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Critical groups and biospheres in the context of radioactive waste disposal

Fourth report of the
Working Group on Principles and Criteria
for Radioactive Waste Disposal

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FOREWORD

Plans for disposing of radioactive wastes have raised a number of unique and mostly philosophical problems, mainly due to the very long time-scales which have to be considered. While there is general agreement on disposal concepts and on many aspects of a safety philosophy, consensus on a number of issues remains to be achieved.

To assist in promoting discussion amongst international experts and in developing consensus, the IAEA established a Subgroup under the International Radioactive Waste Management Advisory Committee (INWAC). The Subgroup started its work in 1991 as the "INWAC Subgroup on Principles and Criteria for Radioactive Waste Disposal". With the reorganization in 1995 of IAEA senior advisory committees in the nuclear safety area, the title of the group was changed to "Working Group on Principles and Criteria for Radioactive Waste Disposal".

The working group is intended to provide an open forum for:

(1) the discussion and resolution of contentious issues, especially those with an international component, in the area of principles and criteria for safe disposal of waste;

(2) the review and analysis of new ideas and concepts in the subject area;

(3) establishing areas of consensus;

(4) the consideration of issues related to safety principles and criteria in the IAEA's Radioactive Waste Safety Standards (RADWASS) programme;

(5) the exchange of information on national safety criteria and policies for radioactive waste disposal.

This is the fourth report of the working group and it is concerned with the choice of critical groups and associated biospheres for application in safety assessments for disposal of radioactive wastes underground. For assessments of safety in the far future, when human behaviour or biosphere conditions cannot be known with any certainty, it is proposed that a stylized approach be adopted. The approach is consistent with that adopted in areas of radiation protection where it is impracticable to establish the precise characteristics of exposed individuals. This publication is consultative and exploratory in nature and does not purport to represent a 'Member State consensus'.

The first, second and third reports were published in 1994, 1996 and 1997 under the titles "Safety Indicators in Different Time Frames for the Safety Assessment of Underground Radioactive Waste Repositories" (IAEA-TECDOC-767), "Issues in Radioactive Waste Disposal" (IAEA-TECDOC-909) and "Regulatory Decision Making in the Presence of Uncertainty in the Context of the Disposal of Long Lived Radioactive Wastes" (IAEA-TECDOC-975), respectively.

The reports of the Working Group on Principles and Criteria for Radioactive Waste Disposal contain the developing views of experts within the international community and should be of use to those engaged in producing national and international standards and guidance in this area.

The IAEA officer responsible for this publication was I.F. Vovk of the Division of Radiation and Waste Safety.

EDITORIAL NOTE

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1. INTRODUCTION

The fundamental problem regarding the safety of geological waste disposal systems is their potential long term radiological impact on human beings and the environment. An important principle in radioactive waste management which seems to have broad acceptance in dealing with this problem is that "**radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today"** [1].

The recommendations of the International Commission on Radiological Protection (ICRP) apply to the control of present day releases of radioactive waste to the environment. ICRP's system of radiological protection encompasses justification, optimization, and dose and risk limitation [2]. Dose limits and dose constraints are applied to the mean dose to an appropriate critical group which is characterized on the basis of currently observed habits. However, in the case of a solid waste disposal facility releases may occur many hundreds or thousands of years into the future and future habits are unknown. Therefore, due to this reason, the demonstration of compliance of geological repositories with safety requirements is a particular challenge. The purpose of this report is to discuss the choice of critical groups and associated biospheres for future time frames for application in assessments being undertaken to demonstrate whether there is compliance with dose or risk criteria. It develops ideas presented in the first report of the INWAC Subgroup on "Safety Indicators in Different Time Frames for the Safety Assessment of Underground Radioactive Waste Repositories" [3].

A stylized approach is proposed for selecting critical groups and biospheres in future situations where human behaviour or biosphere conditions cannot be known with any certainty. This approach is consistent with that adopted in areas of radiological protection where it is impracticable to establish the precise characteristics of exposed individuals. For example, a stylized 'reference man' is used in calculating annual limits of intakes and generic models of radionuclide behaviour are used to calculate dose coefficients. The ideas contained in this report could form the basis for internationally agreed critical groups and associated biospheres that could be used in comparison exercises or as part of a national licensing procedure. The working group recognizes that work along these lines is being conducted within the BIOMASS programme; earlier drafts of this report were one input into that programme.

Section 2 outlines the development of the critical group concept; Section 3 describes the relevance of the critical group concept to waste disposal; Section 4 discusses the relevance of calculated doses and risks as indicators of repository safety; Section 5 describes the guiding principles for characterization of critical groups and biospheres in future time frames; and Section 6 describes the application of those principles. Conclusions are presented in Section 7.

2. BACKGROUND TO THE CRITICAL GROUP CONCEPT

The critical group approach has been applied to the control of exposure of members of the public for many years. The concept was introduced by ICRP in order to take account of the variation in dose which may arise due to differences in age, size, metabolism, habits and environment. ICRP describes the critical group approach in ICRP Publication 26, as follows [4]:

"With exposure of members of the public it is usually feasible to take account of these sources of variability by the selection of appropriate critical groups within the population provided the critical group is small enough to be relatively homogeneous with respect to age, diet and those aspects of behaviour that affect the doses received. Such a group should be representative of those individuals in the population expected to receive the highest dose equivalent, and the Commission believes that it will be reasonable to apply the appropriate dose-equivalent limit for individual members of the public to the weighted mean dose equivalent of this group. Because of the innate variability within an apparently homogeneous group some members of the critical group will in fact receive dose equivalents somewhat higher than the mean. However, because of the maximising assumptions used, the dose equivalent actually received will usually be lower than the estimated dose equivalent." (ICRP 26, para. 85).

The concept is developed further in ICRP Publication 43 "Principles of Monitoring for the Radiation Protection of the Population" [5] which addresses, among other things, the homogeneity criteria that should be used in choosing a critical group. The Commission suggests that if the ratio of the mean critical group dose to the appropriate limits is "less than about one tenth, a critical group should be regarded as homogeneous if the distribution of individual dose equivalents lies substantially within a total range of a factor of ten, i.e., a factor of about three either side of the mean. At higher fractions, the total range should be less, preferably no more than a factor of three" (ICRP 43, para. 69). Therefore, it is accepted that some individuals in the critical group will receive doses somewhat higher than the mean dose.

ICRP published recommendations for "Radiation Protection Principles for the Disposal of Solid Radioactive Waste" as Publication 46 in 1985 [6]. Two situations are recognized in Publication 46: a 'normal' release process in which normal, gradual processes lead to radionuclide releases from solid waste disposals; and 'probabilistic' situations where releases and doses are caused or influenced by probabilistic events and processes. ICRP recommends application of dose limits to the first situation, 'normal' releases, in the same manner as for routine releases from say, a nuclear power station. The "dose limit .... is intended to apply to the maximum value of the average dose in the critical group whether this occurs now or in the future" (ICRP 46, para. 45). ICRP goes on to say "When an actual group cannot be identified, a hypothetical group or representative individual should be considered who, due to location and time, would receive the greatest dose. The habits and characteristics of the group should be based upon present knowledge using cautious, but reasonable assumptions. For example, the critical group could be the group who might live in an area near a repository and whose water would be obtained from a nearby groundwater aquifer" (ICRP 46, para. 46). In probabilistic situations, ICRP recommends that the annual risk to the critical group is limited. However, no guidance is given on how to characterize this critical group.

The basic principles underlying the critical group concept are retained in ICRP's current "System of Radiological Protection", issued as ICRP Publication 60 [2] which states that "in practice, almost all public exposure is controlled by the procedures of constrained optimisation and the use of prescriptive limits. It is often convenient to class together individuals who form a homogeneous group with respect to their exposure to a single source. When such a group is typical of those most highly exposed by that source, it is known as a critical group" (ICRP 60, para. 186).

In Publication 60, ICRP draws the distinction between 'normal exposure' and 'potential exposures'. 'Normal exposures' are those that are virtually certain to occur and which have a magnitude which is predictable, albeit with some uncertainty. One example of normal exposure is the critical group dose from routine discharges. ICRP's discussion of critical groups in Publication 60 is in a section referring mainly to normal exposure and ICRP 26 and ICRP 43 discuss almost exclusively what would now be described as normal exposure. Therefore, the development of the critical group concept by ICRP is in terms of the control of normal or routine exposures.

ICRP's term ‘potential exposures’ refers to situations where there is a potential for exposure but no certainty that it will occur. ICRP, in Publication 64, “Protection from Potential Exposure: A Conceptual Framework” [7], makes it clear that it considers the long term doses from solid waste disposals to be potential exposures. However, no guidance is given in Publication 64 on the applicability of the critical group concept in these circumstances.

More recently, ICRP has published its “Radiological Protection Policy for the Disposal of Solid Radioactive Waste” [8]. This covers disposal of all forms of radioactive waste and, inter alia, addresses the protection of future generations. The Commission makes it clear that the critical group concept applies to the potential exposures arising in the long term from the disposal of radioactive waste and that the annual individual risk to this critical group together with the annual dose to a critical group for normal exposure “will together provide an adequate input to a comparison of the limiting detriment to future generations with that which is currently applied to the present generation”.

In conclusion, ICRP has developed the critical group concept for application in normal situations where the system of dose limitation applies. ICRP considers the normal, gradual releases from a waste repository to fall into this category and some guidance is given on how to characterize the appropriate critical groups. For probabilistic, or potential, exposure situations the critical group concept also applies but no guidance is given on how to characterize the appropriate critical group; for example, should the group be homogeneous in terms of dose or risk? It is the purpose of this document to give guidance on the selection of critical groups and the corresponding environmental situations (biospheres) for application in assessments being undertaken to demonstrate whether there is compliance with dose or risk criteria.

3. RELEVANCE TO WASTE DISPOSAL

In the performance assessment of a radioactive waste repository consideration has to be given to:

– the operational phase
– the closure phase (shafts are being sealed, etc.)
– the post-closure phase.

For the operational and closure phases, the critical group concept for normal, routine situations (Section 2) can be applied, because the exposed population can be characterized. For the post-closure phase, the “critical group” concept has to be modified as the exposed population cannot be identified in advance and their habits cannot be surveyed.

In the post-closure phase, the following elements of the waste disposal system can be distinguished for the purposes of performance assessment: engineered system, geosphere and biosphere.

Each of these elements has a different type and degree of uncertainty associated with it [9]. The uncertainties in the biosphere relate to:

– the natural development of the biosphere (without human effects), e.g., climate and topography, which will influence the radionuclide transport within the biosphere;
– human behaviour, which has a significant effect on the exposure pathways;
– natural temporal and spatial variability.

A major aim of the assessment of a given disposal system is to identify and, to the extent possible, evaluate the uncertainties in the different elements and their influence on the overall performance. This allows the level of detail and precision in the assessment of the subsystems to be balanced. Most efforts should be spent in areas where the effects of uncertainties on performance are the largest, and there is also the possibility of reducing those uncertainties — in this way future work can be directed to where it can do most good.

The performance of the engineered system and the geosphere can be evaluated within certain bounds for relatively long time-scales (depending on host rock and repository design typically 10^3 to 10^6 years). However, one can only speculate on human behaviour at times beyond a few hundred years into the future. Furthermore, as has recently been pointed out by ICRP [8], current judgements about the relationship between dose and detriment may not be valid for future populations. It is for these reasons that calculated doses and risks to humans can only be used as indicators and not as accurate predictors of radiological impact on future populations.

Notwithstanding the uncertainty about future human conditions, it is nevertheless necessary to develop a structured and defensible approach to the problem, that is, to develop a critical group concept appropriate for radiological protection purposes in the context of the long term safety of a radioactive waste repository. This would help to avoid endless speculation about future human habits, etc., and encourage a focusing of performance assessments on the site-specific characteristics of the disposal facility and disposal environment that contribute to waste isolation.

4. DOSE AND RISK AS SAFETY INDICATORS

Protection of individuals from current releases is achieved through application of the International Basic Safety Standards [10] including the system of limits and constraints. However, because of the increase with time of the uncertainty associated with the results of predictive models, detailed quantitative assessments of doses and risks become less and less meaningful the further into the future the assessment is carried. From such considerations, the idea has developed that a variety of safety indicators should be evaluated when assessing the safety of a repository. Certain safety indicators may be useful in particular time frames; the idea being to use only those safety indicators that rely on components of the disposal system whose uncertainty is not too large. This subject is discussed in detail in the first report of the INWAC Subgroup [3].

Estimated doses and risks to future individuals are examples of safety indicators. Other examples of safety indicators considered in the first INWAC Subgroup report are environmental concentrations, biospheric flux and radiotoxicity of waste. The INWAC Subgroup concluded that risk is the primary safety indicator. In order to calculate doses and risks to future individuals, assumptions have to be made about future human habits. The uncertainty surrounding such assumptions increases with time.

The Subgroup used a few specific time intervals as a framework for discussing how the utility of each indicator varies with time. The time frames are:

(a) from closure to 10^4 years;
(b) 10^4 to 10^6 years;
(c) beyond 10^6 years.

The demarcation times of 10^4 and 10^6 years are only indicative. The overall conclusions concerning dose and risk as safety indicators in these time frames were as follows.

In the period from closure to 10^4 years the radiological safety indicators, dose and risk, will be of primary importance in evaluating repository safety and quantitative assessments of these should be made for comparison with the appropriate criteria. Although major changes in climate and human habits could occur, in general, the biosphere could be assumed for radiological protection purposes to remain comparable to present day conditions. Habits used in estimating doses or risks could be based on those currently observed in the particular region. In assessing intrusion into the repository, the future level of technology should be assumed to be at least equivalent to that existing at present. The upper time, around 10^4 years, marks the time when glaciation is expected and such an event would bring about significant changes to man's environment.

In the period 10^4–10^6 years, long term natural changes in climate will occur and the range of possible biosphere conditions and human behaviour is too wide to allow reliable modelling. It is proposed that the calculations relating to the near-surface zone and human activity are based on stylized sets of conditions. These calculations should be viewed as illustrative and the doses or risks as indicative. The assumed biosphere conditions and associated human habits are referred to as reference biospheres and reference hypothetical critical groups, respectively, to emphasize that they are not a statement of what the anticipated situation may be in the future.[1] A reference biosphere is a standardized approach to biosphere modelling which avoids speculative discussion on the future by providing a simple and robust approach to representing transfer through the biosphere to humans. Other safety indicators, requiring less information about near surface conditions, the biosphere and human behaviour, will play an increasing role in assessing repository safety in this time frame. Reference biospheres and reference hypothetical critical groups can be used in calculating doses and risks in the earlier time frame depending upon the particular circumstances (see Section 5.1).

Beyond 10^6 years unpredictable, large scale changes could take place such as continental drift and massive erosion. Therefore, less credibility can be attached to assessments in this time frame than to assessments in earlier time frames.

[1] The Subgroup notes that in other fora, for example BIOMASS, the biosphere is assumed to include humans. The sub-group sees no difficulties in such an approach but, in this document, for ease of discussion, critical groups and biospheres are referred to separately, i.e., the biosphere represents the pathways leading to exposure of the critical group.

5. GUIDING PRINCIPLES FOR DEFINING CRITICAL GROUPS AND BIOSPHERES IN FUTURE TIME FRAMES

In this TECDOC, the purpose of defining critical groups and biospheres for future time frames is to enable assessments of doses and risks to be undertaken in order to form judgements about whether the impacts on the health of future generations are greater than those that would be acceptable today (see Section 1). In order to undertake such an assessment, the characteristics assigned to future individuals should be the same as those of people today to whom the risk levels will be compared; if they had fundamentally different characteristics then such a compara.tive assessment could not be made. Thus, critical group habits and biosphere characteristics have to be derived from present day experience. Futhermore, the habits chosen should be such that it is unlikely that doses and risks will be significantly underestimated — but significant overestimation may also not be desirable.

Principles are given here for characterizing two types of critical group. The first type is appropriate for assessing any release from a repository to the biosphere. The release could be the result of normal gradual processes or it could be an accelerated release, for example, due to discrete events. For the purposes of discussion, this is referred to as the critical group for the normal evolution of the repository. The second type of critical group is for the purpose of evaluating the exposure to an inadvertent intruder into a repository. This critical group is referred to as the critical group for intrusion scenarios. The time frames chosen in the first INWAC Subgroup report [3] are adopted in the following discussion.

5.1. NORMAL EVOLUTION

Because the level of contamination in the environment is likely to remain constant over periods which are considerably longer than the typical human lifetime, it seems reasonable to calculate the average annual dose over the lifetime of an individual. This would mean that it is not necessary to calculate doses to different age groups. In general, it is likely that the error made by using the annual dose to an adult, instead of the real age-averaged annual dose, will be small compared with other uncertainties in an assessment.

For the time period from 10^2 years to 10^4 years post-closure, the biosphere could be assumed to remain roughly comparable to present day conditions. Climatic or other changes may occur which could affect the local biosphere but any such changes are likely to remain within the range of variability of the regional biosphere. Human characteristics may be expected to change significantly beyond around one hundred years into the future but, for the reasons given above, this fact could be ignored. Thus, the prevailing biosphere conditions in the region of interest could be assumed to apply over the time period 10^2–10^4 years. The assumed habits of a critical group have to be such that the exposure of the group is expected to be representative of the highest exposures that might reasonably occur. However, it is important that the habits assumed are not overly conservative; extreme habits representing the behaviour of a few individuals should not be taken. For example, future individuals are unlikely to have total calorific requirements and fluid intakes which are very much different from present day requirements. The habits of the critical group could be derived from those habits which are characteristic of the region in which the repository is situated. Regional habits are more likely to represent those which will occur on a continuing basis than are habits derived for a particular location. For example, in the case of a coastal repository, where the critical group includes seafood consumers, data appropriate to high rate seafood consumers in the general coastal region may be more representative than present day data specific to the neighbourhood of the repository.

In the time period from 10^4 to 10^6 years post closure, long term natural changes in climate will occur and the range of possible biospheres and human behaviour is too wide for reliable modelling. For this time period, hypothetical critical groups in reference biospheres are proposed. The characteristics of the reference hypothetical critical groups and reference biospheres should be chosen in such a way that they are representative of the highest doses that could arise given our knowledge of present day human habits and biospheres (temperate, subtropical, etc.). There are advantages in developing a range of reference biospheres and associated reference hypothetical critical groups. These could be used in 'what if' calculations and it may be the case that one particular biosphere/critical group combination is more relevant to a particular repository location than another. However, there may also be benefits to be gained from choosing one particular biosphere/critical group combination as an international benchmark. This should be selected in such a way that the calculated doses and risks would be representative of the highest likely to be received in the future. An example of one such possibility, a northern temperate inland biosphere with a hypothetical reference critical group of subsistence farmers, is outlined in Tables I and II and is discussed below. The Subgroup is aware that the BIOMASS programme is developing a methodology for characterizing reference biospheres/critical groups and will soon be in a position to comment on these assumptions.

For the international benchmark, it is suggested that the habits assumed for the hypothetical critical group should be representative of subsistence communities living in temperate conditions. Extreme habits observed within such communities should not be taken; the assumption that a subsistence community exists in the future at the appropriate location is considered to be sufficiently conservative on its own. Releases in the future could occur directly to the marine environment, in which case there would be considerable dilution of activity, or to a groundwater aquifer. It is recommended that the subsistence community is taken to be a self-sustaining farming community deriving its water supply from the contaminated groundwater aquifer. Thus, this is a conservative assumption.

The reference biosphere should be based on present day temperate conditions. Data for this environment represents the largest and most reliable database for environmental transfer of radionuclides; thus temperate conditions can be modelled with the greatest reliability and are a practical choice. Temperate conditions may also be amongst those where a release would give the highest radiological impact. Another reason for selecting a subsistence community in a temperate biosphere is that the current system of radiological protection and associated risk factors has been developed for the protection of individuals today and is likely to be applicable to such a situation. Thus, for example, the use of ICRP's recommended tissue weighting factors and risk factors is consistent with the choice of critical group and environment.

The subsistence community and reference biosphere could also be applied in the earlier time period, 10^2–10^4 years particularly in situations where the proposed repository is situated at an inland temperate location.

5.2. INTRUSION SCENARIOS

There are two broad categories of exposure situation that should be considered: exposure of the intruder and exposure of other individuals from enhanced releases from the repository due to the intrusion.

TABLE I. DEFINITION OF THE HYPOTHETICAL CRITICAL GROUP

FEATURES	RATIONALE
Subsistence community	Minimizes dilution of doses
Land based location	Most common site
Water source – Well for drinking use by cattle and crop irrigation	Typically higher radionuclide concentration than for surface water (i.e. less dilution)
Food sources – Within 10 km of homes – Use more than one production zone – Consumption of fish from river or lake	– Minimizes dilution by importing food – Increases local security of supply
Standard intakes – Use ICRP reference man for water intake and calorific intake – Grains) – Root crops) – Meat and dairy) – Legumes) – Leafy vegetables) (amounts based on calorific intake)	– To simplify and standardize the conversion of concentrations to dose – Based on average data known today for subsistence communities
Standard conversion – Use dose coefficients	Internationally accepted

5.2.1. The intruder

The characteristics of this critical group will depend upon whether deep geological disposal or near surface disposal is being considered.

For deep geological disposal, the most credible critical group is a geotechnical worker examining the core of material brought to the surface following inadvertent exploratory drilling into a repository. In the case of a repository containing heat generating wastes, the geotechnical worker could receive high doses, possibly with deterministic effects, in the time period up to around 10^3 years following disposal. There is nothing that can guarantee to prevent this type of intrusion and the objective should be to minimize the likelihood by siting and design rather than by focusing on assessment details.

TABLE II. DEFINITION OF THE REFERENCE BIOSPHERE

FEATURES	RATIONALE
Northern temperate climate	Have best data
	Most sites are likely to be in this zone
	Consistent with existing radiological protection data
Use point of highest isotope concentrations	Conservatism

For example, ICRP/IAEA dose coefficients are derived using biokinetic models based, where possible, on human data. These data refer almost exclusively to western individuals. Another example is the water intake rates in 'Reference Man' which are based on western data — consumption rates in the tropics are much higher.

For a near surface repository, the critical group is represented by a worker excavating, for example, building foundations. It may be more appropriate to assess this situation than intrusion into a deep repository because digging, say, housing foundations could be considered a normal, everyday activity that could be conducted by a society that was significantly less advanced than ourselves and possibly having no understanding of radioactivity. In contrast, a society that could undertake exploratory drilling to several hundred metres would be technologically advanced, have an understanding of radioactivity and, even if the hazard was not recognized immediately, may be able to take subsequent action to lessen the risk. Furthermore, the number of individuals exposed in the digging of house foundations is likely to be more than the number of individuals involved in the initial examination of a core from exploratory drilling.

Thus, in the case of a near surface repository, the scenario details are important as the results of the assessment could have a large influence on the types, concentrations and quantities of wastes that can be disposed. Therefore, realistic estimates have to be taken for the time period of excavation, inadvertent ingestion of material and inhalation of dusts, etc.

5.2.2. Enhanced releases

For both deep geological disposal and near surface disposal, intrusion could result not only in doses to the intruder but also in enhanced releases of radionuclides to the biosphere. The consequences of these enhanced releases could be taken into account using the critical group defined for normal evolution (see Section 5.1), making appropriate allowance for the probability of release and the rate of release, should it occur. However, there may be circumstances where the critical group defined for normal releases is not appropriate. For example, in the time period 10^2–10^4 years, the critical group for a shallow land site situated on the coast may be largely seafood consumers; but if a human intrusion event occurred which brought waste to the surface, the critical group could be, say, subsistence farmers and this would have to be taken into account.

In the case of some disposal options, in particular those involving disposal in salt formations, specific intrusion scenarios may need to be developed. For disposal in salt, the development of such scenarios should take into account the possibility of various forms of mining. The critical groups for normal evolution may be applied, in some circumstances, to any releases to the biosphere from these repositories following an intrusion event.

6. APPLICATION OF PRINCIPLES

This section summarizes the application of the principles developed in Section 5. For the purposes of discussion, the time frames proposed in the first INWAC Subgroup report are taken together with an additional time frame covering the assumed period of institutional control, i.e., up to about 100 years post closure. The critical groups for normal evolution scenarios are discussed in Section 6.1 and summarized in Table III; critical groups for intrusion scenarios are discussed in Section 6.2.

6.1. NORMAL EVOLUTION

6.1.1. Period 0 to ca. 100 years post-closure

Some form of institutional control may be assumed to remain in place for a period of around 100 years after the repository is sealed. Institutional control will preclude any inadvertent human intrusion into the repository and disruptive natural events are not expected to occur over this time period. Therefore, ICRP's system of protection for practices in normal situations applies including dose limitation, etc. This system of protection is further elaborated upon in the International Basic Safety Standards [10]. If any releases are expected to occur in this time frame, an appropriate critical group should be characterized on the basis of a site specific habit survey using criteria set out by ICRP (see Section 2).

6.1.2. Approximately 10^2 years to 10^4 years post-closure

In this time frame either a hypothetical critical group in a reference biosphere or a critical group in a region specific biosphere could be used. In both cases the group could be assumed to exist at any given time at the place where the relevant environmental concentrations are expected to be highest. However, in the case of a region specific biosphere, care should be taken to ensure that the assumed critical group habits are consistent with the type and area of land or the size of the water body which is contaminated.

The assumption that a critical group exists where the estimated environment concentrations are highest is conservative. Therefore, it is important that the habits assumed for the critical group are not overly conservative (see Section 5).

6.1.3. 10^4 years to 10^6 years post-closure

In this time frame, the range of possible biosphere conditions and human behaviour is too great to allow reliable modelling. Therefore, doses and risks could be calculated to a hypothetical critical group in a reference biosphere. These calculations provide an indicator of possible risks and the safety case for this period should place equal emphasis on other indicators (see first INWAC Subgroup report [3]). The hypothetical critical group could be assumed to exist at the point of highest relevant environmental concentration.

TABLE III. USE OF CRITICAL GROUPS AND BIOSPHERES IN DIFFERENT TIME FRAMES (NORMAL EVOLUTION)

TIME AFTER CLOSURE (YEARS)	RECOMMENDED CRITICAL GROUP	RECOMMENDED BIOSPHERE
0–100	Normal group as used for operational releases Use observations of actual groups as a basis	Actual local biosphere receiving releases
10^2–10^4	A region specific critical group based on habits characteristic of the region in which the repository is situated or The hypothetical critical group	Region specific biosphere or Reference biosphere
10^4–10^6	The hypothetical critical group	Reference biosphere

It could be assumed that if the hypothetical critical group in the reference biosphere is protected, then this gives reasonable assurance that any individuals actually alive in this time frame will also be protected.

6.1.4. Beyond 10^6 years

Calculations of dose and risk even as broad indicators of repository performance have little relevance in this time frame.

6.2. INTRUSION SCENARIOS

In the case of deep geological disposal, the selection of a critical group for the inadvertent intruder is not a major issue for the reasons given in Section 5.2. However, for near surface disposal, these scenarios may be important and the same care should be taken over the selection of the appropriate habits as in defining a critical group or hypothetical critical group for normal releases.

Two groups may be required — one representing the intruder and one representing individuals who are exposed following any enhanced release to the biosphere. It may be the case that this latter group corresponds to the critical group or hypothetical critical group applied to normal releases.

7. CONCLUSIONS

(1) For releases during the period of institutional control, the critical group can be identified from habit surveys (see Section 2).

(2) For the time period 10^2 to 10^4 years post-closure, the approach adopted in estimating doses and risks could be either a) a critical group, derived from regional habit data, in an appropriate biosphere or b) a hypothetical critical group in a reference biosphere (see Section 5.1).

(3) For the time period 10^4 to 10^6 years, the recommended approach is to adopt a hypothetical critical group in a reference biosphere. This is a subsistence community in a northern temperate biosphere (see Section 5.1).

(4) For a near surface facility, an additional critical group may be necessary to represent inadvertent human intrusion into a repository.

(5) It is recommended that further work be undertaken to establish an international consensus on the characteristics of the hypothetical critical group in the reference biosphere and on the characteristics of the critical group representing intrusion into a near surface facility. The Subgroup understands that work in this area is being undertaken within the BIOMASS programme.

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