ATTACHMENT 1

DRAFT REPORT

Compilation and Analysis of Information on Critical Groups

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Contents

1. Introduction

The work described below is intended to help the Electric Power Research Institute (EPRI) support the rigorous definition and development of an appropriate biosphere model to be used in Performance Assessment (PA)[1] for the candidate HLW repository at Yucca Mountain, Nevada. In particular, the objective of this report is to provide an appropriate basis for defining the target population(s) in the Yucca Mountain vicinity for dose calculations in the biosphere according to the critical group concept. Consideration is first given (Section 2) to the evolution of the idea of a critical group through review of existing national and international definitions, including regulatory guidance on the interpretation of these definitions. Because the definitions require at least some level of interpretation within a PA, Section 3 then considers how the critical group concept has been applied in previous PAs. Relevant key issues include:

- the degree to which the critical group characteristics have been prescribed in regulations,
- the degree to which the regulatory definitions have to be extended in order to provide a workable performance assessment definition,
- the background assumptions and data necessary to quantify the critical group characteristics,
- the degree of conservatism introduced and consistency within and among different PAs.

Section 4 then goes on to develop specific suggestions for critical group definitions that are relevant to the PA for Yucca Mountain. These suggestions take into account site specific factors as well as the developing regulatory situation in the USA, but are also supported by the wide range of generically relevant factors discussed in Sections 2 and 3. Part of regulatory development in the USA includes a recent report produced by the Committee on Technical Bases for Yucca Mountain Standards [1995]. A provisional commentary on this report is provided as an Appendix.

2. Existing National and International Definitions

This Section reviews existing national and international definitions and associated regulatory and other guidance on or relevant to the definitions of critical groups.

2.1 ICRP and Related International Developments

2.1.1 Origins of the critical group concept and emerging conceptual issues

It is not obvious who first coined the term critical group. The International Commission on Radiological Protection (ICRP) used the term in ICRP 26 published in 1977 [ICRP, 1977], which is probably far back enough to be a suitable starting point for discussion here. ICRP's interest was in

[1] Acronyms and abbreviations used are given in Section 6.

demonstrating compliance with dose limits.[2] The basis for limitation of individual exposures was the quantity weighted mean whole body dose equivalent. The corresponding term post ICRP 60 [ICRP, 1991] is effective dose. ICRP noted [ICRP, 1977, para 85] that :

> 'the actual doses received by individuals will vary depending on factors such as their age, size, metabolism and customs, as well as variations in their environment...... With exposure of members of the public, it is usually feasible to take account of these sources of variability by 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 behavior that affect the doses received. Such a group should be representative of those individuals in the population expected to receive the highest (dose), and the Commission believes that it will be reasonable to apply the appropriate (dose) limit for members of the public to the mean (dose received by members of this group). Because of the innate variability within an apparently homogeneous group, some members of the critical group will receive a (dose) somewhat higher than the mean.'

ICRP recognize the potential difficulty in identifying or selecting critical groups by saying 'usually feasible'. The 'usually' is justified since the majority of situations being analyzed arise today and present day studies can be carried out of behavior etc. A key issue that ICRP point out is the need for homogeneity within the group if the level of protection intended is to be achieved.

According to this approach, it follows that, according to the assessment, some critical group members will get higher than the average dose assessed for the group as a whole. (Some in the group would naturally get more than the average.) In practice the actual highest doses received will not usually be higher than the assessed mean to the group because, as ICRP put it, the assessment generally includes other 'maximizing assumptions', having the effect that estimated doses will generally be higher than those actually received. The group must be reasonably homogeneous since otherwise this would not be true. That is, if there were significant behavioral or other outliers within the group, then these outliers could be at seriously higher risk than the assessment suggests.

It follows that, in this approach, no attempt is made to define the characteristics of literally the most exposed person or to determine their dose. There is a built in recognition of the uncertainties

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[2] The term dose as applied to radiation exposure is a complicated quantity. In precise technical usage, it is necessary to apply various qualifiers according to whether the 'dose' referred to is a measure of charge or energy deposition, or whether allowance is being made for radiation type in terms of linear energy transfer, or whether allowance is being made for the type of tissue receiving the dose and the risk consequences of that particular tissue exposure. ICRP most recently revised dose definitions as relevant to radiological protection (as opposed to dosimetry) in ICRP 60 [ICRP, 1991]. The most generally relevant protection quantity introduced in ICRP-60 is 'effective dose'. For a full explanation see ICRP [1991]. In this report qualifiers such as 'effective' are omitted for easy reading, except where necessary to make important distinctions among types of exposure.

and variabilities which make such a task intractable and a built in assumption that adequate protection is nevertheless provided by consideration of the group of mostly highly exposed people. This still leaves a significantly onerous task of identifying or justifying the assumptions for that group.

ICRP also note in ICRP 26 [ICRP, 1977, para 121-123] that the optimization process may push exposures of individuals into a region near to dose limits. In this case, more realistic assumptions for critical groups should be employed. The logic behind this is that the optimization process should not be biased by unrealistic assumptions; an option should not be ruled out because of unrealistic assumptions leading to unacceptably high estimates of individual dose. However, it is only qualitative advice. It is not obvious when one has been realistic enough, either when demonstrating compliance with limits, or in the context of optimization.

Taking this point further, Kritidis notes [Kritidis, 1991] that critical group doses are no more than estimates of 'more or less upper limits of the actual personal doses'. This working definition seems consistent with all the words of ICRP, but also highlights 'a measure of freedom to (estimates of) the upper values and reduces the credibility of comparisons between estimates provided by different groups'. Finley et al [1994] illustrate the difficulties by presenting distributions of various relevant behaviors, such as fish consumption, water consumption, soil consumption and residential occupancy. These indicate that, generally, the level at which the activity is performed grows steeply somewhere within the upper 25th percentile of the distribution. This means that the average value of some part of the distribution within the upper 25th percentile can be very sensitive to the particular part of the distribution chosen. It follows that the dose to (average members of)[3] a critical group whose behavior is represented by that part of the distribution will also be very sensitive. These data also introduce the difficulty of whether or not to include relatively unusual behavior, such as eating soil. In fact, data in Calabrese and Stanek [1994] suggest non-trivial soil ingestion is more common than perhaps is generally considered, such that any typical group of 30 or so small children could be expected to include a few individuals who consume a lot more soil than average. Are these outliers, to be excluded?

Consider briefly the aspects of critical groups separately: age, diet and other behavior affecting doses. As an illustration, suppose the issue were associated with contamination of dried baby food. The critical group would then presumably include infants and children, but probably not adults. Relevant aspects of diet would include only the consumption of the particular baby food, not other foods.

The situation would be very different for release of contamination into a lake or reservoir, where

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[3] It is common for these words in parentheses to be omitted, so that 'critical group dose' comes to mean the average dose to individual members of that group. Such common usage may be confusing if at some point one wishes to discuss the collective dose to that group. Further on in this report the common usage is applied, but care is used to make discussion of collective doses to critical groups explicitly clear.

many different habits could be relevant to the upper limit of exposures, e.g. drinking water, fishing, consuming fish, playing in the water and mud, not all of which could necessarily be associated with a single homogeneous group. The most relevant exposure pathways (i.e., those giving rise to highest doses) for such a release would be radionuclide dependent. For example, a highly sorbed radionuclide with low biological uptake and a significant gamma emission could give rise to highest doses via external irradiation from lakeside sediments, whereas another radionuclide with high biological uptake but no penetrating emissions could give rise to largest doses via fish consumption. *If many radionuclides with different characteristics are in the release, it will not be obvious before some analysis is carried out which particular behavior gives rise to the largest doses.* The modeling of contaminant migration needs to provide estimates of radionuclide concentrations in all the potentially relevant media, and critical group assumptions pertaining to exposure via all those media are required. For present day releases, it may be possible to determine the assumptions from habit surveys. The survey results may also provide a pointer to the more relevant environmental media, taking into account the characteristics of the radionuclides in the release. For hypothetical situations, for which specific behavioral data are not available, it seems unreasonable to prescribe the critical group assumptions without taking into account the particular circumstances and nature of the release(s) under consideration.

Two potential future developments relevant to critical group assumptions can be discerned. One concerns the unborn, taken here to mean the conceptus, embryo or fetus. Doses to the unborn due to intakes by the mother have not historically been widely considered in critical group dose assessments, possibly because relatively little data were available. However, the store of data is growing, e.g. see Morgan et al [1992] and Stather et al [1992], and further attention may be appropriate, particularly given the emotive connotations. Note, for example, that the US National Council on Radiation Protection and Measurements (NCRP) says that 'the sensitivity of the embryo-fetus for both mental retardation and cancer should be considered in all situations involving irradiation of the embryo-fetus' [NCRP, 1993].

The other issue concerns our growing knowledge of genetic factors in predictive and preventive oncology. The radiological protection quantity 'effective dose' (see footnote 2) averages out the propensity to radiation damage for a given exposure across all the population. However, there is increasing evidence that the excess cancer risk observed among exposed populations is significantly due to a relatively small proportion of carriers of weakly expressing, cancer predisposing mutations [Cox, 1993]. As more is learnt about such genetically determined predisposition, it may be anticipated that there would be a corresponding increase in ability to identify those at risk and correspondingly special interest in protection of that group.

2.1.2 Extension to the long term

All the above relates to dose assessment generally, not just to PA for long term waste disposal systems. It is clear that it is not possible to carry out surveys of future behavior. ICRP recognize this in their advice on protection principles for solid waste disposal [ICRP, 1985]. They suggest, para 46:

> 'When an actual group cannot be defined, 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 of people who might live in an area near a repository and whose water would be obtained from a nearby groundwater aquifer.'

This is a significant extension of the concept as described in ICRP 26 [ICRP, 1977]. Firstly, the group may be represented by an individual. Secondly, the suggestion is that, for assessment purposes, one assumes that the group is present to get the dose, even though they may not be. It is still recognized, however, that the critical group dose represents the upper end of the distribution of dose among the entire exposed population, not the absolute maximum of that distribution.

The NEA offer similar advice [NEA, 1984]:

> '.. the risk should be assessed for a hypothetical individual or group who would be most at risk. The location and time at which the individuals live should be assumed to be that at which, and when, the risks are greatest. The habits of the individual should be assumed to be an average of a hypothetical critical group, defined on the basis of present human behavior using pessimistic but not unrealistic assumptions.'

'Pessimistic but not unrealistic' stands in for ICRP's 'cautious, but reasonable'.

IAEA [1989] define the critical group for HLW assessment as:

> '.. the members of the public whose exposure is reasonably homogeneous and is typical of individuals receiving the highest (dose) from the source.'

They also say the individuals may have to be defined hypothetically and that their basic nutritional requirements and lifestyles are the same as those of people today.

It may be noted that some aspects of the hypothetical critical group characterization are relatively straightforward. Age and body size in the future may be assumed to have the same variability in future as they have now, and that variability is much the same everywhere. The behavioral aspects are less straightforward. ICRP say above that present knowledge may be used; one could hardly use future knowledge. Presumably they mean that knowledge of current day circumstances may be used as a basis for assumptions for the future. This is helpful because it rules out assumptions for technological developments, such as a cure for cancer or clever new ways of detecting radiation so that exposures can be easily avoided. However, it is not clear whether they mean knowledge of current behavior at the site under investigation, or knowledge of any location. Given the potential for climate change over the period of interest in long term PA, circumstances at widely different locations today might be relevant to the assessment of a specific site.

A further aspect of long term PAs recognized by ICRP [1985] is that some releases into the biosphere from a repository, albeit arguably at a very low rate and a long time in the future, are quite likely to occur. ICRP call these expected releases 'normal scenarios'. Others releases would only occur given some unlikely event, such as a major alteration of the geological barrier by a seismic event, or intrusion deep into the ground by humans. ICRP therefore introduced a risk criterion for use in these cases, in addition to the dose criterion for normal scenarios, which allows the probability of exposure to be taken into account in judging acceptability. ICRP do not advise further on the nature of the critical group with respect to these unlikely events. However, it follows that the probability of exposure used in determining the risk is meant to be related to the probability of the unlikely event, be it natural or the result of human action. That is, if the unlikely event is associated with human behavior, such as damage to near field or far field barriers by geological exploration, then one can take the probability of that intrusive event into account. It does not allow one additionally to take into account the probability of the presence of the critical group whose exposure is increased as a result of reduced barrier effectiveness. (They may not be the same group that perpetrated the intrusion.) To do so would be to contradict the approach for normal scenarios. NEA specifically say that no credit should be taken for the probability that an individual might not be present [NEA, 1984].

Justifying assumptions for human behavior in the far future in the context of critical groups is bound to be problematic. In other areas than radioactive waste management, the making of predictions on such a long term basis would not normally be attempted. For example, the view can be taken that human imagination is capable of absolute originality and so human behavior is not amenable to absolute prediction. According to some, sciences which deal with human behavior in terms of probability calculus are, at best, misconceived [Shackle, 1961].

The radioactive waste management community has come to recognize this difficulty and sets out the following conclusion in a consensus document [IAEA/NEA/CEC, 1990] produced by committees of the NEA and IAEA and endorsed by the Commission of the European Communities (CEC):

> 'Calculations of doses resulting from releases of radioactivity into the environment several thousand years or more from now are generally based on current living habits. Any estimate of far future living habits would be largely speculative. Such calculations are, therefore, generally viewed as an illustration of what the doses would be if the release occurred today, than as a prediction of the actual dose to some human living in the future. Thus, the assessed long-term radiological consequences of disposal systems are normally considered as indicators of safety that can be compared to safety standards.'

The term 'indicators of safety' has been taken up and special consideration given to indicators in different time frames by an IAEA group [IAEA, 1994]. They note that:

> 'The size and distribution of future populations in the vicinity of a repository cannot be

known with any useful precision. However, the size of the exposed group is a factor to be considered in assessing the significance of an event.'

IAEA do not quantitatively advise on how this factor should be taken into account and there is no suggestion that there should be a numerical collective dose limit. Swiss authorities have directly considered this factor, see Section 2.2.3.

Other indicators of safety, apart from doses and risks, include radionuclide fluxes, environmental concentrations and radiotoxicity indices, none of which are directly affected by critical group considerations, and to some extent are intended to avoid the problem of defining critical groups.

The international collaborative study BIOMOVS II includes a working group on so-called 'Reference Biospheres' which has the objective to define a methodology for analysis of the biosphere in long term PAs. The idea is that the reference descriptions of the biosphere should present adequate illustrations of the circumstances under which radionuclide release might occur into the biosphere in the far future, and the corresponding consequences, in terms of doses to individuals. It is hoped that discussions can lead to consensus on the meaning of such phrases as 'pessimistic but not unrealistic' and 'cautious, but reasonable', as used by ICRP, etc. Through the structure of the proposed generically relevant list of biosphere features, events and processes, it is also recognized [BIOMOVS II, 1994] that the assumptions for critical groups need to be linked to the wider biosphere assumptions.

2.2 National Regulations, Criteria and Guidance

Regulatory guidance from important example countries is set out below. There is considerable variation from country to country, some having detailed and specific solid waste disposal regulations and lengthy associated guidance while others having only limited regulations referring to broad radiological protection objectives and little or no explanation or guidance on interpretation. In the latter case the operator, or other persons making the assessment, has to significantly interpret or extend the regulations and guidance. Where relevant, these interpretations are discussed in Section 3.

2.2.1 United Kingdom

Regulations in the UK do not refer to critical groups for repository PA. However, regulatory guidance has been issued [Department of the Environment et al, 1984] which sets out an objective of not exceeding a risk limit which applies 'to any member of the public'. NRPB guidance[4] [NRPB, 1992] says that such a criterion should be applied to an 'average member of the critical group'. NRPB staff [Barraclough et al, 1992] offer further advice to the effect that, for the period to 10,000 y, assumptions about human behavior should be based on the concept of hypothetical critical groups,

[4] The NRPB is not a regulatory body but is a national authority whose function includes provision of advice to government departments on radiological protection.

rather than the idea of the most exposed individual. Such groups should be assumed to exist at the time and place where the relevant environmental concentrations are highest, and to have habits such that their exposure is representative of the highest exposures which might be reasonably expected. They also note that, 'it is important, however, that hypothetical critical groups should not be assigned habits which are too conservative, particularly as the assumptions about their existence and location are conservative.' Later, 'Hypothetical critical groups may be selected on the basis of currently observed behavior, but the group's habits should be broadly representative of a type of area, rather than being based on particular extreme habits observed at a particular time at a particular place.' This may be interpreted as allowing for the potential exploitation of resources at a location, but not assuming the more extreme exploitation of those resources. It would appear that examples of behavior from sites other than the repository site are potentially relevant, so long as they are similar in an exploitation context. If this approach were applied to Yucca Mountain, it would suggest that behavior from many communities located in hot, arid parts of the U.S. would represent future behavior in the Yucca Mountain vicinity - not just Amargosa Valley. In addition, over the period before and during radionuclide release to the biosphere, conditions at the site may change, e.g. due to changing weather patterns. Other sites which today represent those changed conditions might provide useful analogues for future conditions at the site in question.

For periods beyond 10,000 y, the increasing uncertainties are recognized and a 'reference community' approach is suggested rather than a critical group. It is not clear how the community would be different from the pre 10,000 y critical group, but the idea seems to be to allow a less precisely defined group, or at least to admit less direct justification for that group's behavior, given the longer time-scale.

The overall NRPB approach may be reasonable for the long term, but is different from the application of the concept to present day releases, where, if extremes are observed then they are taken into account in the assessment. For example, see Robinson et al [1994]. Here, for terrestrial foodchains, the 97.5th percentile of intake is adopted based on sampling from wide areas. For aquatic foodchains, local habit survey data were used, arguably involving extremes of behavior in some instances, e.g. at the Heysham site, local fishermen consuming 54 kg/y of fish, 21 kg/y of crustacea and 22 kg/y of mollusks.

2.2.2 Sweden

The main Swedish regulators have applied the following individual dose related premise in judging the acceptability of LLW and ILW disposal at intermediate depth [SKI/SSI, 1994]:

> 'All radiation doses to individuals, regardless of (when they occur) must be lower than the limits considered as acceptable planning levels for other stages in the nuclear fuel cycle.'

Concerning HLW, the Swedish authorities have worked with other Nordic countries in developing a basis for national regulations [Nordic Radiation Protection and Nuclear Safety Authorities, 1993]. This basis includes limits and constraints on doses and risks (in the case of 'unlikely' disruptive events) to 'individuals'. There is recognition that:

> 'Because of different diets, living habits and environmental conditions, there is alwa · a 'tail' in the individual dose or risk distribution. Sometimes this 'tail' may exceeu :he respective constraint though the average value in the critical group remains below.....Acceptance of the 'tail' in (this) distribution is not contrary to (other) present practices and is consistent with the individual protection principle.'

Dose predictions beyond 10,000 y are regarded as not well founded. Beyond that time, release rates of repository radionuclides into the biosphere are suggested as a relevant alternative indicator of risks, using natural fluxes for comparison. (See discussion of IAEA [1994] above.)

2.2.3 Switzerland

The Swiss regulators provide explanatory comments with their regulatory protection objectives [HSK/KSA, 1993]. They highlight the difficulties of long term dose predictions and refer to indicators of impact rather than realistic estimates. Nevertheless, these indicative dose and risk calculations should be carried out for the distant future, at least for the maximum potential consequences from the repository, despite the uncertainties related to the condition of the biosphere and the existence of a population. They thereby recognize the link between assumptions for environmental conditions and the assumptions for the exposed group. They add that for these calculations, reference biospheres and a potentially affected population group with realistic, from a current point of view, living habits should be assumed. Reference biospheres are not defined, but the Swiss waste management company, NAGRA, participate in the BIOMOVS reference biospheres group referred to in Section 2.1. While no critical group proposals have yet been finalized by BIOMOVS, the background to the 'reference biospheres' has been considered and an interim report produced [BIOMOVS II, 1994].

The Swiss regulations [HSK/KSA, 1993] include an annual individual dose limit of 0.1 mSv y^{-1} at any time after site closure and a 1 in a million risk limit for unlikely events and processes. Relaxation (unquantified) of these limits may be acceptable if the number of persons exposed at these levels is very small and the converse also applies. Thus, here, the size of the most significant population is taken into account, not with a collective dose limit but with a possible variation in the individual limits.

2.2.4 Canada

The Atomic Energy Control Board (AECB) say [AECB, 1987] that:

> 'The individual risk requirements in the long term should be applied to a (hypothetical critical) group of people that is assumed to be located at a time and place where the risks are likely to be the greatest, irrespective of national boundaries.'
>
> 'Definition of the lifestyle of the hypothetical critical group should be based on present human behavior using conservative, yet reasonable, assumptions.'

The requirement to calculate doses and risks is limited to 10,000 y, though reasoned arguments must be used to show that releases are not significantly higher beyond that period. This tends to limit the range of environmental conditions which might need to be considered for the critical group to exist within.

AECB refer to deterministic and probabilistic calculations of risks and indicate a preference for the probabilistic approach. For this approach, they say that:

> 'the arithmetic mean value of the (dose) distribution should be calculated and should be taken as representative of the consequences predicted for an exposure scenario.'

They also require assessment of possible impacts of representative reference communities.

The Canadian Federal Environmental Review Panel [1992], not actually a regulatory body, have recommended looking at doses to non-human biota, which implies identifying critical groups among non-humans biota. This is contrary to apparent requirements, according to advice from IAEA studies [IAEA,1992], which, broadly suggests that controls sufficient to protect mankind (as individuals) will be sufficient not to result in harm to other biota (as species).

2.2.5 France

Radiological protection criteria for deep geological disposal are given in [IPSN, 1992] including basic objectives, and recommendations on scenarios to be analyzed for deep geological disposal. An annual individual dose limit of 0.25 mSv y^{-1} is set for certain or highly probable releases. For unlikely random events, natural or human actions, doses must well below levels liable to give rise to deterministic effects. Characteristics of man are to be assumed fixed as at present with respect to radiation sensitivity, food requirements, and scientific knowledge especially as regards technical and medical fields. Situations to be taken into account include the effects of glaciation, at around 50,000 y, and other climatic changes. It follows that for releases which occur on this timescale, assumptions for the biosphere and exposure pathways should account for these changes. That is, a constant biosphere would not seem a sufficient basis for evaluation.

2.2.6 Japan

Japan has no regulations on deep disposal. For the shallow land burial (SLB) of LLW at Rokkasho, the Science and Technology Agency (STA) has set requirements as follows. The legal framework is not prescriptive and the STA provide supporting guidance:

- During institutional control period (approx. 300 y) the dose to workers and the public should be governed by the ALARA principle.
- After this, the dose to individuals from likely scenarios should not exceed 0.01 mSv/y. For unlikely scenarios, the dose should not significantly exceed 0.01 mSv/y.

No advice is given on the assumptions for individuals.

2.2.7 Finland

Relatively limited guidance is given in the regulations [STUK, 1991]. The requirement is to calculate 'the upper bound for expectation value of annual individual dose to any member of the public'. Note that there is no mention of a 'critical group'.

2.2.8 Spain

Criteria for deep geological disposal are still under development. In BOE [1992] a range of technical requirements and inventory limits are set for the SLB facility at El Cabril, as well as the following radiological requirements.

- Doses to the public shall be ALARA (no mention of economic and social factors being taken into account), and, in any case
- doses to hypothetical individuals from all potential exposure pathways shall be less than 0.01 mSv.

2.2.9 USA

Regulations governing HLW and transuranic waste repository performance for facilities other than the candidate repository at Yucca Mountain have been given in 40 CFR Part 191. However, the Energy Policy Act of 1992 requires new standards to be promulgated for the Yucca Mountain site. The Act states that the standards shall prescribe the maximum annual effective dose equivalent to individual members of the public from releases to the accessible environment from radioactive materials stored or disposed of in the repository [Wilson et al, 1994]. Note the use of pre ICRP-60 dose terminology [ICRP, 1991] (See also footnote 2). The further interpretation of the Act's requirements as regards individual doses will be based on the recently completed study conducted by the National Academy of Sciences (NAS), from which the Environmental Protection Agency (EPA) will develop new standards and then finally the Nuclear Regulatory Commission (NRC) will make its new standards consistent with EPA's. Refer to the Appendix for a very brief discussion of this NAS study.

Although 40 CFR Part 191 no longer applies to Yucca Mountain, two other performance requirements defined there are relevant to the form a new individual dose-based standard might take. Firstly section 191.15 states that, for undisturbed repository performance, there should be a reasonable expectation that for 10,000 years that the annual committed effective dose to any member of the public in the accessible environment will not exceed 15 mrem (0.15 mSv), originally 25 mrem (0.25 mSv). This sounds similar to a dose limit for normal scenarios, as suggested by ICRP (see Section 2.1) but there is no mention of a critical group. Secondly, section 191.24, also amended from its original form, says that radionuclide concentrations in underground sources of water should not exceed limits given in 40 CFR Part 141. This standard is effectively limiting annual individual doses from drinking water to 4 mrem/y, or 0.04 mSv/y. However, this translation to a dose limit, presented in Wilson et al [1994], does not allow for changes in dose definition and dosimetry recommendations given in ICRP [1991]. Thus the concentration limits no longer correspond to the 4 mrem limit, at least according to ICRP.

40 CFR Part 191 also sets containment requirements which have the effect of limiting cancer deaths to less than 1000 within 10,000 years [EPA, 1985a]. Because of the assumed relationship between dose and risk this is effectively a limit on the collective dose commitment, truncated at 10,000 years. However, revised risk estimates per unit dose [ICRP, 1991] mean that the implied limit on collective dose has changed. The population of concern here is not a critical group, but all exposed people. However, the largest contribution to collective dose could arise locally, so assumptions for the local and regional populations are relevant. In EPA [1985b] it says that it is pointless to try to make precise projections of the actual risks over such long time periods. Accordingly, only very general models of environmental pathways (should be used) and population characteristics assumed (should be) similar to today.

2.3 Key Summary Points

While most regulations and guidance refer to ICRP and claim consistency with the ICRP radiological protection objectives, the interpretation of those objectives varies so far as definition of the individual(s) is concerned whose exposure is to be compared with limits. A similar conclusion was reached by a group of NEA experts as regards the limits themselves [NEA, 199].

ICRP have yet to pronounce on the solid waste management implications of the latest revision of their basic recommendations [ICRP, 1991].

Most, if not all, agree that identifying the most exposed person and their exposure is not a practical objective. The actual behaviors (and exposures) cannot be precisely determined for the far future, and to attempt to identify a hypothetical worst case leads to a slippery slope of increasingly pessimistic assumptions. In the extreme, the assumptions for behavior become inconsistent with the metabolic basis behind the definition of effective dose [ICRP, 1991]. This does not necessarily rule out consideration of specialist activities, such as wildfowl hunting and eating, which involve unusual but not extreme behavior. (For example, eating wildfowl was among the critical group activities identified in Robinson et al [1994] relevant to present day activities. Thus, for long term assessments, perhaps eating wildfowl is a relevant activity to consider among the alternative exposure scenarios, but it would not be appropriate to assume the group concerned eat a whole duck every day of the year.)

The wording of the different regulations and guidance varies considerably, but the effect usually is to require some kind of assessment to be made of the more likely highest exposures, based on some set of human behavior assumptions associated with a homogeneous group located in time and place where the environmental concentrations are highest. The regulations sometimes offer background guidance on what this may mean, but in general it is only partially helpful.

'Homogeneous' is not clearly defined in regulations applied to solid waste disposal. Robinson and Simmonds [1992] refer to ICRP's suggestion that the distribution within a critical group should range within a factor of ten, i.e. a factor of 3 either side of the mean. However, the concept is difficult to apply unless some idea is already known of the dose distribution. They therefore recommended further work, and this was in the context of the more tractable case of present day releases.

The different time frames to be considered can affect what may be required for critical group definition. That is, in some cases, consideration beyond 10,000 years is not required or is not required is so much detail.

So far, no regulator appears to require direct consideration of exposures to people other than adults, though the wordings do not rule this out either.

The regulations and regulatory guidance are less advanced than the development of the concepts through actual performance assessments, discussed in the next Section.

3. Application of the Critical Group Concept in Performance Assessments

This Section presents examples of how regulators, operators and others have practically interpreted requirements on dose calculations relevant to critical groups in actual performance assessments. The discussion in each case is not comprehensive as regards each assessment, nor are all assessments from each country reviewed. The objective is to illustrate regulatory interpretation and some of the features and problems of those interpretations.

3.1 United Kingdom

There have been no recent assessments of HLW disposal in the UK, but regulators, primarily Her Majesty's Inspectorate of Pollution (HMIP), as well as the waste management company, UK Nirex Ltd., have been assessing deep geological disposal of low and intermediate level waste (L/ILW) in preparation for such a proposed repository.

Sumerling and Martin [1992] set out the exposure basis for the developing HMIP assessment methodology. Four climate states are considered: glacial, tundra, boreal and temperate. No assumptions are assumed for the glacial state, when the site is covered by ice. Subsistence agriculture is assumed for the other states. Conditions at the site, which is currently temperate, during boreal and tundra climates have been derived from analogue sites presenting these conditions today. These data affect the biosphere compartment model parameters. However, for all three states it is assumed that exposures arise from radioactivity in the following compartments:

- spring water and near-surface groundwater,
- general catchment soil and river water,
- groundwater discharge soil and river water,
- water abstraction soil and river water,
- exposed estuary soil and marine river water,
- estuary water and sediments, and
- nearshore water and sediments.

The consumption rates, breathing rates and occupancies are the same for tundra and boreal states. Although the overall methodology is described as 'probabilistic', whereby many model parameters are sampled from according to a 'probabilistic risk analysis' procedure, the parameters for the critical group exposure are not sampled within this procedure.

The exposure basis for the critical group includes all the above assumptions, which in turn relate to the structure assumed for the surface environment at the time of release. The particular parameters which relate critical group behavior to exposure are given in Table 1. It should be noted that these parameters have been chosen consistent with the overall conceptual model. They have not been chosen independently from the rest of the assessment model, e.g. by reference to regulations, which, in this case do not provide that level of detail.

The numbers for terrestrial foodstuffs are not said to be critical consumption rates because the exposed individual is assumed to eat all of the foods. Critical rates for individual foods are mostly a factor of 2 or 3 higher. (If they ate all foods at the critical rates, they would not have the 'reference man' characteristics [ICRP, 1975] assumed in determining values of dose per unit intake [ICRP,1979-83] and as discussed in ICRP 60 [ICRP, 1991].)

The marine exposures are considered separately. Note that, under the changed climate there is a bigger assumed reliance on fish and less on (local) terrestrial foodstuffs.

While various references are given for these numbers, there is no obvious relationship between the justification for these numbers and the regulatory requirements, beyond that the numbers speak for themselves.

Table 1

	Consumption rate, kg/y	
	temperate	tundra/boreal
grain	80	0
root vegetables	80	0
green vegetables	40	0
herbaceous fruit	10	0
beef	40	40
cow liver	2	2
milk	150	150
pig meat	10	10
pig liver	1	1
chicken	10	10
eggs	10	10
water	600	600
freshwater fish	20	51
marine fish	110	229
mollusks	7	7
crustaceans	18	18
seaweed	10	10
	Occupancy, h/y	
farmland	8760	8760
estuary	2000	2000
	Breathing/ dust	
farmland	1.05E4 m^3/y	1.05E4 m^3/y
dust in air	5E-8 kg/m^3	5E-8 kg/m^3

3.2 Sweden

Several major assessments of HLW disposal have been carried out in Sweden. Project 90 was the most recent major assessment carried out the Swedish Nuclear Power Inspectorate (SKI), but was completed prior to publication of the HLW guidance document [Nordic Radiation Protection and Nuclear Safety Authorities, 1993].

Calculation of doses in Project 90 due to release of radionuclides in groundwater was presented in Charles and Smith [1991]. Limited emphasis was placed on the biosphere in the overall assessment, the greatest concern being with developing an understanding of near field and far field barriers. A dose calculation was required however, to determine barrier performance in terms relevant to radiological protection requirements.

Following the suggestion in SKI/SSI/SKB [1989] a reference biosphere was chosen, based on release into a lake typical of central Sweden. No allowance was made for climate change, perhaps anticipating the emphasis given in the Nordic document referred to above on dose evaluation in the first 10,000 years. Changes in the lake over the period of release were allowed for, as discussed in a BIOMOVS Technical Report [Smith, 1989]. Consideration was also given to the use of contaminated well water for domestic and agricultural use, including irrigation.

Critical group data, for adults only, were assumed to be the same in both cases, as given in Table 2.

Table 2	Consumption rate, kg/y
water	600
root vegetables	120
green vegetables	80
grain	130
milk	300
beef	60
cow liver	20
mutton	30
sheep liver	20
freshwater fish	20
occupancy	1000 h/y
inhalation rate	1 m^3/h
dust in air	1E-10 t/m^3

These numbers were largely taken from data used in UK assessment of SLB. Each pathway was considered separately; it was not considered likely that such high consumption rates should apply to more than one pathway. Results are presented for three major exposure pathways for each radionuclide on a unit release rate basis into the lake or well. Results for the drinking water dose are always presented as these are recognized as less uncertain. (Water consumption is not very variable and there is no detailed migration and accumulation modeling through the biosphere. Some concentration reduction may occur for those radionuclides scavenged from the water column and lost to bottom sediment.) Uptake in the terrestrial foodchain, including animal products, appears more important than the drinking water pathway for some radionuclides, assuming irrigation takes place. Fish consumption is a more important pathway for several radionuclides for release to the lake. For Sn-126, a radionuclide with relatively low biological uptake but a high intensity high energy gamma emission, external irradiation dominates by more than an order of magnitude over ingestion of drinking water. Although the detailed modeling assumptions made may not be directly applicable at other sites and other parameter values could be adopted, these results strongly suggest that drinking water does not necessarily result in the highest individual doses. The degree to which these other pathways are important will depend on the particular radionuclides released, and the receiving environment (here, a lake or a well), but also upon the assumptions for farming practice and land use.

Smith and Charles [1991] briefly considered the implications for doses to infants and children. Generally, the higher committed doses per unit intake for children were balanced by lower intakes, so that differences were less than a factor of 3. Some pathways were higher for infants by a factor of 6 for some radionuclides. Revised dosimetry assumptions, notably gut transfer factors for children, could increase these differences.[5]

The description in Smith and Charles [1991] highlights the importance of the geosphere/biosphere interface assumption. The volumetric flow provided by the lake offers several hundred times more dilution (and hence lower doses) than the same radionuclide flux to the well. While the particular number for dilution may be somewhat arbitrary (both the well and the lake were conservatively assumed to be relatively small), the dilution which can occur due to mixing with near surface waters would generally be significant, as the factor of several hundred suggests. Of course, the radionuclide flux to the well may not be the same as the flux to the lake; this would depend on many geological parameters as well as assumptions for the operation of the well. The latter are directly concerned with assumptions for the critical group.

3.3 Switzerland

Project Gewaehr [Nagra, 1985] presents methods and results for assessment of deep geological disposal of HLW and L/ILW. It was suggested that the study of man and his environment involves the greatest uncertainties as far as extrapolation over very long timescales is concerned. Although lifestyles may alter, human food requirements remain constant, giving a basis for quantitative estimates of radionuclide uptake.

A base scenario for biosphere analysis was adopted, assuming present conditions. A warmer climate state, necessitating irrigation for sustained agricultural production, and a cooler tundra climate have also been considered [Grogan, 1985].

The release of radionuclides from the geosphere to the biosphere was considered to be in contaminated groundwater; different groundwater release conditions were assumed for the L/ILW and HLW repositories because of the different groundwater flow systems associated with each repository. This results in different dilution at the geosphere-biosphere interface. A wide range of exposure conditions was assumed involving foodchains, inhalation and external irradiation. The high variability in concentration ratios in the foodchain (typically 2 to 6 orders of magnitude) was noted and 'rather conservative' values were assumed in the data-base. The assumed consumption

[5] New data are due to be available within weeks, in ICRP Publication 68.

rates for the critical group were as given in Table 3.

Table 3	Consumption rate, kg/y
cereals	145
root vegetables	231
leafy vegetables	60
meat	95
milk	332
drinking water	730
eggs	200 (eggs)
fish	2

Compared with the HMIP values, section 3.1, some of these values are high, e.g. root vegetable consumption is about 3 times higher here. This is explained by the fact that each exposure pathway is considered separately in this assessment. This is generally a more conservative approach. That is, the highest dose arises if you do the most of the worst thing; adding up over all pathways, each of which has only a moderate 'consumption' assumption is less conservative, but also introduces lots of arbitrary detail concerning the make up of the total diet which is hard to justify over long timescales. Such detail also appears superfluous compared to the variation in concentration ratios already referred to.

More recent work has considered the dose arising from release of radioactive gases [Grogan et al, 1992]. This includes assumptions about building occupancy and building air change rates, since release into a building results in much higher breathable air concentrations of radionuclides than release to the open atmosphere.

Not that this assessment work was completed before the latest Swiss regulations were promulgated [HSK/KSA, 1993]. Further assessment work is on-going.

3.4 Canada

Atomic Energy of Canada Ltd (AECL) have completed a comprehensive assessment of HLW disposal. The purpose of the assessment was to demonstrate the feasibility of the disposal concept. It includes a more detailed evaluation of the biosphere than most other assessments.

The biosphere modeling is described in Davis et al [1993]. Since the regulatory objectives focus on the first 10,000 years [AECB, 1987], the dose calculations also focus on that period, based on a generic Canadian Shield environment.

Changes in conditions in the biosphere are taken into account, and anthropogenic effects are discussed. However, in the face of the uncertainties, it is assumed that human activities will not alter the biosphere in any fundamental way over long periods of time.

The Canadian assessment methodology is based on a systems variability analysis approach. The model output is a statistical expression of the consequences predicted in a large number of individual assumptions. The effect of human actions on many of the model parameters is already reflected in the parameter distributions from which values are sampled in each simulation. Natural changes, such as the gradual filling of a lake by sediments and the eventual use of lake-bed sediments for agriculture are considered. In this case, instead of considering the consequences in isolation (such a process is pretty well bound to occur during a period of peak radionuclide release from the geosphere) predicted concentrations in soil are replaced with those (higher) levels in lake-bed sediments in 1% of simulations. On average, this could be a reasonable assumption for the Canadian Shield. (The lack of knowledge of when exactly the process occurs results in dilution of the predicted peak annual risk. They would actually be higher for a small proportion of the time.)

Taking dynamic account of the drying out process introduces complications about assumptions for human use of the sediments and related critical group assumptions. If the drying occurs slowly, then the more highly contaminated area of sediment is only slowly exposed for use. What fraction of the critical group behavior should be associated with the small contaminated area arising each year? By the time a large area is exposed, contaminants may have been leached. Human actions, or natural events, might result in more rapid draining of the lake, and higher exposures. These issues were discussed in a BIOMOVS report [Smith, 1989] and alternative suggestions offered. In the Canadian model, no allowance is made for radionuclide losses from the sediments as the lake-side sediments dry out, which is probably a conservative assumption. Including this in 1% of simulations is probably not conservative. An alternative approach would be to evaluate a separate scenario in which the lake is drained, and to present results for that.

The Canadian model includes specific consideration of the interface between the transport in the geosphere and the biosphere. Separate consideration is given to how exactly release occurs into sediments, surface waters, soils and (shallow) wells. This is followed through with consideration of culturally determined parameters, e.g. how these media are used or could be used in ways giving rise to exposure. This is important within the model not just because the parameters directly affect the exposure, but also because the use assumptions affect radionuclide migration in the respective media. Probabilities are set on some practices, e.g. irrigation.

A very wide range of exposure pathways is considered, including immersion in contaminated waters and atmospheres indoors and outdoors, soil ingestion as well as the more normal ingestion, inhalation and external irradiation pathways. The assumptions are based on present Canadian Shield practices. Distributions of behavior are provided, some based on the local environment and potential for exploitation, some more fundamentally based on the human body. The geometric means are presented in Table 4.

Table 4	Geometric mean, consumption rate, kg/y
terrestrial plants	375.7
milk	199.4
meat	130.9
bird	53.2
fish	10
water	641
air inhalation rate:	8617 m^3/y

Occupancy times and other human related parameters relevant to the other exposure pathways are provided, some of them treated probabilistically. Some parameters used appear to duplicate assumptions implicitly built into the models used for dose per unit intake. The Canadian Assessment [Davis et al, 1993] uses values of dose per unit intake provided through application of similar models to ICRP [1979-83]. The results do not appear to be used probabilistically within the overall assessment.

It is hard to understand the need for some of this detail or, alternatively, to justify some of the distinctions made. For example, concentration ratios to liver for some radionuclides are orders of magnitude higher than to average meat. Separate consideration of liver (as in the HMIP assessment, Section 3.1) would seem to be more relevant than the detail of the distribution on total meat consumption.

The total dose to members of the critical group is formed by summing over all pathways, radionuclides and, where appropriate, food types. Total intakes are normalized to be consistent with requirements of a modern Canadian adult male, which are marginally higher than ICRP reference man requirements [ICRP, 1975].

Davis et al [1993] also present dose assessments for non-human biota. The link between assessment criteria and the dose assessment is described in Amiro and Zach [1993]. The doses to target biota are assessed using models similar to those for human dose assessment.

The approach adopted permits a statistical estimate (the arithmetic mean) of the distribution of consequences to be made for an exposure scenario, as required by the regulator, see Section 2.2.4. The background data on distributions of input parameters are very valuable. However, the justification of what counts as a separate scenario is not very clear. The problem, as in other assessments, is how to decide what temporal and spatial averaging to make in determining the average critical group exposures. The Canadian assessment presents more information than most, but does not especially justify itself any better.

3.5 France

No comparable published assessment of HLW disposal has been published in France. ANDRA (Agence Nationale pour la Gestion des Dechets Radioactifs) has recently started a collaborative project with the Spanish waste management company, ENRESA (Empresa Nacional de Residuos Radiactivos SA), to develop a methodology to integrate climate evolution in biosphere studies in the context of a HLW repository [Menut, 1995]. The approach includes developing assumptions for a Mediterranean biosphere and a boreal biosphere, both of which could be relevant in France and Spain in the long term. This includes developing assumptions for critical groups for each ecosystem. The basis is given as a self-sustaining community, characterized assuming realistic assumptions under current terrestrial conditions and average traditional skills in agriculture. In addition, consideration is being to a critical group based on modern bio-industrial systems.

3.6 Japan

The Japanese Power Reactor and Nuclear Fuel development Corporation (PNC) has published a first progress report on HLW disposal and assessment [PNC, 1992]. For this preliminary work, only a simple dose calculation was made based on consumption of drinking water. Dilution of the geosphere release in 'biosphere' water was assumed to range from 1E4 to 1E8 m^3/y.

The National Institute for Radiological Sciences has produced a Japanese Reference Man [Tanaka et al, 1989], whose characteristics differ from the ICRP reference man [ICRP, 1975]. Cancer propensities for different organs vary significantly among populations. This could affect judgments on organ weighting factors applied in different regions. The implication is not that such distinctions should necessarily be introduced in assessments, but at least be aware of possibilities.

3.7 Finland

Vieno [1994] sets out a stylized well scenario for use as an indicator in assessing the performance of the near fields and geosphere barriers of a deep repository. The scenario assumes releases from the repository are diluted in 100,000 m^3 of water and that an individual drinks 500 litters of water per year. Drinking water is the only exposure pathway considered. It is noted that this result could be achieved many ways, e.g. if 1% of the repository release is abstracted in a well of flow 1,000 m^3 per year.

3.8 USA

Andrews, Dale and McNeish [1994] provides a recent evaluation of the Yucca Mountain proposal.

Here a geosphere release into the accessible environment (which can be below ground) is diluted by an aquifer flow to provide a concentration in groundwater. Factors to convert these concentrations to doses are taken primarily from Eslinger et al [1993], who were considering the same subject. Several exposure scenarios are considered which include use of contaminated aquifer water for irrigation. Consumption rates of farm products assumed are:

Table 5	consumption rate, kg/y
leafy vegetables	15
other vegetables	276
eggs	20
meat	80
milk	230
poultry	8.5
(aquifer) water	730

The farm is assumed to have an irrigated area of 20,000 m^2, requiring a flow from the well of at least 1.8E4 m^3 per year. The time spent outdoors (presumably on contaminated soil) is 4380 h/y. These data were taken primarily from the Hanford Defense Waste Environmental Impact Statement produced for the Department of Energy (DOE) [DOE, 1987]. Site specific issues would seem not to make a difference. However, both sites are dry.

A gaseous release of C-14 was also assessed, but with release direct to atmosphere as opposed to a confined space, as evaluated in the Nagra assessment (see Section 3.2). This is a further illustration of the importance of assumptions for the geosphere-biosphere interface. Would gaseous release be disperse or, predominantly, through a single, or relatively few fissures? The answer would affect sensible assumptions for the critical group. It also reflects the importance of the assessment purpose. That is, the more pessimistic Nagra calculation was intended to identify if there was a potential dose problem requiring more detailed assessment. The calculation was not made in a directly regulatory context.

More detailed critical group assumptions are made in the assessment of contaminated land, e.g. [Nimmagadda and Yu, 1993], where hypothetical situations are of concern, but not so far into the long term future as for HLW disposal. An assumption is made here for soil ingestion, 0.0365 kg/y. Consumption rate assumptions are generally lower but include a wider range of foods.

The Electric Power Research Institute (EPRI) present an assessment approach in EPRI [1994]. This uses the same dose calculation approach and critical group assumptions as in Project 90 [Charles and Smith, 1991] and then adopts a probabilistic approach to determine the associated risks. Some components of the probability of exposure arising are consistent with other approaches, e.g. allowing for the probability that a well is sunk into the accessible contaminated region. (In other countries, the deep geology would not be called accessible. Assuming that it is accessible, but only 5 km from the repository [Wilson et al, 1994], sounds illogical in the context of well drilling. Why would no-one drill a well within the so-called un-accessible region?) Other assessment factors treated probabilistically involve allowing for aspects which are not consistent with ICRP advice and the more common wider interpretation. (See Section 2.) For example, no allowance would normally be made for the chance that contamination would be detected and mitigating action taken, as in EPRI [1994].

Neel [1995] describes the dose model in the latest NRC iterative assessment of Yucca Mountain. Consideration is given to doses to a hypothetical critical group based on a family of three living on an average farm of 'approximately 1093 hectares'. All the other assumptions about this group are similarly precise and have to do with present practice in the region. For example, vegetables and many other foods are assumed to come from outside the region and are uncontaminated. No allowance appears to be made for the more natural exploitation of the region. Such exploitation has been the subject of debate with regard to the Nez Perce tribe and the Hanford Reservation [Harris, 1994].

3.9 International Assessments

IAEA and other international bodies sometimes coordinate international assessments, usually in a generic context, i.e. omitting site specific considerations. The purposes either concern methodology development or production of generic values for waste management quantities, e.g. disposal limits. The methods applied are usually applications of nationally developed methods, but the international context introduces wider discussion of parameter values. Such wider discussion could be useful in the context of long term hypothetical exposure situations.

IAEA [1987] considered hypothetical consumption rates in a waste disposal context and adopted the following values while acknowledging the associated ranges:

Table 6 Consumption rates, kg/y

	Selected value	Reasonably expected range
green vegetables	40	20 - 80
milk	100	50 - 200
meat	50	20 - 100

Interestingly, the upper limit on the milk range is less than the value assumed in Project Gewaehr and Project 90, see Sections 3.2 and 3.3.

The CEC has coordinated a multi-national assessment, PAGIS, of HLW disposal in a variety of geological conditions at various hypothetical choices for disposal sites [CEC, 1988]. Different release situations were considered for the different geologies, but common critical group consumption rates were applied (Table 7). The justification for the numbers appears to be that they are higher (but still reasonable) than numbers obtained from European surveys, primarily a study by NRPB [Harrison and Simmonds, 1980]. A similar CEC study, called PACOMA, was carried out for ILW. The application to PACOMA to a clay site in Belgium was reported in CEC [1991]. Consumption rate data for this study were taken from Belgium surveys.

Table 7 Consumption rate, kg/y

	PAGIS	PACOMA (Belgium)
grain products	130	110
root vegetables	120	140
green vegetables	80	50
beef and veal	60	50 (total meat)
mutton and lamb	30	-
milk	300	160
milk products	40	-
pig meat	60	-
offal	20	2
chicken	30	-
eggs	30	-
water	730	400
fruit	60	-
freshwater fish	7	5
marine fish	55	-
mollusks	7	-
crustaceans	18	-

Each pathway was considered separately.

3.10 Key Summary Points

The exposure pathways considered in most assessments include all the main exposure modes: ingestion, inhalation and external irradiation. Skin adsorption and intake via skin puncture are not commonly considered.

The particular pathways are not defined in quite the same way. For example, sometimes a distinction is made between different types of vegetables, whereas sometimes they are lumped together. Another example, inhalation of dust is considered in many assessments but not necessarily under the same circumstances. That is, normal dust levels might be assumed and associated with a high dust occupancy; alternatively high dust levels associated with agricultural practice such as plowing may be assumed, but with correspondingly low occupancy. These differences make it problematic to present and compare data from different assessments in one table. The reasons for inclusion and exclusion of particular pathways may well be influenced by the availability of models already developed and accessible for use in the assessment.

Most assessments do not consider doses to non-adults, although the critical group concept as applied to present day releases does include such people [Robinson et al, 1994].

Most assessments assume a self-sustaining community, which is (reasonably) pessimistic since it implies a high proportion of foodstuffs derived from the contaminated area. Apart from the ANDRA project, Section 3.5, little recognition seems to be given to modern intensive agricultural practice which has greater potential for concentration of radionuclides due to higher productivity. Intensive exploitation of an area has been suggested by an SKI/SSI/SKB working group as one of the situations to consider [SKI/SSI/SKB, 1989].

The Japanese assumptions (Section 3.6) graphically illustrate the importance of the geosphere-biosphere interface assumptions. Does the receiving body of surface water have a large or small volumetric flow? For direct releases to soil or sediments, what is the area of discharge? The relationship between these parameters and critical group assumptions should be consistent.

Comparison of critical group assumptions directly related to exposure, e.g. root crop consumption rate, does not reflect strongly the relative degree of conservatism in assessments. Much more important are assumptions for 'dilution' at the geosphere-biosphere' interface and the assumptions for concentration ratios which relate radionuclide concentrations in media such as those in soils to those in foodstuffs.

In most assessments and regulatory guidance, the deep geological environment would be not be considered accessible and so some credit is taken for the low chance that a well would be sunk at considerable depth at the location of groundwater contamination. This does not appear to be the case in the USA since 40 CFR Part 191 defines deep geology as accessible, so long as it is at some distance from the repository. At Yucca Mountain, this may be appropriate with respect to groundwater abstraction since the site has no usable surface water.

Overall, previous assessments have either provided too much detail for particular exposure conditions, which cannot be justified, or not considered a sufficiently convincing range of indicative examples of exposure, or both.

4. Recommendations for Definition of Critical Groups Applicable to HLW PA of Yucca Mountain

4.1 Background Assumptions and Objectives

The particular purpose of an assessment should affect the detail in assumptions for critical groups. Concept approval assessments may have less detail compared with assessments carried out specifically to license real disposals to well characterized facilities. Less detail is required, for example, for comparing engineering options [Vieno, 1994].

Yucca Mountain is a specific site and it is assumed that the objective here is to define a critical group in terms relevant to demonstrating compliance with regulatory requirements for HLW disposal at that site. Regulatory requirements are under development.. Therefore the requirement is still somewhat undefined. However, it is assumed that there will be a need to assess annual individual doses to those in the vicinity of the repository most likely to be affected. At this stage, consideration is limited to exposures arising from undisturbed performance of the repository. In the USA context this includes deep well abstraction of contaminated water, at some distance from the repository.

The logic of the examples presented above suggests that the critical group assumptions should not be divorced from the overall assessment methodology. That is, different assumptions will be relevant to different types of release from the geosphere. Based on current assessments [Eslinger et al, 1993; Wilson et al, 1994 and Andrews et al, 1994] the main release is via contaminated groundwater, though the past regulatory requirements have not emphasized consideration of how release into the biosphere occurs, except via wells. Gaseous release of C-14 is also relevant. Because of the potential for different types of release, including different radionuclides under different near and far field scenarios, more than one critical group is anticipated to be necessary.

It is assumed that there is no intention to try to calculate the highest dose which might occur under any circumstances. The intention is to define groups who would be likely to receive among the highest doses and to calculated some representative average dose to members of that group.

4.2 Qualitative Critical Group Descriptions

Reliable prediction of human behavior is assumed to be impractical. It is therefore problematic to define the circumstances of those in the vicinity of the repository. It is therefore considered appropriate to provide a range of assumptions for critical groups which:

- reflect the types of release discussed above,
- allow for all the major potential modes of exposure, in ingestion, inhalation and external irradiation,
- reflect the potential for exploitation of the site vicinity under the conditions of climate which might pertain at the time when releases occur, but with emphasis on those timescales emphasized by regulatory requirements, currently the first 10,000

years, and taking account of different behavior patterns associated with intensive and non-intensive land use.

The inherent subjectivity in the choice of temporal and spatial averaging is openly acknowledged.

To avoid overly detailed and hence arbitrary critical group definitions, the circumstances giving rise to particular exposures should be defined in general terms which could apply to several different behaviors.

The parameters quantitatively describing the exposure should be clearly defined so that alternative values can be substituted.

Ingestion pathways should include:

- root vegetables
- other vegetables, to include fruit
- meat
- offal
- milk
- water
- freshwater fish
- dirt

This is intentionally a short list. The hope is that any other ingested material would fit into one of these categories. There may be a need to add invertebrates or some other broad category. Note that their is large uncertainty about notionally normal foodstuffs.

Inhalation pathways should include:

- gases
- dusts
- aerosols

External irradiation pathways should include from:

- contaminated surfaces
- bulk contaminated materials
- immersion

Again, these lists are intended to be short but comprehensive. The idea is that we all eat , drink and rest somewhere and you can only sleep in one bed at once. The analysis should be kept that simple.

Definition of the surfaces and dust generation mechanisms, etc., awaits development of the FEPlist and RES matrix[6]. These suggestions have implications for their generation but there is also expected to be some feedback from their generation, leading to a final version of this report.

Within the RES matrix construction a range of references and brief calculations can be used to demonstrate that the consequences two or more nominally different exposure routes are similar, or to justify exclusion on the basis of insignificance. These appear to be the chief mechanisms for limiting the scale of detail. This approach can be used as regards inclusion of children and infants. They have to be considered in the analysis but not through an infinite variety of behaviors. It may still be appropriate to consider some special non-adult pathways.

4.3 Quantitative Critical Group Description

It is proposed that each pathway is considered in isolation so that the influence of different assumptions for each pathway is transparent. The scope for addition over pathways should also be acknowledged.

Consumption rates should be chosen that are typical under the circumstances of exploitation assumed. For example, subsistence communities tend to eat more of a limited range of resources. Intensive farming practices may result in higher concentrations but a wider variety of foods, each with a lower consumption rate. A reasonable range should also be provided, to allow sensitivities to be examined. The 'reasonable' ranges should be explicitly recognized as reliant largely on subjective judgments.

Final numbers will be provided here in the light of the NAS report and in the light of the task to produce a Yucca Mountain FEPLIST and RES matrix. Detailed requirements have yet to be finalized but will apply to the assessment context given in the other task report [Smith, Watkins and Little, 1995].

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[6] These are being developed in a separate report for EPRI

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6. Acronyms and Abbreviations Used

AECB	Atomic Energy Control Board, Canada
ANDRA	Agence Nationale pour la Gestion des Dechets Radioactifs, France
BIOMOVS	Biosphere Model Validation Study, International
CEC	Commission of the European Communities
DOE	Department of Energy, USA
ENRESA	Empresa Nacional de Residuos Radiactivos SA, Spain
EPA	Environmental Protection Agency, USA
EPRI	Electric Power Research Institute, USA
HLW	High Level (radioactive) Waste
HMIP	Her Majesty's Inspectorate of Pollution, UK
HSK	Swiss Federal Nuclear Safety Inspectorate
IAEA	International Atomic Energy Agency
ILW	Intermediate Level (radioactive) Waste
ICRP	International Commission on radiological Protection
KSA	Swiss Federal Commission for the Safety of Nuclear Installations.
L/LLW	Low Level (radioactive) Waste
MAFF	Ministry of Agriculture, Fisheries and Food, UK
NAGRA	National Cooperative for Storage of Radioactive Waste, Switzerland
NAS	National Academy of Sciences
NCRP	National Council on Radiation Protection and Measurements, USA
NEA	Nuclear Energy Agency, Paris
NRC	Nuclear Regulatory Commission, USA
NRPB	National Radiological Protection Board, UK
PA	Performance Assessment
PNC	The Japanese Power Reactor and Nuclear Fuel Development Corporation, Japan
PNL	Pacific Northwest Laboratory, USA
SKI	Swedish Nuclear Power Inspectorate
SLB	Shallow Land Burial
SSI	Swedish Radiation Protection Institute
STA	Science and Technology Agency, Japan
UK	United Kingdom of Great Britain and Northern Ireland
USA	United States of America

Appendix: Review Comments on the National Academy of Sciences Report on Technical Bases for Yucca Mountain Standards

The following points are given in the sequence they arise in the report, rather than in order of importance. The points raised are those seen as pertinent to establishment of standards and EPRI interests, particularly as regards assumptions for critical groups.

1. Page 17. Section 801 of the Energy Policy Act requires that EPA produce a standard that prescribes 'the maximum annual individual effective dose equivalent to individual members of the public from releases to the accessible environment.' Effective dose equivalent is a radiation quantity which was superseded in 1991 in ICRP 60 [ICRP, 1991]. The up to date corresponding term is called effective dose, but technically is slightly different and well as being verbally different.

2. Natural discharge to the surface of the aquifer below Yucca Mountain is said, page 26, to be at Death Valley, to the southwest. This is a distance of 40 to 50 miles. NAS go on to describe radionuclide release in groundwater to the accessible environment as being via wells or springs. Within the repository vicinity, only wells deeper than several hundred meters would reach the contaminated aquifer.

3. Table 2.3 is very out of date; see Section 2 of main text of this report.

4. Footnote 3, page 42, does not explain very well the distinctions among lifetime dose, lifetime risk, and lifetime risk due to exposure and intakes arising in a year. It is the latter upon which ICRP, e.g. in ICRP 46 [ICRP, 1985] seek to set limits etc. Once activity is taken into the body, say during one year, you are committed to further dose in subsequent years to the extent that the radionuclide may still remain in the body. 'Effective dose equivalent' and 'effective dose' both include this element of commitment once the intake has arisen, as do the data for risk per unit dose. The means that derived data for risk per unit intake are, among other things, age dependent. If you take activity in young, you have a greater committed dose and hence a greater risk of receiving a detrimental health effect. The values of dose per unit intake for adults assume that intake arises at 20 y of age and that the individuals die at 70 y of age. If you take this value of dose per unit intake (the 50 y committed effective dose, or effective dose equivalent) and multiply by NAS's suggested 5E-2 per Sv to convert it to risk, then you are assuming the critical individual is a healthy 20 y old. All this is standard stuff, but is relevant because it sets some constraint on the critical group definition. It would not be sensible to assume different individuals (i.e. anyone other than a healthy 20 y old) in the critical group, or, if you did, you ought also to modify the dosimetry and risk data too.

5. Page 42. NAS are correct to say the dose received over a lifetime is commonly calculated, but only with respect to each individual year's intake. It is not common in radiological protection generally to calculate lifetime doses from a lifetime's intake. The idea of calculating lifetime intakes and limiting on-going body burdens was dropped by ICRP nearly 20 y ago in Publication 26 [ICRP, 1977] because it was deemed unreasonable to allow a high intake this year on the basis that you would keep future intakes very low. Under the ICRP 26 scheme, each year is treated separately and is not constrained by what you did previously. The only situation where lifetime doses and intakes are considered is in dose reconstruction and claims for damage, where the total risk to the individual becomes relevant. According to ICRP recommendations and application in most countries is concerned, for on-going radiological protection, including radioactive waste management, control is exercised over each year. Lifetime doses are not commonly calculated.

6. Page 47 includes reference to an 'effective-dose' standard required by Section 801. However, it says earlier that Section 801 requires a standard is required based on 'effective dose equivalent'. These two things are not the same and NAS should not confuse them. While this no doubt appears like trivial pedantry, such lapses could make regulatory interpretation difficult. For example, if EPRI asked for an 'effective dose equivalent' dose calculation to be made, competent assessment groups would give a different answer from that if an 'effective dose' calculation were requested. Of course, ICRP might have done better in the past with their naming conventions.

7. Page 49, at top. For global collective dose, C-14 uptake is dominated by through the foodchain. For 'maximum' individual doses it is not so obvious that the foodchain dominates; it depends on the particular nature of the gaseous release. It is unfortunate that NAS have not been clear about which assessment end point they are referring to here. See also p. 83 and 87 which compound the confusion.

8. Page 54. NAS define the critical group as having to be homogeneous with respect to risk, meaning having a risk range in the group of less than a factor of ten, or less if near or above the limit. Since you do not know the risk range to which the group will be exposed before you start the assessment, you cannot define, or defend, the assumptions for critical group before you do the assessment. This is acknowledged in Appendix C. However, if you define the critical group after you've done most of the assessment, i.e. you modify the definition to make the group homogeneous, you could also be open to criticism for fixing the result.

9. Page 64. NAS say release limits standards would not be easy to compare with other risks. In the context of comparison with releases of natural radionuclides, say, from the same rock volume as occupied by the repository, such comparison would be easy and, arguably, instructive. See discussion in Nordic Radiation Protection and Nuclear Safety Authorities[1993] about the regulatory application of this concept. (This is an example of how Table 2.3 is out-

dated.)

10. Figure 3.2 shows climate change affecting the water table but not affecting the critical group. NAS do not discuss this here, but it is hard to see how it could fail to have an effect, at least requiring comment. The point is raised on p. 92.

11. Having dismissed the need to do more than assess critical group risks by p 65, NAS go on to consider global dispersion, e.g. p. 88, which is unnecessary and confusing.

12. Discussion in the middle of P. 96 appears to ignore gas release and the eventual natural discharge of contaminated water to the surface. If read out of context from other parts of the report, which do include these as relevant issues, the text is very misleading.

13. Footnote 2, page 98. Says 'One, or at most a few, exposure scenarios' is enough for defining the standard, except that one should perhaps allow that this applies for each geosphere release type. There should, for example, at least be separate exposure scenarios for gaseous and groundwater releases. This is acknowledged in Appendix C.

14. Last sentence on page 101. ICRP probably did not intend this interpretation. Rather, for any critical group, such as the subsistence farmer group, the average dose/risk to that group would be assessed and that this quantity would be compare with the standard. The implication of the homogeneity requirement is that individuals within that subsistence farmer group could get up to 3 times the dose/risk calculated as the average for the group; i.e. they could get 3 times the value given in the standard.

15. Page 117, last sentence, the word 'eff ~~tive' seems to be missing from in front of 'dose equivalent'.

16. In discussion of probabilistic issues, NAS do not seem to distinguish very clearly between events which may or may not occur according to some (if you are lucky) statistically based probability, and events which will (very) likely occur but to an extent which can be described with a probability distribution function. This may leave the reader confused as to, for example on page 119, 'the standard should include consideration of the probabilistic aspect of future exposures.'

17. NAS could give greater emphasis to their proposal that the exclusion zone should be no larger than the repository footprint, [illegible] '04. This could be a major change from the previous assessment approach since it dram[illegible] reduces the fl[illegible]w pathlength in the aquifer, and therefore, presumably, the geospher[illegible] [illegible]dme.

18. Page 122. 'Both EPA and we [illegible]end the use of (reference biosphere) assumptions that reflect current technologies and living patterns.' It is disappointing that NAS have not been clearer about whether they mean current technologies and patterns as at the site today, or reflecting possible behaviors over a wider area. BIOMOVS II has been more explicit in saying

that the wider behavior is relevant [BIOMOVS II, 1994]. Note that NAS could be criticized for identifying climate change as a major factor in the assessment (see figure 3.2) but then ignoring the climate change effects on assumptions for critical groups and exposure scenarios.

19. Page 148, para beginning 'In a Monte Carlo simulation...'. NAS assume you can quantify 'features' from surveys and studies of the existing population of the region. They also acknowledge that this information has to be extended because current use may be artificially limited due to access restrictions, e.g. on the Nevada Test Site. They suggest that areas with the potential for farming have to be identified. It is hard to see how this would be done from studies of existing populations. Greater emphasis could be given to the implicit need to study the region in terms of its exploitation potential, as suggested in the main text of this report.

20. Page 152. It is not clear why it is necessary to take the average of the critical sub-groups. It could be informative to separately present information on this risk associated with particular plume simulations (the ones giving high doses) and to consider what conditions (parameter combinations) give rise to those simulations. Suppose failure of a canister results in a plug release of I-129 of relatively short duration, say high aquifer contamination for 1E3 y. Suppose that the time of failure is very uncertain, but very likely within 1E6 y. The Appendix C formulation would appear to result in a risk estimate about 0.1 % of the Appendix D formulation. The difference is that Appendix C is based on a limit on annual risk in each year, whereas Appendix D corresponds to limiting risk in all future years. Allowing for the probability that a deep well is sunk has reduced risk estimates in some previous (non-US) assessments; such a release has been considered as a type of human intrusion. For the Yucca Mountain site, if people are present, the absence of surface water makes a deep well rather more likely than in the wetter sites considered in the assessments referred to above. At Yucca Mountain, the probability has more to do with whether people bother to occupy the region in the absence of surface water. A presentational problem is that previous assessments and international recommendations tend to insist on the presence of the critical group, whereas at Yucca Mountain, this is not especially likely. Note that in the I-129 example above, improved knowledge of canister failure would reduce the uncertainty in time of failure and put the risk estimate up.

21. Central para. Page 156. Does not refer to external irradiation, which is the most important exposure mode for some radionuclides. If these radionuclides are significant in the groundwater, then external irradiation could be important.

22. Page 162. Comment 1 is completely unjustified. The subsistence farmer is not the most conservative scenario. (See also p. 163.) For example, a self-supporting, hydroponically cultivating, fish farmer would be more conservative for many releases. Inhalation and external irradiation have been ignored.

DRAFT APPENDIX B TO IE4288-1 V3.0: ADDITIONAL REVIEW COMMENTS PROVIDED BY THE ELECTRIC POWER RESEARCH INSTITUTE

The NAS TYMS Committee suggests that two alternative approaches to the definition of a "critical group" can be used. One is based on a probabilistic approach to defining the average characteristics of an individual in a group who is most at risk. The second is based on the characteristics of a subsistence farmer. The subsistence farmer is chosen because it is assumed that the habits of a subsistence farmer are most likely to be that of a maximally exposed individual.

However, it is not generally recognized that the basic form of the Standard and the definition of the critical group should be consistent. They must both be consistent with a common regulatory philosophy. The TYMS Committee recommends, as a starting point, consideration of an individual health risk limit in the 10^{-6} to 10^{-5} range. Although the Committee relies on precedent in suggesting this numerical range, the fundamental basis for these numbers are the risk levels broadly tolerated by society. Table 1 provides a few examples of a mix of typical risks in US society. These risks can be considered to be "broadly tolerable" because society (and the regulators who represent them) choose *not* to take extraordinary measures to reduce these risks.

Two points about Table 1 are important to remember. First, some of the risk numbers considered broadly tolerable are significantly larger than 10^{-5} per year. However, it can be said that these higher risks are considered "voluntary" or do not have any consequences to future generations. Other risks listed in Table 1 are natural rather than man-made. However, there are a few risks that can be considered man-made (e.g., the risk of being killed on the ground from a plane crash). In addition, two of the "risks" listed are imposed by regulatory bodies. Both of these risk levels are also consistent with the 10^{-6} to 10^{-5} range. None of the risks listed in Table 1 are exactly similar to the case of HLW disposal where the risk is from a man-made source, is involuntary, and has consequences to future generations. Thus, based on the regulatory philosophy of risks "broadly tolerable" to society, it would likely not be broadly tolerable to allow a risk level higher than on the order of 10^{-5} per year due to HLW disposal, although a limit lower than approximately 10^{-6} per year could still be considered overly stringent.

The second point about Table 1 is that, except for the excess health risk of living in Denver, the risk levels listed here are averaged over the *entire* US population, rather than some smaller "most at risk" group. When averaging in this manner, some people are included in the average who have zero to near zero risk; others have a risk presumably much higher than the average. Thus, there is tremendous inhomogeneity in risk in the groups -- an inhomogeneity which society (and regulators) broadly tolerate.

It may also be useful to examine the population risk in addition to the individual risk of the values given in Table 1. Assuming a US population of approximately 200 million, an individual risk level of 10^{-6} per year corresponds to an average of 200 deaths annually. It seems, then, that US society broadly tolerates, for example, approximately 48,000 motor vehicle accident deaths and 120 deaths due to lightning annually across the entire US. In contrast, the affected population due to HLW disposal activity will likely be several orders of magnitude smaller than the entire US population -- assuming aqueous release pathways. For gaseous release pathways (e.g., carbon-14) one could assume the affected population is the entire world population, as was assumed by EPA in promulgating 40CFR191. However, the TYMS Committee has suggested that there is insufficient scientific basis to attempt estimating health effects due to extremely small dose rates.

It appears most regulatory guidance on the size of critical groups imply the critical group should comprise no more than a few tens of people. In some cases a critical group as small as a single individual is considered acceptable. It is reasonable to assume the total local population may be somewhat larger than this critical group size. However, a subsistence farming community (assumed to be the kind of population most at risk by the Committee) may be no more than on the order of 100 persons. Assuming the risk, *averaged over the entire local population*, was a constant 10^{-6} to 10^{-5} per year for one million years, and the total local subsistence community population size, averaged over one million years, was 100, then one could expect 100 to 1000 deaths in the local populations over a one million-year period, or an average of one death every 1000 to 10,000 years (or one death every 40 to 400 generations). A risk level of 10^{-6} to 10^{-5} per year to the *entire local population* affected by the HLW repository for the life of the repository (assumed on the order of one million years) is also less than or roughly equals that due to the hazards from some of the more common risks very large populations broadly tolerate *in a single year*. The conclusion is that an *annual risk to an average individual in the local population* on the order of 10^{-6} to 10^{-5} appears to be reasonably conservative based on the assumptions that: 1) society broadly tolerates annual risks for a much larger population of this same order of magnitude (or even higher); and 2) it is desired to develop a regulatory Standard for Yucca Mountain that is "equitable" (i.e., provides a level of protection similar to that which society broadly tolerates and regulatory agencies use in non HLW-disposal contexts). EPA, in its own internal guidance document[1] recommends that EPA's regulatory limits be equitable, or at a common level of risk. Therefore, it appears that EPA itself should be comfortable with the individual annual risk range of 10^{-6} to 10^{-5}.

If one assumes that risks can be averaged over a population with a large amount of risk heterogeneity, then it is reasonable to take a more probabilistic approach to the definition of the average individual. Such an approach has been taken in an illustrative manner by the Electric Power Research Institute (EPRI) in a recent performance assessment exercise for the candidate HLW repository at Yucca Mountain[2].

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[1]U.S. Environmental Protection Agency, Reducing Risk: Setting Priorities and Strategies for Environmental Protection, SAB-EC-021, September 1990.
[2]Electric Power Research Institute, A Proposed Public Health and Safety Standard for Yucca Mountain, EPRI TR-104012, December 1994.

To summarize our arguments regarding critical groups, the approach to both the form and numerical value of the limit imposed by the Standard must be consistent with the definition of the critical group. This point will be the central theme of a report that is being written by the Reference Biospheres Working Group within BIOMOVS-II[3], an international group of scientists (representing both regulators and implementors) involved in studying the importance of the biosphere in transferring contaminants from the geosphere to humans. This report will also conclude that the use of a maximally exposed individual as the critical group is inconsistent with an individual risk limit in the range of 10^{-6} to 10^{-5} for the same reasons indicated in this report. Therefore, of the two alternative approaches recommended in the TYMS Committee report, only the probabilistic critical group approach seems somewhat consistent with the suggested individual risk limits. However, the average individual in the local population concept would be the most consistent.

Table 1 Annual Risk of Death per Million Persons (US average)

Risk Source	Annual Risk	
Motor vehicle accidents[4]	240	
Home accidents[4]	110	
Motor vehicle pedestrian collisions[4]	42	
Firearms[4]	10	↑
Poisonings (not drugs/medications)[4]	6.0	↑
Electrocution[4]	5.3	↑
Being stuck by a crashing airplane[5]	4.0	(~10^{-6} to 10^{-5}/yr range)
Extra fatal cancer risk living in Denver[6]	1.0	↓
Tornadoes[4]	0.6	↓
Floods[4]	0.6	↓
Lightning[4]	0.5	↓
US FDA food additive regulatory risk "floor"[7]	1	
US EPA general risk limit range[8] 1-1000		

[3]personal communication

[4]Adapted from Wilson and Crouch, 1982.

[5]Harvard Center of Risk analysis, 1992 Annual Report, pg. 3.

[6]relative to living in New York. Wilson, R., Risk/Benefit Analysis for Toxic Chemicals, "Ecotoxicology and Environmental Safety", Vol. 4, pg. 370-383, 1980. Note: this is averaged over all persons living in Denver or New York, respectively, rather than being a US average.

[7]Wilson and Crouch, Science, Volume 236, pg. 293, 1987.

[8]Statement by William K. Reilly, US EPA Administrator on Environmental Tobacco Smoke, Jan. 7, 1992. "Merely for comparison. EPA generally sets its standards or regulations so that risks are below 1-in-1,000 to 1-in-1,000,000."

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Kommentare / Comments

Dear John,

Following is a discussion document produced at a meeting in July 95 in Vienna. It is not (yet?) an official document. It has been strongly based on ICRP documents, although it was recognised that some of the statements in ICRP documents could/should be questioned. On the other hand ICRP has an internationally recognised status.

See you hopefully in Vienna.
Best regards

Frits van Dorp

INTERNATIONAL ATOMIC ENERGY AGENCY

CRITICAL GROUPS AND BIOSPHERES IN THE CONTEXT OF RADIOACTIVE WASTE DISPOSAL

Position Paper

Produced for the Working Group on Principles and Criteria for Radioactive Waste Disposal

History:

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(Participants: K. Bragg (Canada), J. Cooper (UK), F. van Dorp (Switzerland), G. Linsley (IAEA).

1995-07-28

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 describe the critical group approach in Publication ICRP 26 which states:

> 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 maximizing assumptions used, the dose equivalent actually received will usually be lower than the estimated "dose equivalent" (ICRP Publication 26, para 85).

The concept is developed further in ICRP Publication 43 "Principles of Monitoring for the Radiation Protection of the Population "which addresses, among other things, the homogeneity criteria that should be used in chosing a critical group. The Commission suggests that if the ratio of the mean critical group dose to the appropriate limit is "less than one tenth, a critical group should be considered 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 three either side of the mean. At higher fractions, the total range should be less, preferably no more than a factor of three" (ICRP Publication 43, para 69). Therefore, it is accepted that some individuals in the critical group will receive doses somewhat higher than the mean dose.

group should be based upon present knowledge using cautious, but reasonable assumptions. For example, the critical group would 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 recommend that the annual risk to the critical group is limited. However, no guidance is given on how to characterise this critical group.

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 although little guidance is given on how to characterise the appropriate critical groups. Also for probabilistic, or potential, exposure situations no guidance is given on how to characterise the appropriate critical group. It is the purpose of this document to give guidance on those two topics for solid waste management.

The performance of the engineered system and the geosphere can be evaluated within certain bounds for relatively long timescales (depending on host rock and repository design typically 10^3 to 10^4 years). However, one can only speculate on human behaviour at times beyond a few hundred years into the future. It is for this reason that calculated doses/risks to humans can only be used as indicators and not as accurate predictors of the performance of a radioactive waste repository in the longer term.

Given the uncertainty about future human activities, it is nevertheless necessary to develop a structured and defensible approach to the problem, that is, to develop an appropriate critical group concept for the purpose of radioactive waste repository safety assessments.

in climate could occur, in general, the biosphere will probably remain comparable to present day conditions. Reference biospheres could be used in the calculation of doses and risks in this timeframe (see Section 5). In assessing intrusion into the repository, the future level of technology should be assumed to be at least equivalent to that existing at present.

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. The emphasis of the assessment should therefore be changed so that the calculations relating to the near-surface zone and human activity are simplified by assuming present day communities under present conditions, ie. a reference biosphere with a reference hypothetical critical group should be used. The calculations should be viewed as illustrative and the doses or risks as indicative. 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 timeframe.

Beyond 10^6 years unpredictable, large scale changes could take place such as continental drift and massive erosion. Therefore, little credibility can be attached to assessments in this timeframe.

representating 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 to present day requirements. The habits of the hypothetical critical group should 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 hypothetical critical group includes seafood consumers, data appropriate to high rate seafood consumers in the general coastal region should be taken rather than 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. 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.

Although there may be advantages in considering a range of biospheres, for the reasons given below and in the interests of promoting international consistency in decisions concerning radioactive waste disposal, one hypothetical control group in one particular reference biosphere is being recommended. Preliminary ideas are outlined in Tables 1 and 2.

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. This is a conservative assumption.

For both deep geological disposal and near surface disposal the consequences of inadvertent intrusion in terms of enhanced release of radionuclides to the biosphere should be taken into account using the critical group defined for normal evolution (Section 5.1). This may be particularly important in the case of a new surface facility where intrusion would bring significant quantities of radionuclides directly into man's environment.

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..

The assumption of a critical group existing 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 to 10^6 years post closure

In this timeframe the range of possible biosphere conditions and human behaviour is too great to allow reliable modelling. The emphasis of assessment should therefore be changed and doses and risks should be calculated to the hypothetical critical group in the 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 report). The hypothetical critical group should be assumed to exist at the point of highest relevant environmental concentration.

It should 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 timeframe 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 timeframe.

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, this critical group scenario is important and care should be taken over the selection of the appropriate habits.

Table 1. Hypothetical Critical Group Definition

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 concentation than for surface water (ie less dilution)
food sources • within 10 km of homes • use more than one production zone	minimizes dilution by importing food increases local security of supply
standard intakes • use ICRP reference man (?Kg/yr) • 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 ALI's (ICRP 61)	internationally accepted

Table 3. 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 a subsistence community or the hypothetical critical group	region specific biosphere or reference biosphere
10^4 - 10^6	the hypothetical critical group	reference biosphere

ATTACHMENT 3

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Number of pages: 11
(including this one)

Message:

John

REPLY TO QUESTIONNAIRE ON CRITICAL GROUPS

Please find attached a copy of the above. I shall bring a hard copy to Vienna next week.

M. A. B

Martin A Broderick
Biosphere Research & Assessment Manager

FAX
ISSUE 2