencies, in which modelling techniques will be used, all possibilities should be examined. Reference should first be made to ICRP 114 (2011), in which the following pathways were considered.

- Inhalation of (re)suspended contaminated particles or gaseous radionuclides.

  This pathway is relevant for terrestrial animals and aquatic birds, mammals and heptofauna. Respired or otherwise volatile forms of radionuclides may also contribute to the exposure of plants via gaseous exchange.

- Contamination of fur, feathers, skin and vegetation surfaces.

  This has both an external exposure component: radionuclides on or near the epidermis cause irradiation of living cells beneath, and an internal exposure component as contaminants are ingested and incorporated into the body of the animal. This pathway is clearly of considerable relevance to terrestrial fauna in accident situations.

- Ingestion of lower trophic level plants and animals.

  This leads to direct irradiation of the digestive tract and internal exposure if the radionuclide becomes assimilated and distributed within the animal's body.

- Direct uptake from the water column.

  This pathway is relevant to truly aquatic organisms (e.g. fish, molluscs, crustaceans, macrolagae and aquatic macrophytes), leading to both direct irradiation of, for example, the gills or respiratory system, and internal exposure if the radionuclide becomes assimilated and distributed within the animal's body.

- Ingestion of contaminated water.

  For plants the corresponding pathway relates to root uptake of water.

- External exposure.

  This essentially occurs from exposure to γ-irradiation and to a much lesser extent β-irradiation, originating from radionuclides present in the organism's habitat. For microscopic organisms, irradiation from α-particles is also possible. The configuration of the source relative to the target clearly depends on the organism's ecological characteristics and habitat. A benthic dwelling fish will, for example, be exposed to radiation from radionuclides present in the water column and deposited sediments, whereas a pelagic fish may only be exposed to the former.

(A55) It should also be noted that the data sets in ICRP 114 are appropriate under equilibrium or quasi-equilibrium conditions and are primarily applicable to planned and existing exposure situations, and might be considered less suitable for evolving emergency exposure situations. They would, however, serve to indicate potential exposures and, in cases where the most radiosensitive stages in the life cycle are concerned (eggs, larvae, foetus) the biological lifetimes of such stages (eg a bird's egg hatching in 30 days) will also place constraints in relation to estimating dose over relatively short time periods.

A.4. Choosing Representative Organisms and their relationships to Reference Animals and Plants

A.4.1 Basic assumptions

(A56) Although the *actual* animals and plants used to compare with the set of Reference Animal and Plant data on DCRLs in *actual* exposure situations are Representative Organisms, they can be the same as the RAPs, because the RAPs were selected with such a potential application in mind as part of their selection criteria. This is similar to the case for the Reference Person and the Representative Individual: the former can often be assumed to have virtually all of the properties of the latter, and considerable variation can be tolerated because of the inherent uncertainties in the knowledge base. Thus the same numerical values can therefore usually be used for both (as for dosimetry, and the evaluation of effects), the major variable relevant to the Representative Person being the conditions of exposure.

(A57) One area in which selection might be more difficult is that involving the need to meet environmental protection criteria that relate to protecting the entire habitat, or ecosystem as a whole, as is often the case with regard to nature conservation. These issues, and the relevant role of different biological effects that are relevant to radiation exposure, have been discussed further by Larsson (2012). The same difficulties apply to all aspects of managing such habitats, and it is customary to break down the problem as illustrated in Fig. A.2.

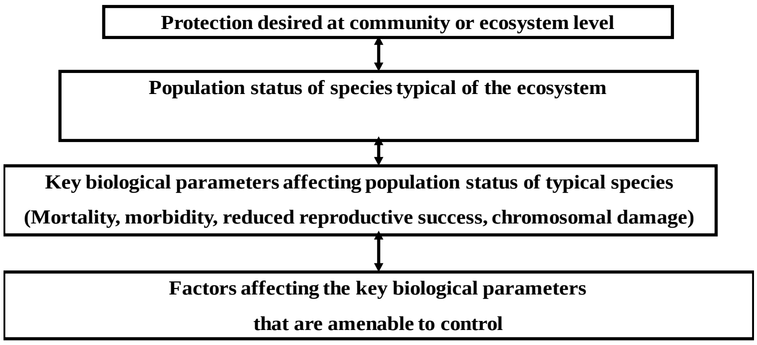

Fig. A.2. Relationships between the aims of protecting a community or ecosystem by way of focussing on the key species and the factors affecting their key biological parameters.

(A58) In practice, as noted in Section 2.4, because of the impossibility of being able to understand all of the numerical components of an ecosystem, sub-sets of 'typical' organisms are used as indicators of the whole. Thus the use of Representative Organisms, and their link to the set of RAPs, as shown in Figure A.3., should therefore prove to be sufficient. In fact, a large number of potential Representative Organisms have been identified in relation to satisfying the requirements of nature conservation, and applied in relation to different ecological sites (EA, 2009).

(A59) Nevertheless, because of the vast variety of potential Representative Organisms, there may be considerable differences between the chosen or necessary Representative Organisms and the set of twelve RAPs. Such differences will fall into one of four areas. If the set of RAPs does not include all or any of the animal or plant types requiring protection then, compared with the RAPs, which are, by definition, a *reference* set, there will be differences from the reference set in terms of:

- their biology, such as life span, or life cycle;
- their means of exposure to different radionuclides, or the times and places at which different stages in their life cycles might be exposed;
- their dosimetry, because of size, shape, or location, and

- their response to radiation at similar rates of (or total) dose.

Such differences were considered in the original Reference Animal and Plant document (ICRP 2008) and are briefly discussed below.

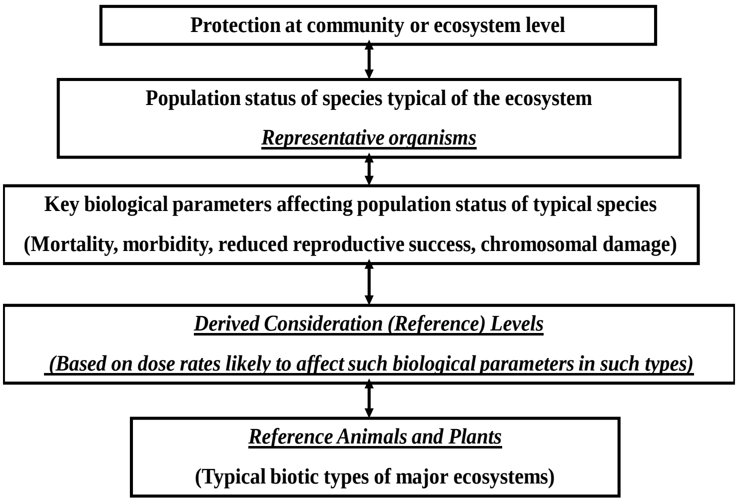

Fig. A.3. Relationships between the aims of protecting a community or ecosystem and the use of Representative organism and RAPs.

A.4.2. Differences in Biology

(A60) The Reference Animals and Plants have to be considered merely as points of reference. It is simply not possible to cater for all of the biotic types in which environmental protection interests may be expressed, and there will clearly be situations in which the biotic objects of interest will be different from those of the RAPs. Such difference could be relatively small, such as differences in the time span of a particular stage in the life cycle, or in overall life span. In other cases, differences in biology could make large differences to estimates of exposure to certain radionuclides via different pathways. Reference to the background information in Appendix A of ICRP 108 (ICRP, 2008) may therefore be of some value in considering to what extent the application of this approach to other types of animals and plants would make a significant difference, simply on the basis of differences in their basic biology. One way in which differences from the set of twelve RAPs would obviously make a difference, however, is that of shape and size, and thus with regard to estimates of dose received.

A.4.3. Differences in Exposure situations

(A61) The set of Reference Animals and Plants have been chosen to represent organisms that are typical of the major habitats, and should be relevant to any exposure situation. The manner by which the relationships between exposure and dose are calculated will, however, be dependent upon a number of factors. In many cases, as in planned exposure situations where actual releases are taking place, or in some existing exposure situations, the most obvious way of estimating doses is that by way of the *direct measurement* of the concentrations of radionuclides within the tissues of, and external to, the relevant organism. The Commission has now provided a set of Concentration Ratios for the Reference Animals and Plants (ICRP 2009).

(A62) Another facet of relevance is what constitutes a population, and the fraction of the population receiving relevant levels of dose. A reference set of population sizes was also provided in ICRP 108 (ICRP, 2008) and is given here in Annex 3.

A.4.4. Differences in Radiation Dosimetry

(A63) Issues relating to differences in dosimetry are more easily addressed. There are several aspects of the extrapolation and interpolation of the basic dosimetry models used here for the Reference Animals and Plants to other biota, including shape, size, and location. With regard to shape, matters have been greatly simplified by the use of solid spheres and ellipsoids, although it is recognised that such shapes may not readily extrapolate to some forms of organism. Nevertheless, some flexibility is possible.

(A64) The RAPs represent a wide range of ecosystems, habitats, masses and shapes, and allow the estimation of a wide range of dose rates to biota caused by radionuclides in the environment to be made. But the variety of the flora and fauna in the natural world is enormous. An examination of the relevant factors is examined in detail in Annex E, particularly in relation to shape and size, and it is easy to draw some general conclusions from them.

(A65) For external exposure, the DCFs decrease with the size of the animal due to the increasing self-shielding effect. The differences in DCFs for external exposure are more pronounced for low energy emitters, because of the effect of self-shielding.

(A66) For internal exposure to γ-emitters, DCFs increase in proportion to the mass of the organism due to the higher absorbed fractions, the dependence being more pronounced for high-energy photon emitters (e.g. ^{137}Cs/^{137m}Ba). For α and β-emitters the DCFs for internal exposure are to some extent size-independent if it is assumed that they are evenly distributed within an organism, which is unlikely to be the case.

(A67) The influence of the shape of the RAPs on both external and internal exposure is relatively small. For a given mass and energy, the external exposure is highest for a shape with the lowest surface–volume-ratio, whereas external exposure increases with increasing surface-volume ratio.

A.4.5 Differences in Radiation effects

(A68) In contrast to dosimetry, it is not currently possible to provide recommendations as to how to perform extrapolations that have general applicability in relation to radiation effects, and thus each case has to be carefully considered on its own merits. Due to the relative paucity of information, the main cases for extrapolations, and challenges for methodological development, include the following. There are clearly issues with regard to extrapolating from high acute doses and dose rates of low LET γ- and X-rays to lower doses accumulated at lower dose rates. In the radiobiological and radioecological literature, the qualifiers "low-level", "chronic", "higher", "acute" and so on are often used without any definition.

But a radiation exposure lasting several days may be effectively "chronic" for a short-lived organism, and yet effectively "acute" for a long-lived organism. Unfortunately, there are very few data that relate directly to the chronic, low-level irradiation conditions of relevance for animals and plants in the wild i.e. exposures at dose rates of 0.1 to 1 mGy day^{-1} over the life span of the organisms, and the response endpoints most commonly assessed after acute, high dose, irradiation are not those that are relevant in such situations.

(A69) Although the information does not cover all taxa to the same depth, there is clear evidence that there are substantial variations in the radiosensitivity of organisms both within, and between taxonomic groups; this differential sensitivity also extends to different stages of the life cycle for any given organism. Possibly, extrapolation becomes easier the more closely related organisms are, and the more similar the effects endpoints considered for the relevant stage in the life cycle (Garnier –Laplace et al., 2004).

(A70) Extrapolation of knowledge, and characteristics of effects, in the individual organism to possible impacts at the population and community levels is an issue that has to be studied further.. This will also, in many cases, involve the extrapolation from laboratory conditions (where most experimental information originates) to field conditions (where populations interact with the physical environment as well as with other organisms). Interactions at community and ecosystem level can be particularly complex (Brechignac, 2003; Doi, 2004).

A.4.6 Existing data sets for different natural environments

(A71) The steps necessary to create a wide range of *representative organisms* have already been taken by way of the concept of various 'reference organisms' that have already been defined, as in the FASSET programme or in the various 'screening' techniques developed for application to different sites or exposure situations (Larsson, 2004). These organisms should now perhaps be referred to as 'representative organisms'. Of course, in some countries, these 'representative organisms' have never been developed at all, and thus the ICRP RAPs could be used as 'default' *representative organisms*, as some are in FASSET, because animals and plants similar to the RAP types are likely to occur in most exposure situations around the world.

A.5. Implementation and application

A.5.1. General context

(A72) The need to make evaluations of the impact of radiation on the environment, now or in the future, will arise for reasons that stem from any or all of the various environmental management requirements discussed in A.1, but probably particularly in relation to pollution control and nature conservation, or under the legally prescribed terms of an Environmental Impact Assessment. The practical consequence, however, is that this need may now be considered to include any of a number of objectives, each of which might need to be expressed, and deemed 'acceptable' or otherwise, in different ways (Pentreath, 2003). These might include a wide range of necessities, from compliance with the requirements of specific national wildlife and habitat protection legislation to providing assuring to the public or their elected or otherwise appointed representatives.

(A73) Common to all of them, however, is the process of having to assess the situation, to analyse its component parts and then, if necessary, consider the various options for managing whatever situations may arise. This is particularly important when attempting to understand the purpose of the environmental evaluation, because each component may need to make use of completely different approaches and interpretations. But what should be common to both assessment and management is the basic scientific understanding, plus the means of expressing and using the relevant scientific information. This has been the basis for the general acceptance of the system for radiological protection of humans, and therefore needs to be carefully considered with respect to protection of the environment generally.

(A74) For the purpose of pollution control, the above protection objectives may, in turn, require the explicit demonstration of the avoidance or minimisation generally of harm to the environment, or the ability to deal with the environment that is already deemed to have been harmed.

(A75) And, for the purpose of nature conservation, the above protection objectives may, in turn, require assessments to be made of the likelihood of harm to individuals of particular species; potential or actual effects on populations of one or more species, in terms of population integrity and viability (this would also apply to environmental exploitation); potential or actual effects on the principal (or majority) components of a specific habitat, or at a specific place; or potential or actual effects at ecosystem level, within a local area or more generally, but without specific reference or preference to any particular faunal or floral type. There may even be other considerations, as where the mere presence of radionuclides, "contaminating" an area, may be of concern to certain individuals or sectors of the public for ethical, moral, or social reasons (IAEA, 2002).

(A76) In order to make an evaluation of the effects of radiation on the environment itself with respect to any particular situation or activity, there are clearly several factors to consider, including the radionuclides of interest, their sources, their rates of introduction, and their environmental distribution and fate. This basic information is also required in order to protect the general public. Many numerical models therefore already exist that can be applied to different activities, situations, and ecosystems. However, for environmental protection, other information is necessary, such as the potential exposure to radiation of the fauna and flora within the area of radionuclide distribution; plus the likely consequences for them, in terms of radiation effects. Of these two, addressing the former should not be too difficult, the nature of the problem having much in common with the environmental information needed for human radiation protection. The latter, however, is more difficult, and the term 'consequences' is far more open-ended than it is for human protection; many other factors therefore need to be considered, not least the original objectives of the assessment.

(A77) The consequences may need to be evaluated with respect to individual animals and plants, depending on the legal framework within which action is being considered, but undoubtedly the major requirement will be the need to make evaluations at the population or ecosystem level. Radiation effects on higher levels of biological organisation (e.g., populations and ecosystems) occur only if individual organisms are affected, and radiation effects' data have generally been obtained for individuals rather than for higher levels of organisation. In the natural environment the situation can become very complex because of the interactions between each individual and its surrounding ecosystem. The effects can also be modified by the presence of other environmental stressors or by combined effects related to the presence of other pollutants, and by interactions between different trophic levels. Because radiation effects at the population level – or higher – are mediated via effects on individuals of that population, it therefore seems appropriate to focus on radiation effects on the individual for the purpose of developing a framework of radiological assessment that can be generally applied to environmental issues. This approach is consistent with many of the existing assessment methods for non-radiological environmental contaminants. It is also essential in order to consider how effects such as reduced reproductive success can be interpreted in the context of the normal biology of different types of plants and animals. Even the concept of what constitutes a 'population' differs amongst the various 'types' of Reference Animals and Plants.

(A78) It also has to be recognized that, in many cases, much more specific data on local animals and plants may already be available with respect to specific sites; or that data are often required for organisms that are more relevant in other respects, such as their ecological importance at a local level, but the data sets will always be limited because of the sheer impracticality of ever deriving some of the required information – such as that relating to radiation effects.

(A79) And in some situations, direct measurement may not be desirable or feasible. In such cases, therefore, it will be necessary to *calculate* the concentration of the radionuclides within the tissues of, or external to, the organism by way of k_d values, transfer and concentration factor values. Some of these values already exist, particularly for external exposure, because of the modelling that has been done to estimate the exposure of humans or of their food chains, under such exposure situations. But this is an area where there is considerable potential for large differences in numerical values being used, which could well introduce far greater variability than that inherent in extrapolating and interpolating the dosimetry.

A.5.2. Evaluations

(A80) The principal components of the system of radiological protection with regard to any evaluation relating to the management of radiation in the environment, with respect to both the public and non-human species, can be summarized as follows.

- A characterization of the possible exposure situations where radiation exposure may occur (planned, emergency, and existing exposure situations).
- A precise formulation of the principles of protection: justification, optimization of protection, and application of dose limits to humans in planned exposure situations.
- An identification of the exposed environments, and of the pathways leading to the exposure of fauna and flora of interest or concern.
- A description of the levels of doses that require protective action or assessment during optimization (DC and RL for humans; ERL and DCRL, for biota).
- Engagement with the relevant stakeholders.

(A81) In the application of the principle of optimization of protection of the natural environment, it is important to approach it in an integrated manner, as would the case for the optimization of protection of workers, patients, or the public. Optimization is always implemented through a procedure aimed at achieving the best level of protection under the prevailing circumstances through an ongoing, iterative process (ICRP, 2006) that involves:

- evaluation of the exposure situation, including any potential exposures (the framing of the process);
- selection of appropriate values for constraining the optimization of protection(dose constraint or reference level or environmental reference level);
- identification of the possible protection options;
- selection of the best option under the prevailing circumstances; and
- implementation of the selected option.

A.5.3. Stakeholder involvement

(A82) The role of stakeholders should be recognised in the wider decision-making process. Indeed, there is a requirement in the Joint Convention on the safety of spent fuel management and radioactive waste management to consult Contracting Parties in the vicinity of such a facility, insofar as they are likely to be affected by that facility, and provide them, upon their request, with general data relating to the facility to enable them to evaluate the likely safety impact of the facility upon their territory (IAEA,1997).Stakeholders include individuals and groups who have a personal, financial, legal or legitimate interest in policy or recommendations that directly affect their well-being or that of their environment. In most cases, the role of stakeholders is to aid and inform the decision-making process, but there may be situations where stakeholders have the authority and responsibility for making or recommending decisions (such as a nationally appointed board or committee). Generally, however, the operator and regulator are the decision makers, and the stakeholders help in the process by providing information and guidance related to decisions being made.

(A83) Stakeholders can be helpful in determining the reasonableness, sustainability, and homogeneity of the data used in the decision making process. Collaboration with stakeholders can significantly improve the quality, understanding, and acceptability of the assessment, and also strengthen support for the process and the results. If stakeholder involvement is used as part of the overall decision-making process, however, guidelines should be established right at the beginning to ensure that the process is effective and meaningful for all parties. Some of these guidelines include, but are not limited to, the following:

- clear definition of the role of stakeholders at the beginning of the process;
- agreement on a plan for involvement;
- provision of a mechanism for documenting and responding to stakeholder involvement; and
- recognition, by operators and regulators, that stakeholder involvement can be complex and can require additional resources to implement.

(A84) The Commission understands that the concept of stakeholder involvement may vary significantly from one country to another for cultural, societal, and political reasons. Therefore, the value and extent of stakeholder involvement should be considered by individual authorities in each country. Nevertheless, the Commission believes that stakeholder involvement can play an important role in the implementation, understanding, and acceptance of the system of environmental protection of the ICRP.

(A85) The objectives for making evaluations of the impact of radiation in the environment with regard to human exposures under different exposure situations are well established. With regard to exposures to biota, however, the needs may arise for reasons that stem from a wide range of environmental management requirements. These may be of a very general nature, or specifically defined in order to meet national or international legal requirements including, in some cases, a specific need in relation to specific types of habitat or to specific types of fauna or flora. The practical consequence, however, is that this need may include any of the following *objectives*, each of which would need to be expressed, and deemed 'acceptable' or otherwise, in different ways:

- compliance with the spirit or the letter of trans-national general pollution or wildlife-protection obligations;
- compliance with national pollution control licensing requirements relating to particular industrial practices or to specific sites or areas;
- compliance with the requirements of specific national wildlife and habitat protection legislation;
- compliance with specific environment-based industry needs, such as those relating to fisheries, forestry, farming, and so on; or
- general assurance of the public or their representatives, at national or international level, of the likely environmental impact of any actual or proposed specific practices, and demonstration of the ability to deal with any consequences should accidents occur.

(A86) Many problems may well arise, particularly with regard to planned exposure situations, because of the lack of relevant data upon which to make an assessment of environmental impact. The Commission intends to produce further information with regard to data bases for its set of Reference Animals and Plants, and further guidance on their application in relation to different exposure situations. In doing so, the Commission fully recognizes that this is still a developing area, and that it will take time and experience in order to achieve a more consistent approach.

A.5.4. Regulatory framework and compliance

(A87) The Commission believes that if the processes and procedures described in this report are carried out then, on the basis of current knowledge, it should be possible to demonstrate compliance with the various forms of legislation relating to protection of the environment with respect to ionising radiation. One particular issue, however, is the manner by which compliance with any ERL might need to be demonstrated on a regular basis. The Commission believes that this should normally be approached by reference to radionuclide concentrations in different environmental media that can then be related to estimates of dose rates to the relevant Representative Organisms over a suitable spatial area. Indeed, the methodology by which such back-calculation from predefined environmental dose rates for biota has already been developed (Larsson, 2008; Howard et al, 2010).

(A88) Wherever possible, protection of the environment from a source should complement controls to protect the public and not add unnecessarily to its complexity. The Commission therefore believes that, having essentially clarified the basis upon which decisions relating to protection of the environment can be made, by way of a framework relating exposure to dose, and dose to effect, for different types of organisms (the set of RAPs), the demonstration of protection of both humans and non-human species as a result of normal planned exposure situations could well be integrated in a relatively simple way, based solely on concentrations of radionuclides in the environment, as suggested when the concept of reference animals and plants was first raised (Pentreath, 1999) and subsequently elaborated (Pentreath, 2012). This should be possible by back-calculating from the relevant site specific sets of dose constraints (for humans) and environmental reference levels (for biota) to derive a rate of discharge of both individual and total radionuclides that would not lead to a breach of either level within a given area distal to the point of discharge.

(A89) For existing and emergency situations, each case would need to be examined in its own way. EIAs are also likely to require an evaluation of what the consequences of different scales of accident would be on the environment. Thus although the risk might be exceedingly low, the consequences (for example of damaging a breeding population of a 'protected' species) might be considered unacceptably high. In an actual situation, where dose rates are assessed to be high, confirmation should be possible by standard methods to determine external dose rates, plus analyses of samples of the biota.

(A90) The practical application of practices and procedures to protect the environment in relation to the Commission's Recommendations is clearly a new and developing area, and the Commission will keep the situation under close review.

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APPENDIX 1: TABLES OF DOSE RATES AND EFFECTS FOR REFERENCE ANIMALS AND PLANTS

Table A.1. Dose rates and effects (Derived Consideration Reference Levels (shaded)) for Reference Deer, Rat, and Duck.

Dose rate ($mGy\ d^{-1}$)	**Reference Deer**	**Reference Rat**	**Reference Duck**
>1000	Mortality from haemopoietic syndrome [$LD_{50/30}$ 1 to 8 Gy]	Mortality from haemopoietic syndrome in adults [$LD_{50/30}$ 6 to 10 Gy]	Mortality in adults [$LD_{50/30}$ 7 to 11 Gy]
100 - 1000	Reduction in lifespan due to various causes.	Reduction in lifespan due to various causes.	Long term effects on developing embryos.
10 - 100	Increased morbidity. Possible reduced lifespan. Reduced reproductive success.	Increased morbidity. Possible reduced lifespan. Reduced reproductive success.	Increased morbidity.
1 - 10	Potential for reduced reproductive success due to sterility of adult males.	Potential for reduced reproductive success due to reduced fertility in males and females.	Potential for reduced reproductive success due to reduced hatchling viability.
0.1 - 1	Very low probability of effects	Very low probability of effects	No information
0.01 – 0.1	No observed effects.	No observed effects.	No information.
< 0.01	Natural background.	Natural background.	Natural background.

Table A.2. Dose rates and effects (Derived Consideration Reference Levels (shaded)) for Reference Frog, Trout, and Flatfish

Dose rate (mGy d^{-1})	**Reference Frog**	**Reference Trout**	**Reference Flatfish**
>1000	Mortality in adults [$LD_{50/160}$ 19 Gy]; mortality in tadpoles [$LD_{50/30}$17Gy]	Mortality in embryos [0.3 to19 Gy LD_{50}] depending on embryonic stage.	Mortality in adults [$LD_{50/50}$ 30 Gy]; mortality in eggs [LD_{50} 1Gy]
100 - 1000	Mortality in eggs [$LD_{50/40}$ 0.6 Gy]	Potential for increased morbidity.	Some mortality expected in larvae and hatchlings.
10 - 100	No positive ‘effect’ information.	Some deleterious effects expected on young fish, e.g., reduction in resistance to infections. Reduced reproductive success.	Reduced reproductive success.
1 - 10	No positive ‘effect’ information.	Possible reduced reproductive success.	Possible reduced reproductive success due to reduced fertility in males.
0.1 - 1	No information.	No information.	No information.
0.01 – 0.1	No information.	No information.	No information.
< 0.01	Natural background.	Natural background.	Natural background.

Table A.3. Dose rates and effects (Derived Consideration Reference Levels (shaded)) for Reference Bee, Crab, and Earthworm

Dose rate ($mGy\ d^{-1}$)	**Reference Bee**	**Reference Crab**	**Reference Earthworm**
>1000	Mortality in adults [20 to 3000 Gy LD_{50}]; larvae [1 to 2 Gy LD_{50}]	Mortality in adults [420 Gy $LD_{50/40}$]	Mortality in adults [650 Gy $LD_{50/30}$]
100 - 1000	Possible reduced reproductive success due to effects on gonads and pupal mortality.	Probable effects on growth rates and reduced reproductive success.	Some morbidity and reduced reproductive success.
10 - 100	No information.	No information.	Effects unlikely.
1 - 10	No information.	No information.	No information.
0.1 - 1	No information.	No information.	No information.
0.01 – 0.1	No information.	No information.	No information.
< 0.01	Natural background.	Natural background.	Natural background.

Table A.4. Dose rates and effects (Derived Consideration Reference Levels (shaded)) for Reference Pine tree, Wild grass, and Brown seaweed

Dose rate ($mGy\ d^{-1}$)	**Reference Pine tree**	**Reference Wild grass**	**Reference Brown seaweed**
>1000	Mortality [5 to 16 Gy LD_{50}].	Mortality [16 to 22 Gy LD_{50}].	Deleterious effects expected at very high dose rates. No LD_{50} data.
100 - 1000	Mortality of some trees after prolonged exposure.	Reduced reproductive capacity.	Effects on growth rate.
10 - 100	Mortality of some trees after very long exposure. Growth defects. Reduced reproductive success.	Reduced reproductive capacity.	Potential effects on growth rate and reproductive success.
1 - 10	Morbidity as expressed through anatomical and morphological damage. Prolonged exposure leads to reduced reproductive success.	No information.	Potential effects on growth rate.
0.1 - 1	No information.	No information.	No information.
0.01 – 0.1	No information.	No information.	No information.
< 0.01	Natural background.	Natural background.	Natural background.

NB The area shaded for brown seaweed is different from that provisionally shaded in ICRP 108.

APPENDIX 2: EXAMPLES OF INTERNATIONAL LAWS AND TREATIES

Largely from Copplestone (2012)

Legislation	Principle
Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (IAEA, 1997)	To protect individuals, society, and the environment from ionising radiation with respect to the management of spent fuel and radioactive waste
Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, 1992	A global environmental agreement on hazardous and other wastes
European Union variousdirectives e.g. Habitats (1992) and Wild Birds (1979)	To protect against water, air and noise pollution, controlling risks related to chemicals and biotechnology and conserving habitats and species of community level value
Kyoto Protocol, 1997	An international agreement linked to the United Nations Framework Convention on Climate Change. Sets binding targets for industrialised countries to reduce greenhouse gas (GHG) emissions
North American Agreement on Environmental Cooperation (NAAEC),	Protection of North America's environment via collaboration between Canada, Mexico and the United States. Seeks to balance the requirements of trade and economic growth in North America with effective cooperation and continuous improvement in the environmental protection within each country
Ramsar Convention on Wetlands, 1991	An intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources
Rio convention on Biodiversity, 1992	A UN convention on the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharingof the benefits arising out of the utilization of genetic resources.

APPENDIX 3: SELECTED EXAMPLES OF NATIONAL ENVIRONMENTAL LEGISLATION

Country	Key Environmental Legislation / Environmental Principles	Reference
Australia	Environment Protection and Biodiversity Conservation Act 1999 providing a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places defined in the Act as matters of national environmental significance	www.australia.gov.au/topics/environment-and-natural-resources/environmental-protection
Canada	Canadian Environmental Protection Act (CEPA) 1988 (revised 1999). Addresses the identification, control and/or prevention of toxic substances in the environment, and the promotion of life-cycle management of toxic substances	www.nrcan.gc.ca
China	Environmental Protection Law of the People's Republic of China covering issues such as protection and improvement of the environment to integration of the environment, economy and social factors	www.china.org.cn
Finland	The Nuclear Energy Act (1987) requiring the use of nuclear energy to be safe, not harming people, or damaging to the environment.Nuclear Energy Decree (1988, amended in 1994) establishing an environmental impact assessment on the effects of the nuclear facility on the environment	www.oecd-nea.org/law/legislation/finland
India	The Environment (Protection) Act. Enacted in 1986 with the objective of providing for the protection and improvement of the environment	www.moef.nic.in
Japan	The Ministry of the Environment (2006) integrates the environment in economic and social functions	www.env.go.jp/policy
New Zealand	Environmental Governance - Resource management. New Zealand's main piece of legislation that sets out how the environment should be managed	www.mfe.govt.nz
Russia	The Ministry of Natural Resources and Environmental Protection is a federal agency. Responsibilities range from implementing policies and legal regulation for environmental protection. Environmental protection, or the right to a clean environment, has a constitutional basis within the Russian Federation	www.government.ru/ eng
USA	Environmental policy is based on federal governmental action, regulating activities that would impact on the environment. The main objective is to protect the environment for future generations, yet with minimal interference to industry thus mitigating environmental costs that would affect competitiveness of those industries	www.hg.org/environ

APPENDIX 4: ASSUMED BASIC POPULATION CHARACTERISTICS OF REFERENCE ANIMALS AND PLANTS

Reference Animal or Plant	Population characteristics
Deer	Iteroparous, distinct cohorts, high female to male ratio, low fecundity, population number < 500
Rat	Iteroparous, equal sex ratio, high fecundity, population number <1000
Duck	Iterparous, distinct cohorts, equal sex ratio, low fecundity, population number < 500
Frog	Iterparous, distinct cohorts, equal sex ratio, high fecundity, population number < 500
Trout	Iterparous, distinct cohorts, equal sex ratio, high fecundity, population number < 500
Flatfish	Iterparous, distinct cohorts, equal sex ratio, high fecundity, population number > 10000
Bee	Semelparous (for males), high male to female ratio, high fecundity, population number < 10000
Crab	Iterparous, distinct cohorts, equal sex ratio, high fecundithigh fecundity, population number > 500
Earthworm	Iteroparous, hermaphrodite, high fecundity, population number > 10000
Pine tree	Iteroparous, canopy forming, high fecundity, population size > 1000
Grass	Iteroparous, high fecundity, perennial with yearly re-growth, population size >1000
Brown seaweed	Iteroparous, low recruitment to adult population, population size >1000