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BIOSPHERE SCENARIO DEVELOPMENT

AN INTERIM REPORT OF AN SKI/SSI/SKB WORKING GROUP

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EXECUTIVE SUMMARY

The Swedish Nuclear Power Inspectorate and the Swedish Nuclear Fuel and Waste Management Co have initiated a Project for the Development of Scenarios for the behaviour of radionuclides in high level waste following deep geological disposal. The main objective is to develop a general consensus on scenarios and conceptual models.

Within the project a biosphere scenarios working group, co-sponsored by the Swedish National Institute of Radiation Protection and the Swedish Nuclear Power Inspectorate, was initiated to consider specific questions of the biosphere. This report describes the results of the group's deliberations up to the end of July 1989. It is called an interim report since it is the view of the group that further iteration would be useful, particularly to take account of progress in other areas of the Scenario Development Project.

A methodology is presented for the development of biosphere scenarios which may be considered alongside scenarios for radionuclide behaviour in the near field and geosphere. The uncertainty associated with human activity and man's potential influence on climate, etc, is such that long term predictions of the biosphere are considered impracticable. Therefore the approach is adopted of identifying a relevant range of illustrative possibilities which nevertheless satisfy the technical requirements of safety analysis.

Two major biosphere elements affecting processes in the surface environment have been recognised, climate and development. Alternative states for climate and level of development are suggested and each combination can be considered with one or more of a range of biosphere receptors, such as a river or a lake. The features, events and processes relevant to each receptor are presented. Consideration is then given to biosphere assumptions for both gradual and direct releases from the geosphere, as well as biosphere effects on the repository near field or geosphere.

The amount of screening which can be done at this stage to limit the number of biosphere scenarios is small. However, considerable potential exists once more details are available for geosphere release scenarios. It may be appropriate to further develop biosphere scenarios, specific to each geosphere release scenario (or group of similar scenarios). It may also be appropriate to consider scenarios specifically in relation to the individual radionuclides which dominate geosphere releases. Both these possibilities could result in considerably reduced requirements for calculations. In addition scoping calculations are suggested to help eliminate unimportant features, events and processes.

Apart from taking account of progress with the development of scenarios for the geosphere it is suggested that further advantage could be gained from closer examination of features, events and processes occurring at the geosphere-biosphere interface.

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1. INTRODUCTION

The Swedish Nuclear Power Inspectorate (SKI) and the Swedish Nuclear Fuel and Waste Management Co (SKB) have jointly instituted a project for the development of scenario development for the behaviour of radionuclides in high level waste (HLW) following deep geological disposal. The main objective is to develop a general consensus on scenario development methodology well before the detailed licensing process begins. Progress in the Scenarios Development Project is described in reference [1].

At the February project meeting it was decided that a working group should be formed to consider specific questions of the biosphere. Membership of the biosphere group, which was sponsored by the Swedish National Institute of Radiation Protection (SSI) and SKI, is given in Annex I.

This report describes the results of that biosphere group's deliberations It is called an interim report since it is the view of the group that further iteration is necessary, particularly to take account of progress in other areas of the Scenarios Development Project. Indeed interfaces between the geosphere and biosphere are recognised as a major issue.

The report takes account of some preliminary ideas [2], which were discussed and expanded upon at a meeting of the biosphere group in Stockholm, April 1989. Account has also been taken of discussions at BIOMOVS workshops dealing with longer term questions of radionuclide migration and accumulation in the biosphere.

Another important aspect of scenario development is how to take account of the possibilities for human intrusion. This has received relatively little technical consideration in the past, and so the opportunity has been taken to include ideas and suggestions made at the recent Nuclear Energy Agency (NEA) workshop on human intrusion, held at the beginning of June 1989 [3].

2. METHODOLOGY

In this Section a particular methodological approach is suggested based on discussion of some basic issues and ideas.

2.1 Some Basic Issues and Ideas

It is clear that the biosphere is very strongly influenced by man, and that man's behaviour is very difficult to predict. The issues are widely discussed, for example, in reference [4]. Not only is human behaviour very complicated (which could equally be said of other aspects of the repository safety assessment), it has associated with it an inherent lack of predictability which can be related to free will or, some would say, perversity. Who would have predicted that the area of the USA under spinach cultivation would increase twenty-one times during a period of twenty years following the arrival of the cartoon character Popeye [5]?

It follows that the unpredictability of human behaviour is different in nature from the unpredictability associated, say, with rocks and groundwater flow, which behave according to a set of physical laws. Our understanding of these laws may not be complete in every detail. However, our understanding of the relevant phenomena in the geosphere operates over longer timescales than for the corresponding biosphere considerations. Noting also man's influence on the biosphere, long term predictions for the biosphere are therefore seen by some as impracticable. According to this argument, attempts at completeness in terms of biosphere scenario development, or environmental simulation, eg reference [6], would also be fruitless. At the same time, it has to be recognised that there is a need to say something about the implications of release of radionuclides to the surface environment. This arises from the need to demonstrate compliance with criteria on waste disposal and, more broadly, to satisfy public curiosity on this matter.

It has also been suggested that the geosphere could be substantially affected by man, and that the same problem of completeness also applies to scenario development for the geosphere. Consideration therefore has to be given to the scale and significance of biosphere effects, including human impacts, on the geosphere.

The term biosphere is used variously. Goodess [7] refers to the biosphere as plants and animals, as opposed to the atmosphere, oceans, cryosphere (snow and ice) and lithosphere (the earth). Others have suggested that is should be taken to mean anywhere where plants and animals live. Another alternative suggested [8] is that the biosphere should be taken to be all those areas to which man normally has access, including soils, the atmosphere and fresh water and marine environments, but not below ground as in mining activities. The corresponding meaning for the term geosphere would then be that part of the globe which is below ground surface and beyond the normal range of man's access. Given this background it is clear that confusion could arise concerning the boundary between the geosphere and the biosphere. A proper understanding has to be reached between those dealing with the biosphere and those dealing with the geosphere to ensure that all areas are covered and that consistent boundary conditions are applied.

Release of radionuclides from the geosphere or lithosphere into the surface environment, where man or other biota are more likely to be affected, is only expected to occur some considerable time into the future [9]. This is the case even for the more unlikely prompt releases which might occur because of some rapid failure in the near field and geosphere barriers. Such releases could continue at near maximum rates for long periods. Therefore, some account needs to be given to changes in the environment between now and the time that release starts, and to changes arising during the period of release, which might result in higher levels of impact.

Goodess has concluded [7] in the context of deep geological disposal in the UK, that almost half of the environmental changes which could bring forward the time of appearance of radionuclides at the surface, or change their subsequent distribution, are controlled by climate. It was also suggested that a large proportion of climate variation cannot be predicted [7]. However, it may be possible to predict more likely longer term averages with reasonable confidence over a particular time period, even if detailed predictions within that time period are not possible. These sorts of problems could be better dealt with in the light of predictions for geosphere releases. For the current exercise no such predictions are available. However broad guidance is available from previous studies, such as KBS-3 [9].

Goodess's conclusion on the significance of climate and the earlier assertion of the significance of man's activity are connected. Man may play a major role in changes in climate at least over the next few hundred years [7, 10]. It is not clear how persistent such man induced changes could be. However the importance of climate and man have also been recognised as major scenario generating aspects by the main SKI-SKB project (see Table 1, taken from a report of the project made to the NEA [11]).

As well as better guidance on the nature of potential releases of radionuclides from the geosphere, another area of advice which might simplify the specification of biosphere scenarios concerns disposal criteria.

2.2 Basic Assumptions, Terminology and Relation to the Overall Scenarios Project

The following basic assumptions provide the basis for the detailed consideration of biosphere scenarios. These assumptions represent the current state of the overall project. At a later stage the assumptions could be modified as the project develops, for example, to take account of details of scenarios for release from the geosphere. However, the subsequent approach described in Section 2.3 has been designed so that such developments can be taken on board in a straightforward way.

i) So far as possible account should be taken of the on-going results from the overall project. Ideally the biosphere methodology and terminology should be consistent with the main project, and account should be taken of the interfaces between the geosphere and the biosphere.

ii) For the purpose of analysis three basic categories have been recognised for biosphere **Features, Events and Processes** (FEP's), ie,

- those which affect the surface environment,
- those which affect the near field or geosphere, providing a direct short circuit to the surface environment, and
- those which affect the near field or geosphere, but only modify geosphere transport processes.

iii) No attempt should be made to predict conditions in the biosphere, but a relevant range of illustrative possibilities should be considered.

iv) In the absence of specific HLW disposal criteria, radiological impact should be interpreted widely. This implies consideration of FEP's for a wide range of exposure scenarios, dispersion in the regional and global environment as well as locally, and accumulation in environmental media not necessarily associated with the exposure of man. Endpoints for calculations might include:

- annual individual doses to ICRP reference man (or child, or infant, or foetus or other more susceptible groups), with exposure arising from ingestion of foodstuffs or other contaminated material, inhalation of dusts or radioactive gases, external irradiation (either whole body or of skin or extremities), and intake via skin puncture,

- some idea (at least) of where and when these doses might arise, (maybe a complete dose versus time curve),

- some idea of the probability that these doses will arise, or at least a qualitative description, based on a clear explanation of the circumstances of exposure,

- temporal and spatial development of collective dose rate and truncated collective dose commitment to man,
- doses to biota,
- distribution and concentration of radionuclides in the biosphere, e.g., for comparison with concentration of natural radionuclides in the environment.

It may be noted that even if criteria are eventually adopted which ignore migration and accumulation in the biosphere and doses to man, ie if a limit is set on geosphere release, then biosphere conditions still exert an influence, particularly via the specification of boundary conditions for the geosphere.

v) Two major biosphere elements relevant to the processes affecting the surface environment have been recognised, Climate and Development (The word development is used in the sense of the level of human activity). Alternative element states are suggested and each combination of these states could be considered for one or more of a number of biosphere receptors. (See Section 2.3). Evolutionary processes need to be considered within these assumed element states. However no attempt is made to provide a sequential prediction of the biosphere evolution from the present day into the indefinite far future.

vi) A single FEP could have surface and sub-surface consequences.

vii) The term biosphere is being taken to mean the last of the alternatives suggested in Section 2.1, not because it is intrinsically any more correct than the others, but because the distinction made between geosphere and biosphere conforms with the areas of assessment expertise into which the overall project has been divided.

The following definitions are adopted directly from the main Project Working Group (PWG) [1].

A scenario is defined by a set of external conditions which will influence processes in a process system. The external conditions determine how to actually model and combine the processes in the process system when evaluating the consequence of the scenario."

"The **process system** (PS) is the organized assembly of all phenomena (FEPs) required for description of barrier performance and radionuclide behaviour in a repository and its environment, and that can be predicted with at least some degree of determinism from a given set of external conditions".

"The **external conditions** are events or processes that are not repository induced and may occur (relatively) independent of the processes in the process system."

Surface FEP's, both natural and human induced, have already been considered by the PWG, at least in so far as they effect the geosphere. Among these, waste retrieval and mining (and presumably associated direct exposure of man) were put in the category of **Isolated Scenarios**. An isolated scenario is one which is based on a FEP which should not be combined with other FEP's to form new scenarios, because "normal" release and transport mechanisms associated with the PS would be unimportant in comparison [1].

An important aspect of converting the list of FEP's into a manageable set of scenarios is screening. The screening criteria used by the PWG include:

- low consequence,
- low probability,
- physical reasonableness.

Lumping, ie considering two or more FEP's together, may be done on the basis that the FEP's have similar consequences.

All the above needs to be taken into account in formulating biosphere scenarios.

2.3 Approach Adopted for Each Broad Category of Biosphere Considerations

Irrespective of the way in which radionuclides are transported through the geosphere some consideration has to be given to the receiving environment in the biosphere. The potential biosphere receptors are discussed first in relation to **gradual releases** from the geosphere, each in the context of the potential biosphere element states. Corresponding consideration is then given to the receptors in the case of **direct release**. For both gradual and direct release it is appropriate to specify in some detail all the relevant FEP's for the various combinations of biosphere element states. Biosphere FEP's only affecting the surface (Item ii) Section 2.2) tend to be associated with gradual geosphere release. Biosphere FEP's which provide a short-circuit through the geosphere can be interpreted as being among the causes of direct release. Gradual releases may also be associated with, and indeed may to some extent be a result of, the third FEP category, ie biosphere FEP's which modify gradual transport through the geosphere.

An attempt has been made to screen out combinations of receptors and biosphere element states. However, significant progress with screening is not possible at this stage without some discussion of the geosphere, which is beyond the scope of the biosphere group. The biosphere FEP's thought to be of potential significance are presented with some observations.

2.3.1 Gradual Releases

Table 2 gives the biosphere elements, the states they could exist in, and the potential biosphere receptors. The meaning of each of these terms is discussed here. Details of FEP's for each combination, and screening, are discussed in Section 3.

The biosphere is assumed to have two basic elements to it relevant to assessment of repository safety, A, Climate and B, Development. Climate is assumed to have five possible states. Definition of the present climate depends to some extent on the assumption for site location, as will the potential for change. However, according to the Köppen classification all but the southern part of Sweden (below about 59° N) is described as a boreal forest and snow climate with no marked dry season [2]. It is additionally assumed that the site would currently have warm summers with at least 4 months above 10°C, and be associated with broad leafed deciduous forest (Köppen classification Dfb). "Colder-dry" would be a cold snow climate of tundra vegetation, with dwarf tree species, mosses and lichen (ET). "Colder-wet" is taken to be similar to the present climate but with shorter cooler summers and needle-tree forest (Dfc). "Warmer-wet" is taken to mean a temperate rainy climate with hot summers, and with broad-leafed evergreen forest (Cfa). Finally "Warmer-dry" is taken to mean an arid climate with bush or poor grassland vegetation (BS).

The range of conditions represented by these five states is a little more detailed than those investigated in reference [13] which were incorporated into Project Gewähr [14]. In this case the extremes of tundra and warmer climates were considered as well as present day conditions.

According to work on climate prediction [7] colder conditions are more likely to persist over most of the next million years or so, ie for about 85% of the time, with the current temperate conditions making up the rest. About 10 such cycles of warming and cooling may be expected in 10^6 y. However this assumes that the current climatic succession is not interrupted, for example, by changes resulting from increased levels of greenhouse gases in the atmosphere. Such change could give rise to warmer conditions for a relatively short period, the next thousand years or so, before the naturally driven climatic succession continues. However if it is possible for such a change to be induced "now" it seems reasonable to assume that similar warm periods might arise later on. In addition such changes could result in a complete break of the current succession, an irreversible "greenhouse" condition. In this case it has been suggested that assessments should take account of the possibility of a continued warmer climate [10].

Although these comments do not offer firm probabilities for any particular climate state, at least some qualitative idea of more likely states and rates of change are available. At this stage it is not worthwhile attempting to be more specific. In addition, it may be noted that strenuous scientific debate continues on the validity of climate predictions, and the theories and interpretation of measurements on which they are based. (See for example discussion of Milankovitch Theory [15], which connects quaternary ice age fluctuations with summer insolation variations due to periodic variations in the earth's orbit).

Development is the shorthand term used here to mean the level of human activity in the region of the disposal site or radionuclide release. The range of possibilities is enormous. It is here particularly that illustrations from a relevant set of possibilities are considered by the biosphere group as more practicable than an attempt at completeness. This is not the same as saying that only trivial effort needs be given to identifying the relevant illustrations.

Present conditions of development are taken to mean current farming and groundwater management, etc, in middle Sweden. More intense exploitation refers to such possibilities as construction of a city at the site or intensive farming methods. Less intense exploitation refers to conditions in which the area reverts to is natural state and use by man of the natural food resources available in those conditions.

So far as development in the wider global environment is concerned, it is suggested that calculations of impact should be done on the basis that no changes occur. Although major changes might arise within regions, the average condition world-wide is not thought to be so variable, and detailed study of areas well away from the disposal location is not warranted.

Although no sequence from the present day is assumed, this does not mean that no changes in the biosphere are to be taken into account. Thus, for any of the biosphere states referred to above, the implications of surface evolution during a period of release have to be taken into account. These are discussed in Section 3. Changes arising before release occurs have been taken into consideration in determining the range of biosphere element states.

2.3.2 Direct Release

Direct release may result in prompt exposure of those people present at the time. The most likely biosphere cause for such release, especially within the first few millennia, would seem to be direct intrusion by man and direct exposure of the intruders. Reasons for such intrusion are therefore suggested, and the potential direct exposure scenarios explored (see Section 3). In addition concurrent release into one or more of the biosphere receptors could result in exposure of a wider population. Estimating the probability of such intrusion over different timescales is especially difficult. Information and ideas on how to deal with intrusion have been incorporated from the presentations to the recent NEA Workshop on the subject [3].

2.3.3 Biosphere Effects on the Geological Environment

The intrusions discussed in Section 2.3.2 could also affect transfer in the near field and geosphere and hence alter release to the biosphere. In addition changes in climate and human activities could also affect below ground conditions. Relevant processes have been investigated within the UK DOE research programme [10]. These have been incorporated into models for climate sequence, glacial effects, sea level change, surface water budget and denudation [16,17]. Biosphere processes have also been reviewed within the Nirex Safety Studies Programme [18]. The processes are examined in so far as they affect the above and below ground environments. The evolutionary sequences of surface conditions, which in the long term can have a considerable effect on the deeper geosphere, may also be important for migration and accumulation processes in the surface environment [19]. FEP's identified from these programmes along with suggestions from the biosphere group, from the PWG [1] and from the NEA workshop [3] are discussed in Section 3. However, as was noted above, progress with scenario specification in this area cannot be divorced from the geosphere scenario work.

3. SPECIFICATION OF BIOSPHERE SCENARIOS AND SCREENING

A first attempt at specification of biosphere scenarios and screening has been made here. Essentially a combination of top-down and bottom-up approaches has been used. The definition of biosphere Elements States and Receptors (ESR's) can be called top-down. It presumes an understanding of broader contolling influences. The justification for the elements and states is given in Section 2 supported by references. The justification for the choice of biosphere receptors is given here along with some limited screening of ESR combinations. The ESR's provide the skeletons of the biosphere scenarios. A bottom-up approach looking at FEP's for each receptor adds the flesh to the bones.

Modelling of radionuclide transfer and accumulation in the biosphere and the corresponding doses to man has a longer history than in the geosphere, and is also supported by a larger more directly relevant data base derived from monitoring of routine discharges [3,17]. However a different set of more significant radionuclides arises in the assessment of solid waste disposal. In addition, for releases from waste disposal facilities there are two other important differences: releases are likely to go on for much longer than routine discharges; and activity enters the biosphere system from below rather than from above. These factors affect the range of relevant receptors and the FEP's which may be associated with them.

The list of receptors given in Table 2 is derived from a wide range of relevant studies [8,9,13,19,22,23,25] and long term release into many of these receptors has been the subject of model comparison exercises within BIOMOVS [26-30]. These receptors are characterised by the FEP's associated with them, given in Table 3.

Results from KBS-3 [9] and other deep disposal assessments [14,31] indicate that release to the biosphere might occur over a very wide range of time periods, and involve radionuclides exhibiting considerable variation in chemical and other characteristics. Therefore it is not possible at this stage to eliminate many ESR combinations on the grounds of low consequence or low probability.

Initially it is assumed that any of the Climate states can be combined with any of the Development states, making 15 possible ES combinations. Then, in general, any of the receptors can be applied to any of the ES combinations. It might be argued that some receptors would not be present under some of the climate conditions, eg, peat in warmer-dry climate. However the peat might still be present even if its further accumulation has been suspended locally due to climate change.

The only ESR combinations screened out at this stage are the artificial receptor with present or lower levels of human activity. The artificial receptor is taken to be a special man-made receiving body, such as a fish farm tank, associated with a high level of resource exploitation at the site. This leaves 155 ESR combinations at this stage. It should be remembered that the detailed FEP's for each receptor have not been discussed yet. However, it is argued below that some of these details may be omitted. In addition some possibilities for reducing amounts of calculations are discussed in Section 4.

To a large extent the fine levels of detail are assumed to be covered sufficiently in existing well established models. Examples include models for human metabolism and dosimetry [32] and for transfer of activity through plants and animals [20]. In fact, though well established, even these models are subject to on-going modification. Apart from changes in assumptions for risk per unit dose, changes in recommendations on gut transfer factors [33] and weighting factors for calculation of effective dose equivalent [34] are in the offing. Nevertheless it was not thought to be within the biosphere group's remit to review the entire spectrum of radioecology and doses to man. The appropriate up to date recommendations available at the time of consequence analysis should be applied.

Instead, attention has been focussed on those FEP's which are concerned with the special features referred to above, ie long term release, and release from below instead of above ground. It is of interest that research programmes for shallow burial may be relevant in both these contexts, eg [35,36].

3.1 Biospheres for Gradual Release

Table 3 lists those FEP's for each receptor which are relevant to gradual release, and which are crucial particularly to long term discharges.

Gradual long term releases to lakes, soil and rivers, and the long term implications of continued irrigation have been considered within the BIOMOVS study [26-30]. Peat has special interactions with some radionuclides, particularly those of uranium. Chemical speciation and migration relevant to this case can be determined from natural analogues, such as that at Broubster, in Scotland [37]. Long term releases to the marine environment have been studied in references [22,23,25,31].

Gradual release to most receptors is assumed to occur in groundwater. Gradual release of radioactive gas to atmosphere is also possible, either as a result of evaporation or emanation from surface soils (eg I-129, radon) or as a result of gaseous transport through the geosphere. The latter might include radioactive gases or aerosols. Release scenarios for gas considered previously have included release to the open air and release into homes built in the relevant area [23].

The range of exposure pathways will include in each case ingestion inhalation and external irradiation as per standard models. The relevant foodstuffs etc will be different for each receptor and will also vary according to climate state. Variability in root uptake data and other relevant concentration factors is already very large, even when considering only today's circumstances. Absence of data for some less commonly studied foodstuffs is not a problem peculiar to waste disposal assessments. Pathways considered in references [9,13,20,23,24,25] provide a very full list, but it is hard to prove that some important foodchain route has not been missed, just as the uptake of Cs-137 in to coconut was not initially recognised following bomb tests in the Pacific. Detailed local land use and agricultural practice data, as suggested in reference [38], was not identified by the group as a requirement for long term radiological assessment although such information may be useful for presentational purposes.

Given the wide range of radionuclides with different chemical characteristics which might be released from the geosphere over various time periods it is not possible to screen out at this stage any of the FEP's mentioned in Table 3. Even with relatively precise details for the particulars of the PS it would still be difficult to screen out receptor FEP's, although it may be possible to screen out some more ESR combinations. For the present it is suggested that all 155 combinations have to be retained and biosphere models adopted capable of incorporating all the receptor FEP's. This is discussed in further Section 4.

3.2 Biospheres for Direct Release

Direct releases correspond with the isolated scenarios mentioned by the PWG [1]. Biosphere FEP's leading to direct release are given in Table 4. Mostly they concern human intrusion. These are expressed in general terms, and it is suggested below that consequence calculations can be kept simple, since essentially the same form of exposures arise for many of the intrusion modes. However, it is very important to consider and explain the circumstances under which direct release from intrusion could occur on a site specific basis.

The human intrusion FEP's are based on the premise that knowledge of the existence of the repository at its particular location has been lost. Hence it has to be recognised that we are considering events concerning human actions at times in the future after final sealing of the repository and also after any subsequent period of institutional control. The latter could include a period of monitoring and surveillance associated with the repository, leading on to a second phase of essentially passive control via, for example, planning restrictions on developments in the vicinity.

A common feature of most human intrusion assessments is that it is assumed that the potentially hazardous nature of the repository is not recognised. In the case of intrusion into contaminated rock this is probably reasonable. For direct intrusion into the waste and repository structural materials, this is more doubtful. The very presence of man-made materials may cause some change in the nature of the intrusion, reflecting civil engineering practice on discovery of "made ground". It may also be that the radioactive nature of the material is recognised and appropriate measures taken and further intrusion ceased. It is also likely that after such discoveries further periods of institutional control would be introduced, reducing the probability of intrusion for a further period of time.

An important feature in the assessment relates to assumptions for the state of human technology. It is proposed that for the current state of development the level of technology is assumed to continue as at present. For example, that deep borehole drilling will continue to be a feature of resource exploration. Yet even now, extensive non-invasive survey techniques exist and it is possible that such techniques might be specifically developed so as to detect a repository, from ground surface eg. by the magnetic anomaly created by its metal content. Also, in a technological society capable of drilling to significant depths, then it is highly likely that both written knowledge of previous drilling in the area would be recorded and results available - hence mitigating against future resource exploration in the area - and that examination of borehole cores would, in any event, rapidly establish the presence of a repository. Down borehole instrumentation during drilling may also detect the presence of activity and the drilling operation cease pending review. For the more highly developed society it could be argued therefore that intrusion is less likely. Equally, a lower level of development implies that intrusion would be less likely, because the technology would not be available.

Investigation by deep drilling results in some contaminated material, eg core material, being brought to the surface. This would result in the exposure of workers involved in the drilling or in the study of the material. Exposure would be localised and the amount of contaminated material brought to the surface would be quite small. Simple exposure models such as those suggested in reference [31] for external irradiation and for inadvertent ingestion or inhalation could be used to evaluate doses. The details for the exposure parameters need to be considered in relation to the possibilities for how the exposure arises. The parameters include:

- period of exposure,
- exposure geometry, eg average distance from source,
- level of dust raised during operations,
- relationship between concentration in dust and concentration in contaminated material.
- amount of inadvertent ingestion per shift,

The drilling scenarios need to be described sufficiently to allow reasonable justification for values of the above parameters. Consideration might need to be given to skin doses as opposed to whole body exposure.

Exploitation of the resources investigated by deep drilling might result in much more extensive spreading of contaminated material (into some of the receptors in Table 3), and also to longer exposure of those directly involved.

It may be noted that the US DOE have analysed processes or events which could disrupt a deep repository. They recognised [39] that a very large set of scenarios could be defined from their list of FEP's, resulting in formidable demands in developing calculational models. Classes of disruptive event were therefore defined and in the context of direct human intrusion these were limited to two: small and large scale exploratory drilling. Broadly speaking these two classes correspond with the classes arrived at independently above, ie exploration resulting in small scale release and exploitation resulting in large scale release.

Erosion of surface materials could lead to contamination reaching the biosphere without the contaminants actually being transported to the surface. Rather, the surface has migrated to the contamination. In one sense this could be called direct release since it does not necessarily involve transport through the geosphere. However, erosion would generally be a slow process compared to drilling. The relevant FEP's would be similar to those for release to soil (see Section 3.1).

Again at this stage none of the FEP's can be eliminated. However details of site geology would certainly permit identification of more significant FEP's, either in terms of consequences, or in terms of probability of occurrence.

3.3 Biosphere Effects on the Near Field or Geosphere

Investigation of these effects has been a significant feature of the Nirex [7, 18, 19] and UK DOE research programmes [10,17]. The list of FEP's in Table 5 comes from a review of these reports, the discussions at the NEA meeting [3], and from independent suggestions of the biosphere group. Those FEP's directly associated with man could have a wide range of significance depending on the degree to which they are assumed to occur, which in turn is extremely hard to predict. On the other hand the significance of the natural FEP's is also arguable, largely because they in turn are controlled by climate which is, as discussed in Section 2, difficult to predict and to some extent affected by man.

AECL have carried out a study of the effects of a well on groundwater flow and nuclide migration in a deep hard rock system [40]. They note the significance of the precise location of the well in relation to the existing contamination plume and the importance of the assumptions for rate and period of abstraction. Experience with modelling the effect of a small hole drilled through a flow system seems to be limited.

Geomorphological processes may have a considerable influence on how gradual release from the geosphere actually occurs because of the influence on surface and near surface groundwater flow [19]. The more drastic effects are to be associated with glaciation, which of course has a major interaction with geology, and could result in direct release (see Section 3.2).

4. IMPLICATIONS FOR PRELIMINARY STAGES OF CONSEQUENCE ANALYSIS

The following brief sections outline some ideas and issues relevant to carrying forward the scenario development exercise. Reference is made to consequence analysis in particular since at this stage, with respect to the biosphere, there are very few clear arguments for screening out FEP's. Scoping calculations seem to offer the best route forward, ie preliminary consequence calculations.

4.1 The Geosphere-Biosphere Interface

When describing release from the geosphere in terms relevant for biosphere modelling it is relevant to note that the areal extent of the geosphere release is or can be important [22] rather than just the flux of radionuclides. In addition the more likely receptors should be indicated corresponding to the assumption for geosphere transport.

There is a need for some consistency in assumptions for groundwater movement at the interface, for example the level and variation of the water table, and the amounts of infiltration. In particular if the geosphere release is associated with advection in groundwater, how much water movement is involved? If the geosphere release is diffusion controlled, what activity concentration is assumed in the biosphere at the boundary? A clear understanding is required of what the boundary actually is. Usually zero concentration is assumed which tends to result in an over-estimate of release. This may not be appropriate for all biosphere receptors.

In addition the assumptions for groundwater chemistry in the near surface geosphere need to be provided. However, these may be affected by conditions in the biosphere. Iteration of assumptions is therefore appropriate.

4.2 Applicability and Availability of Models

Many models are available for biosphere transport and accumulation of radionuclides through various parts of the environment. Until now relatively little emphasis has been given to longer term processes and movement of radionuclides from below, although exercises such as BIOMOVS have helped to some extent. Provisionally the most significant area for model development would seem to be provision of assessment models which deal adequately with geomorphological processes such as erosion, sedimentation and sediment movement. Models for shorter term processes are generally already available. However, it is necessary to check their particular relevance, and not to assume that they can be applied without modification.

4.3 Provision of Data, Scoping and Sequencing of Calculations, and the Reference Scenario Biosphere

Appropriate data relevant to the FEP's listed in the tables are hard to determine. For these longer term processes direct observation is not possible and relevant analogues are not generally available. Interpretation and relevance of analogues may also be questioned. Scoping calculations could be used to determine significant values of parameters in various contexts, which would then be used to justify screening of FEP's and ESR combinations. A different biosphere screening exercise may be necessary for each geosphere scenario, or group of scenarios. Since the models are relatively simple but the data are especially sparse, scoping calculations could be particularly useful in the context of isolated or direct intrusion scenarios.

In Section 3.1 it is suggested that all 155 ESR combinations remain to be tagged onto each geosphere release scenario. Values of parameters associated with the receptor FEP's might be chosen from a relatively narrow range if given the specifics of the geosphere releases. In addition the radionuclides of significance in each specific release will be limited in number so that FEP's irrelevant to those particular radionuclides could be eliminated. By carrying out calculations in the correct order it should be possible to show that some ESR combinations are not of interest. At this stage, however, it is not possible to specify that order. Overall, it seems that major progress can only be made in the light of geosphere specifics. In the meantime it is necessary to develop as far as possible the capacity to model a wide range of environments and a wide range of trace chemical species within them. The area given least attention to date seems to be release from the geosphere of radioactive gases (apart from Ra-226). On the other hand such release may be predicted not to occur.

In order to provide a single point of reference, the biosphere group proposed that a release scenario corresponding to normal mechanisms associate with the PS should be constructed on the basis of release to a lake typical of current day middle Sweden, and assuming the current day level of development.

4.4 Special Radionuclides

Previous studies, like KBS-3 [6], have indicated that among the many radionuclides in waste, only a relatively small number are likely to appear in any gradual release to the biosphere. These are the long-lived and potentially more mobile radionuclides such as Tc-99, I-129 Cs-135, and Np-237. Special considerations of receptor FEP's for these radionuclides might allow for more effective screening than is possible when all radionuclides are considered simultaneously and on an equal footing.

Provisionally the possibility exists for specifying a set of biosphere scenarios for each important radionuclide. Each set would include considerations of FEP's relevant to that radionuclide.* Useful reviews exist in some of the more likely relevant cases, eg for Tc-99 [41] and I-129 [42,43].

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* The same approach could be adopted for behaviour of these radionuclides in the geosphere, to help limit the number of scenarios which can be created from the long list of FEP's.

In addition it is worth noting the special difficulties of modelling C-14 and I-129. Both elements are present in stable form in the environment and play major roles in life processes. In addition, though both are relatively mobile, in some circumstances sorption and accumulation are possible. For example, iodine retention in soil and uptake into plants may be very significant or negligible, depending on circumstances [43]. The conclusions on iodine in the environment taken from reference [43] are summarised in Annex II. Apart from being instructive in themselves, they also illustrate the amount of detailed data which is potentially relevant but not necessarily available for the full range of FEP's for all the possible radionuclides and geosphere releases.

4.5 Sensitivity, Uncertainty Analysis and Validation

The biosphere group has been asked to consider approaches or strategies for sensitivity and uncertainty analysis. This is an exceptionally difficult subject. It is worth noting that the exposure scenarios are illustrative, and that therefore uncertainty should only relate to the uncertainty within each illustration. It may be useful to talk about confidence in results, as well as confidence that the results are not seriously in error. Model validation is relevant in this context, but also very difficult for the long term predictions, especially where man is involved. Given these circumstances it is sensible to limit one's ambitions. Transport modelling in the biosphere following release from waste repositories has been ranked last in scope for model validation [44].

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TABLE 1

PRIMARY FEP'S NOT IN THE PROCESS SYSTEM [9]

1. Random canister defects - quality control.
2. Backfill material deficiencies.
3. Faulting.
4. Stray materials left.
5. Unsealed boreholes and/or shafts.
6. Uplift and subsidence.
7. Permafrost.
8. Human induced actions on groundwater recharge.
9. Glaciation.
10. Surface water chemistry altered by humans.

TABLE 2

BIOSPHERE ELEMENTS, STATES AND RECEPTORS

	Elements		States		Receptors
A.	Climate	1.	As present, Dfb*	1.	well
		2.	Colder - dry, ET	2.	river water
		3.	Colder - wet, Dfc	3.	lake water
		4.	Warmer - dry, BS	4.	river sediments
		5.	Warmer - wet, Cfa	5.	lake sediments
				6.	soil
B.	Development	1.	As present	7.	peat
	(level of	2.	More intense	8.	marine water
	human activity)		exploitation	9.	marine sediments
		3.	Less intense	10.	artificial
			exploitation	11.	atmosphere

Provisionally any of the 5 biosphere states may be combined with any of the 3 development states, and any receptor may be associated with any of the 15 Climate/Development combinations, making a total of 165 potential ESR combinations. Screening of ESR combinations is discussed in Section 3.

* These are references to Köppen weather categories [12] described in the main text.

TABLE 3

FEP'S ASSOCIATED WITH EACH BIOSPHERE RECEPTOR
FOR GRADUAL RELEASE

1. Well

- abstraction rate
- depth of well, Shallow wells might have low abstraction rates, whereas deep wells would be unlikely to be developed if only small amounts of water could be taken.
- period of existence or use of well
- sorption on particulate
- use of water for drinking, with or without treatment
- use of water for irrigation, resulting in plant interception and long term accumulation in soil (see Soil)
- effect on groundwater flow and radionuclide migration owing to the presence of the well

2. River Water

- volumetric flow rate of river
- radionuclide interaction with suspended matter, according to particle size, and organic and mineral content
- interactions with river biota
- loss to bottom sediment and accumulation
- advection in water column downstream
- advection in bottom sediment
- irrigation with river water (see Well)
- topographical and geomorphological effects on nature of sediment and sediment load
- flooding, moving otherwise stable sediment downstream or onto adjacent land
- dam and sluice effects on sediment flow, dredging, and other interference by man
- meandering leading to drying of sediments and conversion to soil
- eventual discharge into estuarine environments (see Marine)
- acidification

TABLE 3 Cont.

3. Lake Water

- similar to River Water, plus
- stratification
- eutrophication
- resuspension from bottom sediment, by bioturbation or diffusion
- evaporation
- interaction with lake biota
- pattern of bed sedimentation
- creation of lake-side soil from lake bed sediment, either gradually or acutely. Gradual changes may be due to sediment accumulation or slow changes in water level. Acute change many arise either because of sudden geomorphological change or because of the intervention of man, eg dredging or draining the lake

4. River Sediment

- as for River Water, plus
- water movement in bed sediment
- diffusion in bed sediment
- special consideration of sediment accumulation and changes in chemistry within the sediment profile

5. Lake Sediment

- as for Lake Water, plus
- water movement in bed sediment diffusion
- diffusion in bed sediment
- special consideration of sediment accumulation and changes in chemistry within the sediment profile

6. Soil

- bioturbation
- capillary water movement
- water balance
- depth of water table
- rise and fall of water table

- wind erosion and aggregation
- water erosion and aggregation
- sorption onto organic, mineral and other soil fractions
- long term breakdown rate of what are usually referred to as stable soil components
- leaching of radionuclides to a surface water body (see River Water, Lake Water and Marine)

7. Peat
   - as for soil, but with special consideration of sorption onto peat by some radionuclides plus
   - combustion leading to unusual resuspension and concentration of radionuclides in peat ash.

8. Marine
   - sediment interactions as for River Water, but with particular data assumptions for the saline conditions.
   - drying of contaminated marine/estuary sediments and conversion to land (see Lake Water)
   - transfer of activity to the terrestrial environment via wind blown sea-spray
   - sea-level rise or fall

9. Marine Sediments
   - similar to Lake Sediment, applied to marine conditions

10. Artificial
    - diversion of contaminated waters to fish farms or hydroponic units, or other special uses, as yet unspecified

11. Atmosphere
    - atmospheric depression
    - dispersion within a building if release is through floor or into cellar

TABLE 4

BIOSPHERE FEP'S LEADING TO DIRECT RELEASE

1. Exploratory drilling for mineral, thermal or water resources. The nature of the geological location should provide an indication of which of these is the more likely at the site.

2. Investigative drilling for purely scientific reasons. It is difficult to anticipate precise motives in this case.

3. Investigative drilling to determine the potential for storage of oil or gas or other bulk materials, or for disposal of wastes, or for civil engineering purposes. Again site specific geological information will help determine the likely scope for such eventualities.

4. Exploitation of the resources identified in 1).

5. Exploitation of the potential identified in 3).

6. Erosion of surface material leading to exposure of contaminated geosphere materials at the surface. The potential here will depend on the nature of the migration of radionuclides through the geosphere.

TABLE 5

BIOSPHERE FEP'S AFFECTING THE NEAR FIELD OR GEOSPHERE

1. All those direct intrusion FEP's listed in Table 4

2. Changes in sea-level

3. Changes in precipitation

4. Modification of degree of infiltration due to permafrost, or snow cover

5. Changes in surface drainage due to farming practices

6. Changes in surface drainage due to civil engineering, including buildings, but also dams or lake drainage

7. Introduction of chemicals into the groundwater flow system, such as fertilisers, biocides and chemical wastes, or chelating agents, which could significantly affect groundwater chemistry

8. Acidification of the groundwater flow system

9. Introduction of microbiological agents into the groundwater flow system, or other agents which might affect radionuclide mobility, such as colloids, or material which degrades to form colloids

10. Geomorphological effects which alter landform and hence groundwater heads, etc., including periglaciation, glaciation, snowmelt flooding, erosion by wind and water, and aggregation of sediments

11. Natural chemical weathering.

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ANNEX II IODINE IN THE ENVIRONMENT (Summary of the conclusions from reference [43]).

Iodine can exist in a number of valence states, is chemically reactive, and forms various inorganic and organic compounds, some with high vapour pressures. Also iodine is an essential nutrient for animals and humans, and is releatively mobile throughout the environment. Methods of analysis that have been used for the determination of stable iodine have often lacked adequate sensitivity and precision. These various factors have contributed to the uncertainties that still exist in our knowledge of the distribution and movement of iodine between components of the environment.

Atmospheric iodine is the major source of the iodine in soils and the process of enrichment continues throughout soil formation and development. There is evidence that the atmosphere is also an important direct source of iodine for plants. Calculations based on measurements of iodine concentration in the atmosphere, and of deposition rates, indicate that direct sorption from the atmosphere could account for almost all the iodine in plants. On the other hand, since iodine deficiency giving rise to goitre in the first half of this century occurred largely in well-defined areas, the soil rather than the atmosphere would appear to be the major source of iodine for foodstuffs.

Iodine in the soils of humid regions is retained by the solid phase, mainly organic matter and the hydrous oxides of aluminium and iron, so that in general less than 2% of the total content is soluble in dilute $CaCl_2$ solution, and less than 0.1% is taken up by plants in any one year. In soils of arid regions, iodine may accumulate in water-soluble as well as in sorbed forms.

There is insufficient evidence to say if soils in humid temperate regions are, in general, in equilibrium with respect to iodine, or whether contents in soils are still increasing, with annual inputs via the atmosphere exceeding losses through leaching, volatilisation and removal in crops. Some of the iodine reaching groundwaters probably results from a continuous slow downward movement through the profile as a whole, and some from a rapid movement down macro-pores. However, the relative importance of these pathways in different soil types is unknown. Estimates of the amounts of iodine lost from soils, via surface run-off and leaching, that are based on concentrations of iodine in stream and river waters are valid only in the absence of other sources of iodine, in particular (i) the iodophor detergents and sterilants that are widely used in dairy farming and (ii) sewage effluents. These two sources, particularly the latter, can considerably increase the iodine content of river water.