Project SAFE – Prestudy

Appendix A6:

Biosphere

Ulrik Kautsky

SKB

Ulla Bergström

ECOSAFE
## Contents

1 INTRODUCTION ............................................................................................................. 1

2 METHODS USED IN PREVIOUS SAFETY ASSESSMENT OF SFR-1 ........................ 2

   2.1 SAFETY ASSESSMENTS, BASE SCENARIOS .................................................. 2

   2.2 MODEL DESCRIPTION ....................................................................................... 3

      2.2.1 Model structure ....................................................................................... 3

      2.2.2 Model function ....................................................................................... 5

      2.2.3 Exposure pathways to individuals and population ..................................... 5

   2.3 REGULATORY REVIEW ...................................................................................... 7

   2.4 COMMENTS ON PREVIOUS WORK ................................................................. 8

   2.5 SUGGESTED IMPROVEMENTS ........................................................................ 10

3 METHODS PROPOSED FOR THE BIOSPHERE IN PROJECT SAFE ...................... 11

   3.1 IMPLEMENTATION OF THE SR97 METHODS ............................................... 11

   3.2 THE STRUCTURE AND FLOW OF LOOSE DEPOSITS .................................. 11

   3.3 WATER-TURNOVER AND OTHER TRANSPORT ............................................ 13

   3.4 THE STRUCTURE AND SUCCESION OF THE ECOSYSTEM ............................. 13

   3.5 EFFECTS ON FAUNA AND FLORA .................................................................. 14

   3.6 THE ECOSYSTEM MODEL ............................................................................. 14

   3.7 INTERACTIONS GEOSPHERE - BIOSPHERE ................................................. 17

4 SAFETY ANALYSIS ..................................................................................................... 18

5 SUMMARY .................................................................................................................. 19

6 REFERENCES .............................................................................................................. 20
This report addresses the biosphere of the safety analysis for SFR. It gives a brief description of earlier performed studies, summarises the review from the authorities and gives suggestions for improvements of the methodology for a new analysis.

In previous safety assessments the biosphere had a minor role or it was described in a stylised way. However, the coming regulations require that the effects should be described for a realistic biosphere as well as potential effects on other organisms than man. This requires a more realistic model of the biosphere based on ecological know-how rather than isolated simplified food-pathways. The current safety assessment for SFR concerns a real site where the different components of the ecosystem are obvious for laymen. Thus presented models must be clearly related to the surrounding natural system to receive common acceptance. Moreover there is a unique opportunity to gain new knowledge from an existing system which can be used for the safety assessment of a high-level repository. Although it will be necessary to develop new methods and collect new field-data the main work can been done with existing knowledge among ecologists and geologists and data gathered in the area for other purposes.

Moreover in the safety analysis of the repository of high level waste (SR97) new methods have been developed which will be used for the SAFE assessment.
METHODS USED IN PREVIOUS SAFETY ASSESSMENT OF SFR-1

The biosphere was handled in the first safety analysis, 1987 (SKB 1987). It was based on Bergström et al, (1987) where model descriptions and results were given. The results from FSAR (SKB 1987) and the review from the authorities lead to a study (Hesböl et al, 1991) dealing explicitly with the problems of C-14. In the revised FSAR (SKB 1993) the results from Bergström et al, (1987) were used with an extension of the well scenario.

2.1 SAFETY ASSESSMENTS, BASE SCENARIOS

Two main scenarios were handled - one for leakage of the nuclides directly to the coast (brackish or marine scenario) and one where the releases occur to an inland area after land-rise. The biosphere was modelled by compartment theory, where the biosphere components were divided into physical areas with uniform properties. The exchanges of nuclides between those compartments were described by rate constants expressed in turnover per year, also taking into account radioactive decay.

The main purposes with the analysis were to assess the radiological consequences to a critical group and global population from calculated releases from the repository. Therefor the model was divided into four spatial scales to be able to simulate the turnover of the radionuclides from the local to the global area. The four scales were:

- Local zone
- Regional zone
- Intermediate zone
- Global zone

The local zone was used for the calculation of individual doses to a critical group living around the effluent area of the discharges of nuclides to the biosphere. For releases during the first thousands years the local zone consisted of a part of Öregrundsgrepen. After land-rise the zone consisted of a well and a lake area.

In the regional zone, the dispersion of radio-nuclides in an expanded area around the point of discharge was considered. Recipients were the entire Öregrundsgrepen and the lake for the coast and inland scenario, respectively. The local zones were consequently included in the regional zone.

The intermediate zone consisted of the entire Baltic Sea.

The global zone included the entire world.
Some additionally analyses were performed to the calculation of doses to critical group and population

An uncertainty analysis was performed addressing Cs-137 for the coast scenario. Several parameters were varied and analysed with PRISM (Gardner at al, 1983). The analysis showed that human consumption and bioaccumulation were the main contributors to the uncertainties in calculated dose.

Variation analysis was performed for a well scenario. This showed that dilution volumes gave the major contribution to the variations in dose estimates. Finally, doses for Pu-239 and Pu-240 were estimated, assuming that all released activity was trapped in lake sediments. These sediments were then used for agricultural purposes. The concentrations of the elements in this soil were lower than those obtained from irrigation of soil with water from the well.

2.2 MODEL DESCRIPTION

2.2.1 Model structure

Local zone

The main recipients Öregrundsgrepen and the lake were subdivided into compartments for water and two sediment layers (Figure 1). Between these compartments exchange of nuclides due to water turnover and particle fluxes were considered.

Homogenous mixing was assumed within the compartments, which made it necessary to subdivide the sediment in two compartments. One compartment was the upper sediment (0-10 cm), where oxidising conditions prevail and where an exchange with the overlying water occurs. The other compartment was the deeper sediment with reducing conditions, low bioturbation and low water-exchange.

The surrounding agricultural area was divided in three compartments, where the upper layer (ca 0-30 cm deep) consisted of the root zone where agricultural practices take place. The next reservoir was the soil beneath the upper surface, and the third level represented the ground water (Figure 1).
Figure. 1 The structure of the model for the coast scenario.

Intermediate zone

The intermediate zone was not dependant on any primary recipient and consisted of the Baltic Sea and its sediment (Figures 1 and 2).
Global zone

The global zone consisted of five compartments. Two compartments for the water in the oceans, one compartment represented the upper, well mixed, surface water down to approximately 150 m, and the other compartment represented the deeper parts of the oceans (Figures 1 and 2).

The other compartments were the ocean sediments, global groundwater and global terrestrial soils. The compartment systems applied are shown in Figures 1 and 2 for the coast and inland scenario, respectively.

2.2.2 Model function

The exchange of radionuclides between the compartments was described by nuclide-specific transfer coefficients. This lead to several first order linear differential equations which were solved numerically by the program BIOPATH (Bergström et al, 1982). The processes included in the models for the turnover of nuclides were as follows:

- Turnover of water in all water compartments
- Transfer to sediments from water
- Leakage from upper soil to deeper soil
- Leakage from deeper soil to groundwater
- Outflow of groundwater to surface water
- Irrigation of farming land
- Resuspension from sediment to water
- Resuspension from soil (global area)
- Deposition from regional and global atmospheres

The element specific rate constants were obtained from water flows and a retardation factor for the soil compartments. The retardation was described with $K_d$-factors in combination with porosity and densities of the soils. The transfers to the sediments were obtained by area-specific mass sedimentation rates coupled to $K_d$-values, concentration of suspended matter and actual mean depths. Resuspension from the sediments back to water and transfer to deeper sediments were generic values in common for all elements.

2.2.3 Exposure pathways to individuals and population

In the assessments only internal exposure pathways were considered. This simplification was justified from the experiences of earlier performed calculations of exposure from disposal of high-level waste (Bergman et al, 1979, Bergström 1983). The internal exposure pathways were those connected to consumption of water and agricultural products or consumption of marine products. The exposures were calculated in a traditional way (IAEA, 1982), that is use of constant parameter values for root-uptake and transfer to milk and meat, respectively. They were also briefly commented and references were given to the sources.
Radioactive nuclides, which may occur in food, are transported in the food chains via a varying number of paths.

- Crops take up radionuclides from the soil by their root system and may be contaminated through deposition on the vegetation surface.
- Occurrence of radionuclides in meat and milk is due to the animals' metabolism from intake of contaminated cattle food, soil and drinking water.
- Fish and other marine products absorb radionuclides from surrounding water and through food.

Crops

The calculated uptake of radioactive nuclides in groceries was based on concentrations of radionuclides in soil and water as a function of time. It was supposed that a steady-state exchange between vegetation/soil and fish/water prevails. Contamination of vegetation surfaces due to irrigation or deposition of resuspended material carrying radionuclides was also included.

Cattle

Animals may take in radioactivity through their food as well as by consumption of water and soil while grazing. The ingested nuclides are then transferred to milk and meat. That transport was described by distribution factors (Ng et al, 1977, 1979), assuming steady-state conditions. These factors expressed as day per litre or kg give concentration of respective element in milk and meat from a daily amount of intake.

Well

In the well scenario, radionuclides reached man through drinking water both directly and via cattle. The wells were assumed to have such a low water capacity that they were not used for irrigation of agricultural crops and thus only irrigation of green and root vegetables was taken into account. However, it was assumed that the critical group was also exposed to contaminated fish from the lake. In addition lake water was used for irrigation of adjacent farming-land.

Lake

When the lake was recipient, it was assumed that the water in the lake was utilised as drinking water for both humans and animals. Furthermore, the assumption was that the lake water was used for irrigation of agricultural areas. This means that man was exposed from all foodstuffs, all of which was locally produced.
Final assessment

In the final assessment the exposure to critical group occurred simultaneously from the well and lake water in the inland scenario. The exposure pathways to critical groups considered for each case are summarised in Table 1 where the compartments used for calculation of each exposure pathway are shown.

Table 1

<table>
<thead>
<tr>
<th>Path of exposure</th>
<th>Inland scenario</th>
<th>Coastal scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inhalation</td>
<td>Regional surface soil</td>
<td></td>
</tr>
<tr>
<td>Drinking water</td>
<td>Well</td>
<td></td>
</tr>
<tr>
<td>Milk</td>
<td>Well, soil</td>
<td></td>
</tr>
<tr>
<td>Meat</td>
<td>Well, soil</td>
<td></td>
</tr>
<tr>
<td>Green vegetables</td>
<td>Local surface soil</td>
<td></td>
</tr>
<tr>
<td>Cereals</td>
<td>Regional surface soil</td>
<td></td>
</tr>
<tr>
<td>Root vegetables</td>
<td>Local surface soil</td>
<td></td>
</tr>
<tr>
<td>Eggs</td>
<td>Well, regional surface soil</td>
<td></td>
</tr>
<tr>
<td>Fish</td>
<td>Lake</td>
<td>Coast</td>
</tr>
</tbody>
</table>

Exposure pathways for the regional zone were considered in a similar way as for the local zone. There was however no exposure of the regional population through the part of Öregrundsgrepen which was primary recipient in the coast case, or from the well in the inland case as doses to critical group were not included in the calculations of collective doses (Bergström et al, 1987). Potential values of annual yield for the agricultural area and Öregrundsgrepen were therefore utilised to calculate doses.

The exposure pathways from the intermediate zone, i.e. the Baltic Sea, were through consumption of fish and algae products. Algae were considered because they may become an important protein source in the future.

In the global zone, all terrestrial exposure pathways were taken into account, as well as the same marine exposure pathways as for the Baltic Sea.

2.3 REGULATORY REVIEW

SSI (Swedish National Radiation Protection) performed a review of the FSAR 1988 (Bergman C et al, 1988). They concluded that the assessments corresponded to the general status of environmental modelling. However, they identified that there was no connection between surface sea and global
atmosphere. This underestimated the collective dose for C-14 in comparison to the calculations performed by SSI (Bergman C et al, 1988). This error in combination with the high importance of exposure from C-14 lead to that a specific study of C-14 was initiated. The authorities pointed also out that realistic estimates of doses should be made.

After the in-depth analysis 1991, SSI and SKI made a joint report reviewing the safety analysis (SSI, 1992). The main comment from that review pointed out that documentation and model descriptions should be improved as well as reasons for uncertainties should be discussed. However, the authorities focused considerably on location of wells, as wells were deemed to give the highest exposure.

2.4 COMMENTS ON PREVIOUS WORK

Since this assessment was performed much more interest has been devoted to radio-ecological models and their reliability. International studies have been carried out to study such questions (BIOMOVS 1, BIOMOVS 2, VAMP). Reasons for uncertainties and mistakes in results from models for environmental assessments may emanate from the following main reasons (IAEA, 1989).

- specification of the problem (scenario)
- formulation of the conceptual model
- formulation of the computational model
- estimation of parameter values
- calculation and documentation of results

Specification of the problem

The main target for the assessments were estimations of the doses to man. Nowadays much more interest is coupled to the consequences to biota than earlier. A new assessment should not only consider man but also estimate the consequences to flora and fauna according to criteria from the authorities.

The consequences to man were addressed by applying one coast and one inland scenario. The nuclides entered the biosphere however directly to the coastal water or into the lake water. Processes in the geosphere/biosphere interface were not taken into account, mainly because of lack of knowledge of processes at this interphase where chemical conditions may drastically change causing strong gradients. The neglecting of this leads to a direct mixing of the elements transported with groundwater in considerable amount of water. Lake and coastal water may, however, not be the only entrance points of groundwater to consider others are running waters, wetlands and soils.
During the transport with groundwater nuclides may also reach soil and thereby be able to give rise to exposure of man. This area though earlier neglected was subject for one scenario within the BIOMOVS 2 study. In a lysimeter experiment some radionuclides were introduced into the ground water table that was kept at a constant level (BIOMOVSIIc, 1996). These radionuclides were detectable along the whole soil profile due, mostly, to capillary rise and biological processes.

**Formulation of the conceptual model**

The conceptual models were generic although the site is a well-investigated area. In order to improve the assessments and give more reliable results more site-specific information should be used when designing the model and select input parameter values. More emphasis is needed for developing of the conceptual model and the documentation behind it. More considerations need to e.g. be taken about biotic processes also for the turnover of nuclides in the biosphere.

It is evident that the C-14 model and parameter values need a review. The model designed in Hesbøl et al, (1991) considered a time-dependent uptake of C-14 at steady-state to fish. The uptake was related to the concentration of C-14 in water. This model was evaluated against experimental data from a lake in Canada where C-14 had been added (BIOMOVS IIb, 1996). The first comparison performed within BIOMOVSII showed that the model results were lower than the observed values. As C-14 is one dose-dominant nuclide it is important that calculated values of levels in fish are not underestimated.

In the coast scenario the applied model is very sensitive to the water turnover. The water turnover in Öregrundsgrepen was calculated with a hydrodynamic model which generated turbulence and velocity fields to a dispersion model which calculated the dispersion of soluble and particulate matters (Rahm et al, 1989). The results were compared to measurements of currents in the area. The comparison showed a reasonable agreement between the model simulations and the observations. A comparison was also carried out with the water turnover rates applied in a box model for the area (Sundblad et al, 1983). The conclusion was that the water turnover rates in the box-model were in agreement with the ones obtained with the sophisticated methods. But they pointed out that the model approach did not take uptake into biota into account. Other limitations were the neglect of diffusion of elements in the sediment/water interface.

**Formulation of the computational model**

The numerical approach used has been verified in national as well as international studies, showing that this step does not cause any substantial contribution to uncertainties (Persson et al, 1975 and Klos et al, 1993).
Estimation of parameter values

In the study (Bergström et al, 1983) some estimates were made for Cs-137 for the propagation of varying parameter values in the model calculations. Such analyses should with preference be used in all assessments, especially as the literature in general shows wide ranges for many parameters, e.g. $K_d$ (Sheppard et al, 1990). By applying such techniques it is also possible to identify the major components to the uncertainties in order to make improvements for these critical parts of models.

2.5 SUGGESTED IMPROVEMENTS

- The assessments should be based on more site-specific information. The area is well studied since the construction of the nuclear power plants.
- A better description of morphology and bottom sediments should help in selecting adequate processes and parameter values.
- A careful study of the area in combination with hydro-geological modelling should help to identify the entrance points to the biosphere of contaminated ground water.
- Studies of local accumulation zones.
- Evaluate in more detail the turnover of C-14 in aquatic systems.
- A new conceptual modelling could be carried out taking ecological interactions into account in a more detailed way.
- All the assessments should be given with estimates of the uncertainties in results.
- Review of data and updating of the dose-conversion factors.
- Consider the exposure to flora and fauna from released radio-nuclides.
The previous model used in the safety assessment is described earlier. Since the last safety assessment the methods have developed, and the aim is to apply at least the same methods for the biosphere in this assessment as in SR97. That means that a modularised concept is introduced. However, there is a need of further improvement of the methods as outlined in the introduction. Moreover is the concept with concentration factors currently used in the biosphere modelling questionable due to high variations and uncertainties introduced. A more appropriate way is to use trophic transfer models or at least subdivide the concentration factors in a physical-chemical and a biological component.

To be able to construct a trophic transfer model a better knowledge of the biological structure of the system is necessary. Moreover the transport of radionuclides in the loose deposits needs more attention. This includes modelling of flow of water as well as the flow of deposits. The loose deposits were estimated in Sigurdsson (1987), but the information was not used.

In the time-perspective of the SAFE assessment we need also to consider feedback-mechanisms from the biosphere to the geosphere, affecting flow-paths and geochemistry.

3.1 IMPLEMENTATION OF THE SR97 METHODS

The current biosphere models, dose-factors and interaction matrix developed and used in the current safety assessment of the high-level waste (SR97) needs to be revised for SAFE. The changes and development of these are described in Section 2. Moreover the knowledge developed in the projects described below will be incorporated in SAFE.

3.2 THE STRUCTURE AND FLOW OF LOOSE DEPOSITS

A detailed geological field survey of the sea-floor above SFR was performed (Sigurdsson, 1987). This detailed information about sediment depth and particle size has not been used in further estimates, however it gives important information on residence time, sorption and transport pathways of elements. Moreover this detailed information is useful to estimate particle
transport due to resuspension. The topography and hydraulic conductivity of the material are also important parameters for the hydro-geological model. The sediment type is also of importance to determine potential dominant ecosystems.

The local area above SFR is well described regarding sediments (Sigurdsson 1987), however to which extent is this useful for estimates over a larger regional area (i.e. Öregundsgrepen)? This needs to be evaluated primarily by studies of available data from sea-charts, core samplers and other sources. If this is not sufficient some echo sounding transects are necessary to show rock bottom vs. sediment bottom.

Due to land uplift the loose deposits will be subjected to erosion and resuspension by waves, ice and wind. These processes are active on deposits down to several tenths of meters below sea level. The resuspension of particles has several important consequences: 1) radionuclides accumulated in the sediment several hundreds of years are rapidly released and causing doses orders of magnitudes higher; 2) accumulated radionuclides from several discharge-points are resuspended and concentrated in the deepest basins and thus causing higher doses directly due to the concentration or in a later stage when the former sea-floor is used for farming; 3) The topography above land will not be the same as the sea-floor topography which will have effects on the pressure gradients affecting the hydrogeological conditions.

This means that these processes need further studies and that it is difficult directly to use the below sea topography as a model for future land topography. Moreover during the land uplift process the water turnover will change, because land and shallow parts will retard water movement.

This needs a development of a model calculating the resuspension of sediments dependent primarily on wave effects, which is estimated from predominant winds and fetch. Probably fetch (i.e. length of open water in each wind-sector) will be the most important parameter. The fetch will vary dependent on how much land will be elevated in the surrounding area. An estimate will be allowed when taking the shore-level displacement in combination with topography into account. Ice and wind strength are dependent on climatic conditions, which are difficult to predict, and thus it is suggested that the present day situation is used with some possible extreme variations.

The results will be presented with maps showing the topography and bays, lakes and accumulation areas at different stages during the coming 10 000 years. The model can be calibrated with the recent deposits on land in nearby area and a reconstruction of sea level changes and fetch.

Thus the most important information is the change of the topography, the accumulation alternative dispersion of particles and the resulting substrate when the sea-floor is converted to land.
3.3 WATER-TURNOVER AND OTHER TRANSPORT

The water-turnover was identified as important factor for the dose-estimates. The water-turnover also affects the transport and dispersion of radio-nuclides in solution and bound to particles (see above) and organisms. A new method to calculate the turnover will be used in the area (Engqvist, 1993, 1997). The turnover will also be recalculated at different stages during the land-rise. The effects of migrating organism and food stuff will be incorporated in the transport calculations.

3.4 THE STRUCTURE AND SUCCESSION OF THE ECOSYSTEM

There is no site specific description of the ecosystems surrounding the SFR. However, some work has been done in the surrounding area on land and in the water, e.g. fish stocks by Kustvattenlaboratoriet, the sediment ecosystem from monitoring programs (PMK), and projects in the biotestlake at Forsmark. This information must be compiled to be useful to describe the structure of the ecosystem. Especially there is a need to describe the aquatic system and this probably requires a field survey to quantify and describe the dominant components of the ecosystem in the area above SFR as well as for dilution effects of $^{14}$C. Some of this general information is available from the monitoring programs around Forsmark nuclear power station and especially from the work that has been done in the biotest basin. The calculation of fetch and sediment-type described above will be useful for generalisations of ecosystem structure.

After the ecosystem structure of today is described, the succession to future states must be predicted. Land-uplift is the most dramatic change which is possible to predict (Påsse, 1996). Especially the change from sea to inland, alternatively lake is important. But changes in the salinity of the sea, acidification of lakes and land-use are more difficult to predict. To estimate the effects of these processes some extreme variations needs to be tested, e.g. a marine and a freshwater area. Moreover the cultural habits of man will be of importance, where the most significant variable is the size of the life support area. A highly self sustainable society has a small life support area, i.e. low dispersion and mixing of radionuclides, whereas a society as today has a large life support area, i.e. high dispersion and mixing of radionuclides through food supply from different regions. Here again some examples of extreme variation of the life support area can be considered.
3.5 EFFECTS ON FAUNA AND FLORA

The coming regulations from SSI stress that effects on other organisms than man should be estimated. From the ecosystem model described below, compartments will be identified which have high mass-flow and storages of radionuclides. The radiation effects in these compartments will be calculated. Moreover two top-carnivores will be selected to illustrate the potential effects of bio-magnification. Two well known and suitable top-carnivores are grey-seal and white-tailed eagle, which are occurring in the area and are well investigated concerning organic xenobiotic substances (e.g. PCB, DDT).

3.6 THE ECOSYSTEM MODEL

The aquatic part of the ecosystem model is shown in Figure 3. It is subdivided in a physical and a biological submodel. The physical model (Figure 3a) describes sedimentation, resuspension and water-exchange mainly affected by physical and chemical processes. The radio-nuclides will enter the system through the sediment. In the sediment interface there is a drastic change in redox conditions, bacterial activity, temperature etc. which affects the retention of radio-nuclides. Probably a large part of the radio-nuclides will be stored there until the sediment is resuspended. The resuspension is affected by wind and sea-level changes. These two factors have large effects also on the water turnover. The sinks of radio-nuclides are radioactive decay, export with the water or suspended particles and through release to the atmosphere (e.g. $^{14}$C).

The ecological part of the model (Figure 3b) is more complex, however several of the compartments (the boxes) can be omitted or aggregated when the structure of system is described as outlined above. The main uptake pathways is through consumption of food contaminated with radio-nuclides. Filter-feeders (e.g. bluemussels, Baltic Sea mussel) receive most of the substances through feeding of suspended particles (plankton and detritus particles) and from gill uptake of dissolved radio-nuclides. Filter-feeders can filter the water in an entire bay within 1-2 weeks in most coastal areas (Kautsky 1995). Filter-feeders are common food source for fish and birds. Moreover filter-feeders deposit large amounts of faecal pellets which means that filter-feeders are an important gateway to transport suspended or dissolved radioactive substances to the bottoms. There are already models (Gilek et al 1997, Kautsky 1995) developed for assessing the turnover of hydrocarbons (DDT, PCB, Dioxin) through filter-feeders. These models can easily be adopted to calculate the turnover of radio-nuclides.

Another potential important transport mechanism it through benthic plants (e.g. algae and reeds). Radio-nuclides sorb to the plant or are actively assimilated. The plants then detach or fragment and sink to deeper bottoms, where they are decomposed and consumed by organisms, which then are
consumed by fish. This is an important pathway in most coastal areas. A minor flow of matter is through grazers feeding on plants, however, this can lead to high accumulation in grazers which then are consumed by fish. Plankton are also efficient transporters of radio-nuclides transferring substances to larger plankton and then to fish or to filter-feeders.

The benefits with ecosystem models are that the transfer of radio-nuclides is dependent on the food transfer and not on concentration coefficients. This means that the large range of variation of the concentration coefficient is reduced. Moreover also transient changes in the environment can be modelled. The ecosystem model is also more transparent for other scientists because it describes existent processes and pathways.

A similar model is necessary for the terrestrial environment, however this model has fewer compartments and is thus easier to construct.
Figure 3 Conceptual ecosystem model of an aquatic ecosystem. Upper part shows physical processes, lower part biological processes. Boxes are reservoirs, thick arrows fluxes of matter, thin arrows relationships to parameters and external variables (circles).
3.7 INTERACTIONS GEOSPHERE - BIOSPHERE

As mentioned earlier at the interface between the geosphere and biosphere important processes occur which have been not addressed in earlier safety assessments. Moreover the transport of nuclides in the loose deposits, i.e. near surface hydro-geology, needs further consideration. In the time-scales and physical distance regarded here there will be a considerable feedback from the biosphere to the geosphere, e.g. trophic status affecting water-chemistry. These issues can only be solved with an integrated approach between geosphere and biosphere.
The ecosystem model will predict where radionuclides will accumulate. This enables that doses to organisms living in the area can be calculated. This will also give new ideas of potential pathways not considered earlier. This information will be incorporated in the development of the BIOPATH model to calculate doses to man. The results from the data collection and field surveys will give the major structure of the ecosystem and estimates of future changes. The models of sediment resuspension and landscape change gives information on transport of particles and input-data to the far-field model. This affects the dispersion and transport of radio-nuclides together with the water-turnover. The interdependence of the project is sketched in Figure 4.

Figure 4 Relationships between subprojects in the biosphere. Rectangles show subprojects within the biosphere program, ellipses external data.
SUMMARY

There has been a considerable development of models used for describing the turnover of radionuclides or other pollutants in the biosphere. New regulations require realistic assessments and description of effects on fauna and flora. Thus the use of trophic transfer models will be a more appropriate way to model the biosphere. These models take all accumulations of radionuclides in the ecosystem into account, not only direct pathways to man. Thus these models must be developed for this area. Moreover the turnover of loose deposits needs to be modelled. To be able to use these models there is a need to collect data on sediment composition, ecosystem structure and potential changes due e.g. sea-level fluctuations. These data will be collected from literature and where it is necessary complemented with field surveys. In some cases new models need to be developed. The integration of the geosphere and biosphere models is identified as an important issue.
REFERENCES

Bergman, R, Bergström, U and Evans, S, 1979 Dose and dose commitment from ground-water-borne radioactive elements in the final storage of spent nuclear fuel. KBS-TR-100,


Bergström, U, Edlund, O, Evans, S and Röjder, B, 1982 BIOPATH – A computer code for calculation of the turnover of nuclides in the biosphere and the resulting doses to man Studsvik AB, (Studsvik/nW-82/261)

Bergström, U, 1983 Dose and dose commitment calculations from groundwater borne radioactive elements released from a repository for spent nuclear fuel, KBS-TR-49


BIOMOVS IIb, 1996 Validation Test for Carbon-14 Migration and Accumulation in a Canadian Shield Lake. BIOMOVS II Technical Report No. 14, published on behalf of the BIOMOVS II Steering Committee by the Swedish Radiation Protection Institute, Stockholm, ISBN 91-972958-3-3

BIOMOVS II c, 1996 Model Validation Studies of Water flow and Radionuclide Transport in Vegetated Soils Using Lysimeter Data BIOMOVS II Technical Report No. 15, published on behalf of the BIOMOVS II Steering Committee by the Swedish Radiation Protection Institute, Stockholm, ISBN 91972958-4-1


Feldt, W., 1989 Proceedings of the XVth Regional Congress of IRPA Visby, Gotland, Sweden, 10-14 September, 1989:

Gardner, R H, Röjdér, B and Bergström, U, 1983 PRISM – A systematic Method for determining the Effect of Parameter Uncertainties on Model Predictions, Studsvik AB (Studsvik/NW-83/55)


Hesbøl, R, Puigdomenech, I and Evans, S, 1990 Source terms, isolation and radiological consequences of carbon-14 waste in the Swedish repository, SKB TR 90-02

IAEA; Safety Series No 57, 1982 Generic Models and Parameter for assessing the environmental Transfer of radionuclides from Routine Releases

IAEA Safety Series No. 100, 1989 Evaluating the reliability of predictions made using environmental transfer models


Ng, Y, C, Colsher, C S, Quinn, D J, and Thompson, S E, 1977 Prediction of the dose to man via the forage-cow-milk pathway from radionuclides released to the biosphere. Univ California rep UCRL-519391

Ng, Y, C, Colsher, C S, and Thompson, S E, 1979 "Transfer factors for assessing the dose from radionuclides in agricultural products" Biological implications of Radionuclides released to the Biosphere Released from Nuclear Industries Proc Int Symp, Vienna, Vol 2 IAEA


Rahm, L., Nyberg, L och Gidhagen, L, 1989 Spridningsmodell för kustzonen SMHI unpublished manuscript


Sigurdsson, T 1987 Bottenundersökning av ett område ovanför SFR, Forsmark. Sveriges Geologiska AB SKB SFR 87-07


SKB, 1993 Slutförvar för reaktoravfall-SFR-1, Slutlig säkerhetsrapport reviderad utgåva maj 1993 (in Swedish)


SSI, 1992 Granskning av SKBs fördjupade säkerhetsanalys av SFR-1 SSI-rapport 92-07 ( in Swedish)
