Protection of the General Public and the Environment

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Abstract. This paper briefly examines the frameworks and issues that have evolved with respect to the protection of the general public and the natural environment. The former has a very long history, although steps have been made recently to ensure that the framework is fully comprehensive with regard to all actual and potential exposure situations, and in line with current ethical and moral views with regard to human values. The latter, however, has only recently begun to be addressed in a structured manner, driven primarily by a need to ensure that protection of the environment can be explicitly demonstrated where necessary, or that any potential damage can be quantitatively estimated. This is still an evolving subject, but nevertheless needs to be centred around some form of parallel framework to that which has evolved for the protection of human beings, although clearly on a different scale.

KEYWORDS: Radiological protection; general public, natural environment.

1. Introduction

The new ICRP Recommendations [1] provide a more inclusive protection framework for situations beyond the workplace, or the specific situations of diagnostic and therapeutic medicine, by broadening the primary aim of contributing to an appropriate level of protection for people to one that includes the environment against the detrimental effects of radiation exposure, without unduly limiting the desirable human actions that may be associated with such exposure. These two appraoches need to be drawn together within a common framework of optimising the level of effort expended upon protection. For human health, the ICRP's objectives are relatively straightforward: to manage and control exposures to ionising radiation so that deterministic effects are prevented, and the risks of stochastic effects are reduced to the extent reasonably achievable. And although there is no simple or single universal definition of 'environmental protection', and the concept differs from country to country, and from one circumstance to another, the ICRP's aim is now also that 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.

The new ICRP's recommendations also include improvements to the framework with regard to situations in which exposure to radiation may occur. It has therefore evolved from the previous process-based approach of 'practices' and 'interventions' to one that is based on the characteristics of the radiation exposure situation. The ICRP therefore now recognises three types of exposure situations: *planned* exposure situations, which are situations involving the planned introduction and operation of sources (and includes situations that were previously categorised as practices); *existing* exposure situations, which are exposure situations that already exist and where a decision on control has to be taken; and *emergency* exposure situations, which are unexpected situations, such as those that may occur during the operation of a planned situation - or from a malicious act, or from any other cause - that requires urgent attention. There have also been some developments in the provision of advice with regard to how assessment of doses to the public can be made to determine compliance with the relevant values, and to guide decisions on the level of control of exposure, and to help identify actions that could be taken to reduce exposure. Of particular relevance is the introduction of new concepts with regard to the use of reference levels to aid in the process of optimisation for both emergency and existing exposure situations.

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The concept of optimisation has been one of the most important contributors to improvements in radiological protection attitudes and practices in recent years. It is an iterative process that involves evaluation of the exposure situation, the selection of an appropriate constraint or reference level, the identification of possible protection options, and the selection and impememtation of the best option under the prevailing circumstances. Its use for human protection therefore naturally raises the issue of how one should optimise the level of effort to be expended on protecting the environment, or in providing assurance that it is sufficiently protected, in relation to the three ICRP exposure situations, and thus meet the ICRP's broader primary aim. The ICRP has previously indicated [2] that it considered the best approach to be one that was similar to that developed for human protection, based on the same principles, and on the same basic science where relevant. This approach is still developing, as discussed below.

2. General Protection Framework

2.1 The necessity for an overall systematic approach

The current systematic approach to human radiological protection has evolved over many years in order to manage situations in the context of medical exposures, occupational exposures, and exposures of members of the general public. It is based on an enormous range of knowledge on the effects of radiation on human beings, supplemented by other data from studies on animals. The ICRP attempts to convert all of these data, together with their errors, uncertainties, and knowledge gaps, into pragmatic advice that will be of value in managing such exposure situations. It bases this advice on a number of principles relating to the justification of the origins and reasons for exposure; the need to constrain the doses that may be received from individual sources, together with dose limits, where relevant, with respect to individuals; and the need to optimise the level of protection, both in relation to the exposure of individuals, and to groups of individuals and populations under a variety of exposure situations.

The advantage of such a comprehensive and 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 experienced gained in its practical application) it is then possible to consider what the consequences of such a change may have elsewhere within the system, and upon the system as a whole. Such a system would not work unless it was based on 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. A key step in developing this scientific framework was the creation of an entity previously known as Reference Man, which has served as a conceptual and analytical tool for many of the ICRPs numeric analyses and resulting conclusions. This systematic approach is now being extended to include a small set of Reference Animals and Plants to serve as the basis for producing and analysing numerical data in order to provide advice with regard to protection of the environment.

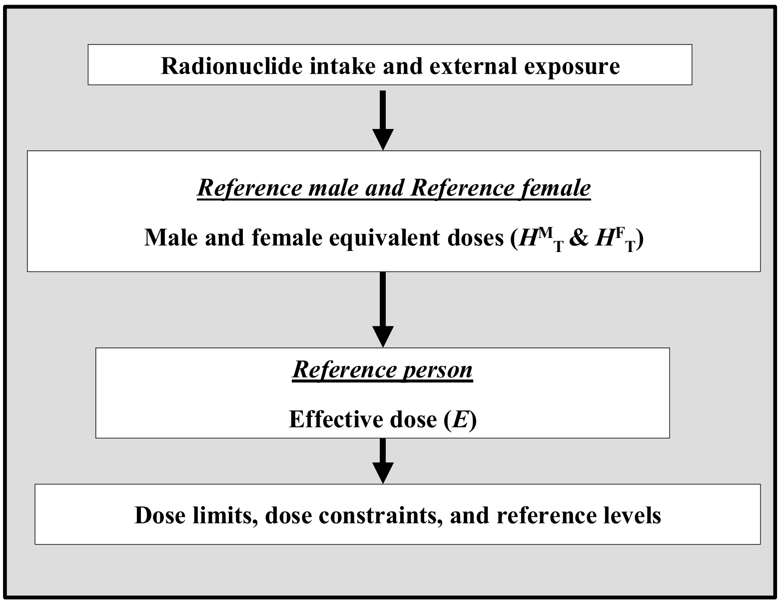
2.1 Protection of people

2.1.1 Basic approach

The objectives for the protection of humans is fairly clear and straightforward: to manage and control exposures to ionising radiation so that deterministic effects are prevented and the risks of stochastic effects are reduced to the extent reasonably achievable. In order to attain this goal, we have a system where the science base relating exposure to dose, and dose to effects, is examined, re-examined, and interpreted by way of a set of conceptual and numeric 'models' (Figure 1). This process started with the creation of a 'Reference Man', who has now evolved into a Reference Individual (male and female), and a Reference Person. The former is an idealised male or female entity with reference anatomical and physiological characteristics, as defined by ICRP [3]. Phantoms based on medical tomographic images are used, consisting of three-dimensional volume pixels (voxels), to compute the mean absorbed dose in an organ or tissue, and these doses are multiplied by radiation weighting factors to provide equivalent doses in the Reference Male and Reference Female. It is intended that similar phantoms will be developed for a pregnant woman, the foetus, and for children.

For the purposes of radiological protection, however, it is currently thought useful to apply a single value of effective dose for both sexes. This is achieved by deriving sex-averaged organ or tissue equivalent doses for an idealised Reference Person; these are then used for the calculation of effective dose by multiplying them by the corresponding tissue weighting factors.

Figure 1: Steps in the derivation of numerical advice for the protection of people



An important factor in the derivation of this approach is that there is sufficient information on the effects of radiation on humans to be able to differentiate between levels of dose that are likely to cause *deterministic* and *stochastic* effects. The former (also referred to as tissue reactions) are characterised by a threshold dose, plus an increase in severity of the reaction as the dose increases. Such effects are unlikely to occur at doses of less than 100 mGy. The latter, stochastic effects, include the development of malignant disease, plus heritable effects, for which the probability of an effect occurring (but not its severity) is assumed to be a function of dose without threshold, and the incidence of which has been determind primarily from studies of various exposed populations. The effective dose relates to the latter, and is not appropriate for the assessment of tissue reactions. It is used primarily for prospective dose assessment in relation to planning and the optimisation of protection, and in retrospective dose assessment for demonstrating compliance with dose limits, or comparing doses with other values used in optimisation. But it is not based on data from individual persons and, in its general application, it does not provide an individual-specific dose, but a dose for a Reference Person under a given exposure situation. The collective effective dose is also sometimes used with respect to exposures of the general public, in the context of optimisation.

2.1.2 Dose limits, constraints, and reference levels

The ICRP recommends a system of protection that not only includes the use of dose limits, but the use of source related dose constraints and reference levels. The purpose of constraints and reference levels is to serve as starting points from which exposures would be reduced to doses that are as low as reasonably achievable, economic and societal factors being taken into account. The chosen value for a constraint or reference level will depend upon the circumstances of the exposure under consideration. In planned exposure situations, there are also risk constraints in order to take account of potential exposures.

The term ‘dose constraint’ is used for this level of dose in planned exposure situations (with the exception of medical exposure of patients). It is a prospective restriction on the individual dose, which serves as an upper bound on the predicted dose in the optimisation of protection for that source. It is therefore a level of dose above which it is unlikely that protection is optimised and for which, therefore, action must almost always be taken. Dose constraints for planned situations therefore represent a basic level of protection, and will always be lower than the pertinent dose limit. For emergency and existing exposure situations, the ICRP has coined the term ‘reference level’ (the difference in terminology being retained to express the fact that, in planned situations, the restriction on individual doses can be applied at the planning stage, and the doses can be forecast to ensure that the constraint will not be exceeded). In the other situations, a wider range of exposures may exist, and the optimisation process may apply to initial levels of individual doses above the reference level.

Numerical values for constraints and reference levels will fall into three defined bands, and apply across all three exposure situations. They refer to the projected dose over a time period that is appropriate for the situation under consideration. Constraints for planned exposures, and reference levels in existing situations, are conventionally expressed as an annual effective dose (mSv per year). But in emergency situations the reference level will be expressed as the total residual dose to an individual as a result of the emergency that the regulator would plan not to exceed, either acute (and not expected to be repeated) or, in the case of protracted exposure, on an annual basis.

The first band, 1 mSv or less, applies to exposure situations where individuals receive exposures (usually planned) that may be of no direct benefit to them, but the exposure situation may be of benefit to society – such as the exposure of members of the public from the planned operation of a nuclear facility. Constraints and reference levels in this band would be selected for situations where there is general information, plus environmental surveillance, monitoring, or assessment, and where individuals may receive information but no training. The corresponding doses would represent a marginal increase above the natural background, and would be at least two orders of magnitude lower than the maximum value for a reference level, thus providing a rigorous level of protection.

The second band, greater than 1 mSv but not more than 20 mSv, applies in circumstances where individuals receive direct benefits from an exposure situation. Constraints and reference levels in this band will often be set in circumstances where there is individual surveillance or dose monitoring or assessment, and where individuals benefit from training or information. For the general public, this would include exposure situations involving abnormally high levels of natural background radiation, such as the setting of reference levels for the highest planned residual dose from radon in dwellings.

The third band, greater than 20 mSv but not more than 100 mSv, applies in unusual and often extreme situations where actions taken to reduce exposures would be disruptive, such as reducing exposures in a radiological emergency. Reference levels (and occasionally constraints, for ‘one-off’ exposures below 50 mSv) could also be set in this range in circumstances where benefits from the exposure situation are commensurately high. The reference level set would be the for the highest planned residual dose from that particular radiological emergency. The ICRP considers that a dose approaching 100 mSv will almost always justify protective action. In addition, situations in which the dose threshold for deterministic effects in relevant organs or tissues could be exceeded should always require action.

A necessary stage in applying the principle of optimisation is the selection of an appropriate value for the actual dose constraint or reference level. The first step is to characterise the relevant exposure situation in terms of the nature of the exposure, the benefits from the exposure situation to individuals and society, plus other societal criteria, and the practicability of reducing or preventing the exposures. This may well raise issues of a moral and ethical nature, in addition to strightforward scientic and managerial ones. Nevertheless, from a pragmatic point of view, the specific value for the constraint or reference level needs then to be established by a process of generic optimisation that takes account of national or regional attributes and preferences together, where appropriate, with a consideration of international guidance and good practice elsewhere.

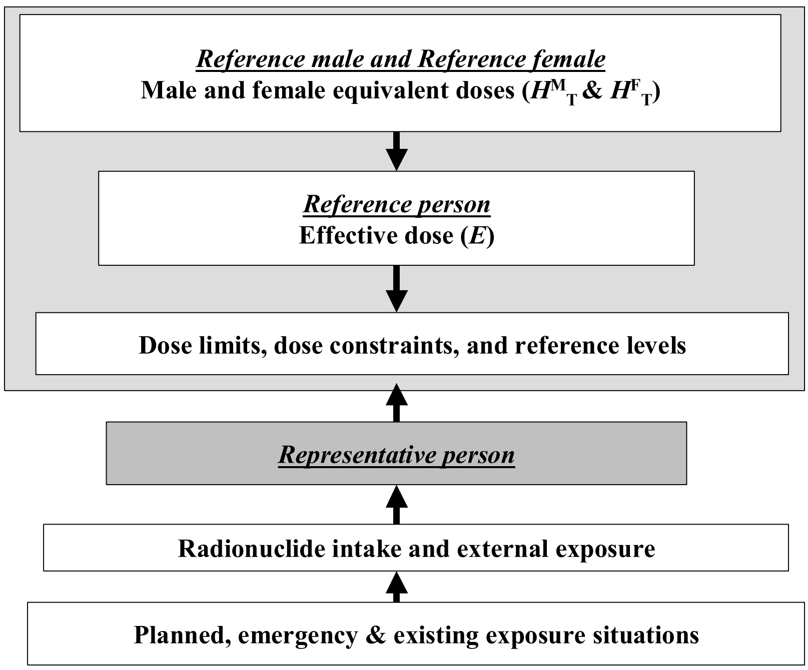
2.1.3 Compliance via Representative Individuals

A member of the public is defined as any individual who receives an exposure that is neither occupational nor medical. In general, especially for public exposure, each source will result in a distribution of doses over many individuals. In the past, the ICRP has used the 'critical group' concept to characterise 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. Over several decades 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 [1] .

The Representative Person may be real or hypothetical, but the habits used (e.g., consumption of foodstuffs, location, use of local resources) should be typical of those of a small number of individuals representative of the most highly exposed, and not simply the extreme habits of a single member of the population. Consideration may be given to some extreme or unusual habits, but they should not dictate the characteristics of the Representative Persons considered.

Calculations based on Representative Persons are therefore made to demonstrate compliance or otherwise with the various dose constraints, dose limits, and refernce levels appropriate to the relevant exposure situation, as indicated in Figure 2.

Figure 2: Relationships of various point of reference for protection of the public



2.2 Protection of the environment

2.2.1 Basic approach

In comparison with the protection of humans, there is no simple or single universal definition of environmental protection. The concept differs from country to country, and from one circumstance to another. Nevertheless, there is clearly a need to address the issue directly and transparently, not only to allay public concern, should it arise, but also increasingly to comply with various forms of regional and national legislation that requires that protection of the environment be explicitly demonstrated, irrespective of the protection of human beings.

There are clearly many obstacles to overcome in attempting to provide advice on this subject. In the absence of any clear definition of environmental protection, the ICRP has adopted the aim of preventing or reducing the frequency of deleterious effects of radiation 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. By and large, therefore, the achievement of such aims implies the need to protect animals and plants at the population level, although in some cases national or other legislation may require that consideration be given to the protection of individuals. (This is not necessarily confined to 'rare or endangered' species, as is often thought, but may simply relate to the 'value' that a community places on a particular species, or group of animals and plants – that is to say, they 'like' them and do not wish to see them harmed.) In contrast to the situation of protection of the general public, however, where numerical values to protect them at an individual level are derived primarily from the study of exposed 'populations', most of the data available to protect animals and plants at the population level are derived from studies on small groups of individuals. Thus there are very few data relating to stochastic effects, except for small mammals, and the effects of interest are, in any case, better grouped into those which would effect them by way of causing early mortality (life shortening), morbidity in some cases, reduced reproductive success (either via effects on fertility or fecundity), and chromosomal damage.

The science base relating to the effects of radiation on biota is poor, and has not been derived within any overall framework. Nevertheless, there is a need to make the best sense of the information that does exist, to convert it into some form of conceptual model, as has been done for the protection of humans, and to set out a framework that will encourage future work to be done that complements, supports, and fills the gaps in our existing knowledge. The ICRP is therefore now embarking [2] upon a more modest exercise of creating the equivalent of the 'reference man' for protection of the environment by developing a system where the science base relating exposure to dose, and dose to effect, for a limited number of different types of animals and plants, can be examined, re-examined, and interpreted by way of conceptual and numeric 'models' based on a set of Reference Animals and Plants (or RAPs), plus their reference 'phantom dosimetric models', reference values and so on, together with what is known about the effects of radiation on these types of animals and plants [4]. The idea is that by establishing such a set there can then be future iterations within it, as new data arise, and the RAPs have been chosen with this need in mind. It is also considered necessary first to understand these inter-relationships in some detail for a few biotic types before attempting to generalise across all types of animals and plants.

But what should the nature of this advice be? It is clearly inappropriate to set generalised dose limits, but some form of numeric guidance is obviously necessary to help guide management decisions under the three categories of ICRP exposure situations. This is particularly important to avoid unnecessary effort being expended, as in the case of most normal exposure situations, or to ensure that limited resources are best used in emergency or some existing exposure situations. In other words, there is also a need for some set of 'reference' values to optimise the level of effort expended on protecting the environment, commensurate with the level of risk of any damage likely to be incurred, the desired outcome of any action taken, and the resources likely to be available. It is also important to ensure that the approach taken is compatible with other approaches being made to protect the environment from other human impacts, particularly those arising from similar activities to those relating to the nuclear industries. Such advice can perhaps thus best be framed within a set of what have been termed Derived Consideration (Reference) Levels for environmental protection.

In view of the limited amount of data available, and the size of the task, an initial set of RAPs is being considered by the ICRP that includes typical animals and plants found in the terrestrial, freshwater, and marine environments. There is no perfect algorithm for such a selection, but a selection has, necessarily, to be made. This has been based on a number of criteria, including the following: that there is a reasonable amount of radiobiological information already available on them, including data on probable radiation effects; that they are amenable to future research, in order to obtain the necessary missing or imprecise data, particularly with regard to radiation effects; that they are considered to be typical representative fauna or flora of particular ecosystems; that they are 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; that their life-cycles are likely to be of some relevance for evaluating total dose or dose-rate, and of producing different types of dose-effect responses; that there is a reasonable chance of being easily able to identify, unambiguously, any effects that could be related to radiation exposure; and that they have some form of public or political resonance, so that both decision makers and the general public at large are likely to know what these organisms actually are, in common language. They are essentially representative of temperate regions; there are insufficient data for typical tropical or other climatic types available.

A further consideration has been the level of generalisation to adopt, and thus how best to describe the chosen selected reference animals and plants, bearing in mind that it has not been the intention to select particular species, but equally not to generalize to the extent that the characteristics of the selected types are of little biological meaning. The most useful biological classification level seems to be that of *Family*. Thus a Reference Animal or Plant is 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 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. The set currently being considered is shown in Figure 3.

Figure 3: Set of Reference Animals and Plants (RAPs) being considered as a preliminary basis for exploring the relationships between exposure and dose, and dose and effects, for different types of animals and plants.

Reference Animals and Plants (RAPs)

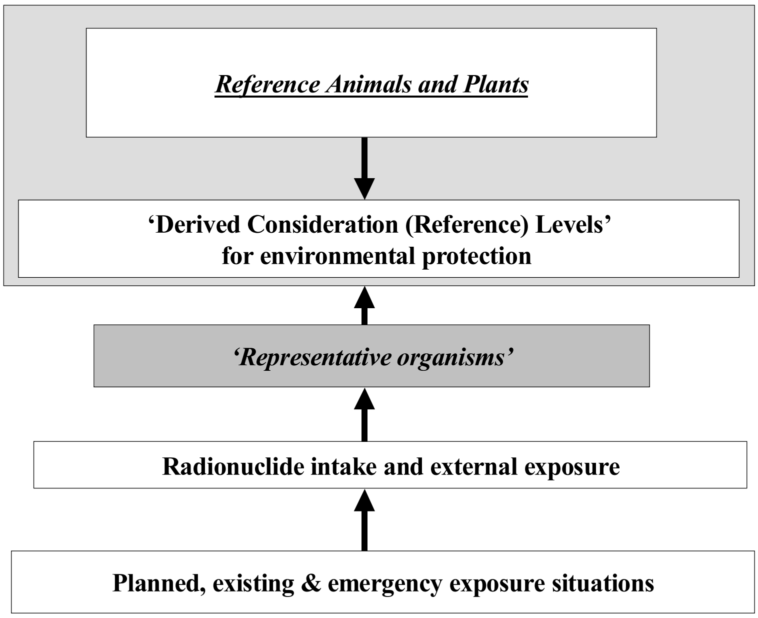
- **Deer** (adult)
- **Rat** (adult)
- **Duck** (egg, adult)
- **Bee** (adult, colony)
- **Worm** (egg, adult)
- **Pine tree**
- **Grass**

- **Frog** (egg, tadpole, adult)
- **Trout** (egg, adult)
- **Flatfish** (egg, adult)
- **Crab** (egg, larvae, adult)
- **Brown seaweed**

A further complication to note is that, for the purpose of relating exposure to dose, it has been necessary in many cases to consider different stages in the life cycle, not only because of the marked differences in size, but because different stages of the life cycle can occur in different environments. Thus, for example, an adult duck may live much of its life on water, but lay its eggs on the ground; whereas an adult frog may spend much of its time on land, but its eggs and tadpoles live in water. Such factors, including allowance for the fact that some organisms live on the soil whereas others live within it, are therefore sufficient to produce a considerable range of complexity for dosimetric purposes, even with a simple set of twelve biotic types.

The Reference Animals and Plants can therefore be regarded as playing a similar, but much simpler, role to that of the 'Reference Man' family of Figure 1 in order to derive some form of numerical guidance to aid management decision making with regard to all three exposure situations, as shown in Figure 4. An important difference being, however, that (so far) no attempt has been made to allow for radiation or tissue weighting factors (even though RBE is reasonably well studied in some small mammals) and that the effects of interest are categorised in a different way from those observed in humans.

Figure 4: Steps in the derivation of numerical advice for the protection of the environment



2.2.1 Derived Consideration (Reference) Levels for Environmental Protection

By and large, very high doses are required to kill animals and plants, although the data are difficult to compare beyond those for mammals (which are in the range of 1 to 10 Gy) because the experiments have been conducted in so many different ways, and over somewhat arbitrary time scales. Nevertheless, it is possible to identify ranges of dose that have different effects, such as embryo mortality, reduced fertility and so on, although it is not always clear where the thresholds, if any, lie. Dose rates of about 0.1 to 1 mGy per day are needed reasonably to expect the chance of some form of effects in higher vertebrates (and pine trees) to be observed, 1 to 10 mGy per day for lower vertebrates, and 10 to 100 mGy per day for various invertebrates. These are some two to four orders of magnitude above their respective natural background dose rates, but could be attained in some exposure situations. It is therefore useful to consider them as trigger points for further *consideration* of management action in certain circumstances, or to serve as benchmarks for assurance that no action needs to be taken, particularly if comparison is also made to their typical background dose rates.

2.2.2 Representative organisms

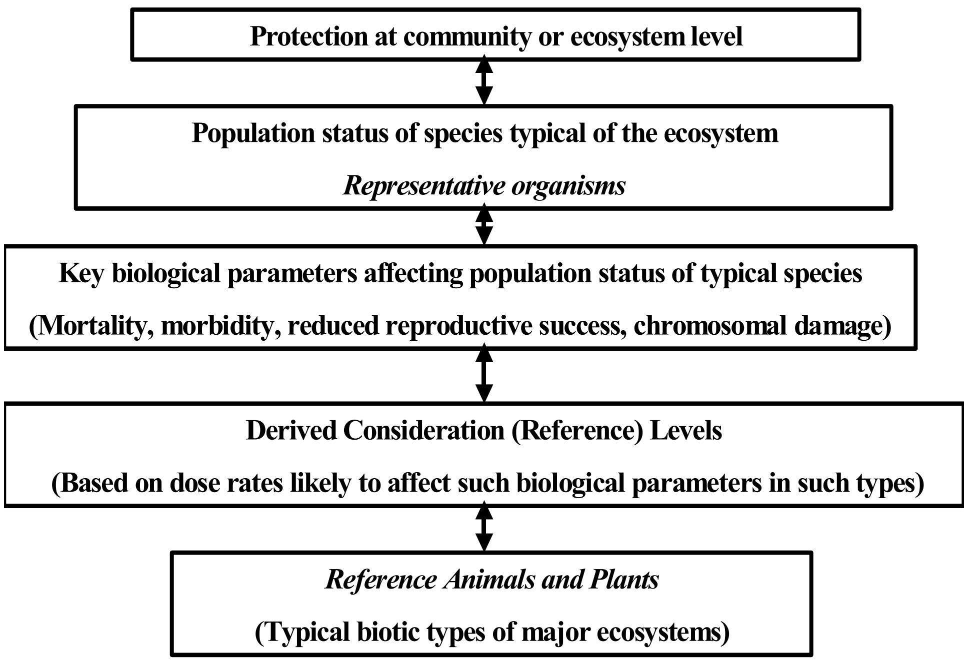
The most important outcome of using the Reference Animals and Plants will therefore be a set of 'reference' dose values to aid decision making under different exposure situations. But as is the case for human protection, although the Reference Male and Female individuals, and the sex-averaged Reference Person, could be used in hypothetical exposure situations, compliance with the ICRP's advice and recommendations is achieved by way of a Representative Person that 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. The same applies to the environment, and thus more precisely defined animals or plants could be used to serve as Representative organisms (Figure 4). In view of the fact that the RAPs are defined as being generalised to Family level, this allows for thousands of species to be used as examples that would be compliant with the assumtions made for the twelve RAPs.

The steps necessary to create such Representative organisms have in fact already been taken by way of the concept of various 'reference organisms', as in the FASSET programme [5], (these organisms should now perhaps be referred to as 'representative organisms') or in the various 'screening' techniques developed for application to different sites or exposure situations [6]. 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.

2.2.3 Actual and potential applications

The use of this RAP approach could be simply that of assuring the public that there is no need for concern about environmental discharges on environmental grounds (as is likely to be the case under most normal exposure situations relating to large nuclear facilities), or to address specific concerns in relation to specific interest groups, such as those responsible for fisheries management, or nature conservation. In other cases, however, more formal use may be required. Of increasing concern to planners is the need to consider the likely environmental consequences of an accident or incident, where the RAP approach could be used to compare the suitability of, for example, different sites for 'new build' nuclear facilities that might otherwise be similar as judged against criteria for potential human exposures. One likely challenge, however, is how such a small group of RAPs could be used to protect the ecosystem as a whole. Simply using twelve types of RAPs is essentially a pragmatic one. It does not imply a lack of concern for other biotic types, nor concern for the environment as a whole (one could not 'protect' any of these biotic types without also conserving the habitats within which they live.) But it is impossible to know about all of the species within any ecosystem, and the 'health' of such areas is often assessed by studying a sub-set of its components. Thus one possible conceptual relationship is that shown in Figure 5. A key point to note, however, is that because almost all of the information on radiation effects arises from data on small groups of individuals, if the objective is that of protecting an actual population, it will also be necessary to assess the fraction of the population of interest that is exposed to such levels of dose. This will vary from case to case.

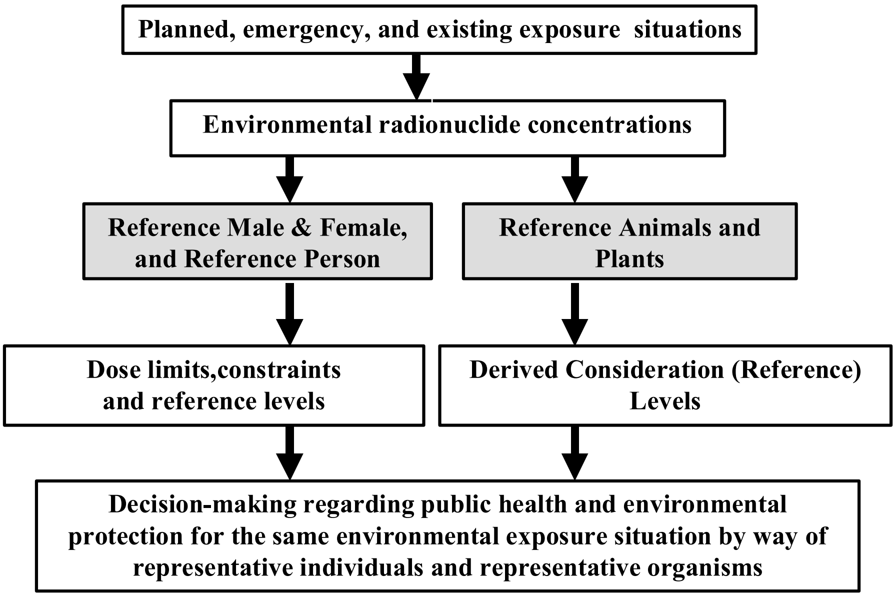
Figure 5: Conceptual relationships betwen a set of Reference Animals and Plants and ecosystems.



3. Conclusions

The framework for the protection of the general public is very sophisticated and has taken decades to develop. In contrast, a system to help manage the actual or potential effects of radiation on the environment is still in its infancy. But now that a more comprehensive system to optimise the protection of people with respect to all exposure situations is being introduced, it is more than appropriate also to begin the development of a parallel system to optimise the effort required to provide assurance that the environment can also protected under the same exposure situations, as indicated in Figure 6. This will take skill and patience, but after more than a decade of discussion it is now more than timely to start to put such a framework into practice.

Figure 6: Schematic approach to the protection of both the public and the environment in relation to any exposure situation



REFERENCES

[1] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, The 2007 Recommendations of the International Commission on Radiological Protection. Publication 103, Pergamon Press, Oxford and New York (2007).

[2] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, A Framework for Assessing the Impact of Ionising Radiation on Non-Human Species. Publication 91, Pergamon Press, Oxford and New York (2003).

[3] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Basic anatomical and physiological data for use in radiological protection. Publication 89, Pergamon Press, Oxford and New York (2002).

[4] PENTREATH, R.J. Concept and use of reference animals and plants. In Protection of the Environment from the Effects of Ionising Radiation, IAEA-CN-109, IAEA, Vienna, 411-420 (2005).

[5] LARSSON, C-M. The FASSET Framework for assessment of environmental impact of ionising radiation in European ecosystems- an overview. J. Radiol. Prot. 24, A1-A12 (2004).

[6] Radioecology and Environmental Radioactivity (Proc. Conf. Bergen, 2008), 2 vols, Norwegian Radiation Protection Authority (2008).