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PAMINA
Performance Assessment Methodologies in Application to Guide the Development of the Safety Case

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Task reports for the third group of topics:
Biosphere
Human intrusion
Criteria for Input and Data Selection

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Foreword

The work presented in this report was developed within the Integrated Project PAMINA: Performance Assessment Methodologies IN Application to Guide the Development of the Safety Case. This project is part of the Sixth Framework Programme of the European Commission. It brings together 25 organisations from ten European countries and one EC Joint Research Centre in order to improve and harmonise methodologies and tools for demonstrating the safety of deep geological disposal of long-lived radioactive waste for different waste types, repository designs and geological environments. The results will be of interest to national waste management organisations, regulators and lay stakeholders.

The work is organised in four Research and Technology Development Components (RTDCs) and one additional component dealing with knowledge management and dissemination of knowledge:

- In RTDC 1 the aim is to evaluate the state of the art of methodologies and approaches needed for assessing the safety of deep geological disposal, on the basis of comprehensive review of international practice. This work includes the identification of any deficiencies in methods and tools.
- In RTDC 2 the aim is to establish a framework and methodology for the treatment of uncertainty during PA and safety case development. Guidance on, and examples of, good practice will be provided on the communication and treatment of different types of uncertainty, spatial variability, the development of probabilistic safety assessment tools, and techniques for sensitivity and uncertainty analysis.
- In RTDC 3 the aim is to develop methodologies and tools for integrated PA for various geological disposal concepts. This work includes the development of PA scenarios, of the PA approach to gas migration processes, of the PA approach to radionuclide source term modelling, and of safety and performance indicators.
- In RTDC 4 the aim is to conduct several benchmark exercises on specific processes, in which quantitative comparisons are made between approaches that rely on simplifying assumptions and models, and those that rely on complex models that take into account a more complete process conceptualization in space and time.

The work presented in this report was performed in the scope of RTDC 1.

All PAMINA reports can be downloaded from http://www.ip-pamina.eu.

Executive Summary

Pamina WP1.1 is devoted to the review of methods and approaches for the Safety Case used in the participant countries and in other important national programmes for the development of geological disposal.

The work plan of WP1.1 is structured in 11 topics which all together cover the scope of a Safety Case. The programme is organised in three successive phases. The first and second phases covered 8 topics and have already been reported in deliverables D1.1.1 and D1.1.2. The present report corresponds to the third phase, during which the topics 9 to 11 have been reviewed.

D1.1.1	**Topic 1**	Safety functions
	Topic 2	Definition and assessment of scenarios
	Topic 3	Uncertainty management and uncertainty analysis
	Topic 4	Safety indicators and performance indicators
D1.1.2	**Topic 5**	Safety strategy
	Topic 6	Analysis of the evolution of the repository system
	Topic 7	Modelling strategy
	Topic 8	Sensitivity analyses
D1.1.3	**Topic 9**	Biosphere
	Topic 10	Human intrusion
	Topic 11	Criteria for input and data selection

This third phase started in September 2008 and concluded with the edition of this report in January 2010.

The treatment of these three topics has followed the steps defined in Annex 1 to the contract "Description of Work":

First step: Target definition.

In this step the scope and the outstanding issues for each topic were clearly delineated and described in written guidelines. This task was accomplished in the workshop hosted by Posiva in September 2008.

Second step: Overview of the methods and approaches.

In this step the participants prepared their individual contributions, presenting the national methodology to treat the topic. Although in the two previous phases technical meetings were held to harmonize the individual contributions, in this third phase no technical meeting was considered necessary.

Third phase: Analysis and synthesis.

The participants made a thorough discussion of the contributions to the three topics in a workshop hosted by ENRESA in April 2009. The synthesis of those contributions and the discussions of the workshop are reported in the three task reports included in this document, that were prepared by the topic coordinators.

The participants and the contributions made on the three topics treated in the third phase of WP1.1 are the following:

	Biosphere	Human intrusion	Criteria for input and data selection
Andra	X	X (*)	X
Bel V-FANC	X	X	X
Enresa	X	X	X
GRS – K	X	X	X
GRS – B	X	X	X (**)
NDA	X	X	X
NRG	X	X	X
NRI	X	X	X
Posiva	X	X	X
SCK-NIRAS	X	X	X

(*) IRSN has contributed to the regulatory aspects

(**) Joint contribution with DBE and BGR

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PART 9: BIOSPHERE

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1 Introduction

Geological disposal of long-lived radioactive waste is being widely investigated as a means of protecting people and the environment from the waste for as long as it remains hazardous. A geological disposal facility may be considered safe if it meets the relevant safety standards that are internationally recommended and those specified by the national regulator.

The radiological hazard posed by the disposal facility is one of the safety criteria upon which the overall long-term safety of the disposal is assessed. The radiological consequences of disposal will arise in the "biosphere", should there be any release from the engineered and natural barriers of the disposal system. The International Atomic Energy Agency (IAEA) [1] defines the biosphere as "*that part of the environment normally inhabited by living organisms*". The biosphere can thus be considered as the environment or system in which radiation exposures can occur. The aim of biosphere modelling is to convert concentration or the flux of activity reaching the environment into a dose incurred by a member of a hypothetical critical group. Thus it provides an indicator of the radiological impact associated to a potential geological repository. The many uncertainties related to biosphere evolution in time and the ensuing difficulties to define hypothetical critical groups, lead to acknowledge that several different modelling assumptions are reasonably thinkable and that each can possibly result in a different calculated dose.

This Task Report collates the views from European organisations participating in the PAMINA Project on their treatment of biosphere issues in safety assessments for geological disposal of radioactive waste. The key issues summarised in this report include the concept of the biosphere and its description in safety assessments, the various interpretations of dose criteria, and the models used for dose conversion in relation to radionuclide releases from the geosphere.

The sections in this report correspond closely with those in the documents submitted by the participating organisations:

- Section 2 summarises regulatory requirements and guidance,
- Section 3 defines key terms and concepts,
- Section 4 summarises how the concepts are treated to create the biosphere models used in safety assessments, and outlines commonalities and differences in approach,
- Section 5 provides conclusions,
- Section 6 contains a list of references.

This report is based on contributions received from the following organisations:

Belgium	
FANC	Federal Agency for Nuclear Control (regulator).
ONDRAF/NIRAS	National Agency for Radioactive Waste and Enriched Fissile Materials (developer), jointly with…
SCK/CEN	National Nuclear Research Centre (research organisation).
Czech Republic	
RAWRA	Radioactive Waste Repository Authority (developer), jointly with…
NRI	National Nuclear Research Institute (research organisation).
Finland	
POSIVA	Posiva Oy (developer).
France	
ANDRA	National Radioactive Waste Management Agency (developer).
Germany	
GRS-K	Company for Disposal and Reactor Safety (Köln, Technical Support Organisation to the German regulators).
GRS-B	Company for Disposal and Reactor Safety (Braunschweig, Research Division supporting the German implementers).
The Netherlands	
NRG	Nuclear Research and consultancy Group (research organisation).
Spain	
ENRESA	National Radioactive Waste Management Company (developer).
United Kingdom	
NDA	Nuclear Decommissioning Authority, Radioactive Waste Management Directorate (developer).

2 Regulatory Requirements and Guidance

The radiological hazard due to the disposal facilities can be measured in terms of the *risk* to individuals. The International Commission on Radiological Protection (ICRP) describes *radiological risk* in terms of the radiation *dose* received during exposure (Sv) [2]. It also publishes conversion factors for the effective dose (Sv) corresponding to the exposure (in Bq). Safety assessments must therefore consider radionuclide transfer rates and environmental concentrations in the biosphere, and how these can be transformed into a measure comparable to applicable health standards. Current guidance from the ICRP suggests a value of 0.073 Sv^{-1} as the risk coefficient, i.e. conversion factor for exposure to ionising radiation [3]. This gives the risk of an exposed individual dying from radiation-induced cancer, and includes potential genetic effects in subsequent generations. The level of risk to the individual that society tolerates can be expressed in terms of an annual individual dose received by potentially affected individuals. In Europe, Euratom Directive 96/29 [4] gives appropriate dose limits for several exposure scenarios. For members of the general public, a dose limit of 1 mSv/year is cited, in accordance with the IAEA's advice on the safety requirements for geological disposal [5]. Interpretation of this value for radioactive waste disposal facilities provides the basis for regulation at the national level, as discussed below. The more advanced national regulatory frameworks complement fundamental dose or risk limits with safety requirements that aim to reinforce the demonstration of safety by suitable arguments and analyses in the safety case. It should also be noted that guidance is evolving in several countries.

Belgium: The Belgian regulator (FANC) has recently issued guidance on the management of licence applications, which contains safety principles that apply to any disposal facility for radioactive waste in Belgium [6]. The FANC is currently developing more detailed guidance for near-surface disposal facilities that will be issued in the next two years. The development of more detailed regulatory guidance for geological disposal facilities for high-level waste is also planned, and will be based in large part on the guidance developed for near-surface disposal facilities. Current regulatory guidance includes five "expectations", setting aspects of the biosphere that should be explicitly addressed:

- For each important biosphere receptor, a critical group or a potentially exposed group and the reference organisms shall be determined,
- For each critical or potentially exposed group, all transfer pathways and exposure pathways shall be identified,
- Regarding reference organisms, the state-of-the-art of international developments shall regularly be checked,
- All receptors, transfer pathways and exposure pathways shall be taken into account in such a way that the radiological impact will not be underestimated,
- Various timescales should be considered.

Czech Republic: In the Czech Republic, the State Office for Nuclear Safety (SÚJB/SONS) is responsible for the licensing of a geological disposal facility. Reasonable assurance must be provided in the safety case that doses to members of the public in the long term will not exceed 0.25 mSv/year for normal evolution of the facility under consideration [7]. A higher dose limit (up to 1 mSv/year) is applicable for lower probability scenarios.

Finland: Finnish waste disposal programme is at a relatively advanced stage, and regulatory requirements for the disposal of spent nuclear fuel are well developed, following the recommendations in the Council of State Decision (478/1999) of 25 March 1999. The Decision places conditions on the geological characteristics of the site, the disposal facility depth, the nature of the barriers, and the implementation and timing of disposal. Also, criteria on long-term radiological protection performance are specified for the disposal system, in terms of dose to humans and release rates of long-lived radionuclides from the geosphere into the biosphere [8]. The constraint is 0.1 mSv/year for the *most exposed members of the public*. In addition, the exposure should be “insignificantly low” for the other people, – more specifically doses must not exceed 0.001 to 0.01 mSv/year, where the applicable dose constraint depends on the size of the exposed group. Consideration must also be given to protect other living species and, although no numerical dose constraint is stated, any exposures should remain below the levels that would affect detrimentally to species of fauna and flora on the basis of the best available scientific knowledge. It is recognised, however, that applicable methods for estimating such exposures are still under development internationally, and they may need to be implemented more explicitly within the regulatory framework at a later date.

Some guidance is also provided in Finland on potential exposure environments and exposure pathways. According to [8], the most exposed individuals should be assumed to live in a self-sustaining family or small village community in the vicinity of the disposal site, at the point where the highest radiation exposure is expected to arise. The community is assumed to be located near a small lake and a shallow water well. Other members of the general public are assumed to live at a regional lake or at a coastal site and to be exposed to the radionuclides transported in these watercourses.

France: The current regulatory framework is based on a guidance initially published by the Nuclear Safety Authority (ASN) in June 1991, the Basic Safety Rule n°III.2.f [9] (RFSIII.2.f) newly released in 2008 (called below “the guidance”) in order to introduce notions and safety approaches developed in the “Dossier 2005 Argile” edited by Andra and to take into account for the Planning Act n° 2006-739 of 28 June 2006. A dose limit for individuals of 0.25 mSv/year is applicable for a reference scenario. This value is set at a quarter of the limit for the general public to take account of exposure by different practices over the period of the assessment. The guidance also provides rules and definitions on aspects of the biosphere.

To verify that the radiological protection objectives of the repository are reached, the post-closure safety assessment must cover the future behaviour of the repository and check that individual exposure is acceptable. The approach adopted shall consist in considering a limited number of situations representative of the different families of events or sequences of events such that the associated consequences are the greatest among those of the situations of the same family. The families of events or sequences of events adopted shall be those considered to be conceivable among all those which are *a priori* possible, considering the expected performances of each component and the disturbances caused by the creation of the repository. It is recommended that the data used in the models should be either pessimistic to overestimate the radiological impact, or best-estimate data associated with sensitivity analysis for exploring their possible variation.

The guidance indicates that the Biosphere is the part of the Environment easily accessible to the activities of human kind and prone to be a transfer way of radioactivity involving an internal exposure (inhalation, ingestion) or an external exposure. The biosphere may include:

- The aquifers used for water consumption,
- The outlet zone of the groundwater that could be affected by the repository,

- The superficial discharge system of these groundwater,
- The soils that could be affected by irrigation or flooding by the previous water system,
- The agricultural or animal production able to be used for human consumption,
- The surrounding atmosphere.

The guidance also indicates that in the biosphere it seems not possible to predict the local evolution of the environment for long time periods; on the other hand, the large climatic events that are predictable at a regional level should be taken into consideration by developing “**biosphere types**”. Concerning the exposed group, the guidance rules, that radiological impact must be calculated for reference hypothetic groups, which are representative of the individuals that could receive the highest doses and who are partially or totally living in autarky.

Germany: The guideline ‘safety criteria for the final disposal of radioactive wastes in a mine’ from 1983 [10] requires that the limit for the effective dose to an individual is 0.3 mSv/a given in the German Radiation Protection Ordinance. According to the current radiation protection ordinance, dose calculations have to be performed for six different age groups to ensure compliance for all population groups. Furthermore, organ doses have to be calculated and compliance has to be shown with organ-specific dose limits. For radionuclides, which accumulate preferably in specific organs, the organ dose might be the limiting value.

The German regulatory framework dates back to 1983, but GRS-K recently proposed a revision [11], which is currently being considered by the advisory bodies to the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). The revision concerns the lowering of the 1983 annual effective individual dose limit, from 0.3 mSv/year to 0.1 mSv/year. Additional guidance is given in terms of what should be calculated over different periods in the future. It is felt that it is not possible to predict the development of the environment at the site for more than about 1,000 years. Therefore, only during this first period of 1,000 years dose calculations for a group of about 30 people of all ages are assumed to be reasonable. Beyond this time, the calculated “dose” transforms into an indicator of the disposal system’s containment function and therefore consequence analysis will employ a “standardised climate depending biosphere models” with only males in the exposed group. The proposed size of the exposed group should consist of about 30 people. Additional guidance for the first 1,000-year period on the constitution of the biosphere models, for example food production will be elaborated in the future.

Netherlands: In the Netherlands, the safety assessment must demonstrate that individual risks and doses are below the regulatory limits, corresponding to 0.1 mSv/year. There are no further regulations relating to the biosphere. However, it should be noted that any licence application must also include an Environmental Impact Statement (EIS), which addresses, amongst other things, the ICRP principles for radiation protection, namely justification, optimisation, and compliance with dose limits. The EIS can use the safety report to show compliance with the ICRP principles.

Spain: In Spain, the Nuclear Safety Council (CSN) in 1987 has established a regulatory safety criterion for the disposal of radioactive waste in terms of a maximum allowable individual risk of 10^{-6} y^{-1}. This is currently the only regulatory requirement in

Spain governing the safety of radioactive waste disposal. There are no specific regulatory requirements or guidelines regarding the treatment of the Biosphere in the Safety Case.

United Kingdom: The UK regulatory framework is defined by the Radioactive Substances Act 1993 and the "Guidance on Requirements for Authorisation" (GRA), which outlines the safety principles and requirements that a developer of a disposal facility must meet. This guidance has recently been reissued [12]. The GRA differentiates between the requirements for near-surface disposal facilities and geological disposal facilities, and introduces a staged authorisation process. For the post-authorisation period, the UK standard is expressed as an annual individual risk guidance level of 10^{-6} y^{-1}. The UK environmental regulators recommend a detriment-adjusted risk coefficient for the whole population of 0.06 Sv^{-1}. An individual risk of 10^{-6} y^{-1} therefore translates to an individual dose of 0.02 mSv/year. During the period of authorisation, the environmental safety measure is a dose constraint of 0.3 mSv/year to a member of the critical group.

A range of dose limits is presented above, but only a few of the regulatory authorities have specified the "individual" for whom the annual individual dose (or risk) is to be calculated in the safety assessment. Similarly, the assessment timescales are generally undefined. Additional information is required to make use of the dose limits in safety assessments. The approaches taken are described in Sections 3 and 4 of this report.

3 Key Terms and Concepts

Regulations in the participating countries define radiological protection in terms of limits, or constraints on annual individual dose or risk. Some of the regulators also provide definitions of some of the key terms and concepts. However, for the most part, the task of deriving representative values of annual individual dose or risk in safety assessments requires that a substantial assessment database of biosphere concepts, FEPs (features, events and processes) and parameter values (including parameter distributions), be assembled to perform the necessary calculations. The IAEA [5] and the Nuclear Energy Agency (NEA) of the Organisation for Economic Co-operation and Development (OECD) [13] aid the process by providing a common set of definitions, such as descriptions of the *Scenario* and *Reference Biosphere* concepts.

PAMINA participants share a number of common concepts, although terminology is not always consistent. For example, for one contributing organisation, the *receptor* is the individual receiving the dose, whereas other organisations use the term *receptor* to mean the abiotic component of the biosphere into which groundwater discharge. The key terms and concepts that are generally used are outlined below.

3.1 Biosphere Concept

As noted in Section 1, the IAEA [1] defines the biosphere as "*that part of the environment normally inhabited by living organisms*". The IAEA [1] notes that:

"In practice, the biosphere is not usually defined with great precision, but is generally taken to include the atmosphere and the Earth's surface, including the soil and surface

water bodies, seas and oceans and their sediments. There is no generally accepted definition of the depth below the surface at which soil or sediment ceases to be part of the biosphere, but this might typically be taken to be a depth affected by basic human actions, in particular farming."

This is the common, but not unique, understanding of the biosphere in countries participating in PAMINA. In general, the biosphere can be thought of as the receptor for radionuclides released from the disposal facility and geosphere.

In Finland, Posiva's concept of the biosphere makes direct reference to the diversity and variability of the system. In Germany, GRS-B notes that the biosphere is part of the entire disposal system and is treated as such in the safety case. Many contributing organisations note that the biosphere serves no safety function, but that its properties influence the distribution of contaminated groundwater. Similarly, in the UK, the NDA does not consider the biosphere to be a barrier, but instead treats it as a receptor for discharge contaminants. In the Netherlands, the NRG considers the biosphere as a barrier, but does not consider it as part of the engineered barriers, the host rock or the overburden.

3.2 Biosphere Description

In Finland, Posiva's description of the biosphere encompasses the climate (including predictable changes in the environment), human habits (for which the nutritional needs and metabolism are assumed to be similar to those of the present-day population), and the routes by which environmental concentrations of radionuclides can lead to exposure. These include use of contaminated water as household water and for irrigation of plants and for watering animals, and use of contaminated watercourses. For Posiva, the evolution of the biosphere includes an additional process not seen in more southerly countries in Europe. The mass of ice during the previous glaciation depressed the crust, such that current land uplift rates (mm per year) will have an impact on the coastline – much of what is currently coastal will transform into terrestrial ecosystems over the next few thousand years. It is perhaps because of this that Posiva considers "reference biospheres" difficult to justify, and directly address evolution of the biosphere.

In France, Andra general approach for biosphere modelling is derived from Biomass programme [16]. It takes into account aquifers used for water resources (via wells and deep boreholes), as well as surface water bodies. Soils can be irrigated or may flood, with contamination of crops used for animal and human foodstuffs. The atmosphere is specifically included. Climate change is also taken into account through the use of individual biosphere scenarios, each defined for a specific set of climate conditions. Consideration of the type of disposal (existing near-surface or geological disposal) and life phase of the disposal is a major issue for the description of the reference biosphere to be studied. According to these elements, one temperate and/or several additional future possible biospheres (based on the climate evolution as proposed in Bioclim [14]) are taken into consideration. Andra also considered the influence of climate changes on the surface environment over 1 million year through a bio-geoprospective study that included several glaciations cycles.

In Spain, Enresa uses the present-day biosphere as the basis for the description of the biosphere, together with another present-day analogue biosphere in a climatic scenario. The chosen analogue is used to investigate the implications of drier, cooler climate conditions, and the exposure pathways are assumed to be the same as those of the present day.

The present-day biosphere, with its wells and springs, and patterns of food consumption, is also used in the Czech Republic by NRI/RAWRA. Inhalation, ingestion and external irradiation exposures are modelled using food, water and soils from the contaminated area.

In Belgium, Germany, the Netherlands and the UK, reviews of how to treat the biosphere in safety assessment are currently underway. In Germany, the current biosphere model is based on the present-day living habits of the people, and research is ongoing into how to address climate change. Six alternative states have been considered by GRS-B (including the present day), and appropriate analogue locations have been identified as the basis for biosphere description. GRS-K proposal under discussion is to describe a range of hypothetical stylised environments due to climate states that have already occurred at the site over the last 1,000,000 years.

3.3 Treatment of non-human biota

The biosphere descriptions provided by the participants note generally the need to address non-human biota. The European Commission (EC) projects FASSET (Framework for ASSessment of Environmental impacT), ERICA (Environmental Risk from Ionising Contaminants: Assessment and Management) and PROTECT (PROTection of the Environment from ionising radiation in a regulatory ContexT) [15] are cited as the basis for this aspect of the biosphere.

3.4 Biosphere Dose Conversion Factor (DCF)

Biosphere transfers can be taken into account either through the use of a set of biosphere conversion factors or by coupling geosphere model with a dynamic biosphere model.

Definition of biosphere conversion factors enables to run independently biosphere and geosphere calculations. They are used to convert any geosphere modelling output into a dose value. Essentially, the biosphere description allows the conversion of J (Bq/year), the radionuclides flux from the geosphere to the biosphere (potentially into different ecosystems), into the annual individual dose D (Sv/year):

$$D = B_{DCF} J \tag{1}$$

The biosphere dose conversion factor (DCF), B_{DCF} (Sv/Bq) represents the full set of biosphere FEPs for each radionuclide in the assessment.

An alternative approach uses a radionuclide concentration in groundwater rather than a release rate. The units of the biosphere dose conversion factor are then (Sv/year)/(Bq/m^3):

$$D = B_{DCF} C_w = B_{DCF} \frac{J}{Q} \quad (2)$$

The groundwater concentrations are usually derived from a release from the geosphere, J (Bq/year), by applying a diluting water flux derived from local conditions, Q (m^3/year). Equation (1) is therefore the more generic form of the biosphere DCF.

Commonly the DCFs are calculated an using unit release (1 Bq/year) or unit concentration (Bq/m^3 or Bq/l) as input to the biosphere model. Models are run until steady state conditions are reached or for a pre-defined time (often 10,000 years). The DCF for each nuclide is then the highest dose calculated.

In the assessment model, the dose is then calculated using the release or concentration history of the radionuclide, and the time dependence of the dose is determined solely by the radionuclide release from the geosphere.

The biosphere model is then effectively decoupled from the geosphere model by use of the biosphere DCF.

The use of DCF relies on the assumption that the different compartments of the biosphere have a quasi-static behaviour. At every calculation time step, an equilibrium is then reached between the source and the biosphere. The contamination state of the compartments can be considered independent from the history of past releases. This assumption can be assumed to be true as long as the variation of the radionuclide flux from the geosphere remains slow compared to the time required by each compartment to reach an equilibrium. In the context of long-term performance assessment of geological disposal, this assumption is much reasonable for river, plant or animal compartments for which dwelling time of radionuclides are usually shorter than a year. However, it can be more controversial for soil because of possibly much longer dwelling time.

In contrast to the biosphere DCF approach, in some assessments the link between geosphere and biosphere is maintained. In these calculations, the release from the geosphere is input directly to the biosphere model and the resulting time-history of dose contains the dynamics of the release from the geosphere and the biosphere.

3.5 Exposed Group

This concept denotes the individual receiving the dose. There must be an individual for whom the dose is calculated. Earlier guidance from the ICRP referred to individuals in the “critical group” [2], but this has proved to be problematic in terms of defining hypothetical critical groups in the far future. More recently, the ICRP has discussed the concept of the “representative individual”, where highly exposed individuals from a local community are identified on the basis of specific habits and patterns of behaviour.

In the UK, the hypothetical critical groups are referred to as “potentially exposed groups” in the GRA [12]. In Germany, according to current radiation protection ordinance, 6 age groups are considered. GRS-K has suggested that in the future the most exposed group should comprise around 30 individuals from all ages. After 1,000 years, the dose calculations can be limited to males. This size should allow self-sustaining conditions to be met. Most contributing organisations apply the "critical group" concept in a relatively straightforward way by assuming that the most exposed group would consist of subsistence group consuming its own produce, derived from the most contaminated parts of the environment.

In Finland, Posiva is required to calculate doses to inhabitants of a landscape which is assumed to be contaminated. As noted in Section 2, the communities and individual lifestyles are specified. The unusual notion of "other people" represented by a larger population than the most exposed groups is introduced and specific low dose constraints must be complied with. Posiva derives the distribution of annual doses to all individuals exposed by the contaminated landscape. From this distribution are doses to representative persons for *the most exposed group* and *other people* identified.

In France, Andra calculates doses to individuals in the age groups infant (3 months to 5 years), children (6–15 years) and adults (16–70 years) by using the recommended dose coefficients for 1 year old infant, for 10 year old child and for adult. Depending on the context of the assessment (type of disposal, timescales under consideration…), Andra considers for the operational phase a reference group having present-day observed habits at local scale and for the post-closure (on the long term) hypothetic reference or critical groups representative of the individuals that could receive the highest dose. The method (in coherence with Biomass) considers a priori about 10 hypothetical groups with specific habits not necessarily observed at local scale but covering different transfer pathways with the view to not excluding future possible behaviours that are not possible to predict today. The objective is to determine the group representative of the maximum potential exposition (see section 4.1).

Other organisations assume only adults, on the basis that the annual dose to an adult is indicative of the dose over a full lifetime.

3.6 Assessment End Point and dose constraints

The end point of safety assessment calculations is a numerical value that can be compared to the regulatory requirements discussed in Section 2. In all cases, the calculated dose is the cumulative value from multiple parallel exposure pathways. In practice, calculated long-term doses are always safety indicators since they are hypothetical doses received by representative individuals. Indeed, some contributing organisations have regulatory frameworks that make a distinction between situations for which the calculated dose is considered as a limit and situations for which it is rather a reference that requires alternative safety indicators to be assessed as end points. Those situations may be characterized by the timescale into consideration on the one hand, and the likelihood of the features, events and processes that are modelled on the second hand.

In Germany, GRS-K suggests calculating dose over the first 1,000 years following closure of the disposal facility, but the same quantity is interpreted as a "safety indicator" for subsequent times. For example, Finnish regulations require the use of alternative safety indicators in the longer term (radioactivity release to the environment) and the dose assessment part of the safety case is only to be used for several thousand of years. Posiva also calculates "complementary safety indicators", for example in the form of the activity inventory in different compartments of the model. Retained fractions – the total amount of activity remaining in landscape model compartments as a function of time – are also used. The end points of the Posiva dose calculations are Annual Landscape Doses to representative persons for the most exposed, and all exposed, individuals inhabiting the landscape.

In France, the current ASN guidance [9] makes a distinction between exposure resulting from normal reference scenario and that which would result from random events which disturb the disposal. For the reference scenario, individual dose equivalents must be limited to 0.25 mSv/year for extended exposure associated with natural external events which are certain or highly probable as well as with events linked to the creation of the disposal, construction defects and expected degradation of the components. This limit of 0.25 mSv/y is only considered as a reference after 10 000 y and the radiological assessment must be completed by qualitative appreciation of the possible evolution of the geological medium. The ASN guide also recommends to treat so-called "altered situations" that should cover uncertain events (natural or linked with human activity). To maintain consistency between exposure in the reference situation and potential exposure associated with hypothetical altered situations, consideration may be given to using the risk concept (the product of the probability of the occurrence of the event and the effect of the associated exposure) to allow for the probability of occurrence of each situation giving rise to exposure. But the definition of a criterion based on an individual risk limits precautions, as it may imply a debatable equivalence between reducing the probability and reducing the exposure. Furthermore, it can be expected to be difficult, if not impossible, to estimate the probabilities of the events which can result in exposure. Under these conditions, the acceptability of individual exposure associated with the occurrence of random events is assessed with allowance made for the nature of the situations taken into consideration, the duration and the nature of the transfers of radioactive substances from the canisters to the biosphere, the properties of the pathways by which people can be affected and the sizes of groups exposed. Therefore, individual exposure expressed as a dose equivalent, associated with hypothetical altered situations that should be considered for conception of disposal must be maintained well below liable to give rise to deterministic effects [9]. Except for the comparison with the above cited values, appreciation of the radiological impact results from the efforts made by the developer in the disposal concept so that individual exposition will always be As Low As Reasonably Achievable (ALARA), counting for economic and social factors.

4 Treatment in the Safety Case

In this Section, we first provide a brief country-by-country summary of the approach to biosphere modelling/assessment in the participating programmes (Section 4.1), and then summarise commonalities in approach and differences in approach (Section 4.2). The Section concludes with a one-page tabulation of the biosphere assessment codes and databases in use by the participating programmes (Section 4.3).

4.1 Biosphere Modelling/Assessment Approaches

The varying level of detail provided in the following programme summaries reflects the varying level of detail provided by each participating organisation.

Belgium: As in other countries, a staged approach to assessment and disposal facility development is being followed in Belgium. ONDRAF/NIRAS is preparing a safety and feasibility case (SFC-1) on geological disposal options for 2013. The most recent assessment of the potential for geological disposal in Boom clay, SAFIR 2, was published in 2001 [23]. Treatment of the biosphere employed a normal evolution scenario (NES) containing FEPs that are certain, or almost certain, to occur. Alternative evolution scenarios (AES) were also considered. The NES used the present-day biosphere as the benchmark, as it is recognised that future conditions and changes of behaviour are difficult to predict. The NES was therefore a constant biosphere; however, alternate climate conditions were evaluated as modifications to the NES base case. The AES cases dealt with potentially disruptive events whose occurrence is uncertain, but which might have high consequences.

The geosphere-biosphere interfaces considered were a well, surface water (river or pond) and soil (where the aquifer extends to the rooting zone of vegetation). Doses were calculated for food and water intake, inhalation of contaminated air, and direct external irradiation from soil, water or sediment. Radionuclide transport in watercourses was modelled, as well as accumulations in agricultural soils. The alternative climate states were represented by a modified water balance (including increased water consumption by members of the exposed group), with respect to the present-day system. The AES dealt with the possibility of an exploitation borehole drilled into an aquifer underlying the host clay. The effects of glaciation were also considered, including the potential for a severe glaciation leading to erosion of the site itself, with subsequent more direct exposure to the waste, were humans to return to the site during the subsequent interglacial period.

The SAFIR 2 study focused on the conduct of deterministic calculations.

Czech Republic: Long-term safety assessment of a geological disposal facility in the Czech Republic is following a staged approach. Initial assessments in 1999 used a simple drinking water pathway in dose calculations [18], but subsequently, multi-pathway models have been introduced for a generic geological disposal concept [19] – a candidate site has yet to be chosen. Three potentially exposed groups are identified, based on alternative conceptualisations of the biosphere: a “farmstead”, a “highland area”, and a “fishpond area”. DCFs for each of these have been calculated for a range of radionuclides. The DCFs are quoted as (Sv/year)/(Bq/m^3), so the geosphere-biosphere interface is interpreted in terms of a water concentration in an aquifer/well (farmstead), aquifer interacting with soil (highland area), or a pond (fishpond area).

Finland: The biosphere models employed by Posiva are richer in detail and complexity than in other countries. The modelling procedure is iterative with a safety case plan produced in 2005 [20] and updated in 2008 [21]. A comprehensive biosphere assessment will be reported during 2009. The Biosphere Description 2006 [22] will be updated and extended with emphasis on providing the necessary data for more detailed modelling. Posiva aims to submit an application for a construction licence in 2012.

The Olkiluoto site is on the south-western Baltic coast of Finland. The site is undergoing isostatic readjustment as the crust rebounds from the load of ice imposed on it during the previous glaciation, and attention is being given to radionuclide releases at far future times potentially occurring to a range of biosphere types and ecosystems. Typically in southern Fennoscandia, the overburden comprises a relatively thin layer of Quaternary material. The thickness is usually no more than a few tens of metres and there are relatively short geosphere transport paths from the disposal facility to the biosphere. Potential release points over the landscape can be traced back to canister failures at different locations in the disposal facility, and it is considered necessary to model radionuclide releases into a range of ecosystem types at different locations in the landscape. Also, land rise means that it is necessary to account for the transition from one type of ecosystem to another as, for example, a lake forms from the Baltic and infills to produce a wetland, which may subsequently be converted to farmland.

In the dose assessment are the relevant releases from the geosphere directly used to calculate the distribution of the Annual Landscape Dose (ALD). The main assumptions and data underlying the ALD are:

- Exposed individuals are assumed to spend all of their time in the contaminated parts of the landscape,
- Exposed individuals are assumed to make full use of food/water production capability of the landscape,
- Estimation of the exposure from food ingestion is based on the annual demand for carbon (production and carbon content weighted average over all edible products in the ecosystem), instead of the traditionally used annual ingestion of different foodstuffs,
- The dose contribution from ^{14}C is calculated using a specific activity model.

Because of the application to a real site, Posiva is confident that the biosphere descriptions employed are valid expressions of potential future conditions. Details are included of FEPs characteristic of the land uplift history, lakes/wetlands and their surroundings, rivers and riverbanks, and historical dwelling and living space, self-sustaining communities (smaller villages), and large-scale land use.

The main assessment calculations are deterministic, but probabilistic techniques are used in supporting sensitivity analyses.

France: The French geological disposal programme is focused in a single area of France, and is currently at a stage of detailed site selection within that area. In 2005, Andra submitted the “Dossier 2005 Argile” which demonstrated the feasibility of a geological disposal in the Callovo-Oxfordian clay investigated with the Bure underground research laboratory operated in Meuse/Haute-Marne [36, and 38]. Regarding the treatment of the biosphere, the Bioclim method was applied to identify the biosphere-type of the Meuse/Haute-Marne area. This modelling considered:

- The case of a "normal" evolution, by leaving the current state of the concentration level of CO_2 in the atmosphere,
- The possibility of an altered evolution, modified by the continuation of the human actions, by taking into account future of CO_2 discharges (main greenhouse gas), according to strong hypotheses: i) on the future discharges of CO_2 (increased), ii) on the dynamics of the atmospheric carbon cycle.

Generally speaking the results of climatic models, whatever they are, remained imprecise, in particular because of uncertainties concerning the climatic parameters (values of temperature and pluviometry), but they gave a strong answer onto the dynamics of the evolution (distribution in time of the periods of warmer and colder climates).

From the climatic modelling applied to the Meuse/Haute-Marne area, three biosphere types could be deduced:

- The Temperate Biosphere type which may be present at any temporal scale and any scenario of the global climate evolution,
- The Cold Biosphere type, which may be possible for any climate evolution scenario after some 50,000 years, particularly if no anthropogenic effects are superimposed.
- The Warm Biosphere type which is potentially possible up to the 600,000 years period as a consequence of global warming climate perturbations

In coherence with the Biomass method, different (hypothetic) reference groups have been considered by Andra including complete self-sufficiency. These groups were defined by their age, their lifestyle and their eating habits. In line with the ICRP81 and RFSIII.2.f recommendations, the group's nutritional habits and lifestyle were determined on the basis of current knowledge relating to similar contexts. These were defined on the basis of lifestyles as they are known today, without attempting to anticipate their evolution, as this cannot currently be reliably predicted.

The individual in the hypothetic reference groups represented in the calculation used similar farming techniques to ourselves, but relied mainly on his own production to subsist. Although unrealistic in the context of the Meuse/Haute-Marne site, the influence of total self-sufficiency was also tested, as this assumption covers the uncertainties relating to future changes.

The following specific groups have been considered for sensitivity studies with respect to the selected group:

- Beef and dairy farmers,
- Sheep farmers,

- Pig farmers,
- Fowl breeders,
- Grain producers,
- Hunter/gatherers.

The main difference between these groups was that they mainly consume the food product they specialise in producing, consuming very large quantities of it, and that they are self-sufficient for the product in question. Such groups are, by definition, hypothetic and unrealistic.

The (hypothetic) critical group was made up of adults. Andra also tested the possibility that children or infants would be exposed as sensitivity analysis.

The reference hypothetical group was living in temperate climate, equivalent to that prevailing these days. This reference hypothetical group for the assessment is represented by an agriculturist living for the most part on his own products (from their own harvest and drinking water from their own wells: drinking water, irrigating a vegetable garden, watering and raising livestock from their own cereal harvest), whose dietary behaviour is characteristic of the Meuse/Haute-Marne region and based on INSEE surveys. This group has been used in the model since it combines the largest number of relevant opportunities for exposure and is highly representative. Food consumption arises from INSEE's surveys.

The basic safety rule RFSIII.2.f, specified that “the outlets shall consist of rivers and shallow water wells“. The development of water circulation models (actual and at 1,000,000 years, considering geomorphologic evolution associated to climatic cycles) at sector scale allowed for the identification of the various possible outlets, i.e., locations susceptible of producing water containing radionuclides released from the repository. The selection of outlet locations within each hydrogeological model (actual and 1,000,000 years) is based on a pessimistic approach (selecting a zone with maximum radionuclide concentration levels). The water resource that fed the reference hypothetical group came from a well, but the possibility of using river water (Saulx for example) was tested including potential fishing.

The reference hypothetical group was living in temperate climate, equivalent to that prevailing these days. Climatic changes that will happen will be marked by alternate temperate and cold or even glacial periods on the very long term.

If a ”cold” climate prevailed in the site, though, the group of agriculturists defined in the context of a temperate climate would remain the most pessimistic critical group, although they would be less likely to be found in such a context. However, Andra has studied groups living in transient manner (semi-nomadic pastoralists) more realistic in a glacial climate. Warm conditions may occur at early stage mostly from CO_2 effect. This type of biosphere was not studied in the framework of the “Dossier 2005 Argile”.

Once this framework has been established, the uncertainties regarding the biosphere related to:

- The choice of the critical group, from among the possible choices, taking into consideration its standardised character and the characteristics of the site, climatic ones, in particular,

- Quantification of the transfer paths of elements into the biosphere.

The parameters connected to the biosphere call for two types of data. Certain of these are related to the site (climate, soils, living practices) but are independent of the radionuclide or toxic chemical being considered.

Others are dependent on the particular chemical in question: these characterise physical, chemical and biological phenomena which allow the transfer of elements. Sensitivity studies have been conducted to characterise the variation in impact as a function of transfer factor values between the different elements of the biosphere: taking account of the possible variations (habits of the (hypothetic) reference group, transfer parameters) and including an uncertainty dealing with water consumption.

As another example, the uncertainty in the biosphere conversion factor for ^{36}Cl includes the uncertainties connected to the specific parameters of the model (for example, the concentration in stable chlorine in the neighbouring environment), of the site, and of consumption.

Andra considers that the Dossier 2005 marked progress, in that, for the first time in the development of the safety case, it explicitly envisaged the influence of climate changes on the hydrogeological model and on the biosphere.

The comparison to international practice showed, moreover, that the values used by Andra are in accordance with standard practice.

During the review of the Dossier 2005 by regulators, the biosphere issue was the object of discussions in particular for the critical group and its food needs. Considering the plurality of models to calculate the transfer in the various compartments of the biosphere, the possible climates on the site of Meuse/Haute-Marne on the long term, potential activities of one or several critical groups and their associated eating habits, the approach for their consideration is being clarified.

As a consequence, the method is currently being developed and consolidated and will aim at to be applicable to all potential repository (existing Centre and future projects) and for all their life phases (operational to long term after closure).

Germany: Safety assessment work focuses on disposal in salt formations. GRS-B has used a stylised biosphere with certain parameter values fixed by legislation, based on the present-day biosphere in the vicinity of the disposal site. The model has been used, e.g. in licensing the Morsleben site for the disposal of low-level and intermediate-level radioactive waste [25], and in a generic study of the disposal of heat-generating waste [26]. GRS-B uses a generic biosphere assessment model for all radionuclides. DCFs calculated using the model are quoted in terms of (Sv/year)/(Bq/m^3). The geosphere-biosphere interface corresponds to a well, and farming pathways are modelled, allowing for irrigation of soil and crops. Humans and animals consume the crops and drink well water. External and inhalation exposures are also calculated [27].

Within research projects alternative climate states (contingent on altered groundwater resource exploitation and modified water balance) have also been considered. So far, each climate state has been evaluated independently in a climate sequence, but ongoing development is considering the possibility of modelling transitions between climate states. Of concern is whether explicit consideration of climate transitions in a model simulation might lead to higher doses than under the assumption of a steady-state biosphere.

Doses have been calculated deterministically, although probabilistic methods are under consideration.

Netherlands: The most recent safety assessment in the Netherlands is PROSA (PRObabilistic Safety Assessment) [24], a generic assessment of geological disposal in salt. The PROSA biosphere model assumed that radionuclide releases would be to river water with potential contamination of the marine environment. Three critical groups were considered: an arable farmer, a cattle farmer, and a sea fisherman. The members of these populations were mainly distinguished by their food consumption patterns. Doses to the arable farmer and the cattle farmer were found to be identical. The dynamic nature of biosphere concentrations was noted, but the DCFs used in calculating dose were based on the distribution of radionuclides in the environment after 10,000 years.

Spain: Enresa's assessment modelling has so far focused on generic sites in the Spanish climate context. A critical group is defined as a small community that raises all their aliments using water that contains radionuclides from the repository. Of the different potential sources of water, the source that produces the highest doses is selected. Uses of the water are consistent with the production capability of the water source.

Doses are calculated for an adult, that is an average member of the critical group, that is assumed to consume average amounts of various foodstuffs (as per present-day patterns), based on work undertaken in the IAEA Biomass project [16].

Dilution at the geosphere-biosphere interface determines the concentration of radionuclides entering the biosphere (in a well or a river). From these water concentrations, the distribution of radionuclides in soils, crops, livestock and drinking water is calculated. Consumption of contaminated food and water, inhalation of airborne contaminants, and external doses are calculated for each radionuclide - to give the DCF in terms of (Sv/year)/(Bq/m^3). A river and two types of well are considered (shallow and deep).

Steady-state concentrations in soils are used to calculate doses. These concentrations assume a constant irrigation rate. A continuation of present-day biosphere conditions is assumed in the reference case calculations. Dose calculations are also undertaken for alternative climate states, based on data derived from locations elsewhere having similar conditions to those expected in the future in Spain.

Both deterministic and probabilistic calculations are performed, enabling the calculation of distributions of DCFs. However, only the best-estimate values are used in the calculation of dose, and the probabilistic results are used to analyse the uncertainty in the biosphere model.

United Kingdom: The UK government is currently seeking potential volunteer communities in locations with suitable geological environments for the disposal of higher activity wastes. A range of potential biosphere types, corresponding to typical UK biospheres, is under review by the NDA. However, there is two decades of assessment experience in the UK, with the most recent assessments being those in [28, 29]. Further development of biosphere models is based on the Biomass reference biospheres methodology [16], and is part of a graded approach that will incorporate site-specific detail when candidate sites become known.

In the NDA concept, the biosphere comprises the near-surface environment of surface fresh waters, surface water catchments, estuaries, the marine environment, and the atmosphere. Stylised biospheres with a credible narrative for landscape development are to be employed [30], and the possibility of modelling landscape evolution is under consideration [31]. Members of the Potentially Exposed Groups (PEGs) are assumed to be exposed to radiation via the following routes:

- Ingestion of crops grown in soil infiltrated by contaminated groundwater and irrigated with water from a well,
- Ingestion of milk and meat from animals grazing in the discharge area and watered with well water,
- Ingestion of soil (as a contaminant of foodstuffs such as open-leafed vegetables),
- Drinking water (from the well),
- Ingestion of freshwater fish (from streams and rivers in the discharge area),
- Inhalation of dust (e.g., soil),
- External exposure from contaminated land.

The NDA is undertaking further work in the following areas: climatology, landform evolution, ice-sheet development, near-surface hydrology and radionuclide transport, soil-plant radionuclide transfer and uptake into the food chain, description of PEGs, and radionuclide-specific research (e.g., on ^{14}C, ^{36}Cl, ^{79}Se and ^{129}I). The NDA is also keeping abreast of the work to establish radiological protection standards for non-human biota in the EC-sponsored Fasset, Erica and Protect projects [15].

4.2 Identification of commonalities and discrepancies

On the basis of the elements presented in section 2, 3 and 4.1, this section contains a compilation of the main common trends in treating the biosphere between participating organisations as well as the major discrepancies that can be highlighted.

Phased approach to assessment: One of the major features distinguishing one contributing organisation from another is the stage reached in the disposal programme. The most advanced programme is in Finland, with detailed site characterisation work underway for some years at Olkiluoto and a licence application to construct the disposal facility scheduled for 2012. The detail and complexity of the biosphere models in the Posiva safety case are at a higher level than elsewhere. Nevertheless, many of the contributors note their use of a phased or graded approach to biosphere assessment to take account of the different stages of the disposal programme (and the national programmes of contributing organisations range from generic studies, to site selection, to licence application at a particular site). Following this staged approach, other organisations are progressing towards more detailed models, as more information becomes available.

The exposure mechanisms considered: Multiple exposure pathways are generally studied but those selected depend on the exact nature of the hydrogeological and climatic environment on the disposal as well as on human habits. The exposure mechanisms considered are common to all contributors. Consumption of contaminated foodstuffs and water contribute to the annual ingestion rate in terms of Bq/year. Similarly, inhalation doses are calculated on the basis of airborne dust concentrations. Conversion to dose via these pathways is facilitated by a set of Dose Coefficients (DC) documented by the ICRP [3], which gives the dose per unit ingestion or inhalation as Sv/Bq. Theses DCs have been used by all contributing organisations that have carried out assessments over the past decade. Of the participants, the only group to employ an integrated approach, where the biosphere models are coupled directly to the geosphere, is NRG in the Netherlands. External irradiation exposure is also common to all participants' biosphere modelling programmes, although there is not a common set of conversion factors that give the external γ-dose for uniform soil concentration. Some organisations also calculate the external dose from immersion in water. This may include both a β-dose and a γ-dose.

Assumption of present-day conditions and consideration of climate-change scenarios: It is commonly agreed that the present-day biosphere conditions at the site represent a useful benchmark for assessment of future radiological impacts. Assuming a continuation of the present-day system allows potentially exposed groups to be identified. Modifications to the description of the present-day conditions also allow climatic change to be addressed.

For major system evolution, alternate non-sequential steady states of the biosphere system are commonly used as a basis for assessment, following the Biomass approach [16]. The participating organizations have a variety of means of specifying stylised scenarios accounting for climate evolution through the study of the past and current environments to develop representative biosphere states from analogue sites in the world (NDA, GRS-K, Andra, Posiva, Enresa…) and consideration of the future impact of greenhouse effects and other human activities (Enresa, Andra, Posiva). For Posiva, system change, driven by land uplift, is so rapid that it is an essential part of the normal evolution scenario that must be addressed in the assessment model.

Dose constraints and timescale/situation dependency: Radiological dose is mainly used to express the hazard posed by the disposal of radioactive waste. However, as seen in Section 2, there is a range of dose constraints specified in different national programmes. While Euratom Directive 96/29 provides a value of 1 mSv per year as the upper limit of chronic exposure for members of the public, the way in which this is interpreted for radioactive waste disposal facilities varies among the participating countries. Regulators in several countries have set a limit for disposal facilities of 0.1 mSv/year, while others have set limits of 0.25 or 0.3 mSv/year. For lower probability (alternative) exposure scenarios, a higher dose limit of 1 mSv/year is used in some countries while others don't specify any limit in that case. In Spain and the UK, the key performance measure is an individual risk of 10^{-6} $year^{-1}$ for all scenarios (corresponding to a dose of 0.02 mSv/year assuming a probability of one of the exposure occurring).

A key difficulty in dealing with the longer term concerns the large uncertainty associated with evolution of the biosphere. A 10,000-year or longer quantitative dose evaluation is envisaged by most participants. There is an agreement that dose calculations far into the future should not be interpreted as true expressions of radiological hazard, but as an illustrative measure of system performance that could be complemented with other safety indicators.

For some organisations (GRS-B, Posiva), additional safety indicators for the longer times are under discussion or already required by the regulator. In other countries, the calculated doses are seen as sufficiently representative safety indicators even over the longer term.

Perturbations to the expected evolution of the system cannot be ruled out, and their possible health effects must be addressed. The normal evolution scenario is thus supported by altered evolution cases which, taken together, support the overall safety case without necessarily expressing health effects for far future conditions other than in an illustrative fashion. Annual individual dose may still be used as a performance measure, but the numerical value may be assessed by taking account of the likelihood of the initiating event occurring. Case-by-case evaluation of such scenarios is appropriate, noting that there is the possibility that some events could lead to relatively high exposures, but for which the likelihood of scenario initiation is extremely low (high-consequence/low-probability scenarios).

Regulatory guidance/fixed parameters, exposed groups: There is a wide range in the level of prescription and advice provided in regulation with regard to biosphere modelling and the consideration of exposed groups. For example, current German regulations specify parameters for use in biosphere modelling and require that organ doses be evaluated, as well as whole body effective dose equivalents. Finnish regulators also prescribe some aspects of the biosphere model. Posiva's ALD is an expression of the potential radiological impact on exposed members of the *local* population. This is set by regulation to be no higher than 0.1 mSv/year. The regulators also specify that the developer should assume that "*other*" members of the public live at a regional lake or at a coastal site. These other members of the public should be exposed to any repository-derived radionuclides in these watercourses at no more than "insignificant" levels, specified as a dose of no more than 0.01 to 0.001 mSv/year, depending on the number of individuals affected – for larger groups the lower limit should be considered.

In other countries, there is a range of interpretations of what constitutes the "critical" or "most exposed" group for whom the exposures are evaluated. Most contributors to this study calculate doses for a traditional critical group defined by present-day habits and practices. Where more than one group is evaluated, the groups are described in terms of location and lifestyle, for example sea fishermen and farmers (arable and cattle) in the NRG case, and farmers, highlanders and fish farmers in the NRI case. The NDA [35] and Andra have, perhaps, the most sophisticated approach to defining exposed groups. For example, Andra has adopted the Biomass methodology and considers a range of lifestyles [36]. For the long term, Andra selects *a priori* the potentially (hypothetic) exposed reference groups by exploring the transfer pathways within a certain level of autarky (in the site and region for a certain biosphere type), in agreement with the recommendations of ICRP101. This approach consists to explore the different transfer pathway of the site and region and not exclude *a priori* some transfer pathway.

Food consumption rates: Radionuclide concentrations in food play a major role in determining overall exposure, and there is some difference as to which consumption rates to apply. Some contributing organisations use average food consumption rates, but assume that all food consumed comes from the most contaminated parts of the environment – the societal context being a self-sustaining farming group. Correspondingly, exposures contingent on location assume maximum times of occupancy of the contaminated areas. Usually there is not assumed to be any dilution of contaminated food from outside the modelled system. Upper limits to foodstuff consumption correspond to the 95th percentile (as adopted by ICRP 101 [17]) and advocated in Biomass. Andra's approach is based on considering combinations of some foodstuffs at normal consumption rates, and selective high exposure from specific food product (high consumption rates of the product in question). Consumption rates are based on statistics available for the present day, or three times the mean consumption rate if data are not available [37]. But, in any case, reasonableness, sustainability and homogeneity are baseline for diet definition and extreme behaviours are not considered.

Future climate states based on analogue conditions take their exposed groups and food consumption rates from analogue sites. Among the WP1.1 participants, Posiva bases its intake model on the total productivity of carbon from the ecosystems represented in the landscape model. This ensures that all available contaminants in the foodstuffs present in the ecosystem reach the exposed individuals (including through primary production of fauna that have consumed local vegetation).

Age groups considered: For most contributing organisations, adults are the age group considered in the assessment, and it is implicit that the adult dose can be used as a measure of lifetime exposure (since environmental concentrations are calculated to vary only slowly). However, Andra evaluates doses to different age groups. Current regulation in Germany also imposes 6 age groups but GRS-K has also proposed to restrict different age groups modelling to the first 1,000 years; thereafter, dose to adult males would be considered to be the appropriate safety indicator.

Assessment philosophy: In Biomass [16], part of the assessment context was identified as "Assessment Philosophy". Addressing this aspect of the assessment context requires a statement about whether the aim of the dose calculation is, for example, to be pessimistic, cautious, or equitable. There is a range of assessment philosophies indicated by the contributing organisations. For example, the Posiva assessment aims to ensure that the safety case does not under-estimate or over-estimate the performance of the disposal system. Similarly, GRS-K suggests the use of best-estimate parameter values in assessment. French guide suggests the use of parameter values that ensure that doses are not likely to be under-estimated, a cautious assessment philosophy.

Deterministic vs probabilistic modelling: The approach to biosphere modelling of most contributing organisations to date has been deterministic, but probabilistic modelling is carried out in some countries (e.g. the Netherlands, Spain), if not as part of the mainline assessment calculations, as an aid in sensitivity analyses.

Many organisations indicated in addition that new underway scientific developments comprise:

Use of radionuclide-specific biosphere models: Current modelling techniques often assume that water balance considerations are a key driver of contaminant transport in the biosphere, and in many countries a single generic modelling framework is used for all radionuclides of interest. However, in some countries, depending on the radionuclide inventory under consideration, some radionuclides, primarily ^{14}C and ^{36}Cl, are treated with radionuclide-specific models. The NDA notes that ^{79}Se and ^{129}I could also be candidates for radionuclide-specific modelling. Posiva, GRS and Andra have alternative biosphere models for ^{14}C, and Andra also models ^{36}Cl and ^{3}H with separate models.

Direct modelling of the **transition between climate states** and associated impacts on the biosphere (e.g., as proposed by GRS-B). Such modelling could consider the influence of transitory climate conditions on the geosphere-biosphere interface. It is of interest if there are radionuclide accumulation and release processes that might lead to increased dose rates during transitions stages.

Non-human biota: There is common ground in recognising that non-human biota should be protected, but it is further acknowledged that, at present, there is not sufficient information to do this to the same level of detail as for models of human exposure. Participation by some of the contributing organisations in Fasset and Erica [15] illustrates the importance of international cooperation in biosphere modelling. There is a long history of international studies concerned with biosphere modelling, and many contributors to this exercise participated in the Biomovs (BIOspheric Model Validation Study), Biomovs II and Biomass (BIOsphere Modelling and ASSessment methods) studies, and are currently active in Bioprota [16, 32, 33, 34].

Health effects: In general, only radiological health effects have so far mainly been considered in safety assessment calculations. However, some organisations are starting to consider potential health effects associated with chemical toxicity. For example, Enresa considers that chemotoxic elements can be treated using assessment tools similar to the radiological dose assessment. Another example is the evaluation of the impact of four chemical toxics: boron, nickel, antimony, and selenium by Andra in its Dossier 2005 [36].

In addition, it is worth noting that, in France, Andra is currently developing an approach that aims at harmonizing the radiological assessment methodology for existing near-surface disposals and possible future geological disposal.

4.3 Databases and Tools

A range of databases and tools are employed for biosphere and dose assessments. These are summarised in Table 1 (next page).

Table 1: Summary of tools and databases used in biosphere and dose assessments by the participants

Participant	Country	Tool / Database	Purpose
FANC	Belgium		No information supplied.
ONDRAF/NIRAS & SCK/CEN	Belgium		No information supplied.
NRI & RAWRA	Czech Republic	Excel, AMBER, GoldSim v9.6, RESRAD v6.4	Algebraic expressions and data are encoded in Excel. For some applications the other codes are employed and results are used for Quality Assurance (QA).
POSIVA	Finland	GIS database, UNTAMO toolbox	Details of the landscape elevations and other spatially bounded data. UNTAMO handles the site data using the ArcGIS environment. Interfaced to the biosphere assessment database.
		POTTI database	Research database for site descriptive data.
		BSAdb	Biosphere assessment database - used for assessment data (in conjunction with other external databases).
		PANDORA / EIKOS	Technical implementation of the biosphere models based on Matlab/Simulink. PANDORA is developed in conjunction with SKB, Sweden, EIKOS is used for sensitivity analysis.
ANDRA	France	Aquabios / MoM	Integrated modelling environment containing application-specific database and model definition.
GRS-B	Germany	EMOS, EXCON, EXMAS	EMOS is an integrated package for safety assessment Including the modules EXCON and EXMAS for calculation of the radiation exposure from radionuclide concentrations or fluxes.
GRS-K	Germany		No information supplied.
NRG	Netherlands	FEP database	Library of FEPs for the assessment model.
		MiniBIOS	Distributions of the DCFs for radionuclides transported via groundwater.
		EXPOS	Radiation EXPOSure in terms of maximum dose rates for individuals.
		UNSAM	Code developed to conduct sensitivity and uncertainty analyses of mathematical models.
ENRESA	Spain	FEP database	Library of FEPs for the assessment model.
		AMBER	Modelling tool in which the assessment model is implemented. Used for both deterministic and probabilistic calculations.
NDA	UK		No information supplied.

5 Conclusions

This document discusses the biosphere programmes in eight European countries participating in the PAMINA Project. These programmes are at different stages of development, ranging from generic studies as a preliminary phase to site selection, to highly sophisticated site-specific landscape models of the evolving surface environment at particular sites. For instance, in contrast to the situation in other participating countries, the Finnish and French geological disposal programmes are active at a single site or area (respectively Olkiluoto and Bure) currently undergoing detailed characterisation. Clearly, the stage of development of the waste disposal programme has a major influence, on the one hand on the national regulatory framework in each country, and on the second hand, on the structure of the biosphere model in the safety case and the associated assessment databases.

Depending on the programme stage, the maturity of biosphere modelling approaches and dose assessment strategy differs strongly between organisations. This heterogeneity implies apparent discrepancies in the different strategies for biosphere modelling. But, considering that these strategies may evolve with programme development, common general approaches and tendencies may be observed. They mainly concern:

- A dose limit, or constraint, specified in most countries to ensure that radiological protection criteria are met. The dose limit acts as a surrogate for the health risk posed by potential radiological exposures. For the “normal” or “expected” evolution scenario, dose limits for members of the public are typically 0.1-0.3 mSv/year (based on a fraction of the value specified in [4]). In countries such as Spain and the UK, the primary regulatory performance measure is expressed as an annual individual risk that can lead to a lower dose. Alternatives are found for protection of the representatives of the most highly exposed individuals for less likely, “alternative” evolution scenarios,
- The interpretation of long-term dose calculations as illustrative performance measures is preferred by moving from the notion of dose limit to a reference or other indicators. At long timeframes (from 1,000 y or several 1,000 y up to 1,000,000 y), it is understood that, where a numerical dose is calculated, the value is more suitable for qualitative evaluation of results and sensitivity analyses,
- The consideration for climate evolution in addition to the definition of a today reference biosphere by, either a set of additional possible biospheres in the future or sensitivity analysis,
- The definition of multiple exposure pathways,
- The definition of food consumption and diet consistent with today habits and database; a reasonable behaviour adapted with the characteristics of the exposed group is preferred and extreme consumption are excluded,
- The identification of specific radionuclides to be modeled with specific models concern ^{36}Cl, ^{14}C, ^{3}H, ^{129}I and ^{79}Se,
- The identification of a need for further consideration of potential impacts on non-human biota, and a focus on assessment of radiological health effects (as opposed to chemical toxicity impacts),

- In addition, because of the complexity of the biosphere and uncertainties concerning its treatment in the safety case, most organisations consider that an iterative approach and a good working relationship between regulators and the developer are essential to facilitate development of the safety case in a manner acceptable to regulators.

But, besides those general common trends, it appears nevertheless that the approach between participating organisations differs greatly in a couple of areas: the potentially exposed groups and the age groups considered. There are good reasons for differences – these largely relate to the national regulatory framework in each country. But, contrary to the above observed variations, it seems that those differences are linked to a less extent to the stage of development of the disposal programme but more to the safety "philosophy" developed in the country. Regulatory differences include variation in the level of prescription in regulatory guidance, particularly with regard to the definition of potentially exposed groups and the use of prescribed parameters in biosphere models fixed by legislation. This important issue should probably be more in depth discussed by participating organisations with the view to better understanding the origins of those discrepancies and the needs for harmonisation.

This review also suggests that there could be benefit in an improved glossary of terms in the context of the biosphere.

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7 Appendices

A1 ANDRA (France)

A2 ENRESA (Spain)

A3 FANC - AFCN (Belgium)

A4 GRS-B (Braunschweig, Germany)

A5 GRS-K (Cologne, Germany)

A6 NDA (United Kingdom)

A7 NRG (Netherlands)

A8 NRI, RAWRA (Czech Republic)

A9 POSIVA (Finland)

A10 SCK·CEN, ONDRAF-NIRAS (Belgium)

A1 ANDRA (France)

Revision: final

CONTENTS

1. Introduction

The present document is devoted to topic 9 “Biosphere”. It completes the set of documents provided within the WP1.1 of the PAMINA RTDC1 framework. Its structure follows the DWG common structure, but it was adjusted according to the recommendations issued during the meeting in Madrid on the 28 and 29th of April.

The contribution from Andra to WP1.1 PAMINA project aims at giving an overview of methodologies used by Andra to define and describe the biosphere issues in its safety cases.

In the framework of the Dossier 2005 Argile, the description of the reference biosphere was in line with the BIOMASS approach [i] developed by the AIEA. This methodology was developed for the description of the long term reference biosphere(s).

The different steps of the approach are being the object of developments in order to take into account the specificity of each repository, including existing surface Center. The document describes Andra’s overall approach that is being developed for Biosphere treatment that will be considered in the radiological impact assessments of all the safety cases for existing facilities and future projects operated by the Agency.

Choices are to be consolidated by some exercises of comparison with the counterparts of Andra [ii], by using the best practices defined within the framework of the AIEA or European project (as in the framework of the PAMINA project), and by exchanges with the IRSN (regulator).

Some example of application performed for the long term biospheres will be extracted from the Dossier 2005 (HLLL project).

The definition and description of the biosphere in order to calculate the impact is related to numerous topics examined within the PAMINA project. However, to keep consistency, all the issues related to biosphere are treated in this contribution.

2. Background and references

The December 30, 1991 French Waste Act entrusted Andra, the French national agency for radioactive waste management, with the task of assessing the feasibility of deep geological disposal. The Basic Safety Rule RFS III.2.f of June 1991 [iii], issued by the French nuclear safety authority, provides a framework for the studies to be conducted. The protection of man and the environment are to be demonstrated. Furthermore, studies should show the ability to limit potential consequences to a level as low as reasonably possible. The concept should include a multiple barrier system, and rely on passive repository evolution without institutional control beyond a given timeframe (500 years). The studies carried out within this framework are presented in the “**Dossier 2005 Argile**” (clay) [iv] and “**Dossier 2005 Granite**” [v].

The *Dossier 2005 Argile* consists in a number of primary references which include the

French Act and the series of reports submitted accordingly:

- The French Waste Act dated 30th December 1991 [vi]
- The French Safety rules namely RFS.III.2.f, guidelines [iii].
- Synthesis Report, Evaluation of the Feasibility of a Geological Repository, Meuse/Haute-Marne Site (in English and French) [iv].
- Architecture and Management of a Geological Disposal System Report (TAG; C.RP.ADP.04.0001) (in English and French) [vii].
- Phenomenological Evolution of the Geological Repository Report (TEP; C.RP.ADS.04.0025), (in English and French) [viii].
- Assessment of Geological Repository Safety Report (TES; C.RP.ADSQ.04.0022) (in English and French) [ix]

Other references such as the presentation made at the symposium hold in Paris in January 2007 [x], and the INTESC questionnaire [xi] have been used when applicable.

The progress of the project is iterative, with repeated feedback exchanged between the various processes. In addition to the routine feedback common to parallel engineering, three main iteration loops have been identified since 1991, each corresponding to a major milestone of the program: License application for construction and operation of the underground research laboratory (in 1996), submission of the Dossier 2001 (in December 2001), and the recent submission of the Dossier 2005.

According to the new French Act [xii], reversible waste disposal in a deep geological formation and corresponding studies and investigations shall be conducted with a view to selecting a suitable site and to designing a repository in such a way that, on the basis of the conclusions of those studies, the application for the authorisation of such repository be reviewed in 2015 and, subject to that authorisation, that the repository be commissioned in 2025.

3. General assumption

According to Andra's approach, biosphere doesn't have a particular “safety function”. However, in all radiological impact assessments to be submitted by Andra to the ASN, the biosphere constitutes a common topic to consider in order fulfilling the objective of protecting human beings and the environment. It is the last component for modelling radionuclide transfers from contaminated water towards human beings and for calculating their impact throughout different exposure pathways (see Figure 1).

In this regard, the role of biosphere in the safety case is analysed during the operation of the facilities and after their closure and concerns in general terms to the scenarios of normal evolution but can also be transposable to scenarios of altered evolution. Consequently, Andra considers the temporal phase (or life phase) of the repository to be considered in the assessment.

Five issues, in accordance with the BIOMASS methodology, have been discussed in order to obtain an overall approach applicable for all existing Center or future project:

1. the regulations, definitions, and international practices,
2. the choice of one or several relevant biospheres,
3. conceptual model of the biosphere including the choice of one or several critical groups,
4. the choice of the outlets, and
5. the choice of the radionuclides transfer models.

Only the key points of the approach are presented in this contribution.

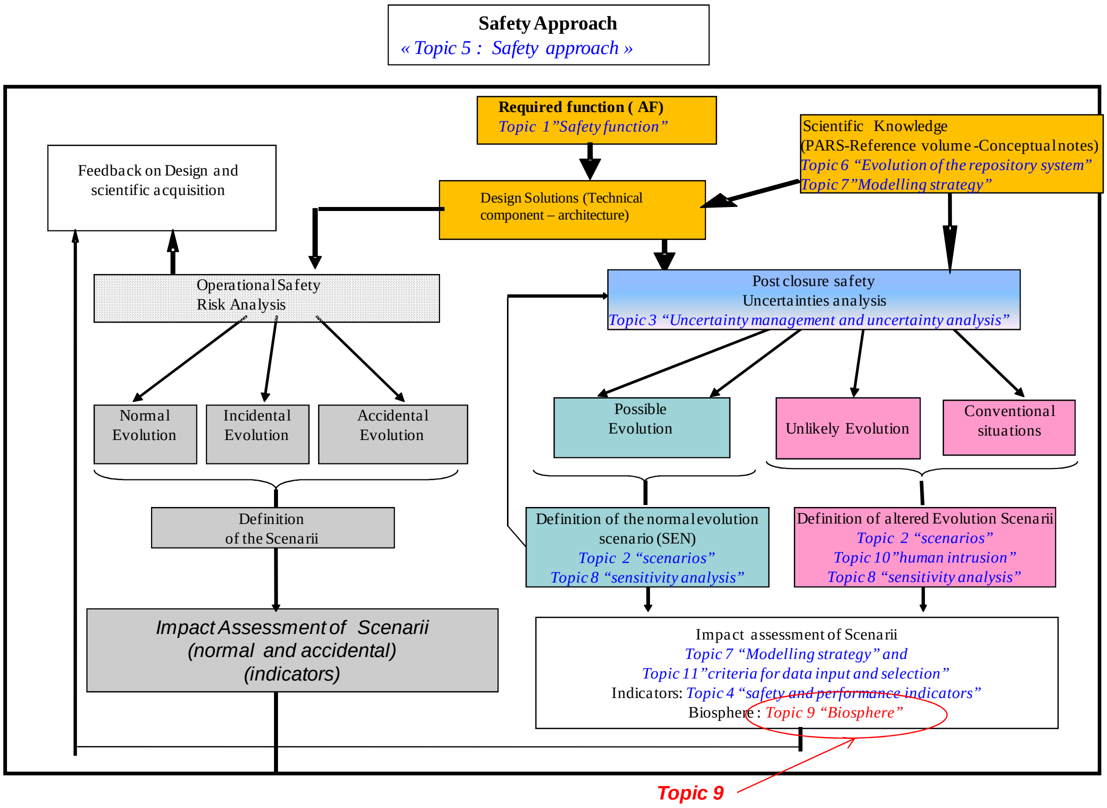

Figure 1: Representation of the various stages of the analysis

4. Regulatory aspects relating to biosphere

4.1 National references

Andra's approach on biosphere considers the applicable guides and regulations issued by the Nuclear Safety Authority (ASN) (e.g. ex RFS.III.2.f or the new 2008 ASN guide). It also follows the guidance and recommendations like the ones emanating from ICPR and sometimes the directives from Euratom. Fundamental Rules of Safety and guidance may be specific to the Centre or project of concern or may imply to consider the phase life of the repository.

As an illustration, the French safety rules (ex: RSF III.2.f[1]) applied to the deep geological disposal of medium and high activity wastes project for the Dossier 2005 Argile, puts forward the following rules and definitions:”*The Biosphere is the part of the Environment easily accessible to the activities of human kind and prone to be a transfer way of radioactivity involving an internal exposure (inhalation, ingestion) or an external exposure*”. The biosphere may include:

- The outlet zone of the groundwaters that could be affected by the repository.
- The superficial discharge system of these groundwaters.
- The soils that could be affected by irrigation or flooding by the previous water system.
- The agricultural or animal production able to be used for human consumption
- The surrounding atmosphere.

The rule also indicates that in the biosphere, it seems not possible to predict the local evolution of the environment for long time periods; on the other hand, the large climatic events that are predictable at a regional level should be taken into consideration by developing “**biosphere types**”. Concerning the affected population, according to the ASN guide [xiii], for the biosphere modelling **reference hypothetic groups** are to be taken into account (or critical hypothetic groups according to the ex RFS.III.2.f), which are representative of the individuals that could receive the highest doses and that, are at least, partially living in autarky.

Andra respect constrain fixed by the guide relative to deep disposal which give a value of 0.25mSv/an for individual effective dose [xiii].

4.2 International references

There are also a number of ICRP recommendations that are followed by Andra, but which are subordinate to the ASN rulings. These are in principle, ICPR 81, ICRP 101 which are specifically devoted to the radiological protection.

For long term assessments, Andra’s approach aimed at defining hypothetical critical groups taking into consideration hypotheses relative to the characteristic and habit that have to be realist but conservative on the base of actual observations made on the site and/or the area. The hypothetical critical or reference group should be connected to its biosphere.

At present there is an evolution of the ICRP guidance in which the notion of critical group as previously defined in ICRP 81 is replaced by the **Representative Individual** (ICRP 101). Andra finds this notion interesting because it corresponds to Andra’s application i.e. considering a representative individual of each critical group in its conceptual model.

[1] A new version «Guide de sûreté relatif au stockage définitif des déchets radioactifs en formation géologique profonde» (ex- Règle fondamentale de sûreté III.2.f) was released in February 2008.

There are also a couple of Directives that also are relevant in Andra's biosphere strategy context, in particular for operational and surveillance phases, they will not be discussed in this document.

5. Key terms

In coherence with the regulations, Andra applies certain definitions as a function of the temporal phase to be considered in the assessment:

- The Biosphere corresponds to the overall set of ecosystems, including all living and their habitat. In the ex RFS.III.2.f, and now the 2008 ASN guide, the biosphere is part of the environment which is easily accessible to the humans.
- For the operational phase (short term, a few centuries), Andra uses the notion of **reference groups** in the sense of what is considered in the Euratom Directive 96/29, is taken to make as realistic dose calculations as possible which implies that the choice of the groups relies upon local observations.
- In the longer term perspective (post-surveillance and/or post-closure), the notion of **hypothetical critical groups** (ICRP 81) or **hypothetical reference groups** are considered according to the 2008 ASN guide. These groups are representative of the individuals that could potentially be exposed to the highest doses. They are established according to specific hypotheses under the explored scenarios.
- The notion of **Representative Individual** corresponds to the individual that is counted for in the conceptual model (i.e. evaluation of the impact on a representative individual of each critical group). It is defined by an age, an activity and a food consumption habit.

In coherence with the 2008 Safety guide Andra uses the term **Biosphere type** which is representative climatic conditions with can occur on the long term due to the global climatic evolution (e.g. temperate type biosphere, boreal type biosphere). A **Reference biosphere** corresponds to the conceptual model of a biosphere type.

Andra also applies some other terms in its approach:

- *Age group.* The age groups are the following: infants (3 months to 5 years), children (6 to 15 years) and the adults (16 to 70 years) which is in line with the CIPR 101 recommendations.
- *Food chain:* overall series of environmental links from the outlet to the human being under study when calculating exposures by ingestion.
- *Average behaviour.* Used for the food consumption on the basis of a statistical average for a given group of individuals, (INSEE, 1991).
- *Particular or specific behaviour.* Abnormal behaviour defined as the 95th percentile of the consumption of a given foodstuff (e.g. heavy beef, milk or fish consumer when a law of probability exists) (BIOMASS). This term **is not a synonym of *extreme behaviour*** which means very unlikely or unrealistic behaviours in the sense that foodstuff is consumed at very high rates (up to >97.5th percentile of more than three

categories).

- *Eating habits or intake:* nature and quantity of consumed food ingested by the group of individuals or animals under study (e.g. water, forage, grass, cereals).
- *Exposure mode:* potential transfer pathway of radionuclides from the outlets to the human beings. The exposure modes are: ingestion, inhalation, external exposure.
- *Outlet:* Natural or anthropogenic transfer zone located at the interface between geosphere and biosphere (spring, borehole, water stream, soil…).
- *Conceptual model of biosphere*. Any simplified representation of the biosphere, broken down into compartments to calculate radiological or chemical impacts. Compartments include climate, outlet, sol, human activity (representative individual), and food stuff entering in the food chain (animal, vegetal and their product).
- *Biosphere conversion factor.* Value that allows to transfer the activity of a radionuclide reaching the biosphere in Bq/l, µg/l or Bq/m3 into a dose to a human being as expressed in Sv/an. It reflects an activity inflow having an impact on human beings via transfers the biosphere and human radiation exposures.
- *Scenario:* Description of one or more given situations and the planned sequence of related events that constitute them. A scenario represents a specific potentially conventional situation to be used in order to account for a series of similar potential situations (glossary dossier 2005).
- *Compartment:* refers to the components of the biosphere that are pertinent towards the assessment context, and the system under assessment.

6. Treatment in the safety case

6.1 Methodology

Andra's structural approach with reference to the Biosphere is based on its own experience but also on references and methodological developments from international programmes and working groups, especially with regards to the BIOMASS programme, which constitutes the basis of the general approach being developed by Andra.

Andra is developing a common strategy that will support the choices to be made in term of biosphere identification and selection, critical group identification and selection, outlet identification and selection, conceptual modelling method and transfer model, and use of a common language. Indeed, the biosphere is a common topic in the different safety cases to be addressed by Andra whether they refer to future Projects or actual disposal facilities either in service or under monitoring (even though the description of the biosphere always remains specific to the repository considered).

Andra's current overall approach on the Biosphere issues is based on the references and methodological developments reached during international workshops and programmes, in particular the AIEA project BIOMASS [i]. It may be summed up as follows:

1. **Defining the assessment context**. It consists in defining the basic elements of the assessments to be performed which may influence choices regarding the biosphere,

notably the applicable reference documents (regulatory requirements or guidance), relevant timescales for each lifetime phase of the disposal facilities (Projects and actual surface Center), waste categories, sites, objective of the evaluation, indicators to be evaluated, international references, etc.);

2. **The identification and justification of biospheres**. It aims at selecting one or more typical biospheres (equivalent to biosphere systems of BIOMASS) to be considered in the assessment, and then at describing their components (in relation to the assessment context): climate, vegetation, fauna, soils, geomorphology, geology, hydrology and hydrogeology, as well as human activities. It is at that stage that inherent choices to the consideration of overall environmental changes of natural or anthropogenic origin are discussed and eventually justified on the basis of models;

3. **The description of reference-biosphere for each selected biosphere-type in order to obtain a conceptual model.** It includes the selection of outlets, the identification and justification of hypothetical critical or reference groups to be defined as an indicator of the maximum potential exposure, and the selection of the associated components such as fauna, and vegetation entering in the food chain.

4. **The description of the transfer pathways** which generate human exposures to each representative individual of the selected hypothetical reference groups. It relies on the construction of the interaction matrix between the various components in relation to the assessment context.

5. **The construction of numerical models**, including specific models for certain radionuclides.

The focus is on the approach to be adopted upstream in order to make choices relatives to biosphere(s) and exposed critical groups issues, and not on the values of the parameters being used. Some topics related to biosphere issues are not explicitly presented in this document, particularly “hydrogeological modelling” which is site specific although it is necessary for the outlet selection, “chemical toxic” and “transfer by air”.

The BIOMASS programme constituted the methodological basis used in the Argile Dossier (2005) developed by Andra, and the methodology for modelling the climate was based on the European project BIOCLIM [xiv], which covered cases of normal and affected evolution (through human activities) of the climate.

6.2 Application in the safety case

6.2.1 Defining the assessment context

The purpose of the assessment is to be defined for each case to be considered. They describe the fundamental elements supporting the evaluation and may consequently influence the choices to be made. They are:

- the type of disposal or project to be evaluated,
- the lifetime of the waste (long or not). The radionuclide source term depends on the waste type considered,

- National guides, recommendations, or regulations,
- the site or the implementation area,
- the objectives of the evaluation (radiological impact, chemical toxic,…)
- the indicators to be evaluated,
- the timescales, including the phase life of the studied disposal waste. In this regard, the role of biosphere in the safety case is analysed during the operation of the facilities and after their closure and concerns in general terms to the scenarios of normal evolution but can also be transposable to scenarios of altered evolution. Consequently, Andra considers the temporal phase (or life phase) of the repository to be considered in the assessment.
- the international references (CIPR, Europeans, projects, AIEA,…).

However, in all radiological impact assessments to be submitted by Andra, the biosphere constitutes a common topic to consider in order fulfilling the objective of protecting human beings and the environment. It is the last component for modelling radionuclide transfers from contaminated water towards human beings and for calculating their impact throughout different exposure pathways. Biosphere does not have a particular safety function.

6.2.2 Identification and justification of biospheres

After defining the assessment context, the second stage of the overall approach corresponds to the identification and justification of biosphere-type(s), in coherence with the guidances and regulations.

Andra recognises that global climate changes are the main driving forces on biosphere variability on the long term. Therefore, any biosphere-type, meaning in some way type of climate states, determination should take into consideration the time scales in which those climate changes may impact. These determine:

- Which climatic conditions are plausible in the future,
- And at which timescale are those climatic conditions plausible or not.

According to the context of the evaluation of the repository (future project or existing Centre), which includes regulatory requirements, life phase of the repository, type of waste and timescales related to radionuclides release at the outlet, Andra considers:

- For the operational and surveillance phases (short time, a few centuries), a **temperate biosphere-type**[2]**.** It is assumed to be constant over the assessment period. The description of this temperate biosphere-type is based on the present local conditions. No climate changes are considered during these phases (except sensitivity studies on the effects on temperature, rainfall, etc)….
- For the longer time scales, beyond the initial few centuries, **one or several biosphere types** are considered taking into account the climatic evolutions and their effects on

[2] In France, the potential area for a repository corresponds to temperate biosphere-type.

the surface environment. The selection of these biosphere types is based on the identification of the plausible biosphere-types that will happen over the concerned timescale. This will be done by appropriate climatic modelling taking into account either natural or induced by the anthropogenic activities (cf. use of BIOCLIM in the Dossier 2005 Argile).

This geoprospective study, realized within the framework of the Dossier 2005, supplied the forecasts on the regional and local evolution of the climate, as well as on the evolution of the geomorphology, the hydrology, the soils and the vegetal ecosystems. It allowed determining:

- the various climatic situations which can succeed one another in the time according to the various possible hypotheses on the climatic evolution (natural and more or less strongly modified by the anthropological discharges of CO_2),
- the possible dates of occurrences of these climatic situations for each of the scenarios of global climatic evolution,
- the range of the plausible types of biospheres for given periods of the future.

By their simple reading, the resulting graphs of the climate evolution allowed a direct identification of the plausible types of biospheres and their succession in time, for each of the scenarios of evolution of the climate.

The plausible biosphere-type obtained after the modelling constituted the base for the choice of the biosphere(s) type to consider for the assessment. The choice is made with respect to the context of the assessment, the safety scenarios (normal evolution or altered evolution) and the dates of potential radionuclides releases to be considered in the future.

There are two main constraints to be considered in Andra's approach to long term biosphere types:

1. The temporal constraints which are mainly dependent on the dynamics of the climate evolution, which in general indicate a succession of temperate, cold and warmer periods. In these climates a series of biospheres may be plausible which are directly linked to the main climatic conditions.

2. The spatial constraints. The characteristics of a certain biosphere type for given climate conditions may vary depending on the location of the repository site. The geographic, geological and geodynamic context of the site will determine the local characteristics of the climate as well as the evolution with time of the local biosphere components (geomorphology, hydrology, soils, fauna,) and consequently on the biosphere type (temperate oceanic or temperate continental for instance).

When the biosphere types are selected, Andra has decided to use a **non-sequential** approximation; this means that the selected biosphere-types are individually assessed without taking into consideration their succession in time. Andra's approach considers that the selected biosphere types are equally probable and are treated as so.

6.2.3 Description of the reference-biosphere

Once the biosphere types have been selected, the description of a "reference-biosphere" is made for each selected biosphere-type in order to obtain a conceptual model.

The methodology to build the conceptual model of each biosphere type is based on the identification and selection of the compartments of a given biosphere type.

In order to construct the conceptual model of the biosphere, Andra identifies and analyses the following biosphere components: climate, vegetation, fauna, soils, geomorphology, geology, hydrogeology and surface hydrology and human activities (see Figure 2). Choices of pertinent element to include in the conceptual model are based on the description made on the site or region or analogous biosphere type and combined modelling (see previous section).

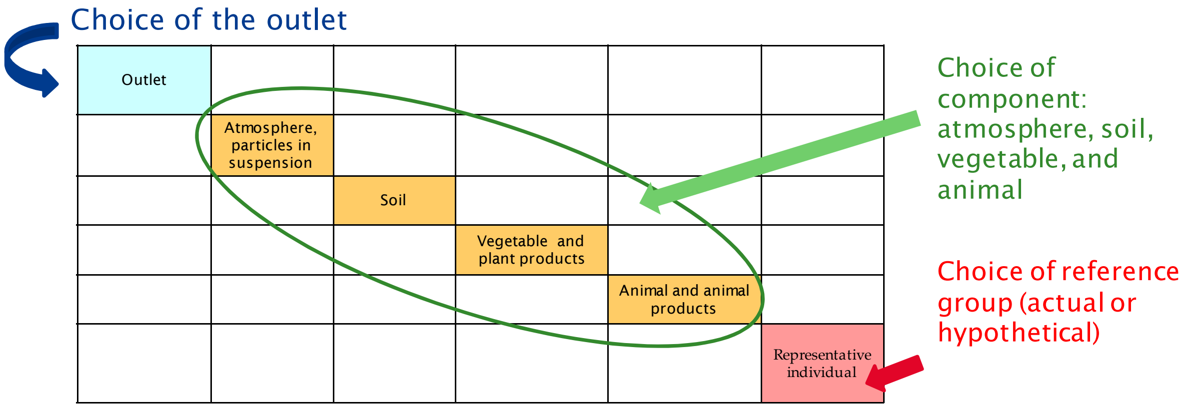

Figure 2: Schematic representation of an interaction matrix showing the selection of the component to be introduced in the conceptual model

Andra's approach distinguishes for the characteristics of the biosphere types, the life phases of the repository:

- For the temperate biosphere type (any repository in France on the short time), the description is based upon the present observations at regional level.
- For biosphere types on the long term (temperate, cold or warm), Andra describes them on the base of observations of actual biospheres in analogous climatic conditions to the ones expected, or past biosphere type using a paleoclimatic interpretation of the region or from other regions in the world which have similar climatic conditions. This is combined with climate, ecosystems, geomorphology, hydrogeology, and modelling of the site or the region.

According to the approach, a conceptual model is built for each biosphere-type which may conduct to several reference biospheres in the sense of BIOMASS.

The selection is made according to the context and objectives of the evaluation, particularly considering the different pathway from the contaminated outlet to the human taking into account the food chain which is strongly linked to the choice of the hypothetical critical groups.

The application of this methodology depends on the specificity of the project or existing centre to be assessed and the spatial and time constraints to be considered (i.e. operational short term vs. long term description):

- For the short term, the compartments identified are those characterised in the present situation and the transfer pathways correspond to those observed under the present situation with the actual variability observed.
- For the long term and for each of the biosphere types selected, the assessment should include all the possible transfer pathways of the contaminated groundwater in the representative region with the potential activities under a certain biosphere type situation (for instance, a fishing activity may be considered if a river exists).

Selection of the outlet(s)

Only the potential outlets for radionuclides are integrated in the conceptual model. The choice will be the natural outlets as defined by the hydrogeological model and/or conventional well or borehole defined for specific situations or requests. The choice of a conventional outlet may result from, for example, a regulator request or uncertainty regarding natural outlets in the region of the disposal.

In general, hydrogeological modelling (associated with the notion of site) does not form part of biosphere modelling. Rather, it is considered that the biosphere interfaces with the hydrogeology only at the selected outlets. In the context of the studies, the surface hydrology (river, springs, ponds, etc.) is distinguished from the hydrogeology (aquifers etc.). Hydrology and hydrogeology are not considered components of the conceptual model of the biosphere but they are important elements to indicate the potential outlets within the interface geosphere-biosphere.

A distinction is made upon the timescales:

- For the short term, the outlets are defined and characterised by the actual hydrogeological model.
- For the long term and for each of the biosphere types selected, outlets are defined and characterised by hydrogeological modelling counting for global climate changes and geodynamic evolution (erosion,). Due to uncertainties on such modelling, some parameters may be defined conventionally.

Identification and selection of the compartments soil, atmosphere, animal and vegetation

Geographic, geological and geodynamic context of the site determine the local characteristics of climate, and physical environments evolution, as a consequence on plausible biosphere(s) type(s).

The selected soils are the most representative, taking into consideration the surface occupied, and the vegetation cover of the region.

Only animal's species consumed by the human beings in the region are introduced in the model. On the short time they are the one currently observed at local scale, on the long term only adapted species of actual biosphere in analogous conditions. In the same way, only vegetation that can be consumed either by human or animal are considered in the conceptual model.

Andra's approach doesn't calculate radiological impact on non human species but considers them in the food chain of potential transfer pathways.

Identification and justification of hypothetical critical groups

In any case, the critical group(s) will be established in consistence with the appropriate rules or guides applying to the specific centre or project to be assessed. For instance Andra assumes the constancy on the characteristics of human kind (sensitivity to radiation, food habits, life conditions…) as recommended in RSF III 2.f.

Regarding the age classification of the critical groups Andra's approach follows the recommendations of ICRP 101, including three different categories:

1. Infant: 0 to 5 years
2. Child: 6 to 15 years
3. Adult 16 to 70 years

In this context Andra's approach assumes the three age classes and uses the dose coefficients recommended for 1 year old infants, 10 year old children and for the adults.

For the operational short time phase Andra takes into consideration a reference group that is based on the present description and habits at local scale.

For the long term, Andra selects ***a priori*** the potentially exposed critical groups by exploring the transfer pathways within a certain level of autarky (in the site and region for a certain biosphere type), in agreement with the recommendations of ICRP 101 (considering reasonableness, sustainability and homogeneity). These approaches consist in exploring the different transfer pathway of the site and region and not exclude a priori some transfer pathways.

Andra considers in this case a minimum of 10 hypothetic groups *a priori* potentially exposed with different activities and food habits. By using this strategy, Andra may identify a group or individual particularly exposed to a specific exposure pathway or to the totality of the exposure pathways. The objective is to determine a specific group as indicator of the maximum potential exposition.

Selection of exposure pathways

The exposure pathways for the groups considered as potentially exposed are adapted to the age categories and following the BIOMASS methodology.

Selection of food behaviour

In the case of an individual submitted to a specific exposure pathway due to a specific activity, a specific food regime is adopted in coherence with CIPR 101. This can be done in two ways:

1. If there are data for a probability law, it is considered that the 95th percentile of the consumption of an aliment is consistent with the recommendations given by the CIPR

101

2. If no data is available to have a probability law, the mean consumption is multiplied per 3 following BIOMASS and CIPR 101 suggestions.

In the case of an individual submitted to several exposure pathways due to several activities, an average behaviour is adopted in coherence with CIPR 101. Food consumption arises from INSEE's surveys.

Extreme behaviours are not considered (97.5th percentile of more than three types of food according to BIOMASS).

6.2.4 Identification of the transfer pathways between the compartments

When the selection of one or several outlets is made, the radionuclides transfer pathways are identified then quantified in coherence with the choice of one or several critical groups. Andra's approach first describes the radionuclides transfer pathways associated with a "defined outlet", which results in studying separately the consequences arising from each potential outlet. This approach allows investigating specific contamination pathway, in particular with regards to specific activities of the hypothetical critical groups.

Andra will follow an interaction matrix approach similar to the one proposed in BIOMASS for the identification of the potential transfers among compartments. Other presentations may be considered, table, text...

Outlet		Irrigation Inondation (river)	Irrigation per aspersion	Water Ingestion	Drinking water
	Atmosphere, particles in suspension	Deposition	Deposition	Inhalation	Inhalation of particles
	suspension	Soil	Root transfer	Ingestion	Ingestion
	Transpiration	Dead leaves	Vegetable and plant product	Ingestion	Ingestion
				Animal and animal product	Ingestion
					Representative individual

Figure 3: schematic illustration of an interaction matrix approach for identification of transfer pathways

The matrix is filled by indicating the possible ways of transfer between each of the compartments. The matrix is read clockwise, that is that the compartment can contaminate the following compartment (to the right) and vice versa. For example, the water from the outlet is going to contaminate the ground by irrigation and by flood, and the atmosphere is going to contaminate the ground by deposit. In a similar way, the soil can contaminate the atmosphere by particles in suspension during the plowing.

The approach consists in describing transfer pathways associated with a defined outlet that is localized and characterized. For example, within the framework of the Dossier 2005, Andra described independently the transfer pathways from an «agricultural well ", and from a “river” (Figure 4).

In the case of a "well", or a "borehole", the contamination pathways which can occur are the ones connected with:

- water consumption by one or several group(s) from pumping contaminated water in an aquifer
- watering animals from the same agricultural well
- irrigation and watering of cultures and gardens by the water of the same agricultural well.

In the case of a "river", additional contamination pathways can be investigated as for example, the consumption of fishes if a fishing activity is identified, and the contamination of grasslands feeding breeding animals including possible flooding.

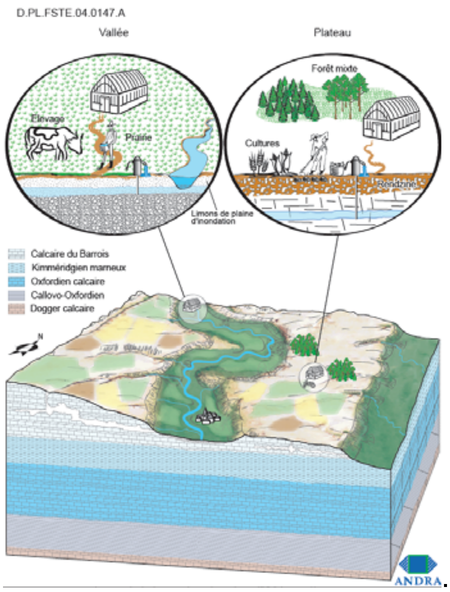

Figure 4: Schematic illustration of the two types of outlet for the definition of transfer pathways towards the man for a temperate biosphere- type (Example of the Dossier 2005). Valley: illustrates a «river» type outlet and Plateau: illustrates a “well” type outlet

6.2.5 The construction of numerical models

This step corresponds to the definition of the transfer parameters and the choice of radionuclide transfer models.

Andra’s approach assumes four different models for all the kinds of waste disposal and temporal scales:

- A compartmental model that applies for all radionuclides except ^{36}Cl, ^{3}H and ^{14}C., which uses constant equilibrium transfer coefficients between the various compartments.

- Three specific models for ^{6}Cl, ^{3}H and ^{14}C. based on isotopic dilution

The compartmental model assumes four compartments for the transfer from water to humans: Wells or river (or other water body), Drinking water, Animal foodstuff and Humans Transfers from drinking water. Animal foodstuffs to humans are considered by ingestion. The soil compartment is assumed to be homogeneous. The Soil compartment is connected to the water compartments by irrigation. The transfer from soil to humans involves both atmospheric suspension in the Air compartment and transfer to ingestion to humans and also through direct ingestion and by external exposure. The Vegetation compartment is connected to the water compartments by irrigation from Wells and to the Soil compartment by root transfer. Humans are connected to Vegetation through ingestion of vegetables.

For the specific radionuclides ^{36}Cl, Andra has developed a specific model for its transfer by ingestion to humans. The model takes into consideration the flow of ^{36}Cl together with the general chlorine flow and calculates the isotopic partition in the various elements of the food chain which together with the isotopic dilution model developed for the transfer from the various compartments to the Vegetation have been integrated into the Aquabios code. This model is presently used for the calculations in all sites and projects of the French agency.

The definition of the transfer parameters and the flows of matter between compartments include the totality of the possible flows of radionuclides and matter between the various compartments. The compartments are considered, for a certain biosphere type, to be constant in time. This allows to use the distribution constants between compartments as wells as the isotopic ratios.

Andra considers two types of parameters:

1. The radionuclide independent parameters (contextual parameters): climate, food habits…These are the result of Andra’s investigations in the region of the site of concern or global data bases for the specific biosphere types.

2. The radionuclide dependent parameters (radioecological parameters), transfer coefficients for radionuclides, Kd’s. Numerous data are to be acquired, in this case.

In general terms, all the radionuclide inventory of a specific repository is considered a priori. The list of radionuclides to consider is established specifically for each disposal. The safety assessment may have to cover a wide range of radionuclides which means numerous data to acquire. Andra’s approach considers differentiation of the radionuclides based on the radionuclide inventory, previous calculations, the biogeochemical behaviour of the radionuclides, and the contribution to the dose.

For the safety assessment of future disposal projects the static approach is usually used, one or many biospheric conversion factors are defined to calculate the impact on humans in Sv/y from the calculated activity in the outcoming water given in Bq/L. The conversion factor is calculated in the 10.000 years time point in order to maximise the accumulation in the Soil compartment.

6.3 Databases and tool

The numerical processing of this transfer pathway comprises five sequentially arranged calculation compartments relating to:

- the near field in which the «waste packages» compartment then the «disposal cells» compartment are distinguished,
- the far field in which the «repository» compartment, the «geological medium» compartment where transfer in the surroundings to the outlets (overlying and Dogger) is modelled, and finally the «biosphere» compartment are represented.

7. Example : Treatment in the dossier 2005 Argile

The AIEA BIOMASS approach was applied for the definition of the reference biosphere(s) in the framework of the Dossier 2005. The aim of this section is to illustrate the application of it on the definitions of biosphere-types and hypothetical critical group(s), as raised by the RFS.III.2f. It also represents a background to the actual development of the approach.

The feasibility assessment of the Dossier 2005 was carried out over a million years which relates to uncertainties when modelling biosphere issues. It is not possible to have an assessment of the lifestyles of the beings that will inhabit the studied sector. The environment conditions and, in particular, the climatic conditions will also be subjected to major variations; their main characteristics are predictable, but it is difficult to accurately consider them in a local context. More generally, the models used for the impact calculation do not pretend to have a predictive character with respect to the transfer times of the radionuclides to the biosphere. They are intended only to provide a view of the impact as large as possible. For all these reasons, the long-term calculated dose is indeed an indicator of the impact and not a prediction of the latter.

7.1 Biosphere types/Global climatic change

Detailed descriptions of the BIOCLIM method and its application in the Dossier 2005 to identify the biosphere-type of the Meuse / Haute-Marne site are given in the Referential notes associated to the Dossier 2005.

Within the framework of the Dossier 2005, a bio – geoprospective study was carried on by Andra to identify the possible evolution during the next million years of the biosphere associated with a possible deep geologic storage which would be implanted in the Meuse / Haute-Marne. The major determinants of climate change and surface geodynamic evolution, to the extent that they can be predicted by models, are however taken into consideration when defining the model (for example, allowance is made for the possibility of cold periods and the natural evolution of the surface hydrographic system).

The determining factor, first of all, on which depends the range of the biospheres-type, is the choice, made upstream, of the scenario of evolution of the climate. This one, indeed, determines:

- which climatic conditions, and in some way which types of biospheres, are possible in the future,
- in which dates it is plausible to consider such or such biosphere in the safety assessment according to the scenarios of climatic evolution (natural or altered) for the

period of radionuclide releases (meaning, for which timeframes the consideration of such or such biosphere is realistic or not realistic).

This modeling considers (Figure 5):

the case of a "normal" evolution, by leaving the current state of the concentration level of CO_2 in the atmosphere,

the possibility of an altered evolution, modified by the continuation of the human actions, by taking into account future of CO_2 discharges (main greenhouse gas), according to strong hypotheses: i) on the future discharges of CO_2 (increased), ii) on the dynamics of the atmospheric carbon cycle.

Generally speaking the results of climatic models (Figure), whatever they are, remain imprecise, in particular because of uncertainties concerning the climatic parameters (values of temperature and pluviometry), but they give a strong answer onto the dynamics of the evolution (distribution in time of the periods of warmer and colder climates).

From the climatic modelling performed for Dossier 2005 located in the Eastern region of France, it can be deduced three biosphere types:

- The Temperate Biosphere type which may be present at any temporal scale and any scenario of the global climate evolution.
- The Cold Biosphere type, which may be possible for any climate evolution scenario after some 50 thousand years, particularly if no anthropogenic effects are superimposed.
- The Warm Biosphere type which is potentially possible up to the 600 thousand years period as a consequence of global warming climate perturbations.

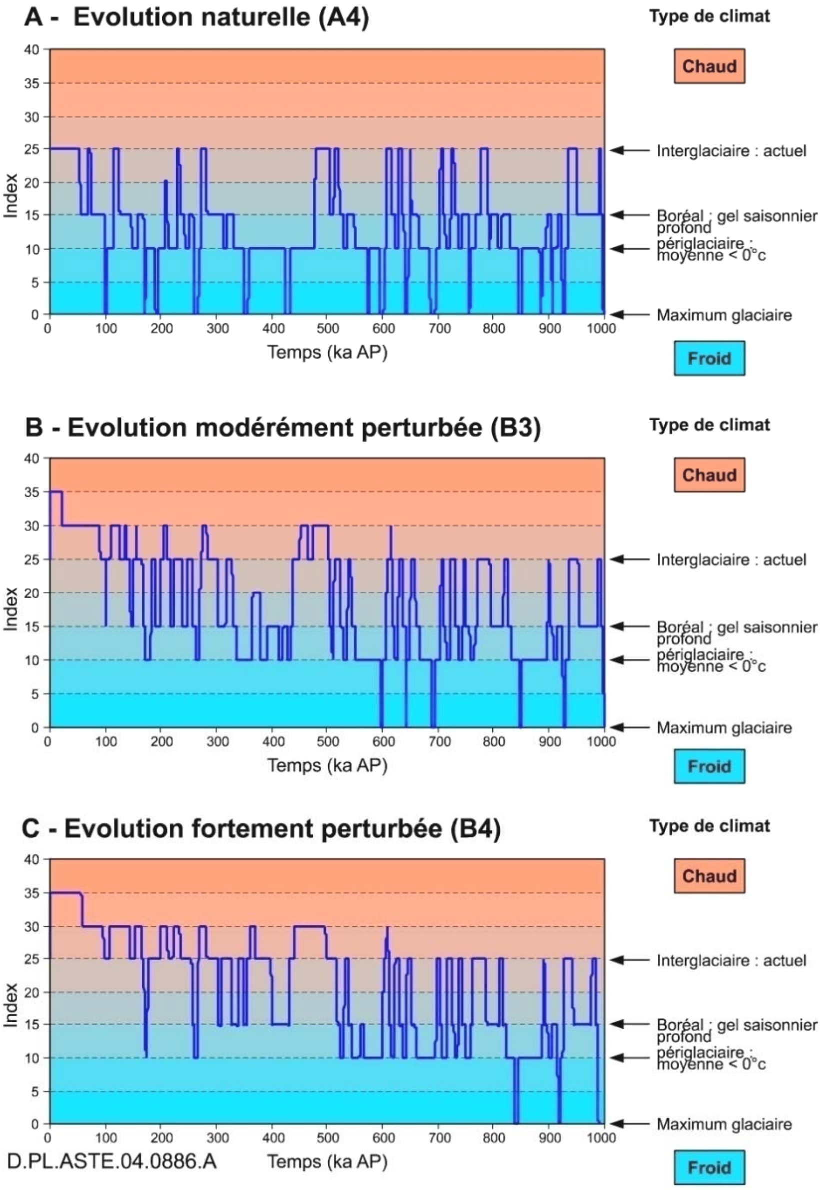

Figure 5: As illustration: the different prognostics for the climatic evolution over the next million years from the European project BIOCLIM (extracted from the Référentiel du site de Meuse/Haute-Marne [xv])

Table 1: Correspondance between indices, classes et climatic states

Indices	Classes climatiques	Etats climatiques
0	FT	Toundra
10	EC	Périglaciaire
15	EO	Boréal
20	DC	Tempéré à tendance continentale
25	DO	Tempéré à tendance océanique
30	Cr	Sub-tropical humide
35	Cs	Sub-tropical à saisonnalité marquée pluies d'hiver

7.2 Hypothetical critical Groups

In coherence with the BIOMASS method, different hypothetical reference groups have been considered by Andra including complete self-sufficiency. These groups were defined by their age, their lifestyle and their eating habits. In line with the ICRP 81 and RFS III.2.f recommendations, the group's nutritional habits and lifestyle were determined on the basis of current knowledge relating to similar contexts. These were defined on the basis of lifestyles as they are known today, without attempting to anticipate their evolution, as this cannot currently be reliably predicted.

The individual in the critical group represented in the calculation used similar farming techniques to ourselves, but relied mainly on his own production to subsist. Although unrealistic in the context of the Meuse/Haute-Marne site, the influence of total self-sufficiency was also tested, as this assumption covers the uncertainties relating to future changes.

The individuals were all subject to uniform concentration, either directly in their drinking water or through contaminated food that they may consume. The water resource that fed the critical groups came from a well, but the possibility of using river water (Saulx for example), was tested, including potential fishing.

The following have been considered for sensitivity studies with respect to the selected group:

- beef and dairy farmers
- sheep farmers
- pig farmers
- fowl breeders
- grain producers
- hunter/gatherers

The main difference between these groups was that they mainly consume the food product they specialise in producing, consuming very large quantities of it, and that they are self-sufficient for the product in question. Such groups are, by definition, hypothetic and unrealistic.

The critical group was made up of adults. Andra also tested the possibility that children or infants would be exposed as sensitivity analysis.

The reference hypothetical group for the assessment is represented by an agriculturist living for the most part on his own products (from their own harvest and drinking water from their own wells: drinking water, irrigating a vegetable garden, watering and raising livestock from their own cereal harvest), whose dietary behaviour is characteristic of the Meuse/Haute-Marne region and based on INSEE surveys. This group has been used in the model since it combines the largest number of relevant opportunities for exposure and is highly representative. Food consumption arises from INSEE's surveys [xvi].

The studies and the evaluation of uncertainty show that a change in critical group, and particularly in eating habits, gives rise to a variation of 1.5, at most, in iodine 129, for example. It is 2.1 for selenium 79 and 3 for chlorine 36 [ix].

If a condition of complete self-sufficiency of the agriculturist is considered, the dose due to iodine 129 does not change, and that due to chlorine 36 is multiplied by a factor of 2.6 while that of selenium 79 is multiplied by a factor of 2.1. It was assumed that the high degree of stability in the biosphere conversion factor of iodine 129 was due to the dominance of drinking water as a means of contamination. As a result, it was less dependent of other aspects of dietary behaviour.

The reference hypothetical group was living in temperate climate, equivalent to that prevailing these days. Climatic changes that will happen will be marked by alternate temperate and cold or even glacial periods on the very long term. The glacial periods should be less pessimistic from the view point of the critical group: cold climate incites the population to lead a nomadic life and leave the valleys to go and live on plateaus, thus increasing dilution and reducing periods of exposure. This will then distance the population of the Saulx or Ornain valley zone. Andra has studied groups living in transient manner in repository environment, in cold conditions. Such groups seemed to be less pessimistic in terms of dose than the group of sedentary farmers in boreal type cold conditions.

If a ‘cold’ climate prevailed in the site, though, the group of agriculturists defined in the context of a temperate climate would remain the most pessimistic critical group, although they would be less likely to be found in such a context. The behaviour patterns of semi-nomadic pastoralists, more realistic in a glacial climate, would result in lower doses.

7.3 Uncertainty Management

Once this framework has been established, the uncertainties regarding the biosphere relate to:

- the choice of the critical group, from among the possible choices, taking into consideration its standardised character and the characteristics of the site, climatic ones, in particular ;
- quantification of the transfer paths of elements into the biosphere.

The parameters connected to the biosphere call for two types of data. Certain of these are related to the site (climate, soils, living practices) but are independent of the radionuclide or toxic chemical being considered.

Others are dependent on the particular chemical in question: these characterise physical, chemical and biological phenomena which allow the transfer of elements. Sensitivity studies have been conducted to characterise the variation in impact as a function of transfer factor values between the different elements of the biosphere: taking account of the possible variations (habits of the critical group, transfer parameters) and including an uncertainty dealing with water consumption.

As another example, the uncertainty in the biosphere conversion factor for chlorine 36 includes the uncertainties connected to the specific parameters of the model (for example, the concentration in stable chlorine in the neighbouring environment), of the site, and of consumption. The uncertainty was not very significant (a factor of 2.2) without exceeding the impact objective, even in the most pessimistic situations.

8. Knowledge/Experience gained with the application of modelling in the context of safety assessment

Dossier 2005 marked progress, in that, for the first time, it explicitly envisaged the influence of climate changes on the hydrogeological model and on the biosphere.

In the framework of the Dossier 2005 Argile, the description of the reference biosphere was an application of the BIOMASS approach [xvii] developed by the AIEA.

The biosphere is one of the areas of the calculation which can present a priori the greatest uncertainty because of the large number of parameters which characterise it and the multitude of its possible evolutions. However, there does remain an uncertainty which reaches a factor of 10 for certain radionuclides. It is for this reason that the biosphere has only been considered when coming to the dose calculation. No safety function has been assigned to it.

A large and very detailed study of the uncertainties bearing on the radionuclides which have the largest contribution to the impact within the specific outline of the Dossier 2005 (essentially, iodine 129) shows that the uncertainty in the dose factors is, in their case, much more restricted. The comparison to international practice shows, moreover, that the values used by Andra are in accord with standard practice.

During the review of the Dossier 2005 by regulators, the biosphere issue was the object of discussions in particular for the critical group and its food needs. Considering the plurality of models to calculate the transfer in the various compartments of the biosphere, the possible climates on the site of Meuse/Haute-Marne on the long term, potential activities of one or several critical groups and their associated eating habits, the approach for their consideration has being clarified.

As a consequence, the AIEA BIOMASS method is being consolidated with the aim to be applicable to all potential repository (existing Centre and future projects) of Andra and for all their life phases (operational to long term after closure).

Currently, Andra is developing a transfer model for Cl-36. The model approach for Cl-36 is consistent with the TRS364 developed in the AIEA EMRAS Programme [xviii]. This approach has also been discussed at the international forum BIOPROTA on the transfer of Cl-36 in the biosphere to study further the validity of the model [xix].

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A2 ENRESA (Spain)

Rev. 2

1. Introduction and background

This document describes the treatment of the Biosphere in the Performance Assessment (PA) exercises for HLW repositories in granite and clay done by ENRESA. The evolution of the treatment and modelling of the Biosphere in ENRESA´s PAs is briefly explained first, and then the methodology used in the most recent PA exercise is described in depth.

The Spanish programme for High Level waste disposal is at a stage of general feasibility studies: several potentially favourable host formations have been identified, generic designs for granite, clay and salt host rocks have been developed, and safety assessments of repositories in granite and clay have been done. There are no definite plans at present to move into a new development stage.

Since no potential sites have been selected yet, PA exercises have been done using synthetic Biospheres. In the initial exercises the Biosphere was created on the base of very generic data, while in the most recent exercises data from different areas of the Iberian Peninsula were used to produce a more "realistic" Biosphere, consistent with potential sites in Spain.

2. Regulatory requirements and provisions

The acceptance criteria for radioactive waste final disposal facilities established by the Spanish Regulatory Body (CSN) was set in 1987 in these terms: "to ensure safety individual risk should be smaller than 10^{-6} yr^{-1}, that is the risk associated to an effective dose of 10^{-4} Sv/yr". This is the only regulatory requirement in Spain.

There are no specific regulatory requirements or guidelines regarding the treatment of the Biosphere in the Safety Assessment.

3. Key terms and concepts

In the PA exercises done by Enresa no formal definitions of the Biosphere are included, but the practical use of this concept done by Enresa is in agreement with the definitions provided by IAEA in [5]: "*Biosphere is the environment normally inhabited by living organisms.*

- *In practice, the biosphere is nor usually defined with great precision, but is generally taken to include the atmosphere and the Earth surface, including the soil and surface water bodies, seas and oceans and their sediments. There is no generally accepted definition of the depth below the surface at which soil or sediment ceases to be part of the biosphere, but this might typically be taken to be a depth affected by basic human actions, in particular farming.*
- *In waste safety in particular, the biosphere in normally distinguished from the*

geosphere".

In ENRESA PA exercises, doses are calculated for an average member of the critical group, which is defined as "*a group of members of the public which is reasonably homogeneous with respect to its exposure to a given radiation source and is typical of individuals receiving the highest effective dose or equivalent dose (as applicable) from the given source [5]*". As a consequence, it is typically assumed (as in ENRESA case) that the critical group is s self-sustained community that raises all their aliments using water that contains radionuclides from the repository.

The average member of the critical group is an adult with average consumption of aliments and habits.

4. Treatment in the Safety Case

The treatment of the Biosphere in the Safety Assessment exercises done by ENRESA has evolved with time:

- In the preliminary exercises for repositories in granite and clay done in the 1990´s a simplified treatment of Biosphere was done. The objective was to define a receptor that would be exposed to the radionuclides that leave the geosphere barrier, in order to be able to quantify the radiological consequences of the repository. Generic data were used to define such receptor.
- The second batch of Safety Assessments for repositories in granite and clay was done in the early 2000´s, in close cooperation with Spanish R&D groups. Since an Spanish R&D group from Ciemat had been actively involved in international projects dealing with the treatment of the Biosphere, such as BIOMASS [7] and BIOCLIM, the concepts developed in these international projects were adopted for the treatment of the Biosphere.

ENRESA treatment of the Biosphere follows IAEA [6] recommendations: "*In estimating the doses to individuals who will be living in the future, it is assumed that humans will be present locally, and that they will make some use of local resources that may contain radionuclides originating from the waste in the geological disposal facility. The representation of future human behaviour in assessment models is necessarily stylized, as it is not possible to predict behaviour in the future with any certainty. The rationale and possible approaches to the modelling of the biosphere and the estimation of doses arising form waste disposal facilities have been considered in the IAEA BIOMASS Project [7]*".

In all the PA exercises done by ENRESA the main purpose of the Biosphere model is to allow calculating doses due to the radionuclides that leave the geosphere. First, the flow of radionuclides is diluted in a given water flow (from a river or a well) to obtain the radionuclide concentration in the water used by the critical group. Second, the radionuclide concentration is multiplied by a Dose Conversion Factor (DCF) that provide the year dose assuming a unit concentration of the radionuclide in water. For each radionuclide a DCF is calculated, that includes all the exposure pathways considered (Figure 4.1).

4.1 Methodology

Since no site has been selected in Spain, ENRESA Performance Assessment exercises have been done for generic sites (in granite and clay) created on the base of the limited data available for Spanish favourable formations.

The biospheres used in the evaluations are created on the base of data selected for areas in the Iberian Peninsula located in one of the favourable formations identified, as well as data at regional and national levels.

The work done on the Biosphere can be structured in these tasks:

- Data base of FEPs in the Biosphere.
- Description of today Biosphere.
- Study of the expected climatic evolution in the repository area in the next million years.
- Selection of an alternative climatic condition in the future.
- Description of the alternative Biosphere (related to climatic evolution).
- Radionulide transport in today Biosphere.
- Radionuclide transport in the alternative Biosphere.

4.1.1 Data base of FEPs in the Biosphere

A data base of Features, Events and Processes (FEPs) of the Biosphere has been developed, using as starting point the data bases of the working group on Reference Biospheres of BIOMOVS II /8/ and NEA /9/. The degree of detail of the fist one was maintained.

This data base was used to identify the Biosphere related FEPs that must be included in the Biosphere description and radionuclide transport.

4.1.2 Description of today Biosphere

A description of today Biosphere in a generic area of Spain is done on the base of data available at different levels: local, regional and even national level. A Warm Oceanic climatic condition (type DO in the Köppen classification) is selected, with these main characteristics:

- 600 mm/yr of rainfall spreaded along the year
- 17ºC of temperature variation between coldest and hottest months

The following information is presented in the description of today Biosphere:

- topography, soils and natural vegetation
- soil and water uses

- agriculture and livestock
- food consumptions of man

In the description of today Biosphere the different geosphere-biosphere interfaces are identified. In section 4.1.8.1 the topic of the treatment of the geosphere-biosphere interface is further developed.

4.1.3 Climatic evolution in the repository area in the next million years

ENRESA and Ciemat have participated in EU BIOCLIM (Modelling Sequential Biosphere Systems under Climate Change for Radioactive Waste Disposal) project, which aim was to provide a scientific basis and practical methodology for assessing the potential impacts of long-term (10^6 years) climatic change on biosphere characteristics in the context of radioactive waste repositories in deep geological formations. The models developed within BIOCLIM were adapted to predict the climatic evolution in the generic repository area.

In ENRESA most recent PA exercise (ENRESA 2003 /3/) the evolution of the climate in the Iberian Peninsula in the next million years was simulated taking into account the natural causes affecting climate evolution and the anthropogenic effects related to a possible burning of all the fossil fuels in the planet in a short time period (greenhouse effect). The evolution of the climatic conditions with and without these anthropogenic effects was analysed.

In the "*greenhouse effect*" case the concentration of CO_2 in the atmosphere would reach a peak value of 1,100 ppm after 300 years, slowly decreasing afterwards. This would represent a significant increase compared with the nowadays´ 300 ppm of CO_2. The increase in the CO_2 concentration in the atmosphere is expected to lead to a significant increase of the temperatures compared with the natural evolution. Analyses have shown that the climatic change due to anthropogenic causes would be relevant during the initial 500,000 years, and afterwards the climate would return to the natural succession of climatic conditions.

The calculations performed show that many different climatic conditions will take place along the next million years, but glacial conditions are not expected in the repository area. This result is supported by the evidence from the past: in the Iberian Peninsula glacial conditions were restricted to mountainous areas, where the altitude and orientation favour the ice build-up. As a consequence, the mechanic, hydraulic and thermal effects related to ice sheets are not expected in the area of interest.

4.1.4 Selection of an alternative climatic condition in the future

Many different climatic conditions will take place in the selected area in the next million year. It is not possible to develop in detail a biosphere consistent with each climatic condition. What has been done is to select a climatic condition very different from the actual and expected to take place for significant periods of time, describe the corresponding biosphere and make dose calculations with this alternative biosphere in the "climatic scenario".

For the climatic scenario it has been selected the BSk (in the Köppen classification) climatic conditions foreseen for 20,000 years after present. These conditions (typical of a steppe) are significantly drier and colder than today conditions and are expected to prevail for roughly 30% of the next million years.

4.1.5 Description of the alternative Biosphere

A description of the biosphere consistent with the alternative climatic conditions is done, on the base of data available for locations that today have such climatic condition. The information included and the degree of detail are similar to the description of today biosphere (section 0).

4.1.6 Radionuclide transport in today biosphere

A critical group is defined as small community that raise all their aliments using water that contains radionuclides released from the repository. Of the different potential sources of water, the source that produce the highest doses is selected. Obviously, the uses given to the water must be consistent with the production capability of the water source.

Human consumptions, water uses and soil characteristics coherent with today Biosphere are used.

The different transport mechanisms through the different Biosphere compartments up to man considered are shown in Figure 4.1. The common approach of using a set of Dose Conversion Factor (DCF) to include the Biosphere in the consequence analysis is followed. For each radionuclide a DCF is calculated assuming a unit concentration (1Bq/m^3) in the water used by the critical group and all the exposure pathways shown in Figure 4.1. DCFs have the following units: (Sv/yr)/(Bq/m^3).

For the concentration in the soil irrigated with water containing radionuclides, steady state concentrations are used. Assuming a constant irrigation rate, the concentration in the soil increases with time and tends to the steady state concentration, that is the maximum value.

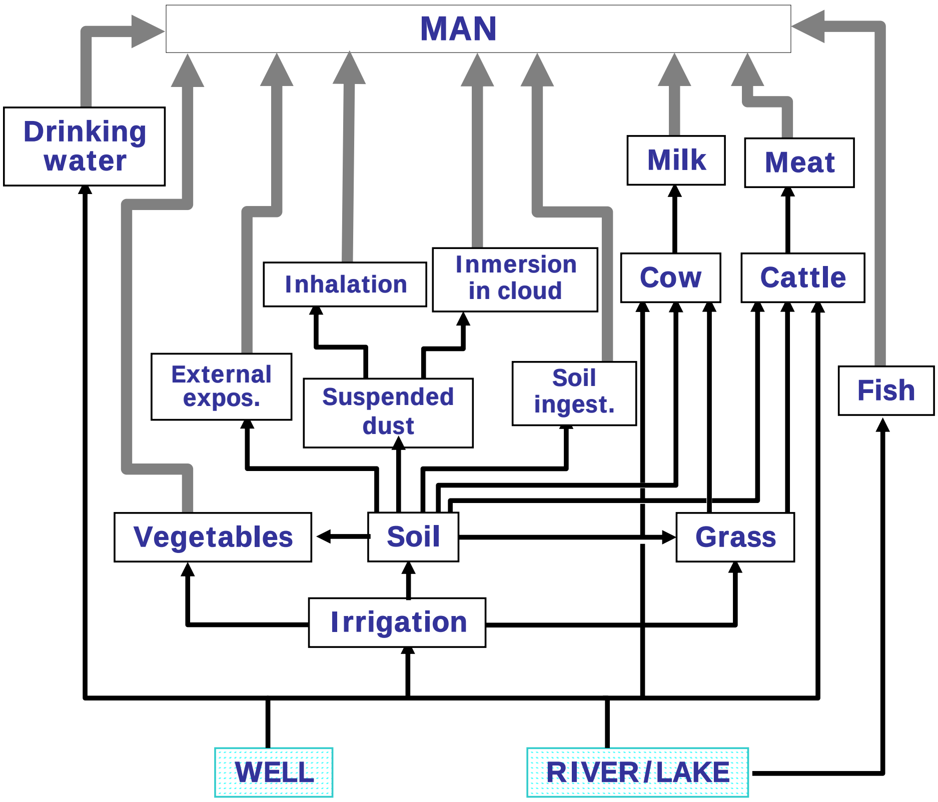

Figure 4.1 – Exposure pathways considered for the critical group

In early performance assessments done by ENRESA the soil was included as a dynamic compartment and 2 different Dose Conversion Factors (DCFs) were calculated for each radionuclide: one containing the exposure pathways related to direct use of contaminated water and other containing the exposure pathways related to the contaminated soil. The calculations performed showed that the doses obtained modelling the soil as a dynamic compartment where nearly identical to the doses assuming equilibrium concentrations in soil. As a consequence, it was found appropriate (and in any case, conservative) to assume equilibrium concentrations in the soil.

For the different transfer and build-up factors involved in the previous exposure pathways their best estimate values are used in the calculation of the DCFs. Average consumption rates are assigned to the receptor of the doses (an average member of the critical group). For the distribution coefficients in the soil best estimate values are used too, consistent with the class of soil selected. The resulting DCFs obtained are best estimate values of such factors, and are used in all the calculations performed, both probabilistic and deterministic.

Stochastic DCFs have been calculated for the different radionuclides too, as explained in section 4.1.8.3, but HAVE NOT been used in the dose calculations. In all the scenarios the deterministic (best estimate) DCFs have been used.

4.1.7 Radionuclide transport in the alternative Biosphere

Human consumptions, water uses and soil characteristics coherent with the alternative biosphere selected in described are used to define the radionuclide transport model. Exposure pathways are the same than for today biosphere (Figure 4.1), but parameter values are modified.

A set of DCFs for the alternative Biosphere is obtained, and used in the Climatic Scenario. Comparison of the DCFs obtained for today Biosphere and the alternative Biosphere shows small differences for most radionuclides as can be seen in Table 4.1.

Table 4.1 – DCFs for selected radionuclides used in ENRESA 2003 /3/

	Today Biosphere	Alternative Bisophere
Cl36	8E-10	2E-09
Se79	2E-07	2E-07
Nb94	2E-08	2E-08
Mo93	3E-09	5E-09
Tc99	5E-10	1E-09
Pd107	7E-10	2E-09
Sn126	3E-08	4E-08
I129	9E-08	2E-07
Cs135	9E-09	7E-09

4.1.8 Additional topics

4.1.8.1 Geosphere-Biosphere interface

The geosphere-biosphere interface is a critical part of the model that has a strong effect on doses. The identification of the different possible geosphere-biosphere interfaces is very important and site-specific. Points of natural discharge should be identified in the hydrogeological calculations. Artificial interfaces (wells) must be defined at different possible locations too. The radiological consequences for the different interfaces must be analysed to ensure that the critical group really receives the highest dose due to the releases from the repository.

In ENRESA 2000 exercise in granite /2/ the radionuclides released from the repository were discharged to a surface stream in the reference scenario, and both shallow and deep water production wells were studied in alternative scenarios.

In ENRESA 2003 exercise in clay /3/ the radionuclides leaving the top and bottom of the host formation were released to aquifers above and below the host formation where water production wells are drilled. The members of the critical group use water from the superficial well in the reference scenario and water from the deep well in an alternative scenario.

In the case of a surface water stream the model is trivial: the radionuclide flows reaching the stream (calculated using the model of transport in the geosphere) are diluted in the stream water flow (provided by the hydro-geologic model) and the radionuclide concentration in the stream water can be calculated. In ENRESA 2000 /2/ the water flow of the surface stream is 10^6 m^3/yr in the Biosphere based on today conditions and $2 \cdot 10^5$ m^3/yr in the alternative Biosphere used in the Climatic Scenario, that corresponds to climatic conditions drier and colder than today conditions.

In the case of wells capturing contaminants from the repository some calculations are performed in order to quantify the dilution provided by the well. In ENRESA 2003 exercise in clay /3/ transport through the aquifers where the wells are drilled is not included in the model of transport in the geosphere. A model of the superficial well (Figure 4.2) is created with the following hypothesis:

- Groundwater flows at regional scale in the different formations correspond to the natural conditions in the reference scenario. Although the repository excavation can produce some modifications of flows at local scale due to the possible formation of a more coductive Excavation Damaged Zone (EDZ), at larger scale these possible effects are considered negligible.
- A pumping well is drilled in the upper aquifer and only produces a local effect on the hydraulic gradients and the water velocities and flow directions.
- Hydraulic boundary conditions of the model and characteristics are constant in time.
- The water well is located downstream of the repository and has a constant pumping rate.
- Transport in the clays (unit D in Figure) and the marls (unit E in Figure) is mainly in the vertical diraction. As a consequence, the releases of radionuclides from the marls to the upper aquifer take place from a source with the dimensions of the repository (2650m x 500m) located at the interface between units E and F.
- The transport calculations consider the following processes: advection, longitudinal and transversal dispersion and diffusion. Sorption on the solid materials of the aquifer is not considered.

Calculations are done with PORFLOW code. The model represents the aquifer as a 3D homogeneous medium of ortohedric shape and 10.000 m long (in the main flow direction), 6.000m wide and 50m high. The well is included in the model as a 30m column with hydraulic conductivity 5 orders of magnitude higher than the aquifer, and a constant extraction flow is imposed at the well upper surface. In the lower surface of the aquifer there is a planar source of 2.650m x 500m where a stable conservative solute is injected into the aquifer at a constant rate of 1 g/s.

Many transport calculations have been done without the well and with a well at different locations and with pumping rates. Transient transport calculations are performed until reaching the long term steady-state conditions. At any location the solute concentration increases with time until reaching a peak value that corresponds to the steady-state.

Calculations showed that the steady state concentration in the water of the aquifer (with and without pumping) is always smaller than the concentration obtained diluting the releases from the source in the groundwater flow crossing the repository vertical (v_D*2650m* 50m=180,000m^3/year). Conservatively, in the calculations it is assumed that the radionuclides released from the marls are diluted in a groundwater flow of 180.000 m^3/year and then extracted by the well.

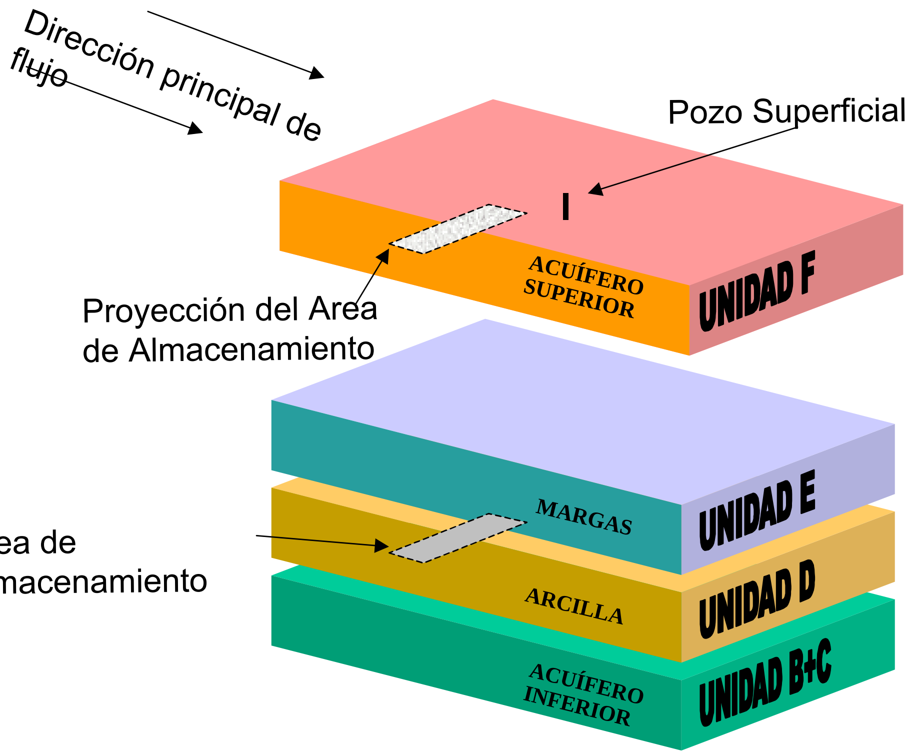

Figure 4.2 – Model used for the superficial well

A similar model was used for the deep well and a groundwater flow available for dilution of 60,000 m^3/yr was obtained.

4.1.8.2 Treatment of non-human biota

In all the performance assessment exercises done by ENRESA only doses to man have been calculated. Although not explicitly stated, ENRESA assumed that, "*subject to the appropriate definition of exposed groups, the protection of people against the radiological hazards associated with a geological disposal facility will also satisfy the principle of protecting the environment*" as stated in /10/. The most recent PA exercise done by ENRESA was finished in 2004, and this was the approach followed by most WMO at that time.

The issue of the radiation protection of the environment from ionizing radiation has become relevant in recent years and is still under discussion internationally. The limitation of radiological protection to human health has been increasingly questioned and the requirement for an internationally agreed rationale to the protection of the environment from ionising radiation is now widely recognised. ENRESA follows the international developments in this area, such as FASSET and ERICA projects of the EC.

In any case, the analysis of doses to non-human biota is a site specific topic because the species of animals and plants living at different sites can be very different. Only when a site has been selected a realistic identification of animals and plants can be done. In addition, climatic conditions will evolve along the next million years, and the species living in the area are expected to change accordingly. It is clear that the topic of the doses to non-human biota can not be treated in full detail and a stylised approach seems the most promising.

4.1.8.3 Deterministic vs. stochastic biosphere

In ENRESA consequence analyses the treatment of the Biosphere is always deterministic, both in the deterministic and the probabilistic calculations.

Stochastic DCFs were calculated for all the radionuclides to take into account the uncertainty in the many parameters involved. These stochastic DCFs were compared with the deterministic DCFs and a good agreement was found. In addition, the sensitivity analysis of the stochastic DCFs allowed to identify the critical exposure pathways for each radionuclide, providing useful guidance for R&D in efforts in the biosphere. But these stochastic DCFs were NOT used in the dose calculations.

ENRESA used deterministic DCFs in the probabilistic dose calculations for several reason:

- The stochastic DCFs typicalled spanned over several orders of magnitude and would have added a significant spreading of the results.
- Proper sampling of the DCFs would have required a significant increase in the number of runs required. ENRESA most recent PA exercises in granite /2/ and clay /3/ stochastic calculations were done with only 100 or 500 runs respectively, due to computer runtime limitations.
- The uncertainty in the biosphere is uncoupled from the uncertainty in the disposal system and the host formation, and can be analysed separately (as we did).
- Including the uncertainty in the biosphere in the stochastic calcualtions would have made harder to interpretate the results of the evaluation and draw conclusions on the relevance of the different barriers of the system.

4.1.8.4 Consideration of the chemotoxic elements in the repository

In all the performance assessment exercises done by ENRESA /2/ /3/ only radiological consequences of the waste disposed of in the repository are considered. The fate of the chemotoxic elements in the waste or other repository materials is not analised.

ENRESA closely follows the international developments on this topic. Future evaluations could include chemotoxic elements if it is required by the regulations or considered advisable on the base of the guidelines provided by the relevant international organisations.

Inclusion of chemotoxics in the Safety Assessmnet of a repository probably can be done with a small extra effort, because most models would remain valid and only additional data would be required (transpor parameters for Cadmium, for instance).

4.2 Related topics

The treatment of the Biosphere in the Safety Case is closely related to the “Modelling Strategy” and the “Definition and Assessment of Scenarios”.

4.3 Databases and tools

A FEP database for biosphere processes has been created. The Dose Conversion Factors were calculated using the code AMBER /11/, /12/. AMBER has been used to calculate both the deterministic and the probabilistic DCFs.

4.4 Application and experience

In the preliminary exercises for repositories in granite and clay done in the 1990´s a simplified treatment of Biosphere was done, with the objective was of defining a receptor exposed to the radionuclides that leave the geosphere barrier, in order to be able to calculate doses.

For the second batch of Safety Assessments for repositories in granite and clay done in the early 2000´s, Biosphere modelling was done in close cooperation with Ciemat that had been actively involved in international projects dealing with the treatment of the Biosphere. As a consequence, these most recent SA exercises included a treatment of the Biosphere coherent with the state-of-the-art at the beginning of the 2000´s.

4.5 On-going work and future evolution

Enresa is making no in-house developments on this topic, but international developments on the different topics related to the Biosphere are closely followed.

5. Lessons learned

The analysis of the expected climatic evolution in the repository area is necessary in order to identify any potential future biospheres very different from the actual. In addition, the effects of the climatic evolution on the hydrogeological system need to be considered too: water recharge, potential evapotranspiration or water sea level can change significantly. The effects of glacial conditions, if reached, can be especially important.

In ENRESA2003 /3/ the values of the DCFs obtained for today Biosphere and an alternative Biosphere for quite different climatic conditions were quite similar, because exposure pathways remain the same and only soil characteristics and some parameter values are changes. Probably only if the climate evolution leads to a very different

Biosphere with different exposure pathways the DCFs can be expected to change significantly.

The geosphere-biosphere interface is a critical part of the system, because controls the dilution of the radionuclides released from the waste, and doses are inversely proportional to such dilution. The potential geosphere-biosphere interfaces are totally site-specific and are expected to change with time due to the climatic evolution. This topic must be analysed in depth in the Safety Assessment.

Biosphere treatment in the Safety Case is a field where some guidance form the regulator can be expected and would be very useful. If guidance is not available, at least open discussions between regulators and implementers should be held at the beginning of the Safety Case on the methodology to follow for the inclusion of the Biosphere in the Safety Case.

6. References:

[1] Not used.

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Table of content

1. Introduction

In Belgium, an R&D research programme related to geological disposal of high-level and long-lived radioactive waste has been conducted during the last three decades.

In 2013, a safety and feasibility case on the geological disposal options developed by the Belgian waste management organization (ONDRAF-NIRAS) will be issued and reviewed by FANC.

ONDRAF-NIRAS is also developing a project of near-surface disposal facilities for low- and intermediate-level short-lived radioactive waste, for which the authorization application is planned to be submitted at the end of 2010.

In parallel, the Belgian nuclear safety authority (FANC and its technical support organisation Bel V, previously named AVN) has been involved, for the last five years, in different types of activities, aiming at developing a specific regulatory framework adapted to radioactive waste disposal facilities and reviewing technical documents. The regulatory framework is made of several guides expressing the expectations of the nuclear safety authority on different facets of radioactive waste disposal facilities.

In addition to these guides, the following documents more specific to deep geological disposal, have been developed:

- “Geological Disposal of Radioactive Waste: Elements of a safety approach” [1]. This document was elaborated in 2004 by FANC, AVN, the French nuclear safety authority (ASN) and its technical support (IRSN) and the waste management organization from both countries (ONDRAF-NIRAS and ANDRA) in the framework of the Franco-Belgian collaboration in the field of nuclear safety.
- A first draft of guidance [2] was elaborated for the siting of disposal facilities in argillaceous formation. It applies the safety approach defined in the aforementioned document [1] to the confirmation of the choice of a host formation.
- In 2007, FANC issued a document [3] describing the licensing process of radioactive waste disposal facilities and the different periods in a disposal programme in Belgium.

The present contribution aims at presenting the preliminary positions developed by FANC about the biosphere and its treatment in the safety assessment of geological repositories.

2. Definition of terms and used concepts

Biosphere

Within this document, the biosphere is a part of the environment where the radioactive waste disposal facility is located and which is easily accessible to human beings (e.g.

via agriculture, water pumping, etc). The biosphere is a component of the disposal system's environment.

Biosphere receptor

The biosphere receptor is the abiotic biosphere component that will suffer from the harmful effects of the ionising radiation and/or of dangerous substances.

Critical Group

A critical group is a relatively homogeneous group of people whose location and lifestyle are such that they represent those individuals expected to receive the highest doses as a result of radioactive releases. It is a self-sustaining agricultural community (subsistence farmers) that obtains no food and water from outside sources and is located in the area of highest potential concentration.

The concept of critical group is used for calculating doses until the closure of the disposal facility.

Environment

Within this document, environment includes water, air, soil, humans, animals, plants and any other living organisms as well as relations between them.

Exposure pathway

Pathway through which living organisms suffer from the harmful effects of ionizing radiations and/or dangerous substances.

Potentially Exposed Group

The definition of "Potentially Exposed Group" is the same as the "Critical Group" except for the considered time frame. The concept of the "potentially exposed group" is used for evaluating the potential exposure situations after the closure of the disposal facility.

Transfer pathways

Physical pathway taken by a radionuclide from the source to the considered receptor.

Reference biosphere

A reference biosphere is a stylized model taken as a reference. Stylization implies introduction of hypotheses and assumptions about the evolution of the biosphere and/or characteristics of the specific model.

Reference organism

A reference organism is a hypothetical entity with assumed basic characteristics of a specific type of animal of plant providing a consistent basis for the determination of exposure/dose and dose/effects relations for various categories of effects.

Representative person

The representative person is the person to be used for determining compliance with the dose constraint. This individual, who will almost always be a hypothetical construct, receives a dose that is representative of the more highly exposed individuals in the population.[3]

3. Regulatory Context

3.1 Regulations and guidance

3.1.1 Detailed national regulations

Although under development, there are currently no specific regulatory texts in force in Belgium concerning radioactive waste disposal facilities.

The general regulatory framework existing for nuclear installations (Royal decree of 20th July 2001) is only partly adapted for repositories: in particular, it does not address the timeframe and the concept of "long-term safety", which constitute major issues for disposal facilities.

According to the Royal decree of 20th July 2001, an Environmental Impact Assessment with emphasis on radiological impacts (REIA) is required for radioactive waste repositories.

It has been decided to develop a new regulatory framework (Royal Decree about long-term management of radioactive waste), applicable to both near-surface and geological disposal facilities. It will describe, amongst others, the licensing procedure to be applied for such facilities. The development of this new Royal Decree has been initiated at the beginning of 2008 and is still on going.

Another document ("strategic note" [3]) was issued by FANC in 2007. It is based on the fundamental principles of radioactive waste management developed by IAEA [7]. Beside the definition of the safety objectives for the disposal of radioactive waste, the strategic note [3] describes the licensing process of a disposal facility.

[3] *Note : for prospective dose assessment, the ICRP (Publication 101 [6]) recommends that the representative person should be defined such that the probability is less than about 5 % that a person drawn at random from the population will receive a greater dose. The representative person is equivalent to, and replaces, the average member of the critical group recommended previously by the ICRP.*

A guidance specifically dedicated to the environment is being developed. It covers all biosphere aspects (the biosphere is part of the environment) and all types of nuclear waste repositories.

All relevant Belgian laws and EC-regulations related to the environment shall be taken into account.

3.1.2 Regulatory framework for biosphere assessment in the safety case

The implementer, operator or developer shall also take into account all non-radioactive contaminants. However the evaluation of these assessments is not the responsibility of the Belgian nuclear safety authority.

Four out of the nine fundamental principles developed by IAEA [7] are related to the biosphere:

1. Protection of human health
2. Protection of the environment
3. Protection of future generations
4. No burden on future generations.

Any nuclear waste disposal facility (near-surface, deep-geological or a disposal facility with extended institutional control) shall be conceived in such a way that the fundamental principles are satisfied. The safety report shall i.e. demonstrate that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today.

Therefore the development of a safety case implicitly requires a radiological impact assessment and a characterisation of the environment (humans and the biosphere).

Taking into account the above mentioned principles, the objectives of the radiological impact assessment could be summarized as follows:

- Assessing the radiological effects on the environment and the possible risks
- Substantiate the acceptability of these effects
- Integrating the radiological protection of the environment into the licensing process.

3.1.3 Link with international guidelines

In most countries, the treatment of the biosphere does not exist as a stand alone guidance but it is integrated into the general guidances for repositories.

For biosphere models a variety of comparison exercises have been carried out internationally as part of the two BIOMOVS projects and more recently in the

BIOMASS programme.

Recent developments have also been realized via EURATOM programs : FASSET (2001-2004), ERICA (2004-2007) and PROTECT (2007-2008).

The specific guidance under development in Belgium is consistent with the relevant IAEA- and ICRP-recommendations, as well as with EC directives. However it is not prescriptive and has to be considered as a framework for preparing a complete and accessible impact assessment.

There is a considerable international consensus about the subsistence farmer approach, which has been used by various countries.

3.2 Specific biosphere recommendations

It is the responsibility of the implementer, operator or developer to provide sufficient and reliable data and analysis on any potential environmental effect in order to permit a proper evaluation by the public, technical and regulatory authorities.

Human activities which can affect the installation and its environment shall be considered. The possibility of one or more individuals coming into contact with the waste in the repository or damaging a number of barriers as a result of human activities must be analysed and the resulting radiological consequences assessed. This has been considered in the “Human Intrusion” guidance [5].

The four principles mentioned above have led to define five general expectations.

Expectation 1

For each important biosphere receptor, a critical group or a potentially exposed group and the reference organisms shall be determined

This expectation implies that a screening assessment has to be performed in order to identify each important biosphere receptor and implies that the adopted screening approach has been described. The choice of the biosphere receptor has to be justified.

Once each important biosphere receptor has been identified, a critical group (dose related) or a potentially exposed group (risk related) associated with this biosphere receptor shall be considered. According to the definitions, the critical or potentially exposed group shall be located on these spots where the activity concentrations are the highest.

The behaviour and characteristics of these groups shall be as generic as possible in order to ensure robustness in the model and to provide a high degree of confidence in the long term assessment results.

For non-human biota, reference organisms shall be taken into account.

The operator has to propose and substantiate the list of biosphere receptors.

Expectation 2

For each critical or potentially exposed group, all transfer pathways and exposure pathways shall be identified.

The approach for selecting the transfer and exposure pathways has to be detailed and the selected pathways have to be justified.

The selection of the exposure and transfer pathways should take into account the current biosphere for the critical group and the future evolution of the biosphere for the potentially exposed group (as identified in expectation 5).

The level of details of the selected transfer and exposure pathways could evolve with the considered licensing phase; this graded approach is further developed in Chapter 4.1.1.

All possible transfer and exposure pathways shall be taken into account. If some of them are not retained, it has to be justified in detail.

Expectation 3

Regarding reference organisms, the state-of-the-art of the international developments shall regularly be checked.

For non-human biota, reference organisms shall be taken into account. Since there is still a lack of radiological criteria for assessing the effects on non-human biota, the licensee shall take the necessary actions to keep up with the evolution of national and international regulations and progress in science.

In any case, rare, protected or endangered species shall be given particular attention.

Expectation 4

All receptors, transfer pathways and exposure pathways shall be taken into account in such a way that the radiological impact will never be underestimated.

It shall be demonstrated that the impact assessment is never underestimated. Depending of the licensing phase and the level of knowledge, the level of details or the level of realism could evolve. This implies that :

- All aspects are examined and treated in a carefully justified way;
- All approaches in defining the characteristics of the environment will be such that an upper bound value will be derived;

Expectation 5

Various time scales should be considered.

Major disruptive events have to be considered.

This shall include climate changes which may modify biosphere receptors and consequently the critical or potentially exposed groups, reference organisms, transfer and exposure pathways.

This shall also include human actions impacting the installation and its environment.

The timescales to be considered are defined on basis of the residual hazard induced by the waste inventory (radioactive decay).

In the long term, quantitative evaluations shall be considered as general indications and not as real predictions.

4. Specific considerations related to the biosphere

4.1.1 Graded approach for modelling the biosphere

The biosphere appears as the less robust component of the safety assessment evaluation. In order to avoid endless discussions about the uncertainties related to the biosphere components, FANC considers that a graded approach for modelling the biosphere has to be followed.

Selection of the biosphere model could evolve with the phase of the project.

During the siting phase (waste inventory should be known), a **stylized approach** can be used using a simplified biosphere (screening). A minimal input data and standardized transfer models can be used (deterministic approach). The results will be compared to fixed regulatory criteria.

If some results of the initial screening process do not meet the fixed criteria or if input data is more detailed or if more information becomes available about the concept and the site, a **generic approach** based on a reference biosphere can be used. In this case, transfer and exposure pathways will be more detailed but still standardized. This approach can be either deterministic or probabilistic depending on the data- and model quality. The results will be compared to fixed regulatory or probabilistic criteria.

When the site is well characterized and the disposal concept is in a detailed engineering phase, a **site-specific approach** shall be used. This approach requires a detailed and in-depth knowledge of the biosphere receptors, an in-depth analysis of all biosphere components, realistic transfer- and exposure modelling and representative reference organisms. This approach can also be deterministic or probabilistic depending on the data- and model quality. The results will be evaluated against fixed regulatory or probabilistic criteria.

All approaches considered above have to be validated in order to ensure that:

- The radiological impact will never be underestimated;
- No future generations will receive a dose higher than the dose incurred by the current generation.

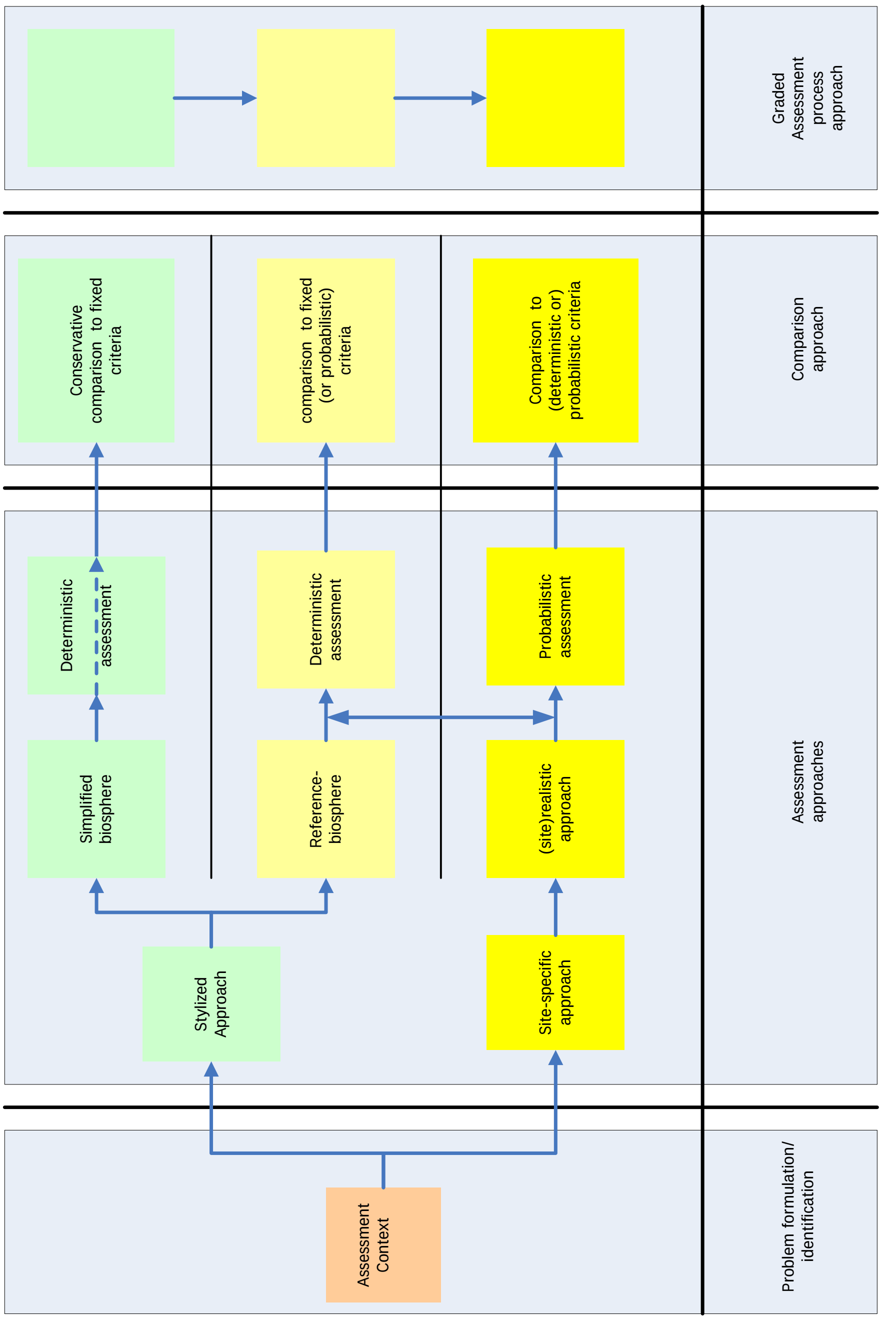

Fig. 1: Approaches

4.1.2 Discussions about the representative person

The ICRP Publication 101 [6] introduced the concept of "representative person".

For the purpose of radiation protection of the public it is therefore necessary to characterise a representative of the more highly exposed individuals in the population. It is the person to be used for determining compliance with the dose constraint (planned exposure) or the risk constraint (potential exposure).

This representative person belongs to the critical group or to the potentially exposed group. According to [6], "the representative person is equivalent to, and replaces, the average member of the critical group recommended previously by the Commission (ICRP, 1985)".

By definition, the critical group is a small group and there should be a relatively small difference between those receiving the highest and the lowest doses. Evolving from the concept of the critical group to the concept of the representative person appears as a logical evolution. FANC considers that the change introduced by ICRP is not a major modification of the approach to be followed.

4.1.3 Selection of outlets

As already stated, the location of the expected maximum activity concentration or flux will be considered for all transfer- and exposure pathways, taking the timescales into account.

This implies that the models should be such that the information related to the activity concentrations has to be provided.

4.2 Experience and lessons learned

The safety case of a surface disposal of low level radioactive wastes is currently being developed in Belgium. It takes the local biosphere into account. Although it is recognized that the time scales are different, the development of this safety case will help in the safety assessment of a geological repository.

4.3 Developments and trends

Major changes are currently taking place in the way the environment is considered in international guidelines and in safety cases. The biosphere was previously only taken into account as a potential transfer pathway to humans (food chain) ; recent documents focus on biodiversity too.

This evolution is the substantiation for expectation 4.

5. Analysis and synthesis

To assess the radiological impact in terms of doses, the biosphere has to be modelled. It is however recognized that the biosphere is the less robust component of the safety assessment evaluation.

Continuing changes in agricultural practices and human diet coupled with the unpredictable nature of future human behaviour mean that the biosphere can change considerably after just a few decades, so the use of “reference biospheres” is unavoidable. A reference biosphere is defined as a set of assumptions which provide a consistent basis for radiological impact calculations for a repository. A graded approach is recommended.

One can also define a reference biosphere for every climate type that is expected in the future in order to avoid contradictions between the climate type considered for the geosphere and for the biosphere. Ways of developing reference biospheres that are consistent with other climatic types which are anticipated in the future (warmer or colder, drier or wetter) may be investigated.

The proposed approach is based on biosphere receptors. Then critical groups, potentially exposed groups and reference organisms are identified.

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Reference: 1.1.d

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1. Introduction and background

This document describes the treatment of the biosphere in performance assessment studies performed by GRS. In recent safety analyses the biosphere was treated with a stylised model based on current consumption habits and modelling approaches and parameters prescribed by legislation (cf. section 2). This biosphere model was applied in generic safety assessments [BUH 91] as well as for site-specific safety cases, namely for the repository for LLW and ILW in Morsleben, ERAM [STO 04].

However, in the context of the development of new safety requirements, the treatment of the biosphere is under discussion in Germany. Therefore, currently research projects are performed, which investigate the impact of environmental changes on the biosphere processes. Results from these investigations are also referred to in this document [NOS 09].

2. Regulatory requirements and provisions

The guideline 'safety criteria for the final disposal of radioactive wastes in a mine' from 1983 requires that the limit for the effective dose to an individual is 0.3 mSv/a given in the German Radiation Protection Ordinance. This has to be demonstrated by consequence analyses with integrated models for relevant scenarios. Currently, the safety criteria are under revision.

Under the existing safety criteria the application of the biosphere model in long-term safety assessment is mandatory under the German government regulations [BfS 02]. Modelling approaches and parameters are fixed.

According to a draft version of the new German Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste (BMU 08), long-term predictions of the potential radiological consequences shall be performed on the basis of representative scenarios and reference biosphere models. However, lifestyles and sensitivities to ionising radiation of future generations are impossible to predict. Therefore, stylised ecosystems should be applied for assessment of radiation exposures. These models should consider the relevant present-day exposition pathways. Additionally, the models should be flexible enough to consider environmental changes in order to provide a reasonable assessment for a range of environmental and climatic conditions.

3. Key terms and concepts

The biosphere is the surface and near-surface environment that is usually inhabited by living organisms and where human beings live. In the framework of the long-term safety assessment, the biosphere is considered to be part of the entire repository system. The biosphere is not considered to fulfil any safety function but its properties have an impact on the distribution of contaminated groundwater in the environment.

The role of the biosphere models is to assess from predicted radionuclide concentrations or radionuclide fluxes individual doses to members of reference persons, which can be compared to the predefined dose limit. The reference persons are assumed to be members of a small self-sustaining community.

According to the current radiation protection ordinance, dose calculations have to be performed for six different age groups to ensure compliance for all population groups.. Furthermore, organ doses have to be calculated and compliance has to be shown with organ-specific dose limits. For radionuclides, which accumulate preferably in specific organs, the organ dose might be the limiting value.

4. Treatment in the Safety Case

4.1 Methodology

The evolution of human societies, future living conditions and food consumption habits and the interaction with and impacts on evolving ecosystems in the far future is highly uncertain. Therefore, assumptions for assessing long-term radiological impacts need to build upon stylised biospheres as recommended for long-term impact assessments of nuclear waste repositories [ICR 98].

4.1.1 Biosphere model based on today's conditions

In Germany, the common approach of using radionuclide-specific dose conversion factors (Sv a^{-1} per Bq m^{-3}) to include the biosphere in the consequence analysis is applied. The key indicator for safety assessment is the average annual individual dose. Therefore, the main task of the biosphere models of the integrated code EMOS is to calculate dose rates from concentrations or radionuclide fluxes in near-surface aquifers.

It is assumed that the radionuclides enter the biosphere via a well in a near surface groundwater aquifer. Basis for the calculation is a self supplying person, who receives his entire foodstuff from the area, where the contaminated well water is used. Additionally it is assumed that the water is used for different applications without any further dilution. The model is based on the living habits of the present population in a typical area of northern Germany. Since changes of living habits in the far future cannot be predicted accurately, no changes are presupposed for the future. The following exposition pathways are considered:

- Ingestion of contaminated drinking water,
- irrigation of pasture and arable land with contaminated water,
- consumption of contaminated plants,
- intake of contaminated water by cattle via watering place,
- feed of cattle with contaminated crops,
- consumption of contaminated meat and milk,
- consumption of fish from contaminated ponds,
- external exposition by occupation on contaminated areas.

Furthermore, the following exposure pathways are usually been considered, which are not explicitly mentioned in [BfS 02]:

- Ingestion of contaminated soil particles,
- inhalation of contaminated soil particles,
- ingestion of contaminated soil particles by cattle,
- external exposition by occupation on contaminated areas and
- exposition by occupation in houses built by contaminated material.

A sketch summarising the considered pathways is given in Fig. 1

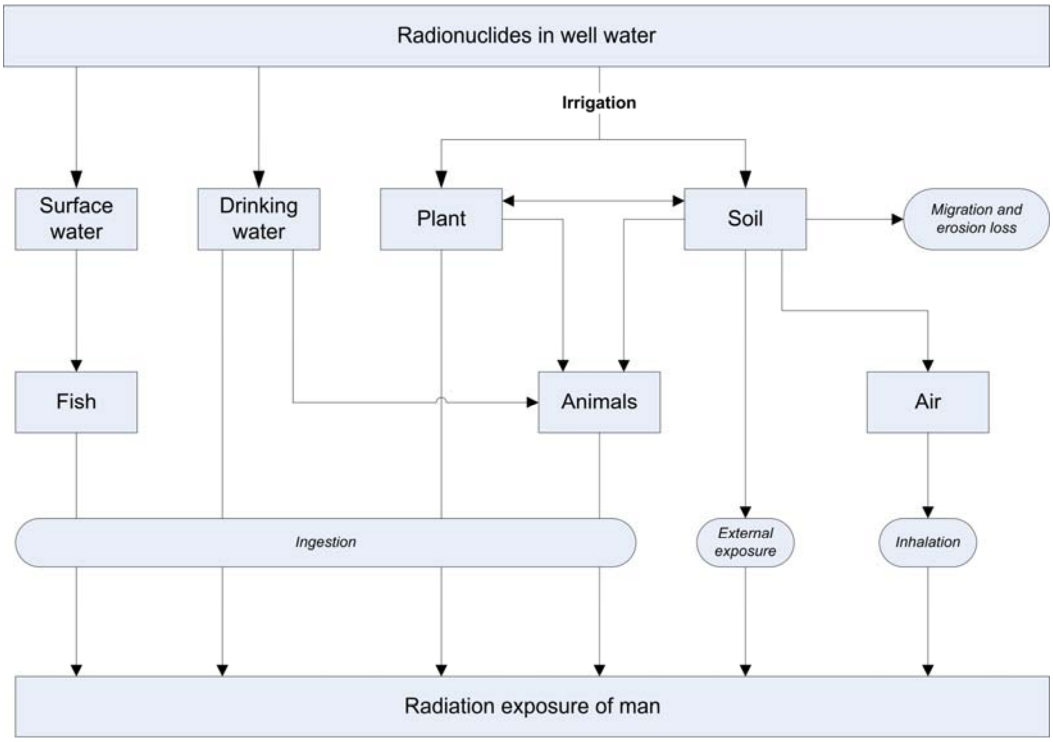

Fig. 1: Conceptual model for estimating the radiation exposure to man, if radionuclides enter the biosphere via well water

Currently used dose conversion factors have been calculated in [PRÖ 02] on the basis of the general administrative regulation [BfS 02] using ingestion dose coefficients from [BMU 01].

4.1.2 Impact of climate changes

Within an R&D project the impact of climate changes on the evolution of the biosphere is assessed. Concerning potential repository sites in Northern Germany a variety of climates may be expected in the long-term future. In order to assess the impact of such different future climatic conditions the potential impact on the base of “what if?” considerations is studied.

In total, six different climate states, which might occur in the far future in the potential repository area, i.e., steppe (Bs), Mediterranean (Cs), temperate (Cfb), boreal (Dfa/Dfb), and tundra (Et) have been considered, respectively. Data for temperature, precipitation, and humidity were taken from so-called analogue sites, which are characterised by these climates today: Marrakesh, Rome, Magdeburg, Rostow, Turku and Vardo, respectively.

Two geosphere-biosphere interfaces (GBIs) have been considered:

- radionuclides enter the biosphere via withdrawal of contaminated groundwater ("well")
- radionuclides enter the biosphere directly (in case of a high water table) and cause contaminations of soils ("rising groundwater")

For all climates, dose conversion factors were calculated by a set of biosphere models. The impact of the climate state on the biosphere modelling was considered by differences in the consumption habits, in the required irrigation amounts, in the considered exposure pathways and GBIs, by adapting parameters for radionuclide behaviour in soils (migration and transfer to the plant), in parameters for erosion and resuspension, and in feeding rations for animals.

The results show that the variations among all climates are relatively small for actinides; mostly the differences are less than a factor of 5 with a tendency for increased dose conversion factors with increased aridity. In general, the transfer for these radionuclides through food chains is relatively low, and the mobility within the plant subsequent to foliar deposition is low as well. Consequently, the intake of radionuclides with drinking water dominates over the other ingestion pathways.

Furthermore, the results demonstrate that the dose conversions factors for other radionuclides vary considerably for the different climate states. This variation is strongly dependent on the different geosphere-biosphere interfaces. For the temperate and the boreal climates, the interface "well" causes higher dose conversion factors, whereas in case of the tundra climate, dose conversion factors are higher for the interface "rising groundwater". The highest variations between the different climates are found for ^{14}C, ^{36}Cl, ^{94}Nb, ^{135}Cs and for the redox-sensitive radionuclides ^{79}Se, ^{99}Tc, and ^{129}I.

With regard to the geosphere biosphere interface, the results from flow and transport calculations in the sedimentary layers above the host rock showed a strong impact on radionuclide pathways, radionuclide transport times and locations of highest radionuclide concentrations.

The model assumptions made for the different climate states require the existence of sufficient groundwater resources. Therefore, the necessary water supply was estimated for an area that is large enough to enable sustainable food production for a small community. It was assumed that this critical group consumes plant food products and has a herd of 30 dairy cows for breeding, meat and milk production that is fed only by locally produced crops. The considerations showed that even for hot and dry climate stages the required well capacities are relatively low. It is not a problem to withdraw such amounts of water even from small aquifers.

4.2 Related topics

The topic biosphere is closely related to the topics safety indicators and modelling strategy.

4.3 Databases and tools

There is no specific database for biosphere processes available in Germany. The biosphere calculations are performed by the Helmholtz Zentrum Munich (HMGU), e.g. [PRÖ 02]. Within the programme package EMOS for integrated safety assessment the modules EXCON and EXMAS are available to calculate radiation exposures from radionuclide concentrations, or radionuclide fluxes, respectively [BUH 99].

For the study on impact of climate changes the treatment of ^{14}C is different to the other radionuclides. The estimation of ^{14}C in food subsequent to application of irrigation water that contains ^{14}C requires special considerations. It is assumed that ^{14}C occurs as $^{14}CO_2$, $H^{14}CO_3^-$ or $^{14}CO_3^{2-}$. The key process for the fate of carbon dioxide is the photosynthesis, during which CO_2 is converted to carbohydrates. The photosynthesis depends on the environmental conditions as day time, insolation, temperature, water supply and plant species. Part of the carbohydrates is lost in the short-term by respiration, which maintains the metabolism of the plant. Part of it is stored in specific parts of the plant as e.g. tubers or grain.

Carbon dioxide is metabolised by the photosynthesis of the plant and enters via this pathway the human food chain and causes ingestion exposures due to the intake of contaminated food. The use of ^{14}C contaminated water for irrigation of crops is modelled assuming a conceptual model as shown in Fig. 2.

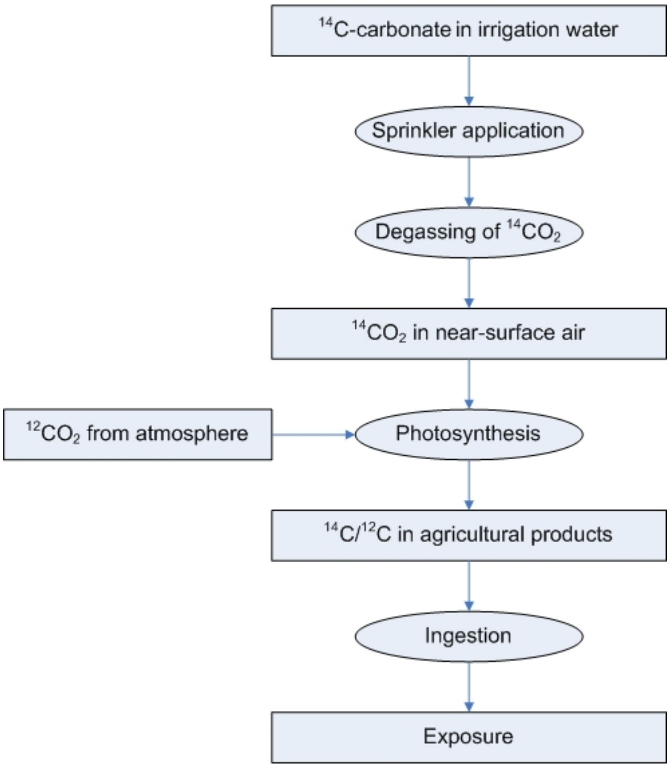

Fig. 2: Flowchart of the model to assess exposures due to use of water containing ^{14}C for irrigation of agricultural crops

4.4 Application and experience

The biosphere model described in section 4.1.1 have been applied in the long-term safety assessments for a generic repository with all kind of waste in rock salt, e.g. [BUH 91] and are currently applied in the frame of licensing applications for real repositories with intermediate and low level waste, e.g. in Morsleben [STO 04].

4.5 On-going work and future evolution

Further R&D work on the uncertainties of dose conversion factors and on the impact of climate changes on flow and transport in sedimentary rock overlying the host rock and on biosphere processes is under way. The next step concerns the analysis of transitions between different climate states and the evaluation of potential consequences. These will be compared to the results for the discrete climate states. It is of interest, whether radionuclide accumulation and release processes exist, which might lead to increased dose rates during transitions stages. Additionally, more work is planned on geosphere/biosphere interfaces, focussing on the interrelation between biosphere and geosphere modelling.

This work might build the basis for the development of reference biosphere models to be used in future safety assessment studies.

5. Lessons learnt

The continuous participation of HMGU in international projects like BIOMOSA or BIOCLIM is of value for the further development of biosphere models; in particular it contributed to the development of models and selection of suitable parameters for the investigation of the impact of future climate changes.

The experience gained so far from these investigations showed the need to adapt the general administrative regulation to the requirements of disposal facilities, especially to consider potential environmental changes at a specific site. Furthermore it showed the need to look in more detail in processes in the geosphere / biosphere transition zone, which are also strongly affected by climate changes.

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Revision: 1

Contents

1. Background/Introduction

At present, the management of radioactive waste and the assessment of the long-term safety in Germany are under review. The policy of Germany is to concentrate and isolate the radioactive material rather than release and disperse it into the environment. According to the international consensus that long-lived radioactive waste has to be disposed of in deep geological formations in order to guarantee that man and environment are protected in the long run from the effects of ionizing radiation by isolation of the radioactive waste. In Germany all types of radioactive waste have to be disposed of in a deep repository.

An important cornerstones of the new waste management plan is the revision /BAL 06/ of the "Safety Criteria for the Disposal Radioactive Waste in a Mine" (in the following named as "Safety Criteria") /BMI 83/.

The revision of the “Safety Criteria” on behalf of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) is done in order to account for the progress in safety-related developments and procedures, e. g. the assessment of the long-term safety and "Safety Case" methodology. The revision of the "Safety Criteria" as well as the development of supporting guidelines is carried out by the Final Disposal Department of GRS Köln with the support of a number of experts from Germany and abroad. The revision accounts for the ideas and requirements given in the OECD/NEA report "Post-closure Safety Case for Geological Repositories" /NEA 04/ and in the IAEA safety requirements guide WS-R-4 (formerly known as DS-154) /IAE 06/.

The revision should deal with the disposal of high level waste in deep geological formations. Waste with negligible heat generation will not be considered because this waste will be disposed of at the Konrad repository which is licenced and has been under construction since 2007. Furthermore, restrictions by existing legal regulations should not be taken into account. The update was completed with the report "Safety Requirements on the Disposal of High-radioactive Waste in Deep Geological Formations" /BAL 07/. The GRS draft proposal took into account both the further development of the state-of-the art in science and technology and the international recommendations recently published, especially the IAEA Safety Requirement WS-R-4 /IAE 06/, the ICRP publications 81 /ICR 00/ and 101 /ICR 06/. The preparation of the draft proposal submitted by GRS in January 2007 was intensively supported by BfS.

Based on the GRS proposal /BAL 07/, BfS workshop's results /BRE 07/, BfS recommendations of June 2007, and the evaluation of the GRS proposal prepared by BMU's advisory-bodies Reaktor-Sicherheitskommission and Strahlenschutzkommission, BMU themselves carried out a Draft Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste and presented this Draft in November 2008 to the public. At present this draft is under discussion in the BMU´s advisory bodies. Currently, regulatory binding safety requirements are further under development.

It should be noted that siting and site requirements are not addressed in detail in the proposal for the criteria revision. The revision is based on the understanding that a repository site has to be chosen in accordance to the requirements of a siting procedure as outlined e.g. in the AkEnd recommendations on site selection /AKE 02/.

The most important aim of a geological disposal of radioactive waste is the protection of man and environment. The limitation of the risk of an individual to suffer from a serious illness due to radiation exposure is regarded as the radiological protection aim. The proof of adherence to this protection goal is done by assessing the dose/the risk resulting from releases from the waste disposal. It is not possible to predict dose and risk for humans living in the far future, because these are influenced by the environment and lifestyle, which are both unknown. The task is to elaborate reasonable scenarios, assess dose and risk for humans and non-human biota living in it and find out the upper limit which probably cannot be overridden.

The present draft document is structured in five main sections. Section 2 includes the definition of terms and concept used. Section 3 comprises the regulatory context. Section 4 titled “Analysis and synthesis” includes the main aspects of the GRS proposal for the implementation of the biosphere into the safety analysis. In Section 5 the references used in this draft document are listed.

2. Definition of terms and used concepts

The safety-strategy is based on the disposal in deep geological formations with the aim of the isolation of the radioactive wastes from the biosphere for a time period of 10^6 years.

The isolation is made sure by

- the site-selection particularly with regard to the host-rock
- the repository design
- the safety-management for the operational phase and the post closure phase

Despite the site lying in a so called isolating rock zone of the host-rock which guaranties the isolation of the radioactive waste for a long time, in the end releases of radionuclides into the biosphere have to be taken into account.

The German Safety Criteria /BMI 83/ do not give advice on how the protection of human and non human biota living in the far future should be proved. Biosphere-related definitions are absent. The safety criteria allow for a dose limit of 0.3 mSv for the proof of long-term safety. At present the safety criteria are under revision.

In the waste disposal projects of Konrad, Morsleben and Asse, the evaluation of the radiological consequences for the biosphere was executed using site-specific parameter values. The lifestyle and food habits of today's humans were assumed. The criteria and standards of evaluation are at present under development. In the course of the year 2009 a recommendation of the BMU is expected.

3. Regulatory context

3.1 Regulations and guidance

At present, there are no specific regulations or guidances for the calculation of long-term consequences in the biosphere available.

All the statements in the following chapters refer to a proposal of the GRS, which are not necessarily consistent with a future set of rules.

3.2 Requirements and expectations

The calculation of the dose to humans and non-human biota caused by a waste repository is done in order to make credible that the risk of dying or suffering from severe diseases does not exceed the limits which are valid today. It is not possible to prove this for the far future in a juridical sense. The doses and risks calculated are mere indicators for the isolation capacity of the repository, not for the radiological impact on man and environment. The trustworthiness of the statement that the actual dose limits will be adhered to also in the far future can be shown by a range of dose calculations for several different biosphere scenarios which might be ruling during the time of release. Experience has shown that a certain upper value of dose exists, which can approximately be reached in different scenarios, but not significantly exceeded /BEC 03/: “The calculated doses are robust”.

Each biosphere scenario has been modelled using best estimate values. The best estimate values must be created using reasonable assumptions. The food uptake can be defined using the necessary caloric and nutritional intake and the kind of plant and animal food which can be produced under the conditions of a biosphere scenario. The irrigation practices can be calculated using data on precipitation and temperature and the monthly necessities of the crops produced.

The chose of best estimate values will make sure that the calculations will not be over conservative. They help making the described potential environments sustainable.

The scenarios investigated are not equally probable. It can be assumed that cooler and colder climates with natural outlets will prevail during longer periods than warmer and dryer climates which imply the use of a well and the necessity of irrigation. It is assumed that warmer climates will be dry when they follow after cold climates with glaciers not too far from the site. But, after some thousand years of warm climate it is expected that they become humid.

Because of the uncertainties increasing with time the biosphere scenario leading to the highest dose should be assumed as the reference biosphere.

3.3 Experience and lessons learned

As mentioned above, it is not possible to forecast the development of the radiation dose to humans and non-human biota due to a waste repository with time. Therefore the weight of the dose calculations should not be overestimated.

3.4 Development and trends

In summer 2008, the German Federal Office for Radiation Protection (BfS) and the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) arranged a workshop with European experts on radioecology with the intention of finding out how the impact of climate change and other major environmental transformations on the biosphere should be modelled, how the geosphere biosphere transition zone should be defined and modelled for various site-specific biosphere scenarios, and which radiation protection criteria should be adhered to.

One of the outcomes was that a common reference biosphere valid for many repository sites all over Europe does not exist. Instead, for every site various biosphere scenarios - each covering the way of the radionuclides from the near-surface parts of the geosphere to humans and non-human biota - must be analysed in order to get a valid picture about the safety of a waste repository.

The climate influence on the radionuclide concentration in groundwater has also to be modelled. This is a new insight because up to now modellers of the geosphere and the biosphere have often worked separately.

Future work should concentrate on the geosphere biosphere transition zone as influenced by stationary and transitory climate conditions. Natural outlets should be investigated more carefully.

4. Analysis and synthesis

4.1 Safety Principles and Safety Objectives

- The disposal of high-level radioactive waste in deep geological formations will ensure the isolation of these wastes for long periods and thus guarantee the long-term protection of humans and the environment from the potentially harmful effects of the disposed radioactive waste.
- Future generations are not to be imposed unreasonable burdens and obligations.
- Future potential impacts due to the waste disposal on humans and the environment may not exceed the measure which is accepted today.
- The potential impact on humans and the environment from the disposal of high-level radioactive waste in Germany may not be larger outside the German borders than permissible within.

4.2 Safety Approach

4.2.1 General

To demonstrate the safety is „to ensure that …before construction of a disposal facility, a systematic safety assessment and an environmental assessment for the period following closure shall be carried out and the results evaluated against the criteria …“ (Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management /IAE 97/).

The Safety Requirements WS-R-4 „Geological Disposal of Radioactive Waste“ /IAE 06/ state relevant requirements of such criteria and to their verification according to the state of the art in science and technology. One of the criteria is the compliance with certain dose limits, but there are no prescriptions about the verification of the compliance.

4.2.2 Proposal of GRS

The proposal of the GRS „Safety requirements for the disposal of high-level radioactive waste in deep geological formations“ is aimed to prove that the radioactive waste will be contained within the isolated rock-zone for a time-frame of one million years: Only a small part of the radionuclides enter the biosphere within one million years. GRS proposed four indicators to furnish proof of the isolation of the repository. By means of these indicators it can be demonstrated that the radiological constraints are met.

The demonstration of the compliance with the radiological protection goals as an indicator for radiological impact on man and environment should be limited to time period of approximately 1000 years. Demonstration can be done as indicated in the next section. After 1000 years the significance of the dose calculated in the same way mutates and gradually becomes an indicator of the isolation of the waste repository.

4.2.2.1 The hypothetic biosphere scenarios

During the time after the closure of the repository many different environments will develop at the site. Therefore, a range of biosphere scenarios (hypothetical stylized environments) must be described. The characteristics of the environments associated with climate states which are known to have occurred at the site during the last million years must be put together. Further biosphere scenarios should describe the consequences of the climate change which is presently occurring. In the case of a waste repository near the sea side the influence of the lowering of the coastal line should be investigated. Transitions between different climate states form the environments which are the most difficult ones to model.

The hypothetical biosphere scenario is the scenario where the public can be subjected to the highest radiation dose. This biosphere scenario is called “reference biosphere.”

The description of each biosphere scenario must be consistent. The influence of temperature and precipitation on the geosphere-biosphere transition zone, hydrology, topography, soil, plants and animals must be modelled. The influence of past climate states on subsequent biosphere scenarios must be described. Note that also the velocity of the change is an important feature of transitions.

4.2.2.2 The geosphere-biosphere transition zone

The modelling of the entrance of radionuclides into the biosphere is crucial.

Some climate states have an influence on the radionuclide concentration in the groundwater at the geosphere-biosphere interface.

- Boulders and stones carried on the undersurface of a glacier together with melt water can dig deep canyons into the landscape above the waste repository by which action the thickness of the overlying rock and soil layers will be weakened. Then the radionuclide concentration in the geosphere-biosphere interface is greater because the decay-time until the entrance into biosphere is shorter than without this disturbance.
- During an ice age without glaciers at the site soil temperatures can go to very low values causing permafrost. Ground water mobility beneath the permafrost layer might be influenced with the result that after the thawing of the permafrost the radionuclide concentration in groundwater is higher than without this impact.

Natural geosphere-biosphere transition zones are wetlands and springs, artificial ones are wells. Climate has an influence on the probability of the kind of transition zone.

The natural transition zone – wetlands – is possible under almost every future climate condition expected for Germany. The contribution of wetlands to human nutrition is low because of low productivity. The population density to be postulated is therefore low with the consequence that the region from which the necessary food must be gathered is large. This reduces the possible radionuclide concentration to sub-maximum values.

The existence of a well is less probable under cold and humid climate conditions than under other climate conditions. The reasons for this assumption are:

- There will be enough surface water for the population
- There is little need to irrigate fields, but it is possible that the community has greenhouses which need to be irrigated.

The population density of game can only be low because of the low net production rate of plants; moreover, most animals are migratory or hibernate. Both habitudes inhibit the all-season feeding of wild animals on plants grown at the site. Cattle (and sheep, goats, reindeers) would need great pastures because of the low productivity, too. It should be checked whether a population of thirty people (see below) can survive on the base of the food influenced by ground water with maximum radionuclide concentration.

4.2.2.3 Climate specific habits

Every reference group assumed in the context of waste repositories in the far future is hypothetic. The reference groups must be constructed in a manner that they fulfil the standards set by ICRP /ICR 06/. This makes them at least possible.

- The habits must be reasonable – that is, the hypothetic population must survive for long times on the base of the food which their environment is able to offer.

- The habits must be sustainable – that is, the hypothetic population must not over-exploit and damage their environment.
- The habit data should be homogenous – that is, mean values should be chosen, not the maxima.
- In every biosphere scenario it should be assumed that the people get all their food from the site.

Human beings must be able to earn their livelihood in every biosphere scenario. They plough and irrigate fields; they breed plants and raise cattle or other animals, or they gather food from natural or semi-natural places. Doing this, man changes the natural environment. This is a contradiction to the demands given above, but the more fertile environment is sustainable for a long period.

The qualitative and quantitative composition of food depends on what a scenario is able to deliver. The caloric intake of humans is dependant on age and gender. The composition of food can be made up using investigations about eating habits and the climate-related possibilities to produce food in regions, where the postulated climate is actually present.

The possible food intake depends on the assumptions about agricultural technology. It is assumed that no new agricultural technologies are implemented. The technologies assumed are: Farming and gardening, plant production using green-houses and hydroponics, gathering food in wetlands, animal husbandry, hunting and fishing.

Biosphere scenarios with wetlands are mostly biosphere scenarios where people gather food on semi-natural or natural surfaces. Wetlands can also be used as a temporary pasture if the climate is not too cold. In temperate and warm climates it is possible to drain the area and produce the whole range of agricultural products typical for the assumed climate, but in this case parts of the radionuclides get lost with the drainage. Furthermore, the former wetland, especially the soil, changes rapidly with time. This scenario is not sustainable.

Well scenarios offer the possibility of extensive agriculture by irrigation, if water shortage is the reason for low productivity. Possible pathways are terrestrial food ingestion and external radiation while staying on irrigated fields and pastures. Inhalation plays a minor role. The possible range of plants and animals is given by the assumed climate.

4.2.2.4 Representative individual: size of the hypothetical reference group, habits

The ICRP has replaced the critical group concept by the concept of the representative person. This person lives in the hypothetical scenario which leads to the highest dose. This person has the typical habits of the representative group /ICR 06/.

The hypothetic reference group may not be too big because the people shall use the water with the highest radionuclide concentration. On the other hand, the assumed communities may not be too small in order to be sustainable.

As a compromise we suggest that the hypothetical reference groups should consist of about thirty people. According to the significance of the dose calculated, during the first 1000 years the reference group consists of people of all ages. Later, when the dose is only an indicator of the isolation capacity, male adults form the reference group.

The amount of food which can be produced per hectare in a given biosphere scenario further delimits the possible number of people living in a biosphere scenario; this will not cause a problem in well scenarios, but in wetland scenarios this should be checked. The solution to this problem can be the assumption of average radionuclide concentrations in the groundwater under a greater surface area.

4.2.2.5 Transfer factors, concentration factors, dose factors

All these factors should be best-estimate factors. It should be taken account of the dependency on ecological factors. The factors are being issued by ICRP and IAEA and in many working groups.

4.2.2.6 Irrigation rate

Climate-specific irrigation rates are crucial because in well-scenarios irrigation is the most important factor which determines the radionuclide concentration in soil. They can be deduced using the formula /BEC 03/:

$$Irr_M = Temp_M * X - Prec_M$$

Where

Irr_M sum of monthly irrigation in mm/month

$Temp_M$ monthly mean temperature in °C

$Prec_M$ sum of monthly precipitation in mm/month

X empiric factor in mm/month/°C

The value for X allows for the season-dependant necessities of the plants. In reality the factor is plant-specific. Acceptable values for temperate climates are:

Jan, Feb, Mar	2	July	5
April	3	Aug	5
May	5	Sept	3
June	6	Oct, Nov, Dec	2

If the mean temperature $Temp_M$ is below 5 °C, X is set 0. The high value in August allows for a second planting of some crops, especially in the garden. The weather data should be taken from analogue weather stations of today. In warmer climates the factors X will differ somewhat, because the vegetation period begins earlier and a second harvest will be possible for more crops, in colder climates the vegetation period is shorter.

4.2.2.7 Radionuclide movement in soil

Radionuclide movement in soil is crucial because the movement determines how long the radionuclides stay in the soil; in case of a steady administration by irrigation, the loss rate determines the radionuclide concentration in soil after reaching steady-state conditions.

Some facts about the loss rate are clear: there is vertical and horizontal movement and plant uptake.

Horizontal movement leads to an irrevocable loss of radionuclides from the soil. These radionuclides enter a river, which might be used for fishing. This form of erosion is determined by precipitation, orographics, and canopy and soil structure.

Vertical movement is influenced by soil composition and structure, earthworms and other animals in soil, precipitation, temperature and other factors.

Loss by plant uptake need not be considered because a sustainable agriculture will use organic fertilizer made of organic farm waste. The take-out by birds and other animals is neglected.

Unfortunately, up to now there is no method to clearly assign correct parameter values for the long-term movement velocity to climate parameters. The topic of radionuclide movement in soil can best be handled using probability calculations. The confidence interval for this parameter should be the 95-percentile. It should be taken into account that there is some dependency of the root uptake from the radionuclide mobility in soil. This effect decreases the bandwidth of radionuclide concentration in plants.

4.2.2.8 Non-human biota

Non-human biota is an integral compound of every biosphere scenario.

Contrary to the approach used for humans, the endpoint calculated will be the risk, because of the great differences in radiosensibility of different biota. The effects to non human biota should be negligible.

It can easily be ruled out that plants and animals which are constituents of human nutrition be at risk, because the dose constraints of humans could not be adhered to if the radionuclide concentration in nutritional plants and animals is high enough to cause a disadvantage to them.

The risk of non-human biota is determined by the dose and the radiosensibility. The terrestrial habitat with the highest radionuclide concentration is the soil. Therefore animals and plants living in soil are supposed to be subjected to the highest doses. The biota whose radiosensitivity is highest is a mammal. The most important mammal living in soil is the mole.

The aquarious habitat with the highest radionuclide concentration is the sediment. Radiosensitive animals which pass part of their life in or on sediment are fish breed such as the lamprey larvae.

Dose and risk to moles and fish breed should be determined. The outcome will be that the dose is higher than the dose to humans in the same biosphere scenario, but that the space between the corresponding risk and the acceptable risk is higher, too. GRS feels that it is not necessary to calculate doses and risks for non-human biota for every biosphere scenario, but it should be calculated for the reference biosphere.

4.2.3 Proposal of the BMU

BMU favours in “Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste – Draft” the individual lifetime risk as a constraint for the assessment endpoints /BMU 08/. Lifetime risk will be calculated from doses using the dose-risk conversion factor.

5. References

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A6 NDA (United Kingdom)

1. Introduction

This document gives an overview of the NDA approach to the treatment of the biosphere in performance assessments which forms part of the NDA capability to carry out a performance assessment to support the different stages in the development of a geological disposal facility. A recent review of the overall NDA approach to biosphere assessment is given in [1].

2. Regulations and guidelines

The biosphere research programme is guided by the need to conform to regulatory requirements and take due account of international best practice. In the UK the Radioactive Substances Act 1993 (RSA93) [2] is the regulation that would apply to radioactive discharges from a closed repository. This legislation is quite general, and applies to a great variety of situations where there may be discharges of radioactivity to the environment. Relevant agencies have therefore published guidance, known as the 'Guidance on Requirements for Authorisation' (GRA) [3], which outlines how an application for an RSA93 authorisation would be judged in the specific case of land based disposal of solid radioactive waste (a repository). The GRA is being revised and the existing single document split into two documents, one dealing with near-surface disposal and the other dealing with deep geological disposal. Draft versions were issued for public consultation in May 2008 and the final versions are expected to be published shortly.

Dialogue with the regulators is an important part of the NDA's work and recently the scrutiny of our work by the Environment Agency's Nuclear Waste Assessment Team included a review of our approach to the treatment of potentially exposed groups (PEGs).

3. Terminology

NDA's approach to terminology is to try to avoid the use of jargon wherever possible. Where specialist terminology is required, NDA tries to use existing terms wherever possible, for example terms that are defined in national regulations or which are defined internationally, for example by the IAEA or NEA. In these ways NDA seeks to avoid introducing 'new' terminology.

4. Treatment

4.1 Definition of biosphere

The biosphere is the surface and near-surface environment. The biosphere is not considered as a barrier to radionuclide releases, rather it is a receptor for such releases. The main components of the biosphere normally considered by the NDA, are:

- Surface fresh waters (streams, rivers and lakes);
- Surface water catchments, including the upper part of the bedrock, soils, sediments, plants and animals;
- Estuaries, including tidal waters, unvegetated and vegetated sediments, and salt marshes;
- The marine environment, including foreshore, nearshore and offshore zones and their sediments;
- The atmosphere.

4.2 Evolution of the biosphere

The evolution of the physical biosphere encompasses climate change and landform changes, which includes changes to sea level, river courses and surface water bodies. Many of the features of the biosphere, for example sea level, climate and surface topography, provide boundary conditions for the groundwater flow field. Therefore, the evolution of the biosphere can have a direct impact on groundwater flow and hence on the migration of radionuclides via the groundwater pathway.

The NDA considers the evolution of the physical biosphere in terms of three timescales: the short term (i.e. up to hundreds of years after disposal facility closure); the medium term (i.e. between hundreds to tens-of-thousands of years after disposal facility closure); the long term (i.e. times of one hundred thousand years or more after closure) [4].

Because of the long timescales involved, it may not be possible to predict what a future biosphere might be like and how it might evolve over time. Best available scientific projections predict that much of the UK will remain ice-free for 200,000 years and that landforms (other than at coastal margins) will evolve only very slowly. Broad predictions on how landforms may change in the UK under specified climate evolution scenarios are given in [5]. In long-term safety assessments the biosphere is often represented by stylised scenarios, based on the understanding of current and past environments. The use of stylised scenarios in long-term safety assessments is also the subject of international discussion and advice on the formulation of biosphere scenarios has been developed through international co-operation during the IAEA BIOMASS [6] programme in which the NDA participated.

In addition, the treatment of the evolution of the biosphere in performance assessments may also change and develop over time in response to site investigation studies and changing regulatory and stakeholder requirements.

4.3 Potentially Exposed Group

UK regulatory guidance requires us to determine the radiological risk from the radionuclides entering the biosphere to a representative individual member of the potentially exposed group (PEG) at greatest risk [1]. For example, the PEG adopted for the groundwater pathway in a recent Nirex† assessment [7] was a farming community making maximum use of local resources. It was assumed that the members of the PEG lived in the area where there is the highest concentration of radionuclides discharging to the biosphere from the geological disposal facility via the groundwater pathway and the individuals were exposed to repository-derived radiation throughout their lives; hence it was appropriate to regard them as adults. Members of the PEG were assumed to derive all their foodstuffs locally and obtain all their water requirements from a well which had been drilled into an aquifer in the area surrounding the disposal facility.

Members of the PEG were assumed to be exposed to radiation via the following routes:

- Ingestion of crops grown in soil infiltrated by groundwater discharging from the repository and irrigated with water from the well;
- Ingestion of milk and meat from animals grazing in the discharge area and watered with well water;
- Ingestion of soil (as a contaminant of foodstuffs such as open-leafed vegetables);
- Drinking water (from the well);
- Ingestion of freshwater fish (from streams and rivers in the discharge area);
- Inhalation of dust (e.g. soil);
- External exposure from contaminated land.

Note that exposure resulting from human intrusion in the form of exploratory drilling for natural resources, and from the generation of gas in the disposal facility are considered separately from the groundwater pathway in the treatment of the biosphere in performance assessments.

4.4 Generic/site specific biosphere models

At the present time the process of identifying a potential site for a geological disposal facility in the UK is at an early stage. The candidate sites will be determined by the Government's "*Managing Radioactive Waste Safely*" (MRWS) programme which considers both voluntarism and geological suitability in deciding a way forward. Although Nirex had performed site specific assessments in the past in the UK [8], because a site and design have not yet been chosen, the NDA is currently developing a generic assessment methodology which includes the treatment of the biosphere. A generic treatment of the biosphere should be able to represent any site within the UK, so it needs to cover a wide range of environmental and societal conditions.

† United Kingdom Nirex Limited (Nirex) was integrated into the NDA as the Radioactive Waste Management Division (RWMD) in March 2007

Once a specific site has been selected it will be necessary to tailor the biosphere characteristics so that they are sufficiently representative of the area. The specific radionuclides, the time at which they emerge and the nature of the interface between the geosphere and the biosphere will be strongly dependent on the geological context of the site in question. Site investigations will result in spatially and temporally extensive, site-specific data such as hydrogeology, local biota, land use and human habits and behaviour that will feed back into the selection of the key biosphere model processes.

5. Applications and experience

The UK biosphere programme has been at the forefront of international biosphere studies for radioactive waste management since the late 1980's and a large volume of information now exists to support our assessment approach. The scope of the studies carried out to-date includes literature reviews, laboratory and field experimentation, and numerical modelling studies of biosphere system components

The NDA biosphere programme has close links with work carried out in overseas radioactive waste management organisations through jointly funded projects and EC supported programmes. International fora such as BIOMASS [5], BIOCLIM [9] and BIOPROTA [10], have provided an opportunity for the NDA to collaborate in biosphere assessment studies. Such collaboration has helped the NDA (and Nirex earlier) to build on experience gained by other countries in addressing similar biosphere assessment issues and enables the NDA approaches to be benchmarked against others and effectively receive peer review by international experts. Participation also helps to ensure that the NDA is kept informed of the latest developments in international radioecological research and biosphere characterisation. In addition, the NDA has carried out comprehensive research studies in collaboration with several UK academic institutes.

6. Developments

Future biosphere conditions are difficult to predict and much of NDA's ongoing work is to ensure that models encompass the range of conditions that could reasonably be expected to occur. The NDA biosphere programme has been divided into a number of project areas which are the subject of ongoing investigation:

- Climatology (evolution of climate and its impact on accumulation of radionuclides);
- Geomorphology (landform evolution);
- Ice sheet modelling;
- Near-surface hydrology and radionuclide transport;
- Soil-plant radionuclide transfer and uptake into the food chain;
- Description of potentially exposed groups (the specification of PEG's has been

reviewed by the Environment Agency and that review, together with guidance from the ICRP [11] on characterising the representative person will be taken into account in future work);

- Nuclide specific research, e.g. C-14, Cl-36, Se-79 and I-129.

The NDA has also been keeping abreast of the work to establish radiological protection standards for non-human biota by the EC-supported FASSET, ERICA and PROTECT projects.

7. Conclusions

We feel that our treatment of the biosphere is in line with current regulatory and international developments, and is appropriate for use in the generic Disposal System Safety Case framework which will support the different stages in the development of a geological disposal facility in the UK. The approach will be developed further as the site selection process progresses.

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A7 NRG (Netherlands)

note

to :	Topic coordinator 'Modeling of the Biosphere'
from :	J. Hart…………………Petten/015.017
copy :	J.B. Grupa, A. Poley, T.S. Schröder
date :	24 February 2009
reference :	21952/09.93898 RE/JH/MH
subject :	NRG Contribution to topic 9 'Biosphere'

Section 1: Background/ Introduction

In the late 1980's the VEOS study (Safety evaluation of disposal concepts in rock salt) has been performed in the Netherlands [1, 2, 3, 4]. The aims of this study were the evaluation of the post-closure safety of some possible disposal concept and the determination of relevant characteristics. VEOS used a scenario approach followed by a deterministic consequence analysis and several deterministic sensitivity studies. The analyses resulted in a number of release scenarios with estimated exposure. For some scenarios with a relatively high exposure the probability of occurrence was also calculated. The resulting risk defined as the product of this probability and the health effect of the exposure was below the risk levels set in neighbouring countries and the IRCP.

In the early 1990's a generic probabilistic safety analysis (PROSA, [5]) of the Dutch generic reference disposal concept has been performed. The PROSA study had two equally important aims, viz. the determination of the radiological effects on humans and the derivation of safety relevant characteristics of a disposal concept for radioactive waste. These characteristics have been derived from sensitivity analyses of the radiological consequences of some disposal concepts in rock salt formations. The PROSA study was restricted to the safety in the post-closure period.

The methodology used for the scenario selection was based on the idea that a repository is a multi-barrier system which' evolution can be characterized by the state of its four barriers:

1. the engineered barriers
2. the isolation shield of salt around the repository
3. the overburden, and
4. the biosphere itself

In addition it was assumed that the first three barriers could have two possible states: i) present and ii) by-passed. This implies that there are 8 possible states of the multi-barrier system. For each barrier state a number of FEPs can then be found which are defining the state of the barrier. These primary FEPs were used to define the scenarios. The remaining FEPs were considered as "secondary" FEPs and described the transport of the nuclides. The

methodology implied that each FEP has to be judged carefully in order to establish whether it is of importance and if so how the role will be and in which part of the repository the FEP applies.

The PROSA study used a systematic approach to scenario selection that ultimately led to a set of representative scenarios that covered all aspects relevant for the long term safety. The method used a FEP catalogue to show comprehensiveness of the obtained set of scenarios.

Two different types of calculations were performed: a probabilistic analysis of the nuclide transport for the subrosion scenarios, and a deterministic analysis for the water intrusion scenarios. The sensitivity analysis aimed at finding the input parameters having the strongest influence on the exposure, whereas the uncertainty analysis aimed to quantify the output variability.

The PROSA study was carried forward and extended in the CORA program [6], in which the options for retrievable storage and disposal of radioactive waste in the Netherlands were investigated, both for a salt-based and clay based repository.

Section 2: Regulatory requirements and provisions

A central policy consideration of the Dutch Government is a stepwise approach to finding waste management options that are feasible, suitable and acceptable, in both technological and societal respects, is. Based on three policy documents, published respectively in 1984 [7], 1993 [8] and 2002 [9], the current strategy can be summarized as follows:

- long-term interim storage in purpose-built stores at COVRA, the Dutch site for surface storage of radioactive waste, for at least 100 years;
- ongoing research, preferably in international collaborative programs;
- eventually retrievable[4] deep geological disposal.

There are presently no regulatory requirements and provisions that directly relate to the topic of “biosphere”. Indirectly however several laws regulate the public against hazardous materials. For example, with regard to nuclear energy, the purpose of the Nuclear Energy Act [10] is to regulate (Article 15b) the protection of people, animals, plants and property. In addition a number of decrees have also been issued containing additional regulations. The most important of these in relation to the safety aspects of nuclear installations are:

- the Nuclear Installations, Fissionable Materials and Ores Decree (Bkse),
- the Radiation Protection Decree (Bs).
- the Transport of Fissionable Materials, Ores, and radioactive Substances Decree (Bvser).

[4] Retrievability means the deposition of radioactive waste in a way that it is reversible for the long-term by proven technology without re-mining.

The Nuclear Installations, Fissionable Materials and Ores Decree regulates all activities (including licensing) that involve fissionable materials and nuclear installations. The Radiation Protection Decree regulates the protection of the public and workers against the hazards of all ionising radiation. It also establishes a licensing system for the use of radioactive materials and radiation emitting devices, and prescribes general rules for their use. The Transport of Fissionable Materials, Ores and Radioactive Substances Decree deals with the import, export and inland transport of fissionable materials, ores and radioactive substances by means of a reporting and licensing system. The Nuclear Energy Act and the above mentioned decrees are fully in compliance with the relevant Euratom Directive laying down the basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation. This Directive (96/29/Euratom) is incorporated in the relevant Dutch regulations.

Section 3: Key terms and concepts.

The Dutch concept for an underground facility for disposal of radioactive waste is still being developed. In the Netherlands attention mainly has been focused on suitable salt domes in the northern part of the country and clay layers in the south. Since the Dutch radioactive waste will be stored in the COVRA (Central Organization for Radioactive Waste) surface interim storage facility for a long time (up to some 100 years) the determination of a suitable concept is at present not a critical issue. For the safety assessment of an underground repository for radioactive waste the PROSA methodology was developed for the determination of scenarios.

There are currently no actual plans to transfer this waste to a national deep geological repository. However there have been several options investigated in the Netherlands, mainly within the above-mentioned PROSA and CORA programmes. Both the options of disposal in rock salt (cf. Figure 1) and in Boom clay, which are both abundantly present in the Netherlands, were investigated.

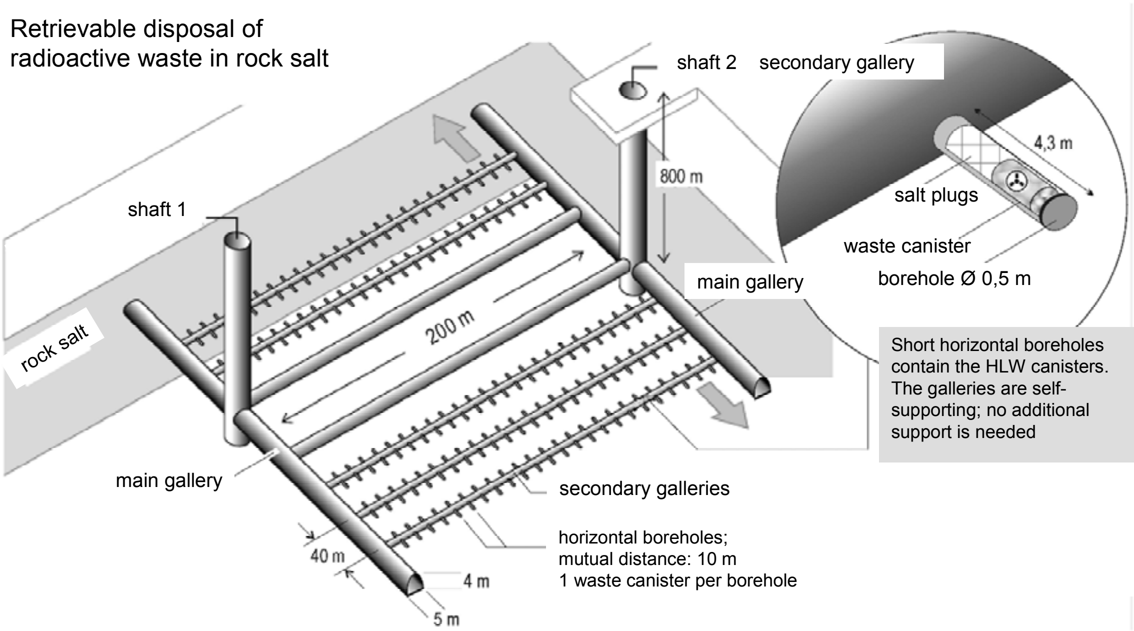

Fig. 1 Rock salt based option for retrievable disposal of radioactive waste [6]

Section 4: Treatment in the Safety Case

Section 4.1.1: Methodology

The modelling strategy in the Dutch PROSA study has been described extensively in the PROSA Final Report [5], and summarized in NRGs contribution to the PAMINA WP1.1 Topic 7 "Modelling Strategy". In the present section the modelling of the biosphere that has been carried out within the PROSA study is summarized.

Overview of the PROSA Methodology

In the PROSA study a scenario type of analysis has been followed by a probabilistic consequence analysis. This implied the following steps:

1. scenario selection, (see Topic 6 'Evolution of the Repository System')
2. determination of the probability of the scenarios,
3. determination of the calculation model,
4. determination of the parameters and their probabilities,
5. dose calculation,
6. reliability assessment (see Topic 7 'Modelling Strategy')

7. sensitivity and uncertainty analysis.

The scenarios were screened on the basis of the results of the previous VEOS study and arguments related to the availability of detailed models. The remaining list of scenarios to be analysed consisted of 2 subrosion scenarios, 4 groundwater intrusion scenarios, and 1 human intrusion scenario.

To facilitate the consequence analysis of these scenarios for each compartment in the transport model a list of FEPs has been developed that were taken into account. These FEPs have been accounted for in the three compartments of the transport and exposure model or in the data and resulted in a set of calculated dose rates for the different cases.

Calculational Tools – EMOS Computer Program

The computer program EMOS (Endlagerbezogene MOdellierung von Szenarien) has been developed by GSF, Germany, for assessing the consequences of the release of radionuclides from a repository in a salt formation, the subsequent nuclide transport through the geosphere, and the release of the nuclides into the biosphere [11]. EMOS is a so-called lumped-parameter code which means that within a chosen control volume, spatial differences of thermal hydraulic variables, like fluid density, concentration, and temperature, are neglected.

The code package can be used for a deterministic as well as a probabilistic consequence analysis. The original code contains three separate modules representing the three different compartments in a repository system:

- REPOS; In REPOS (REPOSitory) a complete disposal mine with all technical barriers can be modelled. REPOS has models for the release of radionuclides from different types of containers and waste forms.
- MASCOT - MASCOT analyses the nuclide transport in the geosphere. The code calculates the time dependent two or three dimensional nuclide transport in an infinitely extended porous and homogeneous continuum.
- EXPOS calculates the radiation ExPOSure in terms of maximum dose rates for individuals or groups based on dose-conversion factors.

Optionally, the TROUGH module can be replaced by MASCOT, a similar module solving the nuclide transport equations in the geosphere. The MASCOT module solves the time-dependent two- or three dimensional nuclide transport in an infinitely extended porous and homogeneous continuum.

The most relevant physical and chemical effects influencing the transport of radionuclides are modeled with EMOS. These features are: temperature distribution, convergence of excavations, permeability of backfilled excavation, dams, seals, gas production by radiolysis and corrosion, diffusion, sorption, and radioactive decay and in-growth. The models for the transport of radionuclides include: transport by density differences, gas transport, transport by pressure gradients, and transport by diffusion.

Submodel of biosphere

In the calculation of radiation doses to humans for long-term safety assessments several difficulties arise. Human behaviour affects, to a great extent, the biosphere and the transport and accumulation of radionuclides in the environment, along with the various exposure pathways. On the time scales involved in a safety assessment of the disposal of radioactive waste, predictions on human behaviour are speculative. Hence, defining a biosphere to be used for these assessments is hardly possible. It is therefore generally accepted that biosphere calculations are to be interpreted as an indication of possible radiation levels in the future, rather than as a prediction. Since it is not possible to predict the future development of mankind, the level of technology of the human populations usually is assumed equal to the present-day level of technology.

In order to determine the consequences of the release of radionuclides to the biosphere the resulting radiation dose to humans has to be calculated with a model of the biosphere. For the PROSA project the biosphere module EXPOS of the EMOS model was selected for this purpose.

The calculation of the radiation dose in the module EXPOS is straightforward. The output of the groundwater module (MASCOT) is multiplied with a nuclide specific dose conversion factor to give the radiation dose to humans. For PROSA, the groundwater module calculates the flux of radionuclides into the biosphere in the units Bq/a. The radiation dose to humans in Sv/a is calculated for every nuclide separately by multiplication of the flux to the biosphere (in Bq/a) by a nuclide-specific dose conversion factor.

As the transport time of the radionuclides in the biosphere is short with respect to the transport time through the geosphere it is necessary to take short-lived daughter nuclides also into account in the biosphere model. In the module EXPOS the concentration of the short-lived daughter nuclides is calculated from the concentration of the parent nuclide. In this calculation equilibrium of activity between the parent and daughter nuclides is assumed. This equilibrium however applies only to the total amount of activity, i.e. to the activity of the radionuclides in solution in the groundwater and the radionuclides adsorbed to the soil. The amount of absorption of nuclides on host rock is calculated be means of the retardation factor/distribution coefficient.

The calculation in the module EXPOS is very simple and straightforward, with the advantage that little computing time is required. However, the modelling of the biosphere is focused on the determination of the dose conversion factors DCF_i (in (Sv/a)/(Bq/a)).

As a consequence of the probabilistic approach of PROSA distributions of the dose conversion factors are needed instead of single values. Hence a probabilistic modelling of the biosphere is required. For this purpose the biosphere model MiniBIOS is used, a simplified version of the model BIOS [12]. In this model several release points of nuclides into the biosphere are possible, like the discharge of contaminated groundwater in a river. Arable land is assumed to be situated near the river and the river water is used as drinking water and as irrigation water. Due to the use of this irrigation water crops are contaminated by direct interception of irrigation water and by uptake of radionuclides from the soil. Cattle products are contaminated by the use of the river water as drinking water and the use of forage, contaminated by the irrigation water. In Figure 5.12 a general overview of the different exposure pathways is given.

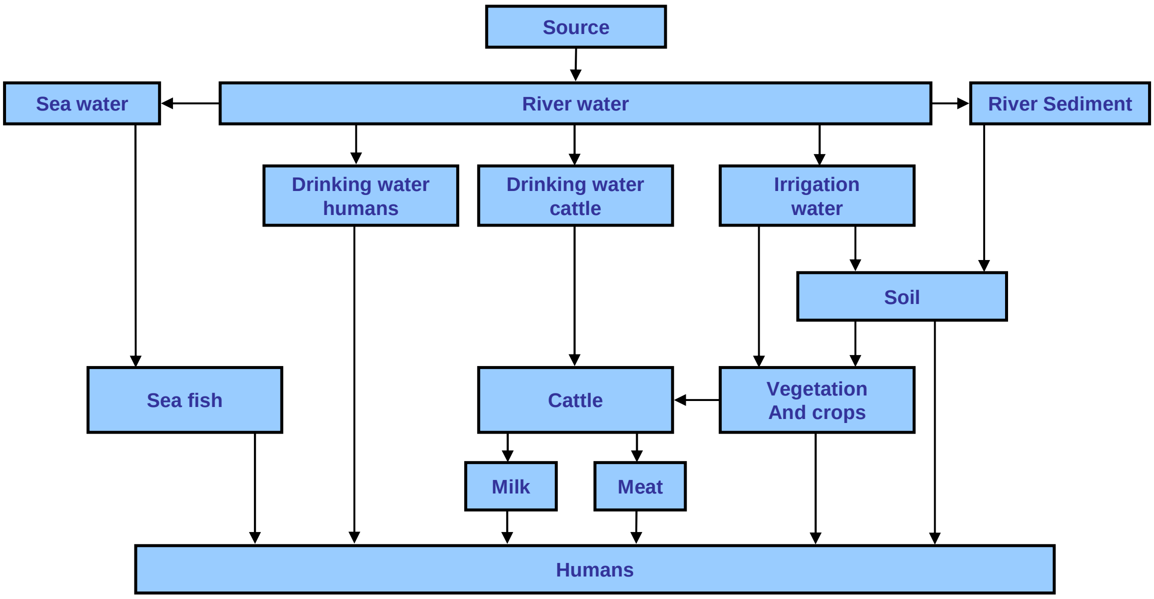

Fig. 1 Contamination pathways for the PROSA biosphere model. The contaminated water is either river water or groundwater

The radiation dose calculations were performed for members of three critical groups: an arable farmer, a cattle farmer and a sea fisher. The members of these populations are mainly distinguished by their food consumption pattern. In the scenario considered in PROSA the results for the arable farmer and the cattle farmer were found to be identical, and these results were used in the comparison.

The dose calculations with EXPOS require dose conversion factors as input data. For the PROSA analyses dose conversion factors found in literature were used [13]. These dose conversion factors were determined with the ECOSYS model, and were based on the use of contaminated groundwater as drinking water and as irrigation water. In the scenario considered in PROSA, radionuclides were assumed to be released in the river. The concentration of the radionuclides in the river water was calculated with the BIOS model.

For the calculation of the dose conversion factors for EXPOS a dynamic environmental transfer model of the biosphere was used. The radiation dose calculated with EXPOS depends on the time period of the model calculation, since the radionuclides accumulate in the soil in time, whereas the required dose conversion factors for EXPOS are constant in time. This problem was resolved in the PROSA study by assuming steady-state conditions. Equilibrium values of the radionuclides in the soil were then used to calculate the radiation dose. When radionuclides with long-lived daughter nuclides, like U-238, are released, equilibrium is only reached after very long time scales. However, it is unlikely that the same area of land will be irrigated and used for agricultural purposes for millions of years. It has therefore been decided to define the dose conversion factors for EXPOS as the radiation dose to humans following a fixed time period of accumulation in the soil. Based on the occurrence of periods of glaciation in the Netherlands, a time period of 10,000 years has been chosen.

Sensitivity and uncertainty of the dose conversion factors

In the PROSA study, the model MiniBIOS [12] was used to determine distributions of dose conversion factors for radionuclides released into the biosphere via groundwater discharge.

The total number of parameters in the model MiniBIOS is 134. Taking all these parameters stochastic into account would require a large calculational effort. Furthermore, it was not considered worthwhile to put a large research effort in the determination of the distributions of parameters, not important in the model results. Therefore it was decided to identify those parameters, that are sensitive and/or important sources of uncertainty.

Using a preliminary set of data, an uncertainty analysis of the model MiniBIOS was performed. From this analysis it was concluded that 29 parameters would have a significant influence on the calculated dose conversion factors, see Table 1.

Table 2 Input parameters of MiniBIOS (stochastic parameters in bold)

Nuclide-specific data	decay constant, dose per unit intake or per unit exposure, **concentration factors** (soil → crop, pasture → animal water → fish), **sedimentation factor, distribution coefficient** in soil and sediment, gamma energies, weathering rate
Biosphere data	**depth** and **volume** of the various compartments, release position, **flow** of river and sediment, interception factors, cropping rate, **sediment transfer to land, erosion rate, irrigation, rainfall**, groundwater velocity, **diffusion coefficients** in soil, sediment and water, **bioturbation coefficient** in soil and sediment, **suspended sediment load**, **density** and **porosity** of soil and sediment, crop yield, dust level
Human data	human consumption rates, inhalation rate, occupancy time
Release data	time-dependent flux

The software package UNCSAM (UNCertainty analysis by Monte Carlo SAMpling techniques) [14]] was used to perform an uncertainty analyses on MiniBIOS.

Method and parameter values

The calculations of the dose conversion factors with MiniBIOS were divided into two parts.

1. First, the inventory of the radionuclides in the boxes of the river and marine compartments was calculated.
2. Second, from the inventory in the surface water box, surface soil box and marine water box, the dose conversion factor including several contamination pathways was determined.

The inventory of the marine water box was only of importance in the exposure pathway ingestion of sea fish. Since the contribution of this pathway to the dose conversion factor was small and only taken deterministically into account, the marine exposure pathways were not considered in the PROSA project. As a result, the uncertainty analysis was also divided into two parts. First, the most important parameters which determine the radionuclide inventory in the water and surface soil box were determined. The inventory of the radionuclides in the other boxes was not of direct importance for the determination of the dose conversion factors. Second, the most important parameters within the various contamination pathways were determined.

Inventory calculations

The parameters used in the calculations of the inventory in the terrestrial and marine boxes of MiniBIOS are all included in the so-called transfer coefficients (cf. Fig. 3). Most of the transfer coefficients are a function of the respective depths of the respective layers, flow parameters and retardation coefficients [5]. Most of these parameters were used in a deterministic way int the MiniBIOS calculations, whereas for several parameters distribution functions were taken into account.

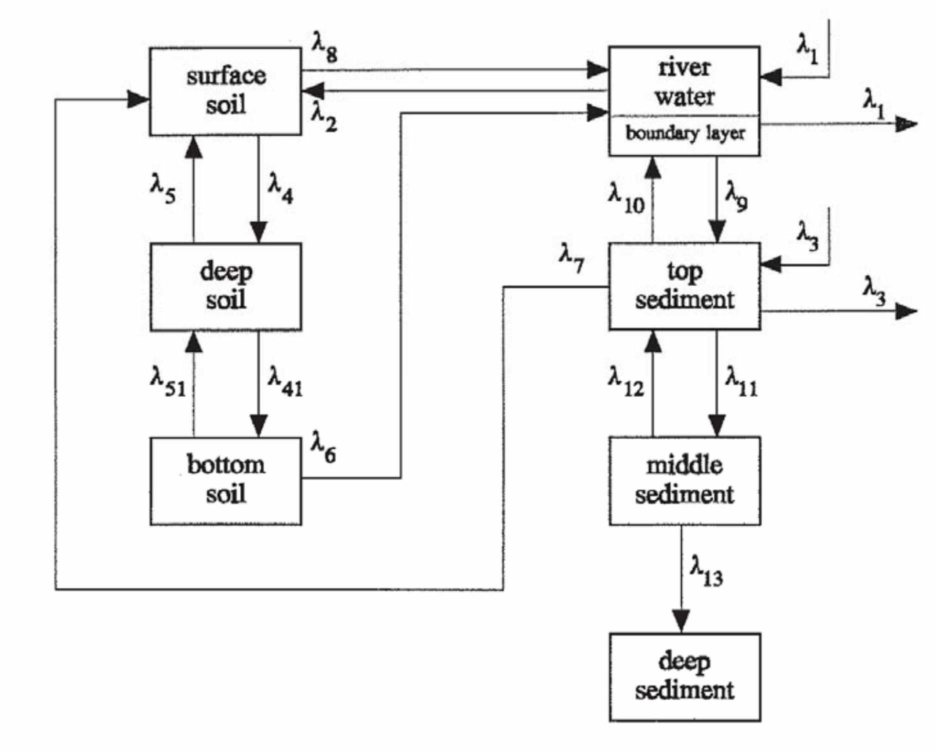

Fig. 3 Structure of the terrestrial component in MiniBIOS

The uncertainty analysis of the inventory calculation was executed for the inventory after 10,000 years of a continuous release of 1 Bq/a, since the dose conversion factors were calculated for this time. It was assumed that after this period concentration equilibrium in the surface water and surface soil was reached. The results of the analyses were only valid for the 10,000 years time period of release.

Dose conversion factors

Distributions of the dose conversion factors were calculated for each nuclide which might be released into the biosphere. Each distribution was the result of 400 individual runs of MiniBIOS. Tests showed that a larger number of runs would not change the calculated distributions significantly. For the deterministic calculations the 50 percentile value of the calculated distribution was taken as the dose conversion factor.

Dose calculations

The most important parameters inside the various contamination pathways were determined. Parameters specific related to the ingestion of sea food, inhalation and external radiation were taken deterministically into account in the calculations of the dose conversion factors. Therefore, only for the ingestion of water, fish, crops and animal produce, the most important parameters were determined. It was expected that both the concentration in the surface water and surface soil would contribute strongly to the uncertainty in the dose conversion factors. Therefore, the results of the uncertainty analyses have only been determined for these two model compartments.

Assumptions for the biosphere

In the case of diapirism without subrosion it is possible that the repository will reach the surface level. In that case the biosphere will consist of a salt desert in which vegetation is assumed to be absent. It is very unlikely that people will live continuously on the rather small repository field (about 0.5 km^2) since they will have to live on crops grown elsewhere and the circumstances outside this field are probably better. In the PROSA project however, the most conservative option was chosen. The dose conversion factors were calculated for an adult who is assumed to live continuously on the repository field without protection against radiation or dust. In addition no protective layer on the repository field as a result of deposition of uncontaminated particles from outside was considered. Further, a uniform distribution of the nuclides in the repository field and an equal resuspension rate of glass and salt particles were assumed.

Processes included were therefore the inhalation of radioactive particles and external radiation. Uncontaminated water and food were assumed to originate from outside the repository field because of the then dry climate and saline conditions.

The external radiation due to gamma and X-ray emission was calculated at a level of 1 m above the ground for nuclides present in the uppermost 30 cm of the soil. The contribution of external radiation due to contamination in deeper layers appeared to be small and could be neglected. The contributions of short-lived daughters have been included, and corrections for attenuation and build-up in the soil and air have been applied. For the calculation of the inhalation dose, dust particles with an activity median aerodynamic diameter of 1 µm have been assumed. Parameters included in the external radiation and inhalation pathways are summarized in Table 2.

Table 3 Parameters included in the external radiation and inhalation pathways of the PROSA biosphere model

external radiation	gamma and X-ray energies, dose factor per unit exposure, residence time
inhalation	dust level, dose factor per unit intake, inhalation rate, residence time

The inhalation rate corresponds with light activity. The dust level used is assumed to be twice the normal median dust level in the Netherlands. Detailed information is given in [36]. The other parameters are either well known or there is international agreement on the value to be used.

A deterministic approach is chosen as the effect of less conservative assumptions can easily be calculated. For example, residence for some time outside the repository field results in a total dose reduction by the same relative amount. A reduction in the dust level gives the same relative reduction in the inhalation dose.

The resulting dose conversion factors $(Sv.a^{-1}).(Bq.m^{-3})^{-1}$ of all nuclides which may be present in the repository field are given in Table 6.31 of Ref. [**¡Error! Marcador no definido.**]. The dose conversion factors take into account the contributions of inhalation and external radiation.

Section 4.2: Related topics

Main related topics are, “Uncertainty Management and Analysis” and “Modelling Strategy”

Section 4.3: Databases and tools

- FEP database and the information included in the procedure for FEP analysis [5].
- REPOS - In REPOS (REPOSitory) a complete disposal mine with all technical barriers can be modelled. REPOS has models for the release of radionuclides from all type of containers and waste forms. The important physical and chemical effects influencing the transport of radionuclides are modelled. These processes are: temperature distribution, convergence of excavations, permeability of backfilled excavation, damms, seals, gas production by radiolysis and corrosion, diffusion, sorption, and radioactive decay and ingrowth. The models for the transport of radionuclides include: transport by density differences, gas transport, transport by a pressure gradient, and transport by diffusion.
- METROPOL – The METROPOL code is capable to perform a detailed 2-dimensional groundwater flow model. The METROPOL analyses were done stochastically in order to account for the large uncertainties of groundwater flow paths and geohydrological conditions.
- MASCOT - MASCOT analyses the nuclide transport in the geosphere. The code calculates the time dependent two or three dimensional nuclide transport in an infinitely extended porous and homogeneous continuum.

- EXPOS - EXPOS calculates the radiation EXPOSure in terms of maximum dose rates for individuals.
- MiniBIOS, a computer program used to determine the distributions of the dose conversion factors for radionuclides transported via groundwater.
- UNCSAM, developed to conduct sensitivity and uncertainty analyses of mathematical models [14].

Section 4.4: Application and experience

The extended PROSA method [15] has been applied for the safety study underlying to the license application for the closure of the Asse (D) salt mine including the experimental disposal facilities (29. January 2007 [16]) and for a review on behalf of the Ministry of Agriculture and Environment of Sachsen-Anhalt (MLU) of two supporting reports issued in 2002 in preparation of the licensing process for the Morsleben Repository for radioactive waste (Endlager für radioaktive Abfälle Morsleben - ERAM) [17].

Section 4.5 On going work and future evolution

We expect that the PROSA procedure for identifying scenarios will be extended by the application of ‘safety functions’ for future safety studies.

Also we expect that it will be very useful to present the results of PA-calculations along the lines of safety functions.

At present there is no ongoing work in the Netherlands on the topic of the biosphere. Research on climatic changes is however a main topic.

Within the PAMINA project (WP2.1.D), a probabilistic study will be performed in cooperation with JRC-IC on specific topics that play a role in the safety of geological repositories.

Section 5: Lessons learned

In the performance assessment there is a need for both deterministic and probabilistic types of analyses. For the analysis of the uncertainty in the exposure the probabilistic analysis is the best tool. The same holds for parameter sensitivity although here deterministic analyses can also be very valuable. Deterministic modelling is needed to be sure that the real physical phenomena are correctly taken into account.

The amount of simulations that is needed in the probabilistic analysis depends on the question one is interested in: the result of the dose calculations or the results of the sensitivity analysis. A limited convergence study of the by-passed overburden with only three stochastic variables has shown that about 100 simulations are sufficient to obtain stable results: stable mean, and maximum of the resulting exposure. However, the results of the ’intact’ overburden have shown that 100 simulations were not sufficient to obtain the correct maximum value. This indicates that the number of simulations depends on the number of stochastic variables.

Probabilistic analyses can handle the uncertainties in parameters in a systematic way. A consequence of large parameter uncertainties is that the resulting exposure also has a large uncertainty. This uncertainty can be handled by introducing the notion of risk. This automatically means that the focus is on the possible exposures with the most serious health effects. Uncertainties caused by models have to be handled with model comparison and if possible by experimental validation.

Conclusions of the Analyses

In the uncertainty analyses performed in the PROSA report, the contribution of the various model parameters to the uncertainty in the dose conversion factors was determined. It was stressed here that in the model calculations with MiniBIOS at least four different sources of uncertainty could be identified:

- uncertainty in the conditions of the biosphere,
- uncertainty in the model description,
- uncertainty in the release point and
- uncertainty in the model parameters.

The model calculations for the safety assessment extended to a period of over millions of years. The biosphere adopted for these calculations was however based on present-day practices and state of technology. Due to lack of knowledge the uncertainty caused by the evolution of the biosphere and humankind was not taken into account although this was considered as probably the largest source of uncertainty. The biosphere calculations done within the PROSA project should therefore be interpreted as an indication of possible radiation levels rather than as a prediction.

To be able to calculate the transport of radionuclides, processes in the biosphere were translated into equations. The associated uncertainty in the model description was not taken into account in the distribution of the dose conversion factors. In a separate model validation study the uncertainty in the model descriptions is investigated. Important discrepancies between the investigated models were observed.

In the calculation of the dose conversion factors it was assumed that the radionuclides are to be released in a river. However, other release points were considered imaginable, like a well, the deep soil or the sea. Although different release points will result in different dose conversion factors, the uncertainty in the dose conversion factors due to the choice of a release point has not been considered in the distribution of the dose conversion factors.

It was noticed that the uncertainty due to different release points will be probably greater as the uncertainty in the calculated dose conversion factors. Further investigations should give more detailed information about the uncertainty caused by the different release points.

It was recognized that the parameters in the model have an uncertainty due to either lack of knowledge or natural variability. This uncertainty has been taken into account in the calculations of the dose conversion factors, since the distribution of the dose conversion factors was solely determined by the uncertainty in the model parameters. The uncertainty due to natural variability in parameter values was considered by choosing the highest and lowest value found in literature as the bounds of the distribution used in the model calculations. In this way some of the uncertainties in the conditions of the biosphere, like the soil conditions, were considered. As a consequence, some parameters exhibited large ranges of uncertainties.

Finally, it must be noted that the described methodology is based on the present conditions of the current climate. It is anticipated that, even disregarding the foreseen greenhouse effect, the climate in the Netherlands will significantly change in the next 10^5 to 10^6 years. This will affect the conditions in the biosphere as well as the groundwater flows. This long-term evolution of the climate has not been systematically taken into account.

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A8 NRI, RAWRA (Czech Republic)

Reference: 1

Version: 1

1. Introduction

This document describes the strategy of treating biosphere in safety assessment of Deep Geological Repository in the Czech Republic. It is based primarily on “Initial safety report” prepared as a part of Reference design report [1], a guide document of State Office for Nuclear Safety (SÚJB/SONS) for elaboration of the safety reports for repository siting and construction permits [2, 3]

2. Regulations and guidelines

Reasonable assurance must be provided that doses to members of the public in the long term will not exceed the dose limit by Reg. on radiation protection for members of the public from all practises with ionising radiation (1 mSv/yr) [4]. To comply with this limit, by reg. on radiation protection the dose from DGR would not exceed more than 0.25 mSv in a year.. For scenarios initiated by an event with low probability the limit is set to 1 mSv in a year. The dose limit of operational workers is set to 20 mSv/yr and/or 50 mSv/5 subsequent yrs. According to guides for elaboration of the safety reports for DGR siting and construction permits [2,3], the evaluation of safety should identify all components of the environment to which radionuclides can get and to perform estimate of the radionuclides transfer in these components of the environment. It is necessary to take into account all transport ways including their accumulation in some components. The results of these analyses are scenarios of the exposure of individuals from critical group of population with radionuclides. Critical groups of population must be evaluated both for operational period of DGR and for period after its closure. In mentioned guides [2,3] potential critical groups of population and exposure ways both for pre-closure and post-closure period are listed (Table 1) .

Table 1 Possible exposure ways of people according to regulatory body guide [2, 3]

Way of Exposure	Potentially exposed group of people	Reason for selection of exposure
By ingestion of groundwater from wells, springs, etc. in the direction of contaminated water spread	Population	Potentially released radionuclides in all periods of DGR lifetime
Inhalation of radionuclides	Workers, population	1) Release of radionuclides during manipulation with waste packages, 2) during inadvertent intrusion to repository or 3) after using area in future as residential area
Outer irradiation	Workers, population	1) During manipulation with waste, 2) During monitoring the state of a repository in institutional period, 3) during inadvertent intrusion to repository, 4) after using area in future as residential area
Ingestion of food (e.g.fish, plants) and water, etc. from contaminated areas	Population	1) After using a contaminated area for agriculture, 2) after using fish or water from contaminated surface water

The decision for screening some of the exposure ways must be justified according to the following assumptions:

1. Very low probability of exposure
2. Negligible consequences of exposure
3. In a given point of contact of organism with radionuclide is this exposure way much less important than other way through the same medium
4. Global negative consequences of a scenario are profoundly higher than consequences of a radionuclide release through this exposure way

3. Terminology

Terminology used in Czech safety approach corresponds to the terminology used in IAEA documents [5].

4. Treatment

4.1 Methodology

A simplified scenario consisted of drinking water from contaminated well was considered in the safety report study for reference design of DGR [1]. The sensitivity analysis has been performed for main parameters of underlying biospheric model (Fig. 1)

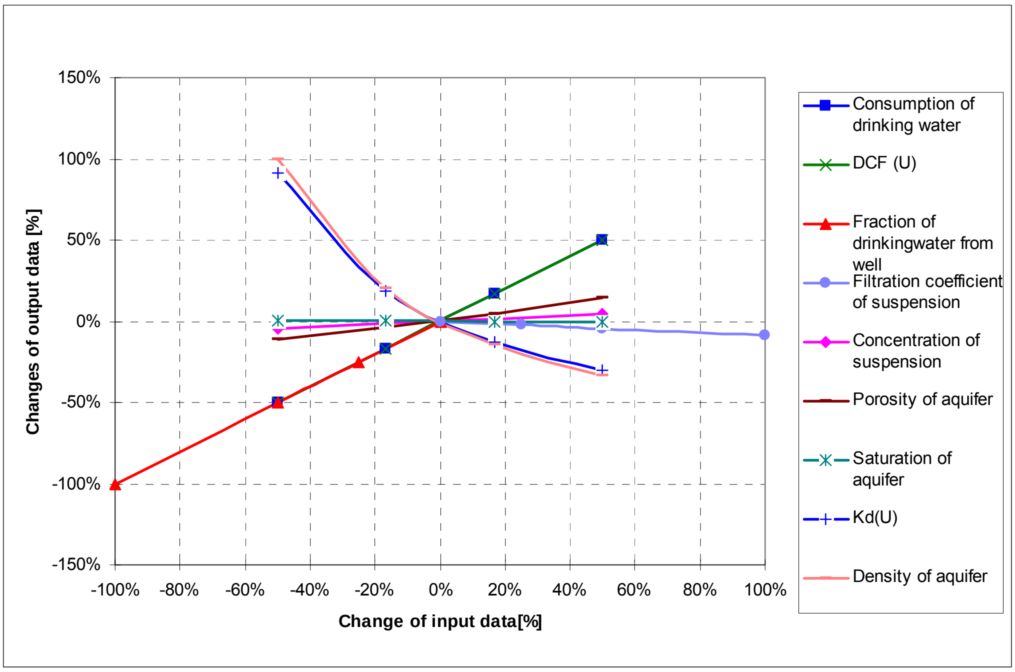

Fig 1. Results of sensitivity analysis performed in initial safety report for scenario of drinking contaminated water from a well

Generic data were collected for following stylised biosphere [6].

- Farmstead (Fig2)
- Highlands (Fig.3)
- Fishpond area (Fig. 4)

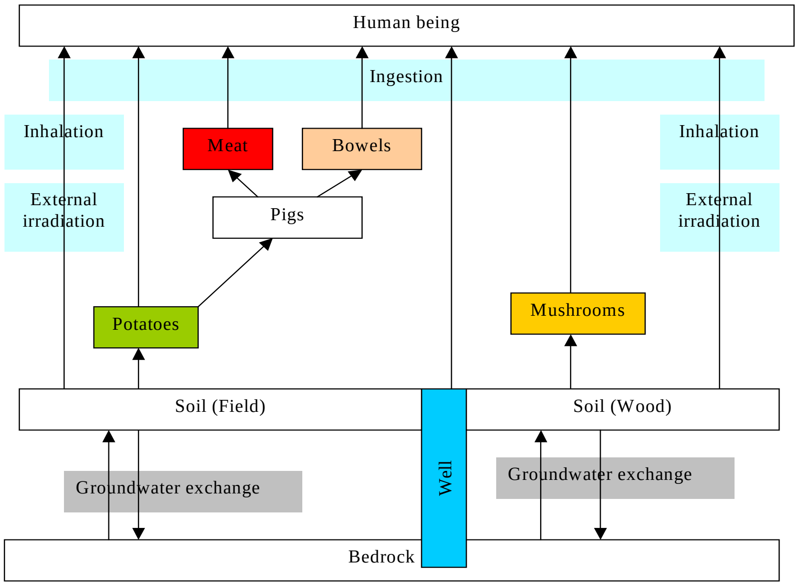

Fig. 2 Conceptual model of human exposure in Farmstead

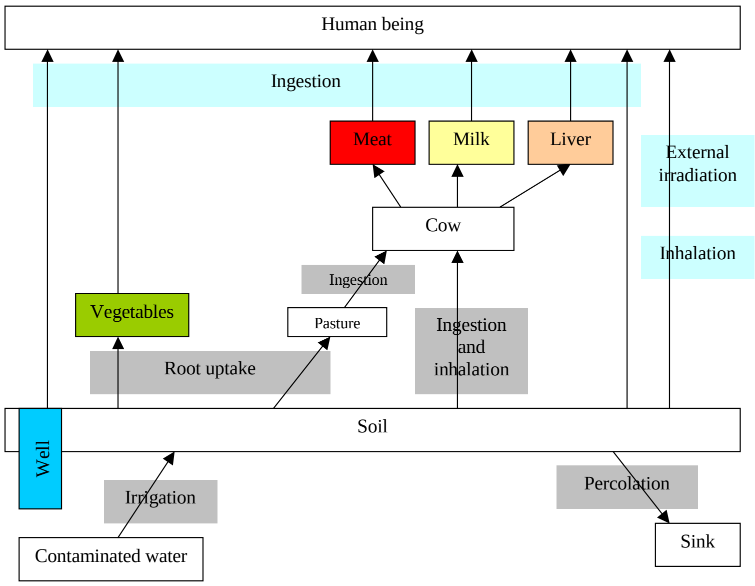

Fig.3 Conceptual model of human exposure in Highlands area

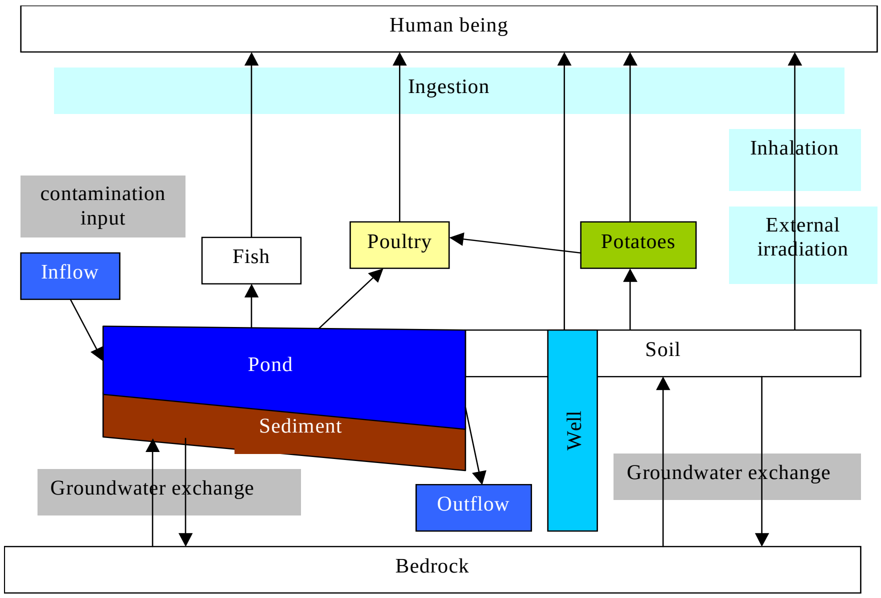

Fig. 4 Conceptual model of human exposure in fishpond area

Biospheric factors were calculated for these stylised biospheres and number of variants using algebraic equations and Excel spreadsheet. Comparison of the results is given in Fig. 5 for basic variants. A very good agreement was achieved for most of radionuclides with RESRAD v. 6.4 calculations.

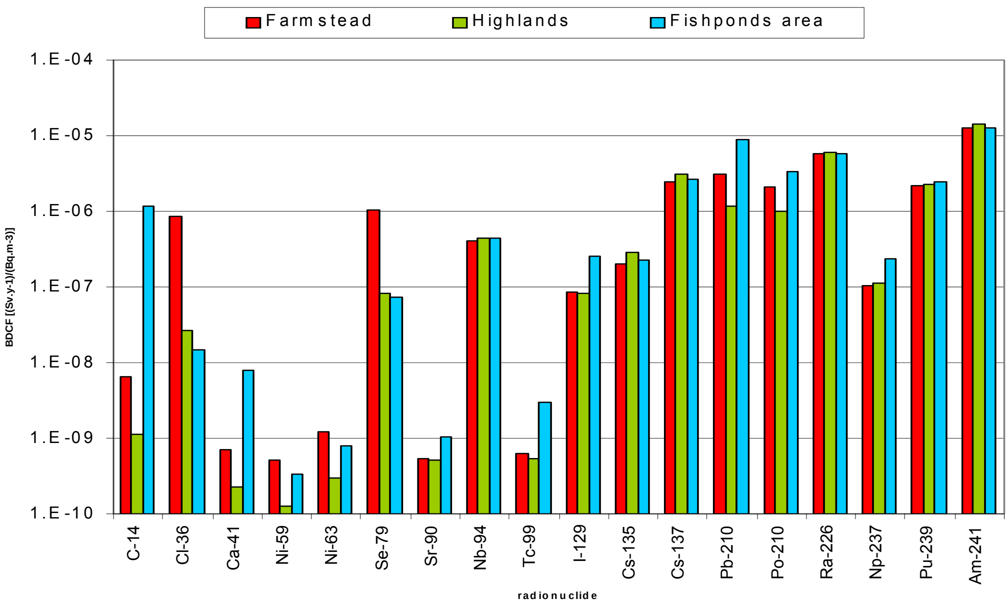

Fig. 5 Comparison of calculations of BCDF for three stylised biospheres

4.2 Databases and tools

A comprehensive review of data available for calculations of biospheric has been performed. A list of documents, where data for conversion and transfer coefficients is possible to find in report [6].

Basic tools used for derivation of BCDF are algebraic equations, which are solved in EXCEL spreedsheet, but for some applications AMBER, GoldSim v. 9.6 and RESRAD v. 6.4. computer codes were used.

5. Applications and experience

No calculations for specific biosphere, where DGR could be located, have been prepared so far, since no site for DGR has been selected. It can be used, however, experience acquired from biospheric calculations for operating near surface repositories at Dukovany [4].

6. Conclusions

In the current stage of DGR development in the Czech Republic modelling of exposure of human is based only on stylised biospheres. The critical scenario was considered drinking contaminated water from a well. The last results, however, suggest that this scenario need not be critical for all critical radionuclides. In the further stage of DGR development we will focus on deeper understanding of the behaviour of radionuclides in biosphere both in the framework of international cooperation (e.g. BIOPROTA forum) and Czech DGR development program.

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A9 POSIVA (Finland)

1. Introduction

Spent fuel from the Finnish nuclear power reactors is planned to be disposed of in a KBS-3 type repository to be constructed at a depth between 400 and 600 metres in crystalline bedrock at the Olkiluoto site (Southwestern Finland).

In 2001 the Parliament ratified the Government's favourable Decision in Principle on Posiva's application to locate the repository at Olkiluoto, being the milestone prior to entering the phase of confirming site characterisation. The next step of the nuclear licensing of the repository is the application for a construction license in 2012.

The required documentation of studies and conclusions on the long-term safety will be published in a step-wise approach with an increasing level of detail. A plan for a synthesis of evidence, analyses and arguments that quantify and substantiate the safety and the level of expert confidence in the safety, i.e. the safety case, was prepared in 2004 (Vieno & Ikonen 2005) and updated in 2008 (Posiva 2008). The planning report introduces the Posiva Safety Case Portfolio as the documentation management approach, facilitating flexible and progressive development of the safety case. In the portfolio, biosphere assessment is planned to be compiled on the basis of several modelling and other report documenting the models and data in detail (Ikonen 2006).

2. Regulatory requirements and provisions

The regulations as follow have been referred to in Ikonen (2006). The regulatory requirements are set forth in the Government Decision on the safety of the disposal of spent nuclear fuel (STUK 1999) and, in more detail, in the regulatory Guide YVL 8.4 issued by STUK (2001). The safety regulations and guidance will be updated periodically.

Assessment time windows

The regulatory guide sets the criteria for the time window to be assessed. It emphasises that the repository design needs to effectively hinder the release of disposed radioactive substances into the host rock for several thousand years. Considering the quantitative safety assessment calculations, the regulatory constraints for a period up to *"at least several thousand years after the closure of the repository"* but *"adequately predictable with respect to assessments of human exposure"* are dose-based (Table 2-1). After that period, in the long term, the quantitative regulatory constraints are based on constraints on the release rate of long-lived radionuclides from the geosphere into the biosphere, and the license applicant thus does not need to present any biosphere assessment for that period.

In the long term, after several thousand years, the quantitative regulatory criteria are based on constraints on the release rates of long-lived radionuclides from the geosphere into the biosphere. The nuclide-specific constraints are set in the Guide YVL 8.4 (STUK 2001). The constraints apply to radionuclide releases, which arise from the expected evolution scenarios. In the assessment calculations the activity releases can be averaged over 1000 years at the most. The sum of the ratios between the calculated nuclide-specific activity releases and the respective constraints shall be less than one.

In the very long term, after several hundred thousand (Ruokola 2002) or one million years, no rigorous quantitative safety assessment is required but the judgement of safety can be based on more qualitative considerations, such as bounding analyses with simplified methods, comparisons with natural analogues and observations of the geological history of the site.

General requirements to assessment models and input data

The models and data employed in the safety assessment shall be selected on the basis that the results, with high degree of certainty, overestimate the radiation exposure and radioactive release likely to occur. Simplification of the models as well as the determination of input data for them shall be based on the principle that the performance of any barrier will not be overestimated but neither overly underestimated. The various models and input data shall be mutually consistent, apart from cases where the simplifications in modelling or the aim of avoiding the overestimation of the performance of barriers implies apparent inconsistency.

Table 2-1. Safety assessment constraints stated in the Finnish regulations (STUK 2001) for a time period of at least several thousand years from the closure of the repository

Criterion	Constraint
Annual effective dose to the *most exposed* members of the public	Less than 0.1 mSv
Average annual effective dose to the *other members of the public*	Insignificantly low
Biodiversity of currently living *populations*	No decline
Effects on *populations* of fauna and flora	No significant detriment
Effects on *individuals* of domestic animals and rare plants and animals	No detrimental effects

Biosphere assessment endpoints

For the quantitative safety assessment calculations, the regulatory constraints for a period that shall be extended to at least several thousand years after the closure of the repository (see *Assessment time windows* above) are (STUK 2001):

- The annual effective dose to the most exposed members of the public shall remain below 0.1 mSv.
- The average annual effective doses to other members of the public shall remain insignificantly low. The acceptability of these doses depends on the number of exposed people, but they shall not be more than 1/100 to 1/10 of the constraint for the most exposed individuals, *i.e.* no more than 0.001 to 0.01 mSv per year.

It is also clearly stated that also the radiation exposure of flora and fauna shall be considered. The typical radiation exposures of terrestrial and aquatic populations in the environment of the repository, assuming the present kind of living populations, shall be assessed (Table 2-1). These exposures shall remain clearly below the levels that would cause decline in biodiversity or other significant detriment to any living population on the basis of the best available scientific knowledge. Moreover, rare animals and plants as well as domestic animals shall not be exposed detrimentally as individuals. However, the applicable methods are still internationally under development and may be implemented more explicitly within the regulatory framework at a later date.

Exposure environments and pathways

The Guide YVL 8.4 (STUK 2001) also gives guidance on the potential exposure environments and pathways to be considered. The biosphere assessment in general should be based on climate, human habits, nutritional needs and metabolism that are similar to those of the current day, but should also take account of reasonably predictable changes in the environment, *i.e.*, at least the land uplift and subsequent emergence of new land areas. At least the following exposure pathways shall be considered (STUK 2001):

- use of contaminated water as household water
- use of contaminated water for irrigation of plants and for watering animals
- use of contaminated watercourses and relictions.

The most exposed individuals live in a self-sustaining family or small village community in the vicinity of the disposal site, where the highest radiation exposure arises through the pathways discussed above. In the environs of the community, a small lake and a shallow water well are assumed to exist. The other members of the public are defined to live at a regional lake or at a coastal site and to be exposed to the radionuclides transported in these watercourses. In the latter case, no fixed dose constraint is set, but the acceptability of the doses depends on the number of exposed people, and they shall not exceed values from one hundredth to one tenth of the constraint for the most exposed individuals (STUK 2001).

3. Key terms and concepts

The **biosphere** is a diverse system that is changing continuously; it is impossible to model accurately. Thus some inherent uncertainty has to be accepted already in the conceptual level of modelling and also communicated throughout the assessment.

By **environmental studies** we mean investigations into the surface systems at the site that are conducted so as to provide a realistic description in the good scientific manner. In contrast, **biosphere** relates to the scenario-based discussion and modelling of situations in the future usually involving at least some conservative assumptions. It should be noticed that these areas overlap significantly especially for the process descriptions, which are likely to remain the same for past, present and future.

The transport and fate of radionuclides released into the biosphere is calculated in the **landscape model**, which is a time-dependent linked transport model built by a set of biosphere objects.

A **biosphere object** is a continuous evolving section of the modelled area, described by one ecosystem-specific compartment model (e.g., lake, coast, river, forest or wetland) and one set of data.

The **Terrain and Ecosystems Model** (TESM) provides a quantitative description of the evolution of the surface systems from the emplacement of the first canister in the repository up to several thousands of years into the future, and is the key input when developing the landscape model.

4. Treatment in the Safety Case

4.1 Methodology

In the biosphere assessment the process of building up exposure pathways for the calculation of endpoints is done according to Figure 1. The results of the analyses of assessment scenarios (in the geosphere) and repository calculation cases are release rates (Bq/year) used as input to biosphere assessment. In the biosphere assessment exposure pathways are used to define biosphere calculation cases. The exposure pathways comprise terrain and ecosystem development modelling (TESM) and landscape modelling (Figure 1). Future human activities (FHA) can be included or not in the build-up of exposure pathways. The final results of biosphere calculation cases are endpoints (or quantities) used to demonstrate compliance with regulatory limits.

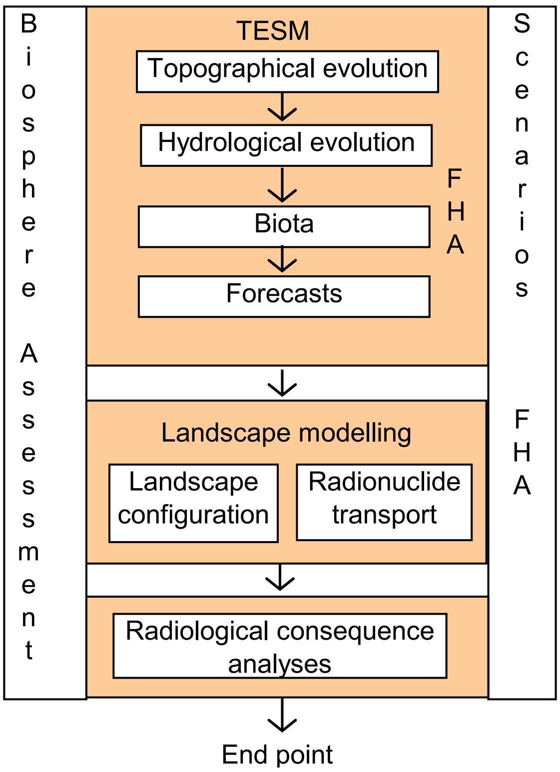

Figure 1.

Terrain and ecosystems development

For constructing site-specific biosphere models, descriptions of present-day conditions and future evolution of the Olkiluoto site focusing on the next several thousand years are needed (Vieno & Ikonen 2005). The level of details depends on the models, and the models should be based on the knowledge and data on the site; thus an iterative process is required. A stepwise methodology for this has been outlined in (Posiva 2003c, 2006) and further elaborated by Ikonen *et al.* (2005) and Rautio *et al.* (2005).

The future biosphere states at the Olkiluoto Island are largely determined by the high rate of land uplift and sea level changes. The projections for sea level changes and other climate scenarios for the next several thousand years should be provided externally by the Evolution report of the Safety Case (Vieno & Ikonen 2005). Essentially, the description of the future development of the Olkiluoto site and surroundings for the next several thousands of years is produced in a step-wise process to be iterated a couple of times to produce a mature and well-balanced view: Firstly, the location of the shoreline at different times is calculated from the digital elevation model applying the vertical movement and tilting of bedrock due to the land uplift (Mäkiaho 2005). Sedimentation and erosion processes will also need to be taken into account acknowledging that the uncertainties may be greater here. In the process, the known spatial distributions of soil and sediment types (Rantataro 2001, 2002) are used. Locations and dimensions of surface water bodies, *i.e.* lakes and streams, are estimated using the topography forecast, knowledge on overburden and rock surface, and estimates of water inflow to the model area from upstream. With these premises, vegetation succession is presented using higher-level *vegetation types* correlated to the topography, overburden type and water bodies (Rautio *et al.* 2005). The likely fauna populations can then be associated to ecosystem areas on the basis of the vegetation types and other known features. Finally, mass balances and flows, or the *conceptual ecosystem models* (section 3.3.1), can be estimated with the help of literature and regional or site data on the present-day ecosystems. In order to assess *future human activities*, such as probability of different land-use types and location of drilled wells, description of past evolution and history of the site are needed, too (Ikonen *et al.* 2005). The knowledge of also the past semi-natural evolution supports the process evaluation.

Landscape models and biosphere objects

In order to model the fate and transport of the potential releases from the repository over long time periods for a large number of scenarios, variants and cases, the terrain and ecosystem development together with the various process models and site knowledge have to be simplified to an operational level. Traditionally, the biosphere is conceptualised as individual models representing a certain ecosystem type producing a dose conversion factor (Sv/Bq) to translate the outflux (Bq/y) from the geosphere to effective doses or dose rates to members of the public (Sv/y) for a constant unit release over a long time period (usually 10 000 years). Considering the changing landscape on the rims of the Gulf of Bothnia, an area with high land uplift rate and usually a shorter lifespan of certain types of ecosystems, necessitates to reconsider not only the averaging time of individual ecosystems and other shortcomings of the traditional models, but also to connect the ecosystem models to follow the natural flows of matter, and to consider the changes from one ecosystem to another over time within the evolving landscape. In Ikonen (2006) was first proposed the ecosystem-based approach and compared to the traditional bioconcentration approach to outline the Posiva's strategy for model development. Thereafter, the needed set of ecosystem-specific radionuclide transport models (applied in the *biosphere objects*) was described and the approach for connecting them into *landscape models* illustrated.

Ecosystem-based approach

Following the assessment strategy presented above, and as indicated already in (Posiva 2003c), the biosphere modelling is developed into utilising functional radionuclide groups (bioavailability and chemical properties; *cf.* Greger 2004, Ikonen *et al.* 2005) and stable analogues, ecosystem models based on the knowledge of the site – and their development as the main modelling approach – and traditional transfer factor models (Bergström *et al.* 1999, Nordlinder *et al.* 1999, Karlsson & Bergström 2000, Karlsson *et al.* 2001) as the existing, largely valid basis for the radionuclide transport modelling: The present site can be studied in detail, and its evolution over the assessment time window can be forecasted rather realistically on the basis of the physical, geoscientific and ecological facts and by applying a proper scenario approach. Thus, *with time and effort*, a firm realistic basis can be established to model the hydrological and element cycles at the site over the required timeframe. However, this will not be feasible to the fullest extent in the near future, and thus a synthesis between the transfer factor models and pure ecosystem modelling is needed.

Landscape models

As referred above, the *landscape models* are sets of biosphere objects connected together to represent the long-term fate and transport of radionuclides throughout a configuration of linked ecosystems. The most important connections between the ecosystems are the natural mass fluxes following mainly surface waters but also in some cases transport of sedimentary material. In addition, irrigation can be a major connection transporting radionuclides from one ecosystem to another.

Within the landscape models, it is the spatial and temporal patterns of radionuclide concentrations in the different environmental media that are first simulated. Landscape models may then be used to calculate the contributions of the different parts in the system to the total dose and the size of exposed population. By connecting the biosphere objects to form a single model, sensitivity analyses of the entire landscape model are enabled, so that, for example the relative importance of different modules and their parameters can be determined, thus supporting the analysis of the results of the simulation cases.

Endpoints

The main outcome from the biosphere assessment, dealing with radiological safety and compliance with regulatory requirements, is the annual landscape dose, which is related to individuals fully utilising the maximum production of food and water from the potentially contaminated area. Also are presented time-dependent doses to individuals fully utilising the modelled area (landscape doses), or landscape dose conversion factors (LDF), specific for Olkiluoto. This approach was used in the KBS-3H safety studies (Broed 2007b).

The concept of deriving doses based on landscape modelling is a rather novel approach, which has been previously applied only in the KBS-3H safety studies (Broed 2007b), the safety assessment SR-Can (SKB 2006a), and in some case studies (Smith & Robinson 2006, Broed 2007a). The radionuclide transport part of the landscape modelling results in time-dependent nuclide-specific activity concentrations in the biosphere objects identified in the model.

Doses can be derived from these activity concentrations in many ways, depending on the purpose of the assessment. Below, the assumptions behind the quantity *annual landscape dose* (ALD) are summarised. The ALD concept was introduced in Broed (2007b), and is used here to evaluate compliance with the regulatory dose constraint for the most exposed members of the public.

The main assumptions, and data, underlying the ALD are:

- Exposed individuals are assumed to spend all their time in the contaminated parts of the landscape
- Exposed individuals are assumed to make full use of food/water production capability of the landscape
- Estimation of the exposure from food ingestion is based on the annual demand for carbon (production and carbon content weighted average over all edible products in the ecosystem), instead of the traditionally used annual ingestion of different foodstuffs
- The dose contribution from C-14 is calculated separately, using an ecosystem-specific dose conversion factor derived with specific activity models.

Dose to most exposed individual

In the most recent biosphere assessment (Broed et al. 2007b), the quantity *annual landscape dose to most exposed individual* (ALD_{max}) is derived as the main endpoint for demonstration of compliance with the dose constraint for the most exposed members of the public. The assumptions for the ALD_{max} are:

- Only the most exposed sole individual is considered
- The most exposed individual spends all his time in the single biosphere object capable of producing the highest exposure
- The most exposed individual makes full use of the food/water production capability of the single biosphere object capable of producing the highest exposure.
- The use of shielding factors for external radiation due to spending time inside dwellings is not considered
- The dose arising from C-14 is, conservatively, added to the dose calculated using the landscape model for other radionuclides.

This approach to derive ALD_{max} is not optimised in respect to conservativeness, nor is the ALD_{max} necessarily the most suitable quantity for evaluating the compliance to regulatory constraints. Issues for further development include especially identification of an individual that is representative of the most exposed members of the public, revisiting the parameter selection especially in the C-14 model, and refinement of the summation of dose contributions from different radionuclides.

Role and use of the annual landscape dose

The annual landscape dose to the most exposed individual, ALD_{max}, is used as the main quantity for the evaluation of compliance with the annual effective regulatory dose constraint to the most exposed members of the public, which applies during the first several thousands of years.

4.2 Related topics

Criteria for data selection: Parameter values for biosphere assessments

As arising from the discussion above, it is clear that an extensive database for the parameter values used in the multiple steps of the biosphere assessment and modelling is needed. The variety of the data is great, already the broader *types* include

- universal properties such as Avogadro's number,
- properties specific to the element or nuclide, like half-life or Kd,
- exposure factors, e.g. intake dose factors or consumption habits, and
- site properties, directly measured or derived from other data, as lake volume or evapotranspiration over an area.

Also the *spatial and temporal scales* need consideration: some parameters vary from place to place, some of them might get different value for different extents of context, and some vary also in process of time. Plenty of data is *available* not only from the site investigations but as well from specific studies at potential reference sites, literature in general and grey, like some in-house databases – still it is well recognised that there are large gaps in the data available compared to the needed.

This all underlines the necessity of clear *parameter strategy*: The main concern is, on the other hand, the variety of different ecosystems, habitats and their management histories; lakes, rivers, proper wetlands and so on need to be studied outside of the actual site where those do not exist at present but virtually certainly emerge abundantly in the future. This arises from the *temporal perspective* of the Biosphere Assessment – at the moment the site is an island in outer archipelago but within some thousands of years practically inland. Knowing the history of the landscape in the western coast of Finland, obviously the current inland regions are analogues to the future site, and concerning the radionuclide transport calculations these are important for the case of secondary contamination as a result of exposing sediments as new land, not to mention the overall understanding of the site and the processes. The dense grid of forest plots at Olkiluoto (e.g. Haapanen et al. 2007) also offers perspectives into the spatial variability in the scales of the biosphere modelling; and, of course, the use of data from reference sites needs sound justification. Therefore also intensive studies at the site are required.

Concerning the *priority of different data sources*, primarily site data should be used, complemented with more generic data where needed, *e.g.* for the quantified ecosystem models). For the ecosystems not found at the Olkiluoto site at present, regional data should be used whenever possible, with proper attention to the representativeness of the area. Only secondarily generic literature data should be used with focus to most similar conditions taking into account also the needed amount of data entries for establishing a solid basis.

In addition to the exemplars for the biosphere objects used in the radionuclide transport simulations several other aspects are of interest regarding the inland reference sites. They include

- land uplift history, both conceptually at large and regarding specific processes at least up to 80 meters above sea level,
- processes related to the relationship of lakes/wetlands and their surroundings, as well as of rivers and riverbanks,
- cultural and social statistics and history (*e.g.* Satakunta Province, Rauma economical area), and information on historical dwelling and living space, self-sustaining communities (smaller villages) and grand scale land-use such as the Vuojoki Manor.

The more sensitive to the parameter the models are, the more important it is to use well-founded distributions such as from the procedure established at the recent OPG assessment (*e.g.* Garisto & Gierszewski 2002, Sheppard *et al.* 2002, 2004a,b, 2005a,b). As slightly modified, the derivation of the parameter distribution consists of the following steps:

- listing, with adequate descriptive comments, all potentially relevant data entries available (site studies, generic literature; monitoring, experimental; *in vitro*, *in vivo*),
- reasoning whether include or not with regard to the scenario/case definition, the assessment context and other factors affecting to the parameter selection (the "parameter strategy"),
- using weighing factors if reasonable, *e.g.* based on data quality assessment methodology,
- deriving probability/occurrence distribution from the included data entries, preferably supported by theory (*e.g.* maximum entropy theory, or supporting knowledge *e.g.* on that ratio quantities can be expected to have a lognormal distribution) especially if the shape of the distribution is not obvious from the data set collected,
- determining the parameters fixing the distribution, and finally
- using the established distribution as input in the modelling both deterministically and in sensitivity and uncertainty analyses.

Throughout all the acquisition and handling of the parameter values, *tracking of origin* is vitally important both for ensuring the data quality and for maintaining the transparency and traceability of the assessment. While acquiring the data, careful review of the original research papers by a qualified person is the best practise for categorising the data; with the same effort usually also any hidden pessimism many times included in compendia values is revealed and thus the unrecognised level of over-conservativeness in the assessment can be decreased. For evaluating the strength of the knowledge or data base, *pedigree analysis* is adopted (Ikonen 2006, Hjerpe 2006). It is acknowledged, however, that the procedure is laborious and in practise possible only for a limited set of most important data.

Safety indicators

Only safety indicators directly related to the regulatory guideline (see above) have been utilised in the most recent biosphere analysis (Broed et al. 2007b). To enable comparison with the regulatory guidelines, the safety indicators need to take the form of annual effective doses; in the report they are based on two stylised well scenarios, WELL and AgriWELL denoted as WELL-2007 and AgriWELL-2007.

Complementary safety indicators

Activity inventory. The activity inventory is the sum of the activity, for each radionuclide, in all compartments in the model, and is calculated for each biosphere object.

Retained fractions. The *retained fraction* of radionuclides released to the biosphere is defined here as the total radionuclide activity inventory in the landscape, excluding the object *Baltic Sea*, divided by the integrated activity release. The loss of radionuclides from the landscape is due to both outflow from the main modelled area into the Baltic Sea, and losses due to the radioactive decay.

Environmental activity concentrations. The final result from the landscape modelling, used as input in the assessment of radiological consequences, is the time-dependent radionuclide-specific activity concentrations in individual biosphere object types and environmental media (soil, water and sediment). The time-dependent spatially distributed radionuclide- and media-specific environmental activity concentration is the main result from the radionuclide transport modelling in the biosphere analysis. It is used as input to the radiological consequence analysis, both for humans and for other biota. Since activity concentrations are based on physical properties, they are suitable for use when comparing to other assessments; this is in contrast to dose quantities, which may also include assumptions about *e.g.*, definition of exposed groups, living habits and food intake. Activity inventories and retained fractions are mainly used to improve the understanding of transport and accumulation behaviour for individual radionuclides in the biosphere. Activity inventories are in some cases also used to evaluate inheritance of radionuclides when modelling the transition from one ecosystem type into another during the evolution of the landscape.

Modelling strategy

The overall aims of the biosphere analysis are to describe the past, present and future conditions of and the processes in the surface systems of the Olkiluoto site, model the transport and fate of radionuclides released from the repository through the geosphere to the biosphere, and assess possible radiological consequences to humans and other biota. In the biosphere description process, comprehensive site understanding is achieved by integrating the information from the various disciplines of environmental sciences. From that perspective, also bearing in mind the needs of further modelling, the site data is collated and interpreted into site-specific parameter values for the modelling, and the prevailing processes are described by the means of ecosystem modelling. The further modelling process can briefly be expressed as, firstly the forecasts of the future biosphere are produced, secondly the landscape model is established and finally, the models for assessing potential radiological consequences to humans and other biota are defined. In parallel to this main modelling process, complementary models are also established, such as safety indicators. The modelling process is illustrated in Figure 2, where the landscape model is further divided into two components, landscape model set-up and biosphere objects.

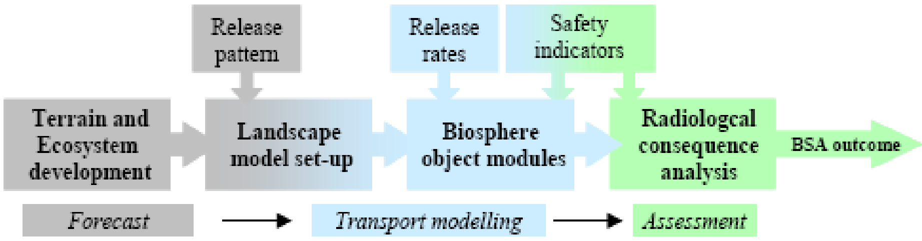

Figure 2. Simplified illustration of the biosphere assessment modelling process after the biosphere description part (processes and handling of site data). The colours indicate the main activity performed in the component.

4.3 Databases and tools

The information infrastructure for the Biosphere Assessment is presented in Figure 3 with four (sets of) databases:

- the POTTI research database for the site data,
- the GIS database for spatially bounded data,
- the Biosphere Assessment Database for the assessment data, and
- external databases.

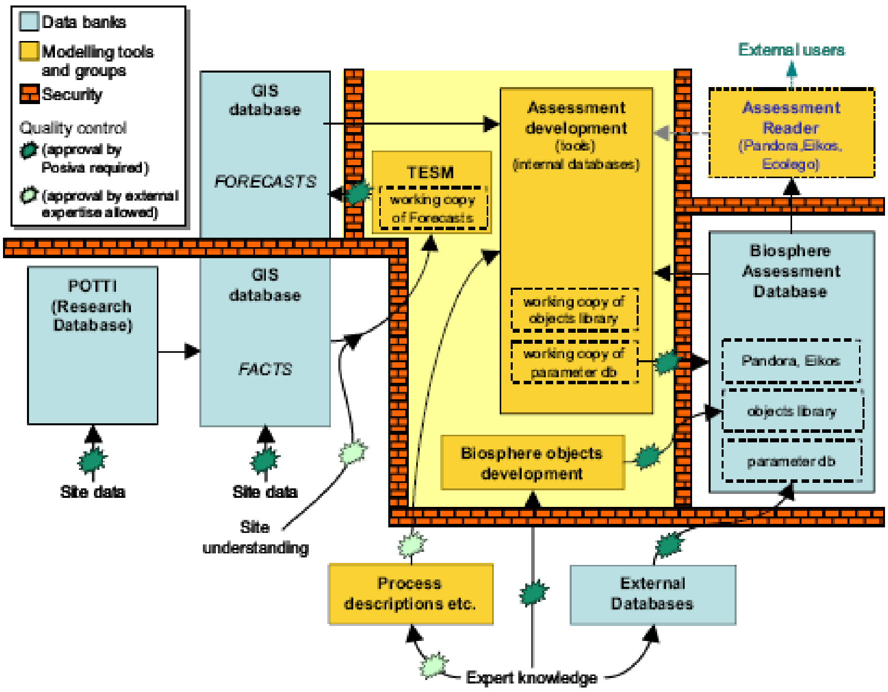

Figure 3. Information infrastructure in the Biosphere Assessment.

Modelling tools

Technical working environment and streamlined workflow incorporating good means of communication within the persons involved are essential for transparent, effective and highly qualified modelling. Thus several tools are developed or customised for Posiva biosphere assessment team as presented shortly in the following

Geographical information system (GIS) and site investigations database (POTTI). Both site description and the terrain and ecosystems development modelling require handling of location information of massive data sets. This information, together with the attribute data, has to be further delivered into the landscape modelling and the underlying data reports. Naturally, a geographical information system (GIS) will be the main working environment and the means of dialogue between the tasks.

For storing the alphanumerical site investigations data, a database called POTTI has been implemented. In addition, the information possible to present as maps, or the location data with relevant attributes, forms the GIS database. These databases are intended to the different processing levels of site data. However, for the biosphere assessment, and safety case in general, these data need to be processed further. In order to maintain the difference, the *site data* used in the biosphere assessment is referred to as *environmental data* and the *derived forecasts* as *biosphere data*.

Biosphere Assessment Database (BSAdb). For the BSADb storing the assessment data in general and chosen for specific assessment cases, detailed requirements on security, data integrity and quality assurance have been outlined (Hjerpe 2006) and implemented. The requirements on security handle issues such as physical protection, redundancy and backup strategy. For data integrity, it is required that access to the database should be divided into a five-level user profile system. The five levels range from an anonymous “read-only” access profile, to a personal profile with full access to add and modify data entries. In addition to the five-level system, there is a user profile intended for reviewers involved in the quality assurance procedure. The quality assurance of data to be used in the BSA is a vital part of the Knowledge Quality Assessment (KQA) strategy, described in Ikonen (2006), and Hjerpe (2006). To be able to be confident in the overall quality of the BSA it is important to ensure that appropriate and reliable data has been used. To facilitate this, two features have been implemented in the database: *usability status* and *data history*.

Usability status. Each data entry in the BSADb has a usability status (US) value, corresponding to a usability class, ranging from rejected-in-quality-check to the quality-approved data to be used in the assessment simulations. Permission to change US is dependent on the profile of the user, e.g., low level users are not permitted to do any changes. The approach to populating the database is to permit a relatively large number of users to add data entries, resulting in a large amount of data at the US2 level. A smaller group of users are permitted to change the US to US3, after checking that the data entry is relevant and that the information given is complete. Sending the data for quality checking (US4) will be permitted by an even smaller group of users, mainly the members of the biosphere assessment team, and approving data in the quality check (US5) can only be made by a reviewer. And finally, the formal quality approval of a data entry (US6) can only be performed by the project manager of the biosphere assessment. The default requirement in the assessment modelling is that only data from the BSADb with US6 will be allowed for usage.

Data history. When a field value for a data entry is changed (e.g., usability status, numerical value, numerical uncertainty, added references, etc.) the data entry get an inherent data history. All changes in the data history are tagged with time and full affiliation of the user performing the action. The full data history is retrievable.

UNTAMO Toolbox. To handle the large amounts of GIS data, to control the processing procedures and, especially, to automate the laborious routines, a series of analysis tools – the UNTAMO toolbox - is being developed for the ArcGIS environment for use in terrain and ecosystems development modelling. The toolbox comprises a number of customised processing tools for

- simulation of changes in the topography (land uplift, sea level changes, physical and biological sedimentation and erosion),
- identification of surface water bodies and estimation of runoff,
- forecasts of vegetation types and typical fauna populations,
- handling of modifications to the simulations for cases of future human activities,
- post-processing of the data sets for analysis and reporting, and iteration and batch run procedures for extensive simulation chains,
- interface to the Biosphere Assessment Database with log and audit functions.

Modelling and simulation environment PANDORA. For technical implementation of the models for radionuclide transport in the biosphere, a commercially transparent environment, specifically Matlab/Simulink (www.mathworks.com), has been chosen to serve as an engine of the model implementation and simulations, but also other platforms are possible in future if significant benefits are found. However, the user interface as default is rather atomistic and engineering oriented. In order to make the Matlab/Simulink platform more easy to use, whilst keeping its advantages, a library of blocks and a free standing Manager toolbox for facilitating the creation and handling of radioecological models were developed and implemented as an extension to Simulink as a joint project of Posiva and SKB. The main feature of PANDORA is the improved graphical user interface better presenting the layout and structure of the radionuclide transport models

Sensitivity and uncertainty analysis tool EIKOS. The predictive capability of models is limited by the uncertainty in the value of the variables, and thus sensitivity analysis is used to apportion the relative importance each uncertain input parameter has on the output variation. Sensitivity analysis is therefore an essential tool in simulation modelling and for performing risk assessments. A software package for the Matlab environment, EIKOS, was implemented with funding from Posiva and the Norwegian Radiation Protection Authority (NRPA).

Nuclide-specific models: The C-14 models. In addition to the biosphere objects, a set of simplified models, developed by Avila & Pröhl (2007), has been used for assessment of human exposures resulting from potential underground releases to the biosphere of C-14. These are non-dynamic simplified models based on the ratio at equilibrium between the stable isotope C-12 and the radioisotope C-14 in the biota (a so-called specific activity model). Transport between biosphere objects is not considered; instead it aims at estimating the maximal activity concentrations within individual biosphere objects, receiving an input of C-14. The models are applicable on both continuous and pulse-like releases. The ecosystem types considered are forest, coast (sea basins), lake and agricultural land. The agricultural land module also takes into account exposures resulting from the possible use of contaminated fresh waters, for example from an affected well, for irrigation of vegetables. Schematic representations of the conceptual models proposed for assessment of exposures to C-14 released from the geosphere to terrestrial and aquatic ecosystems are shown in Figure 4. The models in their mathematical structure are thoroughly discussed in Avila & Pröhl (2007).

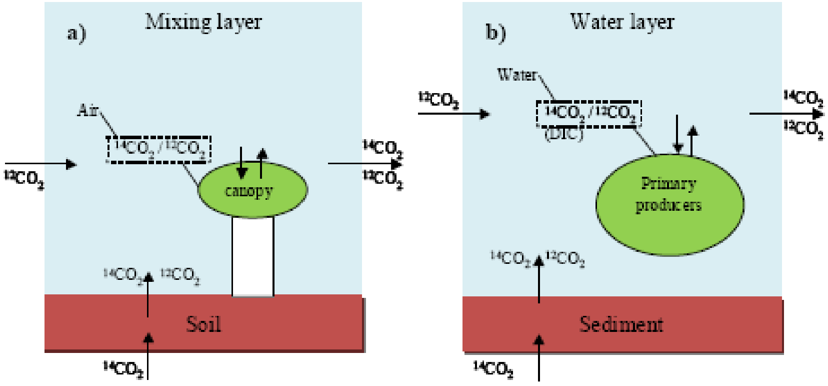

Figure 4. Schematic representation (modified from Avila & Pröhl 2007) of the conceptual models for assessment of exposures to C-14 released from the geosphere to a) terrestrial ecosystems (forest and agricultural land) and b) aquatic ecosystems (lake and coast). The arrows represent fluxes of carbon dioxide.

4.4 On-going work and future evolution

For 2009, a comprehensive biosphere assessment is planned. The Biosphere Description 2006 (Haapanen et al. 2007) will be updated and extended with emphasis on providing the necessary parameter data for the further modelling evaluated through the multi-disciplinary site understanding. Terrain and ecosystem development modelling (TESM) will be carried out first time in the full extent using the UNTAMO tools, providing the spatial context to the landscape modelling. Also the surface and near-surface hydrological model (Karvonen 2008) will be used iteratively with the UNTAMO tools to refine the release locations from the bedrock to the bioavailable region. The radionuclide transport model of the area (landscape model, Broed 2007b) will be reconstructed with some further development to the biosphere object modules (ecosystem-specific transport models interconnected in the landscape level). The dose quantities will be redefined to better correspond to the regulatory criteria and to decrease the pessimism. Finally, a number of assessment cases will be calculated and the results evaluated following the example of (Broed et al. 2007b).

The biosphere assessment of 2009 will feed into the overall safety case and the outline of the preliminary safety assessment report (PSAR) for the spent fuel repository. In the following years, the focus will be in complementing the outline assessment in order to be able to submit the construction license application for the repository, including full PSAR, in 2012.

5. Lessons learned

The recent biosphere assessment (Broed et al. 2007b) showed that none of the analysed cases exceeds the regulatory dose constraint for most exposed members of the public, even though the applied approach to derive doses was considered to be pessimistic. The analysis, with its background reports, also demonstrated significant advance in the biosphere assessment in the last few years. However, some important open issues remain, especially concerning the definition of dose quantities matching the regulatory criteria and the level of pessimism of the dose estimates, both in terms of dose/concentration and as dose/release relationships. Despite of the deficiencies of the present approach, no obstacles to the development of a fully balanced biosphere assessment in 2009 and 2012 are foreseen, although details have to be worked out.

The experience with terrain and ecosystems development modelling and site-specific landscape modelling is strongly suggesting that using any reference biospheres would be extremely hard to be justified without going through the whole site-specific biosphere assessment first, especially for the chosen site with significant post-glacial land uplift. On the other hand, since the site-specific modelling is needed anyway, there does not seem to be any significant use of the reference biospheres as such. Even in the very long term, *i.e.* over the time window of dose calculations, the information on the site and its evolution would supersede any reference biosphere, since making regional climate simulations and forecasts will enable better justified modification of the site-specific biosphere models than trying to fit a generic reference case to the site.

In this respect, one might question the usefulness of international co-operation. On the other hand, it must be acknowledged that the site work is costly, but necessary, and takes time. Thus, the aim of developing fully site-specific ecosystem models for all relevant nuclides/elements stays somewhat remote and a synthesis between that approach and the conventional transfer factor modelling is needed. This in turn makes international co-operation valuable in the level of radionuclide transfer processes and related data. Furthermore, co-operation in site characterisation planning and methodologies remains highly useful, not to mention shared costs of most expensive investigations and experimental work where analogues can be justified on the basis of the site understanding.

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A10 SCK·CEN and ONDRAF-NIRAS (Belgium)

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Contents

1. Introduction and background

Biosphere modelling aims to assess the impact of the release of radionuclides from a geological disposal facility into the biosphere. This document summarises the approach to biosphere modelling used in ONDRAF/NIRAS's second Safety Assessment and Feasibility Interim Report (SAFIR 2), published in 2001 [1]. SAFIR 2 was a programme of methodological research designed to establish feasibility of designing and building a geological disposal facility in Belgium for higher-activity radioactive wastes (termed Category B & C wastes). Belgium has yet to select a disposal site and, although SAFIR 2 was based on data from specific sites, there was no intent to prejudge the site where a geological disposal facility would be located.

The ONDRAF/NIRAS programme for such wastes is focused on study of the Boom Clay beneath the Mol-Dessel nuclear zone, and the biosphere component of the assessment considered the local context of the Mol–Dessel reference site. The approach to biosphere modelling accounted for the work of international projects that developed a systematic methodology for conceptual and mathematical modelling of the biosphere (i.e., the BIOMOVS [2] and BIOMASS [3] projects of the International Atomic Energy Agency).

The biosphere model that was used in SAFIR 2 is summarised here. The detailed assumptions and equations underlying the model are given in [4, 5, 6] and are not repeated here.

2. Regulatory requirements and provisions

The Belgian regulator (FANC) has recently issued guidance on the management of license applications, which contains safety principles that apply to any disposal facility for radioactive waste in Belgium [7]. FANC is currently developing more detailed guidance for near-surface disposal facilities that will be issued in the next two years. The development of more detailed regulatory guidance for geological disposal facilities is also planned, and will be based in large part on the guidance developed for near-surface disposal facilities.

At the time the SAFIR 2 study was conducted, there was no regulatory guidance in Belgium pertaining specifically to radioactive waste disposal facilities. Therefore, international guidance was used as a basis for the study.

The main assessment endpoint considered in SAFIR 2 was annual individual radiological impact.

3. Key terms and concepts

The *annual individual radiological impact* is the annual effective dose to an individual in the critical group or in a representative exposed group.

A *critical group* is a hypothetical but conceivable group of people, which is reasonably homogeneous with respect to its exposure to a given radiation source, for a given exposure pathway(s) and dose or equivalent dose (as applicable) from this source through the given pathway. Critical groups must be determined in such a way that the expected radiological impact on future generations will be no greater than the levels regarded as acceptable today. Members of a critical group display average dietary and living habits – they belong to a critical group based on the substantial time they are assumed to spend in contaminated areas and to the level of contamination of their food.

The radiological impact to an individual of the critical group was assessed using the *a posteriori approach*, as presented in BIOMASS [3], and in which all possible contributions to radiological exposure from all relevant exposure pathways are assessed in order to determine which combination of characteristics of human behaviour lead to the highest dose or risk.

The results of the biosphere modelling are expressed as *dose conversion factors*. These are maximum annual doses per unit of input flux or per unit of concentration of the radionuclide in the biosphere receptor concerned. Dose conversion factors are used to calculate individual radiological doses for the calculated radionuclide fluxes and concentrations in the biosphere receptors.

The *biosphere receptor* is a medium in the biosphere that receives radionuclides after their release from the disposal facility and their migration through an aquifer.

4. Treatment in the safety case

There are a number of ways in which the radionuclides released from a geological disposal facility can reach the biosphere. Many features, events, and processes, (FEPs) play a part in this, and involve the characteristics of the disposal facility and the geological environment, and relevant physical, chemical, mechanical, radiological and biological processes.

Two types of scenario are considered:

- The normal evolution scenario (NES), containing FEPs that are certain, or almost certain, to occur. This is the most likely scenario.
- Alternative or altered evolution scenarios (AES).

The biosphere receptors considered in SAFIR 2 were:

- A well.
- Surface water (a river or pond).
- Soil, where the aquifer extends into root zone.

From these biosphere receptors, the radionuclides can be dispersed into the biosphere by natural processes and by human action, and can accumulate in different biosphere media. Eventually, humans will be exposed by the presence of or through the use of the contaminated media. This can happen via three pathways:

- Ingestion of contaminated food or water.
- Inhalation of contaminated air.
- Direct radiation from contaminated soil, water or sediment.

Over the periods considered in long-term safety assessment, the characteristics of the biosphere will change. In particular, changes in the habits and behaviour of the exposed (critical) groups can be important, and could occur within just a few decades or centuries. Relevant changes could occur in farming techniques, for example, or in human lifestyles and dietary habits. However, most of these changes are difficult to predict and harder to quantify. Therefore, in the initial approach to assessment of the NES, it was assumed that the present-day state of the environment will continue unchanged. Thus, the present-day biosphere is taken to be the reference biosphere. The NES with constant biosphere is discussed further in Section 4.1.

Climate change will have a significant impact on human exposure. However, there are major uncertainties in the time of occurrence and potential effects on the biosphere. Further analysis of the NES considers climate sequences that can occur as a result of changes in the Earth's orbital (Milankovitch's theory) [11] or climatic warming. Climatic warming caused by human activities – the greenhouse effect – could have significant consequences for the biosphere in the near term. Analysis of the NES shows, however, that radionuclides will only reach the biosphere after several thousands of years. Depending on the timescales considered, the climate types that must be taken into account comprise the present-day climate, a warm climate (‘Mediterranean’ type), a cold climate (‘boreal’ type), and a very cold climate (‘peri-glacial’ type). These different types of climate are dealt with in the NES with biosphere changes, and are discussed in Section 4.2.

For the NES, the times which the radionuclides in the biosphere need to achieve equilibrium in the different compartments (media), assuming constant release from an aquifer, are usually much shorter than the times over which the release can vary to any degree. Therefore, an equilibrium model can be applied in which the concentrations of radionuclides in the various biosphere compartments can be derived from each other on the basis of simple ratios or analytical solutions (taken at certain times) of linear differential equations that describe the transfers of radionuclides between the compartments. The exposure and individual dose is then calculated from the concentrations of radionuclides in the biosphere media.

In the biosphere model for the NES with constant biosphere, the parameters that characterise the biosphere are assigned best estimate values that are constant in time. It is also possible to use this biosphere model for the NES with climate change, provided the values of the parameters that are affected by climate change, e.g. those of irrigation flow rates, can be adapted to the climate considered.

The alternative or altered evolution scenarios (AES) deal with potentially disruptive events whose occurrence is uncertain, but which – if they do occur – can cause higher levels of radiological exposure. These events or scenarios are systematically identified with reference to their effects on barriers. Important scenarios are those in which both the natural and the engineered barriers of the disposal system are short-circuited, and transfers of radionuclides to humans can take place almost instantaneously. Such scenarios can be brought about by human intrusion, such as exploratory drilling. Human intrusion could theoretically take place just a few hundred years after the end of the operational period. Some types of intrusion could lead to a relatively high dose for a small number of persons. The dose impact can usually be calculated directly from exposure times and contamination levels, and only a simple biosphere model is required. The AES are discussed further in Section 4.3.

4.1 Normal evolution scenario with constant biosphere

4.1.1 Receptors and exposure pathways

As stated previously, the radionuclides released from the disposal facility will reach the biosphere via transport by groundwater in the aquifer. The biosphere receptors considered are:

- A well sunk into the radionuclide-bearing aquifer on the edge of the disposal facility (in the direction of the groundwater current). A limited flow rate is attributed to this well so that dilution with uncontaminated groundwater is minimised.
- Small water courses - brooks that the radionuclides can reach through transport by groundwater.
- Larger water courses - rivers that the radionuclides can reach through transport by the groundwater and/or via smaller water courses.
- Fish ponds fed by contaminated groundwater. Transport calculations carried out previously [8] indicate, however, that the input of radionuclides that can be expected in these ponds is minimal; therefore, these fish ponds are not considered further.
- The soil (root zone), which the radionuclides will reach through transport by groundwater.

From these receptors, the radionuclides will disperse further into the biosphere and transfer to other biosphere media. This can happen by natural means as a result of:

- Transport by the water in the rivers.
- Uptake by fish in the rivers.
- Deposition onto the sediment bed of the rivers.
- Root uptake by crops grown in contaminated soil.
- Ingestion of contaminated soil and crops by animals.

Radionuclides are also spread and transferred in the biosphere by human intervention:

- Use of water for production of drinking water (for human consumption), irrigating crops (fields and pastures), and watering of cattle.
- Use of contaminated soil for crop cultivation and cattle grazing (on pastures on the contaminated soil).

Other uses of the receptors do not lead to the spread or transfer of radionuclides in the biosphere, but cause direct exposure of humans, e.g. use of the river for leisure or fishing. Note that the media need not be actually used – human proximity to the contaminated media can be sufficient for exposure to occur. The main ways in which humans can be exposed, and for which dose conversion factors are needed, are:

- Ingestion of contaminated drinking water.
- Ingestion of contaminated food crops.
- Ingestion of contaminated milk and meat.
- Ingestion of fish from the contaminated river.
- Inhalation of particles resuspended in the air above the contaminated fields.
- Inhalation of radon from radium in the soil.
- External irradiation on the contaminated fields.
- External irradiation on riverbanks from contaminated sediment.

External irradiation on the water (boating, fishing) or in the water (swimming) is not considered because the external dose rates and exposure times are far lower than with exposure from contaminated sediment.

Figure 4.1 provides a schematic overview of the biosphere transfers and exposure pathways considered in SAFIR 2. The assumptions and equations governing the various transfers are derived in [4, 5, 6], and are summarised in the main report of SAFIR 2 [1].

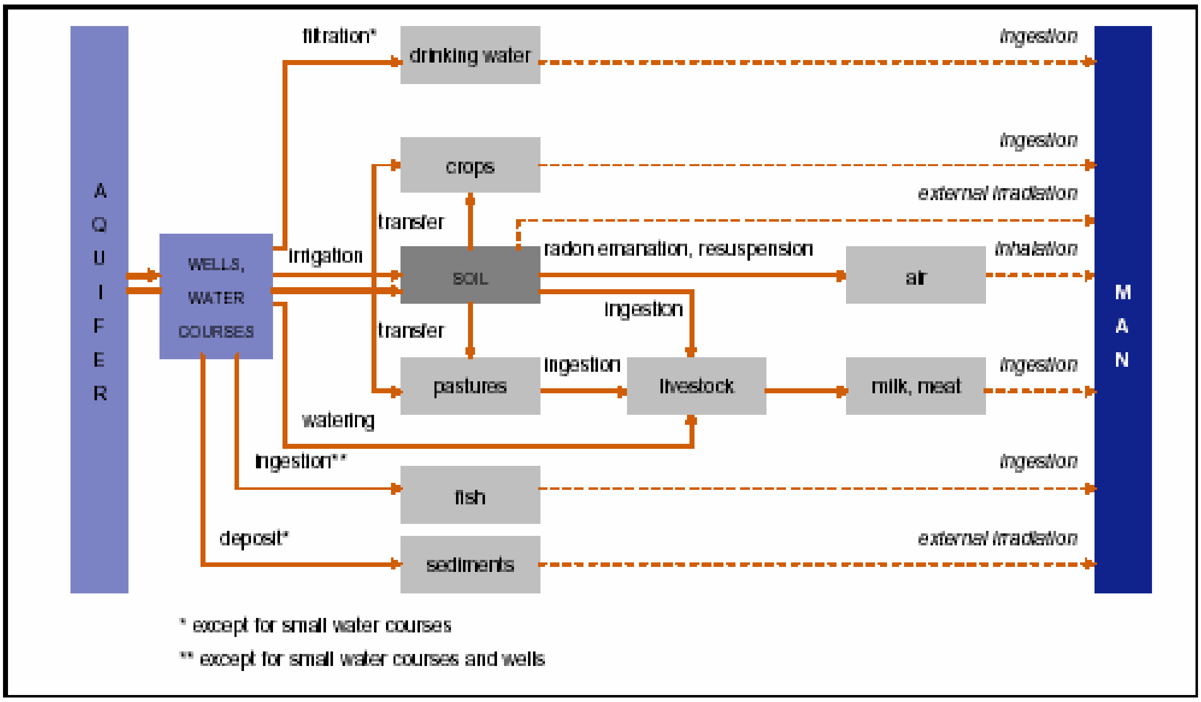

Figure 4.1: Conceptual model of the biosphere in SAFIR 2 [1]

4.1.2 Dose calculations

Critical group exposures are calculated from ingestion, inhalation and external irradiation. The committed annual doses to members of the critical group owing to the types of exposure are easily calculated from the concentrations of radionuclides in the relevant biosphere components:

- The ingestion dose is calculated by multiplying the concentration of radionuclides in drinking water and foodstuffs by the annual amounts consumed and the dose factors for ingestion.
- The inhalation dose is only considered for farmers on the field, and is calculated by multiplying the concentration of radionuclides in the air with the annual amount of contaminated air inhaled (= exposure time x inhalation rate) and the dose factors for inhalation.
- The external irradiation dose is considered for farmers on the field and anglers on the river bank (the same persons), and is calculated by multiplying the concentrations in the soil or in the sediment with the annual exposure times and with the dose rate factors for external irradiation. Allowance must also be made for any reduction factors for the geometry of the source and for shielding. It is assumed that the exposure point of the critical group on the river banks is at the downstream end of each of the considered river sections. These are the locations with the highest level of contamination of the sediment for the river sections considered.

For dose assessment for radionuclides from decay chains, allowance is made for the ingrowth of radioactive daughters during migration in the geosphere and in the aquifer. Long-lived radionuclides will be in equilibrium with their shorter-lived daughter radionuclides. For long-lived daughter radionuclides (e.g., with half-lives greater than 1000 years), the growth from the parent radionuclide during migration through the geosphere and the aquifer is calculated and the doses determined separately. In contrast, short-lived daughter radionuclides are taken into consideration by adding their dose factors to those of their parent.

4.2 Normal evolution scenarios with biosphere changes

Changes will occur in the biosphere owing to climate changes. These are gradual changes where the biosphere model for the NES with constant biosphere continues to apply, subject to the adjustment of certain parameter values to account first for global warming and then for future glaciation. In the very long term (>100,000 years), major changes can be expected in the biosphere (e.g. a succession of ice ages and interglacial periods) as a result of which the NES biosphere model will cease to apply.

Future climate changes and their influence on the performance of a geological disposal facility have been considered in [9, 12], but it has not been possible to formulate robust decisions as to how to perform an assessment of radiological impact owing to the lack of adequate data about the consequences of these climate changes. Climate changes can have repercussions on:

- The biosphere receptors and their characteristics.
- The transfer parameters between biosphere compartments.
- The exposure pathways and location of the exposed group(s).

One important factor is the groundwater balance, which is highly sensitive to climate changes. These changes will have a significant effect on precipitation, evapotranspiration and irrigation which, in turn, determine the rate of infiltration. The rate of infiltration is an important parameter for radiological impact calculations (through the leaching rate from the soil). Changes in irrigation flow rates also represent an important factor about which not enough is known. It is generally assumed that a colder climate would lead to a drop in irrigation while a warmer climate would require more irrigation. However, aside from the certainty that a glacial climate would need no irrigation, much would depend on the exact amount of precipitation and its distribution throughout the year. The changes in the types of crops grown as climatic conditions change will also be an important factor.

As far as the biosphere receptors are concerned, it can be assumed that the well and the major river will continue to act as receptors under a changed climate, albeit with different (unknown) characteristics as regards the input flux of radionuclides and water flow rates. Smaller water courses and the soil may cease to act as biosphere receptors, certainly in a glacial climate (because of permafrost) and possibly in a warmer climate (as a result of drying out).

As far as transfers in the biosphere are concerned, much depends on the rate of infiltration in the soil and on the irrigation rate of the crops. In a glacial climate, the types of crops and livestock and the methods of husbandry will change dramatically.

The exposure pathways of the exposed groups are closely linked to their habits and customs, which will adapt to any changed climate. Under extreme climatic conditions, such as in a glacial climate, certain exposure pathways will no longer be present, e.g. leisure activities on river banks. The consequences of climate changes on customs and habits could include (*inter alia*):

- Higher consumption of drinking water in a warmer climate.
- Greater intake of certain foodstuffs in a colder climate (higher demand for calories).
- A change of exposure times.

The location of the potentially exposed groups could also change significantly. A glacial climate could prompt a significant population migration to coastal areas and a reduction of inhabitants in inland areas. If this happened, the critical group could become a group of fishermen dwelling on the coast.

Few is known about the key parameters to be able to account for biosphere changes in radiological impact assessments with any confidence. That is the reason why the biosphere

is neither a barrier nor a component of the disposal system but considered as a receptor of the radioactive flux in safety assessment calculations. It results that the calculated doses in the near and far future can only be interpreted as indicators of safety and not as a prediction of anticipated future doses.

4.3 Alternative evolution scenarios

The AES include scenarios that can change or disturb the biosphere or the entire disposal system. While the AES do not occur with certainty, they may result in significant doses if they do occur. These disturbances *may* mean that the radiological impact will have to be assessed in a different way from the NES, and their probability of occurrence may also have to be taken into account.

For a systematic analysis of the potential AES in SAFIR 2, the disposal system was reduced to its two main barriers – engineered, geological (host clay rock) - and the hydrogeological system. Several types of disturbance of natural and human origin were proposed, each of which bypassed specific main barriers or rendered them ineffective. Several of the AES influence the biosphere and *may* require an adjustment of the biosphere model or its source term. The AES need to consider:

- ***The greenhouse effect*** (affecting the hydrogeological system). This effect was not considered further as at the time of the SAFIR 2 study it was thought to operate over timescales much shorter than required for the migration of radionuclides to the biosphere in the ONDRAF/NIRAS disposal concept (several thousand years). Moreover this effect had no consequence on the Boom clay.
- ***An exploitation borehole*** (a well located in the aquifer underlying the host clay formation). Pumping of water from an aquifer was investigated. The biosphere model for the NES, with a well as biosphere receptor, still applies to this scenario.
- ***Glaciation*** (affecting the hydrogeological and geological barriers). Sub-glacial and glacial erosion can occur in a severe ice age. These phenomena alter the topography of the biosphere and the lithostratigraphy of the soil and affect the geological barrier and hydrogeological system. If humans return during the subsequent inter-glacial period, this can result in more direct exposure pathways (e.g. direct irradiation by the remnants of the waste) and a more rapid contamination of the media (water and soils) used by them.

  A more severe glacial period than the last glacial periods of the Quaternary might be assumed in the safety assessments, with the possible formation of glaciers in the Mol-Dessel region and subglacial erosion compromising the geological and engineered barriers. Based on the orbital theory of Milankovitch, a glacial period is predicted that will be comparable in severity with the three most recent glacial periods of the Quaternary.
- ***An exploratory borehole penetrating the disposal facility*** (affecting all barriers). Three variant scenarios can be considered: (1) contaminated drill cores are examined in a laboratory; (2) contaminated drilling waste is left on site, with potential exposure of future inhabitants; and (3) the borehole is not filled and groundwater comes into contact with waste, allowing radionuclides to leach directly into groundwater. The third variant requires no adaptation of the biosphere model for the calculation of dose, but the model must be adapted for the other two variants. However, individual dose can be calculated from exposure times and contamination levels and requires only a simple model.

Exploratory borehole AES – particularly the examination of contaminated drilling cores – can give rise to relatively high individual doses for the critical group, which, however, consist of a small number of people. Such scenarios are inherently uncertain and have a low probability of occurrence, and their relevance to assessing the long-term safety of a geological disposal facility is unclear. For example, it can be noted that geophysical measurements play a central role in the drilling of exploratory boreholes today. Such measurements would establish the presence of high radioactivity during drilling (instrumentation in the drill head) or during subsequent downhole measurements, and thereby eliminate the risk of high exposure during the analysis of drilled cores. Similar thinking applies to future generations with a level of knowledge comparable to, or more advanced than, our own. For possible future generations with a level of knowledge significantly lower than our own, it is unclear whether they would be capable of drilling deep boreholes and performing detailed laboratory analysis of the samples.

To conclude, it may be interesting to assess the radiological consequences of such AES, but it is impossible to apply quantitative risk criteria [10]. Such AES can be used to illustrate the most extreme consequences of disposal (i.e. what happens when all barriers fail?), but they cannot be used to judge safety.

5. Lessons learned and future programme

A well-developed biosphere model was implemented in SAFIR 2, based on international good practice from IAEA projects such as BIOMOVS and BIOMASS. Consideration was given to a NES with a static biosphere, a NES with a biosphere that responded to expected, but uncertain, climate changes, and AES with a biosphere that responded to potentially disruptive events. It is possible to calculate doses for all of these scenarios, but there are large uncertainties associated particularly with the NES with biosphere changing in response to climate change and the AES.

Further work on understanding the way climate change could impact the biosphere over long timescales could build confidence in dose calculations. Such work has been conducted recently at international level (e.g. European Commission BIOCLIM project). It seems however that substantial improvements of the prediction of the biosphere evolution on timescales of the order of a geological disposal system will remain impossible. Therefore the methodology intended to model the biosphere in SFC1 will be based on a stylised approach representing a biosphere in today conditions. Different stylised climate states will be taken into account in alternative assessment cases of the reference or altered scenarios. No time sequence of future climate types will be considered in SFC1. Recent climate model studies tend to indicate that global warming would retard significantly the occurrence of a glacial era in Northern Europe by tens of thousand years [13].

ONDRAF/NIRAS will learn from the recent and ongoing international work and related work in other countries in undertaking its next major assessment – the Safety and Feasibility Case 1 (SFC 1) – planned for 2013.

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PART 10: HUMAN INTRUSION

(Prepared by Thomas Beuth, GRS)

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Revision: 2

1 Background/ Introduction

1.1 General Information

The topic "Human Intrusion" is one of overall 11 topics which have to be dealt within the framework of RTDC-1 of the integrated project PAMINA. The main objective of RTDC-1 is to provide a current and comprehensive overview of safety assessment methodologies, tools and experiences along with the identified Safety Case topics.

This task report summarises the main facts, aspects, and views regarding human intrusion. The basics for the task report were primarily the contributions to the topic from several participating organisations (from hereon referred to as the ‘contributors’) and the findings gained in a workshop of the participants. Additionally, recommendations from international organisations are considered and also statements of national organisations from countries with advanced disposal programmes, which do not participate actively in the project PAMINA. Table 1.1 shows the organisations which provided a report to the topic human intrusion. Submitted reports are enclosed in the appendix.

Table 1.1: Organisations which provided a contribution to the topic “Human Intrusion”

Acronym	Organisation	Country
ANDRA, IRSN[1)]	Agence Nationale pour la Gestion des Déchets Radioactifs, Institute de Radioprotection et de Sureté Nucléaire	France
ENRESA	Empresa Nacional de Residuos Radiactivos S.A.	Spain
FANC, BEL V[2)]	Federaal Agentschap voor Nucleaire Controle, BEL V	Belgium
GRS-BS	Gesellschaft für Anlagen- und Reaktorsicherheit mbH (Braunschweig)	Germany
GRS-K	Gesellschaft für Anlagen- und Reaktorsicherheit mbH (Köln)	Germany
NDA	Nuclear Decommissioning Authority	United Kingdom
NRG	Nuclear Research & Consultancy Group	Netherlands
NRI	Nuclear Research Institute Rez plc.	Czech Republic
POSIVA	Posiva Oy	Finland
SCK•CEN, ONDRAF/ NIRAS[3)]	Studiecentrum voor Kernenergie - Centre d'Etude de l'Energie Nucléaire/ Nationale Instelling voor Radioactief afval en verrijkte splijtstoffen	Belgium

[1)] IRSN follows Andra's explanations regarding the regulatory aspects.

[2)] BEL V follows FANC's explanations.

[3)] Joint contribution from SCK□CEN and ONDRAF/ NIRAS

This report includes several sections and an appendix with the following content:

Some general information concerning this document and an introduction into the subject human intrusion are given in section 1. Section 2 addresses existing regulations and guidelines in terms of human intrusion. Different aspects concerning relevance, usefulness, and expectations to regulations and guidelines are considered. A detailed overview of definitions regarding "human intrusion" and other used terms are presented in section 3. Section 4 presents the underlying methodologies for the treatment of human intrusion in different countries and section 5 sets the focus on the application of the methodologies and lessons learnt. New developments, possible trends, and revised views are the subject of section 6. Section 7 summarises the essential aspects of the previous sections. Section 8 contains references which are of common interest e.g. international documents or important reports from countries that did not prepare a contribution. For more detail, the reader is referred to the papers and respective references presented in the appendix.

The topic "Human Intrusion" is related to other topics in RTDC-1 such as "Definition and Assessment of Scenarios" and "Analysis of the Evolution of the Repository System" which will be handled separately. These topics are addressed in this task report. Details concerning the related topics are subject of the respective task reports.

Quotations and Relations to the contributions in the following sections are indicated as follows:

- These signs "<< " and ">> " indicate the beginning and end, respectively, of an extract or quotation of text from a contribution.
- The acronym of an organisation enclosed in brackets indicates the reference of the contribution, e. g. [ENRESA].

1.2 Human Intrusion

The worldwide favoured option of isolating highly active and long-lived radioactive waste is disposal in deep geological formations. The proof of the safety of such disposal systems has to be demonstrated in a safety case. An essential component in the framework of the safety case is the scenario development, wherein the features, events and processes (FEPs) that affect the evolution of the disposal system have to be identified, and combined to give representative scenarios. In carrying out a safety analysis the possible consequences have to be calculated from the developed scenarios.

The evolution of the disposal system can be affected in principle by natural induced phenomena, anthropogenic phenomena as well as waste and repository induced phenomena. In terms of “anthropogenic phenomena“ human activities that alter the isolation capacity or the site situation of the disposal system are often distinguished from activities that destroy or directly bypass the isolation capacity (cf. also section 3). The latter activities will be termed as “Human Intrusion“ (HI) and are the subject of this document.

The following list includes the key issues, which were subject in most of the discussions of national and international organizations:

- Predictability of HI;
- general assumptions and provisions;
- likelihood and probability of HI;
- measures against HI;
- types of HI actions and scenarios;
- anomalies and noticeable features;
- evaluation criteria, exposures, limits, and consequences.

Each of the listed items is discussed in detail in the respective subsections of section 4 “Methodology”.

2 Regulations and Guidelines

Regulations and guidelines are, in general, a worthwhile basis for both the developer and the evaluator. The developer benefits from guidance which indicates how the compliance with provided requirements could be demonstrated. The evaluator can draw on a framework given by regulations that facilitates the review work, assessments etc. of relevant records in the licensing procedure.

Therefore, regulations should not only include requirements that have to be fulfilled by the developer, but also acknowledge inevitable uncertainty about future developments. Moreover, they should offer guidance in areas with great uncertainties about the future that makes uncertainty management difficult. This applies especially to the topic “Human Intrusion“ where accurate predictions are not possible and it is known that human actions can lead to high radiological exposures, for humans and the environment under certain circumstances.

In principle, international guidance is addressed in the respective legal national frameworks. The international guidance gives some recommendations as to how “Human Intrusion” should be treated. These recommendations are understandably, for the most part, rather general and not specific. However, the recommendations constitute an initial basis for the elaboration of specific national rules and guidelines with respect to the topic “Human Intrusion”.

The regulations and guidelines considered in this section refer to HI in relation to the disposal of high active waste in deep geological formations. The review of the different contributors to HI has yielded the following:

All in all four of the participating countries, namely: Czech Republic, Finland, France, and UK have regulations or guidelines in place where the subject HI is addressed.

In Belgium, a specific regulatory framework, applicable to both near-surface and geological disposal facilities is currently being developed. A general guide and a number of associated guides, including for HI, already exist for near-surface disposal facilities. This guide will be used when developing the regulation related to geological disposal [FANC].

The existing regulations in Germany include no specific regulatory requirements for HI. These regulations are currently being revised to address the issue of how to deal with HI in the safety case.

Other participating countries like the Netherlands and Spain presently have no regulatory requirements or provisions that directly relate to the topic of HI.

Apart from the above contributors, there are some recommendations to HI from international organisations such as the IAEA, ICRP and OECD/ NEA. In addition to these international recommendations, some national regulating views from European countries like Sweden and Switzerland that do not participate actively in PAMINA, but have an advanced waste disposal programme, will be referenced in this document, as required.

It should be noted that guidelines and regulations affect for some part the methodology regarding the treatment of HI in the safety case. Furthermore, it is in the nature of things that HI has in terms of the predictability and associated uncertainties a great influence on both the regulation and methodology. Therefore, it was decided to address the key aspects of HI in section 4 “Methodology“ including those aspects which actually relate to the task of the regulators.

Outcome of the workshop:

The outcome of the workshop that directly relates to the expectations of guidelines and regulations for HI is addressed as follows:

- The treatment of HI should be addressed in regulations and guidelines provided by the respective responsible authorities.
- Requirements concerning the framework, scope of the investigations, constraints and conditions etc. should be provided.
- The relevant actions e.g. drilling, mining for HI scenarios should also be provided.
- It should be acknowledged that selected HI scenarios can never be complete or comprehensive.
- HI scenarios should be determined on a stylised basis, since a systematic development of HI is not possible.
- It should be a requirement that HI has to be considered in the site selection process and in the design phase of a repository.

There is some information from the regulator part that it will be the task of the implementer to develop a strategy how to deal with human intrusion:

<< SKI (the Swedish Nuclear Power Inspectorate) pointed out that SKB:

“… must develop their own strategy for how issues relating to human intrusion should be handled in future safety assessments.” >> [SKB, 2006]

3 Terminology

There are many national and international references which describe the study of human impacts on repositories of radioactive waste. The terms used for those impacts vary widely, e.g. human events, intrusion events, future human actions, inadvertent actions, human intrusion etc. Some of them are similar and some are slightly different in their meaning. In this context, human intrusion as the subject for this task report constitutes a subset of the overall term human action. Human actions can be divided into those that influence the environment of the disposal system, e.g. alteration of the groundwater flow regime, and those which directly impair or bypass the barriers or safety functions of the disposal system e.g. drilling of a borehole through the waste emplacement area. Further examples for both types of human actions can be found in [NRG]. As mentioned in section 1.2, human actions of the latter type which are caused inadvertently, i.e. without knowledge of the repository site and the hazard of the waste, are called human intrusion.

Given the fact that there are different methodologies, approaches and procedures for addressing human intrusion in safety cases, it is understandable that the meaning and also the number of terms and terminologies vary significantly. The use of different terms and additional concepts accompanying the topic of “Human Intrusion” like deliberately, intentional, unintended, stylised, future human actions etc. does not help and may even lead to some confusion. At the very least it makes the communication on a national as well as international level more difficult. Therefore, international bodies, like IAEA, ICRP and OECD/NEA aim for a common harmonized terminology and provide glossaries and definitions in the area of nuclear technology and waste disposal. However, in this case, the IAEA glossary does not provide definitions for human intrusion, human action, inadvertent action or other related terms. In this context the following definitions are given from ICRP and OECD/ NEA:

<< A human action affecting repository integrity and potentially having radiological consequences is known as human intrusion. >> [ICRP, 1998]

<< ... by definition, an intrusion event bypasses some or all of the barriers that have been put in place as part of the optimisation of protection. >> [ICRP, 1998]

<< Future human actions of concern are those occurring after repository closure that have the potential to disrupt or impair significantly the ability of the natural or engineered barriers to contain the radioactive wastes. >> [NEA, 1995]

Examples from references of national organisations that do not actively participate in RTDC-1 of the integrated project PAMINA are as follows:

<< ... future human activities are activities that may take place in the vicinity of the disposal site at some time in the future and which may affect the performance of the repository by by-passing or affecting the characteristics of the engineered and natural barriers. >> [SKI, 1999]

<< Intrusion is defined as “inadvertent human actions that impair the protective capability of the repository” >> [SKB, 2006]

There are few definitions relating to HI from the contributors, but the terms and definitions used correspond more or less with the terminology from international bodies. The main observations from the contributors can be summarised as follows:

- No specific definition related to HI is given [ANDRA].
- No formal definition for HI is given, but the definition provided by NEA is applicable [ENRESA].
- Distinction between HI and FHA is made. A description to HI scenarios is given [GRS-BS].
- Used terms correspond mostly to the terminology proposed by international bodies like IAEA, OECD/ NEA [NDA, NRI, POSIVA].
- No terms, definitions etc. related to HI were given [NRG].
- Definitions of terms related to human intrusion are provided. The definitions to FHA and inadvertent actions are used from a NEA report. A definition to HI is also included in the contribution of [SCK•CEN, ONDRAF/NIRAS]
- Some concepts like SF, disposal system etc. are described. A definition to HI is also included in the contribution of [FANC].
- There are no definitions and descriptions of terms and concepts related to HI in the legal regulatory frame [GRS-K].
- Several definitions, terms and concepts regarding the HI topic were listed for the most part from a NEA document and from recent developments. This includes definitions to FHA, HI, stylized scenarios, inadvertent actions and intentional actions [GRS-K].

As a result, only four out of ten contributors provide a definition for HI. These are cited in the following:

<< Human action causing partial or full degradation of one of several safety barriers of the disposal system, and that may expose the author of the intrusion (named as “the intruder”) or the surrounding population to a radiological risk. >> [FANC]

<< ... inadvertent action that has the potential to disrupt or impair significantly the ability of the natural or engineered barriers to contain radioactive waste >> [SCK•CEN, ONDRAF/NIRAS]

<< Human intrusion scenarios comprise those future human actions that lead to a direct penetration of a repository and damage the barriers within the backfilled and sealed repository area and the host rock. These may either cause direct releases into the biosphere or impair the barrier system of the repository or its safety functions. >> [GRS-BS]

<< Human intrusion (HI) is understood as any human activity following the closure of the repository mine that will directly damage the barriers within the backfilled and sealed mine workings and the isolating rock zone /AKS 08/. >> [GRS-K]

It should be pointed out that the above listed definitions of both national and international organisations are rather different in terms of the wording. However, the general statement that human actions involve a direct damaging of barriers is more or less the same.

Outcome of the workshop:

Like other topics of RTDC-1 of the integrated project PAMINA, it would be a great challenge to harmonise the used terminology relating to HI across the participating organisations and countries. There is no mandatory reason for it. However a common understanding of used terms is necessary in order to avoid misunderstandings. As a result of the workshop the participants agreed on the following description with respect to HI:

Description of HI:

HI can be understood as human actions which have the potential to directly jeopardise the isolating capacity of the barriers of the disposal system and therefore might have radiological consequences.

Additional notes:

The term “disposal system” in the description above, can be defined as the combination of engineered and natural barriers that isolate radioactive waste when disposed in geological formations (this definition corresponds to a large extent to the provided definition in the US Environmental Standards for Disposal 40 C.F.R. § 191.12 Definitions).

Other terms:

It was further agreed by the participants that other terms associated with HI will be those adopted by the NEA [NEA, 1995]. These include, for example, the following terms relating to unintended and intentional actions:

Unintended actions:

<< Those in which either the repository or its barrier system are accidently penetrated or their performance impaired, because the repository location is unknown, its purpose is forgotten, or the consequences of the actions are unknown. >> [NEA, 1995]

Intentional actions:

<< In contrast, if future intruders are aware of the waste and the consequences of disturbing the repository or its barrier system, then their actions are intentional. >> [NEA, 1995]

Another commononality relates to stylisation of HI scenarios. Stylised HI scenarios are composed of regulatory provisions and should take into account the specific conceptual design of the disposal system as well as present site conditions.

4 Methodology

This section primarily considers the treatment of HI from a methodological point of view as well as safety issues. In addition, regulatory aspects as described in section 2 will be also discussed in this section due to the close connection of required/ expected regulations and the methodology with respect to the handling of HI.

The concept of concentrating and isolating the radioactive waste in a disposal system involves an increased risk of radiation exposure in the case of HI. Otherwise, the prediction of safety cases in terms of when, where and how future generations might intrude into the disposal system is strongly limited even in the short-term after closure of the repository and will be impossible as time goes by. This in turn determines on the one hand the requirements of regulations and guidelines, and the development of the methodology for the treatment of HI in the safety case on the other.

Methodological viewpoints should demonstrate the strategy of how to deal with possible future impacts on the disposal system caused by human beings and the underlying conditions, assumptions, arguments and provisions for analysis.

Regulatory viewpoints should provide the framework and the expected scope for the investigation of HI and should also give guidance on how to interpret calculated consequences.

Different key aspects for the treatment of HI are considered e.g. assumptions, the likelihood of such events, possible measures against HI, assessment of consequences etc. (cf. also section 1.2), and will be presented in the following subsections:

4.1 Predictability of HI

There is a broad consensus that human behaviour cannot be predicted with the necessary accuracy over the relevant timescales for radioactive waste disposal. There are several examples of this conclusion in the following text from international organisations, national organisations and participating organisations:

<< The representation of future human behaviour in assessment models is necessarily stylized, as it is not possible to predict behaviour in the future with any certainty. >> [IAEA, 2006]

<< The inherent difficulty in predicting human actions and our own inability to delve into the far future will always limit the ability to make definitive statements about the risks to future societies from the disposal of long-lived wastes. >> [NEA, 1995]

<< The prediction of future human actions is fraught with uncertainty >> [NEA, 1995]

<< ...there is little or no scientific basis for predicting the nature or probability of future human actions... >> [ICRP, 1998]

<< Future human actions that can affect the safety of a repository involve questions concerning the evolution of society and human behaviour. These are questions that cannot be answered by conventional scientific methods. For example, it is not possible to predict knowledge that does not exist today, and knowledge is judged to be a key factor in this context. >> [SKB, 2006]

<< Swiss regulations (HSK and KSA, 1993) acknowledge the impossibility of predicting future human actions, but do require events and processes that could disrupt a repository to be considered in developing scenarios. >> (note that this statement refer to Swiss regulations) [SKI, 1999]

<< …we conclude that there is no technical basis for predicting either the nature or the frequency of occurrence of intrusions. >> [NAS, 1995]

<< Given the impossibility to predict future human actions and technologies, the assessment

of the impact of human intrusion will be made by means of arbitrary stylized scenarios. >> [FANC]

<< ...the evolution, way of life, and behaviour of the society, inclusive human intrusion, cannot be predicted over time frames, which have to be considered for the isolation period of radioactive wastes. >> [GRS-K]

<< There is agreement that the development of the mode of live and the behaviour of mankind, or social communities can only be assessed over a short time frame of few generations. >> [GRS-BS]

<< Assessments of the post-closure safety of a repository typically extend over periods of hundreds-of-thousands of years. Over this period of time, the form of human society will change in a manner that cannot be predicted. >> [NDA]

Outcome of the workshop:

As a result from the contributions, other references and the discussion at the workshop, the participants agreed unanimously to the following statement:

HI cannot be predicted over timescales which are relevant or of interest for the disposal of high active waste.

4.2 General assumptions and provisions

In the following there are some general assumptions and provisions which can be attributed to the fact that HI is unpredictable. These general assumptions and provisions can serve as a basis for the elaboration of rules and guidelines that provide the framework for the treatment of HI.

<u>Unintended and intentional actions:</u>

A distinction is often made whether the human intrusion will be performed intentionally or unintentionally. The difference indicates that in the case of an intentional intrusion the society/intruder is aware about the location of the repository and the associated hazard. An unintended intrusion in turn indicates that the society/intruder has no information and knowledge about the disposal site and the radiological hazard of the emplaced waste. There are some other terms for intentional intrusion and unintended intrusion in use. The different terms are discussed in section 3 “Terminology”.

For many countries it is only the unintentional human intrusion that has to be taken into account in safety cases. The intentional human actions are for some part considered in terms of protection goals (cf. [FANC]) but will be generally excluded from safety assessments. Examples from the contributors which include statements about unintentional and intentional actions are as follows:

<< ...it is necessary to fix a date before which no involuntary human intervention can occur because of the preservation of the memory of the existence of the repository. >> [ANDRA]

<< ENRESA has adopted NEA´s recommendation and only inadvertent human intrusions are analysed. >> [ENRESA]

<< ...both types of intruders should be protected through appropriate measures to be taken by the operator. However, as it is impossible to totally prevent deliberate intruders from accessing the waste, the main concern for determining the measures related to the intrusion problematic will focus on the protection of the inadvertent intruder. >> [FANC]

<< From the human intrusion scenarios, usually those initiated by an intentional intrusion are not included as they are in the responsibility of the respective society and the intruder is in charge of the radiological implications [NEA 95]. In case of inadvertent human actions the knowledge of the repository has to be lost at the time of occurrence. >> [GRS-BS]

<< It is exclusively considered the inadvertent human intrusion. Scenarios which describe the intentional human intrusion into the barrier system are not considered. These are put in the responsibility of the respective acting society. >> [GRS-K]

<< Human intrusion could be intentional or inadvertent. Intentional human intrusion, that is deliberate intrusion into the repository in the knowledge that it contains radioactive materials, is generally considered to be the responsibility of the society taking the action, and UK regulatory guidance states that the associated risks need not be considered in a performance assessment [2]. >> [NDA]

<< For the treatment of human intrusion the document states that only inadvertent intrusion, most often associated with a loss of memory of the existence of the repository, has to be taken into account... >> [SCK•CEN, ONDRAF/NIRAS]

Outcome of the workshop:

The above examples and the results from the discussion at the workshop lead to the conclusion that only unintended human intrusion has to be taken into account. Intentional human intrusion, i.e. human actions with knowledge of the disposal site and the hazardous waste, are the responsibility of the society taking that action.

<u>HI cannot be ruled out:</u>

The fact that human actions cannot be predicted with adequate accuracy for the required timeframe does not imply that those actions can be excluded from safety considerations. In fact, the contrary is the case.

With regards to the loss of information and termination of institutional control it was often stated by contributors that HI cannot be ruled out. Examples that reflect this context are:

<< The safety assessment methodology has to be developed based on the assumption that human intrusion cannot be ruled out after the release of the institutional control (postulated loss of memory of the repository existence). >> [FANC]

<< However since human intrusion scenarios, after loss of the information about the repository, cannot be ruled out, they have to be assessed within the overall safety case. >> [GRS-BS]

<< Inadvertent human intrusion into the repository system cannot be excluded totally, after a loss of information about the repository in the far future. >> [GRS-K]

<< It cannot be guaranteed, however, that intrusion might not occur at some time in the

future after administrative controls have been discontinued. >> [NDA]

<< Inadvertent intrusion can be assumed to be excluded during the period of institutional control which can last for 100 or 300 years. ... However at longer time scales the loss of information about the repository can take place. >> [NRG]

<< In spite of all the countermeasures, it cannot be completely ruled out that human being may, intentionally or inadvertently, intrude into the repository in the future. >> [POSIVA]

Outcome of the workshop:

There was a common consensus that HI has to be considered when discussing the safety of the disposal system. However, there were different opinions about where and how HI has to be treated in the safety case. There was overall agreement that this depends on the respective conditions and regulations in the different countries.

<u>HI cannot be developed systematically:</u>

As indicated in section 1.2, the evolution of the disposal system is in principle determined by natural phenomena, anthropogenic phenomena and waste and repository induced phenomena. The evolution is usually considered in safety assessments by a so called central scenario that reflects in most cases the expected evolution of the disposal system and a set of alternative scenarios which include additional potential evolutions. These scenarios should be developed in a systematic, transparent, and traceable manner through a structured analysis of relevant FEPs that are based on current and future conditions of the disposal site. Unfortunately, this requirement cannot be applied to HI scenarios due to the unpredictability of social behaviour and human actions. The following examples reflect this conclusion:

<< … a systematic development of the scenario group human actions is not possible. However since human intrusion scenarios, after loss of the information about the repository, cannot be ruled out, they have to be assessed within the overall safety case. >> [GRS-BS]

<< ...a systematic scenario development, like for natural phenomena, is impossible for human intrusion phenomena. >> [GRS-K]

Outcome of the workshop:

As a result from the discussion at the workshop the participants concluded the following:

It is not possible to derive HI scenarios in a systematic way as for other scenarios.

<u>HI scenarios should be treated separately from the other scenarios:</u>

Another issue is the consideration of HI scenarios in connection with the treatment of other scenarios such as the central scenario and altered scenarios. In this context there are some references that require human actions and HI scenarios to be treated separately. Examples of this are:

<< Because the assumed intrusion scenario is arbitrary and the probability of its occurrence cannot be assessed, the result of the analysis should not be integrated into an assessment of repository performance based on risk, but rather should be considered separately. >>

[NAS, 1995]

<< The human intrusion scenarios were distinguished from the other scenarios as exposure is the direct or indirect result of a deliberate human action in or close to the geological formation where the waste is stored. >> [NRG]

<< Scenarios involving unpredictable future human actions leading to the partial or full degradation of the isolation and/or confinement properties of disposal facilities (amongst which human intrusion) have to be considered independently from the other types of scenarios (such as the reference evolution scenario / altered evolution scenarios / "what-if?" scenarios) >> [FANC]

The participants at the workshop concluded the following:

HI scenarios should be treated separately from the other scenarios. In fact, HI should be already considered in the site selection process and in the design phase of a repository.

Stylised HI scenarios should be provided:

As previously stated the HI scenarios have to be provided in a stylised way. Stylised scenarios related to HI are taken as selected scenarios which have to be derived on the basis of specific repository plans and site conditions (cf. section 3). Stylisation comprises a set of conditions and provisions that should allow the developer to analyse the provided scenarios according to the respective requirements of the responsible authorities. Providing stylised scenarios is strongly related to rules and guidelines and is therefore one of the tasks of the regulator. In the following are some examples from international and national references as well as from the contributors that refer to stylisation and respective regulation:

<< Because the occurrence of human intrusion cannot be totally ruled out, the consequences of one or more typical plausible stylised intrusion scenarios should be considered by the decision-maker to evaluate the resilience of the repository to potential intrusion. >> [ICRP, 1998]

<< Irreducible uncertainties related to the biosphere and future human actions are treated by examining stylised and illustrative cases. >> [NAGRA, 2002]

<< Given the impossibility to predict future human actions and technologies, the assessment of the impact of human intrusion will be made by means of arbitrary stylized scenarios. >> (cf. also section 4.1) [FANC]

<< … the spectrum of human intrusion scenarios to be considered in a safety case should be confined and that the regulator should establish the boundary conditions for the development of such scenarios. >> [GRS-BS]

<< ...selected scenarios, referred to as reference scenarios (stylised scenarios), have to be established and analysed. >> [GRS-K]

<< ...the following aspects are essential for describing and analysing the reference scenarios:

- Intrusion area concerned

- Point in time for intrusion
- Waste category concerned
- Exposure type and exposure path
- Exposed group of people
- Spatial extent of a potential contamination. >> [GRS-K]

<< The human intrusion scenario is taken into account as a regulatory demand and it is not derived from FEP analysis. >> [POSIVA]

Outcome of the workshop:

The outcome of the discussion at the workshop was already mentioned in relation to the expectations of guidelines and regulations for HI. It was agreed that HI scenarios should be determined on a stylised basis, since a systematic development of HI is not possible (cf. section 2).

Today´s technology and practice should be assumed:

A set of assumptions is needed for both the selection and the analysis of stylised HI scenarios. The assumptions derive from issues such as data or information about drilling techniques and usual borehole dimensions. Since these data and techniques cannot be predicted over the timescale considered for intrusion, the status quo with respect to knowledge and technology is often assumed. These circumstances are reflected in the following statements from the contributions:

<< The characteristics of the borehole are based on the RFS III.2.f recommendation stating that « the level of technology used is the same as today »...>> [ANDRA]

<< For the evaluation of human intrusion scenarios in the safety case scenarios should be consulted that are based on today's social conditions and state of the art in science and technology. >> [GRS-BS]

<< The reference scenarios have to be selected on the basis of today´s social conditions, customs, behaviour patterns and state of the art in science and technology. >> [GRS-K]

<< To avoid any need to speculate how society and technology will evolve, the approach to the assessment of the human intrusion pathway is therefore to develop scenarios based on current technology and understanding ... >> [NDA]

<< ... only inadvertent intrusion, most often associated with a loss of memory of the existence of the repository, has to be taken into account and that the same level of technology as at present can be assumed. >> (according to Franco-Belge Working Group, 2004) [SCK•CEN, ONDRAF/NIRAS]

Outcome of the workshop:

The participants of the workshop concluded the following:

HI scenarios should be developed on the basis of today´s available technology and social behaviour.

4.3 Likelihood and probability of HI

The terms “likelihood“ and “probability“ are almost always mentioned in the discussion of HI. Actually, these terms mean nearly the same, but they are quite often used in a different context. The term “likelihood“ relates to a more qualitatively evaluation to the possibility that HI can take place and it is often used in connection with the requirement for reducing the risk of a HI event. On the other hand, the term "probability" is more used in a quantitative manner, concerning the discussion on how probable it is that a specific HI event occurs. This is known as the occurrence probability. The following are examples from an international organisation, a national organisation and a participating organisation that reflect the view of reducing the likelihood or risk of HI:

<< To isolate the waste from the biosphere and to substantially reduce the likelihood of inadvertent human intrusion into the waste >> [IAEA, 2006]

<< By locating the repository at a site where the host rock can be assumed to be of no economic interest to future generations, the risk of human intrusion is reduced. >> [SKB, 2006]

<< ...the main approach to dealing with the human intrusion issue for a geological disposal facility lies in the measures taken for limiting the likelihood of human intrusion events. >> [FANC]

The reduced likelihood of HI is often addressed in connection with information preservation, institutional control and avoiding sites with valuable resources. These issues are close to possible measures against HI and therefore will be discussed in the next section.

Some contributors mentioned that the likelihood of HI into a deep geological repository is low or possibly may be low. The following examples highlight this:

<< Therefore, it is necessary to assess such events and estimate their consequences, even though their likelihood may be low. >> [NDA]

<< It was considered in the preliminary safety assessment of the Czech concept of Deep geological repository [4] that the probability of human intrusion will be significantly reduced by meeting site selection criteria. >> [NRI]

<< Even if information about the repository were lost, it is very unlikely that someone would intrude or drill into the repository by accident. >> [POSIVA]

The conclusion from the workshop on the likelihood issue is presented in the next section. It should be noted that it seems to be somewhat contradictory that on one hand human behaviour and therefore HI cannot be predicted, and on the other hand it is believed that the likelihood of HI into the repository is low and furthermore that the likelihood can be reduced. The rationale behind this is that the likelihood cannot be reduced in the long run if the actual initiating actions, events, processes, motivations etc. are unknown.

Concerning the probability issue the contributors views are rather different. The following quotations reflect this:

<< ENRESA has focused on the definition and consequence analysis of a human intrusion event (or scenario), and no efforts are done to quantify the probability of the human intrusion. >> [ENRESA]

<< ...the probability of occurrence of a HI event could be considered as extremely low (and thus the resulting risk acceptable)... >> [FANC]

<< In a semi-quantitative approach the probabilities of occurrence of the scenarios and their radiological consequences had been classified for each generic repository. >> (according to a study of the BfS) [GRS-BS]

<< Protection criteria for such activities are not prescribed, since neither the probability nor the type of impacts can be assessed with an adequate degree of reliability. >> (according to the draft requirements from the BMU) [GRS-K]

<< It is difficult to assess the human intrusion pathway comprehensively, as the range of phenomena to be considered is difficult to define, and both the impact on the repository and its environs, and the probabilities of occurrence, are difficult to determine. >> [NDA]

<< ... it was decided that the probability of human intrusion is negligible and human intrusion will not be evaluated. >> [NRI]

<< Determination of the probability of the scenarios >> (according to the PROSA methodology) [NRG]

<< The working group of Nordic safety authorities, which discussed and drafted safety criteria for high-level waste disposal, concluded that the estimation of probabilities and consequences of human intrusion is very approximate or speculative. >> [POSIVA]

Outcome of the workshop:

Again, taking into account that human behaviour cannot be predicted, the majority of participants at the workshop conclude that it is not possible to derive occurrence probabilities for HI events.

It should be mentioned that also investigations were carried out in order to obtain some estimates of the probability for HI in certain areas based on historical drilling/deep exploration data for that area. For example UK aims to minimise the likelihood of HI by avoiding areas where they has been a history of drilling (e.g. for water or mineral resources).

4.4 Measures against HI

The treatment of HI in the safety case calls for the identification and investigation of possible measures that can prevent or hamper such actions or mitigate their consequences. In this context, almost always the same questions arise regarding the effectiveness, effective period and reliability of measures against HI. Another issue in some cases is the requirement that measures should not influence each other and that they should not impact to other safety concern.

Some of the measures should be considered and implemented in due time, in particularly those which relate to the site and concept of the disposal system. For example, if avoiding sites with valuable resources is one of the issues in the concept of measures, then this point has to be addressed in the site selection process.

In the following are some general aspects to measures against human actions that reflect more or less the brief introduction above:

<< Future human actions can adversely impact radioactive waste disposal systems; these actions must, therefore, be considered both in the siting and design of waste disposal systems, and in assessments of their safety. >> [NEA, 1995]

<< Measures for preventing human intrusion need to be taken as early as possible in the development of a project and have to be considered at all stages of the development (e.g. site-selection, design…) even though some stages may be more critical than others. >> [FANC]

<< … scenarios need in particular be considered during planning and designing of the repository in order to identify appropriate counter measures. >> [GRS-BS]

<< It is suggested that events of inadvertent human intrusion shall already be taken into account in the site selection process and the planning and design phase of the repository system. >> [GRS-K]

<< ...the regulator will pay a particular attention to the set of measures proposed by the developer ... for preventing human intrusion ... for limiting the differed radiological consequences... >> [FANC]

<< For each measure taken to prevent HI intrusion, it is in any case essential to verify if it could not be unfavourable to other safety considerations. >> [FANC]

<< Measures against human intrusion are hardly to determine, due to the unpredictability of future activities at the repository site. Apparently, there are only few measures, such as the deep geological disposal and information preservation, which are suitable to prevent human intrusion for a certain time or make it at least difficult. >> [GRS-K]

<< The following aspects should be considered when discussing measures against human intrusion:

Measures, that

- hamper or make it difficult to intrude;
- reduce the interest for the intrusion in relevant depth of the repository in a geological formation;
- preserve the information for a long period on the site and the potential hazard of the repository;
- facilitate the recognition of the hazard based on the repository before, during and after an intrusion;
- restrict the potential radiological consequences in case of an intrusion;
- retard the point of an intrusion as long as possible >> [GRS-K].

<< In spite of all the countermeasures, it cannot be completely ruled out that human being may, intentionally or inadvertently, intrude into the repository in the future. >> (according to TVO-92) [POSIVA]

Outcome of the workshop:

Results from the discussion of the workshop to general aspects of measures against human actions are as follows:

Since HI cannot be predicted, the consideration of appropriate measures against HI is limited.

HI has to be considered in the site selection process and in the design phase of a repository (cf. also Section 2 and 4.2).

If HI scenarios are examined, then the effectiveness of specific measures should be evaluated, e.g. the construction of compartments in the emplacement area in order to reduce the amount of radionuclides that can be affected by HI events.

Measures themselves must not compromise other safety concerns of the repository and measures should not counteract each other.

In principle, there are three main types of measures that can be observed from the contributions and other national and international references. These types relate to measures that inform, control and alert society and possible intruders, make it difficult or reduce the interest to intrude and limit the consequences of an intrusion. The first two types refer to measures which take place before and during an action. Whilst the latter type refers to actions that have already taken place (after an intrusion). In the following different measures from the contributions are listed and discussed:

<u>Avoiding resources:</u>

As mentioned in section 4.3 the issue likelihood is often discussed in connection with resources at the disposal site. There are several examples from international organisations, national organisations and participating organisations which state that the likelihood of HI can be reduced if the disposal system will be located away from valuable resources. Some require the exclusion of sites with exploitable resources:

<< Consideration will be given to locating the facility away from known underground mineral, geothermal and water resources so as to reduce the risk of human intrusion into the site and the potential for uses of the surrounding area that are in conflict with the facility. >> [IAEA, 2006]

<< Location away from known areas of underground mineral resources is desirable to reduce the likelihood of inadvertent disturbance of the geological disposal facility and to avoid resources being made unavailable for exploitation. >> [IAEA, 2006]

<< Furthermore, the absence of any currently recognised and economically viable natural resources and the lack of conflict with future infrastructure projects that can be conceived at present reduces the likelihood of inadvertent human intrusion. Finally, appropriate siting ensures that the site is not prone to disruptive events and to processes unfavourable to long-

term stability. >> [NAGRA, 2002]

<< The reduced likelihood and consequences of human intrusion is supported by (i) the preservation of information about the repository, (ii) by the avoidance of resource conflicts (i.e. the absence of viable natural resources in the area proposed for the repository), and (iii) by the compartmentalisation of the repository and the solidification of the wastes. >> [NAGRA, 2002]

<< For geological disposal of high-level and long-lived waste, the absence of natural resources in the vicinity of the repository combined with the implantation of the repository at sufficient depth are the two key features for reducing the probability of a HI event. >> [FANC]

<< The choice of an appropriate site and host rock (lower drilling frequencies can be associated with rocks that are not of economic significance) >> [NDA]

<< ... a site with exploitable natural resources should be excluded already in the selection site process. >> (according to STUK 2001) [POSIVA]

Outcome of the workshop:

It was agreed by the participants at the workshop that sites with valuable resources should be avoided in order to reduce the likelihood of HI. There were some reservations as to whether the likelihood can be really reduced over timeframes considered in safety assessments. The main issues of the discussion included:

The reduction of the likelihood of HI through selecting a disposal site with no valuable materials or substances includes the assumption that future generations have the same requirements about needs and resources, as the present generation. This may not necessarily be the case given the long timescale for the isolation period of high active waste. There are some doubts, whether it can be really assumed that today´s habits and needs are applicable for the entire demonstration period for a safety case. However, the real situation at a specific time cannot be predicted, and secondly it can be assumed with sufficient reliability that habits and needs will not change dramatically in the near-term. So that the assumption of the reduction of the likelihood of HI by avoiding sites with valuable resources from today´s perspective is only valid for a certain period of time shortly after repository closure. On the other hand, a geology that mainly consists of materials occurring in large amounts near the surface can be expected to make intrusions less attractive over long time periods. The avoidance of sites with valuable resources that could attract human actions can be compared to the measure of information preservation (see below) which is assumed to prevent unintended HI for at least several hundred years.

<u>Depth of the repository:</u>

The worldwide favoured option for high active waste disposal is the emplacement of such wastes in deep geological formations. The envisaged depth is about several hundred metres below ground in most of the concepts of the different countries. This design option limits from a today´s perspective the number of

- kinds of actions e.g. drilling, leaching and excavation;
- motivations e.g. exploration, exploitation, mining, disposal;
- groups of persons which have the intention, means and resources for such an

endeavour.

The following are some examples from the contributors that consider the depth of the repository in connection with HI:

<< For geological disposal of high-level and long-lived waste, the absence of natural resources in the vicinity of the repository combined with the implantation of the repository at sufficient depth are the two key features for reducing the probability of a HI event. >> (cf. also "Avoiding resources") [FANC]

<< The location of the facility at sufficient depth to reduce the probability of human disturbance (drilling frequency decreases with depth of rock penetrated) >> [NDA]

<< ... placing the waste deep underground is a robust method of reducing the potential for, and likelihood of, human intrusion ... >> [NDA]

<< With respect to the type of formation to be used for radioactive waste disposal, it was felt that storage at greater depths is the most important factor for reduction of the effects of human intrusion. Disposal at great depths might also reduce the probability of human intrusion. >> [NRG]

<< The repository shall be located at a sufficient depth in order to mitigate the impacts of above-ground events, actions and environmental changes on the long-term safety and to render inadvertent human intrusion to the repository very difficult. >> (according to Finish regulations) [POSIVA]

Outcome of the workshop:

The participants of the workshop concluded unanimously that:

A sufficient depth of the repository is one of the most appropriate measures against HI.

<u>Institutional control:</u>

As previously indicated, there is a strong relationship between preservation of information and maintaining awareness of that information. The requirement of institutional control is seen as a measure in order to prevent people taking some adverse actions at the disposal site and to keep future generations aware about the location and the associated hazard. Active and passive institutional control is often distinguished. Active institutional control involves limitations on access to the disposal site and its use. Passive measures include organised systems of information conservation and site marking.

Analogous to the issue of information preservation, the same questions arise about the required timeframe for institutional control and how long people can rely upon this measure from a safety point of view. Again, these questions relate to the task of the regulator. The first question about the required timeframe of institutional control is often discussed in connection with one of the main principles, namely to manage radioactive waste disposal without imposing undue burdens on future generations. The answer to the second question depends largely upon the specifications to the first question. However, the duration and effectiveness of institutional control cannot be predicted over all times.

Statements from international organisations and from participating organisations reflect some specific issues in connection with institutional control:

<< Geological disposal facilities do not rely on long term post-closure institutional control as a passive safety function (see para. 3.19). Nevertheless, institutional controls may contribute to safety by preventing or reducing the likelihood of human actions that could inadvertently interfere with the waste, or degrade the safety features of the geological disposal system. Institutional controls may also contribute to increasing the societal acceptability of geological disposal. >> [IAEA, 2006]

<< ...the Commission recognises that institutional controls maintained over a disposal facility after closure may enhance confidence in the safety of the disposal facility particularly by reducing the likelihood of intrusion. >> [ICRP, 1998]

<< The most effective countermeasure to inadvertent disruptive actions is active institutional control of the surface environment above and for some distance around the disposal site. >> [NEA, 1995]

<< However, active institutional control cannot be relied upon over the timescales for which the waste presents a potential hazard. >> [NEA, 1995]

<< The concept should include a multiple barrier system, and rely on passive repository evolution without institutional control beyond a given timeframe (500 years). >> (according to the Basic Safety Rule RFS III.2.f of June 1991) [ANDRA]

<< In this human intrusion scenario it is assumed that 500 years after repository closure, when the institutional control period has passed there are mining activities in the area of the repository. >> (cf. Section 4.5) [ENRESA]

<< ENRESA considerers that human intrusions are possible as soon as institutional control ends. >> [ENRESA]

<< The long-term safety of the final repository must not be based on active monitoring and maintenance measures, excluding a period of at least 500 years following decommissioning, during which current estimates predict that the competent offices will be able to preclude all human activities in the vicinity of the final repository which could threaten the permanent containment of the waste. >> [GRS-K]

<< Inadvertent intrusion can be assumed to be excluded during the period of institutional control which can last for 100 or 300 years. Thereafter a period of administrative control can be foreseen during which deep excavations or drillings at the repository site will be forbidden. However at longer time scales the loss of information about the repository can take place. >> [NRG]

<< Recently in a draft update of the YVL Guide 8.4 it is stated that human intrusion scenarios need to be considered starting only after 200 years have passed from the closure of the repository, as some credit is taken on institutional control and preservation of information about the repository. >> [POSIVA]

<< The statement of “not imposing undue burdens on future generations” implies that the long-term safety of such a facility shall not rely on human actions, such as an extended institutional control period. >> [FANC]

<< After closure of the repository, institutional controls remain in place for a limited period, amongst others to prevent intrusion into facilities, which is a particular concern for near surface repositories. As such controls cannot be maintained forever, additional measures have to be taken in order to limit the likelihood and the radiological consequences of human intrusion (HI) after the end of the institutional control period. >> [FANC]

Outcome of the workshop:

Although this issue was addressed at the workshop the participants decided not to discuss institutional control in a detailed manner because this is primarily the task of the regulators to make decisions and to provide appropriate guidance. It was acknowledged that institutional control might be an effective measure against HI, at least in the short term after repository closure.

Information preservation:

The main intention of preserving information and taking precautionary measures to preserve the knowledge for future generations is to maintain the awareness of existing disposal sites and of the potential hazard posed by the respective repository. As a result, the risk of inadvertent intrusion into the disposal system can be excluded or at least reduced. Other intentions relate to the development of an information database that can serve for future generations as a sound basis for decision-making processes with respect to future uses of the site or in case of need to take suitable precautions and to plan the activities accordingly.

Information preservation is basically a passive control measure and involves the necessary condition for preventing inadvertent human intrusion. However, the sufficient condition is, that the future generations keep aware of the preserved information and that they interpret them appropriately. The latter condition is often discussed in connection with active institutional control. This issue will be addressed in the following separately (cf. “Institutional control”).

The topic of the preservation of information involves a wide spectrum of issues which were discussed on a national and international level at different occasions. These questions concern e. g. the kind, form and amount of information to be preserved, the choice of suitable data media and data management systems, the strategies for making future generations aware of the information and the financing options. These issues were not primary concern of the contributors and therefore they are not discussed any further. Other issues are of interest, like the required timeframe for information preservation and the assumption for the earliest possible time of HI in safety assessments after repository closure. The latter issue relates to the matter of how long people can rely upon information preservation as a measure for preventing HI.

Actually, both the required timeframe and the earliest possible intrusion time cannot be determined on a scientific basis and should be therefore fixed in regulations. A common approach is to equate the earliest possible intrusion time with the time of loss of information. The preservation of information on the other hand should be carried out as long as possible. Since this is an undefined specification, some countries take into account historical documents e.g. maintained by archives, registers or national libraries. The experience shows that information could be preserved for some hundreds of years. The following are some examples from the contributors that refer to the issue information preservation:

<< In these conditions, the loss of memory of the existence of the repository can be reasonably situated beyond 500 years. This value of 500 years will be retained as earlier

date of occurrence of a human intervention. >> [ANDRA]

<< In case of inadvertent human actions the knowledge of the repository has to be lost at the time of occurrence. Thus, such kinds of scenarios are assumed to occur not before several 100 years after repository closure. Within the ERAM study human intrusion after 500 years has been assumed and in PAGIS and EVEREST 1000 years have been regarded as reference values >> [GRS-BS]

<< It is assumed that for the treatment of the scenarios, which describe the inadvertent human intrusion, the knowledge about the repository remains at least 500 years. Therefore, no earlier point in time for the intrusion scenario needs to be chosen. >> [GRS-K]

<< Therefore in the dose calculations for these scenarios it was assumed that this kind of action would not take place earlier than 250 years after discharge of the reactor fuel to be reprocessed. >> [NRG]

<< Information of the repository and the waste is stored in several archives. Storing of the information and markers, which might be constructed at the disposal site, are currently being studied in co-operation by the Nordic countries as well as in a wider international context. >> [POSIVA]

Outcome of the workshop:

It is obvious that information preservation cannot last for eternity. However, experience shows that information could be preserved for some hundreds of years but this time span is only marginal compared to the considered isolation period. However, there was a general consensus that like the depth of the repository, the preservation of information and the maintenance of knowledge is one of the most appropriate measures against HI. It is expected by the majority of participants that specific guidance in this matter should be provided by the regulator.

<u>Other measures like marker, making access difficult etc.:</u>

In addition to the measures discussed above there are some other possible measures like markers and monuments which could act as passive institutional controls. Further options include design measures that shall increase the resistance against HI actions e.g. an increased wall thickness of waste casks as a barrier against drill bits. The following are some examples from international organisations and participating organisations which address further measures like markers and make it difficult to intrude:

<< ...incorporating robust design features which make intrusion more difficult, or employing active institutional controls(such as restricting access or monitoring for potential releases) and passive institutional controls (such as records and markers). >> [ICRP, 1998]

<< At somewhat greater times, large-scale physical markers at or near the site may help reduce the likelihood of disruptive human actions. Recent work in the U.S. suggests that well designed markers have a high likelihood of maintaining their effectiveness for periods on the Order of several thousands of years. On the other hand, some argue that far in the future the message concerning the hazard associated with the repository might not be properly understood, and that markers may serve primarily to increase interest in the repository (see below). In any case, surface-based marker systems located in areas prone to glaciation are unlikely to survive such glaciations when they next occur (On the Order of 10,000 years from

now). >> [NEA, 1995]

<< Physical barriers to intrusion (e.g., a thick concrete Cover above the disposed waste or a strong canister) may lower the probability of inadvertent intrusion. However, this is probably the least effective countermeasure, and is not discussed further. >> [NEA, 1995]

<< NAS [6] concludes that we can not rely on passive control (markers and archival of records) to ensure that no human intrusion takes place because „there is no technical basis for making forecasts about the reliability of such passive institutional controls“. >> (ENRESA follows the recommendations of NAS) [ENRESA]

<< Complementary means, independent from the characteristics of the system, may also contribute to reduce the likelihood of a HI event. These means are aimed to make the intruder conscious of the presence of the repository and of the radiological and non-radiological risks that it represents. >> [FANC]

Examples of complementary means are:

- ensuring the long-term conservation of the memory of the repository
- physical markers
- land-use restrictions

<< ...the possibility of implementing complementary measures for limiting the dispersion of radionuclides following a HI event (using for instance intermediate sealing plugs) and for increasing the resistance of the system against intrusion should be investigated. >> [FANC]

<< An aboveground marking of the repository is not required in terms of the routinely environmental protection measurements and topographic measurements. >> (according to the regulations "Safety Criteria" from 1983) [GRS-K]

<< The use of site markers and archives to increase the probability that information about the site is retained for as long as possible >> [NDA]

<< ...to demonstrate that all practicable steps to record information about the facility have been taken. This might include: The provision of durable site markers ...>> [NDA]

<< Storing of the information and markers, which might be constructed at the disposal site, are currently being studied in co-operation by the Nordic countries as well as in a wider international context. >> [POSIVA]

Outcome of the workshop:

It was decided at the workshop that the participants will not formulate a joint statement on the issue of markers and other additional measures besides those which are discussed above. During the discussion it was recognised that there is a wide spectrum of opinions regarding markers which include the pros and cons in terms of preventing HI. The given examples from international references and contributors demonstrate this. However, it was again agreed that this issue is also a subject for the regulators.

4.5 Types of HI actions and scenarios

This subsection describes different human actions which constitute the initial basis for HI scenarios. It also considers motivations and different purposes for those human actions.

The following gives several examples for HI events/ scenarios from the contributors which were developed and in some cases have been used in safety assessments:

<< ... scenarios are drilling for water, exploratory drilling with the extraction of core, operation of a mine near the repository or direct physical human intrusion into the disposal facility. >> [FANC]

<< ...the following sources for “Human Intrusion“ into a deep geological repository have to be discussed depending on respective site conditions:

1. Exploratory drilling;
2. Construction of a mine;
3. Extraction of geothermal energy;
4. Utilisation as reservoir rock (pore-space store, cavern) >> [GRS-K].

According to a guide from the regulatory body ASN in France, several specific altered situations connected to human activities were defined [ANDRA]:

- Exploratory drilling crossing a repository structure
- Exploitation of a mine
- Abandoned and badly sealed exploratory drilling crossing a repository structure
- Drilling in a deep aquifer for exploitation of water destined to food or agricultural usage
- Geothermic and heat storage

<< In this HI scenario it is assumed that 500 years after repository closure, when the institutional control period has passed there are mining activities in the area of the repository. An exploratory borehole intersects vertically a disposal canister, and the drilling head cuts pieces of the spent fuel disposed in the canister and significant amounts of radionuclides are released from the waste. Most of the contaminants will be extracted in the core or the drilling slurries sent to the slurry pool in the surface. The rest of the radionuclides released will remain sorbed on the surface of the borehole or will dissolve in the groundwater. After the drilling the borehole is left unsealed, and since that instant radionuclides in the borehole column can be transported by groundwater. >> [ENRESA]

<< In the selected HI scenario, the radiological consequences of the exploratory borehole on people who perform the drilling or inspect the cores are not analysed. The long term consequences of the pool of slurries are not considered either. The objective of the scenario is to analyse the effects of the intrusion on the isolation capability of both the engineered and natural barriers. The borehole damages the engineered barriers (canister and bentonite) of the intersected canister. In addition, since water travel time usually increases with depth, the radionuclides deposited in the borehole column will reach the Biosphere faster than the

radionuclides released at repository depth. >> [ENRESA]

<< Inadvertent human intrusion scenarios are mainly possible in the scope of exploration or mining activities of future generations. ... These are borehole drilling, constructions of a mine, and cavern leaching. >> [GRS-BS]

According to [GRS-BS], a general evaluation of the issue human intrusion has been performed on behalf of the Federal radiation protection office (BfS). In the framework of this evaluation the following six human intrusion scenarios were investigated to different host rocks:

- Mining into the contaminated host rock region, drilling into a waste container,
- drilling into a waste container
- drilling into the repository without hitting any waste
- opening up of an underlying groundwater reservoir under overpressure by drilling
- opening up of a contaminated aquifer by drilling and
- solution mining of evaporite rocks.

<< Possible inadvertent acts of human intrusion include drilling or excavation into the repository or the surrounding rocks, for the purpose of exploring for or exploiting natural resources (e.g. coal, oil, gas or minerals). >> [NDA]

<< Human intrusion is considered in guide reports ... Specifically, drilling activities are mentioned. >> [NRI]

In case of [NRG] a FEP list of numerous human induced phenomena was taken into account. The FEPs of human induced phenomena were divided into the following classes:

- post-closure and sub-surface activities;
- post-closure and surface activities.

The analysis of the FEPs led to the following human intrusion scenarios which were subject of safety assessments [NRG]:

- Leaky storage cavern,
- reconnaissance drilling
- solution mining and
- conventional mining.

According to [POSIVA], STUK (2001) stated that human intrusion scenarios should include

- boring a deep water well at the disposal site and
- core-drilling hitting a waste canister.

<< Postulated possible scenarios, taking the regional context into account, are drilling for water, exploratory drilling with the extraction of cores, the operation of a mine near the repository or direct physical human intrusion into the disposal facility. >> [SCK•CEN,

ONDRAF/NIRAS]

<< It is now planned to develop a number of unsealed borehole scenarios and to evaluate the radiological consequences resulting from these scenarios. >> [SCK•CEN, ONDRAF/NIRAS]

Although the HI actions/ scenarios by the different contributors differ according to their requirements, the range of initiating events is limited. Hence, the HI actions/ scenarios were developed primarily on the basis of drilling and mining activities. The range of envisaged reasons and techniques is also restricted, but include:

- drilling and operation of a borehole
  - exploration,
  - exploitation of resources e.g. oil, gas, minerals,
  - extraction e.g. of groundwater, geothermal energy
  - injection e.g. liquids and gases
- construction and operation of a mine at the site or in the vicinity
  - excavation, solution
  - solution mining e.g. minerals,
  - conventional mining e.g. coal, ores, other minerals
  - utilisation e.g. storage and disposal of substances
- construction and operation of a cavern
  - excavation, solution
  - leaching e.g. salt
  - utilisation e.g. storage and disposal of liquids and gases

From the examples above, only [ENRESA] has described a HI scenario "exploratory borehole" which includes all the elementary data for the investigation. It should be also noted that in this HI scenario the borehole is left unsealed after the drilling.

Outcome of the workshop:

With regards to events, techniques and reasons which form the HI scenarios the participants concluded:

The main sources for HI events are drilling and mining, whereas the main purposes are exploration of the site, exploitation and extraction of natural resources and injection of substances and/ or resources for storage and disposal. These topics take into account the assumption that HI should be considered in the view of today´s available technology and habits of the society. It was also concluded that exploratory drilling is actually the initial event for all the other actions like mining and exploitation.

4.6 Anomalies and noticeable features

At the end of construction disposal systems in deep geological formations might leave no visible footprint at the surface, but may leave underground traces including unnatural, abnormal or unexpected environmental features. Some indications of the existence of waste and repository characteristics are:

- Differences of porosity, permeability and density in consequence of mining activities and backfilling of e.g. bentonite, crushed salt.
- Differences in temperature of such disposal areas caused by heat generating wastes.
- Emplacement of dissimilar material into the underground such as waste containers, canisters, casings, concrete, radioactive waste etc.
- Ionising radiation, radiotoxicity

In relation to this the question arises whether there is potential for the detection of such anomalies in connection with human actions, e.g. by accompanying measurements during exploratory drillings and other activities. Therefore, specific investigations can give information whether future generations should be wary as to the existence of an underground construction and/ or the associated hazard before, during and after their site activities. Results of the investigations might deliver additional arguments for the evaluation of HI in the safety case.

There are only few examples from the contributors that discuss the possible detection of the disposal system and the associated hazard:

<< Deep boreholes and shafts are not made arbitrarily in common rock types, but drillings and excavations are preceded by airborne and ground-based geophysical investigations, by which the repository will be detected. >> (according to TVO-92) [POSIVA]

<< The construction of a repository in deep geological formations ... indicate abnormal or unexpected environmental properties. ... In this connection the question arises of detection potentials of anomalies through exploratory drillings and other activities. The investigation of such detection potentials should be also one of the different tasks in analysing the provided reference scenarios. >> [GRS-K]

<< For the core inspection scenario it is proposed to assume that the presence of the thick metallic overpack will make an inadvertent intrusion into the disposed waste unlikely during several thousands of years. Also for the dispersal of radioactive materials it can be expected that during long time spans the drilling team should become aware of the presence of exotic materials in the cuttings and that they should take protective measures. >> [SCK•CEN, ONDRAF/NIRAS]

Outcome of the workshop:

The investigation of HI scenarios should also include discussion of whether the anomalies induced by the waste and the repository could be detected based on today´s knowledge and applied technology.

4.7 Exposed groups, doses and risks and evaluation of consequences

This section considers the different aspects of HI scenarios with regards to the calculated doses resulting from assessments. This encompasses the exposed groups of people, evaluation of consequences and risks, applied dose limits, exposure paths and appraisal of results.

The underlying questions here relate to the general objectives for the analysis of HI scenarios, and if dose calculations are required, how and where are doses included in the evaluation of safety.

Exposed groups of people:

For most of the contributors the groups of people that should be considered for HI scenarios are groups of intruders and/ or a group of residents. Some consider a reference group which can be a group of the surrounding population [FANC]. For [ENRESA] the receptor in the HI scenarios is the same average member of a critical group considered in the reference scenario.

Another feature was the distinction between direct and indirect contact with the waste for the two groups as a consequence of HI [SCK•CEN, ONDRAF/NIRAS]. A direct contact with the waste, e.g. as a result from contaminated material brought to the surface, is assumed to occur to both the group of intruders and the resident group. Indirect contact is assumed to occur only to the resident group that, for example, assimilate contaminated groundwater.

Doses and risk:

There is a broad consensus that HI scenarios can lead to high doses particularly for the group of intruders. Some contributors point out that the comparison of calculated doses for the group of intruders with regulatory limits or the considerations of such cases is not appropriate. Concerning risk, it is also mentioned in one case that due to the expected extremely low occurrence probability of HI the resulting risk is acceptable. The following are excerpts from international references and from the contributors which relate to these considerations:

<< In the event of inadvertent human intrusion into a geological disposal facility, a small number of individuals involved in activities such as drilling or mining into the facility could receive high radiation doses. >> [IAEA, 2006]

<< Whenever highly dangerous materials are gathered into one location and an intruder inadvertently breaks in, that intruder runs an inevitable risk. >> [NAS, 1995]

<< ...it does not make really sense to consider the case of the intruder himself, as the level of doses received by a non-protected person coming into direct contact with the waste will surely be lethal. >> [FANC]

<< ...the probability of occurrence of a HI event could be considered as extremely low (and thus the resulting risk acceptable)... >> [FANC]

<< Inadvertent human intrusion scenarios, if they occur, can lead to very high doses ... >>

[NDA]

<< ... doses received by the intruders can be high and it would be difficult to reduce them by the repository design. However, these high doses are closely linked to the "concentrate and contain" strategy and, consequently, comparison with a regulatory limit is not considered relevant. >> [SCK•CEN, ONDRAF/NIRAS]

Dose limits

A comparison of calculated doses with thresholds calls for regulations that provide respective dose limits. In this context, since the receptor is the same than in the reference scenario, [ENRESA] uses the same dose limit of 10^{-4} Sv/yr for the HI scenario, even though there are no specific regulatory requirements or guidelines.

Exposure paths:

It was suggested by another contributor that the exposure of people from external irradiation, inhalation of radionuclides and ingestion as a consequence of drilling activities should be evaluated [NRI].

Evaluation of consequences:

There are references from international organisations [IAEA, 2006], [ICRP, 1998] which recommend that calculated doses from HI scenarios should not be compared with doses and risks but the resilience of the disposal system to such events should be evaluated. Similarly, [NAS, 1995] and [FANC] recommended appraisal of the robustness of the disposal system in terms of HI. Others indicate that quantitative assessments are practically impossible and suggest therefore the interpretation of HI scenarios as rest risks [POSIVA].

Outcome of the workshop:

Taken into account the discussion above the participants concluded the following:

There are actually two types of exposed groups in the case of HI events:

- Group of intruders which might receive immediate or direct consequences;
- group of people (residents, public) which might receive direct and indirect consequences).

Due to the widely varying underlying assumptions for HI scenarios, the radiological consequences vary greatly.

The investigation of HI scenarios should be undertaken in a more qualitative manner. The participants held the view that calculated doses should not be measured against radiological thresholds. However, they acknowledged that there might be some cases that allow the developer to treat the HI scenario like a common alternative scenario, e.g. release of radionuclide via groundwater path.

Finally, it was stated that the consequences should be more seen as indicators which give information about the resilience and robustness of the disposal system.

5 Application and Experience

The following examples show that the participating organisations have gained a lot of experience in dealing with the subject of HI. In fact, a wide range of applications and reasons are in evidence. This includes the practice in safety analysis, performance assessment exercises, licence applications and review processes. Few contributors thought the participation in the program was not helpful.

The range of HI scenarios considered is rather limited as indicated in section 4.5 and can be mainly attributed to borehole drilling, mining activities and construction of a cavern. It is also noted that borehole drilling is the basis accounts for a HI scenario for almost all contributors.

<< In the framework of the Dossier 2005 Argile, the description of the Human Intrusion was defined as a “Borehole scenario” [vii]. This document describes some consequences of the creation of a borehole in the repository, particularly in coherence with regulations (RFS.III.2.f [i] of 1991). Quantification of such an activity is discussed in the Assessment of Geological Repository Safety Report [vii]. >> [ANDRA]

<< ENRESA has considered human intrusion only in one of the PA exercises carried out: ENRESA2000 [2] for a repository in granite. In ENRESA2000 [2], on the basis of the FEP analysis, a human intrusion scenario (exploratory drill) is identified, defined in detail, and a consequence analysis of such scenario carried out. >> [ENRESA]

<< Human intrusion scenarios have been applied in the safety assessment studies for high-level waste PAGIS and EVEREST and in the framework of licensing applications for real repositories with intermediate and low level waste in Morsleben. >> [GRS-BS]

<< There is experience with treating human intrusion scenarios for near surface repositories... No evaluation of human intrusion has been performed for deep geological repository. >> [NRI]

<< The extended PROSA method [12] has been applied for the safety study supporting the license application for the closure of the Asse (D) salt mine including the experimental disposal facilities (29. January 2007 [13]) and for a review on behalf of the Ministry of Agriculture and Environment of Sachsen-Anhalt (MLU) of two supporting reports issued in 2002 in preparation of the licensing process for the Morsleben Repository for radioactive waste (Endlager für radioaktive Abfälle Morsleben - ERAM) [14]. >> [NRG]

<< Four different scenarios were studied in PROSA in an attempt to assess the potential radiological effects of human intrusion into a repository. Although these four scenarios do not deal exhaustively with the potential consequences of human intrusion, they seem adequate for obtaining an idea of the similarities and differences between disposal concepts (with respect to the consequences of human intrusion). >> [NRG]

<< Calculation cases for the human intrusion scenario have not been developed since the TVO 85 Safety analysis (Vieno et al. 1985). >> [POSIVA]

<< No new analyses on human intrusion were considered necessary for TILA-96 or TILA-99.

>> [POSIVA]

<< The experience on the treatment of human intrusion scenarios in Belgium is rather limited because the interaction between the waste agency and the radiological protection authority has not yet started for safety cases for geological disposal ... >> [SCK•CEN, ONDRAF/NIRAS]

The participating organisations have gained a lot of experience in dealing with HI. As a result, every participating organisation has learnt their own lessons, which can be valuable for all of us. Some of which include:

- The analysis of a borehole scenario with different considered situations has revealed that the disposal system reacts in a robust way [ANDRA].
- A close collaboration between the implementers and regulators regarding the treatment of HI is recommended [ENRESA], [SCK•CEN, ONDRAF/NIRAS].
- The potential of HI does not lead to a preferred disposal technique [NRG].
- Due to the potential of high exposures, HI scenarios should be the subject of further studies [NRG].
- The treatment of HI has changed drastically from the consideration of pure disruptive scenarios to more realistic events [SCK•CEN, ONDRAF/NIRAS].

Finally, it has to be stated, that we can learn a lot from each other and should learn from the experiences of our partners abroad, both in a positive and negative sense.

6 Developments

Developments in HI are mostly due to experience gained from previous work, lessons learnt, reviews or revised conditions and frameworks. In this document a broad variety of developments and future work from the developers is in evidence. Some are planning to re-examine HI scenarios [ANDRA] or extend existing methods [NRG] while others currently do not have specific work on HI but will start to consider it in the near future [NRI] or will follow international developments [ENRESA]. Others will develop stylised HI scenarios in clay [SCK·CEN, ONDRAF/NIRAS] or will formulate calculation cases for HI by the end of 2010 [POSIVA].

Regarding regulatory developments, it was mentioned that the recently revised regulatory guidance in the UK now places a greater emphasis on presenting assessments of doses to individuals representative of those undertaking the intrusion and to those who might occupy the area after and intrusion, rather than presenting the risk from HI [NDA]. Others refer to the recent initiation of the development of regulatory guides for geological disposal facilities [FANC] and the revision of existing regulations [GRS-K]. There is also the envisaged interaction between the regulatory authority and the waste management organisation in Belgium on safety cases for geological disposal by the end of 2009 [SCK•CEN, ONDRAF/NIRAS].

Some work from a regulatory view will be done in the frame of WP 3.1 in RTDC-3 of the

PAMINA project regarding the development of stylised HI scenarios in salt [GRS-BS], [GRS-K].

Further developments from the contributors are:

<< In line with the new 2006 French Act and the 2008 revised version of the safety rules (guide), the scenario “borehole” will be re-examined taking account of design optimisation and knowledge acquisition (including new data on the site of Meuse Haute-Marne). >> [ANDRA]

<< ENRESA is making no in-house developments on this topic, but international developments are followed. >> [ENRESA]

<< Currently an evaluation is performed lead managed by GRS-K to work out a joint view, how to treat human intrusion scenarios in a German safety case. >> [GRS-BS]

<< ...the revised regulatory guidance has an updated section on human intrusion, which places a greater emphasis on presenting assessments the doses should human intrusion take place, rather than on the risk, which includes an estimate of the likelihood. >> [NDA]

<< No specific decision has been accepted so far for treating human intrusion scenarios in next performance assessments of DGR in the Czech Republic, but discussion on this issue will start this year in the framework of RAWRA project focused on update of reference design DGR from 1999. >> [NRI]

<< We expect that the PROSA procedure for identifying scenarios will be extended by the application of ‘safety functions’ for future safety studies. >> [NRG]

<< Currently there is not ongoing work on human intrusion scenarios, but measures to diminish the likelihood are being taken (Saanio et al. 2006). The formulation of calculation cases for this kind of scenario are to be planned by the year 2010, well in time for the application of construction permit in 2012. >> [POSIVA]

<< Within the framework of PAMINA work package 3.1 SCK•CEN will develop a number of stylised human intrusion scenarios that are relevant for geological disposal in clay formations. >> [SCK•CEN, ONDRAF/NIRAS]

<< ... the interaction between the radiological protection authority FANC/AFCN and the waste management agency ONDRAF/NIRAS on safety cases for geological disposal will start during the last months of 2009. >> [SCK•CEN, ONDRAF/NIRAS]

Developments from the perspective of the evaluators are:

<< FANC recently initiated the development of regulatory guides for geological disposal facilities. The implications of the high-level requirements developed in this framework on the treatment of human intrusion were also considered in the discussions and positions presented in this paper. >> [FANC]

Existing suggestions and draft reports that include new and revised requirements are currently under discussion. These documents serve as a basis for the intended replacement of the current legal regulations “Safety Criteria“ from 1983 [GRS-K].

In addition, HI activities and their possible implications have been discussed in the German Working Group on “Scenario Development”. As a result, the Working Group prepared a joint position that contains recommendations how to deal with “Human Intrusion” in the safety case. This joint position will serve as a basis for the development of stylised HI scenarios in salt from a regulatory perspective in the framework of WP 3.1 in RTDC-3 [GRS-K].

7 Conclusions

The topic "Human Intrusion" (HI) is one of many other topics which have to be addressed within the framework of RTDC-1 of the integrated project PAMINA. The main objective of RTDC-1 is to provide a current and comprehensive overview of safety assessment methodologies, tools and experiences along the identified Safety Case topics. This task report summarises the main facts, aspects, and views regarding HI on the basis of contributions provided from participating organisations, international references as well as selected national reports from countries with advanced disposal programmes. In addition, a number of specific aspects of HI were discussed at a workshop, taking into account the above points. The outcome of the workshop provides a set of common opinions with only a few reservations from participants. There is a good degree of consistency amongst contributors on the subject of HI.

The main results of the topic HI can be summarised as follows:

Regulations:

There are different positions concerning the regulatory aspects of HI in the various countries. Some countries have established regulations, others currently work on specific regulations or revise existing ones, and others in turn do not have any regulations at all. However, there is a broad consensus about the strong need of regulations for the treatment of HI in the safety case. In terms of regulatory requirements the workshop concluded that:

The treatment of HI should be addressed in regulations and guidelines provided by the respective responsible authorities. Regulations and guidelines should include e.g. the framework for the analysis of HI scenarios, scope of the investigations, constraints and conditions. In addition, the scenarios should be determined on a stylised basis, since a systematic development of HI is not possible. However, it should be acknowledged that stylised HI scenarios can never be complete or comprehensive. Furthermore, the topic of HI should be already considered in the site selection process and in the design phase of a repository.

Terminology:

There are few definitions from the contributors. Some contributors explicitly defined the term HI, but the definitions are rather different in terms of the wording. However, they do share the view that human intrusion involves a direct damaging of the barriers.

As a result of the workshop the participants agreed on the following:

HI can be understood as human actions which have the potential to directly jeopardise the isolating capacity of the barriers of the disposal system and therefore might have radiological consequences. Other terms associated with HI like unintended actions will be accepted according to provided definitions from the OECD/NEA. Another agreement relates to stylisation of HI scenarios.

Methodology:

This issue comprises a number of aspects for the treatment of HI from both the view of the developer and the evaluator. The main observations from the contributors and from the discussion at the workshop can be summarised as follows:

Human actions over timescales which are relevant or of interest for the disposal of high active waste are unpredictable. In addition, it is not possible to derive HI scenarios in a systematic way like for the other scenarios. The same applies to the derivation of the occurrence probabilities for HI events. As a consequence, the HI scenarios should be determined on a stylised basis whereas current technology and social behaviour have to be taken into account. Furthermore, only unintentional human intrusion should be considered. Intentional human intrusion, i.e. human actions with knowledge of the disposal site and the hazardous waste, are the responsibility of the society taking that action.

It was agreed that HI is a major concern when discussing safety of the disposal system. However, there are different opinions about where and how HI has to be treated in the safety case. It was the majority view that this depends on the respective conditions and regulations in the different countries, but if HI scenarios are examined then the effectiveness of specific measures has to be evaluated. Although HI cannot be predicted, the consideration of appropriate measures against HI is limited, but a sufficient depth of the repository and information preservation, are considered as the most appropriate measures against HI. There is general agreement that measures themselves must not compromise other safety aspects of the repository.

It was also agreed that sites with valuable resources should be avoided in the site selection process in order to reduce the likelihood of HI. There are some reservations as to whether the likelihood can be really reduced over the long timeframes that are considered in safety assessments. Other measures like institutional control and markers were not discussed in detail because these issues should be part of regulations and guidelines.

In terms of the types of HI action, the participants hold the view that the main type of action is drilling and mining associated with exploration of the site, exploitation and extraction of natural resources and injection of substances and/ or resources for storage and disposal. It was concluded that exploratory drilling is actually the initial event for all the other actions like mining and exploitation.

Finally, it was agreed that the investigation of HI scenarios should also consider if the anomalies induced by the waste and the repository could be detected based on today´s knowledge and applied technology.

Application and experience:

A wide variety of applications and purposes were noted amongst contributors. This includes the practice in safety analysis, performance assessment exercises, licence applications and review processes. Again, it was apparent obvious that the close cooperation between evaluators and developers on the treatment of HI in safety assessments and the safety case is needed.

Developments:

Again a broad range of developments and future work from the developers is being carried out. Some are planning to re-examine HI scenarios or extend existing methods while others currently do not have specific work on HI but will start discussion soon or will follow international developments. Others will develop stylised HI scenarios in clay and salt or will formulate calculation cases for HI.

8 References

[IAEA, 2006] IAEA, Geological disposal of radioactive waste, safety requirements, WS-R-4, IAEA, Vienna 2006

[ICRP, 1998] ICRP, PUBLICATION 81, Radiation Protection Recommendations as Applied to the Disposal of Long-lived Solid Radioactive Waste, December 1998

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9 Appendices

A1 ANDRA (France)

A2 ENRESA (Spain)

A3 FANC, BEL V (Belgium)

A4 GRS-BS (Germany)

A5 GRS-K (Germany)

A6 NDA (United Kingdom)

A7 NRG (Netherlands)

A8 NRI (Czech Republic)

A9 POSIVA (Finland)

A10 SCK•CEN, ONDRAF/·NIRAS (Belgium)

A1 ANDRA (France)

Revision: Final

Contents

1. Introduction

The present document is devoted to topic 10 "Human Intrusion" (see Figure 1). It completes the set of documents provided within the WP1.1 PAMINA RTDC1 framework. Its structure follows the DWG common structure, but it was adjusted according to the recommendations issued during the meeting in Madrid on April 28th and 29th 2009.

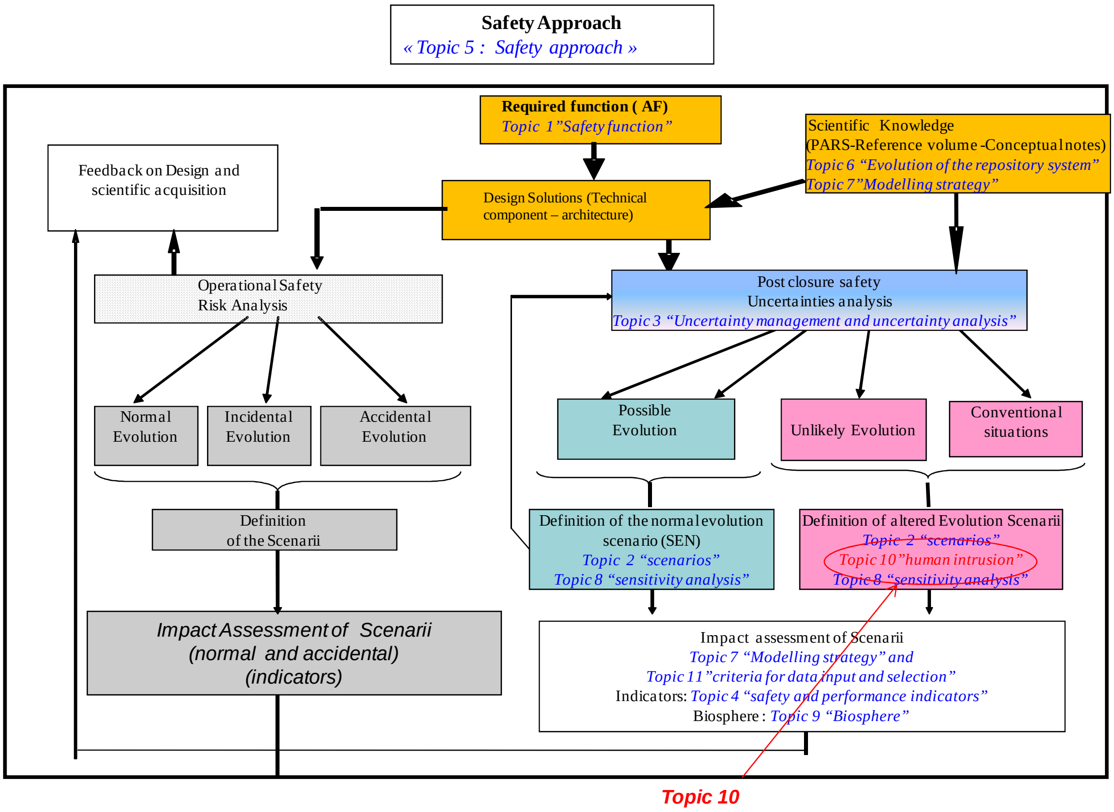

Figure 1: Representation of the various stages of the analysis

The contribution from Andra to WP1.1 PAMINA project aims at giving an overview of how the Human Intrusion issues were defined and described the Dossier 2005 Argile. Some example of application will be extracted from the Dossier 2005 (HLLL project).

In the framework of the Dossier 2005 Argile, the description of the Human Intrusion was declined in a "Borehole scenario" [vii]. This document describes some situations resulting from the creation of a borehole in the repository, particularly in coherence with regulations (RFS.III.2.f [i] of 1991). Quantification of such situations is discussed in the Assessment of Geological Repository Safety Report [vii].

Two types of situations were examined:

- The Immediate impact situations, and
- The Differed impact situations

2. Background

The December 30, 1991 French Waste Act entrusted Andra, the French national agency for radioactive waste management, with the task of assessing the feasibility of deep geological disposal. The Basic Safety Rule RFS III.2.f of June 1991 [i], issued by the French nuclear safety authority, provides a framework for the studies to be conducted. The protection of man and the environment are to be demonstrated. Furthermore, studies should show the ability to limit potential consequences to a level as low as reasonably possible. The concept should include a multiple barrier system, and rely on passive repository evolution without institutional control beyond a given timeframe (500 years). The studies carried out within this framework are presented in the "**Dossier 2005 Argile**" (clay) [ii] and "**Dossier 2005 Granite**" [iii].

The objective is to present the Andra's overall modelling strategy that has been developed in the framework of the so-called *Dossier 2005 Argile* which consists in a number of primary references which include the French Act and the series of reports submitted accordingly:

- The French Waste Act dated 30th December 1991 [iv]
- The French Safety rules namely RFS.III.2.f, guidelines [i].
- Synthesis Report, Evaluation of the Feasibility of a Geological Repository, Meuse/Haute-Marne Site (in English and French) [ii].
- Architecture and Management of a Geological Disposal System Report (TAG; C.RP.ADP.04.0001) (in English and French) [v].
- Phenomenological Evolution of the Geological Repository Report (TEP; C.RP.ADS.04.0025), (in English and French) [vi].
- Assessment of Geological Repository Safety Report (TES; C.RP.ADSQ.04.0022) (in English and French) [vii]

Other references such as the presentation made at the symposium hold in Paris in January 2007 [viii], and the INTESC questionnaire [ix] have been used when applicable.

The progress of the project is iterative, with repeated feedback exchanged between the various processes. In addition to the routine feedback common to parallel engineering, three main iteration loops have been identified since 1991, each corresponding to a major milestone of the program: License application for construction and operation of the underground research laboratory (in 1996), submission of the Dossier 2001 (in December 2001), and the recent submission of the Dossier 2005.

According to the new French Act [x], reversible waste disposal in a deep geological formation and corresponding studies and investigations shall be conducted with a view to selecting a suitable site and to designing a repository in such a way that, on the basis of the conclusions of those studies, the application for the authorisation of such repository be reviewed in 2015 and, subject to that authorisation, that the repository be commissioned in 2025.

3. Regulatory aspects relating to Human intrusion

Andra's approach on human intrusion considers the applicable guides and regulations issued by the Nuclear Safety Authority (ASN). These constitute the Fundamental Rules on Safety.

Both the RSF III.2.f that was issued in 1991, and its revised version released in 2008 [i,xi] consider human intrusion as an altered situation:

«*Après la fermeture de l'installation de stockage, certains événements incertains, mais plausibles, naturels ou liés à des actions humaines, peuvent perturber l'évolution du système de stockage et par conséquent modifier la migration des substances radioactives. Certaines situations résultant de ces événements pourraient éventuellement conduire à des expositions individuelles plus élevées que celles associées à la situation de référence*». Which means that after the closure of the repository, some uncertain events but plausible, natural or connected to human actions, can disrupt or perturb the evolution of the repository system and consequently modify the migration of radioactive substances. Certain situations resulting from these events could possibly lead to individual exposures higher than those associated with the reference situation.

"Les événements liés à l'activité humaine comprennent les intrusions humaines directes ou indirectes (forages,…» i.e : The events connected to the human activity include the direct or indirect human interventions (e.g. drillings)….

The 2008 ASN guide recommends the site to be chosen so that the depth retained for the emplacement of the waste repository allows to guarantee that the safety of the disposal system will not be affected in a significant way by the phenomena of erosion (in particular, when following glaciations), by the effect of an earthquake, or by the consequences of "commonplace" human intervention (e.g. sub-surface).

The guide also recommends the absence of sterilisation of subterranean extractable resources; the site must be chosen so as to avoid zones which can present an exceptional interest in terms of subterranean/underground resources.

The guide defines in its Annex 2, several specific altered situations connected to human activity to consider in future safety cases[5]:

2-2.2.1. Intrusion humaine (Human intrusion)

The guide considers that for this type of situation, it is necessary to fix a date before which no involuntary human intervention can occur because of the preservation of the memory of the existence of the repository. This memory depends on the perpetuity of the measures which can be implemented during the filing of the institutional documents resulting from the regulations…In these conditions; the loss of memory of the existence of the repository can be reasonably situated beyond 500 years. This value of 500 years will be retained as earlier date of occurrence of a human intervention. The definition of the characteristics of the situations of human intervention retained is based on the following hypotheses:

- the existence of the repository and its location is forgotten,

[5] Not an official translation

- the level of technology is the same as today.

From Annex 2 of the ASN guide, should be considered:

- Exploratory drilling crossing a repository structure

A situation supposing a drilling crossing the repository with extraction of borehole cores must be retained. The exploitation of cores constituted by high activity waste gives place to an external exposure which will be estimated according to the type of examination made on these cores.

- Abandoned and badly sealed exploratory drilling crossing a repository structure

For the sedimentary sites, it will be necessary to study the consequences resulting from to the connection of aquifers or between an aquifer and the repository.

- Drilling in a deep aquifer for exploitation of water destined to food or agricultural usage

The plausible character of water exploitation for food or agricultural usage by pumping in a deep aquifer will be appreciated according to water resources. The influence of the pumping on the drainages will be appreciated with the aim of the individual exposures evaluation.

4. Terminology

Andra distinguishes the temporal phase to be considered in the assessment. In the longer term perspective (post-closure), human intrusion will be considered as a "borehole scenario" including several situations to be defined.

Andra applies the definition given by 2008 ASN guide (revised version of the RFS.III.2.f), i.e.:

- The direct human intervention which refers to "Immediate impact situations", and
- Indirect human intervention which refers to "The Differed impact situations".

5. Related topics

The definition and description of the Human Intrusion is related to definition of the safety function and their performance indicator. The uncertainty management, together with the regulations aimed at defining a scenario borehole, representative of human intrusion on the long term safety.

6. Treatment in the safety case

6.3 General assumptions

The approach, in the framework of the Dossier 2005 focused mainly on the definition and consequence analysis of inadvertent human intrusion and their likelihood. No specific studies were done to “quantify” the probability of the human intrusion.

Predictability of HI

Human intrusion cannot be ruled out. The ASN guide considers that after closure of the repository, some uncertain events, but plausible, natural or connected to human actions, can disrupt or perturb the evolution of the repository system and consequently modify the migration of radioactive substances. Certain situations resulting from these events could possibly lead to individual exposures higher than those associated with the reference situation.

The ASN guide fixes a date before which no involuntary human intervention can occur because of the preservation of the memory of the existence of the repository. This memory depends on the perpetuity of the measures which can be implemented during the filing of the institutional documents resulting from the regulations. In these conditions, the loss of memory of the existence of the repository can be reasonably situated beyond 500 years. This value of 500 years is retained as earlier date of occurrence of a human intervention.

Unintended and intentional actions

The human origin actions concern only inadvertent intrusions. These would be due to a loss of the memory of the repository after 500years. The human origin actions concern only inadvertent intrusions. These would be due to a loss of the memory of the repository after 500years. After this date it is considered inadvertent intrusion. The possible means of maintaining a record of the repository were presented in the Dossier 2005, chapter 3[vii]. It nonetheless remains highly likely that on a million year time-scale the memory of the repository, of its location and of its purpose, could be lost.

Human intrusion scenarios should be treated separately from the other scenarios

This intrusion could have a variety of causes and consequently take various forms. The typology exposed in the Dossier 2005 Argile was inspired by the cases proposed in basic safety rule RFS.III.2.f...The human intrusion was treated separately from other scenarios. A specific « borehole » scenario considered two cases (an immediate impact due to operation during drilling and a differed impact resulting from the abandonment of an exploration borehole badly sealed).

Andra’s approach on human intrusion considers the applicable guides and regulations issued by the Nuclear Safety Authority (ASN). The 2008 guide suggests in its Annex 2, various altered situations connected to human activity to consider in future safety cases with regards to their likelihood. According to this guide, several specific altered situations connected to human activities were defined:

- Exploratory drilling crossing a repository structure

- Abandoned and badly sealed exploratory drilling crossing a repository structure
- Drilling in a deep aquifer for exploitation of water destined to food or agricultural usage

Technology and practices

It is extremely hard to predict the social changes and the technologies that will be accessible to future generations. In accordance with the recommendations of ASN 2008 (ex basic safety rule RFS.III.2.f.), this type of uncertainty was dealt with by assuming that their technical level will be equivalent to our own. For instance, the characteristics of the borehole described in scenarios reflect the level of technology used today.

Likelihood and probability of human intrusion

As mentioned in the 2008 ASN guide (and ex RFS.III.2.f) the site should be chosen so that the depth retained for the emplacement of the waste repository allows to guarantee that the safety of the disposal system will not be affected in a significant way by the phenomena of erosion (in particular, when following glaciations), by the effect of an earthquake, or by the consequences of "commonplace" human intervention (e.g. sub-surface). The guide also recommends the absence of sterilisation of subterranean extractable resources; the site must be chosen so as to avoid zones which can present an exceptional interest in terms of subterranean/underground resources.

The localisation of the site in the Meuse/Haute-Marne area is chosen, in coherence with the 2008 guide, so as to avoid zones which can present an exceptional interest in terms of subterranean/underground resources. To isolate the waste, the repository emplacement is designed in the Callovo-Oxfordian clay formation at depth of around 500 meters.

Measure against Human intrusion

Due to its conception and assigned safety functions, the repository can be partly protected from drilling by its fractioning, with parts made hydraulically independent of the others, which would prevent propagation of the drilling effects beyond one or more seals. The radionuclide immobilisation function also plays a role in supplementing the other repository safety functions, which could be more directly affected by the drilling. In the situation of a borehole crosscutting the repository, the seals revealed to play a role in limiting the hydraulic perturbation due to the borehole. As a consequence, the amount of radionuclides reaching the borehole was reduced to the nearest “modules” or “compartment” of the disposal.

The reduced likelihood is also supported by the choice of the site as mentioned in the previous section (“chosen so as to avoid zones which can present an exceptional interest in terms of subterranean/underground resources”), by the depth of the repository (more than 200m so that the safety is not affected by common sub surface human intrusion), by its conception and assigned safety function, and by the preservation of the memory (500years according to regulations).

Institutional control and information preservation

The concept should include a multiple barrier system, and rely on passive repository evolution without institutional control beyond a given timeframe (500 years) (according to the RFS III.2.f of June 1991). The 2008 revised version of the RFS indicates that for this type of situation (HI), it is necessary to fix a date before which no involuntary human intervention can occur because of the preservation of the memory of the existence of the repository. In these conditions, the loss of memory of the existence of the repository can be reasonably situated beyond 500 years. This value of 500 years is retained as earlier date of occurrence of a human intervention. The definition of the characteristics of the situations of human intervention retained is based on the following pessimistic hypotheses:

- the existence of the repository and its place is forgotten,
- the level of technology is the same.

Type of human intrusion actions and scenarios

According to the 2008 ASN guide from the regulatory body in France, several specific altered situations connected to human activities have to be defined, they are:

- Exploratory drilling crossing a repository structure
- Abandoned and badly sealed exploratory drilling crossing a repository structure
- Drilling in a deep aquifer for exploitation of water destined to food or agricultural usage

In accordance with the regulations, human intrusion was dealt with an immediate impact situation (from operating borehole cores) and a differed impact situation. This last situation include several cases resulting from abandonment of boreholes in various location of the repository (drifts, disposal cells, or in the packages) were assessed. In order to mobilize the maximum radiological inventory it was presumed that the event took place after exactly 500years.

Anomalies and noticeable features

The intrusion could first of all be the result of detection of the fact that there is a particular object in the ground and the desire to find out what it is. The disposal could in theory represent a geophysical « anomaly » that can be detected from the surface: a magnetic anomaly owing to the presence of metal materials in the repository, a gravity anomaly owing to the materials density different from that of the geological medium. The studies performed by Andra show that only a 3D seismic investigation could detect the anomaly caused by the repository. In terms of a gravity anomaly, the repository's visibility is very low as the densities of the various materials on the whole compensate for each other. The repository may also have been detected from the surface: excavations bringing to light traces of former surface installations or old access structures. In such a case, an « archaeologist » might attempt a reconnaissance of the structure. Good practice would require that he begins by looking for the origin of his discoveries in the archives, where he could then identify that he had found a radioactive waste repository.

Exposed groups, dose

Consistent with the Basic Safety Rule (RFS) III.2.f, applicable for the Dossier 2005 two types of situations were examined:

- Situations resulting from the resurfacing of cores, debris, or cuttings and contaminated rock from a borehole. In these situations the radiological impact is immediate. Waste first give rise to an exposure by external irradiation, of one or more of the workers causing the intrusion.

- Situations resulting from the abandonment of one or more boreholes. Such situations, in which the potential radiological impact is deferred, bring to the biosphere part of the radionuclides initially contained in waste and which have migrated from the package through the borehole. The persons potentially exposed in the medium or long term are assimilated with individuals belonging to a hypothetical critical group.

6.2 Application and experience: the dossier 2005 Argile

This section describes assumptions and results of the altered evolution scenario “Borehole”. As mentioned in previous sections, two types of situations resulting from the creation of one or two boreholes in the repository were examined:

- For immediate impact situations, the analysis focuses on elements resurfaced through the borehole ;
- In deferred impact situations, analyses focuses on a repository zone located in the hydraulic influence radius of the borehole. The remaining repository follows normal evolution and is not subject to evaluation as its impact is covered by the SEN findings.

The characteristics of the borehole are based on the RFS III.2.f recommendation stating that « the level of technology used is the same as today » ; the borehole diameter corresponds to the order of magnitude of plausible exploration borehole diameters at repository depths, that is to say in the decimetric range. The repository architecture is similar to that defined in the SEN (normal evolution scenario).

6.2.1 Immediate impact situation

6.2.1.1 Definition

This situation which considers a driller who is exposed to external radiation from a core taken directly from a waste package was retained.

Due to the inventory of the waste to be disposed, the dose rate of the core depends on the date of the intrusion and also on the nature of intercepted waste. Search for the conservative case required to perform numerous preliminary evaluations taking different reference waste package into account: spent fuels, HA vitrified waste (C) and MA-VL waste (B).

The scenario considers intermediary dates (500 to 1000 years), the dose rate calculation point is situated 40 cm from the surface of the core. The cores are meant to be one metre long and have a diameter of 10 cm, a realistic value for a repository at this depth. The length of the active part depends on the volume of waste in the package used and on how the package is disposed of. The specific activity of the active parts comes from the waste and is deducted from the reference inventory of reference package.

Radiation attenuation and transport code used to evaluate the dose received by the driller: The attenuation and transport code used is the *Mercure* 6 code, developed by the Atomic Energy Commission. *Mercure* is a straight line attenuation code that allows for the calculation of a dose rate on one or more points and for one or more gamma emission sources. This code has been extensively used and is widely recognised for its validity.

6.2.1.2 Results

The calculated impacts were limited to values inferior to ten millisieverts. The most pessimistic situation was extraction of a B1 package core, due to the presence of large quantities of silver-108m. The latter has a relatively short half life; if the intrusion occurred after one thousand years the observed doses for this reference package would be no different from those for C2 packages or spent fuels. Another pessimistic situation is the interception of the B8.3 package, which contains radium-based objects designed specifically to give strong doses. For the other waste the doses received remain moderate, even if exposure lasts more than 10 minutes and so long as direct contact does not last more than one or two hours.

The diagram in Figure 2 shows the results for different dates and different reference package successively addressed. Although the dates inferior to 500 years are not envisaged as they fall within the institutional surveillance phase [i], they were nonetheless dealt with to further demonstrate the marked effect of radioactive decay on the dose rate of waste. The short-lived radionuclides are the most irradiating and we can observe that the dose rate of waste diminishes by several orders of magnitude from the first hundreds of years onward.

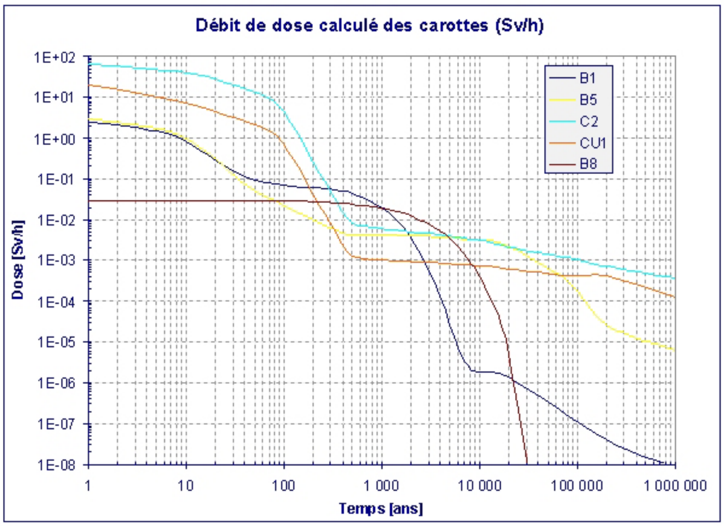

Figure 2: Borehole in the repository with resurfacing of core waste SEA – Dose rate of core waste – B1, B5, C2, CU1, B8 reference package (Figure 7.4-1 of TES)

6.2.2 Deferred impact situations

6.2.2.1 Definition

This situation which considers an abandonment of an exploration borehole in the repository was retained.

Date and location

The instigating event is an exploration borehole completed after the loss of repository memory, meaning at the earliest 500 years after its closure (cf. regulations). In order to mobilise the maximal radiological inventory it was presumed that the event took place after exactly 500 years.

Situations resulting from the abandonment of a borehole in the repository vary depending on hydraulic and geographical location (in the Callovo-Oxfordian formation, in the drifts, in the disposal cells, or in the packages; in an area where the head gradients are ascending or descending in the Callovo-Oxfordian formation), and its depth, date of occurrence, and evolution over time.

Type of waste packages

As for the previous situation, search for conservative cases required to perform numerous preliminary evaluations taking different location into account. Analysis of the results allowed considering a limited number of pertinent situations that were included in the “borehole scenario”.

For each repository zone (MA-VL, HA, SF), a « reference » location was defined for the borehole: near the waste packages, in a repository structure (gallery) whose diameter was sufficiently large for realistic interception (see Figure). For the HA vitrified waste cells and spent fuel cells, the borehole used for reference intercepts an access drift near the cells. The case of a borehole intercepting a cell was addressed in the sensitivity studies for FSI spent fuels (The spent fuels situation was identical to that for C waste, except that the reference concept has a swelling clay buffer).

This situation was quantified for all HA vitrified waste package and spent fuels, meaning the module holding vitrified C0 reference package; modules containing the vitrified C1/C2 reference package (processed together), the borehole was located next to the vitrified C2 reference package; modules with the vitrified C3/C4 reference package (processed together), the borehole was located next to the C4 reference package; CU1 and CU2 spent fuels modules. For MA-VL waste, the borehole met a repository cell in reference; such an interception was less improbable as the cells have a larger extension. The sensitivity study addresses the case of a borehole reaching an access drift. It also addresses cells hosting nonorganic reference package not releasing hydrogen (type B1x cells) or bituminised sludge packages (B2 reference package), which are the cells likely to lead to the most pessimistic impact.

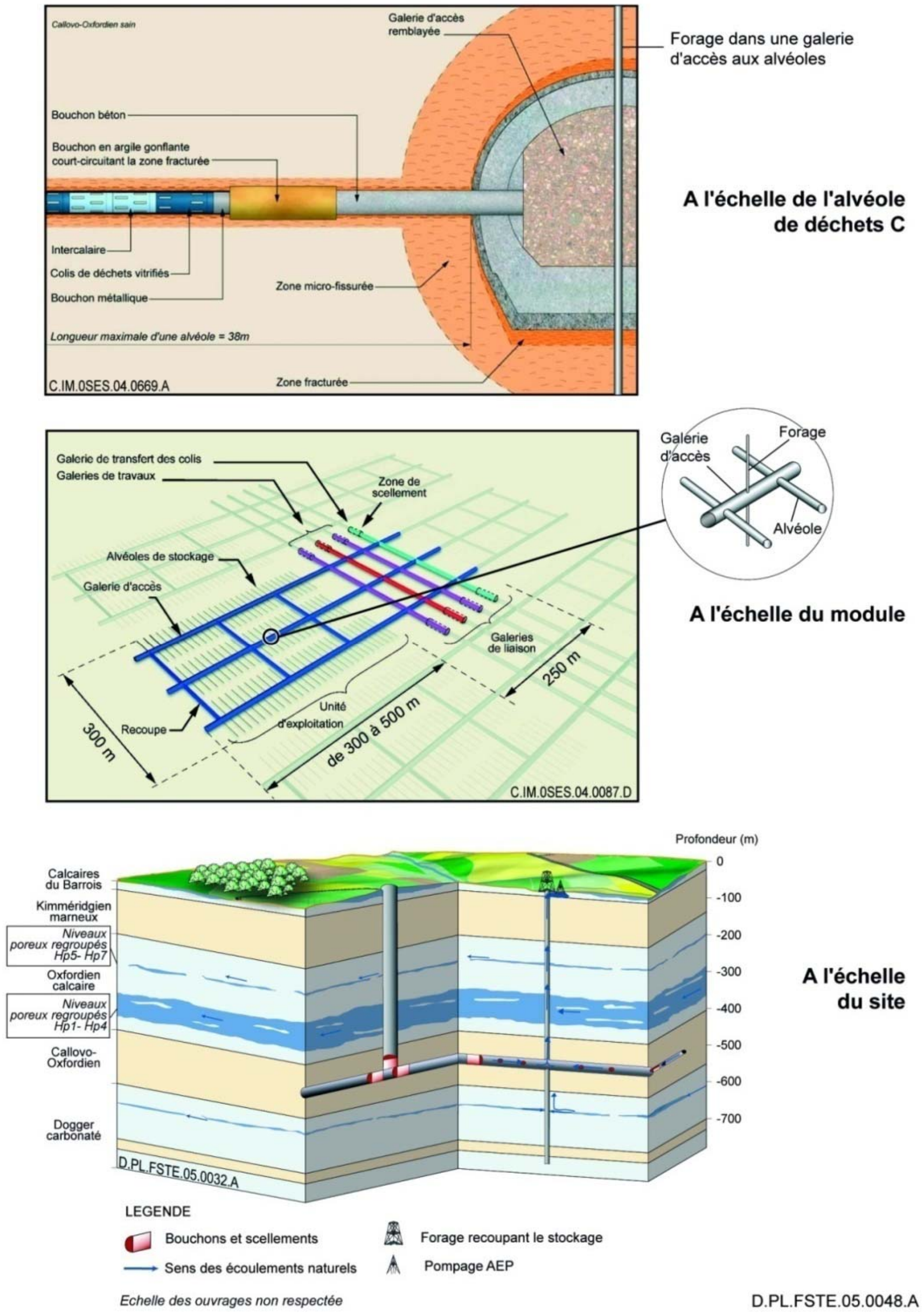

Figure 3: Abandoned borehole in the repository SEA – reference situation for vitrified C waste package – borehole in an access drift [Figure 7.4-2 from TES, vii]

Abandoned exploration borehole

The borehole was assumed to be permanent (an improbable case, but bounding of impact which can result from several successive drillings in the same area).

The borehole was meant to extend to the Dogger. This exploration borehole is abandoned and poorly sealed. This borehole can (Figure 4):

- be located near a drinking-water supply pump in the Barrois formation; the pumping drawdown passes into the borehole. This scenario leads to creating a potential transfer pathway for elements from packages to the biosphere and humans by totally or partially short-circuiting the intermediate geological formations between the repository and the biosphere. This hypothesis is very pessimistic and implies a double accident as having a borehole and pumping at the same site would be a very rare coincidence;
- lead to creating a potential transfer pathway for elements from the packages to the overlying formations. Once in the overlying formations the radionuclides in this case evolve similarly to the SEN case.

These two examples were presented as alternatives to each other. It was presumed that only components in the hydraulic influence radius of the borehole have an altered evolution. The other components evolved as in normal evolution and the impact associated with these elements is not re-evaluated.

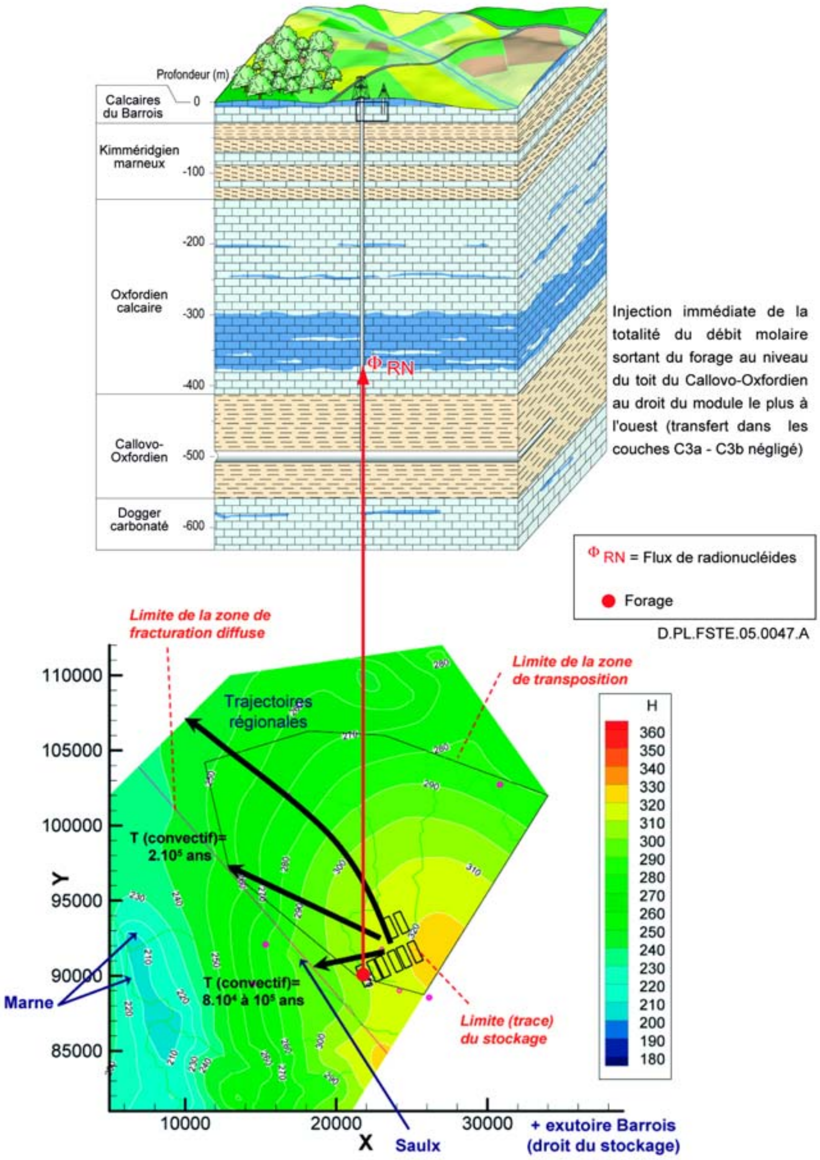

Figure 4: Abandoned borehole in the repository SEA – radiological impact calculation at the Saulx outlet of the Oxfordian limestone – present day hydrogeological model (Figure 7.4.5 from TES)

Sensitivity analyses

A wide range of sensitivity studies has been planned to offer more comprehensive coverage of the effects of a hypothetical borehole (see Table 1). These studies could be classified into different categories:

- Sensitivity studies on borehole position: For vitrified waste and spent fuel, the focus was on the case of a borehole which does not intercept the adjoining drift, but the cell itself. This situation was studied on CU1 spent fuel for illustrative purposes. All other previously described parameters were the same as in the reference case. It was supposed that the waste containers were effective for 10,000 years. On the other hand, the borehole is located in close proximity to a package, offering maximum impact by placing it within the range of low-mobility radionuclides.

- Sensitivity study on a borehole reaching the Dogger and crossing a secondary connecting drift near a MA-VL waste cell. The case of the B1x repository zone was addressed (cell containing the most pessimistic situation in terms of inventory).
- A borehole doublet was studied, whereby two boreholes were placed near to each other, on either side in a drift. The aim was to study whether this layout can lead to « U-shaped » advective circulation of water between the boreholes. This situation was considered for the CU1 repository zone.

Table 1: Abandoned borehole in the disposal SEA - List of sensitivity studies performed for the « borehole in the disposal » scenario (Table 7.4-6 of TES [vii])

Sensitivity studies performed	Reference package included in the sensitivity study	Page
Sensitivity to borehole position		
Sensitivity to borehole position – in a spent fuel cell	CU1	569
Sensitivity to borehole position - in the B waste access drifts	B1x	572
Borehole doublet	CU1	575
Sensitivity on the barriers		
Sensitivity to the C waste concept – variant with clay engineered barrier	C2	579
Sensitivity on the hydraulic parameters		
Sensitivity to the EDZ parameter – « degraded EDZ »	C2	580
Sensitivity on the chemical parameters		
Sensitivity to the engineered barrier parameter (conservative geochemistry)	C2, C4 CU1, CU2	583
Sensitivity to the glasses release model : model $V_0.S \rightarrow V_r$ instead of reference model $V_0.S$	C2	586
Sensitivity to the vitrified waste release model parameter (conservative parameters)	C2, C4	588

6.2.2.2 Results - illustrations

Effects on safety functions

The borehole will degrade or modify performance relating to the three safety functions defined in chapter 3 of [vii]: «Resist to water circulation», «limiting the release of radionuclides and immobilising them in the disposal» and «delaying and reducing the migration of radionuclides». Indeed, the scenario as defined in the reference situation totally or partially short-circuits the geological medium (Callovo-Oxfordian and possibly surrounding formations) located between the packages and humans. This leads to local deterioration in performance of the third safety function «delaying and reducing the migration of radionuclides», once the latter have been released by the packages. Moreover, it immediately results in a change in head and flow profiles in the repository zone affected; it thus « disturbs » performance related to the « resist to water circulation » safety function.

The effects of the borehole on the « limiting the release of radionuclides and immobilising them in the repository » safety function stem only result from disturbances on the packages, and chiefly on the kinetics of radionuclide release by waste. Therefore, to integrate the potentially damaging effects of the borehole on the waste package, a conservative release model for the glasses has been considered in the altered evolution scenario, taking into account the potentially higher water flows circulating in the cell. The other aspects of the function (mainly radionuclide precipitation) are very little affected by the borehole given its minor influence on the chemical conditions in the cell. It can however be noted that the sensitivity study planned on the geochemical properties of the fractured EDZ (endowing it with infinite solubility) chiefly covers a potential failure in the near-field immobilisation function.

The presentation thus focuses on the « resist to water circulation », then « delaying and reducing the migration of radionuclides » functions using intermediate indicators which are the same as those used in the normal evolution scenario.

The results may differ depending on the waste zone, and radionuclide-specific analysis. Whenever required, the results are separated by waste type and by radionuclide. The special default case of the CU1 fuel zone and iodine-129, providing the strongest impact, is used when the aim is simply to illustrate a result.

The effects on the « resist to water circulation » function indicate that seals limit the propagation of hydraulic head loss from the module with the borehole to modules furthest away from the borehole due to their permeability. Preliminary calculations have shown that hydraulic head variations over a seal fall by a factor of 2 on each seal passage. Thus, the repository modules furthest away from the borehole are less affected from a hydraulic point of view and the module intercepted by the borehole forms the main water supply, with approximately a third of the total flow in the case of HA vitrified C packages or spent fuel packages and 95 % in the case of MA-VL (B) packages.

The effects on the « Delaying and attenuating radionuclide migration » function is presented. The analysis revealed that the system remains diffusive in the disposal modules in spite of the presence of the borehole. Once released by the packages, radionuclides migrate into the cell body or plug. A fraction of the disposal cell's total activity reaches the borehole after passing through the structures or into the media between the packages and the borehole. The activity reaching the borehole depends on:

- initial activity in the packages ;
- distribution between transfer pathways at the level of the cell itself. A fraction of this activity follows a horizontal trajectory (pathway 2) before reaching the access drifts; the other follows a vertical trajectory (pathway 1) before reaching and remaining in the Callovo-Oxfordian.

Distribution between these two transfer pathways depends, among others, on the radionuclides' ability to be sorbed into the host formation and structures. Since the transport regime is diffusive (or codominantly diffusive-corrective), distribution between transfer pathways is comparable to that observed in SEN; the ability of the radionuclides which reach the access drifts to migrate and remain in them before reaching the borehole. Indeed, the flow of radionuclides which migrate into the drifts may be attenuated between the cell exit and the borehole because the radionuclides may reach the Callovo-Oxfordian and migrate into it by diffusion or undergo radioactive decay before reaching the borehole. Because of this, the importance of attenuating flow between a cell and the borehole increases with the distance of the cell from the borehole. For reasons of simplification, the analysis presents the total amount of activity reaching the borehole, without splitting it into the respective contributions from each cell according to its position relative to the borehole. This is a mean value comparable to the total initial inventory disposed of in a zone, subzone, or module, or to activity in a cell or released from a cell into the access drifts. In fact, a limited number of cells contribute to supplying the borehole.

Illustrations

As an example, for spent fuel, the reference situation consists of a borehole in an access drift contiguous to spent fuel cells. Therefore, radionuclides reaching the borehole pass through the body of the clay engineered barrier, the plug or the Callovo-Oxfordian before reaching the access drifts, then the borehole. Only the horizontal fraction of this activity which follows on horizontal trajectory in the structures or associated damaged zones is likely to reach the borehole.

Radionuclide transfer follows different pathways depending on the chemical behaviour of the elements concerned. It has therefore been decided to present the results, distinguishing four different types of radionuclide:

- long-lived soluble and non- or very weakly sorbed radionuclides (^{129}I, ^{36}Cl, ^{41}Ca) ;
- moderately long-lived, weakly sorbed radionuclides and long-lived, moderately or strongly sorbed radionuclides (^{135}Cs, ^{14}C, ^{107}Pd, ^{59}Ni, ^{93}Zr, ^{93}Mo) ;
- radionuclides which are not sorbed but precipitated in bentonite or argillite (in this case only ^{79}Se) ;
- moderate or long-lived, very strongly sorbed radionuclides (^{126}Sn, ^{99}Tc, ^{166}mHo, ^{94}Nb).

Long-lived soluble and non- or very weakly sorbed radionuclides: ^{129}I, ^{36}Cl, ^{41}Ca can leave the cell. The mass attenuation in the near field is very low, or zero. The fraction of iodine 129 activity reaching the borehole is greater, on a scale of one million years, than that of chlorine 36, because the latter undergoes radioactive decay. Indeed, it has been shown that the mass of iodine 129 captured by the borehole corresponds to the mass initially present in 15 cells, whereas for chlorine 36, it corresponds to the mass initially present in 8 cells. The fraction of calcium 41 which reaches the borehole is more limited than that of iodine 129 and chlorine 36. This difference results from the effective coefficient of diffusion of cations in the host formation, which is stronger than that of anions; it tends to promote radionuclide transfer from the drifts to the Callovo-Oxfordian rather than to the borehole.

Moderately long-lived, weakly sorbed radionuclides and long-lived, moderately or strongly sorbed radionuclides: In the cells, moderately long-lived radionuclides which are very weakly or weakly sorbed (^{14}C, ^{93}Mo) and long-lived radionuclides which are moderately or strongly sorbed (^{135}Cs, ^{59}Ni, ^{107}Pd, ^{93}Zr) into the Callovo-Oxfordian and structures, profit from radioactive decay and/or remain essentially confined (at least 80 %) in the near field. Indeed, the mass emitted by the structures varies from less than one percent (0.15 % for ^{93}Mo) to several tens of percents (14.46 % for ^{135}Cs) ; their sorption allows for radioactive decay and diffusive spreading through the cell near-field and the signal of the labile fraction emitted by the package is attenuated at the cell exit. Moreover, the radionuclides migrate nearly towards the host formation.

Moderately long-lived, weakly sorbed anions (^{14}C, ^{93}Mo) only reach the borehole in limited quantities, because their capacity for sorption into the host formation promotes their migration from the drifts to the host formation and they also profit from radioactive decay when the cells are a certain distance from the borehole.

Radionuclides which are not sorbed but precipitated in bentonite or argillite: ^{79}Se, is not sorbed but precipitates in the near field, displaying a highly attenuated rate of activity at the cell outlets. This attenuation is reflected in the mass released from the cell near-field over the period of analysis (1 million years). The transfer of selenium to the borehole is also limited.

Moderately or long-lived, very strongly sorbed radionuclides: These radionuclides remain almost totally confined in the near field of the cell and/or profit from radioactive decay. For ^{126}Sn and ^{99}Tc, a very small quantity of the mass diffuses into the structures and reaches drifts adjacent to the cell plug. However, these elements are strongly sorbed into the host formation, and the latter continues to trap them on their way to the drifts, and the small amount of 99Tc and 126Sn which reaches the drifts cannot reach the borehole.

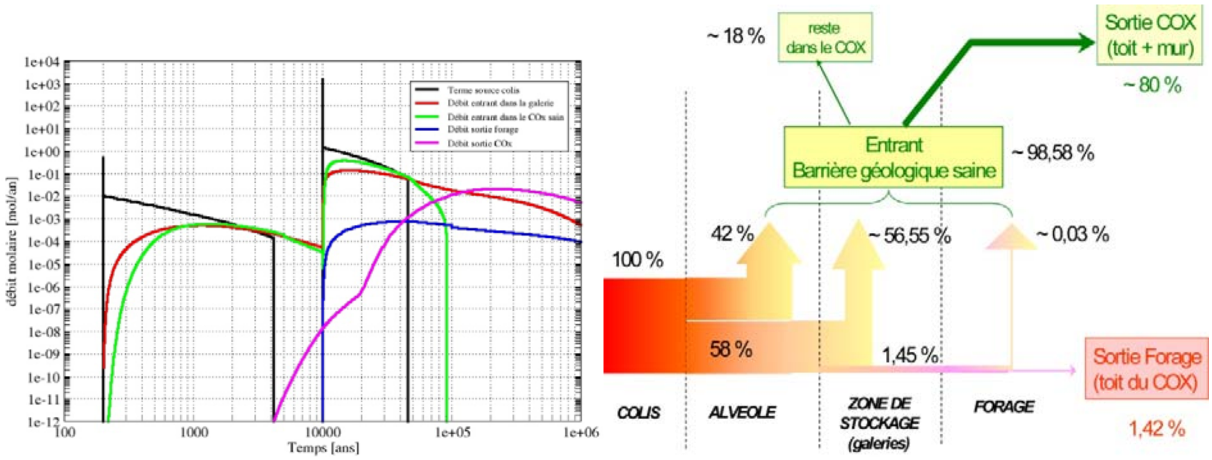

Figure 5: SEA borehole abandoned in the repository – History of molar flow rates in the near field and details of distribution of - ^{129}I– CU1 reference packages - I transfer pathways (Figure 9-3 from TES [vii])

Radionuclides which are strongly sorbed into the host formation (^{135}Cs, ^{107}Pd, ^{59}Ni, ^{93}Zr, ^{126}Sn, ^{99}Tc, ^{166m}Ho, ^{94}Nb) migrate by diffusion from the access drifts to the geological medium, strongly limiting the mass of radionuclides which reach the borehole. For those radionuclides which do reach the borehole, their capacity for sorption by the host formation again promotes their return into the rock from the borehole and the molar flow rate leaving the borehole at the top of the shaft is extremely slow, or zero (See Table 2).

Table 2: SEA borehole abandoned in the repository – transfer pathways from repository structures to the borehole – mass percent leaving the borehole over 1 million years. - moderately long-lived, weakly sorbed radionuclides and long-lived, moderately or strongly sorbed radionuclides (Table 7.4-11 from TES)

Radionuclides	Mass % «entering the drift» (pathway 2)	Mass % reaching the borehole via the drifts (pathway 3)	Mass % reaching the top of the Callovo-Oxfordian via the borehole (pathway 5)
^{14}C	3.98 %	0.0085 %	0.0075 %
^{93}Mo	0.15328 %	0.000165 %	0.000125 %
^{135}Cs	4.91 %	0.00046 %	0.00003 %
^{107}Pd	3.10 %	0.00026 %	0.00001 %
^{59}Ni	1.15 %	0.0001 %	0.000005 %
^{93}Zr	0.18 %	0.000015 %	Zero

Actinides: Due to their high retention in the engineered structures and in the Callovo-Oxfordian, the actinides reaching the borehole are characterised by considerably reduced molar flow rates and late maxima. Only ^{240}Pu and ^{239}Pu, the quantity of which is relatively high, have a maximum molar flow rate out of the borehole towards the 100,000-year mark due to the fact that they are relatively less sorbed into the bentonite. The maximum molar flow rate of ^{239}Pu out of the borehole is around 5.10^{-9} mol/year after 90,000 years. The maximum molar flow rates of the other actinides occur after a million years. For the case of ^{237}Np, the retardation coefficient of which in bentonite is identical to that of plutonium but does not benefit from a radioactive decay.

The calculations results show that such a borehole would have only a limited effect on the repository and its behaviour. From a hydraulic viewpoint, the efficiency of the various design systems, in particular seals and repository compartmentalisation, limits the borehole influence to the disposal cells close to the borehole. The borehole is not therefore in a situation where it could drain contaminated water from the host formation which, although water bearing, can, in any case, produce only very little. Even in the “dual boreholes” case, there is no likelihood of inducing circulation between the two boreholes leading to a significant increase in radionuclide transport.

The dose associated with drinking water from a borehole is not more than 0.012 mSv per year for a borehole intercepting a repository drift or disposal cell. Dose peaks nevertheless appear earlier, taking in account a deliberately early drilling date, in consistency with the RFS III.2.f recommendations.

The possible influence of a damaged zone with degraded permeability properties (which means poorly performing seals) was included in the sensitivity study. This extremely penalising case can be compared with a situation of double alteration. The calculation was performed for C2 waste. The dose due to the borehole is very small (0.00067 mSv per year against 0.00065 mSv per year in the reference calculation).

7. Knowledge/Experience gained

The localisation of the site in the Meuse/Haute-Marne area is chosen, in coherence with the 2008 guide released by French Nuclear Safety Authority, so as to avoid zones which can present an exceptional interest in terms of subterranean/underground resources.

The reduced likelihood is supported by the choice of the site ("chosen so as to avoid zones which can present an exceptional interest in terms of subterranean/underground resources"), by the depth of the repository (more than 200m so that the safety is not affected by common sub surface human intrusion), by its conception and assigned safety function, and by the preservation of the memory (500years according to regulations).

The study of the « borehole » scenario has revealed that the repository system is robust when subject to the drilling followed by the abandonment of one or more boreholes in the repository.

Studying the "borehole" scenario underlines the fact that the repository system is robust relative to this type of external event. All together, the low permeability of the geological barrier, associated with its "dead-end" architecture, seal efficiency and extra confinement provided by the waste packages, contribute to limit the impact of any partial bypass of the geological barrier. As the geological barrier is partly bypassed, the « delay and attenuate the migration of radionuclides function » is certainly degraded, but offers some effectiveness for elements sorbed in the geological barrier by forcefully limiting the fraction of activity reaching the borehole.

In line with the new 2006 French Act and the 2008 revised version of the safety rules (guide), the scenario "borehole" will be re-examined taking account for design optimisation and knowledge acquisition (including new data on the site of Meuse Haute-Marne).

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A2 ENRESA (Spain)

Revision: 0

1. Introduction and background

This document describes the treatment of human intrusion by ENRESA in the Performance Assessment (PA) of a HLW repository. Human intrusion is considered only in the PA exercise ENRESA2000 [2] for a repository in granite. Human intrusion was not considered in the most recent PA exercise for a repository in clay ENRESA 2003 [1] due to time constrains and to limit the workload, but ENRESA considers that human intrusions are relevant for repositories both in granite and clay.

In this document a detailed description of the treatment of human intrusion in ENRESA2000 [2] is done. Both the rationale followed to define the human intrusion scenario, the models used to evaluate such scenario and the results obtained are described.

2. Regulatory requirements and provisions

The acceptance criteria for radioactive waste final disposal facilities established by the Spanish Regulatory Body (CSN) was set in 1987 in these terms: “to ensure safety individual risk should be smaller than 10^{-6} yr^{-1}, that is the risk associated to an effective dose of 10^{-4} Sv/yr”. This is the only regulatory requirement in Spain.

There are no specific regulatory requirements or guidelines regarding whether to consider or how to treat future human intrusions in the repository.

3. Key terms and concepts

In ENRESA 2000 [2] no formal definition for human intrusion is given, but the definition provided by NEA [7] for the inadvertent human intrusions is applicable, i.e. actions *“in which either the repository or its barrier system are accidentally penetrated or their performance impaired, because the repository location is unknown, its purpose forgotten, or the consequences of the actions are unknown”*.

4. Treatment in the Safety Case

4.1 Methodology

4.1.1 General concepts

ENRESA has not made in-house developments on the topic of human intrusion but has been involved in the work done by international organisations. As a consequence, ENRESA position on the topic of human intrusion is consistent with the ideas developed by the international organisations [7] or in the national programs of different countries. The findings of the US National Academy of Sciences (NAS) [6] are the main basis for ENRESA´s treatment of human intrusion.

The key points of ENRESA approach to human intrusion are presented in the following paragraphs.

NEA Working Group on Assessment of Future Human Actions at Disposal Sites recommends that safety assessments should not deal with intentional human intrusion [7]. It can be reasonably assumed that the intentional intruder will take the necessary precautions. **ENRESA has adopted NEA´s recommendation and only inadvertent human intrusions are analysed.**

It is widely accepted that future human intrusions can not be prevented. For a brief inital period, institutional control can prevent human intrusion [6], but *„there is no basis in experience for such an assumption beyond a time scale of centuries“*. NAS [6] concludes that we can not rely on passive control (markers and archival of records) to ensure that no human intrusion takes place because *„there is no technical basis for making forecasts about the reliability of such passive institutional controls“*. **ENRESA considers that human intrusions are possible as soon as institutional control ends.**

There are three categories of hazards resulting from intrusion:

- Hazards to the intruders (drillers, handlers of material teken from the repository);
- Hazards to the public from material brought to the surface by the intrusive activity; and
- Hazards to the public that arise because the integrity of the repository´s engineered or geological barrier has been compromised by the intrusion.

For the first two categories of hazards the NAS report [6] concludes that *„analysing the risks to the intrusion crew and the risks from any material brought directly to the surface as a consequence of the intrusion is unlikely to provide useful information about a specific repository site or design and therefore should not provide a basis for judging the resilience of the proposed repositoryto intrusion. Whenever highly dangerous materials are gathered into one location and an intruder inadvertently breaks in, that intruded runs an inevitable risk“. The NAS report recommends „that the compliance analysis should concentrate on the third category of hazard posed by human intrusion, the one resulting from modification of the repository barriers*“. **ENRESA endorses these conclusions and only the third category of hazards are considered: i.e. „hazards to the public that arise because the integrity of the repository´s engineered or geological barrier has been compromised by the intrusion“.**

Although some organisations, such as SKI [5] recommends to consider also doses due to the dispersal of radioactive materials in the biosphere as a result of drilling activities, ENRESA does not include such material in the evaluation, because it would lead to the same consequences independently of the site and disposal concept.

NAS [6] considers that *„it is not technically feasible to assess the probability of human intrusion into a repository over the long term*“. There seems to be some consensus on this topic (with some exceptions, such us UK).

Contrarily to the probability of the human intrusion, its consequences can be calculated with some confidence as stated by NAS [2] *„..it is possible to carry out calculations of the consequences for particular types of intrusion events, for example drilling one or more boreholes into and through the repository*". **ENRESA has focused on the definition and consequence analysis of a human intrusion event (or scenario), and no efforts are done to quantify the probability of the human intrusion.**

SKI report [5] points that *„the focus of assessment of future actions should be on longer-term doses received by groups of people who might anyaway be considered in the Reference Scenario. In particular, human intrusion assessments should include groups considered in assessments of groundwater releases who may receive additional doses from new pathways arising from future human actions...*". **In ENRESA´s human intrusion scenario the receptor is an average member of the critical group defined for the Reference Scenario that uses water from a stream (arroyo 3 in Figure 4.). Due to the the drilling of a borehole that penetrates a canister there are additional radionuclide releases to the stream compared with the Reference Scenario.**

ENRESA has followed the recommendations given in the NAS report [6]: *„we consider a stylized intrusion scenario consisting of one borehole of a specified diameter drilled from the surface through a canister of waste..." and „consider current drilling technology but assume sloppy techniques such as not plugging the hole carefully when abbandoning it*."

Regarding the dose limits applicable to the human intrusion scenario, there are no regulatory requirements or guidelines in Spanish. In ENRESA2000 [2] for the human intrusion scenario **ENRESA has adopted the same reference value for dose than in the Reference Scenario: 10^{-4} Sv/yr.**

4.1.2 Definition of the human intrusion scenario

On the base of the general concepts presented in the previous section ENRESA generated the human intrusion scenario for a repository in granite of ENRESA 2000 [2].

In this human intrusion scenario it is assumed that 500 years after repository closure, when the institutional control period has passed there are mining activities in the area of the repository. An exploratory borehole intersects vertically a disposal canister, and the drilling head cuts pieces of the spent fuel disposed in the canister and significant amounts of radionuclides are released from the waste. Most of the contaminants will be extracted in the core or the drilling slurries sent to the slurry pool in the surface. The rest of the radionuclides released will remain sorbed on the surface of the borehole of will dissolve in the groundwater. After the drilling the borehole is left unsealed, and since that instant radionuclides in the borehole column can be transported by groundwater.

The canister adopted in the Spanish disposal concept is made of carbon steel and has a thickness of 10cm. Only when a significant thickness of the canister has been corroded, the drilling head can penetrate it.

The purpose of this scenario is not to analyse the radiological consequences of the exploratory borehole on the people who perform the drilling or inspect the cores. The long term consequences of the pool of slurries are not considered either. The objective is to analyse its effect on the isolation capability of both the engineered and natural barriers. The borehole damages the engineered barriers (canister and bentonite) of the intersected canister. In addition, since water travel time usually increases with depth, the radionuclides deposited in the borehole column will reach the Biosphere faster than the radionuclides released at repository depth.

On the base of bibliographic data, a value of 8inches (20cm) has been adopted as representative for the typical diameter of the drilling head. Since the active length (with UO_2 pellets) of the reference PWR fuel assembly is around 3.6m and the fuel element has a square section with 21cm of side, the drilling head can intersect 1/18th of 2 fuel assemblies (of the 4 fuel assemblies in the canister) as a maximum: i.e. less than 3% of the waste disposed in a canister. This fraction of the fuel assembly would be powdered by the drilling head and could be deposited in the borehole column. The remaining 97% of the waste would remain unaffected at repository depth.

In this scenario doses are calculated for the canister affected by the borehole. In order to understand the relevant parameters in the scenario, several calculations are performed for different values of the fraction of canister inventory deposited in the borehole column (a realistic value of 3% and a conservative value of 100%) and three different transport models: cases A, B and C (described in section 4.1.4).

Total dose in the human intrusion scenario is the sum of the dose due to the perforated canister plus the doses due to the remaining 3599 canisters. Conservatively, the doses due to the penetrated canister are calculated assuming that 100% of the inventory in the canister is deposited in the borehole column. Doses due to the intact canisters are taken from the Reference Scenario.

4.1.3 Hydrogeological modelling and calculations

The borehole column (SONDEO) has been included in the local hydrogeological model as a highly conductive region. Boundary conditions from the regional hydrogeological model to the local hydrogeological model are the same than in the Reference Scenario. Conservatively, the borehole has been located close to the main discharge of the system (stream 3) as can be seen in Figure 4.1.

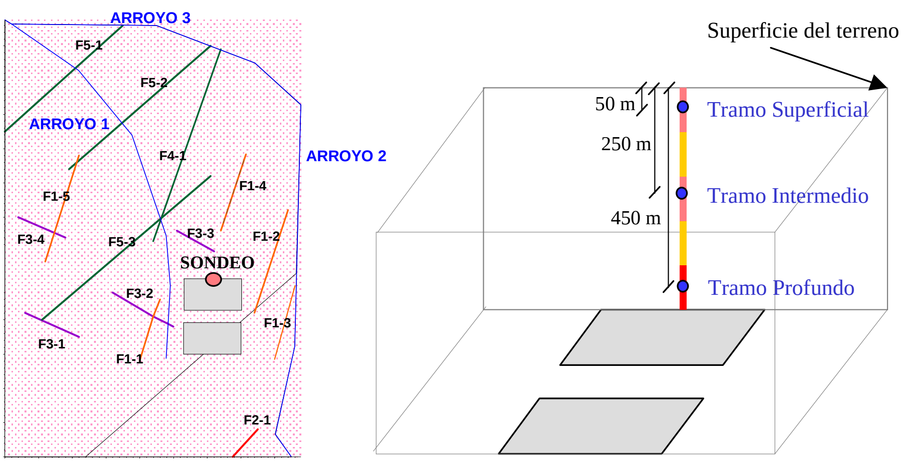

Figure 4.1 – Scheme of the human intrusion scenario

Using the model of Figure 4.1, water flows are calculated with INVERTO code and then the particle tracking code 3DTRANS is applied. Particles are released from 3 points of the borehole located at different depths (50m, 250m and 450 m below the surface). 500 particles are released in each of the three simulations.

Figure 4.2 presents 50 representative trajectories for each of the 3 simulations performed, that are identified as lower section (450m deep), medium section (250m deep) and upper section (50m deep). When the release point moves closer to the surface, travel times decrease significantly because hydraulic conductivity and gradients are greater, and water moves faster. In the 3 simulations all the particles arrive to the intersection of fracture zone F4-1 with stream 3.

Travel times obtained in each of the 3 simulations have been analised separately, and the histogram of frequencies and the cumulated frequencies are obtained (Figure 4.3 presents the results for the medium section).

The travel times obtained in each simulation have been used to generate 3 cumulative distributions for the travel time (one for each depth of emission). Figure 4.4 shows the distributions obtained, that present an increase of the water travel time with the depth of the release point, as expected. These travel times are input parameters for the three 1D advective-dispersive pathways that represent the granite formation from the borehole column to stream 3.

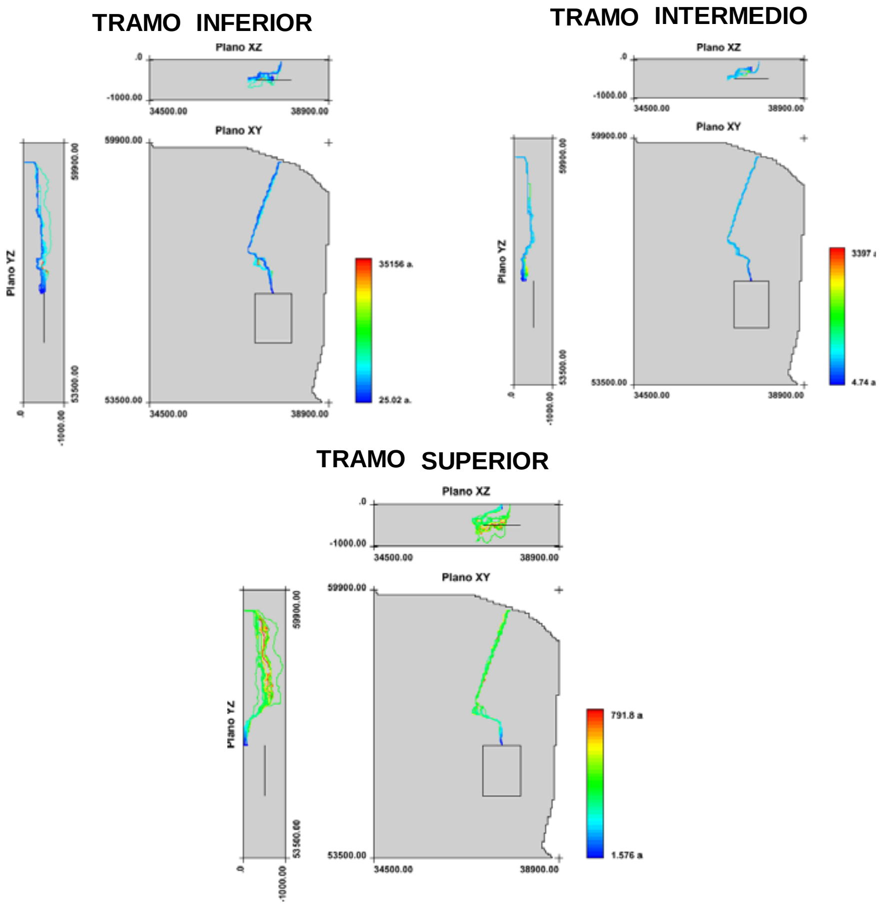

Figure 4.2 – Scheme of the trajectories followed by the particles in the 3 simulations done (lower, medium and upper sections of the borehole) for the human intrusion scenario

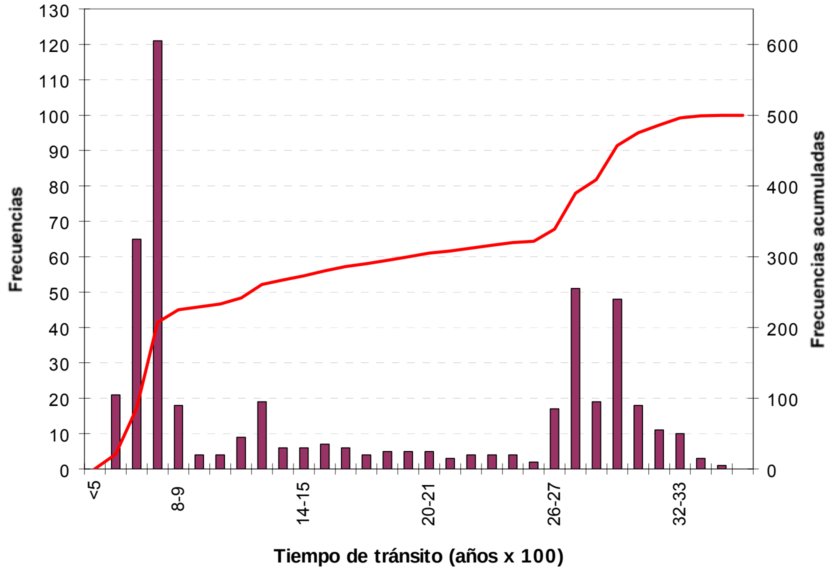

Figure 4.3 – Histogram of frequencies and cumulated frequencies for the travel times for the 500 particles released from the medium section (250m of depth)

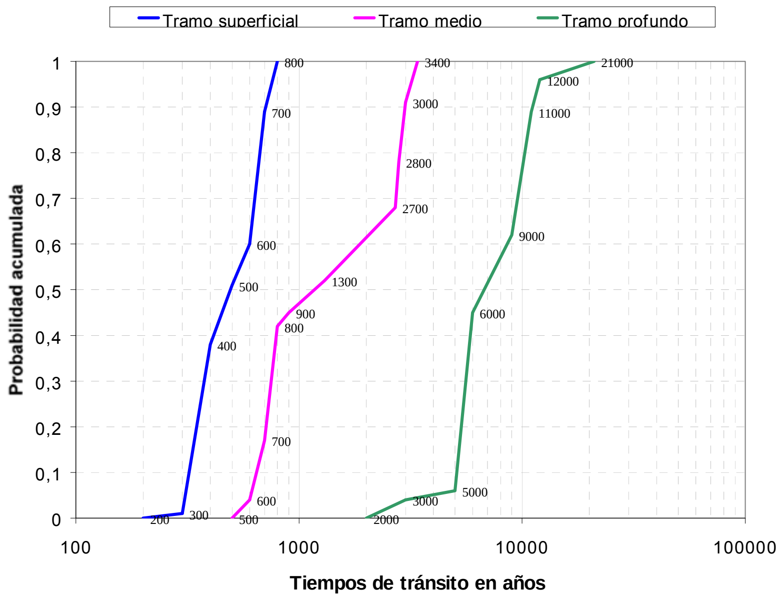

Figure 4.4 – Cumulated distribution functions for the water travel time for 3 different depths

Transport models

In order to calculate the doses due to the perforated canister the borehole column is divided into 3 sections of equal length, each containing 1/3rd of the radionuclides released from the canister by the drilling head. The distribution of travel times obtained with the particles released at a depth of 50m is assigned to the upper section of the borehole. The distribution of travel times obtained with the particles released at a depth of 250m is assigned to the medium section of the borehole. The distribution of travel times obtained with the particles released at a depth of 450m is assigned to the lower section of the borehole.

Doses due to the perforated canister have been calculated using three different models, with different degree of conservatism:

Case A: Five hundred years after repository closure, 1/3rd of the inventory of radionuclides released by the drilling head enters immediately into each of the 3 geosphere pathways obtained. This is a very conservative model that does not give credit to the solubility limits of many radionuclides or the sorption on the crushed granite that fills the borehore.

Case B: Each section of the borehole column is represented as a cylinder of crushed granite with high porosity. Assuming 20cm of diameter and 166m of length, the volume of each cylinder is around $5 m^3$, with a mass of 10,000kg of granite. A 10% porosity is assumed. The radionuclides released by the drilling head distribute homogeneously along the borehole column. In this case both solubility limits and sorption on the crushed granite in the borehole are taken into account.

In order to quantify the release of radionuclides from the cylinders of crushed granite that represent the borehole a simple model is adopted, in which radionuclides are transported out of the granite cylinders dissolved in the groundwater that flows through the granite. It is assumed that the water flow that moves across the borehole column is 10 times greater than the value corresponding to its geometrical vertical section ($0.2 m \times 166 m \approx 30 m^2$). Using the Darcy velocity at repository depth ($2 \cdot 10^{-6}$ m/yr) the groundwater flow through each section of the borehole would be 10^{-4} m^3/yr. Conservatively, much higher water flows are adopted, that depend on the depth: 0.1 m^3/yr for the lower section, 1m^3/yr for the medium section and 10 m^3/yr for the upper section.

Case C: This case is identical to Case B, but the groundwater flows washing the different sections of the borehole are 100 times smaller than in Case C. Case C probably is the most realistic of the 3 cases considered.

4.1.5 Consequence analysis

Calculations have been made using the 3 models described in section 4.1.4 (Cases A, B and C) assuming that 100% of the radionuclide inventory in the penetrated canister is distributed homogeneously along the borehole column. A probabilistic calculation was done for 1000 runs, and the mean doses due to the penetrated canister are presented in Figure 4.5 (Case A), Figure 4.6 (Case B) and Figure 4.7 (Case C), where only radionuclides that originate mean doses above 10^{-8} Sv/yr are represented.

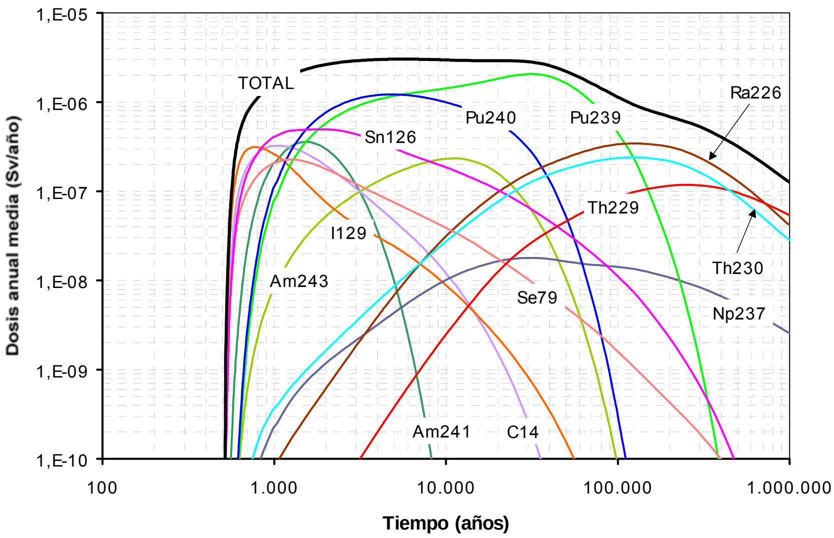

Figure 4.5 – Mean doses due to the perforated canister in Case A (100% of the waste powdered)

Assuming that 100% of the waste is powdered, peak doses due to the penetrated canister are $3.03 \cdot 10^{-6}$ Sv/yr (case A), $1.12 \cdot 10^{-6}$ Sv/yr (case B) and $6.58 \cdot 10^{-7}$ Sv/yr (case C).

Calculations have been repeated assuming that only 3% of the waste in the canister is powdered by the drilling head and deposits along the borehole column, which is a more realistic value. The peak doses calculated are $9.10 \cdot 10^{-8}$ Sv/yr (case A), $6.27 \cdot 10^{-8}$ Sv/yr (case B) and $2.51 \cdot 10^{-8}$ Sv/yr (case C), much smaller than assuming that 100% of the waste in the perforated canister is powdered. Only in case A the peak dose is proportional to the fraction of the waste that is deposited in the borehole. With models B and C the factor 33 of reduction in the inventory in the borehole column translates into a significant reduction in the peak dose too: a factor 18 in case B and a factor 26 in case C.

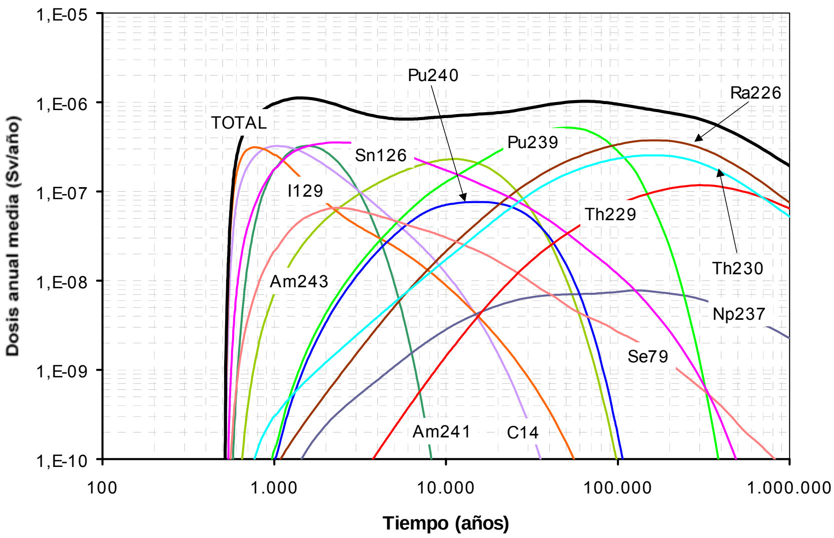

Figure 4.6 – Mean doses due to the perforated canister in Case B (100% of the waste powdered)

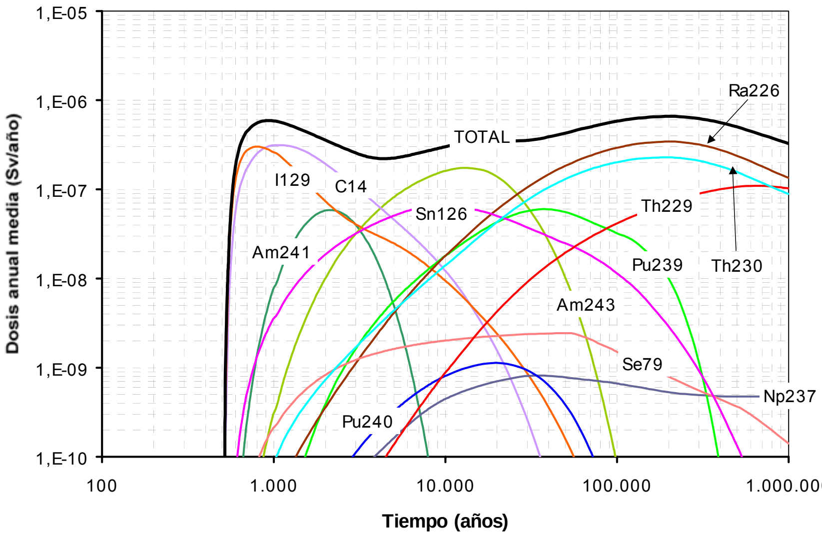

Figure 4.7 – Mean doses due to the perforated canister in Case C (100% of the waste powdered)

It has been found that peak doses are little affected by the model used to perform the transport calculation for the perforated canister (cases A, B or C). By the contrary, the fraction of the waste in the canister that is powdered by the drilling head and deposits on the borehole column has a strong effect on doses.

4.1.6 Doses in the human intrusion scenario

Total dose in the human intrusion scenario is the sum of the dose due to the perforated canister plus the dose due to the remaining 3,599 canisters. Conservatively, for the doses due to the perforated canister the values calculated in case A assuming that 100% of the inventory in the canister is deposited on the borehole column. For the doses due to the intact canisters the values calculated in the Reference Scenario are used.

Figure 4.8 shows the doses calculated for the human intrusion scenario. Results are presented for the (more realistic) case in which just 3% of the waste in the penetrated canister is deposited on the borehole column, too.

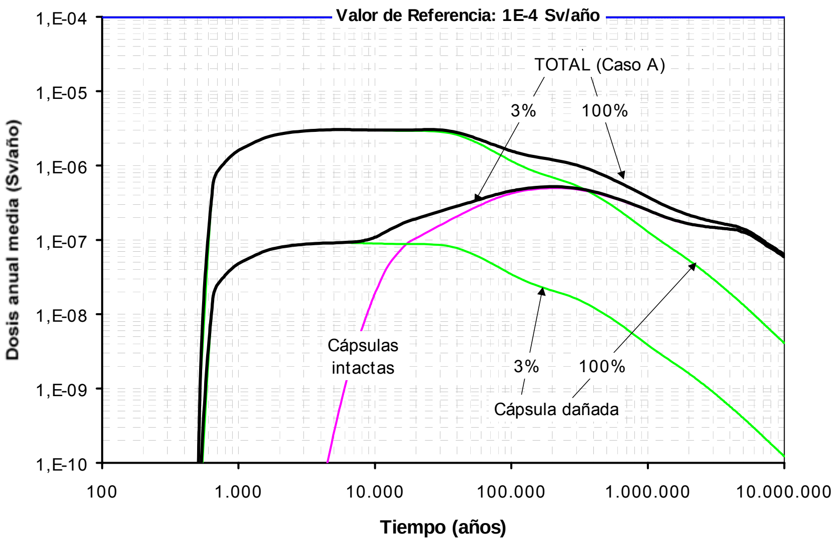

Figure 4.8 – Total doses in the human intrusion scenario

Peak dose in the human intrusion scenario is $3.03 \cdot 10^{-6}$ Sv/yr, roughly 3% of the reference value: 10^{-4} Sv/yr. Peak dose is controlled by the perforated canister and is reached 3,000 years after repository closure.

If only 3% of the waste in the canister is powdered by the drilling head, peak dose is $5.19 \cdot 10^{-7}$ Sv/yr, slightly higher than in the Reference Scenario. In this case, the peak dose is controlled by the intact canisters and is reached 200,000 years after repository closure.

The results obtained show that the drilling of one canister does not lead to a significant degradation of the isolation capability of the repository. Even with very pessimistic assumptions the doses to a member of the critical group are well below the reference value.

4.2 Related topics

Human intrusion is closely related with the Definition and Assessment of Scenarios. Typically the process of scenario definition leads to the selection of one or several human intrusion scenarios to be evaluated.

4.3 Databases and tools

In ENRESA2000 [2] the FEP database (see the topic “Definition and Assessment of Scenarios”) is the starting point for the FEP screening and classification process that led to the identification of human intrusion (exploratory drilling) as one of the scenarios to be considered in the Safety Assessment.

Consequence analysis for the human intrusion was done using GoldSim computer code [4] and models developed on the base of those used in the Reference Scenario.

4.4 Application and experience

ENRESA has considered human intrusion only in one of the PA exercises done: ENRESA2000 [2] for a repository in granite. In ENRESA2000 [2], on the base of the FEP analysis, a human intrusion scenario (exploratory drill) is identified as relevant, defined in detail and a consequence analysis of such scenario is done.

4.5 On-going work and future evolution

ENRESA is making no in-house developments on this topic, but international developments are followed.

5. Lessons learned

Human intrusion in HLW repositories has been a matter of discussion in national programmes and international organisations for many years. Consensus has been reached on many topics, while for others there remain different views. When dealing with human intrusion in a new iteration of the Safety Case, it would be very useful to rely on the common ground identified on this topic in order to avoid lengthy discussions on topics already "solved" i.e.: intentional vs. inadvertent intrusion, credit for institutional controls,….

Human intrusion is a topic to be discussed by regulators and implementers at the initial stages of the Safety Case, to ensure that there is agreement on the basic assumptions. Only when there is such agreement the implementer should start to define the scenario in detail and develop the necessary models.

The consequence analysis of the human intrusion scenarios usually requires the development of specific models. When selecting the computer codes for the Safety Case the particular needs of the human intrusion scenario should be considered.

6. References

[1] ENRESA 2003. Evaluación del Comportamiento y de la Seguridad de un Almacén Geológico Profundo de Residuos Radiactivos en Arcilla. 49-1PP-M-A1-01 Rev.0. February 2004. (In Spanish)

[2] ENRESA 2000. Evaluación del Comportamiento y de la Seguridad de un Almacenamiento de Combustible Gastado en una Formación Granítica. 49-1PP-M-15-01 Rev.0. December 2001. (In Spanish)

[3] Not used.

[4] GoldSim Technology Group. 2007. GoldSim User´s Guide. http://www.goldsim.com.

[5] SKI. Elements of a Regulatory Strategy for the Consideration of Future Human

Actions in Safety Assessments. SKI Report 99:46. September 1999.

[6] National Academy of Sciences. Technical Bases for Yucca Mountain Standards. National Academy Press. Washington 1995.

[7] NEA. Future Human Actions at Disposal Sites, Safety Assessment of Radioactive Waste Repositories. A Report of the NEA Working Group on Future Human Actions at Radioactive Waste Disposal Sites. 1995. OECD/NEA. Paris. France.

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1. Introduction

In Belgium, a R&D research programme related to geological disposal of high-level and long-lived radioactive waste has been conducted during the last three decades. In 2013, a safety case on the geological disposal options developed by the Belgian waste management organization (ONDRAF-NIRAS) will be issued and reviewed by FANC. ONDRAF-NIRAS is also currently developing a project of near-surface disposal facilities for low- and intermediate-level short-lived radioactive waste, for which the authorization application is planned to be submitted at the end of 2010.

In parallel, the Belgian nuclear safety authority (FANC and its technical support organisation Bel V, formerly named AVN) has been involved, for the last five years, in different types of activities, aiming at developing a specific regulatory framework adapted to radioactive waste disposal facilities and reviewing technical documents. The regulatory framework is made of several guides expressing the expectations of the nuclear safety authority on different aspects of radioactive waste disposal facilities. In addition to these guides, the following documents more specific to deep geological disposal, have been developed:

- "Geological Disposal of Radioactive Waste: Elements of a safety approach" [1]: This document was elaborated in 2004 by FANC, AVN, the French nuclear safety authority and its technical support (ASN and IRSN) and the waste management organization from both countries (ANDRA and ONDRAF-NIRAS) in the framework of the Franco-Belgian collaboration in the field of nuclear safety.
- On the basis of the above mentioned document a first draft of guidance [2] was elaborated for the siting of disposal facilities in argillaceous formation. This document is applying the safety approach defined in the aforementioned document [1] to the confirmation of the choice of a host formation.
- In 2007, FANC issued a document [3] describing the licensing process of radioactive waste disposal facilities and the different periods in a disposal programme in Belgium.

The present contribution aims at presenting the recent but preliminary positions developed by FANC about human intrusion and its treatment in the safety assessment of geological repositories.

2. Definition of terms and used concepts

Disposal system: The disposal system includes all the components (man-made and natural) that contribute directly or indirectly to the implementation of the "isolate and confine" strategy. The disposal system comprises the conditioned waste packaging, the engineered barriers and the part of the geological formation that fulfils safety functions.

Environment of the disposal system: The biosphere and parts of the geosphere that are not considered as parts of the disposal system, as they do not participate in the implementation of the "isolate and confine" strategy.

Safety functions: Function assumed by one or several components of the disposal system that contribute, through its (their) physico-chemical properties, to the implementation of the safety strategy “isolate and confine”.

Human intrusion: Human action causing partial or full degradation of one of several safety barriers of the disposal system, and that may expose the author of the intrusion (named as “the intruder”) or the surrounding population to a radiological risk.

3. Regulatory Context

3.1 Regulations and guidance

Although under development, no specific regulatory texts as such are currently in force in Belgium concerning radioactive waste disposal facilities. The general regulatory framework existing for nuclear installations (Royal decree of 20th July 2001) does not address the specificities of repositories, in particular, the timeframe and the concept of “long-term safety”.

It has thus been decided to develop a specific regulatory framework (Royal Decree about long-term management of radioactive waste), applicable to both near-surface and geological disposal facilities describing, amongst others, the licensing procedure to be applied for such facilities. The development of this document has been initiated at the beginning of 2008, and is still on-going.

In parallel, as it is planned that a license application for a near-surface disposal facility will be submitted in 2010, FANC is developing technical guides related to the safety of near-surface disposal, including a general guide [4] and a number of associated guides on several specific topics (e.g. human intrusion[5], seismic hazard assessment, biosphere…).

Although the guide on human intrusion [5] was initially developed for near-surface disposal, some particular points can also be applied to a certain extent to geological disposal facilities.

Additionally, FANC recently initiated the development of regulatory guides for geological disposal facilities. The implications of the high-level requirements developed in this framework on the treatment of human intrusion were also considered in the discussions and positions presented in this paper.

3.2 Requirements and expectations

In Belgium, no specific regulatory document on the topic of human intrusion in geological repositories exists until now but, as aforementioned, both FANC and Bel-V (ex AVN) have participated in the elaboration of the Franco-Belgium document [1] which gives some orientations about the basis, the elements and the development of a safety approach.

The fundamental principles applying to disposal facilities in Belgium are defined in the Note [3] issued by FANC. These principles are consistent with the safety fundamentals and safety principles defined by IAEA.

Concerning human intrusion, specifically the following fundamental principles or requirements are considered:

- Radiation protection principles (ICRP recommendations)
- Protecting future generations with the same level of protection as actual standards
- Not imposing undue burdens on future generations
- Limiting the occurrence of inadvertent human intrusion events into the disposal system
- Ensuring the security of installations, by preventing the risk of malevolent actions that could impair the repository safety

Both the application of these principles and the implementation of a “Isolate and Confine” safety strategy are required by FANC and will be further referred to in this document.

Discussing on human intrusion leads to distinguish between deliberate and inadvertent human intruder.

A deliberate intruder is someone who is well aware of the radiological and non radiological hazard of the repository and who despite of this hazard, regardless of its motivations, wants to access the disposal system and even the waste itself.

An inadvertent intruder is someone who has no preconceived idea of the hazard and by his activities, degrades partially or totally one of more barriers of the disposal system.

From a regulatory point of view, if one considers the intruders as members of the public, both types of intruders should be protected through appropriate measures to be taken by the operator. However, as it is impossible to totally prevent deliberate intruders from accessing the waste, the main concern for determining the measures related to the intrusion problematic will focus on the protection of the inadvertent intruder. Once a sufficient level of protection of the inadvertent intruder is reached, it can be considered that there is no need for adding any supplementary protective measures.

4. Analysis and synthesis

4.1 General considerations

The fundamental principles applying to any radioactive waste disposal facilities can be summarized as follows: “*ensuring protection of man and the environment, now and in the future, without imposing undue burdens on future generations*” [3].

The statement of “*not imposing undue burdens on future generations*” implies that the long-term safety of such a facility shall not rely on human actions, such as an extended institutional control period.

After closure of the repository, institutional controls remain in place for a limited period, amongst others to prevent intrusion into facilities, which is a particular concern for near surface repositories. As such controls cannot be maintained forever, additional measures have to be taken in order to limit the likelihood and the radiological consequences of human intrusion (HI) after the end of the institutional control period. The approach to be adopted is highly dependent on the type of facility:

- For near-surface repositories dedicated to low-level and short-lived waste, the means to prevent the occurrence (= reduce the likelihood of occurrence) of human intrusion are limited. So the strategy has to focus on limiting the direct and differed radiological consequences of HI by limiting the radiological content of the waste.
- For geological repositories dedicated to high-level and long-lived waste, it is not feasible to reduce the radiological content of the waste so as to reach an acceptable level of consequences in case of HI. Indeed, the doses received by an intruder coming into direct contact with the waste would surely be lethal (in its Publication 81, ICRP highlights that the implementation of a “concentrate and retain” approach by disposing of radioactive waste in a dedicated repository leads to the *inescapable consequence of the possibility of elevated exposures from disruptive events.*

4.2 Regulatory considerations

As previously mentioned, the long-term safety of geological disposal of radioactive waste requires the implementation of a “Isolate and Confine” safety strategy. “Isolation” here means that appropriate barriers are emplaced in order to isolate the waste from the man and his environment. Human intrusion events are to be considered as particular types of events that totally or partially disrupt mainly an “isolation” barrier of the disposal system (and that also can possibly affect the “confinement” performance), and whose direct consequences are critical.

Consecutively, when assessing the acceptability of a disposal project submitted by an operator, **the regulator will pay a particular attention to the set of measures proposed by the developer,** on the one hand **for preventing human intrusion** by selecting an appropriate site and making appropriate design provisions and, on the other hand, **for limiting the differed radiological consequences** linked to such an event. Both types of measures are to be considered when assessing the extent to which the **optimisation of protection principle** recommended by ICRP has been applied as regards the issue of HI in a geological repository. These two types of measures are further detailed in § 4.3 below.

The safety assessment methodology has to be developed based on the assumption that human intrusion cannot be ruled out after the release of the institutional control (postulated loss of memory of the repository existence). In case a human intrusion event would occur, all the possible consequences of this event will have to be considered including the radiological impact on human health (intruder and/or surrounding population) as well as the consequences on the long-term safety of the repository.

The present expectations of FANC regarding the treatment of HI in the safety assessment are presented in § 4.3 below.

4.3 Prevention measures

As previously stated, the main approach to dealing with the human intrusion issue for a geological disposal facility lies in the measures taken for limiting the likelihood of human intrusion events.

Measures for preventing human intrusion need to be taken as early as possible in the development of a project and have to be considered at all stages of the development (e.g. site-selection, design…) even though some stages may be more critical than others.

Site selection

The choice of implanting the repository at depth can constitute *per se* the appropriate mean for preventing human intrusion events, compared to other disposal options such as surface disposal for instance.

Site selection is a critical stage in limiting the likelihood of human intrusion. During this stage, the following considerations should be addressed as regards the human intrusion issue:

- Absence of exploitable natural resources in the surroundings of the disposal system (minerals and groundwater),
- Depth of the repository: indeed, the depth of the disposal and its environment is a key factor influencing to a great extent the probability of occurrence of human intrusion. It is considered *a priori* that the ability of the disposal system to isolate the waste increases with depth. However, this statement needs to be further discussed and assessed taking into account other considerations such as the confinement performance of the system. Optimising the depth of the repository may also involve a historical analysis of the number and types of boreholes drilled in the region of the disposal site as a function of depth. A particular attention should be paid to human intrusion at this stage. Furthermore, one has to keep in mind that once the site is selected, the possibility of reducing the probability of occurrence of HI through the design of the disposal system may be limited.
- Choice of host rock (e.g. potential for self-sealing after degradation)
- …

For geological disposal of high-level and long-lived waste, the absence of natural resources in the vicinity of the repository combined with the implantation of the repository at sufficient depth are the two key features for reducing the probability of a HI event.

Design of the facility

Once the site is selected, additional means for diminishing the likelihood of occurrence of HI after the institutional control period and limiting the radiological consequences of a HI event may also be considered in the design stage of the project. In any case, these means must necessarily be passive.

It is up to the developer to argue how the human intrusion preoccupation has been taken into account within the design (e.g. through the choice of the configuration of the facility, choice of materials, etc.).

Complementary means, independent from the characteristics of the system, may also contribute to reduce the likelihood of a HI event. These means are aimed to **make the intruder conscious of the presence of the repository and of the radiological and non-**

radiological risks that it represents. In particular, these means may include:

- Means for ensuring the long-term conservation of the memory (data conservation, archiving, communication to public…): these means are essential, whatever the type of repository to be considered.
- Physical markers: When considering physical markers to indicate the presence of the facility, one can also wonder if this could not at the same time enhance the potential interest of some people for committing an intrusion into the repository (malevolent intrusion). A careful approach is thus required.
- Land-use restrictions (including groundwater-use restrictions): this type of measure can be envisaged for surface disposal, but one can ask whether it would still be relevant for geological disposal.
- …

These measures can be referred to as **complementary means to prevent HI**. They must be thought of in the early stages of the development of the project, even if the implementation of some of them will only take place in the last stages.

For each measure taken to prevent HI intrusion, it is in any case essential to verify if it could not be unfavourable to other safety considerations.

4.4 Requirements / expectations of the regulator on HI treatment in safety assessment

As previously noted, only the case of inadvertent intrusion is to be considered in the safety assessment. Deliberate intrusions can be discarded as it is not feasible to protect somebody against a risk that he knows and that he is ready to undergo.

4.4.1 Reference groups

Two different types of reference groups can be distinguished when considering human intrusion into a radioactive waste disposal facility:

- The group of the inadvertent intruders who undergo the direct effects of the intrusion.
- The group of the surrounding population: this group is composed of people undergoing the differed effects consecutive to the intrusion, as a result of partial or total degradation of one or more safety functions of the disposal system. The exposure of the people from this group can occur a long time after the moment of the intrusion.

As previously stated, for geological disposal, it does not make really sense to consider the case of the intruder himself, as the level of doses received by a non-protected person coming into direct contact with the waste will surely be lethal. Nevertheless, the probability of occurrence of a HI event could be considered as extremely low (and thus the resulting risk acceptable), if sufficient provision to prevent HI has been made during the site-selection and design stages, as described above.

Consequently, for geological disposal, the reference group to consider in the human intrusion scenarios will be the group of the surrounding population, undergoing the

differed effects of the HI event.

4.4.2 Human intrusion scenarios (HIS)

Scenarios involving unpredictable future human actions leading to the partial or full degradation of the isolation and/or confinement properties of disposal facilities (amongst which human intrusion) have to be considered independently from the other types of scenarios (such as the reference evolution scenario / altered evolution scenarios / “what-if?” scenarios), due to the difficulty of assessing precisely their probability of occurrence.

- In case of deep geological disposal of high level waste and spent fuel, as recognized by ICRP, the radiological consequences incurred by the intruder are inacceptable. For this reason, it is recommended to assess the order of magnitude of the probability based on previous and current industrial practices for different depths and design options. Qualitative arguments showing how the provisions made during the site-selection and the design stages contribute to reduce the probability of occurrence of a HI event could be provided.
- Concerning the differed consequences, it is assumed that the intrusion has occurred and the intrusion event is then regarded as a particular case of accelerated degradation of the isolation and confinement performance of the disposal system. Consequently, it has to be considered within the “altered evolution” scenarios.

Examples of such postulated scenarios are drilling for water, exploratory drilling with the extraction of core, operation of a mine near the repository or direct physical human intrusion into the disposal facility. To define the list of human intrusion scenarios to be developed for a particular disposal facility, one has to take into account the regional context of the repository (e.g. presence of natural resources…).

Given the impossibility to predict future human actions and technologies, the assessment of the impact of human intrusion will be made by means of arbitrary stylized scenarios. The choice and development of relevant stylized scenarios is the responsibility of the operator.

The consequences of human intrusion also need to be assessed for different time scales, to take account of the evolution of the radiological source term within the repository.

FANC expects the operator to justify that the selected scenarios are envelope scenarios that cover all the possible intrusion scenarios that can be envisaged in the region of the repository site. A scenario consisting in the drilling, extraction and analysis of core samples for geological investigations should be taken into account in the assessment of HI and included in the list of envelope scenarios developed by the operator. For each envelope scenario, the differed effects of intrusion should be evaluated considering a family living in autarky on the repository site.

4.4.3 Assessment of the residual performance of the disposal system after a human intrusion

By definition, a human intrusion results in a local but complete bypass or degradation of one or more disposal system components. Hence, in case of intrusion, the isolation and confinement performance of the system will decrease. Consecutively, the operator should assess the residual performance of the disposal system after a human intrusion, in order to assess the robustness of the disposal system.

In order to improve this residual performance, the possibility of implementing complementary measures for limiting the dispersion of radionuclides following a HI event (using for instance intermediate sealing plugs) and for increasing the resistance of the system against intrusion should be investigated.

4.4.4 Appraisal of the results of the assessment of HIS

When considering how the radiological impact of HI should be carried out and assessed, one can first ask whether it would be appropriate or not to define reference values to be met for this type of scenarios, such as dose or risk constraints.

For geological disposal, due to the provisions made during the site-selection and design stages for preventing HI (see § 4.2 above), one could consider that the likelihood of HI is such that no regulatory limit on the radiological impact incurred by the intruder (such as a dose constraint) should be required.

However, any substantiation regarding the magnitude of the probability of occurrence as well as the description of any site characteristic leading to a decrease of the likelihood of human intrusion have to be provided.

As concerns the differed effects of HI, the repository should be developed in such a way that in case of intrusion the influence on the radiological impact on the surrounding population remains limited. A dose limitation could be defined in such circumstances, as for the other altered evolution scenarios (AES). It should be demonstrated that the radiological differed consequences of HI events remain acceptable, whatever the time of occurrence of the intrusion after the release of institutional control.

The developer should present assessments for different human intrusion scenarios of radiation doses to individuals who might occupy the site or the neighbourhood (cf. 3).

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1. Introduction and background

In Germany three formations have been under discussion for final disposal of heat-generating and high level radioactive waste, namely rock salt, claystone and granite. Integrated performance assessment models for long-term safety assessment have been developed for all three formations. However, concerning human intrusion, scenarios have primarily been addressed in safety assessment for repositories in rock salt so far. Therefore, the description here is mainly focussed on safety assessments for disposal in rock salt, which has been the preferred disposal option for several decades.

There is no recent safety case for a repository with heat-generating and high level radioactive waste. The information presented is based on the studies PAGIS [STO 88] for a generic repository with HLW and Everest [GOM 97] for a generic repository with HLW and ILW, and the safety case for the repository for LLW and ILW in Morsleben, ERAM [STO 04]. Additionally, this topic was evaluated on behalf of BfS (Federal Office for Radiation Protection) as one single issue in the report on conceptual and safety related issues regarding the disposal of radioactive wastes [BfS 05].

2. Regulatory requirements and provisions

The currently valid safety criteria for the final disposal of radioactive waste in a mine stem from 1983 [BMI 83]. Since then, regulatory expectations have advanced. On this account, GRS-K proposed “Safety requirements for the disposal of high active wastes in deep geological formations” [BAL 07] on behalf of BMU (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety). The BMU is presently elaborating the final version of the Safety Requirements. A draft version of the Safety Requirements was presented in November 2008 to the public [BMU 08].

In the currently valid safety criteria no specific regulatory requirements or guidelines are given regarding whether to consider or how to treat future human intrusion into the repository. In the scope of the revision of safety requirements several aspects how to handle human intrusion in the safety case are discussed. A detailed description of these aspects can be found in the contribution from GRS-Cologne.

3. Key terms and concepts

Human intrusion scenarios comprise those future human actions that lead to a direct penetration of a repository and damage the barriers within the backfilled and sealed repository area and the host rock. These may either cause direct releases into the biosphere or impair the barrier system of the repository or its safety functions. Human actions with no direct penetration of the repository or the waste canisters form a different type of human action scenarios. These scenarios comprise e.g. those human actions which disturb the groundwater flow regime in the repository system leading to an increase of radiation exposures in the biosphere.

In general, we follow the definitions given by GRS-K.

4. Treatment in the Safety Case

4.1 Methodology

There is agreement that the development of the mode of live and the behaviour of mankind, or social communities can only be assessed over a short time frame of few generations. Therefore, a systematic development of the scenario group human actions is not possible. However since human intrusion scenarios, after loss of the information about the repository, cannot be ruled out, they have to be assessed within the overall safety case. For the evaluation of human intrusion scenarios in the safety case scenarios should be consulted that are based on today's social conditions and state of the art in science and technology. Such scenarios need in particular be considered during planning and designing of the repository in order to identify appropriate counter measures.

Within the discussion of the new safety requirements in Germany, there is a tendency that the spectrum of human intrusion scenarios to be considered in a safety case should be confined and that the regulator should establish the boundary conditions for the development of such scenarios.

From the human intrusion scenarios, usually those initiated by an intentional intrusion are not included as they are in the responsibility of the respective society and the intruder is in charge of the radiological implications [NEA 95]. In case of inadvertent human actions the knowledge of the repository has to be lost at the time of occurrence. Thus, such kinds of scenarios are assumed to occur not before several 100 years after repository closure. Within the ERAM study human intrusion after 500 years has been assumed and in PAGIS and EVEREST 1000 years have been regarded as reference values including an analysis of the impact of the occurrence time by sensitivity analyses.

Inadvertent human intrusion scenarios are mainly possible in the scope of exploration or mining activities of future generations. In PAGIS three categories of human activities have been identified, which can lead to an unintentional contact between radioactive waste disposed of in a salt dome and the population [STO 88]. These are borehole drilling, constructions of a mine, and cavern leaching.

Borehole drilling: During drilling of a borehole, which is usually done for exploration, waste containers might be struck. Radioactive material as drilling core or fines can be lifted up to the surface. It appears that very high exposures can occur to a small group of some individuals. The probability of this exposure is, however, extremely low, and during the accident very few people will come into contact with the waste fragments. If the borehole will be abandoned, water intrudes into the borehole and leaches the waste. However, the exposed surface of the waste matrix is very small. The scenario with water intrusion is similar to the cavern leaching scenario, which is discussed below. However, the consequences are expected to be smaller due to the smaller volume of the drilling borehole.

Mining: A mine can be constructed for the purpose of exploitation of salt, for storage or for final isolation of hazardous chemical or radioactive wastes. In the case that newly mined drifts should contact the already existing disposal areas, it is assumed that it will be recognized that a repository for radioactive waste is already present. For further human actions the people living at that time would have to take the responsibility. If the mine is given up and sealed, the old situation will be re-established. During the accident very few people will come into contact with wastes. The doses they receive have shown to be comparable to those for the borehole drilling scenario. On the other hand, newly mined drifts may pass very near to the waste, but in a distance that the containers cannot be recognized. In this case, miners may obtain direct radiation from the waste.

Cavern leaching: A cavern can be created in a salt dome by means of the solution mining technique. The cavern can be used for the storage of oil or gas as well as for exploitation of salt.

Storage cavern: Mining of a storage cavern is a fast process, lasting a couple of months. If the cavern is mined in the area of a repository for radioactive waste, a part of waste packages might be laid open and fall into the sump and can be transported to the biosphere. The highest impact is expected after the operational phase of the storage cavern, when the cavern will be abandoned. The storage medium will be replaced by brine or water. Radionuclides can be transported out of the sump by diffusion and by advection with the brine squeezed out of the sump due to the convergence process.

Salt production cavern: Mining a cavern for salt production can last some decades. Containers are laid open for a much longer time. A considerable amount of radioactivity may contaminate the brine, which is brought to the surface. Since this brine is used for salt production, a not negligible health hazard to the people consuming contaminated salt is to be expected in this case. After solution mining is completed, the scenario is the same as that of a storage cavern after replacement of the stored medium.

Beside these scenarios, which have been addressed in several safety assessment studies for repositories in rock salt, a general evaluation of the issue human intrusion has been performed on behalf of the Federal radiation protection office BfS. Following the agreement between the German Federal Government and the energy supply companies in the year 2000 a total of 12 fundamental and safety-related issues relevant to all potential host rocks for a radioactive waste repository in Germany had to be investigated by different expert organisations. One of these issues was related to the possible influences of human intrusions into a repository and the consequences for the demonstration of its long-term safety. The results of this study were published in detail [COL 05] and in short within the Synthesis Report of the BfS [BFS 05].

The investigations focused at different generic repository types with salt, clay, granite host rock and for a repository where the main geological barrier is formed by an overlying clay capping. For these cases, a set of six covering human intrusion scenarios which lead to an exposure of the public had been identified. Scenarios with intended intrusion or exposures of the intruder were ruled out from the outset. These reference scenarios are:

- *Mining into the contaminated host rock region*: Mining taking place in the surroundings of the repository and host rock material already contaminated is conveyed and deposited at a stockpile. The radionuclides are eluted by the rain and enter into near-surface groundwater, which is used by the population.
- *Drilling into a waste container*: An exploration drilling directly hits the waste and perforates a container. The groundwater flow through the borehole (which is assumed to be backfilled in the meantime) releases the radionuclides adhering at the borehole

wall into the groundwater of a hydraulically coupled near-surface aquifer that is directly used by the population.

- *Drilling into the repository without hitting any waste*: An exploration drilling in the vicinity of the repository taps groundwater or brine in the repository region. Flow through the borehole (which is assumed to be backfilled in the meantime) releases contaminated groundwater or brine from the nearby regions of the borehole, which is transported along the borehole into the biosphere where it is used by the population.
- *Opening up of an underlying groundwater reservoir under overpressure by drilling*: An exploration drilling passes through the repository without hitting any waste and enters into an underlying groundwater reservoir under overpressure. The groundwater raised by the overpressure entrains some contaminated brine from the repository region, seeps away at the surface and enters into a near-surface aquifer, from which water is extracted which is used by the population.
- *Opening up of a contaminated aquifer by drilling*: An exploration drilling for drinking water is put down to an aquifer located next to the repository into which radionuclides from the repository had entered. The contaminated drinking water is raised und is used by the population.
- *Solution mining of evaporite rocks*: In the repository region salt is produced by means of solution mining. Waste containers enter into the brine sump. After corrosion of the containers the radionuclides will be raised with the brine. Table salt will be produced from the contaminated brine which is eaten by the population.

In a semi-quantitative approach the probabilities of occurrence of the scenarios and their radiological consequences had been classified for each generic repository. For evaluation, the probabilities and the consequences were combined to a criterion defined as “relevance” which is a parameter which is similar, but not identical to the “radiological risk”. The results of the study are condensed in Tab. 1.

Comparing the relevance of the scenarios and the host rock types it can be stated that the relevance of the scenarios for repositories in salt and clay can be ranked into the categories “moderate” to “low” taking into account the assumed input data and boundary conditions (complete inclusion of the waste forms, repository design, etc.). Notwithstanding a relevance ranking from “moderate” to “high” was obtained for the scenario “Solution mining of evaporite rocks” for salt but only for the wastes with negligible heat generation, because of the long lifetime of the containers with heat generating waste.

For the permeable host rocks (granite and other host rocks under clay capping) relevancies in the range from “moderate” to “very high” were determined for the six scenarios considered. As a result, the relevance of human action scenarios is generally higher for the permeable host rocks. From the low permeable host rocks (salt and clay) the salt overall showed slightly lower relevancies (except for the solution mining scenario), which mainly results from the comparatively lower probabilities of occurrence.

Tab. 1: Comparative rating of the relevance of different human intrusion scenarios and geosystems (from /BfS 05/)

Categories in brackets apply for the case that pressurized gas is stored in the host rock after creation of secondary porosity

Geosystem	Salt Diapir	Salt bedded 800 m	Salt bedded 1.300 m	Claystone	Granite	Other Rocks with Clay Capping
Scenario 1. Mining within contaminated host rock						
total consequence	- (+++)	- (+++)	- (+++)	- (+)	+++	+++
probability of occurrence	- (+)	- (+)	- (+)	+	+	+
relevance	- (++)	- (++)	- (++)	- (+)	++	++
Scenario 2. Drilling into a waste container						
total consequence	++	++	++	++	++	++
probability of occurrence	+	+	+	++	++	+++
relevance	+/++	+/++	+/++	++	++	++/+++
Scenario 3. Drilling into the repository without hitting waste						
total consequence	++	++	++	++	++	++
probability of occurrence	+	+	+	++	++	+++
relevance	+/++	+/++	+/++	++	++	++/+++
Scenario 4. Drilling into a reservoir with overpressure						
total consequence	++	++	++	++	+++	++
probability of occurrence	+	+	+	++	++	+++
relevance	+/++	+/++	+/++	++	++	++/+++
Scenario 5. Drilling into contaminated aquifer						
total consequence	-	- (++)	- (++)	-	++++	++++
probability of occurrence	-	- (+)	- (+)	++	+++	+++
relevance	-	- (+/++)	- (+/++)	-	+++/++++	+++/++++
Scenario 6. Solution Mining of evaporites						
total consequence	+++	+++	+++			
probability of occurrence	++	+++	+++	-	-	-
relevance	++/+++	+++	+++	-	-	-

relevance: ++++ very high, +++ high, ++ moderate, + low, - no consequence(s)
caused by: blue – waste with negligible heat generation, violet – all waste categories

4.2 Related topics

The topic human intrusion is related to the topics evolution of the repository system and modelling strategy.

4.3 Databases and tools

No explicit databases with regard to human intrusion scenarios are available. A new German FEP catalogue based on the classification of the NEA FEP catalogue was recently developed [BUH 08]. In this catalogue relevant FEPs for human intrusion scenarios are included.

In several cases simple models are used to estimate the impact of human intrusion scenarios. For calculations of the solution mined cavern the near-field code LOPOS (REPOS) [BUH 99] with modified segment models is (was) used (cf. section 4.4).

4.4 Application and experience

Human intrusion scenarios have been applied in the safety assessment studies for high-level waste PAGIS and EVEREST and in the frame of licensing applications for real repositories with intermediate and low level waste in Morsleben.

Within PAGIS three activities, which can lead to radioactive waste release from the salt dome, have been analysed: mining, borehole drilling, and leakage of an abandoned storage cavern, which was constructed by solution mining [STO 88]. Valuations showed that the latter scenario is the one, which leads to a maximum release of radioactivity. The assumptions for this scenario were: A storage cavern is created by solution mining technique. The waste canisters of an old HLW borehole, which are laid open during mining of the cavern, are buried in the sump of insolubles. After the storage cavern falls into disuse, it becomes filled with water. The waste form is dissolved and contaminated brine is squeezed out through the entrance shaft. A maximum dose of about $3 \cdot 10^{-5}$ Sv/a has been calculated mainly caused by Np-237 during a time frame from 500,000 to 1 million years. Although the probability of this scenario is difficult to estimate its consequences appear still acceptable.

Within EVEREST the scenario of mining a salt exploitation cavern has been treated in a detailed deterministic and probabilistic computer simulation [GOM 97]. The uncertainty analysis yields a mean dose rate of 8.1·10-5 Sv/year and a standard deviation of 8.7·10-5 Sv/year. The results are spreading over three orders of magnitude and 3.2% of the runs yield a dose rate above 3·10-4 Sv/year. A sensitivity analysis gives in the order of importance the parameters, (1) time span between waste disposal and cavern mining, (2) reduction factors describing the salt cleaning process, (3) number of caverns mined at the same time, and (4) the freshwater injection rate, as the most sensitive ones, concerning the maximum dose rates. The time span between waste disposal and solution mining of a cavern is, of course, the most sensitive one, since the leading nuclide in most of the simulations is the short-lived Am-241. It can be generally concluded that solution mining followed by salt consumption remains the scenario with the most severe consequences for waste disposal in rock salt. It is therefore recommended to search for design alternatives, which may limit the consequences in terms of probability and exposure of the solution mining scenario.

Within ERAM only those human intrusion scenarios have been considered, which might cause radiation exposures to a larger group of people [STO 04]. The exposure of single persons, as it is the case for workers directly involved in drilling or mining has not been regarded. The three scenarios construction of a cavern, construction of a new mine for raw materials production and an exploration drilling have been considered. The first two scenarios could be ruled out for the respective site, mainly because of the strong folding and high heterogeneity of the salt structure Morsleben, with frequent interstratifications of potassium and rock salt, which would not allow an economic operation of a cavern or mine. Model calculations for the scenario exploration drilling have shown that the water inflow through a backfilled exploration borehole is very low and none of the disposal areas can become flooded within one million years. Hence, no release of radionuclides via the exploration borehole will occur.

4.5 On-going work and future evolution

Currently an evaluation is performed lead managed by GRS-K to work out a joint view, how to treat human intrusion scenarios in a German safety case. This is part of the PAMINA project.

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Revision: 1

Contents

1. Background/ Introduction

The safety proof of radioactive waste repositories has to be provided in the so called safety case. An essential component of the safety case is the scenario development, in which the influencing features, events and processes (FEPs) related to the evolution of the repository will be identified and combined to representative scenarios. The safety proof will be demonstrated by means of these representative scenarios through an analysis of the resulting consequences. Concerning the scenarios it will be distinguished between the evolution of the repository as a result of natural phenomena and scenarios in connection with future human actions (FHA). With regard to the consequences of human activities a further distinction is made between actions that alter the isolation effect or the site situation and such actions that destroy or directly bypass the isolation effect. The latter actions, which are referred to as “Human Intrusion”, are the subject of this report.

As outlined in the Annex I "Description of Work" of the Integrated Project PAMINA the tasks in WP 1.1 will be carried out by bringing together and by including the perspectives from both the “developers” and the “evaluators”. For this reason each task will be addressed by the “development working group” (DWG) and by the “evaluation working group” (EWG) whereas the latter group will be the working platform for GRS Köln.

Therefore the present document includes the background, fundamentals, and the regulatory basis as well as recent developments /BAL 07, BMU 08/ in revising the existing "Safety Criteria" from 1983 /BMI 83/concerning the topic "Human Intrusion".

2. Definition of terms and used concepts

Actually, there are no definitions and descriptions of terms and concepts related to “Human Intrusion” in the legal regulatory frame of the "Safety Criteria" from 1983 /BMI 83/. Therefore, the following defined terms and used concepts were extracted for the most part from recent developments regarding “Safety Requirements” and “Human Intrusion”:

Scenario development

The scenario development represents an identification and selection of relevant alter-native developments (scenarios) of the repository system for further treatment in safety analyses /BAL 07/.

Scenario

Scenario describes a postulated evolution of a repository system and its safety functions, specified by a combination of relevant factors that characterise or influence the repository system /BAL 07/.

Future Human Actions (FHA)

FHA are human actions, which can adversely impact radioactive waste disposal systems

/NEA 95/.

Human Intrusion (HI)

Human intrusion (HI) is understood as any human activity following the closure of the repository mine that will directly damage the barriers within the backfilled and sealed mine workings and the isolating rock zone /AKS 08/.

Stylized Scenarios

Stylised Scenarios related to Human Intrusion, are selected scenarios which have to be derived based on the specific repository plans and site conditions. These HI scenarios need not be covering or conservative /AKS 08/.

Inadvertent Actions

Those in which either the repository or its barrier system are accidently penetrated or their performance impaired, because the repository location is unknown, its purpose is forgotten, or the consequences of the actions are unknown /NEA 95/.

Intentional Actions

If future intruders are aware of the waste and the consequences of disturbing the repository or its barrier system, then their actions are intentional /NEA 95/.

Isolating rock zone

The isolating rock zone is the geological subsystem of the repository that has to ensure the isolation of the waste in combination with the geotechnical seals (e.g. shaft seal) /BAL 07/.

Reference scenario

Cf. stylised scenarios

Repository system

The repository system comprises the repository and its geological environment, which in turn includes all rock areas that have to be considered for the compliance proof of the safety principles and protection objectives for final disposal /BAL 07/.

Repository

The repository is part of the repository system in which high active waste will be placed. It comprises the repository mine, the host rock and the isolating rock zone /BAL 07/.

Safety case

The safety case is the compilation of all arguments and analysis regarding the justification of the safety of the repository system and the confidence in the safety statement. A distinction is made between the safety case for the operational phase and the safety case for the long-term phase following the closure of the repository /BAL 07/.

3. Regulatory context

The legal basis for licensing is the "Plan Approval Procedure" required by the German "Atomic Energy Act" /ATG 85/ for federal installations for the safekeeping and final disposal of radioactive waste. The "Plan Approval Procedure" has a so-called “concentrating effect” for several fields of law and will generally lasts for the whole duration of a project. A stepwise approach is not explicitly implemented. Nevertheless it is the opinion of GRS that such an approach could be applied within a "Plan Approval Procedure" if the stakeholders would commit themselves on a voluntary basis. Within such an approach, a safety report based on the knowledge achieved so far would be produced at well-defined decision points, communicated to regulators and other stakeholders, and utilised to support decisions about how to proceed (“Safety Case”). In application of the "Plan Approval Procedure" the formulated “Safety Criteria" /BMI 83/ have to be considered.

3.1 Regulations and guidance

In Germany, the present regulatory frame for the disposal of radioactive wastes in geological formations dates from 1983 /BMI 83/ (“Safety Criteria”). Since then, regulatory expectations have advanced and reflect the international standards set out by ICRP /ICRP 98/, NEA /NEA 04/ and IAEA /IAEA 06/. Based on that, GRS proposed safety requirements for the disposal of high active wastes in deep geological formations /BAL 07/ ("Safety Requirements"), which is expected to serve as a sound basis for a new regulation. Earlier stages of the draft are reflected in several published documents /BAL 04a, BAL 04b, BAL 05a, BAL 05b, EUS 06/.

Based upon the GRS proposal /BAL 07/, BfS workshop's results /BRE 07/, BfS recommendations of June 2007, and the evaluation of the GRS proposal prepared by BMU's advisory-bodies “Reaktor-Sicherheitskommission” and "Strahlenschutzkommission”, BMU themselves carried out a draft “Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste” /BMU 08/ and presented this draft in November 2008 to the public. At present this draft is under discussion in the BMU´s advisory bodies. Currently, regulatory binding safety requirements are further under development.

This contribution refer predominantly to the existing regulation "Safety Criteria" /BMI 83/, the GRS proposal of "Safety Requirements" /BAL 07/ and the BMU draft report related to safety requirements /BMU 08/.

The subject “Human Intrusion” is not explicitly addressed in the "Safety Criteria" /BMI 83/. However, it contains few requirements which can be associated with certain aspects in the frame of the subject “Human Intrusion”, like the preservation of information. In contrast to that, the revised safety requirements /BAL 07, BMU 08/ are more elaborated and include several requirements which relate directly on human intrusion. As indicated before, the latter references should be seen as a preliminary work with no binding regulatory basis. However, the documents include the recent developments in the field of regulatory requirements on the basis of broad and thoroughly performed discussions and exchange of information and experience with experts from Germany and abroad.

In the following section the regulatory framework and the ongoing work concerning human intrusion will be shown. Specific topics which strongly relate to human intrusion like scenario development, and the evolution of the repository system are described regarding their context but will be addressed in detail separately as part of the respective topics "Definition and Assessment of Scenarios" and "Analysis of the Evolution of the Repository System".

3.2 Requirements and expectations

As mentioned above, the "Safety Criteria" /BMI 83/ do not include directly regulations and/or criteria concerning the topic "Human Intrusion”. Therefore, the hereafter listed requirements refer, with few exceptions, exclusively to /BAL 07/ and /BMU 08/:

Note: The underlined and bold text indicate titles in the references where the listed requirements are described.

Extracted requirements from the "Safety Criteria" /BMI 83/ which have a relation in a figurative sense to “Human Intrusion”:

The following paragraph relates to the aspect, that repository sites without valuable resources reduce the likelihood of human intrusion:

Natural resources

“With the choice of the site the conservation of economically important mineral deposits inclusive groundwater occurrences has to be considered.”

The next paragraph relates to institutional control in the post closure phase. Institutional control is often seen as a measure against inadvertent human intrusion:

Monitoring of the environment

“Construction, operation and closure of the repository mine will be performed in such a way, that a separate control and monitoring programme in the post operational phase is dispensable. General environmental protection measurements as well as topographic measurements on a routine basis give information about the radiology and the long-term thermo-mechanical behaviour of the host rock formation, the overlying rock and adjoining rock.”

The following paragraph can be associated with information preservation and markers as measures against inadvertent human intrusion:

Documentation and marking

“The mine surveyor data of the repository, the characterisation of the emplaced wastes as well as the essential technical measurements during the construction, operation and closure of the repository mine have to be documented. Complete sets of documents have to be preserved at separate, suitable, and protected sites. An aboveground marking of the repository is not required in terms of the routinely environmental protection measurements and topographic measurements. The knowledge of the position of the site has to be sufficiently preserved through documentation.”

Extracted requirements from the GRS-K proposal /BAL 07/:

Disposal objectives

One of several disposal objectives is the following:

"Arranging precaution against the possibility of inadvertent human intrusion into the waste and therewith connected effects."

Site investigation and site characterisation

"The implementer has to suggest the site, for which a suitability investigation shall be performed, to the responsible authority as well as to substantiate the potential suitability of this site. Aspects of resource protection and human actions after repository closure have to be included in the substantiation."

Basic requirement

"Measurements for the avoidance of human actions, which might have a negative impact on the isolation capacity of the repository system, or for the reduction of effects from these actions, have to be adequately considered in terms of resource protection."

Scenario development

"A scenario development for the repository system has to be performed. Herein the potential evolutions of the repository system, which are caused by endogenous and exogenous processes, have to be considered. In addition, the relevant scenarios for the safety case – with exception of human intrusion in the isolating rock zone - have to be indentified." (Note: Human intrusion will be treated separately.)

"Human actions which take place in knowledge of the closed repository will not be considered in the scenario development. These are put in the responsibility of the respective acting society."

Inadvertent human intrusion

"Inadvertent human intrusion into the repository system cannot be excluded totally, after a loss of information about the repository in the far future. Through the concept of concentrating and isolating the high active waste, a potential risk of radiation exposure exists in case of human intrusion, which can only be reduced conditionally."

"Human intrusion into the repository system has to be treated in the site selection process and for the compliance of requirements in the safety concept with regard to the optimisation of safety.

- It is exclusively considered the inadvertent human intrusion.
- Scenarios which describe the intentional human intrusion into the barrier system are not considered. These are put in the responsibility of the respective acting society."

"Reference scenarios have to be taken into account for the assessment of inadvertent human intrusion. The reference scenarios have to be analysed and assessed in consideration of specific site conditions as well as today´s state of the art in science and technology. This assessment has to take into account the number of persons affected, the spatial and temporal extent of any possible contamination, and the possibility of reducing the effects through planning countermeasures."

"It has to be shown, that through the planning and the design, all practicable countermeasures have been taken."

"It is assumed that for the treatment of the scenarios, which describe the inadvertent human intrusion, the knowledge about the repository remains at least 500 years. Therefore, no earlier point in time for the intrusion scenario needs to be chosen."

Documentation of the safety case

"The documentation of the safety case must include in a comprehensive, transparent and comprehensible way, the combination of arguments and analyses for the substantiation of the safety of the repository system as well as for the confidence in the safety statement of the proof."

Extracted requirements from the BMU draft /BMU 08/:

Safety principles

"The long-term safety of the final repository must not be based on active monitoring and maintenance measures, excluding a period of at least 500 years following decommissioning, during which current estimates predict that the competent offices will be able to preclude all human activities in the vicinity of the final repository which could threaten the permanent containment of the waste.

For the first 500 years after the repository's decommissioning, care must be taken to ensure that information about the final repository is forwarded to and held on file by the offices responsible e. g. for civil engineering projects, the construction of wells, and mining. Such offices must ensure that any human activities that could threaten the permanent containment of the waste are precluded in the vicinity of the final repository. Even beyond this guarantee period, it is important to ensure that such knowledge is permanently maintained wherever possible."

Stepwise optimisation

"...The applicant shall also outline the extent to which the site designation and design of the final repository take advantage of all currently foreseeable opportunities for reducing the likelihood of unintentional human intrusion into the isolating rock zone of the final repository and the effects thereof, as well as confirming that this design does not impair the long-term safety of the repository system as long as it remains undisturbed by human intrusion."

Safety cases

"The radiological and other consequences of unintentional human intrusion should be analysed using reference scenarios based on current common human activities.

A suspected use as a raw material source or a suspected other form of use could increase *the likelihood of human activity (drilling, driving, flooring of caverns) in the deep subsoil. Such considerations should be taken into account by the Federal Government, in its capacity as the party responsible for site designation, at the time of site specification and initial conceptual planning of the final repository. One consequence of the decision, prompted by safety considerations, to concentrate and contain waste in the deep subsoil is that unintentional human intrusion could lead to the perforation of safety-relevant barriers or could weaken the safety functions of the barriers in the final repository, which could in turn cause increased releases. Human activities which unintentionally affect these barriers should have the minimum possible impacts on the safety functions of the barriers.*

Protection criteria for such activities are not prescribed, since neither the probability nor the type of impacts can be assessed with an adequate degree of reliability. However, high levels of radiation exposure which would place a large number of people living in the vicinity of the final repository at risk of effective individual doses in excess of 10 mSv/a are to be avoided where possible. Human activities with knowledge of the final repository and its risk potential are at the responsibility of the individual concerned, and need not be taken into consideration. No protection criterion is prescribed for people e. g. who drill into a waste container, and come into contact with the drillings. Although the individuals concerned must accept responsibility for activities performed in the knowledge that there is a final repository in the immediate vicinity, the repository must be designed and documented in such a way that a misjudgement of the risks cannot easily occur. Guidelines should be drawn up containing reference scenarios for human intrusion and optimisation requirements to reduce the associated risk."

3.3 Experience and lessons learned

The subject “Human Intrusion” was taken into account in the plan approval procedure of the "Konrad" repository according to the provided legal regulatory basis. The plan approval procedure of the "Konrad" site (a former iron ore mine) for disposal of radioactive waste with negligible heat generation (roughly equivalent to low and intermediate level waste) lasted from 1982 until 2002. The basis for the license application was developed over these 20 years and complied – as required in the "Safety Criteria" /BMI 83/ and in the Atomic Energy Act /ATG 85/ and as acknowledged in the court decision – with the current state of science and technology.

In the following the main aspects of “Human Intrusion” considered in the plan approval procedure are listed /NMU 02/:

The plan approval procedure of the “Konrad“ site considered exclusively the inadvertent intrusion. It can in principle be assumed, that for a period of some hundred up to one thousand years sufficient knowledge will remain and that the inadvertent intrusion into a repository can be prevented by corresponding administrative controls. This assumed time for the information preservation, is negligible compared to the required isolation time for the radioactive waste. According to the repository depth of approx. 1000 m an inadvertent intrusion is however, only possible with a significant technical effort.

The probabilities, reasons and consequences of potential inadvertent intrusions in a repository were investigated for several time horizons. The result was that for times greater than 1000 years an inadvertent drilling into the repository cannot be excluded, however the potential consequences for the public and for the drilling staff would be well below the admissible limits.

An evaluation of potential consequences of such intrusions was carried out by the order of the plan approval authority. Here, calculations of radiation exposures with respect to the drilling staff and the public were performed, under the assumption that intrusion will occur approx. 300 years after repository closure. The calculations take into account different drilling techniques and for the most unfavourable case the drilling through waste packages stacked in a disposal chamber of 6 m height. In addition, the maximum contamination downstream of the repository was considered in terms of later possible mining activities at the former iron ore deposit.

The possible use of resources was analysed, combined with the investigation of potential consequences of inadvertent intrusion into the repository area through exploration drillings. Based on this study, it was stated, that the evaluated risk of radiation protection was performed in a plausible manner and is regarded as a reasonable residual risk.

3.4 Development and trends

The worldwide favoured option to isolate high active and long lived radioactive waste is the disposal in deep geological formations, in order to provide protection against ionising radiation. It is the concept of concentrating and isolating the waste that leads to the increased risk of radiation exposures in case of human actions that might impair the barriers of the repository system.

In this context, potential adverse effects on the isolation capacity of the repository through future human actions, such as human intrusion into the repository, and the resulting consequences have been discussed in the German Working Group on “Scenario Development”. However, any prediction of human actions over a demonstration period of one million years is speculative. It is therefore not possible to derive scenarios involving human intrusion systematically. As a consequence, regulatory guidelines are necessary for placing and dealing with the problem in the safety case. Against this background, the above mentioned Working Group on “Scenario Development” prepared recently a joint position /AKS 08/. The Working Group was formed in 1997 with the aim of developing a common understanding of the different main emphases in the context of scenario development. The Working Group is organised and chaired by GRS-K and consists of representatives of different German institutions which cover the interests of both the implementer and the regulator.

The prepared joint position of the Working Group contains recommendations how to deal with “Human Intrusion” in the safety case. The recommendations refer to the following different aspects which are subjects in a lot of national and international discussions related to human intrusion into deep geological repositories for high active wastes:

- Definition of human intrusion
- Inadvertent vs. intentional human intrusion
- Predictability of human actions and human behaviour
- Treatment of human intrusion regarding scenario development and safety assessment
- Preserving information and knowledge about the repository site and the waste

- Assumed point in time for human intrusion
- Potential preventions and measurements
- Evaluation of consequences
- Need of reference scenarios (stylised scenarios)
- Potential sources for reference scenarios

The output of the joint position will be presented and addressed in detail in the milestone report M 3.1.14 “Development of stylized scenarios” of WP 3.1 in RTDC-3.

4. Analysis and synthesis

There is a common understanding that the main provisions for the treatment of human intrusion in the safety case have to be provided in legal regulations and that stylised scenarios for human intrusion regarding their specific framework, conditions and assumptions as well as the expected scope of investigations should be provided in a guideline. Such a guideline does not exist so far, but some preparatory work has been done towards reference scenarios of human intrusion into a repository in salt /GRS 05/. In the following the main aspects from this reference will be shown:

General aspects

A broad consensus exists, that the evolution, way of life, and behaviour of the society, inclusive human intrusion, cannot be predicted over time frames, which have to be considered for the isolation period of radioactive wastes. Therefore human intrusion into the repository system cannot be excluded. In addition, a systematic scenario development, like for natural phenomena, is impossible for human intrusion phenomena. For this reason, selected scenarios, referred to as reference scenarios (stylised scenarios), have to be established and analysed. It is suggested that events of inadvertent human intrusion shall already be taken into account in the site selection process and the planning and design phase of the repository system.

The reference scenarios have to be selected on the basis of today´s social conditions, customs, behaviour patterns and state of the art in science and technology. In addition to that site specific conditions in terms of resources, potential motivations for the intrusion into deep underground, developed processes and techniques, practical aspects, efforts and economical considerations have to be taken into account.

The reference scenarios represent therefore possible interventions on the integrity of the repository under comprehensible, plausible and realistic assumptions from today´s perspective. Here it is consciously intended that the reference scenarios do not cover all conceivable possibilities of human intrusion up to the speculative area.

Potential sources for human intrusion scenarios

From the series of internationally discussed scenarios of human intrusion, only those will be taken into account, which allow due to the depth of the disposal horizon (according to present conceptual considerations approx. 500 m - 1.000 m) an intrusion into the repository.

Other scenarios like

- Settlement and road construction
- Drinking water abstraction and process water abstraction
- Utilised agricultural area
- Tunnel construction downstream of the repository

will be assigned to the scenario group of the potential evolutions of the disposal site and therefore have to be dealt with in the frame of the systematic scenario development.

From view of the GRS the following sources for "Human Intrusion" into a deep geological repository have to be discussed depending on respective site conditions:

- Exploratory drilling,
- Construction of a mine,
- Extraction of geothermal energy
- Utilisation as reservoir rock (pore-space store, cavern).

The mentioned sources constitute the initial basis for the determination of reference scenarios. These sources are the result of considerations, associated with current practices and techniques as well as given facts, e.g. properties of potential host rocks, national natural resources, conceptual specifications and the depth of the repository.

Essential aspects in describing and analysing reference scenarios

In addition to the procedure that leads to an intrusion into the repository the following aspects are essential for describing and analysing the reference scenarios:

- Intrusion area concerned
- Point in time for intrusion
- Waste category concerned
- Exposure type and exposure path
- Exposed group of people
- Spatial extent of a potential contamination.

Special attention should be given to the exploratory drilling because this action will be the initial event for all the other above listed sources for human intrusion.

Distinction of cases

In analysing the above mentioned sources for reference scenarios the resulting consequences depend on the concerned area affected by the respective human intrusion. Therefore different cases of starting and end points of the specific reference scenario have to be considered. The exploratory drilling for example could have different pathways of the borehole. The relevant conceivable distinct cases for an exploratory drilling into the repository system are as follows:

Exploratory drilling through

- a spent fuel disposal cask or HAW package located in a backfilled emplacement drift,
- a backfilled emplacement drift between spent fuel casks or HAW packages,
- a MAW/LAW package located in a backfilled chamber,
- a backfilled MAW/LAW chamber,
- a backfilled drift without radioactive waste and
- the isolating rock zone outside the repository mine.

Measurements against human intrusion

Measurements against human intrusion are hardly to determine, due to the unpredictability of future activities at the repository site. Apparently, there are only few measurements, such as the deep geological disposal and information preservation, which are suitable to prevent human intrusion for a certain time or make it at least difficult.

The following aspects should be considered when discussing measurements against human intrusion:

Measurements, that

- hamper or make it difficult to intrude,
- reduce the interest for the intrusion in relevant depth of the repository in a geological formation,
- preserve the information for a long period on the site and the potential hazard of the repository,
- facilitate the recognition of the hazard based on the repository before, during and after an intrusion,
- restrict the potential radiological consequences in case of an intrusion and
- retard the point of an intrusion as long as possible.

Anomalies and abnormalities

The construction of a repository in deep geological formations offers after finalising of all work at the surface indeed no visible building, but it leaves some tracks behind the posterity which indicate abnormal or unexpected environmental properties. Such abnormalities in connection with the repository are as follows:

- Differences of porosity, permeability and density in consequence of mining activities and backfilling of e.g. crushed salt.
- Differences in temperature of such disposal areas with heat generating wastes.
- Emplacement of dissimilar material into the underground such as waste containers, canisters, casings, concrete, radioactive waste etc.

In this connection the question arises of detection potentials of anomalies through exploratory drillings and other activities. The investigation of such detection potentials should be also one of the different tasks in analysing the provided reference scenarios.

Responsibility for the analysis

Finally, it is up to the implementer to analyse the provided reference scenarios according to the regulation and guideline. Beside the assessment of the consequences the analysis should include the discussion of possible measurements against human intrusion and the investigation of the likelihood for discovering anomalies induced e.g. by the repository and the heat generating waste.

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This document summarises the main elements to be developed in the safety case concerning the description of the evolution of the repository system. This topic includes the description of the various phases of development of the repository by defining the initial state of the components and the system as a whole, by clarifying their probable evolutions and by understanding the behaviour of the system. The guide of repository safety edited by the French regulator describes precisely the elements to be focussed on during the safety assessment like the climatic evolution, the past evolution of the site, the transient phases and the human activities. The safety case should demonstrate how the implementers deal with those elements and their uncertainties associated and how they integrate them in the thoughts leading to the definition of the expected and altered evolutions of the repository system and the development of the scenarios.

2. Regulatory context

The regulatory requirements are provided by the guide of the repository safety published by the French regulator. This guide is issued from the discussion between ANDRA, ASN and IRSN on a new release of the basic safety rule 3.2.f. The safety approach recommended by this guide is used as a basis for developing present IRSN approach.

2.1. Regulations and guidance

The regulation emphasises on the level of performance of the components and the fulfilment of the safety functions associated to them. However, the long term aspect of a deep underground repository and the passive safety lead to identify the probable disturbances jeopardising the safety of the repository system. The safety principles require analysing the ability of the components to reach a level of performance regarding the uncertainties associated to the evolution of these components and the environmental conditions. The level of performance of the components should be demonstrated taking into account the disturbances, which the repository would undergo. Therefore, the evolution of the repository system should be described on a very long period. In particular, the technical feasibility of the waste packages and the engineered components, as well as the manners and techniques of control used to ensure quality of their achievement.

2.2. Requirements and expectations

Concerning the operational phase, the ASN guide indicates that according to the timescale of this phase and the perturbations resulting from this phase, the instrumentation of the site and the engineered components should be anticipated in order to control the evolution of the parameters. The instrumentation concerns particularly the piezometry, the behaviour of the walls, seismic movements, the thermal evolution and their effects, and the hydraulic evolution.

Concerning the evaluation of the performance of the system, the ASN guide requires that the evolutions of the repository system and the migration of the radiological and chemical substances should be modelled in order to analyse the safety of the repository and to evaluate the impact on man and the environment. This modelling should be based on the knowledge of the physical and chemical processes and events possibly influencing the evolution of the system and the environment, as well as research programme and studies. The evolution of the system is determined by the behaviour of the various and interdependent subsystems. Normally, two subsystems are distinguished and should be modelled. First, the near field includes the waste packages, the engineered components and the part of the rock irreversibly disturbed. Second, the far field takes into account the part of the rock normally non disturbed by the disposal facility and radionuclide transfer zones to potential outlets. In addition, the models are simplified representations of the real phenomena, but they shouldn't leave aside important phenomena and they should lead to upper bound evaluations.

In particular, the modelling and the development of the scenarios should take into account various situations assumed to make evolved the system and to be caused either by the disposal facility (drilling phase and transient phases) or by natural events (climatic evolution, seismic activities…) when radioactivity contained in the system is not negligible. The reference situations should take into account expected disturbances and events, whereas altered situations should take into account exceptional events, human intrusion (mine operation, borehole drilling).

The description of the future natural evolution of the repository is central for the IAEA requirements and is based on the presentation of the present day characteristics of the repository site and on the interpretation of the information collated describing the past evolution of the site. Site characterization is an important task in order to improve the understanding of past and probable future evolutions over the period of interest with regard to safety, as well as the understanding of the influence of site properties on safety of features, events and processes associated with repository system. Long term stability of the geosphere with respect to climatic changes and tectonics should be highlighted in order to define timescale and properties of interest concerning the models representing the probable future evolution. Moreover, it should be ensured that the facility does not introduce unacceptable long-term disturbances to the site. To the contrary, the components of the facility should be protected by the site and complement the natural barrier with regard to safety. Materials used in the facility should be resistant to degradation under the conditions expected in the repository and also selected so as not to interfere with the safety functions of any component of the geological disposal system.

In the framework of the safety case, the demonstration of the understanding of the evolution of the repository should be done by using: in situ testing, data analysis, modelling and natural analogues.

2.3. Experience and lessons learned

Within the technical appraisal of the 2005 Clay Dossier, IRSN has attached importance to analyse how ANDRA develops approaches to identify the features, events and processes able to take part to the probable evolutions of the repository system. The studies and researches of ANDRA were summarised through different reports and technical notes, which have been evaluated by IRSN. IRSN integrated the results of those studies in the analysis of the 2005 Dossier in order to present synthetically the main topics related to the safety of a disposal system. In that goal, IRSN organised its evaluation by highlighting successively the base data on the state of the knowledge concerning the site characterisation, the approach of designing the disposal, the description of the disposal options, considering particularly, the introduction of materials and the probable perturbations induced by them, and finally, the evaluation of safety in both operational and post closure phase.

The definition of the base data and the description of the disposal concepts are central topics to understand the probable future evolution of the repository system. The base data concern the radiological inventory, the site characterisation and the physical and chemical properties of the host layer. Those data can allow a first description of the probable future evolution. As an example, within the studies of the past evolution of the Bure site, ANDRA has developed scenarios and models to simulate the probable evolution with respect to assumptions on future human activities involved in global warming, particularly CO_2 production, as well as the effects of past glaciations on flow patterns and erosion. The improvement of the knowledge on geomorphology and past evolution allowed geosprospective models to be developed.

The description of the disposal concepts should integrate the demonstration of the improvement of the knowledge on the materials introduced in the facility, as well as the methods and techniques to introduce them. The interactions between materials and perturbations induced by those interactions depend on the differences and the amount of materials introduced in there. Some of those perturbations are either due to the waste (heat producing phase, dissolution products, radiolytic effects), or due to the engineering methods (desaturation of the rock, ventilation, mechanical stresses), or due to materials introduced (oxydations, alkaline plume, Iron/clay interactions, Iron/concrete interactions), or due to reactivated phenomenon (microbiology). Those perturbations influence the performances of all the components in the operational and post closure phase, but, also have consequences during the retrievability period by hardening the retrieval of the packages.

2.4. Developments and trends

IRSN performs its own studies to improve its knowledge and understanding of the processes occurring during the period of a repository system. Those studies concern the main topics related to the evolution of the repository system. Most of them are performed within European project focussed on specific aspect of the repository like NF-PRO or MICADO projects.

3. Analysis and synthesis

Site characterization is the first step to highlight the processes and phenomena potentially affecting the performance of the repository components and the disposal system as a whole, including the natural evolutions of the components and the interactions between natural and engineered components. This characterization should thus be conducted at length scales and of scope sufficient to acquire an adequate understanding of the phenomena potentially influencing site safety for the time periods of concern, as well as relevant information to support scenarios for the future probable evolution of the site and to develop credible physical process models. The demonstration of this understanding of the probable future evolutions of the disposal system is an important task in the safety demonstration to be supported by in-situ testing, data analysis, pertinent modelling, as well as comparison with suitable analogues.

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A6 NDA (United Kingdom)

1. Introduction

This note gives an overview of the NDA approach to the treatment of human intrusion in performance assessments which forms part of the NDA capability to carry out a performance assessment to support the different stages in the development of a geological disposal facility.

2. Regulations and guidelines

The treatment of human intrusion is guided by the need to conform to regulatory requirements and take due account of international best practice. In the UK the Radioactive Substances Act 1993 (RSA93) [1] is the regulation that would apply to radioactive discharges from a closed repository. This legislation is quite general, and applies to a great variety of situations where there may be discharges of radioactivity to the environment. Relevant agencies have therefore published guidance, known as the 'Guidance on Requirements for Authorisation' (GRA) [2], which outlines how an application for an RSA93 authorisation would be judged in the specific case of land based disposal of solid radioactive waste (a repository). The GRA was revised and the existing single document split into two documents, one dealing with near-surface disposal and another dealing with deep geological disposal [3] which were published in 2009. The 2009 revision to the GRA contains updated guidance on the treatment of human intrusion.

3. Terminology

NDA's approach to terminology is to try to avoid the use of jargon wherever possible. Where specialist terminology is required, NDA tries to use existing terms wherever possible, for example terms that are defined in national regulations or which are defined internationally, for example by the IAEA or NEA. In these ways NDA seeks to avoid introducing 'new' terminology.

4. Treatment of Human Intrusion

Human intrusion encompasses a range of human activities that have the potential to disrupt or impair significantly the containment properties of the repository engineered system or the geosphere. An important part of the case for long-term safety of geological waste management is that placing the waste deep underground is a robust method of reducing the potential for, and likelihood of, human intrusion, compared to say the case of a surface storage facility, or a surface or near-surface waste management facility. It cannot be guaranteed, however, that intrusion might not occur at some time in the future after administrative controls have been discontinued. Therefore, it is necessary to assess such events and estimate their consequences, even though their likelihood may be low.

A common approach in performance assessment is to consider a 'reference case' or 'base scenario', together with a range of 'variant' scenarios. The base scenario represents the natural, or expected, evolution of the repository system in the absence of any major disturbances, and considers the groundwater pathway (natural discharge, and water extracted from wells and subsequently used for drinking and irrigation), and an assessment of the consequences of gas generated in a repository. Human intrusion is a variant scenario.

Human intrusion could be intentional or inadvertent. Intentional human intrusion, that is deliberate intrusion into the repository in the knowledge that it contains radioactive materials, is generally considered to be the responsibility of the society taking the action, and UK regulatory guidance states that the associated risks need not be considered in a performance assessment [2]. Inadvertent actions are those where the repository or part of its barrier system are accidentally penetrated because knowledge of the repository location has been lost or its purpose forgotten. Possible inadvertent acts of human intrusion include drilling or excavation into the repository or the surrounding rocks, for the purpose of exploring for or exploiting natural resources (*e.g.* coal, oil, gas or minerals). Such actions could affect the long-term performance of the repository system, affecting people long after the intrusion event, as well as having direct radiological consequences for those involved in the intrusion activities.

Inadvertent human intrusion scenarios, if they occur, can lead to very high doses, because they may result either in the exposure of intruders to repository materials *in situ*, or the transfer of repository materials into the accessible environment and subsequent exposures at the surface. However, these high doses have low probabilities of occurrence: in a risk-based assessment, the radiological risk arising from variant human intrusion scenarios is the product of the dose (conditional on intrusion) and the probability of occurrence, multiplied by the dose-to-risk conversion factor.

It is difficult to assess the human intrusion pathway comprehensively, as the range of phenomena to be considered is difficult to define, and both the impact on the repository and its environs, and the probabilities of occurrence, are difficult to determine. In order to identify the range of human intrusion scenarios to be considered, it is necessary to consider the likely range of future human actions that might take place at the site of the repository. The International Commission on Radiological Protection (ICRP) argues (see, for example, reference [4]) that this is not possible (or at least, requires an inappropriate level of speculation about advances in technology and future human behaviour), and therefore a different approach is required. One of the challenges is to present an assessment of human intrusion that provides a broad indication of the hazards associated with human interaction with repository wastes, and yet is defensible in terms of the assumptions made regarding the human behaviour that leads to radiation exposure.

Assessments of the post-closure safety of a repository typically extend over periods of hundreds-of-thousands of years. Over this period of time, the form of human society will change in a manner that cannot be predicted. To avoid any need to speculate how society and technology will evolve, the approach to the assessment of the human intrusion pathway is therefore to develop scenarios based on current technology and understanding, and patterns of behaviour in the locality of the site or, in the absence of suitable information, at similar locations. The modes of intrusion considered are those that might occur given present economic needs and technology, and the current pattern of resource exploitation. Such assumptions are consistent with UK regulatory guidance [2] and international views, identified through an OECD-Nuclear Energy Agency Working Group, see reference [5]. This basic approach of assuming scenarios based on current technology and behaviour has been widely used in performance assessments in other national programmes, e.g. [6, 7, 8]. Thus quantitative assessments of risk are based on evaluations of frequencies of human activities observed in the recent past. Such assessments of risk are not intended to be predictions of future human behaviour and of its consequences. Rather, by basing them on current technology and behaviour, they provide present-day society with an understandable basis for deciding whether the wastes would be sufficiently isolated and contained.

There are various mitigating factors that may act to reduce the probability of an intrusion or the likelihood of significant exposures should an intrusion occur. For example, material recovered from the repository might be recognised as hazardous waste or planning controls might prevent the intrusion. It is difficult to account for these effects quantitatively, although some attempts have been made, particularly for near-surface facilities, e.g. [9]. However, there are also other factors that might act to increase the probability of intrusion. For example:

- Any geophysical or geochemical anomalies produced by the repository might attract interest; and
- Repository access tunnels and shafts, albeit backfilled with rock originally excavated during repository construction, might also attract interest due to having different properties (e.g. appearance, hydrology) from surrounding, unexcavated rock.

Notwithstanding the difficulties, frequencies should still be estimated. Such frequencies are useful. For example, they can be used as an input to siting strategies or to avoid undue focus on high consequence, but very low probability events. Use of such frequencies in risk calculations is appropriate but they cannot be considered as effective predictions of the future or in any sense bounding (*i.e.* providing an indication of a minimum or maximum frequency). Because of these difficulties, attention to other arguments is needed [10], for example:

- Demonstration that frequencies and doses have been reduced, as far as is practicable, through appropriate design and siting decisions (as recommended by the ICRP [4]), and actions to preserve knowledge of the facility;
- Comparison of deep repository waste management with other management options;
- Comparison of the radiological consequences from a deep repository with consequences arising from uranium mines and/or exposure to radon in the environment, and other natural sources of radioactivity;
- Evaluation of the various actions that may prevent or mitigate the effects of a future human intrusion.

It would also be desirable to demonstrate, as part of an assessment, an understanding of the sorts of measures that could increase or decrease the probability of human intrusion events and resulting radiation exposures. In the context of a deep repository, the relevant actions are less likely to relate to repository design and more likely to relate to the following issues:

- The choice of an appropriate site and host rock (lower drilling frequencies can be associated with rocks that are not of economic significance);
- The location of the facility at sufficient depth to reduce the probability of human disturbance (drilling frequency decreases with depth of rock penetrated);
- The use of site markers and archives to increase the probability that information about

the site is retained for as long as possible. Note that an assumption here is that maintaining knowledge of the repository, its contents and purpose, or warning potential intruders of the hazard posed by the repository contents, reduces the probability of unintentional human intrusion. However, complicating factors, such as the retention of knowledge of the presence of the repository but loss of knowledge regarding its purpose, need to be acknowledged here, and could unintentionally lead to intrusion into such a facility. Also, maintaining knowledge of the repository could increase the probability of intentional, malicious intrusion, possibly leading to a radiological risk to people not responsible for intruding into a waste facility, but affected by the consequences of such an intrusion.

A key part of a performance assessment related to the human intrusion pathway should be to demonstrate that all practicable steps to record information about the facility have been taken. This might include:

- The provision of durable site markers;
- Recording the location of the facility on maps, e.g. Ordnance Survey;
- Ensuring that records of the facility are placed in local, national and international archives.

5. Applications and experience

Nirex undertook a number of human intrusion studies and assessments over the period 1992 to present. (Nirex was incorporated into the NDA in April 2007.)

The assessment of the human intrusion pathway considered in Nirex's Generic post-closure Performance Assessment has evolved from that undertaken for early Sellafield studies. Nirex Report 337 [11] presented an assessment of the human intrusion pathway for Sellafield; the treatment of human intrusion and natural disruptive events in a post-closure performance assessment was further discussed in 1995 in [12] (however note that the Nirex 95 [13] and Nirex 97 [14] assessments focussed on the groundwater pathway, and on the groundwater and gas pathways, respectively, and therefore neither included an assessment of human intrusion scenarios). The assessment of the human intrusion pathway in Nirex Report 337 was utilised as a basis for an assessment of human intrusion in Nirex Report N/011 "Evaluating Performance" [15]; an assessment of the human intrusion pathway was subsequently included in both the GPA [16] and the GPA 2003 update [17] assessments.

The human activities of relevance differ depending on the waste management option under consideration. Assessment of the human intrusion pathway for deep geological waste management focuses on the penetration of a repository, e.g. by deep exploratory boreholes, with subsequent radiological exposure occurring as a result of what happens to the extracted core material. There are additional exposure routes, e.g. quarrying, excavation, surface erosion, that could affect a near-surface waste management facility and would need to be included in the assessment of the human intrusion pathway of that waste management option.

6. Developments

As noted in Section 2, the revised regulatory guidance has an updated section on human intrusion, which places a greater emphasis on presenting assessments the doses should human intrusion take place, rather than on the risk, which includes an estimate of the likelihood.

When NDA undertakes a site specific performance assessment, we will consider how best to follow the updated regulatory guidance on assessment of human intrusion.

7. Conclusions

We feel that our treatment of the human intrusion is appropriate for use in the generic Disposal System Safety Case framework which will support the early stages in the development of a geological disposal facility in the UK. The approach will need to be developed further, however, as the site selection process progresses, and also to reflect recent changes in regulatory guidance in the UK.

8. References

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note

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date :	24 February 2009	
reference :	21952/09.93896 RE/JH/MH	
subject :	NRG Contribution to topic 10 'Human Intrusion'	

Section 1: Background/ Introduction

In the late 1980's the VEOS study (Safety evaluation of disposal concepts in rock salt) has been performed in the Netherlands [1, 2, 3, 4]. The aims of this study were the evaluation of the post-closure safety of some possible disposal concept and the determination of relevant characteristics. VEOS used a scenario approach followed by a deterministic consequence analysis and several deterministic sensitivity studies. The analyses resulted in a number of release scenarios with estimated exposure. For some scenarios with a relatively high exposure the probability of occurrence was also calculated. The resulting risk defined as the product of this probability and the health effect of the exposure was below the risk levels set in neighbouring countries and the IRCP.

In the early 1990's a generic probabilistic safety analysis (PROSA, [5]) of the Dutch generic reference disposal concept has been performed. The PROSA study had two equally important aims, viz. the determination of the radiological effects on humans and the derivation of safety relevant characteristics of a disposal concept for radioactive waste. These characteristics have been derived from sensitivity analyses of the radiological consequences of some disposal concepts in rock salt formations. The PROSA study was restricted to the safety in the post-closure period.

The methodology used for the scenario selection was based on the idea that a repository is a multi-barrier system which' evolution can be characterized by the state of its four barriers:

1. the engineered barriers
2. the isolation shield of salt around the repository
3. the overburden, and
4. the biosphere itself

In addition it was assumed that the first three barriers could have two possible states: i) present and ii) by-passed. This implies that there are 8 possible states of the multi-barrier system. For each barrier state a number of FEPs can then be found which are defining the state of the barrier. These primary FEPs were used to define the scenarios. The remaining FEPs were considered as "secondary" FEPs and described the transport of the nuclides. The

methodology implied that each FEP has to be judged carefully in order to establish whether it is of importance and if so how the role will be and in which part of the repository the FEP applies.

The PROSA study used a systematic approach to scenario selection that ultimately led to a set of representative scenarios that covered all aspects relevant for the long term safety. The method used a FEP catalogue to show comprehensiveness of the obtained set of scenarios.

Two different types of calculations were performed: a probabilistic analysis of the nuclide transport for the subrosion scenarios, and a deterministic analysis for the water intrusion scenarios. The sensitivity analysis aimed at finding the input parameters having the strongest influence on the exposure, whereas the uncertainty analysis aimed to quantify the output variability.

The PROSA study was carried forward and extended in the CORA program [6], in which the options for retrievable storage and disposal of radioactive waste in the Netherlands were investigated, both for a salt-based and clay based repository.

Section 2: Regulatory requirements and provisions

A central policy consideration of the Dutch Government is a stepwise approach to finding waste management options that are feasible, suitable and acceptable, in both technological and societal respects, is. Based on three policy documents, published respectively in 1984 [7], 1993 [8] and 2002 [9], the current strategy can be summarized as follows:

- long-term interim storage in purpose-built stores at COVRA, the Dutch site for surface storage of radioactive waste, for at least 100 years;
- ongoing research, preferably in international collaborative programs;
- eventually retrievable[6] deep geological disposal.

There are presently no regulatory requirements and provisions that directly relate to the topic of "human intrusion". Indirectly however several laws regulate the public against hazardous materials. For example, with regard to nuclear energy, the purpose of the Nuclear Energy Act [10] is to regulate (Article 15b) the protection of people, animals, plants and property. In addition a number of decrees have also been issued containing additional regulations. The most important of these in relation to the safety aspects of nuclear installations are:

- the Nuclear Installations, Fissionable Materials and Ores Decree (Bkse),
- the Radiation Protection Decree (Bs).
- the Transport of Fissionable Materials, Ores, and radioactive Substances Decree (Bvser).

[6] Retrievability means the deposition of radioactive waste in a way that it is reversible for the long-term by proven technology without re-mining.

The Nuclear Installations, Fissionable Materials and Ores Decree regulates all activities (including licensing) that involve fissionable materials and nuclear installations. The Radiation Protection Decree regulates the protection of the public and workers against the hazards of all ionising radiation. It also establishes a licensing system for the use of radioactive materials and radiation emitting devices, and prescribes general rules for their use. The Transport of Fissionable Materials, Ores and Radioactive Substances Decree deals with the import, export and inland transport of fissionable materials, ores and radioactive substances by means of a reporting and licensing system. The Nuclear Energy Act and the above mentioned decrees are fully in compliance with the relevant Euratom Directive laying down the basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation. This Directive (96/29/Euratom) is incorporated in the relevant Dutch regulations.

Section 3: Key terms and concepts

The Dutch concept for an underground facility for disposal of radioactive waste is still being developed. In the Netherlands attention mainly has been focused on suitable salt domes in the northern part of the country and clay layers in the south. Since the Dutch radioactive waste will be stored in the COVRA (Central Organization for Radioactive Waste) surface interim storage facility for a long time (up to some 100 years) the determination of a suitable concept is at present not a critical issue. For the safety assessment of an underground repository for radioactive waste the PROSA methodology was developed for the determination of scenarios.

There are currently no actual plans to transfer this waste to a national deep geological repository. However there have been several options investigated in the Netherlands, mainly within the above-mentioned PROSA and CORA programmes. Both the options of disposal in rock salt (cf. Figure 1) and in Boom clay, which are both abundantly present in the Netherlands, were investigated.

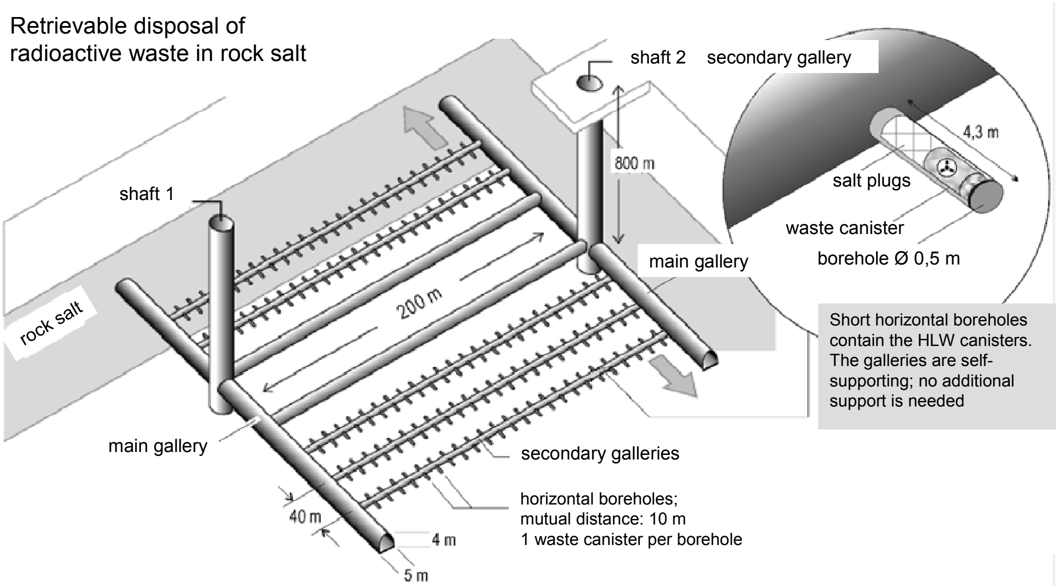

Figure 1: Rock salt based option for retrievable disposal of radioactive waste [6]

Section 4: Treatment in the Safety Case

Section 4.1.1: Methodology

The modelling strategy in the Dutch PROSA study has been described extensively in the PROSA Final Report [5], and summarized in NRGs contribution to the PAMINA WP1.1 Topic 7 "Modelling Strategy". In the present section the modelling of the human intrusion that has been carried out within the PROSA study is summarized.

Overview of the PROSA Methodology

In the PROSA study a scenario type of analysis has been followed by a probabilistic consequence analysis. This implied the following steps:

1. identification of FEPs which might influence the state of the barriers, the release, transport, and state of radionuclides. The list should be comprehensive and not be restricted to FEPs induced by nature or the waste but also contain human induced FEPs. An overview of the FEPs that were considered to play a role from the human intrusion point of view is given in the next section "FEPs – human induced phenomena - post-closure and sub-surface activities".

2. First screening of the list of FEPs. The first screening of this list was performed with respect to the type of host rock (repository in a rock salt formation) and the probability of occurrence.

3. Classification into primary and secondary FEPs. A primary FEP directly attacks or bypasses one or more of the barriers from the multi-barrier system. The primary FEPs consequently define the state or evolution of the repository. In particular they lead to

a change in the size or the short circuiting of the barriers. The remaining FEPs were defined as the secondary FEPs. These FEPs influence the transport and the state of the radionuclides. The secondary FEPs define the transport and the state of the nuclides for a given state or evolution of the repository and should be included in the transport model and/or code.

4. Definition of possible multi-barrier states (MBS). In the definition of the state or evolution of the barriers in the multi-barrier system a simple division into attacked or by passed was proposed. Here also a relatively small number of barriers was proposed to limit the number of possible MBS. The main reason for the use of the MBS was the simplification of the further screening prior to the combination of primary FEPs.

5. Assignment of the primary FEPs to each of the multi-barrier states taking into account that some processes attack more than one barrier.

6. Screening of the FEPs for each of the multi-barrier states. In this screening a classification of FEPs with respect to time was considered very helpful.

7. Definition and selection of the scenarios to be analyzed further. This step also included the selection of the processes to be taken into account in the consequence analysis.

8. Determination of the secondary FEPs for each of the multi-barrier states.

9. Scenario selection, (see Topic 6 ‘Evolution of the Repository System’)

10. Determination of the probability of the scenarios,

11. Determination of the calculation model,

12. Determination of the parameters and their probabilities,

13. Dose calculation,

14. Reliability assessment (see Topic 7 ‘Modelling Strategy‘)

15. Sensitivity and uncertainty analysis.

The scenarios were screened on the basis of the results of the previous VEOS study and arguments related to the availability of detailed models. The remaining list of scenarios to be analysed consisted of 2 subrosion scenarios, 4 groundwater intrusion scenarios, and 1 human intrusion scenario.

To facilitate the consequence analysis of these scenarios for each compartment in the transport model a list of FEPs has been developed that were taken into account. These FEPs have been accounted for in the three compartments of the transport and exposure model or in the data and resulted in a set of calculated dose rates for the different cases. One set of FEPs related to human induced phenomena and it listed below for the post-closure and sub-surface activities. This list covers step i) of the afore-mentioned list of steps of the PROSA methodology.

FEPs – human induced phenomena - post-closure and sub-surface activities

2.3.1 Archeological investigation

This cannot be completely outruled especially after loss of records. Warning messages might be contraproductive as they may encourage an ambitious researcher. In the case that waste materials are brought to the surface from a drilling, the archaeological investigation of these materials leads to a scenario that is very analogue to the exploratory drilling scenario. Large scale archaeological excavations of the waste forms are considered as unrealistic because a high technology is required in combination with a loss of knowledge about radioactivity.

2.3.2 Attempt of site improvement

Although very unlikely, it can be assumed that in a (future) attempt of improving the site the opposite is reached viz. a deterioration or reduction of the isolation capability of the geologic disposal system.

2.3.3 Exploitation drilling

The construction of a water abstraction well in the aquifers in the overburden has to be taken into account.

2.3.4 Exploratory drilling

Exploratory drilling has to be considered in the safety studies.

2.3.5 Geothermal energy production

Although the area in the North-East part of the Netherlands is not very interesting for geothermal energy production it will be considered in the scenario study.

2.3.6 Groundwater abstraction/recharge

Groundwater abstraction from the overlying aquifers has to be analyzed in the safety study.

2.3.7 Injection of fluids

The storage of fluids into the salt formation can be considered as the most serious case and has been analyzed further.

2.3.8 Malicious intrusion, sabotage/war

Release scenarios related to war or sabotage were not included in the safety analysis. The near surface consequences of a war are considered to be much larger than the consequences related to a repository at a depth of 1000 m. Intentional sabotage actions to impair the barrier functions of the repository may be planned or performed during the operation stage and were therefore not considered further.

2.3.9 Recovery of repository materials

Salt is presently used for consumption and as base material in the chemical industry. It may be assumed that the same holds for the future. Although a good administrative system will be applied it cannot totally be excluded that in the future the salt from the salt formation in which the waste is stored will be used. This can be done using conventional dry mining or solution mining techniques. This has to be evaluated in relation with 2.3.10 to 2.3.12.

2.3.10 Resource mining

See 2.3.9

2.3.11 Tunnelling

A reason to construct a tunnel at a depth of 1000 m in a salt formation could be seen in relation with mining and has been considered further, see 2.3.9.

2.3.12 Underground construction

Possible underground constructions in a salt formation could be a storage cavern, a conventional mine, or a waste repository. These have been evaluated further.

2.3.13 Underground nuclear testing

Underground nuclear testing implies that a good knowledge of the nuclear technology is available. In the near future it can thus be assured that information about the presence of the repository and radioactivity is still available. In a later stage the radioactivity due to the underground nuclear testing will be more important than the one present in the remnants of the repository.

2.3.14 Water table changes

Changes in the water table such as a temporary lowering due to construction activities, a long term lowering due to agricultural purposes or an increase will be considered in the groundwater calculations.

FEPs – human induced phenomena - Post-closure surface activities

2.4.1 Alteration of soil

Altered soil or surface water chemistry can change significantly the biosphere transfer factors and K_d-values. These alterations can be taken into account by assigning ranges of parameter values to the biosphere K_a-values and transfer factors.

2.4.2 Anthropogenic climate changes (greenhouse effect)

The consequences of an anthropogenic climate change can be evaluated together with climate changes from natural origins.

2.4.3 Changes in land use

Land use changes will eventually influence the biosphere parameters and the biosphere calculations will have to be adapted accordingly. In the biosphere modelling the present situation was taken as the starting point. Changes in land use have been evaluated.

2.4.4 Construction of dams/reservoirs

The fiat landscape of the North Eastern part of the Netherlands makes that this area is not a preferred area for the construction of large dams. Smaller reservoirs can eventually be constructed in the river valleys. This type of reservoir can only influence the surface hydrology and will not change the regional hydrological system.

2.4.5 Developments and changes

- agricultural
- fisheries
- demographic
- urban development

In the biosphere modelling the present situation was taken as the starting point. Changes in land use and developments have been evaluated.

2.4.6 Drainage of dams reservoirs

See 2.4.4.

2.4.7 Irrigation

Irrigation is considered in the biosphere model as an important contamination pathway.

2.4.8 Loss of records

Inadvertent intrusion can be assumed to be excluded during the period of institutional control which can last for 100 or 300 years. Thereafter a period of administrative control can be foreseen during which deep excavations or drillings at the repository site will be forbidden. However at longer time scales the loss of information about the repository can take place.

2.4.9 Quarrying, surface mining

Quarrying is not important for the NE Netherlands. Surface mining influences the land use and the near surface hydrology. It is not expected that these activities will influence the dose rates resulting from the radioactive waste repository.

2.4.10 Rechanneling of rivers

A river rechannelling will modify the velocities of the river water and the riverbed sediments. This modification can be included in the biosphere modelling. Another consequence of river rechannelling can be that the river bed sediments of an old river reach become accessible for agricultural uses.

Classification into primary and secondary FEPs

Following the screening of relevant FEPs the next step in the PROSA methodology was to classify the FEPs into primary and secondary FEPs. A primary FEP directly attacks or bypasses one or more of the barriers from the multi-barrier system. The primary FEPs consequently define the state or evolution of the repository. In particular they lead to a change in the size or the short circuiting of the barriers. The remaining FEPs were defined as the secondary FEPs. These FEPs influence the transport and the state of the radionuclides.

The secondary FEPs define the transport and the state of the nuclides for a given state or evolution of the repository and should be included in the transport model and/or code.

Possible barrier states

For a repository in a salt formation the multi-barrier system has been supposed to consist of three main barriers:

1. The engineered barriers: waste form, waste container, borehole backfill, borehole plugs and seals, backfilled gallery, dams, and backfilled shafts.

2. The isolation shield between the repository and the boundary of the salt formation (host-rock).

3. The overburden between the salt formation and the biosphere. This barrier includes the groundwater system with the aquifers and aquitards (geosphere).

It is assumed further that there are in principle two possible states of each of the barriers:

1. the barrier is present

2. the barrier is not present (bypassed).

The biosphere is not included in the MBS as a barrier, but it has to be accounted for in the dose and risk estimates. In case the scenario involves nuclide migration through biosphere water, the ingestion pathways have to be explored. In case of 'direct' release pathways (e.g. in case of an exploration drilling that accidently hits the remains of the facility) the biosphere is limited to the biological human response of exposure to radiating waste in a drilling core.

The possible barrier states for each barrier then lead to the following combinations:

Engineered Barriers	Isolation Shield	Overburden	State Number	State Symbol
Present i	Present ii	Present iii	1	Qqq
Present i	Present ii	Bypassed III	2	qqQ
Present i	Bypassed II	Present iii	3	qQq
Present i	Bypassed II	Bypassed III	4	qQQ
Bypassed I	Present ii	Present iii	5	Qqq
Bypassed I	Present ii	Bypassed III	6	QqQ
Bypassed I	Bypassed II	Present iii	7	QQq
Bypassed I	Bypassed II	Bypassed III	8	QQQ

For each FEP, including those related to human intrusion, it was evaluated whether a FEP would challenge one or more of the main barriers or not. In other words the state of the barrier was evaluated for each FEP in terms of "present" (i, ii, iii) or by-passed (I, II, III). From the evaluation of the barrier state of a particular FEP scenarios were identified where groups of FEPS could be allocated to a "State Number" indicated above. This evaluation resulted into three families of scenarios:

1. the subrosion scenarios
2. the flooding scenarios
3. the human intrusion scenarios – see table below

Dominant Primary FEPs	Scenario Id.
Leaky storage cavern*	16
Reconnaissance drilling Solution mining Conventional mining Archaeological investigation	19 20 21 22

*Scenario 16 is formed by the underground construction, a storage cavern which starts to leak after closure.

Impact of human intrusion on the safety assessment

The human intrusion scenarios were distinguished from the other scenarios as exposure is the direct or indirect result of a deliberate human action in or close to the geological formation where the waste is stored. This sort of action only can occur supposing knowledge of the presence of radioactive waste has been vanished. Therefore in the dose calculations for these scenarios it was assumed that this kind of action would not take place earlier than 250 years after discharge of the reactor fuel to be reprocessed. In this way consideration has been given to; a period of interim storage, a period of operation of the repository, and a period of at least 100 years in which knowledge of the presence of radioactive waste is retained through administrative measures. In addition doses were calculated for a duration of 1000 years after discharge of fuel from the reactor. This period has been chosen as the minimum duration of the efficiency of other passive, time resistant, marking methods.

Reconnaissance drilling

This scenario assumed that in the future a canister containing nuclear fuel waste will be penetrated during geological exploratory drilling, and that the 0.16 m drilling core will contain the vitrified waste over a length of 1 m. It was also assumed that the radioactive nature of this material would not be discovered until the core had been inspected in a surface laboratory, either after a short routine inspection or as part of a longer, detailed investigation. Exposure could occur via external radiation, ingestion and inhalation of the radioactive material. The calculated total dose, 250 years after discharge, would be about 10 Sv for a routine and 100 Sv for a detailed investigation; about 0.4 Sv and about 20 Sv would be ascribable to external radiation, respectively, and the rest of the total dose largely to inhalation of Am-241. After 1000 years the calculated total dose rates would be 2 and 24 Sv for routine and detailed investigation respectively.

The probability of occurrence of exposure was considered low, since it was assumed that the radioactive character of the core segment will not be discovered immediately. During investigation of the cores only a small number of people will be affected. If this scenario were actually to occur, it would lead to the death of one or several core investigators, but this should be seen in the light of the probability of occurrence.

Solution mining

In this scenario it was assumed that in the future a cavern would be leached out in a dome used for the disposal of nuclear-fuel waste. A cavern of this kind would have been made for salt mining or other purposes. When the brine would be evaporated above ground, factory workers will be exposed via inhalation of grains of salt dust to which radioactive nuclides from the waste are attached. The estimated annual dose calculated for inhalation was in the order of tens of microsieverts per year.

With respect to the probability of occurrence of the exposure described above, it is evident that the probability of salt being mined from deep formations is small, because there are also other salt deposits in the vicinity which are much closer to the surface; moreover, the assumed awareness of the danger of radiation and radioactivity and inspection of the working environment would further reduce the probability of prolonged exposure.

Leaking storage cavern

When a cavern is leached such that an existing borehole for disposal of nuclear-fuel waste is affected virtually the whole inventory of the borehole will be found on the floor of the cavern after the site has been exploited for several decades. If the cavern is then filled with brine and sealed, the waste will continue to dissolve and will be extruded from the formation by convergence. The maximum source term for migration to the geosphere has been calculated on the basis of an assumed complete solution of both the vitrified matrix and the waste. The maximum individual radiation dose after migration of the radionuclides through the geosphere and biosphere was estimated from the calculated dose for the water intrusion scenario and the source term to the geohydrosphere used for these dose calculations. This estimate put the annual dose less than 10^{-7} Sv/a, which is received by a small group of agricultural workers about 1 million years after disposal of the waste.

Conventional mining

The conventional-mining scenario assumed that in the future, for some reason, a mine will be constructed in a repository and the presence of radioactive waste will not be noticed during excavation. For example, a gallery running along an unnoticed bore hole might be excavated. The calculated exposure rates at that spot in the gallery were estimated to be 0,3 mSv/h after 250 years and 3 µSv/h after 1000 years. The calculated exposures are of course hypothetical, because of the assumption that the presence of the repository and the increased exposure rate in the gallery would both remain unnoticed during construction of the mine shaft and the gallery.

Section 4.2: Related topics

Main related topics are, “Uncertainty Management and Analysis”, “Sensitivity Analysis”, and “Modelling Strategy”

Section 4.3: Databases and tools

- FEP database and the information included in the procedure for FEP analysis [5].
- REPOS - In REPOS (REPOSitory) a complete disposal mine with all technical barriers

can be modelled. REPOS has models for the release of radionuclides from all type of containers and waste forms. The important physical and chemical effects influencing the transport of radionuclides are modelled. These processes are: temperature distribution, convergence of excavations, permeability of backfilled excavation, damms, seals, gas production by radiolysis and corrosion, diffusion, sorption, and radioactive decay and ingrowth. The models for the transport of radionuclides include: transport by density differences, gas transport, transport by a pressure gradient, and transport by diffusion.

- METROPOL – The METROPOL code is capable to perform a detailed 2-dimensional groundwater flow model. The METROPOL analyses were done stochastically in order to account for the large uncertainties of groundwater flow paths and geohydrological conditions.
- MASCOT - MASCOT analyses the nuclide transport in the geosphere. The code calculates the time dependent two or three dimensional nuclide transport in an infinitely extended porous and homogeneous continuum.
- EXPOS - EXPOS calculates the radiation EXPOSure in terms of maximum dose rates for individuals.
- MiniBIOS, a computer program used to determine the distributions of the dose conversion factors for radionuclides transported via groundwater.
- UNCSAM, developed to conduct sensitivity and uncertainty analyses of mathematical models [11].

Section 4.4: Application and experience

The extended PROSA method [12] has been applied for the safety study underlying to the license application for the closure of the Asse (D) salt mine including the experimental disposal facilities (29. January 2007 [13]) and for a review on behalf of the Ministry of Agriculture and Environment of Sachsen-Anhalt (MLU) of two supporting reports issued in 2002 in preparation of the licensing process for the Morsleben Repository for radioactive waste (Endlager für radioaktive Abfälle Morsleben - ERAM) [14].

Section 4.5 On going work and future evolution

We expect that the PROSA procedure for identifying scenarios will be extended by the application of 'safety functions' for future safety studies.

At present there is no ongoing work in the Netherlands on the topic of the evolution of the repository system. Research on climatic changes is however a main topic.

Section 5: Lessons learned

Discussion and conclusion

Human activities are an important factor for the evaluation of a repository for radioactive waste. This factor was taken into consideration in the safety study performed in the

Netherlands. Man-induced phenomena are given much weight in the biosphere analyses. With respect to the 'normal evolution' of the repository in a salt formation this introduces uncertainty, because exposure associated with the subrosion scenarios will occur more than 0.1 Ma after disposal, i.e., in a very distant future.

Man-induced phenomena can also alter the 'normal evolution' if either the exploration of the formation or the design and operation of the repository are defective. In the scenarios these phenomena are considered. The hydrological consequences of subterranean human activities were dealt with, and it was found that these effects could be taken into account in the transport calculations.

It is clear that in the future, destruction of the geological barriers formed by the salt formation and the overburden could occur due to intentional or unintentional human intrusion in the repository. The chance that that will happen and the conditions under which it could occur, are difficult to determine. Four different scenarios were studied in PROSA in an attempt to assess the potential radiological effects of human intrusion into a repository. Although these four scenarios do not deal exhaustively with the potential consequences of human intrusion, they seem adequate for obtaining an idea of the similarities and differences between disposal concepts (with respect to the consequences of human intrusion). The results showed that extremely high doses could be received by anyone coming into direct contact with high activity waste after several hundred years, which is hardly surprising because this characteristic of the waste is the most important reason for long-term isolation. If remnants of protection persist around the waste or some degree of dilution occurs before exposure, doses will be low to extremely low.

For a final assessment of the consequences it is also necessary to calculate the probability that a dose will be received. An estimate is given of the probability of the occurrence of situations in which extremely high exposure might take place. The result suggests that the risk is not unacceptable according to the limits for all the combinations of dose and probability analysed. These findings also show that the possibility that other kinds of human intrusion could evolve, a risk even higher than in the four cases considered, cannot be excluded.

An evaluation of the results showed long interim storage to be favourable because any finally disposed waste encountered unintentionally by man would be less active. However, this favourable effect disappears rapidly. There are also health risks associated with long surface storage which have to be considered.

It was also concluded that the possibility of human intrusion does not lead to a preference for a particular disposal technique.

With respect to the type of formation to be used for radioactive waste disposal, it was felt that storage at greater depths is the most important factor for reduction of the effects of human intrusion. Disposal at great depths might also reduce the probability of human intrusion.

Because the human-intrusion scenarios were associated with the highest exposure rates and possibly the highest risk, these scenarios should be the subject of further research.

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A8 NRI, RAWRA (Czech Republic)

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1. Introduction

This document describes the strategy for treating human intrusion in safety case of Deep Geological Repository (DGR) in the Czech Republic. Czech concept of DGR is similar to KBS 3 concept of disposal of spent fuel assemblies in granite in a vertical position. The repository layout in granite host rock consists in spent fuel waste packages surrounded by bentonite bricks and located in the tunnels at least 500 m under the surface. Instead of copper based canisters in KBS 3 concept, carbon steel canisters were proposed for assemblies from VVER reactors, but this concept is going to be reviewed in a new project initiated recently by RAWRA. In the current stage only generic data are available since no site has been selected for DGR.

This document is based primarily on requirements of Degree of State Office for Nuclear Safety (SUJB) on Radiation protection [1], guides of SUJB for elaboration of the safety reports for DGR siting and construction permit [2, 3] and data acquired during preparation of initial safety report for “Reference design” of DGR [4].

2. Regulatory requirements and provisions

Human intrusion is considered in guide reports of SUJB for elaboration of the safety reports for DGR siting and construction permit [2,3] as one of the events, which should be taken into account in the evaluation of the safety of radioactive waste repositories. Specifically, drilling activities are mentioned. As a consequence of drilling activities exposure of people from outer irradiation, inhalation of radionuclides and ingestion should be evaluated. According to these guides, the human intrusion scenario should be evaluated as altered scenario using probability approaches, but no specific approach is mentioned. These guides are intended for all radioactive waste repositories. There is no specific guide only for deep geological repository. For near-surface respository at Dukovany, a dose of 1 mSv in a year of exposure of people from a critical group of population should not be exceeded in contrast to 0.25 mSv in year for normal exposure scenarios with high probability.

3. Key terms and concept

Key term and concepts used in Czech safety approach corresponds to the terminology used in IAEA documents [5].

4. Treatment in the safety case

It was considered in the preliminary safety assessment of the Czech concept of Deep geological repository [4] that the probability of human intrusion will be significantly reduced by meeting site selection criteria. For example no natural resources or sources of drinking water should be present in selected sites for DGR. From this reason it was decided that the probability of human intrusion is negligible and human intrusion will not be evaluated.

5. Applications and experience

There is experience with treating human intrusion scenarios for near surface repositories operated in the Czech Republic [6] according to procedures recommended in IAEA documents [e.g. 7] were applied. No evaluation of human intrusion has been performed for deep geological repository.

6. Conclusions

No specific decision has been accepted so far for treating human intrusion scenarios in next performance assessments of DGR in the Czech Republic, but discussion on this issue will start this year in the framework of RAWRA project focused on update of reference design DGR from 1999.

7. References

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In the Czech DGR programme, analyses of the evolution of a repository are closely connected with other topics of post-closure safety analysis approach, as outlined in Fig. 1. They are involved mainly in the second stage of safety analysis methodology, which covers: identification and analyses of FEPs, scenario development, analyses of safety functions and derivation of the assumptions.

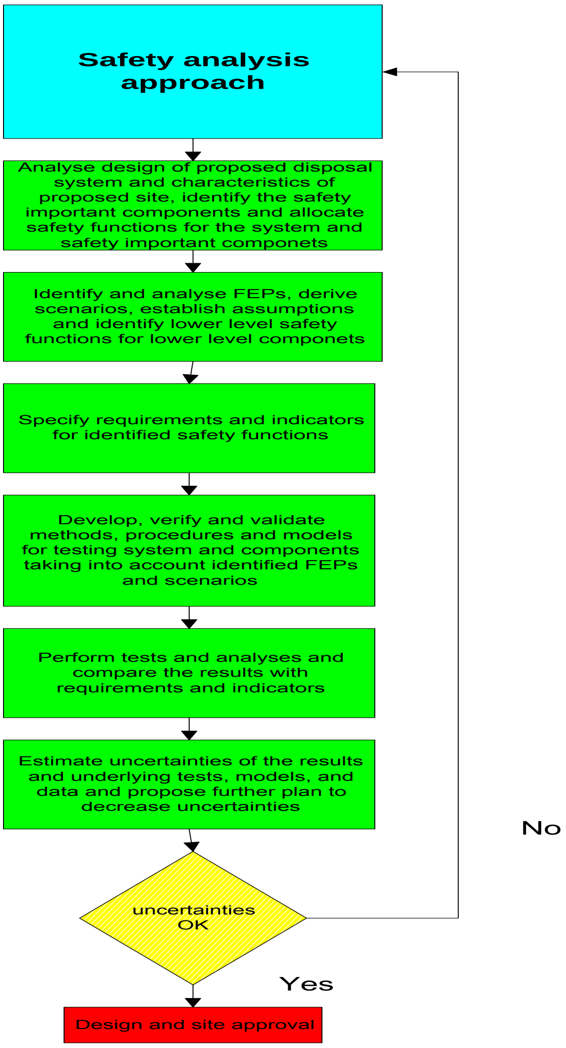

Fig 1. Scheme of safety analysis approach

2. Regulatory requirements

The safety analyses, used for the preparation of safety reports, require according to SONS/SÚJB guide [4] the evaluation of repository evolution, but it is not exactly defined how this evaluation should be done.

3. Key terms and concepts

Terminology used in modelling strategy corresponds to the terminology used in IAEA documents [7].

4. Treatment in safety case

The introductory safety case performed in the Czech Republic in 1999 [6] was related to conceptual reference design of a repository located in a granite host rock. Czech concept of DGR is similar to KBS 3V concept of disposal of spent fuel assemblies in granite in boreholes in a vertical position. The repository layout in granite host rock consists in boreholes with spent fuel waste packages surrounded by bentonite bricks located in the tunnels 500 m under the surface. Instead of copper based canister, planned in Sweden or Finland, carbon steel canisters were proposed for spent fuel assemblies from VVER reactors.

The approach used for the description of the evolution of the DGR system in the mentioned safety case for “Reference design” of the DGR in granite host rock has been based on expert judgments. The evaluation of the repository evolution was divided into the evaluation of the evolution of external system and the evolution of the internal system . External system is defined in an agreement with NEA-OECD report [5] as a system outside the disposal system domain. External factors affecting disposal system are FEPs with causes or origins outside the disposal system, i.e. natural or human factors of a more global nature. In general, external factors are not influenced, or only weakly influenced, by processes within the disposal system.

The following categories of external factors are used in agreement with International database of FEPs :

- Repository issues
- Geological processes and effects
- Climatic processes and effects
- Future human actions
- Other (e.g. meteorite impact)

Disposal system domain covers:

- Waste and engineered structures,
- Geological environment
- Surface environment - biosphere
- Human behaviour.

Disposal system domain also covers radionuclide/contaminant factors such as:

- Contaminant characteristics (e.g. decay constant),
- Release/migration factors (e.g. solubility, sorption properties)
- Exposure factors (e.g. biospheric transfer factors and dose factors).

Except radionuclide decay, which is constant independently of changes in a disposal system, other radionuclide factors can change with the external or internal system evolution. The evolution of the system is treated in hierarchical – top down approach, similarly as the development of scenarios described in other topics of this RTD 1. The evolution of an internal disposal system is affected by the evolution of external system.

4.1. Evolution of external system

The evolution of an external system is relevant to the geographical and geological conditions of the Czech Republic. In the mentioned safety report, it was concluded that:

- Climatic periodical changes on the territory of the Czech Republic in future (no timescale was specified, but it was implicitly considered that maximum doses are in time frame 10000 – 50000 years) will not differ significantly from the current state and will not affect significantly the hydro-geological environment of a disposal system. It means that:
  - There will be formed no significant layer of ice during glaciation period on the surface of the site which could affect repository conditions during glaciation or deglaciation period
  - There will be no permafrost in expected depth of the repository
- The maximum values of earthquakes on the candidate sites will not exceed 7 – 8°MSK (Scale of Medvedev-Sponheur-Karnik). It is expected that the earthquakes of the intensity of less than 7 – 8°MSK would not affect disposal system during the considered period
- There will be no future human actions, that would affect disposal system domain
- There was no decision or process connected with repository development and construction, which would change "design" parameters of a repository

These preliminary assumptions define normal/central evolution scenario of the repository. In further stages of DGR development the possible altered scenarios will be identified and the evolution of the system will be studied under altered external conditions.

4.2. Evolution of the disposal system

Only the evolution of the disposal system under normal evolution conditions was considered in initial safety calculations in 1999 [6]. The evolution of the internal system has been studied also using expert judgement approach. Individual studies have been devoted to the evolution of near and far field components. This approach was based on study of interactions between major disposal system components. The interaction matrices like matrix in Fig. 2 were prepared.

Waste	C, G, R, M		C, G, R, M			
C	Canister	C	C, G			
	M, C	Canister internals and void	C			
C, H, M	M, C, H	M,C,H	Buffer backfill, and Seals			
C	C		C, H	Other engin. struct.		
C	C, M		C, H, M	C, M	Host rock	
			T		H, T	Repository layout

Fig. 2 Example of interaction matrix prepared for study of interaction between components and internal system evolution

For identification of all the possible interactions and functions, the following interaction classification was used:

- 1) Chemical (C)
- 2) Thermal (T)
- 3) Hydraulic (H)
- 4) Mechanical (M)
- 5) Gas formation (G)
- 6) Radiation (R)

It turned out that using interaction matrices can make some interactions between system components more visible and will help not to forget some important issues, but this approach is difficult to formalise and relate directly to the main objective of the system. It is also very difficult to estimate the importance of some interactions. The system of estimating the importance of some special interactions using expert judgement approach was not very successful because of strong bias of the experts, who considered as the most important the interactions from their own point of view. Therefore this approach is currently modified under the influence of knowledge acquired since the preparation of the safety report in 1999 and other international and national DGR programmes. Al the identified interactions will be specified and transformed into indirect safety functions with some tentative, quantitative requirements.

Research project devoted to the study of the evolution of near field components started in the framework of project coordinated by NRI in years 2005 – 2008 for RAWRA. The research was divided into the following topics:

- Spent fuel and other waste form materials in repository environment (Corrosion of spent fuel and the effect of various factors on corrosion rate)

- Canisters materials (carbon steel, copper corrosion)
- Radionuclide/contaminant migration factors
- THMC conditions in near field (temperature evolution, stress evolution, saturation, etc.)
- EDZ (e.g. the effect of stress on permeability of fractures)

The analyses have been based primarily on literature data analyses and limited experimental or modelling work, which was focused primarily on the preparation of experimental (including laboratory evaluation of important parameters and processes) and modelling methodologies, which will enable to better understand the evolution of a repository and its components.

An expected normal evolution of a disposal system was divided into six periods as described in Table 1.

Table 1 Important phases of a repository evolution under normal evolution scenario

No.	Title	Description
1	Pre-construction period	This period is characterised by unperturbed host rock conditions before construction of a repository. i.e. by: geothermal gradient, chemistry of groundwater (pH, Eh, composition), rock fracture mineralogy, hydrogeological flow pattern. For the evaluation of host rock future evolution it is also useful to know past evolution of a repository site.
2	Construction period	Repository excavations will induce deformation of intact rock, formation of new fractures, extensive ventilation can cause change of redox conditions in a repository and consequent change of groundwater compositions, which can be also changed by added engineered barriers, hydrogeological flow pattern can be significantly changed.
3	Aerobic period	This phase is very important for the description of the evolution of some engineered barriers. A repository is returning slowly to the state before wastes emplacement. Repository saturates slowly by water. Corrosion of canisters is affected by oxygen remained in a repository after construction period and by increased temperature, and possibly radiation (depending on canister design) from waste. This period could be the most detrimental to steel canisters, because aerobic corrosion is much higher than anaerobic one. THMC conditions are changing significantly.
4	Containment period	In this period it is expected that a repository is fully saturated by water, and conditions were changed to reducing ones. Very slow anaerobic corrosion will start under the effect of water. No failure of canisters will occur in this period. It is expected that this period will last until a decrease of temperature and radiation almost to the level before waste emplacement.

No.	Title	Description
5	Corrosion period	It is expected that in this period first canisters will fail due to decrease of canister walls by corrosion and surrounding pressure. Water will go to the contact with the waste, which begins to dissolve, and radionuclides start to escape to the near field environment. Soluble radionuclides released from spent fuel construction materials and from gap between spent fuel matrix and cladding will migrate through bentonite layer and later, they will reach geosphere and biosphere. THMC conditions in this period will get to steady state, except their change due to corrosion products (solid and gas) from anaerobic corrosion of carbon steel.
6	After corrosion period	After all the canisters corrode, radionuclides will slowly release from waste forms. THMC conditions are in steady state since there is almost no disturbance from corroding canisters. A repository will change only due to natural changes similar to past changes before repository construction.

It is very difficult to estimate the time of outlined evolution periods. The construction and possibly aerobic period will last several tens of years depending on repository design. Containment period is significantly canister design specific. If copper canisters were selected, this period could take more than 1 million of years. For carbon steel canisters this period can take several tens of thousand years in anaerobic conditions supposing that thickness of canister wall is about 10 cm. The time of corrosion period will start by failure of the first canister and can take for very long time, but now it is very difficult to specify the time. Possibly it is hundred thousands to millions of years. An optimisation study that should the effect of canisters life time on the repository safety will be a part of future activities. Optimisation process will also determine the scope of research in the field of canisters performance. For carbon steel canisters further research focusing on determination of the effect of some important parameters for corrosion rates estimation, such as temperature or flux of water around disposal units is needed. After-corrosion period could take millions of years.

4.3. On going work and future evolution

Further experimental and modelling work is needed to determine the evolution of repository barriers. This work will be based on the results achieved in international or national projects of other countries.

5. Lessons learned

As was said before, using interaction matrices can make some interactions between system components more visible and help not to forget some important issues, but the system is difficult to formalise and relate directly to the main objective of the system. It is first of all difficult to estimate the importance of interactions in respect to the objectives of assessments.

It seems that evaluation of hierarchically arranged components of a repository in relation to their safety functions and in the respect to the main objectives of the assessment is more transparent, because the importance of FEPs can be assessed more directly using sensitive analyses and/or optimisation studies. This approach must be, however, supported by comprehensive testing and analysis program (see Fig. 1).

6. Link with other topics

The analyses of the evolution of the repository are closely connected with identification of FEPs, safety functions and the development of scenarios.

7. References

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[6] Reference project of surface and underground structures of DGR, RAWRA 23-8024-51-001/ EGPI 443U-6-990 009, 1999

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A9 POSIVA (Finland)

1. Background

The treatment of the potential activities of individual people or communities affecting the potential overall radiological consequences from the repository is dealt with in the Posiva's biosphere assessment part of the Safety Case.

The future human actions possibly affecting the repository at depth are within the realm of the Evolution report at the main level of Safety Case, including also the anthropogenic climate change.

To systematically include all relevant features, events and processes (FEPs) related to the future human activities, a working list of FEPs is collected by reviewing existing FEP list and other such sources, collecting items arisen in the discussions in the process reporting work and any other sources appearing. The working list is kept updated, and the FEPs are at least commented concerning how they are taken into account, for publication at latest together with the PSAR documentation in 2012.

As an example, alternative diets are one FEP related to uncertainties related to (future) human activities. In studies where alternative diets or lifestyles have been considered, the highest doses are similar to that of a self-sufficient farmer within about a factor of three (Zach *et al.* 1999, BIOMASS 2002, Garisto *et al.* 2005). However, considering the long timeframes and also considering other stakeholders, it is seen useful to calculate doses or corresponding coefficients for additional exposure groups with other diets and lifestyles, *e.g.* hunters, modern rural community or urban residents, to ensure the robustness of the conclusions on the dose endpoints, to accommodate expected and unexpected changes in the biosphere, and to provide more explicit indicators for variety potential exposure groups and related stakeholders.

The cases of inadvertent human intrusion are discussed in the Assessment Report that includes both, the assessment of releases from the geosphere and the assessment of the fate of the release of radionuclides in the biosphere.

2. Regulatory requirements and provisions

The Finnish regulatory follows the requirements set by the Council of State Decision (478/1999) about safety of disposal and set up the following in the regulations about hampering human intrusion and about the scenarios related to human intrusion. These requirements are quoted below in *italics*.

The geological characteristics of the disposal site shall, as a whole, be favourable for the isolation of the disposed radioactive substances from the environment. An area having a feature that is substantially adverse to long-term safety shall not be selected as the disposal site.

The repository shall be located at a sufficient depth in order to mitigate the impacts of above-ground events, actions and environmental changes on the long-term safety and to render *inadvertent human intrusion to the repository very difficult.*

To this it added in the YVL Guide 8.4 (STUK 2001) that a factor (among others) indicating unsuitability of a disposal site may include the proximity of exploitable natural resources, that is, a site with exploitable natural resources should be excluded already in the selection site process.

STUK (2001) classifies the human intrusion (inadvertent) scenarios as the result of "unlikely disruptive events" that should include

- Boring a deep water well at the disposal site
- Core-drilling hitting a waste canister

Recently in a draft update of the YVL Guide 8.4 it is stated that human intrusion scenarios need to be considered starting only after 200 years have passed from the closure of the repository, as some credit is taken on institutional control and preservation of information about the repository.

3. Terminology

Posiva uses as most the terminology in the IAEA glossary of 2007. Whenever any term is adapted from other sources its definition is specified in detail. Comparisons and correlation with the terminology used by the Finnish regulator is also specified in order to avoid misunderstandings.

4. Treatment in the Safety Case

4.1 Methodology

Calculation cases for the human intrusion scenario have not been developed since the TVO-85 Safety analysis (Vieno et al. 1985). In TVO-92 (Vieno et al. 1992) it is stated that:

"The five candidate sites are located in areas of a low ore and mineral potential. Rock types at them are common in the Finnish bedrock. When the repository is closed, seals will be constructed in the tunnels. The shafts will be backfilled with a mixture of sand and bentonite, and reinforced concrete plugs approx. ten metres in thickness will be constructed at the upper ends. Information of the repository and the waste is stored in several archives. Storing of the information and markers, which might be constructed at the disposal site, are currently being studied in co-operation by the Nordic countries as well as in a wider international context.

In spite of all the countermeasures, it cannot be completely ruled out that human being may, intentionally or inadvertently, intrude into the repository in the future. If the intrusion is to retrieve materials from the repository, the intruder can be assumed to operate in a careful way and also to bear the responsibility of their acts. Even if information about the repository were lost, it is very unlikely that someone would intrude or drill into the repository by accident. Deep boreholes and shafts are not made arbitrarily in common rock types, but drillings and excavations are preceded by airborne and ground-based geophysical investigations, by which the repository will be detected.

It is not very meaningful to try to quantify the risk due to inadvertent intrusion. The probability that, for instance an exploratory drilling would hit a canister is very low, in the order of 10^{-8} per year (Vieno et al. 1985). So far (up to 1992) about 150 deep boreholes (approx. 500 m or more) have been drilled in Finland. About 30 of them have been made in the site investigations for spent nuclear fuel. If our base our estimates of future drilling probabilities on these figures, we indirectly assume that, for example over 100 000 years, about one million deep boreholes would be drilled in the Finnish bedrock, and that approx. 200 000 of them would be made in site investigations for nuclear waste disposal!

The working group of Nordic safety authorities, which discussed and drafted safety criteria for high-level waste disposal, concluded that the estimation of probabilities and consequences of human intrusion is very approximate or speculative. They further noted that such human intrusion scenarios, for which quantitative assessments are, in practice, impossible, can be interpreted as “rest risks” on which detailed analyses are not needed (Nordic 1993). This conclusion is justified also by the fact that the risk is more or less independent of the disposal site, provided that the repository is located in a common rock type.”

No new analyses on human intrusion were considered necessary for TILA-96 or TILA-99. It was nevertheless interesting to notice that SKB (1995) analysed an intrusion scenario similar to the one considered already in the TVO-85 safety analysis (Vieno et al. 1985): the radiation dose caused to the members of the drilling crew in case of an accidental drilling through a canister after the sealing of the repository. The results were similar: SKB (1995) estimates the probability of an accidental drilling through a canister to be 10^{-7} yr^{-1} when the knowledge about the repository is assumed to be lost after 500 years. In TVO-85, the probability for the smaller repository in Finland was estimated to be $2{\cdot}10^{-8}$ yr^{-1}. Also the estimates of the consequent dose to the drilling crew are similar: SKB (1995) estimates the dose to be $2{\cdot}10^{-2}$ Sv/yr, if the drilling occurs 100 years after the sealing of the repository, and $1{\cdot}10^{-4}$ Sv/yr after 1 000 years. In TVO-85, the corresponding doses were $4{\cdot}10^{-2}$ Sv/yr and $1{\cdot}10^{-4}$ Sv/yr, respectively. The expectation value of the dose in this scenario is very small, at the maximum $2{\cdot}10^{-11}$ Sv/yr at 500 years when all information of the repository is assumed to be lost (SKB 1995).”

Recenty, in the Safety Case plan (Posiva 2008) it is stated that the characterisation of the Olkiluoto site and the strategy for repository design are focused on a volume of bedrock situated between 400 and 700 metres below the ground surface, where favourable and predictable bedrock and groundwater conditions are expected to be found. Therefore, the safety concept automatically includes the depth requirement from YVL 8.4, instructing Posiva to locate the repository “*at a sufficient depth in the bedrock in order to mitigate the impacts of above-ground events, actions and environmental changes on the long-term safety and to render inadvertent human intrusion to the repository very difficult*” (YVL 8.4, section 3.3). “

Other repository system components, including e.g. backfill, plugs, structural and sealing components have not been assigned safety functions. They are, however, designed to be compatible with, and support the safety functions of, the canister, the buffer and the host rock. For example, backfilling and sealing of the repository cavities support the safety functions of the host rock by preventing the formation of water conductive flow paths and by discouraging inadvertent human intrusion into the repository.

Events

Nonetheless the likelihood of human intrusion seems to rest very small, calculation cases could be set up to estimate doses. The approach could be similar to that of SKB in SR-Can (SKB 2006), where it is assumed for the consequence analysis that:

1. The canister is penetrated by core drilling.
2. The borehole is grouted but left an open pipe from the penetrated canister to the surface.
3. There is no delay from the radionuclide transport in the geosphere.
4. The instant release fraction of the inventory, as well as the radionuclides in the cutting are brought to the surface and spread on the ground.

Quantitative assessment:

Only doses to the family that settles on the site were considered in the SR-Can assessment (SKB 2006). The dose originated from two sources. The abandoned borehole used as a well by the family and the cutting containing the instant release fraction and the fuel particles spread on the ground. The important parameters were:

- Time of drilling – determines the radionuclide inventory left in the canister
- Time of settlement – the time the family settles on the site and starts using the borehole as a well and the contaminated soil for cultivation determine the content of radionuclides in the well and on the ground.
- Amount of fuel brought to the surface – will determine the dose from the cuttings spread on the ground
- Instant release fraction (IRF) – radionuclides not embedded in the fuel matrix will be immediately released.
- Fuel alteration rate – The fuel alteration rate will directly determine the release of most radionuclides under most circumstances
- Water flow through deposition hole – the water flow will determine the release rate of radionuclides. The flow rate may also control fuel matrix dissolution under some circumstances.

The data used in the calculations is in Table 1 (Table 12-4 in SKB 2006). See results in Figures 1 and 2.

Table 1. Data used in the calculation

Parameter	Value/assumption	Comment/reference
Time of drilling	300 years after closure of the repository or later	-
Time the family settles at the site	One month after the drilling	IAEA 2005
Time the exposed individual spends in the middle of the contaminated area	365 h	1 hour per day every day of the year
Radionuclide inventory	12 x BWR 38 MWd/kgU	SKB 2006
IFR	Included in the inventory left on the ground	-
Fuel alteration rate	10^{-7}/y	-
Water flow through deposition hole	1 m^3/y	-
Dose conversion factor for the open borehole	Site-specific mean value for a well case	Avila et al. 2006
Dose conversion factors for contaminated ground	Different factors for external irradiation, inhalation and ingestion of food cultivated at the site	Avila & Bergström 2006 IAEA 2005
Radius of contaminated area	3 m	-
Thickness of contaminated soil layer	0.1 m	-
Borehole diameter	0.056 m	-
Core diameter	0.053 m	-
Portion of fuel in the cuttings	0.1 m	Volume of the fuel/volume of the canister
Contaminated drilling length	5 m	-
Dust concentration in the air	5 x 10^{-7} kg/m^3	IAEA 2005
Inhalation rate	1 m^3/h	Avila & Bergström 2006
Yearly intake of carbon	110 kgC/y	Avila & Bergström 2006
Productivity of contaminated area	0.15 kfC per m^2 and y	SKB 2006

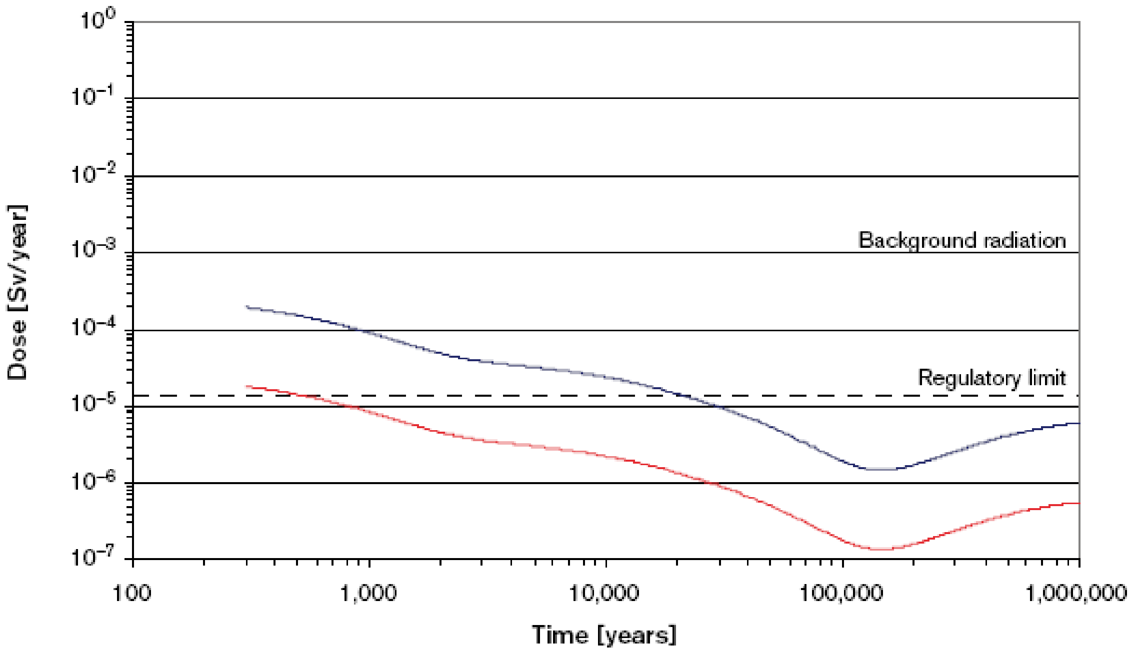

Figure 1. Calculated annual effective doses from using the borehole as a well for drinking water and irrigation at Forsmark (red line) and Laxemar (blue line) (SKB 2006)

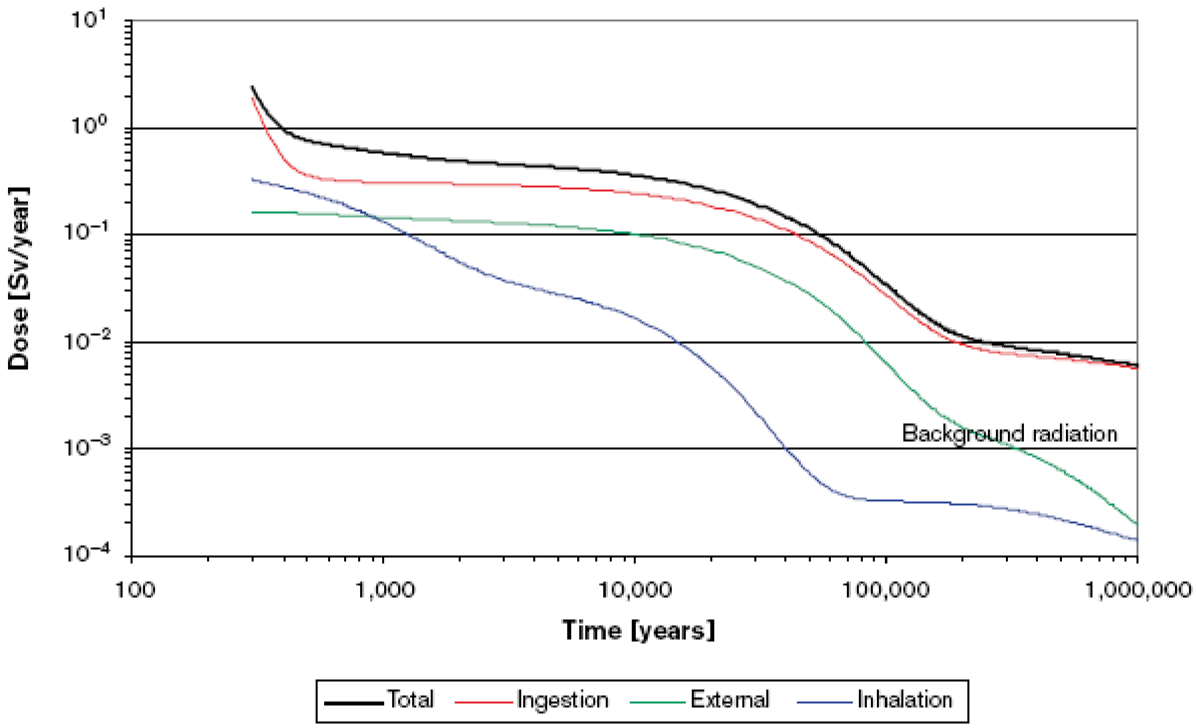

Figure 2. Calculated annual effective doses from the cuttings left on the ground. The doses are those that an adult would get the first year after settlement if the person spends one hour per day in the middle of the assumed contaminated land area around the borehole and the contaminated area is used for domestic farming (SKB 2006)

It must be noted that the assumptions behind those calculations are extremely over-conservative; e.g. in current drilling campaigns no drill cuttings are left all spread on the top of the soil.

4.2 Related topics

The human intrusion scenario is taken into account as a regulatory demand and it is not derived from FEP analysis alone. The calculation cases that may be derived from this scenario will however depend on parameters related to features of the repository and the site and on the processes that result from the events that human activities may cause at the site and its environment.

4.3 Ongoing work and future expectations

Currently there is not ongoing work on human intrusion scenarios, but measures to diminish the likelihood are being taken (Saanio et al. 2006). The formulation of calculation cases for this kind of scenario are to be planned by the year 2010, well in time for the application of construction permit in 2012.

5. Lessons learnt and the way forward

In the selection site process the probability of inadvertent human intrusion was reduced avoiding sites with extractable mineral resources. The available technical solutions for repository design and constructions reduce the likeliness even more taking into account first the depth of the repository and the technical barriers to isolate it.

However intrusion may have consequences both for the intruders and for the long-term performance of the repository after the intrusion. Intrusion scenarios are thus evaluated separately from other scenarios in the safety assessment. Therefore, it is not straightforward how to assess this kind of scenarios.

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A10 SCK·CEN, ONDRAF-NIRAS (Belgium)

Revision: 0

1. Introduction and background

In Belgium, during the first half of the nineties the analyses of human intrusion scenarios mainly focused on drastic types of human intrusion, i.e. the geotechnical worker scenario. In this scenario it is assumed that a geological exploration drilling crosses the repository and that cores, containing fragments of the disposed high-level waste, are taken in that borehole and that the cores are examined by a geotechnical worker.

After the publication of the report of the American Academy of Sciences on Yucca Mountain Standards (NAS, 1995) international consensus was growing that the relevance of such drastic intrusion scenarios is highly questionable. In the SAFIR 2 report (ONDRAF/NIRAS, 2001) it was proposed to focus the human intrusion scenarios considered in the safety assessments on the robustness of the repository system, but no analyses were yet available when the SAFIR 2 report was published. In 2005 a report on the treatment of human intrusion scenarios in safety assessments of geological disposal (Marivoet, 2005) was prepared and this report was submitted by ONDRAF/NIRAS to the Belgian radiological protection authority FANC/AFCN. However, the discussion between ONDRAF/NIRAS and FANC/AFCN on the treatment of human intrusion scenarios in the case of geological disposal has not yet started.

2. Regulatory requirements and provisions

Regulatory requirements and guidelines concerning long-term safety of high-level radioactive waste disposal are still in preparation in Belgium.

The discussion between the radiological protection authority FANC/AFCN and the waste management agency ONDRAF/NIRAS on safety cases has been started for a surface disposal facility for short-lived low-level and medium-level radioactive waste, but not yet for a geological repository for the disposal of high-level and long-lived radioactive waste.

In the period 2000-2003 the Belgian radiological protection authority FANC/AFCN, its technical support organisation AVN, as well as the waste management agency ONDRAF/NIRAS have participated in a French-Belgian working group on the safety approach to geological disposal (Franco-Belge Working Group, 2004). For the treatment of human intrusion the document states that only inadvertent intrusion, most often associated with a loss of memory of the existence of the repository, has to be taken into account and that the same level of technology as at present can be assumed. Postulated possible scenarios, taking the regional context into account, are drilling for water, exploratory drilling with the extraction of cores, the operation of a mine near the repository or direct physical human intrusion into the disposal facility. Two types of possible consequences are distinguished:

- doses to intruders;
- deferred consequences mainly associated with the transfer by water in situations where part of the barriers has been by-passed.

For the first type of consequences the doses received by the intruders can be high and it would be difficult to reduce them by the repository design. However, these high doses are closely linked to the "concentrate and contain" strategy and, consequently, comparison with a regulatory limit is not considered relevant.

For the second type of consequences the situation is comparable to that of an altered evolution scenario, i.e. limited disturbance of the barrier system, and it can be expected that only a fraction of the disposed waste will be affected. The resulting radiological consequences can be assessed in the general framework of the altered evolution scenarios.

3. Key terms and concepts

The two following definitions of terms related to human intrusion given in a NEA report (1995) are used within the Belgian high-level radioactive waste disposal programme.

Future human actions: actions occurring after repository closure that have the potential to disrupt or impair significantly the ability of the natural or engineered barriers to contain radioactive waste.

Inadvertent actions: actions in which either the repository or its barrier system are accidently penetrated or their performance impaired, because the repository location is unknown, its purpose is forgotten, or the consequences of the actions are unknown.

For the term *human intrusion* itself we now use the following definition: inadvertent action that has the potential to disrupt or impair significantly the ability of the natural or engineered barriers to contain radioactive waste

4. Treatment in the Safety Case

4.1 Methodology

As already mentioned in the introduction, we have decided after 1995 to change our approach to the treatment of human intrusion in the safety evaluations. Therefore, we report hereafter the old approach as well as the new one, which is, however, still in development and waiting for discussion with the radiological protection authority.

4.1.1 Old approach

In the beginning of the nineties we have introduced analyses of the "core examination" or "geotechnical worker" scenario in our safety assessments. This scenario was defined by Smith et al. (1987). The scenario assumes that a borehole is drilled through the repository, of which the existence has been forgotten, and that cores containing fragments of the disposed high-level waste are taken from the borehole and that a geotechnical worker examines the cores. He will be exposed mainly by external irradiation and inhalation.

Sillen and Marivoet (2002) applied the core examination scenario to the case of disposal of spent fuel. The dose to a geotechnical worker can be as high as 500 Sv in the case of a close inspection of a core containing fragments of spent fuel (uranium oxide with a burn-up of 55 GWd/tHM) occurring 300 years after disposal, and 45 Sv in the case of a routine inspection.

4.1.2 New approach

After the publication of the report of the American Academy of Sciences (NAS, 1995) on safety standards for Yucca Mountain the use of drastic human intrusion scenarios such as the core examination scenario has been abandoned in most recently published safety cases. The focus is now on the resilience or robustness of the barrier system in the case of an accidental human intrusion.

A first type of analysis that has already been performed in this perspective consisted of the calculation of the time during which a borehole is expected to remain open when it is drilled in the Boom Clay formation. Geomechanical calculations based on a visco-elasto-plastic model of the Boom Clay have shown that the convergence of the clay makes that a 10-cm diameter borehole will be closed in just a few weeks.

In the new approach it is proposed to distinguish, on the basis of the contact between man and the waste, three types of human intrusion:

- direct contact of the intruders with the waste itself, e.g. a core inspection scenario;
- direct contact with drilling cuttings containing fragments of disposed waste by people not involved with the drilling operations, e.g. dispersal of radioactive materials scenario;
- indirect contact with the waste, e.g. via groundwater flowing through an unsealed borehole and coming in contact with the disposed waste.

For the core inspection scenario it is proposed to assume that the presence of the thick metallic overpack will make an inadvertent intrusion into the disposed waste unlikely during several thousands of years. Also for the dispersal of radioactive materials it can be expected that during long time spans the drilling team should become aware of the presence of exotic materials in the cuttings and that they should take protective measures.

It is now planned to develop a number of unsealed borehole scenarios and to evaluate the radiological consequences resulting from these scenarios.

4.2 Related topics

4.2.1 Pumping well scenarios

Pumping wells are also related to future human actions, but they are not assumed to affect the barriers of the repository system (if they do, they fall in the unsealed boreholes group of human intrusion scenarios). We consider two types of pumping wells in our safety assessments. The first one consists of the drilling of a pumping well in the Neogene aquifer, which is overlying the Boom Clay formation. This type of well is considered in the reference scenario as a geosphere-biosphere pathway because this aquifer is at present intensively used as a drinking water resource.

The second type of well is assumed to be sunk in the Under-Rupelian aquifer which is underlying the Boom Clay formation. This aquifer is only about 20-m thick and is not used at present as a drinking water resource. Its hydraulic conductivity is of the order of 10^{-6} m/s, which is rather low for an aquifer, and the horizontal hydraulic gradients in those deep aquifers are of the order of 0.001. This makes that the groundwater flow in that aquifer is very low (about 20 m/a) and, as a consequence, the dilution in that aquifer is very limited what can lead to relatively high concentrations in the groundwater of the radionuclides that are released from the host clay layer.

4.3 Databases and tools

The list of scenario-building elements for development of future human action scenarios given in the NEA report (1995) has been used as checklist for a completeness check for the derivation of human intrusion scenarios.

For the calculation of doses for core examination and dispersal of radioactive materials scenarios specific biosphere models have been developed. For the evaluation of the unsealed borehole scenarios the standard computer codes used for the evaluations of the reference and altered evolution scenarios can be applied.

4.4 Application and experience

The experience on the treatment of human intrusion scenarios in Belgium is rather limited because the interaction between the waste agency and the radiological protection authority has not yet started for safety cases for geological disposal and this interaction is considered to be an essential element for the development of a methodology for the treatment of human intrusion in a safety case.

4.5 Ongoing work and future evolution

Within the framework of PAMINA work package 3.1 SCK•CEN will develop a number of stylised human intrusion scenarios that are relevant for geological disposal in clay formations.

We also expect that the interaction between the radiological protection authority FANC/AFCN and the waste management agency ONDRAF/NIRAS on safety cases for geological disposal will start during the last months of 2009.

5. Lessons learned

One can observe a drastic change in the treatment of human intrusion scenarios in safety cases during the last 10 years. Whereas in the nineties the focus was on analyses of drastic types of human intrusion such as the core examination scenario, recent safety cases focus on the resilience or robustness of the disposal system in case of an accidental human intrusion.

The interaction between the waste agency and the radiological protection authority is considered to be an essential element for the development of a methodology for the treatment of human intrusion in a safety case.

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PART 11: CRITERIA FOR INPUT AND DATA SELECTION

(Prepared by Enresa, Spain)

2009-08-14

Revision: 1

1 Introduction

The main objective of RTDC-1 of the integrated project PAMINA is to review the state of the art of the methodologies and approaches followed for developing the Safety Case of geological repositories, and identify the lessons learned from the experience accumulated in their development and application. During the definition of PAMINA project it was found useful to organise this review on the bases of 11 different topics, and one of such topics was the “Criteria for Input and Data Selection” in a Safety Case.

The ten organisations presented in Table 1.1 have provided written contributions describing their points of view and experiences on the “criteria for input and data selection” for the Safety Case. As shown in Table 1.1, the ideas on data generation and selection of the organisations responsible for developing (implementers) are well represented while only one regulator (GRS-K) has provided a formal contribution. The contributions of the individual organisations are included in the Appendices to this task report.

The present task report is based on the previous 10 contributions and the discussions and conclusions of a workshop held in Madrid in April 2009, where another regulator (IRSN from France) participated in the discussions.

Table 1.1 – List of organisations contributing to the “criteria for input and data selection” topic

Organisation	Country	Implementer	Regulator
Andra	France	X	
ENRESA	Spain	X	
FANC-Bel V	Belgium		X
GRS-B+DBE+BGR	Germany	X	
GRS-K	Germany		X
NDA	United Kingdom	X	
NRG	The Netherlands	X	
NRI, RAWRA	Czech Republic	X	
POSIVA	Finland	X	
SCK·CEN ONDRAF/NIRAS	Belgium	X	

This task report is focussed on the methodology followed to produce and selection the data used in the Safety Case, not on describing the data used. Some contributions provide detailed descriptions of the data used, in addition to the strategy followed for generate and select such data. These examples of the data required by a Safety Case can be found in the Appendices (section 9), but are not discussed in the main body of this task report.

2 Regulations and Guidelines

In IAEA Safety Standards for geological disposal [1] there are several paragraphs dealing with the data generation and data use in the development of a geological disposal facility:

- "The step by step approach (to develop a safe repository) involves: the ordered accumulation and assessment of the necessary scientific and technical data: the evaluation of possible sites; the development of disposal concepts; iterative studies for design and safety assessment with progressively improving data;…."
- "The operator is also responsible for carrying out all the necessary investigations of the site or sites and of materials and for assessing their suitability, and for providing data for safety assessments".
- "An understanding of the performance of the disposal system and its safety features and processes evolves as more data are accumulated and scientific knowledge is developed. Early in the development of the concept, the data and the level of understanding gained should provide the confidence necessary to commit the resources for further investigations……"
- "As site investigation progress, safety assessments become increasingly refined, and at the end of a site investigation sufficient data will be available for a complete assessment. Safety assessments also identify any significant deficiencies in scientific understanding, data or analysis that might affect the results presented".
- "A safety assessment in support of the safety case is performed and updated throughout the development and operation of the geological disposal facility and as more refined data become available."
- "Justification and traceability both require a well documented record of the decisions made and the assumptions made in the development and operation of a geological disposal facility, and of the models and data used in arriving at a particular set of results for the safety assessments".
- "The management system and the supporting QA programme for the geological disposal facility will provide for the production and retention of documentary evidence to illustrate that the necessary quality of data has been achieved;…"

The previous bullets summarise the main expectations of the regulators regarding data generation and use in the development of a repository.

In some countries, such as Spain and The Netherlands, no detailed regulations have been developed for deep geological repositories, and no specific requirements or guidelines are available on the topic of data generation within the project and data selection for models.

Other countries, with geological disposal programmes at more advanced stages, already have regulations (at least in draft form) or discussions between the implementers and the regulators that provide information on the expectations of the regulators regarding the selection of data to be used in a Safety Case. In the next sections the information gathered regarding regulations and guidelines from the regulators is presented on a country basis.

Belgium (SCK·CEN/ONDRAF-NIRAS)

Regulatory requirements and guidelines concerning long-term safety of high-level radioactive waste disposal are still in preparation in Belgium.

The Belgian regulator (FANC-Bel V) requests the use of "best estimate" values of the parameters in the analysis of the performance of the barriers and "conservative" values in the analysis of the radiological consequences.

Czech Republic (NRI, RAWRA)

According to guides of the Czech regulator SUJB, safety reports must contain data describing comprehensively all components of site and Deep Geological Repository (DGR) design (topography, geology, hydrology, geochemistry, demography, design of repository, waste packages, etc.). Primarily the following data are needed to judge criteria for siting according to Degree of SUJB 215/2007 e.g.:

- The occurrence of karstic phenomena in the extent endangering the stability of the rock massif in the bedrock and in the rock cover of the land selected for the siting.
- The manifestation of post-volcanic activity such as the escapes of gases, thermal, mineral and mineralised waters, found on the lands or area of the supposed siting and in their site vicinity zones.
- The achievement or exceeding of the value of intensity of the maximum calculated earthquake 8 °MSK (scale of Medvedev-Sponheuer-Karnik for estimation of the macroseismic effects of earthquakes) on the lands of supposed siting.
- The occurrence of the capable and seismogenic faults with the recent surface deformations of area and with the possibility of origination of secondary faults, found by a geological survey on the land of supposed siting.

All the data needed for evaluation of impact of radionuclides on the environment must be gathered. Modelling of transport of radionuclides shall be based on detailed knowledge of site for DGR. A list of parameters, their substantiation a possible change of parameters in space and time and their maximal and minimal values must be given. A list of reports with data and information not directly given in the safety report must be included at the end of safety report and must be given their availability.

Finland (POSIVA)

The Finnish Regulatory Body (STUK) states about modelling and input data that "In accordance with Section 29 of the Government Decision, the computational methods shall be selected on the basis that the results of the safety analysis, with high degree of certainty, overestimate the radiation exposure or radioactive release likely to occur" [2].

In order to assess the release and transport of disposed radioactive substances, conceptual models shall first be drawn up to describe the physical phenomena and processes affecting the performance of each barrier. Besides the modelling of release and transport processes, models are needed to describe the circumstances affecting the performance of barriers. From the conceptual models, the respective calculation models are derived, normally with simplifications. Simplification of the models as well as the determination of input data for them shall be based on the principle that the performance of any barrier will not be overestimated but neither overly underestimated.

The modelling and determination of input data shall be based on the best available experimental knowledge and expert judgement obtained through laboratory experiments, geological investigation and evidence from natural analogues.

The models and input data shall be appropriate to the scenario, assessment period and disposal system of interest. The various models and input data shall be mutually consistent, apart from cases where just the simplifications in modelling or the aim of avoiding the overestimation of the performance of barriers implies apparent inconsistency."

France (Andra and IRSN)

The RFS.III.2.f of 1991 [3], which was the reference for the Dossier 2005 Argile [11], recommended in section [7] "2.2.1. Reference situation …The evaluations will be based on a modelling of the repository evolution, in particular of the barriers, and on a modelling of the groundwaters and transfer of radionuclides" and in section [7] "5.4. Modelling …. The models are simplified representations of the real phenomena: it must be shown, on one hand that these representations do not leave aside important phenomena, and on the other hand that the simplifications of the phenomena have a character pessimistic enough. Considering the importance of the modelling, particular care must be taken in the validity of the models and the data." (not an official translation). It also rules the type waste to take account for (as input data): [7] "The installation of radioactive waste disposal in deep geologic formation is conceived to receive the ultimate radioactive waste which, after their storing, cannot for reasons of safety or radioprotection be stored on surface or in shallow depth. It can involve in particular:

- Waste of average activity (based on mass) containing radionuclides of long period. Their quantity is such that it would not allow their storage, either in an installation of surface weak activity short half-life storage, nor in an installation of weak activity and long half-life storage,
- Waste of high activity (based on mass) containing significant quantities of radionuclides of long period. This waste mainly arises from the reprocessing of the used fuel and are characterized by an important release of heat,
- Used fuels which would not be reprocessed."

The revised version of this safety rule issued in 2008 includes some specific recommendations about modelling and data selection: …."*This modelling has to rely upon sound knowledge of the physico-chemical processes and events which can affect the evolution of the repository system and its environment and thus on investigations, as well as an advanced research program"…." Considering the importance of the modelling, a particular care must be taken in the quality of the data…"…" Considering the iterative character of the demonstration of safety, the level of detail of the modelling will also depend on the progress of the studies and on the level of precision of the data which will have been collected at the time of the modelling*"(not official translation).

Germany (GRS-K and GRS-B)

At present, no legal regulation exists in Germany which demands a specific data selection in the framework of a safety case (SC) respectively safety assessment (SA). Only general

[7] To Note: not an official translation

requirements for input and data selection are mentioned for the safety case, the safety analysis and its review:

“During exploration, the applicant shall ascertain the principal site data relating to safety of the repository in an adequate level of detail as required for the safety cases. Where this requires the quantitative determination of site data, the accuracy / range of and any potential changes in such site data under emplacement conditions should be ascertained. The applicant must prove the validity of such data to the licensing authority. Where data obtained from other sites is to be used, the transferability of such data must be justified.”

“For long-term forecasts, where applicable, reference data and reference models should be used for periods during which the uncertainty of the input data and calculation models is so high as to cast doubt on the validity of the results. Qualitative evidence should additionally be used for such periods”.

“Deterministic calculations should be based on as realistic as possible modelling (e.g. by use of median values as input parameters”.

“In order to review the safety assessments for emplacement operations, decommissioning and the post-closure period, a measurement programme should be carried out which can be used to analyse the input data, assumptions and statements of these safety assessments. In particular, this measurement programme should record the impacts of thermo mechanical rock reactions to heat-generating waste, geotechnical measures, and rock-mechanical operations. For evidence purposes, such measurements should continue to include the initial status and the development of activity concentration in spring water and groundwater, soil, water bodies and the air within the repository’s sphere of influence. Significant deviations from the relevant data, statements and assumptions in the cited safety cases should be notified to the competent authority immediately, and evaluated with regard to their safety relevance. If necessary, counteractive measures should be carried out by the operator in order to avoid any impairment to important safety functions. Where approval is needed for such counteractive measures, this should be obtained by applying to the competent authority. The competent authority shall also decide on discontinuation of the measurement programme.”

Netherlands (NRG)

There are presently no Dutch regulatory requirements and provisions that directly relate to the topic of “data selection”. Indirectly however several laws regulate the protection of the public against hazardous materials. For example, with regard to nuclear energy, the purpose of the Nuclear Energy Act [14] is to regulate (Article 15b) the protection of people, animals , plants and properties. In addition a number of decrees have been issued containing additional regulations.

United Kingdom (NDA)

Relevant agencies have published guidance, known as the GRA [9], which outlines how an application for land based disposal of solid radioactive waste would be judged. A revised version of the GRA was published in February 2009 [10].

In terms of specific recommendations on data, the GRA requires assurance of the adequacy of a developer's proposals for collecting information and data to support a decision to start underground operations and to support a decision to move to each stage of development.

The GRA outlines requirements for the developer to have procedures for documentation and record keeping, quality management of data, and to be alert to possible future changes to standards and to basic data. In circumstances where there is uncertainty due to lack of relevant data it recommends the use of expert judgement and states that where "*few or no relevant data can be gathered, a 'stylised ' approach may be adopted, in which arbitrary assumptions are made that are plausible and internally consistent but tend to err on the side of conservatism*".

From the previous regulations and guidelines some important topics can be identified:

- The implementer is responsible for carrying out all the necessary investigations of the site or sites and of materials and for assessing their suitability, and for providing data for safety assessments.
- Regulations may consider the "waste" as an input and, as a consequence, contain instructions relative to the type of waste to take into account in design and associated safety approach to consider (Andra).
- Regulations usually do not contain detailed instructions on how to select the data to be used in the Safety Case. Only in UK there exists a recommendation of using expert judgement in circumstances where there is uncertainty due to lack of relevant data.
- The data available for the Safety Case is expected to improve along the development of a repository. In early stages generic data can be used in the Safety Case while in later stages more site specific data will be available (all).
- The degree of detail and completeness of the data used in a Safety Case must be consistent with the purpose of the Safety Case.
- Models and the data used should try to be realistic (GRS-K), and should not lead to a gross underestimation of the performance of a barrier (POSIVA).
- One regulator (FANC-Bel V) requests the use of "best estimate" values of the parameters in the analysis of the performance of the barriers and "conservative" values in the analysis of the radiological consequences.
- Model development and the generation of data to be used in the models are closely related topics. The quality of the data used in the models must be justified (Andra, IRSN, POSIVA).
- Data generation and selection must be done following established quality assurance procedures (GRS-K, NDA) and the process of model and data generation must be properly documented. Transparency and traceability of the whole process of data selection are key requirements.

3 Terminology

Most participants have adopted the terminology used in the IAEA glossary [8] and other international references. In general, the introduction of "new" terminology is avoided (NDA).

In the methodology under development in Belgium for the next Safety Case, the assessment basis group expresses parameter data under the form of a source range and an expert range defined as:

- Source range of a parameter is the range of values outside of which the parameter value is unlikely to lie, considering the current knowledge.
- Expert range of a parameter is the range of values within which experts expect the parameter value to lie; the expert range is thus a subset of the source range.

Andra introduced some specific terminology in its Dossier 2005 for data selection: phenomenological, conservative or pessimistic values of parameters.

4 Methodology

The analysis of the contributions received shows a common view on the generation and selection of data necessary to develop and demonstrate the safety of a deep geological repository. In section 4.1 the main ideas on the general methodology on data selection are presented. Sections 4.2 to 4.10 further develop some particular topics.

4.1 General methodology

Since the radiological consequences of the repository are expected to occur after several thousands of years, and continue far into the future, an assessment of those consequences can only be made on the basis of simulations of the evolution of the disposal system and of the resulting transport of radionuclides through the repository system.

The calculations undertaken with these models, plus natural analogues and any other arguments available will be used to justify that a repository is safe, when presenting the Safety Case. As a consequence, **adequate models and the data required by those models are critical to demonstrate the safety of a repository.**

Laboratory and in-situ experiments generate data for short duration experiments under a given set of conditions (temperature, pressure, water composition,…). The applicability of the data generated in the far future under different conditions (that evolve with time) is a critical topic that needs to be addressed explicitly when selecting input data for the models (ENRESA).

In order to select input data for the long term modelling it is necessary to have a good scientific understanding of the basic processes expected to take place in the repository and their potential effects on the barriers and the relevant parameters.

Model and input data must be developed on the basis of the best available scientific and technical knowledge (POSIVA, GRS-K and Andra). The whole process of model and data generation must be undertaken following quality assurance procedures, and must be properly documented.

Safety Cases are prepared at selected decision points in the repository development programme (depending on the regulatory requirements). The degree of detail of the models and the quality of the data used must be consistent with the objective of the Safety Case.

The models and data will evolve along the repository development, but it is important to follow a frozen modelling strategy and use frozen models and data in each iteration of the Safety Case, to ensure transparency and traceability. In each iteration the possible model improvements and data needs for the next step should be clearly identified and documented (Bel V).

Independent reviews of the data selected for the Safety Case are important to ensure the proper quality of the data. The need for independent review of the data increases with the successive stages of repository development: while early iterations of the Safety Cases can be done without external review, later iterations for site selection or repository construction applications should include independent reviews of the data selected.

In France (Andra), a peculiar attention was paid in the Dossier 2005 Argile [14] to the basic input data which includes two main aspects: the radiological inventory model and site characterisation. They were presented in specific documents. Andra considers that any repository development project must start with an analysis of the technical input data on which it is based. The number and variety of these data increase with each iteration of the repository's definition process. The input data and the fruit of the analyses conducted under the Dossier 2005 are structured into a documentary architecture organised according to the safety approach (see section 4.10).

4.2 Site characterisation

Site characterisation and the development of a good understanding of the main properties of the host formation is one of the most challenging tasks in the development of a safety repository. Due to the great amount of raw data that will be produced and the numerous organisations that will be involved, site characterisation requires a specific data management strategy to ensure that the whole process is done following the highest standards.

4.2.1 Initial stages

In the initial phases of a repository program, when no site has been selected or site specific data are scarce, Safety Assessments can be done on the basis of generic geosphere data (GRS-B, ENRESA, NRG, NRI and NDA). These preliminary safety assessments can provide useful guidance for the site characterisation.

In repository projects it was aspired to firstly achieve a largely comprehensive data set to have the basis available for a site specific safety assessment. The recent development appears to tend towards a partly interchange in the sequence of data collection and safety assessment. Instead to firstly trying to collect a data set which should be as comprehensive as possible, a safety assessment is already required in an early project phase regardless of the current grade of completeness of the collected geological data set. Those data, which are needed to be fed into the safety assessment but which are still to be determined, have to be soundly estimated for the safety assessment and reasonably varied. The benefit from the early safety assessment before exploration is completed, is to be aware of the significance of the different geological data for the safety and furthermore the knowledge, with which degree of exactness the geological data have to be explored (GRS-K).

As the site and design for a geological disposal facility in the UK have not yet been chosen, the NDA is currently developing a "generic" safety case to support the different stages in the implementation of a geological disposal facility. As the assessing of specific sites starts, NDA will be able to refine the approach to include site-specific parameters.

ENRESA safety assessment exercises have been done for synthetic sites, created on the basis of the limited data available for Spanish favourable areas. As a consequence, the detailed data that will be generated during the site characterisation phase were not available, and only generic, but plausible, sites have been analysed. Similarly, NRG has performed several Safety Assessments using generic data representative of the conditions met in the underground and biosphere in the Netherlands.

4.2.2 Detailed site characterisation

Site characterisation will generate a great amount of raw data that must be processed, interpreted and integrated in order to develop a good understanding of the site. The ideas presented in this section on how to carry on the site characterisation process have been provided mainly by NDA but are representative for other countries.

For NDA the process of site characterisation is comprised of five inter-related stages:

- Data acquisition – to obtain measurements and to collect data utilising a range of measurement techniques and surveys;
- Data processing – to transform measurement data into information that is meaningful in terms of the properties of the site;
- Interpretation – to understand the significance of that information in terms of the individual aspects of the site (e.g. groundwater flow, geology, environmental processes, etc);
- Integration – to develop a self consistent understanding of the site as a whole which includes all the individual aspects;
- Communication – to communicate the understanding obtained to others (e.g. those involved in performance assessment, engineering design and key stakeholders) and to obtain feedback that could influence the ongoing process of site characterisation.

For GRS-B/DBE-Tec/BGR the process of site characterisation consists of five steps: data review, data acquisition, interpretation, data matching and the prediction for future variability.

For Andra one of the first steps is to define the expected functions of the geological medium: "The geological medium and the repository architectures must, in the very long term, ensure the confinement of the long-lived radionuclides which could be released into the biosphere, in order to protect man and the environment. This geological medium is therefore the key part of the disposal system". In coherence with the regulations, and the assigned safety functions, the research work on clay aims at designing a deep repository, and ensuring the good performance of the host formation. Acquiring knowledge of the host formation and surrounding formations was organised by pursuing several complementary strategies including the work carried out in the underground laboratories located in the selected site (Meuse/Haute-Marne Laboratory) or in other clay formation (Mont Terri Laboratory in

Switzerland).

The overall site characterisation will be carried out in a series of stages. At discrete, pre-determined stages during the investigations there are 'data freezes' at which stage the interpretation activities commence followed by engineering design and safety assessment studies. However, during this time further investigations are progressing. At the next data freeze further information is fed into the interpretation, design and safety assessment teams such that they can maintain a rolling programme of work. Monitoring the progressive development of the engineering design and safety assessment through the stages following each of the data freezes may provide a means of evaluating progress towards completion of the surface-based investigations.

The process of site characterisation is usually undertaken by the development and progressive updating of a series of discipline based 'Site Descriptive Models'. The descriptive models are a convenient means for interpreting and presenting the results of investigations at a site. The various descriptive models do not exist in isolation and there is transfer of information between models. The descriptive models are also used as input to the performance assessment models and engineering designs for the facility at the site. The descriptive models that may be developed for a site are likely to include the following: geology, hydrogeology, hydrochemistry, geotechnical, transport properties, thermal properties and biosphere

The geology model provides the framework on which all the other models are built because it gives a basic understanding of the nature and distribution of the various rocks and soils that are present at the site.

Descriptive models may change significantly as new information on and understanding of site characteristics is obtained. However, as understanding develops during the later stages of the investigations, it is anticipated that the descriptive models will become stable and not change significantly as further information is obtained. Hence, the stability of site descriptive models is also a potential criterion for defining completion of the surface-based investigations.

4.3 Waste characterisation

Some organisations (Andra and NDA) foresee that many different wastes will be disposed of in the repository, and for them waste characterisation (determination of radionuclide inventory and waste properties) is a complex topic that requires an effort similar to site characterisation. Handling the great amount of data generated in the waste characterisation requires a specific strategy. The rest of participants consider only spent fuel or HLW in their assessments, and waste characterisation is simpler.

In France (Andra) the waste is described in terms of typology, radiological contents and physico-chemical characteristics in a specific document associated with the Dossier 2005 Argile [11]. As input to the repository feasibility study, this inventory model allows for both *the waste already produced*, that is stored in conditioned and unconditioned form on the production sites and *the waste that will be produced in the future by the current nuclear power plants.* This dimensioning inventory model provides an envelope of volume and nature of the waste likely to be considered, in order to assess its geological disposal feasibility with dimensioning margins.

In coherence with the guidance, deep geological disposal concerns two categories of waste: the high-level waste (or vitrified waste) and the intermediate-level, long-lived waste.

The characteristics of the waste considered for the storage are a function of scenarios of envisaged reprocessing and conditioning. Four scenarios were defined in collaboration with the producers, in order to examine how repository architecture could adapt to the various management processes for the electro-nuclear fuel cycle (but they did not predict an industrial blueprint). In the Dossier 2005 the evaluation was based on two envelope scenarios.

4.4 Sources used for data generation

The main sources used by the contributors to generate input data for the Safety Case are laboratory experiments, in-situ experiments, natural analogues, modelling and calculation, expert elicitation and bibliography.

Laboratory experiments allow studying the processes taking place in the repository under well controlled conditions, to understand the basic processes taking place in the repository and measure parameter values.

In situ experiments allow obtaining data under more realistic conditions and at a larger spatial scale compared with laboratory experiments, although at a higher economic cost. Even in-situ experiment will be limited compared with the real dimensions of the repository and the formation and timeframe of the evolution of the disposal system.

In theory, natural analogues can be used both to validate models and generate data valid in the very long term. However, in many cases the uncertainties in initial and boundary conditions are too high and, consequently, will hinder the use of natural analogues for data generation. Natural analogues are expected to be especially useful as supporting arguments for the Safety Case, while its usefulness for data generation would be mainly through comparison with the data generated by other means (laboratory or in situ experiments) to increase the confidence on the data selected.

A great number of process level models (that can be quite complex) are developed and used by R&D groups in order to reach a good scientific understanding of (and identify the basic processes that control) a limited part of the disposal system evolution. These models usually are not included explicitly in the Safety Case, but their results are used to build the models used in the Safety Case, generate data for them or support the data selected by other means. An example is the Thermodynamic Sorption Models (TSM) developed to understand sorption processes on solids (bentonite, clay or granite). These TSMs are not included explicitly in the Safety Case but are used to justify the simplified models (use of distribution coefficients Kd to represent sorption) and the parameter values (Kd values) used in the Safety Case. The justification of the validity of the data generated using these process models relies on the validation of the process level models and codes used. Another example is the Thermodynamic Data Base (TDB) developed to understand the radionuclide behaviour in solutions (Andra).

Expert elicitation can be used to assess the uncertainties about events and variables when the source of uncertainty is lack of knowledge (epistemic uncertainty). Expert elicitation is a complex and time consuming process and most contributors do little or no use of it. Only

NDA strongly relies on expert elicitation for generating data for the Safety Case.

Bibliographic data can be used extensively as long as its applicability to a particular disposal concept and site can be justified.

4.5 The role of the sensitivity analysis in the selection of input data

There is an agreement that the sensitivity analyses from previous Safety Assessments are a useful tool to identify the parameters with high/low relevance for the model and prioritize the efforts of the input data selection process. The effort devoted to the determination of the value or range of values of a given parameter should be proportional to its influence on the results of the model where it is used. Nevertheless, if the models and/or parameters of the new iteration of the Safety Assessment differ form the previous ones (as probably will be the case), the conclusions from previous sensitivity analyses could be not totally applicable (and should be reviewed to include a reduction of uncertainty, for instance).

In the first iteration of the Safety Case no previous sensitivity analysis is available, and a review of the assessments done by other organisations can be used instead.

POSIVA intends to include in the “Models and Data Report” (section 4.10) information on the impact of the parameter on assessment results, including any sensitivity analysis or bounding calculations that may have been performed to evaluate how the system evolution and ultimately the radiological consequences are affected by the data at hand.

Sensitivity analysis is an important tool of the Safety Assessment and is one of the 11 topics in which the Safety Case has been structured in PAMINA WP1.1.

4.6 Expert elicitation

Expert elicitation has been used during roughly the last seventy years in different areas of science, technology, weather forecasting, strategic planning, economy and many other fields as a reasonable way to assess uncertainties about events and variables when the source of uncertainty is lack of knowledge (epistemic uncertainty)

During the development of a Safety Case in general, and in the selection of data values for the assessment in particular, a great amount of expert judgement is involved. The safety assessment experts and the supporting specialists must take many decisions during the selection of parameter values, and these decisions must be justified and documented.

In the Czech case (NRI) the main tool of obtaining data was informal expert judgement from subject experts. Generalists from the coordination group identified the issues and tasks related with safety analysis of a repository.

Most implementers do little or no use of expert elicitation to generate the data used in the safety assessment models. Only NDA uses expert elicitation to generate the probability distribution functions for all the uncertain parameters. POSIVA uses expert elicitation only for very uncertain parameters, such as the element solubility.

ENRESA has not used expert elicitation in their in-house Safety Assessment but has been involved, together with JRC and Amphos21 in an expert elicitation exercise developed within PAMINA Task 2.2.A. In this exercise the probability distributions for the solubility of 5 key chemical elements in a generic Spanish repository concept in granite.

Expert elicitation is seen by most organisations (with the exception of NDA) as the last resort to generate input for the safety case, to be used only when more conventional ways to accomplish the task are not applicable.

4.7 Definition of probability distribution functions for stochastic calculations.

One of the advantages of probabilistic calculations is that the parameters uncertainty is explicitly taken into account in the calculations and the uncertainty in the input parameters is propagated to the output result (usually the dose). But assigning probability distribution functions to the parameters used in the calculations is not straightforward.

On the basis of the experience gained in previous iterations of the Safety Case it is possible to identify that only a few parameters control the repository behaviour. The uncertainties affecting these relevant parameters must be identified during the process of data selection. These uncertainties will be the basis to define the probability distribution functions to be used in the stochastic calculations. For other less important parameters broad probability distributions can be appropriate.

The methodology used by SCK·CEN/ONDRAF·NIRAS in SAFIR 2 [6] is representative of the pragmatic approach usually followed by the implementers to derive the pdf´s for uncertain parameters:

- On the basis of the available data sets the experts estimate a minimum and a maximum value for the parameter of interest.
- When the range of possible values was larger than a factor 5 a logarithmic distribution is adopted. If the range is smaller than a factor 5, a linear distribution is used.
- If it was considered necessary to give a higher statistical weight to a particular region of values (around the best estimate value, for instance), a (log)triangular distribution is selected. When this is not considered necessary, i.e. the real value is expected to be somewhere between the minimum and maximum, a (log)uniform distribution was selected.

ENRESA has followed a similar approach in the definition of the pdf´s for stochastic parameters: if the range of potential values covered one order of magnitude or more, logarithmic distributions while linear distributions were used when the uncertainty was smaller than a factor 10. Solubility limits are examples of the first class of parameters and the instant release fractions of the inventory are examples of the second.

For probabilistic calculations usually triangular distributions, i.e. minimum, best estimate and maximum are used by NRI.

4.8 Selection of parameter values for deterministic calculations

For deterministic calculations typically two different classes of parameter values are selected:

“best estimate” and “conservative” values.

During the generation of input data in SAFIR-2 project (ONDRAF·NIRAS/ SCK·CEN) experts were requested to provide “best estimate” values of the parameters. It was found that the “best estimate” values selected by the experts and the safety assessors tended to lie systematically on the conservative side and were not always representative of the best estimation of the parameter. This resulted in a loss of information regarding the “true” value expected for a particular process.

The Belgian regulator (FANC-Bel V) requests the use of “best estimate” values of the parameters in the analysis of the performance of the barriers and “conservative” values in the analysis of the radiological consequences.

Andra (France) uses a classification of data values based on the degree of knowledge acquired on phenomenon or data: “best estimate”, “conservative”, “pessimistic or penalising” and “alternative” values.

- A “pessimistic or penalising” value designates a value that is not based on phenomenological understanding, however empirical, but that definitely overestimates the repository impact. These values can be used in scoping calculations with the purpose of bounding potential effects.
- An “alternative” value stands for a value that can not be classified according to the three previous items. This category covers values that appear to be more realistic that the selected best estimate but have been less thoroughly validated.

In France (IRSN) best estimate values are used in low likelihood scenarios (altered evolution scenarios due to low likelihood events) while conservative values are used for normal evolution scenarios.

In Czech Republic conservative, best estimate values or ranges of values are used in the deterministic calculations (NRI).

Andra, ONDRAF·NIRAS/ SCK·CEN and ENRESA consider useful to generate both “best estimate” and “conservative” values of the parameters to be used in different sets of calculations. This would reduce the tendency of the experts to be conservative when selecting “best estimate” values. The comparison of the results of the two sets of calculations (best estimate and conservative) provides an indication of the margin of improvement of the calculated performance of the repository if the uncertainties leading to the conservative values are reduced.

In the Netherlands, a principal criterion for the selection of model data that has been applied in the VEOS, PROSA and CORA studies was that the data must be generic, but representative of the conditions that are met in the underground and the biosphere of the Netherlands.

In Germany the draft of a new regulation (GRS-K) specifies that deterministic calculations should be based on as realistic as possible modelling (e.g. by use of median values as input parameters).

In general, most organisations perform the deterministic calculations using “best estimate” values for the parameters.

4.9 Quality Assurance

There is an agreement in the need for a comprehensive Quality Assurance system to cover all the activities concerning de development of a deep geological repository, including data gathering. The quality assurance system and quality assurance programmes must be documented before the start of relevant activities. All organizations participating in the development of deep geological repository must have established a quality assurance system (NRI).

The QA programme to ensure data quality should put special emphasis on transparency, traceability, external review and proper documentation.

A quality plan must be prepared to cover all activities related to the site characterisation programme. The intended use of the data will be documented as part of the planning; other uses of the data will be evaluated and justified. The quality plan will assure the compatibility of data derived from scientific investigations with any conceptual or mathematical models. The quality plan will also establish provisions for the evaluation of data quality to assure that the data generated are, as far as possible, complete, representative and accurate. Uncertainties in data and their analyses will be identified and documented. A data management system will be planned in advance of characterisation activities to ensure the highest standards of data access and storage. Peer reviews of methods and documentation will be employed to provide additional confidence in the data gathering and storage process (all).

The NDA has been working in collaboration with the British Geological Survey to develop a high-level data management strategy. It will be essential that the systems are in place, tested and are fully operational before acquisition of investigation data commences. Such a system would ensure that the data are:

- Coherent and consistent through the application of scientific standards;
- Captured and processed using industry standard data capture systems;
- Provided with a clear audit trail to data sources;
- Managed in an environment that permits full version control and maintenance of archives;
- Accessible as and when required;
- Maintained in a secure and controlled environment.

4.10 Documentation

In SAFIR-2, SCK·CEN/ONDRAF-NIRAS used two types of forms in order to ensure In order to ensure the traceability of the data collection process. The first form is the **data collection form**, which gives a one-page overview of the selected values for the input parameters (both best estimate value and pdf), the main references and the names of the experts (at least one) from the assessment basis group and of the safety assessor involved with the data collection. The second form is called the **annex** which can give much more detailed information on the data that were available, a (short) discussion on their relevance, the reasoning applied to derive a best estimate value, and the distribution and its parameters.

The data collection forms as well as the annexes have been collected in a report [7].

In recent Safety Assessment a significant effort has been spent in the documentation of the models and data used. For instance, in Finland POSIVA foresees that in the next step, a major implementation is the collection of Models and Data used in the Safety Case to be published as a report in its own right. The *Models and Data Report* will act as an interface between the safety case activities and the principal supporting activities. The information included in the *Models and Data Report* is selected on the basis of its safety relevance: the EBS and site data that directly provide the input to the safety case are discussed in these reports, while more details can be found in the supporting background reports, such as the Site Descriptive Model report and various technical descriptions of the engineered barrier system. The quality of the Site Descriptive Model report is mainly ensured by the application of scientific principles, while the methods of quality control for the technical barrier design and implementation depend on the nature of the materials and technology in question. The *Models and Data Report* captures the most significant information related to safety, the quality of which is of primary importance for confidence in long-term safety.

The most recent Safety Cases include separate documents to present the models and the data used in the assessments. In Sweden SKB described the models and data used in SR-CAN project in two separate documents, one dealing with data [12] and other with models [13]. In Switzerland NAGRA summarised the data and the models used in Project Opalinus Clay in a single report [4]. A similar approach was followed by Andra in Dossier 2005 and SCK·CEN/ONDRAF-NIRAS in SAFIR 2 [7].

In France (Andra), the input data and the fruits of the analyses conducted under the Dossier 2005 are structured into a documentary architecture organised according to the safety approach. The peculiarity of the Dossier 2005 is that it is based on the observations and the results from experiments carried out on a real site, namely, on the Meuse / Haute-Marne laboratory site. Input data is structured in five different documents, with the following contents:

- The input data on the packages are described in the design inventory document which presents the main characteristics of the packages.
- The state of knowledge on the Meuse / Haute-Marne laboratory site is presented in the site reference document which includes detailed results on experimental work.
- The knowledge regarding the behaviour of the different materials in the repository and the transport of radionuclides and chemical toxics is presented in three reference documents: one for the "materials" in the repository, one for the "behaviour of the packages" and one dealing with the "behaviour of the radionuclides and the chemical toxics".

5 Application and experience

The implementers included in Table 1.1 have been developing and using models for the safety assessment of geological repositories for many years. Regulators are familiar with the safety assessment methodologies also.

The individual contributions detail the particular experiences of the contributors and can be found in the Appendices.

To process such amount of data and models, implementers have developed simulation platforms that enable to manage very large amount of data and execute complex calculation. The ALLIANCE platform developed by Andra and CEA is an example.

6 Developments

The developments foreseen by the different organisations are strongly affected by the stage of the national waste disposal programme. Ongoing and future developments are presented in this section.

Implementers

Within PAMINA Task 2.2.A, a systematic procedure to generate probability distributions for uncertain parameters has been developed [5]. The guidelines presented in that document are in agreement and support the methodologies already used by some implementers and that are described in section 4.7.

In PAMINA Task 2.2.A an expert elicitation exercise has been undertaken by ENRESA, JRC and Amphos21. In this exercise a generic protocol for the expert elicitation has been developed by JRC, and has been applied to the definition of probability distributions for the solubility limits of five relevant chemical elements in the near field of a repository in granite,

All the implementers that are preparing a new iteration of the Safety Case are developing more advanced models and improving data quality. An example could be NDA current and future activities related to data needs for site description and safety case models:

- Update the national radioactive waste inventory to reflect the evolutions or changes in waste management strategies, decommissioning programmes, commercial, technological or regulatory reasons, and current information;
- Complete the study to develop a strategy for the development of a data management system to store and manage the information arising from a site characterisation programme;
- Continue with the studies to develop an improved definition of discipline-based information requirements for a site characterisation project with peer review by a group of specialists;
- Continue to identify gaps in information in the models that would need to be addressed by site investigations;
- Further develop the procedures for addressing uncertainty in data;
- Develop a strategy for communication of information on the site geosphere characterisation to all interested stakeholders. This entails: organisation of data and information in a form that it is readily available to potential audiences ranging from a lay audience to technical specialists; the use of appropriate reports, brochures, and

web sites together with a 'helpline' for requests for information;

- Maintain the research and development programme on waste form research, gas generation, near-field research, geosphere research, biosphere research and criticality safety research.

For the next Safety Case SCK•CEN/ONDRAF-NIRAS intend to express parameter values as a range rather than as a best-estimate. Experts will be requested to provide two ranges of values for a specific parameter, the so-called "source range" and "expert range".

- The source range of a parameter takes account of the uncertainties due to the simplifications inherent to the conceptual modelling but also of those stemming from hypotheses of the conceptual model which are less well supported and remain to be confirmed. This range rests on little expert judgment since all possible values of the parameter induced by the poorly-supported hypotheses of the conceptual model are covered.
- The expert range is meant to be a more realistic range of parameter values than the source range and is arrived at by making expert assumptions regarding the poorly-supported hypotheses. Therefore the expert range implies much more expert judgment than the source range. The expert range is a subset of the source range: it is equivalent to the source range less the impact of the uncertainties on parameter value. Whereas the source range is defined by a minimum and maximum value representative of the conservative and optimistic case, the best estimate of the expert range represent the value expected by the expert for a particular parameter.

Using the two-range approach, the safety assessor will select the minima, maxima or best estimates to represent a conservative or realistic calculation case.

For the next Safety Case SCK•CEN/ONDRAF-NIRAS intends to discuss the uncertainties in parameter data according to three categories of uncertainties (arising from the specificities of the Belgian RD&D programme):

- Upscaling - the degree to which observations and measurements made over relatively short intervals of space and time may be assumed to apply over the larger spatial and temporal scales of interest in safety assessment.
- Transferability - the degree to which observations and measurements made at one location in the host formation (e.g. in the Mol-Dessel area) may be assumed to apply at another location (the actual repository site, which may be elsewhere in the potential siting area).
- Evolving conditions - the impact of phenomena, such as climate change and geological events, that may affect the disposal system occurring over time in a given scenario and assessment case.

Finally, SCK•CEN/ONDRAF-NIRAS is currently implementing a database system equipped with a versioning and reviewing system in order to guarantee the traceability of the selection of the parameter ranges from evaluations, based on experimental, process modelling or literature studies, performed by the assessment basis group up to their use in the safety calculations.

In France, Andra is working in order to present a Demand of Authorization of Creation of the storage at the end of 2014. Andra will optimize the concept and will complete the knowledge to answer to the regulators, reduce the margins of uncertainties and so increase the degree of confidence in the safety in operational and after closure phases. In practice, the studies will aim in:

- completing the knowledge on waste packages, the site and the phenomenology of the evolution of the disposal system to reduce the residual uncertainties,
- prolonging the acquisition of experimental data in the underground laboratory,
- performing new technological essays at real scale,
- performing detailed geological survey and Callovo-Oxfordian characterisation on a restricted zone with the aim of the setting-up of the future surface and underground facilities, toward license application,
- understanding more finely the phenomena governing the evolution of the storage and their coupling,
- reducing the residual risks during the operational phase without degrading the long-term performance of the repository.

Such refinements imply the development of simulations tools, databases and their management.

Regulators

Some countries (Finland, France and United Kingdom) already have detailed regulations that provide broad guidance and requirements on how the implementer should generate the data to be used in a Safety Case. Other countries (such as Belgium and Germany) are in the process of developing their own detailed regulations that will include guidance and requirements on modelling and data selection (both topics are closely related). There is a general trend of moving from generic regulations (focused on a dose/risk limit for the disposal facility) to more detailed regulations that establish requirements and provide guidance on the different aspects of repository development, when a national disposal programme moves from the phase of conceptual studies to more advanced phases of site selection and detailed design of the facilities.

Implementers are responsible for carrying out all the necessary investigations of the site or sites and of materials and for assessing their suitability, and for providing data for safety assessments. Regulations provide guidance and requirements applicable to the data generation and selection processes, and will remain at that degree of detail. Regulations set state-of-the-art standards for input and data selection to demonstrate safety, but leave the details of how to provide evidence to the implementer (and their appraisal up to the regulatory body).

Open discussion between implementers and regulators is very useful from the initial stages of the development of a repository. For the implementers it is particularly useful to have guidance on regulators expectations.

The following topics related to data selection are expected to draw particular attention of the regulators in the future:

- Quality assurance procedures implemented for developing the models and generating the data to be used in the Safety Assessment. Proper documentation and traceability of the process of data generation.

- Inclusion of uncertainties in the data generation process.

7 Conclusions

During the workshop fruitful discussions on modelling strategies were held. The conclusions of these discussions are summarised in this section.

Site characterisation

At early stages of the development of a repository, Safety Assessments can be done using generic geosphere data. The results obtained can provide useful guidance for site characterisation, identifying the properties of the geosphere that have greater effect on repository behaviour.

At later stages site characterisation is a long and complex process that will generate a great amount of data during a long time period. Several complementary strategies are used to generate data, including boreholes and experiments in an underground research laboratory. Handling these data requires a particular strategy. Before the start of site characterisation a QA programme must be available, covering all the organisations involved.

Site characterisation can be organised through the development and progressive updating of a series of interrelated Site Descriptive Models (Geology, Hydrogeology, Geotechnical, Transport properties, Thermal properties and Biosphere, for instance). The geology model is the framework on which all the other models are built, and the data generated during the site characterisation will be organised around these models.

Initially Site Descriptive Models may change significantly when new site information is available, but at later stages models will become stable as further information is included. This stability of the models can be used as a potential criterion for deciding completion or continuation of the investigations.

Waste characterisation

For the organisations that foresee the many different wastes will be disposed of in the repository, waste characterisation (determination of radionuclide inventory and waste properties) is a complex topic that requires a significant effort. For those organisations, the radionuclide inventory to be disposed is considered as basic input data to be considered for repository design.

For the participants that consider only spent fuel or HLW in their assessments, waste characterisation is simpler.

The role of sensitivity analysis

Sensitivity analyses from previous Safety Assessments are useful to identify the parameters that control repository behaviour. This allows paying special attention to the most relevant parameters during the data selection process, and focusing R&D efforts in reducing the uncertainty on these parameters.

POSIVA intends to include in the document presenting the data used in the Safety Case information about the relevance of each parameter, on the basis of the results of the sensitivity analyses.

Definition of parameter values for deterministic calculations

Most organisations consider that probabilistic and deterministic calculations are complementary and include both types of calculations in the Safety Case. As a consequence, there is a need to generate values and probability distributions for the different parameters included in the calculation models.

For deterministic calculations two different classes of parameter values are usually selected: “best estimate” and “conservative”. In general, the use of “best estimate” parameter values in the deterministic calculations is favoured, although in some cases “conservative” values are preferred for the consequence analysis.

Some organisations consider useful to generate both “best estimate” and “conservative” values of the parameters to be used in different sets of calculations. This would reduce the tendency of the experts to be conservative when selecting “best estimate” values (a problem identified by SCK·CEN/ONDRAF·NIRAS). The comparison of the results of the two sets of calculations (best estimate and conservative) provides an indication of the margin of improvement of the calculated performance of the repository if the uncertainties leading to the conservative values are reduced.

Definition of probability distribution functions for stochastic calculations

The uncertainties in the parameters must be identified explicitly during the process of data selection. These uncertainties will be the basis to define the probability distribution functions to be used in the stochastic calculations.

The criteria followed by the different organisations to produce the probability distributions are quite similar.

- First a reasonable range of values is identified.
- If there is more than a factor 5 or 10 of difference between the high and the low values in the range, a logarithmic distribution is used. Otherwise, a linear distribution is adopted.
- If it is considered convenient to give more statistical weight to a particular region of values (around the „best estimate“, for instance) a triangular distribution with the most probable value in that region is used. Otherwise, an uniform distribution is adopted.

The previous criteria are in good agreement with the results obtained within PAMINA Task 2.2.A [5].

Expert elicitation

During the development of a Safety Case in general, and in the selection of data values for the assessment in particular, a great amount of expert judgement is involved. Safety assessment experts and the specialists must take many decisions during the selection of parameter values.

Most implementers do not use formal expert elicitation to generate the data used in the Safety Case. Only NDA uses this technique to generate the probability distributions for all the uncertain parameters, and POSIVA uses expert elicitation only for very uncertain parameters.

Quality Assurance

All the participants agree on the importance of a comprehensive QA programme that must cover, among other topics, the generation of data within the project (experiments, site characterisation,…) and the selection of data to be used in the Safety Case. The objective must be to ensure the high quality of the data generated and fulfil the following key requirements:

- Justification and traceability of the whole process of data generation and selection.
- Review by independent experts of the process followed and the values obtained.
- Proper documentation of the process.
- Data consistency.

Many documents will be produced in the process of data generation. One of the "top level" documents of the Safety Case should be a document summarising the parameter values selected for the different models, and the basis for their selection. This document should provide enough information to allow understanding the basis for the data selection done, and contain references to reports where more detailed information is available.

In some countries two different documents are generated, one describing the models developed and other describing the data selected. Since models and data are closely related, other countries prefer to present models and data in the same document.

8 References

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9 Appendices

A1 Andra (France)

A2 ENRESA (Spain)

A3 FANC-BelV (Belgium)

A4 GRS-Braunschweig / DBE-Tec / BGR (Germany)

A5 GRS-K (Germany)

A6 NDA (United Kingdom)

A7 NRG (The Netherlands)

A8 NRI, RAWRA (Czech Republic)

A9 POSIVA (Finland)

A10 SCK·CEN, ONDRAF·NIRAS (Belgium)

A1: ANDRA (France)

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CONTENTS

1. Introduction

The contribution from Andra to WP1.1 PAMINA project aims at giving an overview of methodologies that have been used by Andra in the framework of the Dossier 2005 Argile [vii].

The present document is devoted to topic 11 “Criteria for Input and Data Selection”. It completes the set of documents provided within the WP1.1 PAMINA framework (Safety functions, Definition and assessment of scenarios, Uncertainties management, Safety and performance indicators, Safety strategy, Analysis of the repository evolution, Sensitivity analysis, Modelling approach, Biosphere, and Human Intrusion). Its structure follows the DWG common structure, but it was adjusted according to the recommendations issued during the meeting held in Madrid on April 28th and 29th.

2. Context

The December 30, 1991 French Waste Act entrusted Andra, the French national agency for radioactive waste management, with the task of assessing the feasibility of deep geological disposal. The Basic Safety Rule RFS.III.2.f of June 1991 [i], issued by the French nuclear safety authority, provides a framework for the studies to be conducted. The protection of man and the environment are to be demonstrated. Furthermore, studies should show the ability to limit potential consequences to a level as low as reasonably possible. The concept should include a multiple barrier system, and rely on passive repository evolution without institutional control beyond a given timeframe (500 years). The studies carried out within this framework are presented in the “Dossier 2005 Argile” (clay) [ii] and “Dossier 2005 Granite” [iii]. Although the process thus summarized may suggest a linear progression from basic input data to designing a “solution” and assessing its safety, the process is in fact highly iterative, with repeated feedback exchanged between the various processes. In addition to the routine feedback common to parallel engineering, three main iteration loops have been identified since 1991, each corresponding to a major milestone of the program: License application for construction and operation of the underground research laboratory (in 1996), submission of the Dossier 2001 (in December 2001), and the recent submission of the Dossier 2005.

3. Place of «input and data selection» and primary documentation

The objective is to present the Andra’s overall strategy that has been developed for this topic “criteria for Input and Data Selection” in the framework of the *Dossier 2005 Argile.* This case consisted in a number of primary references which include the French Act and the series of reports submitted accordingly:

- The French Waste Act dated 30th December 1991 [iv]
- The French Safety rules namely RFS.III.2.f, guidelines [i].

- Synthesis Report, Evaluation of the Feasibility of a Geological Repository, Meuse/Haute-Marne Site (in English and French) [ii].
- Architecture and Management of a Geological Disposal System Report (TAG; C.RP.ADP.04.0001) (in English and French) [v].
- Phenomenological Evolution of the Geological Repository Report (TEP; C.RP.ADS.04.0025), (in English and French) [vi].
- Assessment of Geological Repository Safety Report (TES; C.RP.ADSQ.04.0022) (in English and French) [vii]

The feasibility assessment for the argillaceous site builds upon a number of key elements:

- Basic input: the inventory model of the waste and the geological site,
- Safety functions and requirement management, the functional analysis (FA) to determine the safety functions and associated requirements – what do we want? - [viii]
- Technical solutions based on industrial experience,
- Reversible management and monitoring,
- Phenomenological Analysis of Repository Situations (PARS) [ix] and detailed, coupled process modelling, [vi] providing a good scientific understanding based on scientific studies from surface and underground laboratory – what do we get?
- Qualitative Safety Assessment (QSA), [x] uncertainty management, and scenarios, the qualitative safety analysis (QSA) [x] managing uncertainties and the quantitative assessment [safety and performance indicators] including sensitivity analysis –. What is the impact of a given uncertainty (or set of uncertainty factors) on the robustness of the system? – And eventually: does the concept meet the safety/acceptability criteria?
- ALLIANCES simulation platform and calculation results.

Other references such as the presentation made at the symposium hold in Paris in January 2007 [xi], and the INTESC questionnaire [xii] have been used when applicable.

From this list, it can be seen that the repository development project started with an analysis of the technical input data on which it is based. The number and variety of these data increased with each iteration of the repository's definition process. At the step of the Dossier 2005, the input data and the fruit of the analyses conducted are structured into a documentary architecture organised according to the safety approach as described above:

- The input data on the packages are described in the design inventory model which presents the main characteristics of the packages [xiii].
- The input data on the geological site: The peculiarity of the «Dossier 2005 Argile» is that it is based on the observations and the results from experiments carried out on a real site, namely, on the Meuse / Haute-Marne laboratory site. The state of knowledge on the Meuse / Haute-Marne laboratory site is presented in the site reference document which includes detailed results on experimental work [xiv].
- Other data concerning the question of the transfer of the radionuclides and the chemical toxics from the waste up to the biosphere are presented in reference documents which are respectively the «materials» reference document [xv], the «behaviour of the packages» reference document [xvi] and the «behaviour of the

radionuclides and the chemical toxics» [xvii]. Those documents support the definitions of PARS and concept models and their associated uncertainties.

The following sections of the document focus in more details on the first item “basic input: the inventory model of the waste and the geological site”; other elements of the analysis being described in the other contributions to the WP1.1 PAMINA project.

4. Regulatory Requirement

The evolution of RFS.III.2.f of 1991, which was the reference for the Dossier 2005 Argile, in guidance entitled: “*Guide de sûreté relative au stockage definitive des déchets radioactifs en formation géologique profonde*” (issued in February 2008), will be the reference for the future. It rules that the installation of radioactive waste disposal in deep geologic formation is conceived to receive the ultimate radioactive waste which, after their storing, cannot for reasons of safety or radioprotection be stored on surface or in weak depth. It can involve in particular:

- Waste of average activity (based on mass) containing radionuclides of long period. Their quantity is such that it would not allow their storage, either in an installation of surface weak activity short half-life storage, nor in an installation of weak activity and long half-life storage,
- Waste of high activity (based on mass) containing significant quantities of radionuclides of long period. This waste mainly arises from the treatment of the used fuel and are characterized by an important release of heat,
- Spent fuels which would not be the object of treatment.

Relative to the geologic formations, the guide excludes a priori no type of geologic formation as far as the considered formations respect the essential criteria (that is no exploitable resources).

It also recommends that safety will have to be made to point out the most important parameters and to justify simplifying hypotheses made for the evaluation of the radiological impact. Sensitivity analyses should allow prioritizing the effort for definition of situations taken into account, for the understanding and the hierarchy of processes involved (models) or for the characterization of parameters in order to increase the credibility of the results of the evaluations. They contribute to the appreciation of the uncertainty on the results of the evaluations of the individual exposures from the uncertainties on scenarios, models, numeric techniques, values of the parameters entering the approach having led to these results.

5. Radionuclides inventory and Waste packages

5.1 Input data

In France, radioactive waste is classified according to its level (very low, low, intermediate, and high), i.e. the intensity of emitted radiation, and *its half-life* (short- or intermediate-lived on the one hand, long-lived on the other hand) of the main radionuclides they enclose. These two characteristics allow defining how long they will remain potentially harmful. Waste management methods must be adapted to this potential harm.

There are three types of radionuclides produced in a reactor:

- *fission products* are produced directly from the fission of the uranium and plutonium atoms: caesium, strontium, iodine, technetium, etc. or through fission fragment disintegration. *Caesium137 (and its daughter product barium137) and strontium90 (and its daughter product yttrium90) cause most of the radiation and heat release of the HLLL waste, that are very high during the first 300 years* given their half-life of thirty years.
- *actinides* are natural or artificial elements with a nucleus counting a proton quantity higher than or equal to 89. Four actinides exist in the natural state: actinium, thorium, protactinium and uranium. Minor actinides (mainly americium, curium and neptunium) are formed in a reactor by successive neutron captures from fuel nuclei. *Their radioactivity and heat rating decrease slowly.* After decay of the fission products with average half-lives, the waste generates residual heat from the activity of americium241, which in turn decreases gradually.
- *activation products* are formed by the capture of neutrons mainly in fuel cladding and structure materials. They have considerably less radioactivity than fission products and minor actinides, but must be taken into account as some of these radionuclides have a long radioactive half-life.

In coherence with the guidance, deep geological disposal concern two categories of waste

- **The High-level waste (or vitrified waste) (also known as C waste in the Dossier 2005)**

It accounts for 1% of the volume of radioactive waste and relates to unrecoverable material contained in solutions from spent fuel reprocessing in the Cogema plants: fission products, minor actinides, activation products. Its high β-γ level generates *considerable heat* which decreases over time, principally with the radioactive decay of the fission products with average half-lives (Caesium137, strontium90). Nowadays it is incorporated in a borosilicate glass matrix (R7T7 glass), with a particularly high and long-lasting containment capacity (several hundreds of thousands of years) under favourable physico-chemical environment conditions. The radionuclides are thus spread uniformly in the glass matrix. This vitrified waste is poured into stainless steel drums, to make up vitrified (C) waste primary packages.

- **Intermediate-level, long-lived waste (MAVL), also known as B waste in the Dossier 2005**

This comes mainly from nuclear fuel manufacturing and processing plants, and research Centers. It therefore includes a large variety of items such as structural elements from fuel assemblies (cladding from the fuel rods called "hulls", end pieces called "end caps" and assembly spacer grids, etc.), sludge from effluent treatment, miscellaneous equipment (filters, pumps, etc.). This is basically metal but organic and inorganic components such as plastics and cellulose may also be included. Its β-γ level is low or intermediate and it therefore generates little or no heat. However, the quantity of long-lived elements that it contains justifies a very long-term confinement, like that for high activity vitrified waste. Depending on type, it is conditioned in bitumen (sludge from effluent treatment), in concrete or by compacting (hulls and end pieces, technological waste). The conditioned waste is then placed in concrete or steel drums. These drums make up the MAVL (B) waste primary packages which are both more numerous and more diverse through their conditioning.

5.1 Radionuclide inventory model

The waste is described in terms of typology, radiological contents and physico-chemical characteristics in a specific document (referential) associated with the Dossier 2005 Argile, the inventory model of waste packages with high activity [xiii].

As input to the repository feasibility study, Andra, in close collaboration with the waste producers, has drawn up an inventory model of HL-LL waste. This inventory model allows for both *the waste already produced*, that is stored in conditioned and unconditioned form on the production sites and *the waste that will be produced in the future by the current nuclear power plants.* This dimensioning inventory model (MID) associated to the Dossier 2005 Argile provided an envelope of volume and nature of the waste likely to be considered, in order to assess its geological disposal feasibility with dimensioning margins It refers to *conditioned waste*. That entails knowledge or formulation of hypotheses on the nature and conditioning methods of as yet unconditioned existing and future waste. The selected hypotheses are based on the industrial processes currently used by the producers: vitrification, compaction, cementation and bituminisation.

The inventory of existing waste is based on the knowledge of the processes that generate radioactive waste and effluents, the waste production balance figures that each installation regularly issues, the identification of the storage locations for the produced waste and the control of their contents. The inventory model *for future productions* is based on waste production and conditioning hypotheses, primarily nuclear power plant management scenarios worked out with the waste producers (EDF, CEA, COGEMA). The document will be reviewed for the future DAC[8] to be produced in 2014.

In the framework of the Dossier 2005, to investigate the specific problems that they would pose in terms of influence, operation (including the not proliferation[9]) and of long-term safety of the storage, certain scenarios of studies take into account used fuels stemming from nuclear reactors of EDF or from the CEA (Atomic Energy Authority) in a hypothesis where they would not be treated.

The characteristics of the waste considered for the storage are a function of scenarios of envisaged reprocessing and conditionings. Four scenarios of study were defined with the producers to place the orders of height of the waste HAVL which will be produced in the future by the park of EDF:

- **Scenario S1a** *assumes that all the spent fuel unloaded by EDF power plants currently operating will be reprocessed* (45000 MTHM[10], comprising 8000 MTHM of UOX1[11],

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[8] DAC,Dossier d'autorisation de création d'une installation de stockage

[9] For the record, used fuels raise problems of no proliferation because of the quantity of fissile material they contain.

[10] MTHM: Millions of Tons of Heavy Metal

[11] UOX: Uranium oxides

20500 MTHM of UOX2, 13000 MTHM of UOX3, 800 MTHM of URE and 2700 MTHM of MOX[12]).

- **In scenarios S1b and S1c**, the 42300 MTHM of UOX/URE are reprocessed. However it is assumed that the MOX spent fuel (2700 MTHM) will not be reprocessed and this hypothesis entails the feasibility of their direct disposal. In scenario S1b, the vitrified waste packages are assigned a higher heat rating than current waste packages, in scenario S1c, their heat rating is equivalent.
- **Scenario S2** *has been introduced to analyse the feasibility of direct disposal of UOX and MOX spent fuels*. It considers the partial reprocessing of the UOX spent fuel until 2010 (8000 MTHM of UOX1 and 8000 MTHM of UOX2), then direct disposal of 29000 MTHM with 12500 MTHM of UOX2, 14000 MTHM of UOX3, 500 MTHM of URE and 2000 MTHM of MOX.

These scenarios aim to examine how repository architecture could adapt to the various management processes for the electro-nuclear fuel cycle back-end and do not to predict an industrial blueprint. The principle that has been adopted is to outline possible industrial strategies without favouring one over another. In the dossier 2005, the evaluation is based on 2 envelopes scenarios, S1b and S2.

The waste inventory and definition of appropriate conditioning methods has led to a wide variety of primary waste package families (61 in all) that differ in their radiological content, heat release, the physical and chemical nature of their waste or conditioning materials, dimensions and quantities.

The inventory model groups the families together into a lower number of representative reference packages covering all these HLLL waste package families, so that:

- the scientific and technical studies can be developed further by limiting the number of cases to be dealt with specifically yet without overlooking the diverse nature of the waste packages,
- standardised structures and resources can be designed for implementation in a repository facility.

This approach has led to a disposal concept for each of the listed waste packages. Each inventory model reference package corresponds to the characteristics of various primary packages from different families, which makes the studies easier.

5.1.1 Radiological inventory

The radiological inventory of the waste packages, intended for the deep disposal, represents more than 99 % of the radioactivity contained in the French waste. It results from the presence of fission or activation products in the waste as well as actinides as shown in the following table.

[12] MOX : Mixed oxides (uranium and plutonium)

Radiological inventory (144 radionuclides) – Dossier 2005 Argile
Radionuclides differ by their radioactive period; they divide accordingly: - radionuclides with short half-life (31 %), with a radioactive period not exceeding 6 years, - radionuclides with average half-life (11 %), with a radioactive period included between 7 and 30 years, - radionuclides with long half-life (58 %), with a radioactive period superior to 31-year. The activity with long half-life is very much concentrated in the high active waste: 91 % of the activity of long lived fission and activation products, as well as 97 % of the activity of long lived actinides.

5.1.2 Selection of radionuclides for safety calculations

A selection has been made among the radionuclides to be considered for the transport calculations. The objective was to obtain a representative base to assess the impacts and cover the main issues associated with the transfer of radionuclides towards man and the environment.

For the normal evolution scenario, the following approach has been adopted:

- analysing actinide chains via a simplified preliminary calculation, so as to demonstrate that they do not need to be taken into account in the complete calculation. Given their high retention and precipitation in the geological medium, they do not contribute to impact at the scale of the safety assessment (million years),
- taking into consideration the fission and activation products that are *a priori* the most penalising ones over time.

The method defined consists of selecting only the radionuclides with a half-life of more than 1000 years and presenting, a priori, the most penalising behaviours. This approach has led to selecting 15 radionuclides: ^{129}I, ^{107}Pd, ^{135}Cs, ^{10}Be, ^{93}Zr (^{93}Nb), ^{36}Cl, ^{99}Tc, ^{41}Ca, ^{126}Sn, ^{59}Ni, ^{79}Se, ^{94}Nb, ^{14}C, ^{93}Mo, and ^{166}Ho (for the Dossier 2005 Argile).

Complementary analyses (transport calculations) have shown that radionuclides not selected do not effectively contribute to the impact.

For the toxic chemicals associated with the waste and with the repository components, a few chemical elements, seeming the most significant ones, were considered: boron, nickel, antimony and selenium.

The radionuclides of period lower than 1000 years decrease totally in the disposal system when considering a normal evolution situation, but if necessary they are analyzed in altered situation (such as a “borehole”).

5.2 Long term evolution of the waste

Besides the radionuclides inventory and chemical toxics, the other characteristics of the waste and radionuclides, as well as their long-term evolution in disposal condition, are input data to design and dimension the disposal system and to demonstrate its safety, with different problems and levels of uncertainties according to the families of waste.

Andra, the waste producers (EDF, COGEMA, CEA) and CEA research laboratories, have studied long-term waste package behaviour to assess radionuclides release when disposed of in a geological repository. After identification of the phenomena likely to first alter the matrices and waste in the presence of water and then to release the radionuclides into the solution, key phenomena are selected and their modelling provides a quantitative evaluation. The uncertainties and limits of complex interactions inevitably lead to simplifications: as a general rule modelling adopts conservative hypotheses which overestimate the release.

The example of the vitrified C waste packages is given:

The issue is to model the behaviour of the glass matrix when water comes into contact with it, that is once the waste package is no longer watertight. Thus the phenomenon involved is slow dissolution of the constituents of the glass - mainly the silica. Several parameters govern this solution process. Some of them relate to the chemical and physical properties of the glass, primarily its fracturing rate which determines the amount of reactive surface area between the glass and the water. Other parameters relate to the waste package environment such as temperature and pH, which influence silica solubility. The chemical equilibrium between the glass, silica in solution and the other solid phases in the vicinity come into play through the processes of dissolved silica precipitation and the sorption of this silica (primarily on the corrosion products of the metallic container).

Study of these mechanisms has led to the adoption of two behaviour models for glass:

- The “V0 à Vr “model is applicable to the glasses produced by the COGEMA La Hague plant (R7T7) since the 1980s and the glasses to be produced by similar methods in the future (C1-C4 reference packages). This model fits with experimental observations, firstly of an initial dissolution rate (V0), not controlled by the silica concentration in water (because of interactions with the surrounding materials), then the deceleration of this rate to a residual rate (once the surrounding materials have been saturated in silica). This model leads to glass matrix lifetimes of at least several hundreds of millennia.
- The "V0.S" model is for reference packages C0, that contain legacy waste primarily produced at Marcoule in the 1960s-1970s. This penalising model does not allow for a second phase with deceleration of the initial rate and leads to glass matrix lifetimes at the scale of one to a few millennia. Because of the lack of available data at this stage, this model has been adopted.

Using a cautious approach, modelling considers that the radionuclides embedded in the glass matrix dissolve congruently (that is at the same rate) to the other constituents of the glass. Thus no allowance is made for their possible retention in the altered phase of the glass.

Indeed, the waste package has to delay and limit the migration of radionuclides. Besides, it must not alter the favourable properties of the host rock. For example, for the HA waste, the integrity of the metallic envelope of the glass matrix during the thermal phase, and the fracturation rate of the glass are two essential parameters to control the source term of the radionuclides release in the long term. For the MAVL waste, the confinement, as well as the control of radiolysis gases (together with the associated risk of explosion), are essential, at least during the exploitation phase. After closure, besides the degradation rate of the glass matrix, it is essentially the chemical disturbance of the environment and the formation of complexant being able to facilitate the migration of the radionuclides which need to be controlled. Andra contributes and so uses international databases such as those developed within the framework of Thermodynamics Data Base [xviii] and the European FUNMING [xix] project.

The precise knowledge of the waste from the conception of the disposal allows their consideration:

- in designing and engineering studies (ex: geometry, mass, thermal power of HA waste for the design of the waste tunnel),
- of safety (ex: molar flow of radiolysis gas against the risk of explosion, presence of complexants against the mobility of radionuclides), and
- phenomenological studies (ex: the mechanical evolution, physico-chemical interactions "glass-iron-clay").

6. Geological medium: the Meuse / Haute-Marne site

6.1 The expected functions of the geological medium

The Dossier 2005 Argile indicates that "*The deep underground disposal concept is based upon the idea that there are geological formations capable of confining the disposal packages that are emplaced within them, for very long periods of time, until they reach a negligible level of radioactivity. The geological medium (clay, granite, salt, etc.) and the repository architectures must, in the very long term, ensure the confinement of the long-lived radionuclides which could be released into the biosphere, in order to protect man and the environment. This geological medium is therefore the key part of the disposal system*".

In line with this statement and in coherence with the regulations, the research work undertaken by Andra on clay aims at designing a deep repository:

- which protects the disposal packages from phenomena such as erosion and the main human activities by emplacing them away from the surface,
- which mobilises the properties, particularly in terms of confinement, of the geological medium chosen as a barrier preventing the dissemination of radionuclides contained in the waste, or slowing it down to a minimum (no water flow, reducing environment). These properties must be appraised accurately and guaranteed over very long time scales (from one thousand years to several hundred thousand years),
- which preserves the favourable properties of the geological medium over very long periods of time despite disturbances (thermal, chemical and mechanical) imposed on the medium both by the waste packages which may give off heat, by the repository construction and operation and by long term deterioration of the repository components (packages, cells, drifts).

By the type and layout of their minerals and by their compactness and low permeability, deep argillaceous formations, such as the Callovo-Oxfordian formation of the Meuse/Haute-Marne site which is approximately 155 million years old, have intrinsic properties which are valuable for the study of a geological repository of HLLL radioactive waste:

- *water circulation*, which is the main factor leading to package deterioration, radionuclides dissolution and transport in the repository, *is very low*,
- *the chemistry of the medium remains stable* over time no matter what disturbances occur due to the deterioration of the materials used for the installations, and this does guarantee preservation of the argillites confinement properties,
- *the mechanical behaviour of these formations* limits disturbances (micro-fissuring, fracturing) due to excavation of underground installations and likely to increase permeability in the immediate vicinity of the drifts.

From a macroscopic viewpoint, this geological medium provides:

- *long term geological stability*, ensured by a very low-activity geodynamic context (low seismicity in particular) and by the depth of the layer (500m) which protects it from any impact of the surface processes (erosion and climatic changes),
- *the homogeneity of the argillaceous strata* related to a uniform deposit environment and a geological history relatively undisturbed by tectonic movements and interactions between fluids and rocks.

Examples of the properties for the disposal of radioactive waste are given:

- **The argillite: properties for the disposal of radioactive waste packages**
  - Very low permeability
  - A diffusive means of transport of the radionuclides dissolved in the water and the ability to delay their migration into the environment
  - The capacity to absorb chemical disturbances
  - Sufficient mechanical strength and thermal conductivity
- **The argillaceous host formation: physical characteristics required for deep disposal over very long time periods**

  Apart from the qualities linked to the type of argillite, the host formation must have certain physical characteristics favourable to the layout and operation of a repository over very long time periods.

  - Ability to accommodate a repository
  - Ensuring long-term radionuclide retention capacity in order to slow down dispersion
  - The stability of the geological structure in the long term
  - The existence of low local hydraulic head gradients, vertical ones in the host formation and horizontal ones in the surrounding water-bearing formations

6.2 The characteristics of the Meuse/Haute-Marne site: collecting data – the main stages

Acquiring knowledge of the geological medium in the Meuse/Haute-Marne sector (Callovo-Oxfordian host formation and Dogger, Oxfordian and Kimmeridgien surrounding formations) was organised by pursuing several complementary strategies:

- Checking the arrangement of the geological layers
- Obtaining the first data to characterise the Callovo-Oxfordian clay formation
- Specifying the characteristics of a possible research Laboratory site
- The work carried out at the Mont Terri (Switzerland) underground Laboratory
- Experimental programme of the Meuse/Haute-Marne Laboratory

For the objective of feasibility of the Dossier 2005, it consisted in:

- drilling 27 bore-holes several hundred metres deep, carrying out 2D (1994-1996) and 3D (end of 1999- beginning of 2000) seismic campaigns on the site, geological surveying to observe the outcropping formations both at local and regional scales, ascertaining the main features of the geological environment and taking samples,
- laboratory analyses and experiments, in Mol (Belgium) and in Mont Terri (Switzerland) in particular, to test methods and tools and to validate modelling,
- shaft sinking starting in 2000 with in situ survey of the medium and full-scale appraisal of its behaviour,
- excavating experimental drifts at “-445 meters level” from 2004 and at “-490 meters level” from 2005 with their related experimentations.

These works aimed at obtaining a detailed understanding of the Meuse/Haute-Marne site geological environment in order to:

- ensure that this geological configuration, and in particular the Callovo-Oxfordian argillaceous layer, presents the expected properties,
- assess its long term behaviour, and especially the effect of the disturbances that repository structures installation would imply.

The surveys, measurements and analyses of the current state of the site and of the properties of the Callovo-Oxfordian argillaceous layer have enabled us *to produce an image of the site* (commonly referred to as a *conceptual model)* providing us with a reconstruction of its geological history and presenting its future evolution. This image, consistent with the sedimentological, structural, hydrogeological, geomechanical and geochemical data acquired, *serves as a basis for simulations allowing us to assess the repository performance.*

6.3 Kwowledge acquired

According to the requirements of the RFS.III.2.f, Andra chose a site the favourable properties of which were investigated from the surface and by means of a laboratory situated in 500 meters deep in the Callovo-Oxfordian. The referential describes the data acquired together with their respective uncertainties [**¡Error! Marcador no definido.**].

Main results are:

- in-depth understanding of the geological environment
- layers with simple, regular geometry and a geologically stable environment: a stable old clay formation of 150 million years, situated in a depth between 400 and 600 m, and a known and simple geologic context, a sector situated away from faults, stable from a seismic point of view and without exceptional natural resources,
- the absence of exploitable natural resources,
- a low permeable rock, capable of trapping the radioactive elements,
- a homogeneous argillaceous layer over a large surface area,
- a thick layer (130 m on the laboratory) and homogeneous, exempt from faults,
- the definition of a zone of 250 km^2 possessing properties similar to those of the underground laboratory.

6.4 Geo-prospective evolution

The long-term evolution of the geological medium like its past evolution at the geological time scale result, on the one hand, from the ground surface climate and, on the other hand, the internal geodynamic evolution of the plates forming the earth's crust.

6.4.1 Climatic evolution

Since the beginning of the quaternary period, climatic cycles have succeeded in a fluctuating fashion according to astronomical parameters with an alternation of glacial and interglacial ages. Periodically the surface soils are durably frozen down to a significant depth (permafrost) on the Meuse / Haute-Marne site (40 to 50 % of the time during the last 130 000 years). The frost penetrates to a depth of about a hundred metres. The deeper Callovo-Oxfordian formation is not directly affected by the frost. Notwithstanding the influence of the greenhouse effect, which could slow down this evolution, permafrost could appear in about a hundred thousand years.

These climatic cycles have as a consequence a periodic resumption of surface erosion. The main erosive phenomena are the cutting of valleys and the raising of limestone plateaus, which change surface water runoffs by the evolution of the karstic networks and possible captures of rivers.

6.4.2 Long-term geodynamic stability

The only imagined tectonic movements are limited to the regional faults (the Marne's faults to the West, the Gondrecourt-le-Château trough to the Southeast). Except for these zones, no deformation of the geological strata seems imaginable. The great geodynamic stability of the region explains the practically no-earthquake character of the sector at the scale of historic times.

7. Data selection

Data selection was already described within the topic "Modelling strategy", therefore only the main principles are presented in this section.

A specific terminology was defined for the purpose of describing the conceptual models and parameters values. This standardised vocabulary provides a framework for the safety calculation model selection process.

Depending on the knowledge acquired for each phenomenon or material, the different types of selection were:

- A "*phenomenological*" value is considered to offer the best match between the model's results and the measured results. This choice must be supported by detailed arguments which may include a representative number of measurements, a physical reasoning that demonstrates that the chosen value is the most representative based on reliable data, or a judgement by recognised experts unambiguously designating it as the most appropriate value for the study context.
- The "*conservative*" value is chosen among those generated by the studies and measurements which give a calculated impact in a range of high values, all other parameters being equal. In the simplest case, where the impact increases (or conversely, decreases) as the value of the parameter increases, a value in the highest (or lowest) range of available values. "Conservative" values cannot be defined if the variations in impact are not monotonic with changes in the parameter.
- A "*pessimistic*" value is one that is not based on a state of phenomenological understanding, but is chosen by convention as definitely yielding an impact greater than the impact that would be calculated using possible values. Such values can represent physical limits. A pessimistic value can also be equal to the conservative value plus (or minus, where applicable) an appropriate safety factor that places it significantly beyond the range of measured values. A value cannot be described as "pessimistic" if the variation in impact in response to a variation in a parameter cannot be characterised.
- In order to explore the possible parameter variation ranges, one or more so-called "*alternative*" values can be suggested as a means of investigating the effect of contrasting values.

A parallel classification is defined as regards parameter values:

- A so called "*modèle phénoménologique*", or "*best estimate model*", is either, the model that is based on the most comprehensive understanding of the phenomenon to be modelled, and whose ability to account for direct or indirect measurements has been confirmed, or in comparison with the other available models it might be the one offering the best match between the reality that it is supposed to represent and the numerical results that it generates in the impact calculation. Examples of the former include basic physical models (Coulomb's law, etc.) and mechanistic models representing Fick's law or Darcy's law for example. Examples of the latter include all models subject to a broad-reaching experimental validation and/or a solid international consensus among experts in the field.

- A so called "*modèle conservatif*", or "*conservative model*", addresses a case in which it is possible to demonstrate that its use, all things being equal otherwise, tends to overestimate the repository's impact, compared with the results that would be obtained by taking into consideration all the relevant phenomena in the chosen parameter variation range. For example, selecting a transport model that ignores chemical retention could, in situations where retention has a potentially significant effect, be deemed "conservative".
- A so called "*modèle pénalisant*", or "*pessimistic or penalising model*", designates a model that is not based on phenomenological understanding, however empirical, but that definitely overestimates the repository's impact. For example, making an assumption that waste packages immediately release radionuclides is, except in special cases, a pessimistic choice.
- Finally, an "*alternative*" model stands for a model that can't be classified according to this three items list but offers a different perspective. Examples might include models that don't have an unequivocal effect on the impact, or models that appear more comprehensive than the selected reference model but have been less thoroughly validated.

8. Quality assurance (QA)

According to the principles defined in the ISO 9001 standard, Andra has defined processes regrouping activities, which contribute to the same finality and are oriented toward a customer's satisfaction. The definition of a process allows transversally looking at the units' activities and defining the actions of improvement related to the relevance, effectiveness and efficiency of the process with respect to its objectives. The performance of the processes is reported through indicators. The processes are assessed in one or two annual reviews during which the results obtained are examined. They are linked to the notion of « continuous progress », which is essential in the quality field. A progress action does not necessarily indicate an insufficiency in the process, but rather an opportunity to improve its operation. This organisation allowed inciting engineers in charge of the studies to identify possible ways of improvement. They involved especially the management of the project's configuration and the control of the scientific data. A general document management procedure is related to project management (on the establishment of management plans, controlling reviews, etc.). Additionally, according to adequate procedures, at each key step of the establishing of the safety case (design options, scenarios, quantification of scenarios and related data sets), internal reviews are implemented and recorded in order to get experts' views and make decisions.

9. Methods, models, computer codes and databases

As regards scientific understanding of the system, models and databases have been developed. To be able to process such amount of data and models, efforts have also being made on computer codes and databases.

As regards computer codes and databases, a specific effort has been carried out since 2000 with the development of "Alliances". Alliances is a project common to Andra and the CEA , later joined by EDF, for the development of a simulation platform offering all the means required to model the repository and conduct safety calculations. At present, it especially authorises:

- the selection and coupling of various numerical components,
- the simulation of multi-physical (hydraulic, transport, chemical, mechanical etc.) and multi-scale (package, disposal cell, repository, geological medium) phenomena,
- sensitivity analysis and uncertainty assessment,
- study management and traceability.

“Alliances” enables the user to integrate computer codes from various origins and couple the various phases of calculation within a single environment. Alliances structure is centred on a common data model forming a pivot of communication between all of the calculation modules. This data model contains characteristic values (geometric, physical and numerical) used for modelling and simulation. It associates physical properties to the geometric characteristics of the investigated item. Except for a few sensitivity calculations, all the safety cases assessed within the 2005 dossier have been modelled and computed in Alliances.

Andra has used codes specifically dedicated to the various phenomena (transport, hydraulic, thermal, etc.) and integrated into a simulation platform called “ALLIANCES“ and co-developed with the French Atomic Energy Commission (CEA).

Alliances Simulation Platform

The ALLIANCES platform is intended to provide researchers and engineers with a tool to perform safety assessments that takes into account the specificities of such work, i.e.:

- the requirement to manage very large amounts of data
- the need to execute complex calculation sequences involving different models
- a significantly large number of calculations (several thousands of simulations)
- a requirement to control data and results so as to produce specific analyses for each parameter.

The other main objective of the ALLIANCES is to eliminate the numerical difficulties associated with code coupling. Indeed, code sequencing can generate digital artefacts if the overall consistency is not observed. One of the main assets of this platform is to provide a software framework in which consistency is checked.

Finally, the platform also enables benchmarking various softwares, thereby testing the consistency of the results obtained and constituting an additional guarantee of data reliability. The modelling capacities of the ALLIANCES platform version are listed in the table below.

Models	Components	Examples of applications
Hydraulic - satured - unsatured - transient	Castem Porflow Trace	- flow in porous mediums - resaturation of disposal cells
Transport - simple - extended	Castem Porflow Trace	contaminant transport (toxic chemicals or radionuclides)
Chemistry - complexing - ion exchange	Chess PhreeqC	- leaching - alkaline disturbance - oxidising disturbance - ageing - release
Chemical transport	Castem MT3D Trace Chess PhreeqC	leaching - alkaline disturbance - oxidising disturbance - ageing - release
Package - glass - bitumen	Prediver Colonbo	- package degradation - release
Sensitivity - sampling - analysis	LHS Kalif Pastis	Sensitivity to hydraulic and transport characteristics for safety assessments

In 2004 and 2005, the ALLIANCES platform has been used operationally by Andra and its partners to perform safety calculations and performance assessments. This work amounts to several thousand calculations and only a very small number of incidents have been encountered during its execution, thus demonstrating the good control of the digital aspect of the evaluations.

10. Conclusions

Regulations may consider the “waste” as an input and, as a consequence, contain instructions relative to the type of waste to take into account in design and associated safety approach to consider.

Concerning the data selection, Andra introduced some specific terminology in its Dossier 2005 for data selection: phenomenological, conservative or pessimistic values of parameters.

A peculiar attention was paid in the Dossier 2005 Argile to the basic input data which includes two main aspects: the radiological inventory model and site characterisation. Andra considers that any repository development project must start with an analysis of the technical input data on which it is based.

For instance, one of the first steps is to define the expected functions of the geological medium: “The geological medium and the repository architectures must, in the very long term, ensure the confinement of the long-lived radionuclides which could be released into the biosphere, in order to protect man and the environment. This geological medium is therefore the key part of the disposal system”. In coherence with the regulations, and the assigned safety functions, the research work on clay aims at designing a deep repository, and ensuring the good performance of the host formation. Acquiring knowledge of the host formation and surrounding formations was organised by pursuing several complementary strategies including the work carried out in the underground laboratories located in the selected site (Meuse/Haute-Marne Laboratory) or in other clay formation (Mont Terri Laboratory in Switzerland).

Model and input data was developed on the basis of the best available scientific and technical knowledge. The number and variety of these data increase with each iteration of the repository’s definition process. The peculiarity of the Dossier 2005 is that it is based on the observations and the results from experiments carried out on a real site, namely, on the Meuse / Haute-Marne laboratory site.

The input data and the fruit of the analyses conducted under the Dossier 2005 are structured into a documentary architecture organised according to the safety approach. The whole process of model and data generation was undertaken following quality assurance procedures, and was documented in specific documents associated to the Dossier 2005 Argile. Input data is structured in five different documents, with the following contents:

- The input data on the packages are described in the design inventory document which presents the main characteristics of the packages.
- The state of knowledge on the Meuse / Haute-Marne laboratory site is presented in the site reference document which includes detailed results on experimental work.
- The knowledge regarding the behaviour of the different materials in the repository and the transport of radionuclides and chemical toxics is presented in three reference documents: one for the “materials” in the repository, one for the “behaviour of the packages”, and one dealing with the “behaviour of the radionuclides and the chemical toxics”.

With the aim of a Demand of Authorization of Creation of the storage at the end of 2014, Andra will optimize the concept and will complete the knowledge to answer to the assessors, reduce the margins of uncertainties and so increase the degree of confidence in the safety in operational and after closure phase. In practice, the studies will aim in:

- completing the knowledge on waste packages, the site and the phenomenology of the evolution of the disposal system to reduce the residual uncertainties,
- prolonging the acquisition of experimental data in the underground laboratory,
- performing detailed geological survey and Callovo-Oxfordian characterisation on a restricted zone with the aim of the setting-up of the future plants (on surface and at depth),

- understanding more finely the phenomena governing the evolution of the storage and their coupling.

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A2 ENRESA (Spain)

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1. Introduction and background

In 1985 ENRESA started working on deep geological disposal of spent fuel and HLW, adopting a stepwise approach to develop a safe repository and demonstrate its safety. Work was performed on 4 basic areas: site identification, development of generic repository concepts in granite, clay and salt, development and application of safety assessment methodologies and R&D activities.

Since 2004 the resources allocated to the Spanish deep geological disposal programme have decreased significantly, and in-house developments are very limited. At the present time, the Spanish programme is at a stage of general feasibility studies: several potentially favourable host formations have been identified, generic designs for granite, clay and salt host rocks have been developed and safety assessments of repositories in granite and clay have been done.

This document describes the methodology followed to select the data used in ENRESA´s most recent Performance Assessments of spent fuel repositories: ENRESA 2000 [2] for a granite formation and ENRESA 2003 for a clay formation [3]. In addition, ENRESA´s ideas regarding how to undertake the selection of date in future iterations of the Safety Case are presented too.

2. Regulatory requirements and provisions

The acceptance criteria for radioactive waste final disposal facilities established by the Spanish Regulatory Body (CSN) was set in 1987 in these terms: “to ensure safety individual risk should be smaller than 10^{-6} yr^{-1}, that is the risk associated to an effective dose of 10^{-4} Sv/yr”. This is the only regulatory requirement in Spain.

There are no specific regulatory requirements or guidelines regarding how to select the data used in the Safety Case in general, or in the models in particular.

3. Key terms and concepts

In the PA exercises done by ENRESA no formal definitions related to data selection are included. The terminology used is consistent with the IAEA glossary [5] and other international references.

4. Treatment in the Safety Case

4.1 Methodology

In the Spanish HLW disposal program the engineered barriers systems are well defined for the disposal concepts in granite and clay, but there are no preliminary sites selected. As a consequence, Performance Assessment exercises have been done for synthetic sites, created on the basis of the limited data available for the Spanish favourable formations.

Since real site information was not available, it was necessary to rely on general data from Spanish formations and bibliographic data for similar formations to generate the geosphere model and the data used in the safety assessments.

The Spanish R&D program already had generated useful information for the engineered barriers system, that was used to generate the input data used in the calculations, together with applicable data from the bibliography. For instance, for the bentonite buffer experimental data obtained with the FEBEX bentonite (reference buffer material) was used when available, but data from the bibliography for other bentonites (MX-80, Kunigel,…) were used also.

It must be taken into account that the Safety Assessment exercises done by ENRESA represent early iterations of the Safety Case. As the disposal program progresses, more information specific of the site and the design selected will be available, and the reliance on generic data from the bibliography will decrease.

4.1.1 Sources used to generate data

The main sources used to generate input data for the Safety Case are laboratory experiments, in-situ experiments, natural analogues, modelling and calculation, expert elicitation and bibliography.

Laboratory experiments allow to study the processes taking place in the repository under well controlled conditions, to understand the basic processes taking place in the repository and measure parameter values. Laboratory experiments will represent the bulk of the experimental basis that will be used to select the data to be used in the models.

In situ experiments allow to obtain data under more realistic conditions and at a larger spatial scale compared with laboratory experiments, although at a higher economic cost. Even in-situ experiment will be limited compared with the real dimensions of the repository and the formation and timeframe of the evolution of the disposal system.

In theory, natural analogues can be used both to validate models and generate data valid in the very long term. However, in many cases the uncertainties in initial and boundary conditions are too high and, consequently, will hinder the use of natural analogues for data generation. For instance, old man made iron objects found in natural formations can be used to estimate a corrosion rate for a carbon steel container, but it could be difficult to justify that the environmental conditions suffered by such objects are equivalent to those found by the canister in the repository.

Natural analogues are expected to be especially useful as supporting arguments for the Safety Case, while its usefulness for data generation would be mainly through comparison with the data generated by other means (laboratory or in situ experiments) to increase the confidence on the data selected.

As explained in ENRESA contribution on the WP1.1 topic “Modelling Strategy”, a great number of process level models (that can be quite complex) are developed and used by R&D

groups in order to reach a good scientific understanding of (and identify the basic processes that control) a limited part of the disposal system evolution. These models usually are not included explicitly in the Safety Case, but their results are used to build the models used in the Safety Case, generate data for them or support the data selected by other means. An example is the Thermodynamic Sorption Models (TSM) developed to understand sorption processes on solids (bentonite, clay or granite). These TSMs are not included explicitly in the Safety Case but are used to justify the simplified models (use of distribution coefficients Kd to represent sorption) and the parameter values (Kd values) used in the Safety Case.

The justification of the validity of the data generated using these process models relies on the validation of the process level models and codes used.

Expert elicitation can be used to assess the uncertainties about events and variables when the source of uncertainty is lack of knowledge (epistemic uncertainty). Expert elicitation is a complex and time consuming process that should be used only when data can not be generated using the other data sources described in this section.

Bibliographic data can be used extensively as long as its applicability to a particular disposal concept and site can be justified.

4.1.2 Generation of the input data

The sources presented in the previous section provide the basic input data that will be used to select the data to be used in the Safety Case, and in the models in particular. The process of generating data can be done by the team specialised in the Safety Assessment or by the different scientific groups involved.

In the preliminary exercises undertaken by ENRESA the selection of data was done by the group making the Safety Assessment mainly on the basis of bibliographic data. In more recent exercises the scientific groups involved provided data to be used in the assessment, and their contributions are expected to increase in later iterations.

In some cases, when directly applicable data was not available or scarce, a robust approach for data selection was adopted. An example is Figure 4.1, where measured values of De(HTO) in different bentonites and natural clays are represented to show that this parameter depends only on the dry density of the material, that is an easy to measure and well known property of the clay formation.

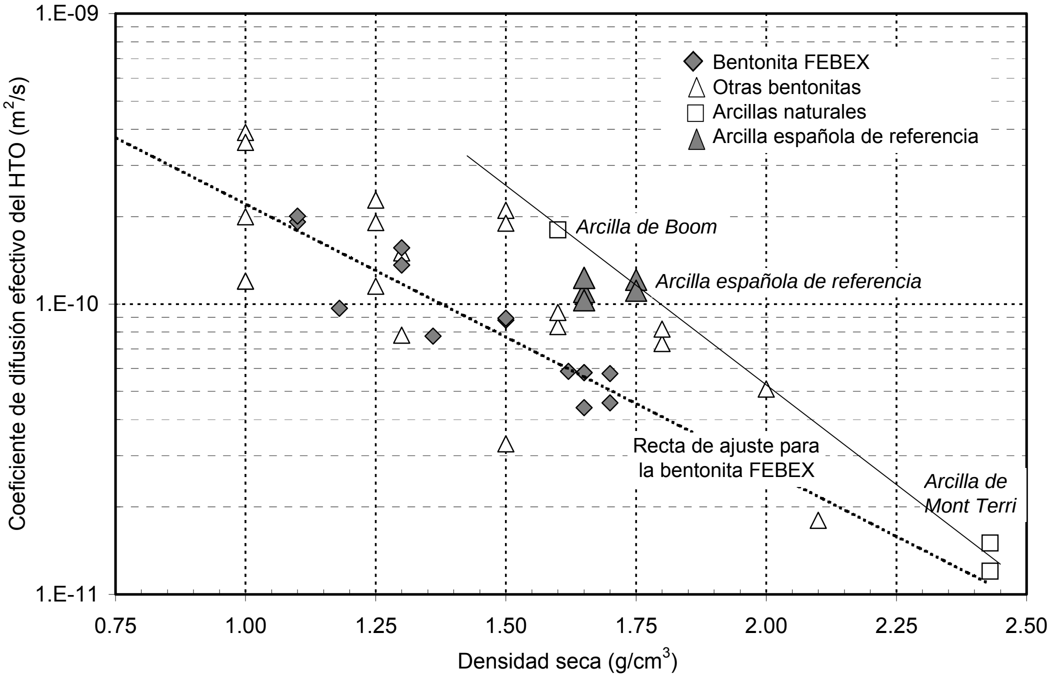

Figure 4.1 – Values of De(HTO) measured in different clay materials

Whatever the approach used to derive the data for the Safety Assessment or the group doing such work, it is of outmost importance that the process of data generation be properly documented. The basic input data must be clearly identified, as well as the assumptions and simplifications done. The resulting document must contain the information required to understand the process followed and references to other more detailed documents, where the full supporting evidence can be found.

The data selection process should be reviewed by independent experts, whose feedback should be considered before adopting the final data set for the assessment.

4.1.3 Long time validity of the data generated

Laboratory and in-situ experiments generate data for short duration experiments under a given set of conditions (temperature, pressure, water composition,…). The applicability of the data generated in the far future under different conditions (that evolve with time) is a critical topic that needs to be addressed explicitly when selecting input data for the models.

For instance, for a repository in granite it is not obvious that the diffusion coefficients measured in short term experiments in fresh bentonite with a given porewater composition (controlled by bentonite accessory minerals) are appropriate after hundreds of thousands of years for a bentonite that has suffered the thermal transient, contains corrosion products from the canister and has a different porewater composition (controlled by natural groundwaters).

In order to select input data for the long term modelling it is necessary a good scientific understanding of the basic processes expected to take place in the repository and their potential effects on the barriers and the relevant parameters.

4.1.4 Site characterisation

Site characterisation and the development of a good understanding of the main properties of the host formation is one of the most challenging tasks in the development of a safe repository, especially in a fractured media such as granite. Due to the heterogeneity of the host formation and the incomplete knowledge of the fracture system (that is unavoidable), the characterisation of the granite formation is a complex task.

Enresa Performance Assessment exercises have been done for synthetic sites, created on the basis of the limited data available for Spanish favourable areas. As consequence, the detailed data that will be generated during the site characterisation phase was not available, and only generic, but plausible, sites have been analysed.

When one or several potential sites are selected, the characterisation process will start, and the amount of site data available will increase steadily. In particular, it can be expected that an Underground Research Laboratory (URL) will be excavated in the formation selected and provide a great amount of site-specific data. In the URL many experiments can be performed to produce data on the thermal, mechanical and transport properties of the host formation under very realistic conditions.

Site characterisation will generate a great amount of raw data that must be processed, interpreted and integrated in order to develop a good understanding of the site, consistent with the information available. All this process must be done following appropriate QA procedures and properly documented.

The “site model” developed on the basis of the data produced during the site characterisation will be used to generate the models and data related to the host formation to be used in the Safety Assessment. Again this process must be done in a traceable way and be properly documented.

4.1.5 The role of the sensitivity analyses

The modelling of the disposal system requires many different parameters. It is not necessary to know all of them with the same precision, because their relevance for repository behaviour is uneven.

One of the most useful sections of the Safety Assessment is the sensitivity analysis, that allows to identify the parameters that control the repository isolation capability. This information will help focus R&D resources to reduce the uncertainty in the critical parameters. In addition, when selecting data for a new iteration of the Safety Case, the results of the sensitivity analyses of the previous Safety Case will be very useful: effort will be concentrated in selecting data and quantifying uncertainties for the most relevant parameters. In general, the need of precise data for a parameter is proportional to the effects of the parameter on the assessment results. For parameters found irrelevant in previous assessments probably an overly conservative (and easy to justify) value can be enough in deterministic calculations and a broad distribution will suffice for stochastic calculations.

4.1.6 Data selection for deterministic calculations

For the deterministic calculations two different criteria are usually followed when selecting parameter values: using “best estimate” or “conservative” values. For most parameters selecting the conservative values is straightforward (maximum solubilities and minimum Kd´s, for instance) but for other parameters it is not so clear. For instance, ^{79}Se half-live effect on selenium doses is not clear because there are opposing effects: activity inventory decreases with half-life while decay in the barriers decreases with half-life too.

ENRESA considers that it would be useful to perform two sets of deterministic calculations: one with conservative values of the parameters and other with best estimate values and present both results. If even the doses calculated performed with conservative values are well below the reference values, the great safety margin provided by the repository would be highlighted.

Comparison of the results obtained with conservative and best estimate parameters would show the potential benefit of going from conservative (and easier to justify) parameter values to others more realistic.

4.1.7 Data selection for probabilistic calculations

One of the advantages of probabilistic calculations is that the parameters uncertainty is explicitly taken into account in the calculations and the uncertainty in the input parameters is transmitted to the output result (usually the dose). But assigning probability distribution functions to the parameters used in the calculations is not straightforward.

On the basis of the experience in previous iterations of the Safety Case it is possible to identify that only a few parameters control the repository behaviour. The uncertainties affecting these relevant parameters must be analysed and used to generate the probability distribution functions to be used in the calculations. For other less important parameters broad probability distributions can be appropriate.

The generation of probability distributions for uncertain parameters is one of the areas where expert elicitations can be specially useful.

4.1.8 Biosphere data

Due to the intrinsic uncertainties, no reliable detailed prediction of the biosphere evolution can be done. When the radionuclides releases from the geosphere start, the biosphere is expected to be quite different from today, but it can not be predicted in detail how it will be. As a consequence, it does not make much sense to gather a great amount of biosphere data specific of today conditions in a given area.

The topic of biosphere data selection is further developed in ENRESA´s contribution to WP1.1 topic “Biosphere”.

4.1.9 Quality Assurance

A comprehensive Quality Assurance (QA) program must be established from the beginning of the project to ensure the quality of all the work performed and its adequate documentation. This QA program should apply to all the groups involved in the project.

One of the main topics to be included in the QA program is the selection of the data used in the Safety Case in general and the computer codes in particular. It is essential that the QA program is implemented before starting the generation of data to be used in the Safety Case. Data generated before the implementation of the comprehensive QA can be challenged as non reliable, and be of limited usefulness.

The development of a repository will generate a great amount of data along several decades. In order to handle these data it is necessary to develop a high-level data management strategy for the different areas in repository development. This strategy must be fully operational before site characterisation starts.

The whole process of data selection for the Safety Assessment must be done in a transparent and traceable way, and must be documented. It would be useful to prepare a document summarizing the data used in the assessment and the way in which it was obtained, the uncertainty in the parameter value and its potential relevance for the assessment results (on the base of previous assessments). Recent Safety Assessment exercises done by NAGRA [4] in Switzerland and SKB [6] in Sweden include one document with this information. In Finland POSIVA intends to include a document called “Models and Data Report” in the Safety Case under preparation.

4.2 Related topics

Data selection is closely related with the modelling strategy, and is an important point of the Safety Strategy followed to develop a repository and demonstrate that it is safe.

The approach adopted to treat the Biosphere in the Safety Case will have a strong effect on the effort to be devoted to generate Biosphere related data.

4.3 Databases and tools

In the Safety Assessments ENRESA 2000 [2] and ENRESA 2003 [3] R&D groups developed databases with bibliographic data for UO_2 alteration, sorption and diffusion in bentonite, sorption on granite and solubilities under near field conditions.

4.4 Application and experience

ENRESA undertook preliminary Safety Assessments for repositories in granite and clay in the 1990s, and more advanced Safety Assessments for repositories in granite and clay in the 2000s.

In the preliminary exercises the process of data selection was done mainly by the team performing the Safety Assessment with little interaction with the R&D groups. By the contrary, in the most recent Safety Assessment exercises ENRESA 2000 [2] and ENRESA 2003 [3] the R&D groups were involved from the beginning in the evaluation, providing models and data.

4.5 On-going work and future evolution

Enresa is making no in-house developments on this topic.

Enresa has been involved in an expert elicitation exercise done within PAMINA Task 2.2.A, in collaboration with JRC and Amphos21. In this exercise the probability distributions for the solubility limits for 5 relevant chemical elements in the near field of a repository in granite were generated.

5. Lessons learned

One of the key reports in the Safety Assessment should be a document summarizing the data used in the assessment, the way in which were obtained and the uncertainties in the parameters. This document should contain enough information to be readable and include references to other more detailed reports. Since models and the data used in the models are closely related it would make sense to prepare a report covering both models and data.

Expert elicitation is a complex and time consuming process that can be used only to select the values or probability distributions of a handful of parameters. It should be used only to select the values for those parameters that can not be obtained in a more conventional way through the review of experimental data available or by calculation.

6. References

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[4] NAGRA. NTB-02-06. Project Opalinus Clay. Models, Codes and Data for Safety Assessment. December 2006.

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A3 FANC, BEL V (Belgium)

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Contents

1. Background/Introduction

In Belgium, an R&D research programme related to geological disposal of high-level and long-lived radioactive waste has been conducted during the last three decades.

In 2013, a safety and feasibility case on the geological disposal options developed by the Belgian waste management organization (ONDRAF-NIRAS) will be issued and reviewed by FANC.

ONDRAF-NIRAS is also developing a project of near-surface disposal facilities for low- and intermediate-level short-lived radioactive waste, for which the authorization application is planned to be submitted at the end of 2010.

In parallel, the Belgian nuclear safety authority (FANC and its technical support organisation Bel V, previously named AVN) has been involved, for the last five years, in different types of activities, aiming at developing a specific regulatory framework adapted to radioactive waste disposal facilities and reviewing technical documents. The regulatory framework is made of several guides expressing the expectations of the nuclear safety authority on different facets of radioactive waste disposal facilities.

In addition to these guides, the following documents more specific to deep geological disposal, have been developed :

- "Geological Disposal of Radioactive Waste : Elements of a safety approach" [1]. This document was elaborated in 2004 by FANC, AVN, the French nuclear safety authority and its technical support (ASN and IRSN) and the waste management organization from both countries (ONDRAF-NIRAS and ANDRA) in the framework of the Franco-Belgian collaboration in the field of nuclear safety.
- On the basis of the above mentioned document a first draft of guidance [2] was elaborated for the siting of disposal facilities in argillaceous formation. This document applies the safety approach defined in the aforementioned document [1] to the confirmation of the choice of a host formation.
- In 2007, FANC issued a document [3] describing the licensing process of radioactive waste disposal facilities and the different periods in a disposal programme in Belgium.

The present contribution aims at presenting the recent but preliminary positions developed by FANC about the data selection and criteria for input data.

2. Definition of terms and used concepts

<u>Qualification of a conceptual model:</u> The process of ensuring that it is consistent with scientific understanding within the assessment basis and adequately represents the phenomena and interactions relevant to its application or intended use.

<u>Validation:</u> Validation of safety assessment models can be defined as the process of building scientific confidence in the methods used to perform the assessment <u>(confidence building</u>

view).

Model verification: The process of determining whether a computer model correctly implements the intended conceptual model.

Code verification: The process of showing that the results generated by the code for simpler problems are consistent with the available analytical solutions, or are the same, or similar, as results generated by other codes (benchmarking).

3. Regulatory Context

3.1 Regulations and guidance

Although under development, there are currently no specific regulatory texts in force in Belgium concerning radioactive waste disposal facilities. The general regulatory framework existing for nuclear installations (Royal decree of 20th July 2001) is only partly adapted for repositories: in particular, it does not address the timeframe and the concept of "long-term safety", which constitute major issues for disposal facilities.

It has been decided to develop a new regulatory framework (Royal Decree about long-term management of radioactive waste), applicable to both near-surface and geological disposal facilities describing, amongst others, the licensing procedure to be applied for such facilities. The development of such a document has been initiated at the beginning of 2008, and is still on going.

Another document ("strategic note" [3]) was issued by FANC in 2007. It is based on the fundamental principles developed by IAEA. Beside the definition of the safety objectives for the disposal of radioactive waste, this document describes the licensing process of a disposal facility.

According to the Royal decree of 20th July 2001, repositories, as any other types of nuclear installations, require a Safety Case which includes a safety assessment.

No specific guidance dedicated to the data selection and criteria for input are under development. However, some considerations on the qualification, validation and verification processes are developed in order to provide guideline for reviewing some technical documents dealing with code and qualifications programmes. And it is expected in Belgium that models and codes used in a safety assessment are subject to a review process including at least the following steps:

- Qualification of the used conceptual models;
- Validation of the safety assessment models
- Verification of models and codes.

3.2 Requirements and expectations

3.2.1 Criteria for inputs and data selection according to objectives

In the following subsections, data and inputs have to be interpreted from a broad point of view: Data may be for instance quantitative parameters of a physical model as well as qualitative information about the long-term evolution of an analogue disposal system.

In order to select data and identify criteria for inputs, expectations from the point of view of the regulatory body at the present stage of the geological disposal programme in Belgium are especially qualitative and deal mainly with the structure of the selection and identification process of the data. Consequently, the chosen approach for the structure of this document is guided by the objectives to be achieved by the safety assessment.

These lasts are:

- Understanding of the disposal system behaviour;
- Assessment of the radiological impact.

It is important to notice in the following sub-sections that:

- Data can be different according to the objectives considered or can be identical but interpreted in different ways with regard to these objectives;
- Criteria for inputs and data selection have to be considered as an iterative process following programme and licensing stages and should be accordingly updated. This aspect refers to an evolution in time to be considered independently from the time evolution of the disposal system developed in section 0.

3.2.1.1 Understanding of the disposal system behaviour

The first main issues to be considered with regard to the selection of data and identification of criteria for inputs are:

- The understanding of the global disposal system and of each component of this disposal system;
- The identification of phenomenology's related to the different considered processes like thermal, hydraulic, chemical and mechanical processes which can be distinguished, and finally;
- The identification of uncertainties for each type of data.

3.2.1.2 Performance Assessment

The second main issues - as the logical outcomes from the understanding of the disposal system - are related to the Performance Assessment (PA) of this disposal system.

From a regulatory point of view the phenomenology's used in the PA model and which have been selected from the phenomenology's explaining the behaviour of the global disposal system and of each component of this system as well as the related data should be thoroughly justified.

In this context, the main considerations driving the selection of data and identification of criteria for inputs are:

- The defence in depth principle, the robustness and the passivity,
- The computations illustrating the confinement levels for each components and the global system.

3.2.1.3 Impact Assessment

The Impact Assessment (IA) is related to PA but deals also with biosphere considerations. In this perspective, criteria for inputs and data selection should be considered as a function of the evolution of the biosphere.

3.2.1.4 Specific objectives

Optimisation and monitoring are specific objectives and have to be highlighted in the structural approach adopted to select the data and identify the criteria for inputs.

3.2.2 Criteria for inputs and data selection according to time evolution

Time evolution is one of the most important sources of consideration for data selection and inputs criteria [NEA 2009], since the time scales involved are huge and their influence could consequently be very important. Some general remarks for consistency can be developed:

- Safety functions contribute to the safety of the disposal system on different time scales. Data and inputs used for defining and supporting these safety functions should have a validity time scale consistent with the safety functions themselves;
- Uncertainties related to those data and inputs should also reflect the predictability of the safety functions with the same consistency. When predictability could not be argued or justified, uncertainties have to be reasonably defined to meet the expectations on the performance objectives.

Robustness and stability of the host rock over long time scales is one of the best examples in order to illustrate the aspects mentioned above.

4. Analysis and synthesis

In this chapter, based on national feedback experiences on review, examples on some open questions related to “data selection and criteria input” are provided. These examples illustrate what could be the safety concerns related to the data selection process provided by an operator. Three themes are considered in the following subchapters: “Selection process on the probability density functions”, the “correlations between parameters” and the “experimental conditions”. As more and more, selected data are a result of a selection process made by a expert panel, some development on how to appreciate the result of such panel is also provided in this chapter.

4.1 Selection process on the Probability density functions

Looking at the Probability Density Function « PDF » provided for some physical and/or chemical parameters and for some relevant long-lived radionuclide's, some proposed "PDF" shapes seems to be mainly first a result of a mathematical fitting than from an assessment of considerations based on the physical and/or chemical features associated to the investigated parameter.

Knowing the possible impact of the "PDF" shape on the results of the safety assessment [Bel V WP2.2.A.10], a pure mathematical fitting approach seems highly questionable. According to this, it seems important in a first step to review the selection process of the "PDF" shape more than the value themselves. In a second step, the determination of some value like the best-estimate one or the conservative one has also to be reviewed.

The starting point for the review process deals with some high level considerations like the nature and the kind of selected approach that will be considered for the safety assessment. Example of area of investigations are provided hereafter:

- Would the "PDF" shape be used in a best-estimate or conservative approach?
- Are there assumptions that allow defining a conservative "PDF" shape?
- Does the "PDF" shape be a bounding parameter for some uncertainties related to the data themselves?
- Should the "PDF" shape be representative of physical and chemical features? In this case, are there some assumptions for allocating the same "PDF" shape for all radionuclide's? If not, why?

  Behind this, the question is why is it justified to allocate a different weight in the safety assessment to a radionuclide in comparison to other one? Indeed, some "PDF" shape could be more stringent than other one.

The objective of this review process is getting the main reasons sustaining the choice of a specific "PDF" shape and having a clear idea of the conditions for their uses.

4.2 Correlations between parameters

For some parameters, there exist some equations/laws establishing relation between them. In some cases, chemical or physical equations give this relation. In other cases, due to the measurement procedures, the determination of a value of a specific parameter needs values from other parameters that could be subject to a probability density function.

Examples:

- The pore water diffusion coefficient is related to the free water diffusion coefficient by a factor function of the porosity;
- The apparent diffusion is a function of the free pore water diffusion coefficient and of the retardation factor;
- In practical cases, the effective porosity is often considered as a fixed fraction of the total porosity. However in principle, the total and effective porosities could have their

own "PDF".

- Diffusion accessible porosity model is an alternative to a more general model which uses both kinematic/effective and total porosities.

In such a case, the final value of a parameter or the boundary values and the associated "PDF" shape could be strongly dependent on the adopted link and assumptions.

As for FANC / Bel V, the choice of the input data has to be done in accordance with the objectives of the safety assessment, a cautious approach has to be followed.

For example, in the general case, choosing conservative values for some parameters in a mathematical expression does not lead to a conservative value of the expression itself. Hence, assumptions made have to be clearly detailed in order to provide and substantiate the final result and the level of conservatism of the final result.

For example, if we are looking for a conservative value of the apparent diffusion coefficient from the free pore water diffusion coefficient, the use of a conservative value of a Kd value should be avoided as it will provide a smaller value of the apparent diffusion coefficient.

When a parameter is a function of two or more other parameters, in a probabilistic assessment, it has to be checked that the final result is consistent. For example, the total porosity is the sum of the effective porosity and the porosity of the closed pore due to dead-end pores and to adhesion of water to the solid matrix. Sample for the effective porosity should be such that the total porosity is always higher..

4.3 Experimental conditions and measurement accuracy

Often migration codes are uncoupled regarding the mechanical and the chemical evolutions of the facility. As these codes require a limited set of parameters characterizing the migration properties of the considered components, the temptation to gather all the available data is quite high. Indeed, as the experimental conditions could not be taken into account, it could be assumed that the different experiments could be brought together for the determination of parameter values. This gives the false impression that as the number of samples becomes higher, a better determination of some statistical data (mean, variance and "PDF" shape and limits) will be achieved. This is without taking into account the sensitivity of the parameters to some experimental condition such as the pH.

In such cases, once again, a cautious approach has to be adopted. It is recommended in a first step to identify the main conditions/factors that could have a strong influence on the parameter. When it has been done, the justification of a gathering approach will be easier and appropriated results will be obtained for increasing the statistic.

Finally, the use of the appropriated set of data should be justified by the context of the scenario in which they are used.

4.4 Expert judgment

Expert judgement may sometimes be useful in both the quantification of uncertainties and in their qualitative treatment where reliable quantification is not possible. This is because experts are potentially capable of bringing information together from a range of sources and distilling it into a relevant form. Experts, however, can obviously not generate new information outside the range of their knowledge and experience. Thus, expert judgement cannot be seen as a substitute for scientific research.

To facilitate the application of expert judgement, systematic elicitation techniques have been developed which help to eliminate or minimise personal bias. The role of the experts is not creating knowledge, but instead to synthesize disparate and sometimes conflicting sources of information to produce an integrated picture (Hora, 1993). Historically, expert judgement has sometimes been used to provide probability distribution functions for uncertain events, where data are lacking or unclear. Meaningful data cannot, however, be conjured out of thin air and there must always be an identifiable basis for any expert judgement. Therefore, the elicitation of the relevant scientific knowledge needs to be documented in a traceable and transparent manner.

It is commonly considered that it is a matter for the implementer to decide whether, where and how to use expert judgement. If expert judgement is used, the implementer must apply appropriate quality standards, both formally and in terms of ensuring that the results of using expert judgement make sense in the context to which they are applied. Moreover, the implementer has to describe the elicitation process that was followed and substantiate that this process allowed minimizing personal biases and validating the conclusions of the experts.

5. References

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A4 GRS-Braunschweig / DBE-Tec / BGR (Germany)

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1. Background/Introduction

The long-term performance assessment of deep underground repositories for radioactive waste is based on numerical calculations. These calculations are performed using more or less simplified models that describe the behaviour of the total system, including engineered and natural sections of the near field, the far field with its specific geological properties and the biosphere. Such models can only work properly if adequate and validated input data are used. The quality of the calculations stands and falls with that of the data used. Therefore, data selection is an important topic within PA that requires a thorough proceeding. While, in some cases, it may be relatively easy to determine the input data – either because there is a comprehensive and reliable database, or the model is insensitive to the parameters – in other cases it can become necessary to establish extensive measurement and work programmes aiming at the determination of one specific input value.

Different kinds of data are typically needed in PA calculations. In this paper we use the following categorisation:

- Geological data: data referring to the natural geological environment of the repository,
- Geotechnical data: data referring to the engineered barrier system,
- Other data: everything else, especially including inventory data and chemical data.

In Germany, the geological data are mainly provided by BGR, which is the governmental research organisation dealing with geological issues. Geotechnical data are closely related to the preparation of the repository site and the construction of the EBS. Therefore, DBE-Tec as one of the main contractors of a final repository for high-level waste in Germany is most qualified to provide such data. Finally, all other data that are needed for a PA have to be established by the performance assessor himself, evaluating the available sources. Therefore, this paper has been made in co-operation between GRS, DBE-Tec and BGR.

2. Regulatory requirements

The currently valid safety criteria for the final disposal of radioactive waste in a mine stem from 1983 [3]. Since then, regulatory expectations have advanced. On this account, GRS proposed “Safety requirements for the disposal of high active wastes in deep geological formations” [2] on behalf of BMU (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety). The BMU is presently elaborating the final version of the Safety Requirements. A draft version of the Safety Requirements was presented in November 2008 to the public [4].

As a radioactive waste repository in a deep geological formation is located in a mine, the mining regulations must be regarded, e.g. in Germany the federal mining law and the UVP-V Bergbau [9]. In addition the repository mine is in fact a geotechnical structure. For this reason the technical guidelines Eurocode 1 “Basis of structural design” [5] and Eurocode 7 “Geotechnical Design” [6] and the associated national application documents should be applied. Particularly, the European standards provide important information on data selection, e.g. when designing a geotechnical structure. Further on, the method of partial factor design and reliability analysis is exemplified, a semiprobabilistic method permitting the coupling of deterministic approaches and probabilistic approaches in order to design highly reliable structures in practice. However it has to be noted that for the design of special constructions works, e.g. nuclear installations, dams etc. other provisions than in the Eurocodes might be necessary. The Eurocodes rely on state-of-the-art technology. Nevertheless they serve as a basis for the licensing procedure.

3. Key terms and concepts

Regarding the European standards, terms and definitions commonly used in the Eurocodes (EN 1990 to EN 1999) are given in chapter 1.5 of the Eurocode "Basis on structural design" (EN 1990:2002).

In section 2 of EN 1990:2002 requirements on structural design are established, subdivided in

- Basic requirements,
- Reliability management,
- Design working life,
- Durability (= the technical expression for long-term stability),
- Quality management.

Quality management measures comprise the definition of reliability requirements, organisational measures and controls at the stages of design, execution, use and maintenance. The quality management includes internal control as well as external control, e.g. by the experts of the licensing authority or certified testing laboratories.

4. Treatment in the safety case

4.1 Methodology

Establishing of input data is an important task within the safety case. First the data needs have to be identified. That means that all model input is checked with regard to the reliability of the values. Data that are clear and well-established can be excluded from the further process. For all other input traceable procedures should be applied and documented that can considerably differ depending on the type of data. In all cases there should be a quality assurance procedure, which includes a checking of the procedures and values by independent experts.

Sensitivity analysis is a good means for discriminating data with a high relevance for the model from those which, though possibly rather uncertain, have low effects to the PA results. If the latter can be proven there is no need to put a high effort in determining such values. Sensitivity analysis is an important tool in PA and is therefore dedicated a specific topic within PAMINA.

4.1.1 Geological Data

Based on the German waste management concept, radioactive wastes should be concentrated and isolated in deep geological formations. The long-term safe entombment of wastes in a repository and the isolation against the biosphere will be provided by a barrier system, which consists of geological and technical barriers. In this context the geology is vitally important.

A precondition for a qualified repository site is primarily a favourable geological situation as a whole with a suitable geological barrier. Several layers in overlying and underlying strata of the repository, each with individual different facies, represent the system of the geological barrier. They are individually and at large analysed and evaluated. To ensure the effectiveness of the geological barrier in future a series of minimum requirements have to be met [1]. The effective properties of a barrier are defined by geological, geochemical, mineralogical, physical, hydraulic and strength-related variables. The effective properties of a barrier consist of several single properties as components of the overall effect. No geological component is meaningful describable without the components mineralogy, geochemistry, geomechanics, hydraulic or physic. In fact, if a question deals only with some of the components the other components take a back seat, but basically, they are always relevant.

Beside these properties of a geological barrier also the conditions of repository location, that means geographic and geological condition in the vicinity the repository site, play an important role.

4.1.1.1 Approach and Database

Before the geological investigations of a site for a repository start, suitable rock types for the geological barrier are identified according to constraints which arise from the type of waste, the repository concept or legal requirements [8]. After this a qualified site is chosen on the basis of exclusion criteria and minimum standards by means of geological methods.

There are different methods of data acquisition, data processing and data analysing. Which method is used depends on the considered variables/criteria, the considered kind of rock, or the task of research. Basically the process of site characterisation consists of five steps: data review, data acquisition, interpretation, data matching, and the prediction for future variability.

Data Review

Data bases are technical and lab reports as well as maps which are stored in archives of the BGR (Federal Institute for Geoscience and Natural Resources), the Geological State Offices, the Federal Office for Cartography and Geodesy, and the LIAG (Leibniz Institute for Applied Geophysics). These documentations were mostly established in the context of repository- or disposal projects as well as exploration programs. Furthermore scientific relevant result from other scientific institutes and universities and industry are involved.

Data Acquisition

In addition to data, reports and maps which are already known, extensive field investigations are carried out. There are indirect and direct methods. Direct methods are exploration excavation and field mapping, sounding, drilling as well as geotechnical measurements, e.g. dislocation measurements on ground surface and in boreholes. Indirect methods are geophysical explorations methods like seismic exploration methods, seismo-stratigraphy by stratigraphic levels, geoelectric, etc.

Further data originate from laboratory tests, calculations and modelling. This data deliver insight into currently conditions and changes in future. Several important criteria are based on laboratory tests, e.g. strengths, dilatancy boundary, stress, permissible strains, permeabilities, composition of groundwater and rocks, etc. The results of numerical modelling, e.g. stresses, strains, deformations, groundwater flow (currently and in future) etc., are basic values to evaluate the stability of the components of the repository and the integrity of the host rock barrier.

Interpretation/Data Matching/Prediction of Future Variability

Proper data documentation allows an interpretation of the geological overall situation and the barrier properties. On basis of the collected data and individual aspects the current geological suitability to dispose radioactive waste in host rock will be assessed and if it necessary further required information are specified.

In this context also the future development of a potential repository site plays an important role. For the assessment of future behaviour of geological structures and formations the consideration of past geological processes are an important aid in addition to modelling. The reference to natural analoga can support the scientific line of argumentation for disposal of radioactive wastes in deep geological formations.

4.1.1.2 Data for the conditions of repository site

Not suitable to host a repository are areas with intensive seismicity and tectonic, increased trend of uplift, recently volcanism and unfavourable hydrogeological conditions.

Vertical movement

The basis for classification of areas with vertical movements in Germany is provided by maps from the Federal Office of Cartography and Geodesy, maps from geological the State Offices as well as scientific publications on special areas. Additionally, the consideration should also include, that a vertical movement within an area is linked with the occurrence of geodynamic activities and, therefore, should be interpreted in connection with earthquakes and arrangements of fault zones.

Tectonic stability (active fault zones)

In the emplacement zone, active fault zones (movements within the neotectonic period) must not exist. A general definition describes faults as tectonic or atectonic processes, which modify the primary stratification form of rocks. Therefore, the term comprises both ductile and brittle strain. Dislocation with an explicit off-set can be detected and documented by normal field mapping or seismic exploration methods. For localisation of damaged zones more special methods have to be used, e.g. remote sensing or geoelectricity which registers humidity anomalies, or other geophysical methods.

Seismic activity

The general basis for the indication of earthquake-jeopardised areas in Germany is provided by the German earthquake-catalogue (where all earthquakes in Germany are listed since the year 800), the map of seismotectonic areas in Germany, and the distribution of realised damage quakes in Germany.

Volcanic activity

The assessment whether a region is susceptible to volcanic activity is based on expert poll which assess recent and former volcanic activities, the probability of revivals, and the locations of eruption centres and extensions. Although an intrusion of magma into a repository is very improbably, but nevertheless the consequences of volcanic activities like temperature stress, volcanic quakes and induced fault movements have to be assessed.

Hydrogeological conditions

The hydrogeological conditions mainly consist of surface hydrography (river arrangement, water stage determinations, leakage effects, lakes, water divide, drainage areas, etc.) and the groundwater flow. The hydrography is investigated by means of hydrogeological analysing methods. A minor groundwater flow and therefore an old groundwater age points to a favourable geological situation. The groundwater age can be determined from the concentration and concentration ratios of particular environment-isotopes, e.g. tritium- and C14-values give an indication for young groundwater.

4.1.1.3 Data about Effective Barrier Properties

For the acquisition of data about the effective barrier properties surface explorations and subsurface investigations have to be conducted. This exploration work yield knowledge about geological conditions, hydrogeological conditions and geomechanics. Geological descriptions also involve geographic information of the location as well as geometric data, coordinates and the depth of the layers.

4.1.1.3.1 Geological Conditions

The general theme of “geology” includes subcategorisations like lithology, stratigraphy, facies, disposal area, structural conditions (macro-fabric like bedding and faulting), thickness, sedimentology, grain size, fabric, rock structure and tectonics. These parameters provide information about evolutionary history and further development of the barrier rocks. Additionally it has to find out, whether a sufficient thickness and extension of homogeneous host rock are available.

In general most of the data rest upon drilling, results of physical measurements, field mapping and laboratory tests.

Drilling and borehole-measurements

In addition to the lithological descriptions of deep drillings the correlation of geophysical borehole-measurements are used for the geological processing of the stratification investigated by drilling. Predominantly used are methods which allow conclusions about petrographic properties of intersected rocks and conclusions about the hydrogeological situation. These also include e.g. the measurement of natural gamma-radiation, self-potential log, focussed resistance measurement, density-measurements [7]. Different methods of borehole-measurements e.g. electric-electromagnetic-, acoustic- and gravimetric methods, methods regarding the determination of geometrical values, or regarding the property-state variable-movement of borehole-fluids [1] provide information about important rock parameters used for the realisation of the final disposal of radioactive waste. Geophysical and geological analyses in connection with drilling give evidences about the borehole and its surrounding rocks. This means that borehole measurements only provide one-dimensional information with respect to the elected parameter.

Geophysical exploration programs

In order to extrapolate the results of borehole-measurements into plane or space it is necessary to conduct two-dimensional section-measurements or three-dimensional measurements. The choice of measuring methods depends on the parameters to be determined. A possibility for correlation is the interpretation of results from seismic measurements (reflection-, refraction- and surface wave seismicity, as well as high frequency absorption measurement). Seismic measurements are electro-magnetic wave methods and detect impedance differences. Therefore they indicate lithostratigraphic boundaries and other petrophysical heterogeneities (e.g. moist zones). Seismic measurements are done on surface and in deep drillings. By means of the application of high-resolution seismicity the bedding properties of tertiary and quaternary layers are more precisely determined. Results of geophone-immersion in boreholes serve to the interpretation of high-resolution seismicity [7].

Results of geophysical exploration programs allow the processing of a rim syncline analysis, the identification of potential migration paths of fluids within the overburden, and allow inferences on lithological bedding, stratification and fault zones. Furthermore the more exact position and shape of the salt dome, the relief of the top salt and the basement of the salt dome as well as the contour lines of the salt dome boundary can be assessed by the geophysical exploration.

Geological Field mapping

Within the framework of data collection geological field mapping can be conducted. Field mapping provides information about lithology, thickness, bedding and structure of rocks and sediments on the surface and in outcrops.

Laboratory tests

Rock samples can be obtained by drilling or during field mapping. In laboratories this samples are analysed with respect to sedimentary, lithostratigraphical, biostratigraphical features and palaeomagnetic age determination of rocks.

Sedimentary analyses involve e.g. grain size determination, carbonate content determination, determination of organic carbon content, heavy metal analyses, mineralogical-geochemical composition, etc. These analyses provide a detailed acquisition of lithological/petrographical sediment properties and resolve genetic-facial questions. The method of analysis is orientated on the main issue of analysing.

The grain size determination is carried out by means of the sieving method. This analysis exemplify the acquisition of the grain spectrum and amongst other things also the investigation of the Kf-value, a parameter for hydogeological modelling. The genesis and the maturity stage of hydrocarbons can be deduced from the mineral content as well as the type and portion of organic material. The mineralogical composition affects considerably the hydraulic and strength-mechanical properties of the analysed rock. The qualitative mineral identification is conducted by X-ray diffractometer analyses, X-ray fluorescence analyses, petrological microscopy and geochemical methods. Bromine content analyses are an important tool for the genetic interpretation of brines or stratigraphic characterisation of the salt formations. The determination of the qualitative content of minerals is carried out by computations.

Results of biostratigraphic and palaeomagnetic analyses give information about the relative age of the rocks and sediments.

In addition to the geological analyses mentioned above, the continuous monitoring of local earthquake occurrences by an installed seismic observational network and the geothermic analyses relevant for interpretation of the natural temperature field belongs to the exploration work.

4.1.1.3.2 Hydrogeological Conditions

Hydrogeology is primarily concerned with exploration of groundwater and the groundwater balance. Interactions between water and rock, the dependency on structures or bedding as well as changes of properties are considered. The hydrogeological structure, the hydraulic properties and the groundwater are analysed hydrogeologically.

Hydrogeological Structure

Basis of the hydrogeological structure is the knowledge about the structure of the geological layers in the underground provided by geological maps, results from drilling and three-dimensional models. Therefore aquifers and aquitards are identifiable. Beside the geological structure the groundwater-morphology has a significant relevance. In that involved parameters reflect the state of equilibrium of the geohydraulical dynamic. For this the groundwater table is measured based on distributed control points, and water table contour maps are constructed.

Hydraulic Properties

The hydraulic properties describe important features of the geological barrier conditions. Parameters of barrier rock properties are necessary for long-term safety considerations with respect to surface and subsurface disposals. The parameters can describe the diffusion of hazardous fluids into the biosphere. The theoretical migration paths and migration mechanism are supposed as known. If they apply for the barriers of the considered site must be analysed and evaluated individually. The permeability coefficient (Kf-value) is in the centre of hydrogeological interest. It is used for the classification of the quantitative permeability of rocks. Other parameters can be derived from the Kf-value which are important for hydrogeological considerations: transmissivity, seepage velocity and transported volume of water. Grain size distributions, tracer tests, long and short pumping tests as well as laboratory tests give information about parameters like porosity, geometry of pores, permeabilities for fluids and diffusion. By means of numeric groundwater modelling e.g. hydraulic arrangements or effects of environmental damages can be calculated in advance.

Groundwater

In this area of activity data of groundwater composition, water density, groundwater recharge and groundwater movement are primarily collected. For characterisation of groundwater composition and water density water probes are mainly analysed chemically in laboratory. Furthermore geoelectric field measurements for the exploration of brine and accordingly water and electromagnetic field measurements for exploration of near-surface groundwater salinisation are made. Within the framework of extensive monitoring of the groundwater recharge rate pedologic field mapping is conducted. This mapping involves bearing tube drilling and test hole exploration and is supplemented by soil-physically field measurements and laboratory tests. Regional investigation of groundwater recharge can be made by several methods, e.g. lysimeter, from moisture balance, by groundwater models, by discharge and water level measurements, etc. Data for groundwater movements mostly originate from technical measurements, e.g. soil-moisture tension measurement. When the movement of water is to slow (deep-groundwater) technical measurements are not suitable and the data are calculated by hydraulic models.

4.1.1.3.3 Geomechanics

Geomechanical data provide information about the strength and the mechanical behaviour of rocks. The main categories of parameters are: density-values, strength-values, water content and swelling behaviour.

The geomechanical in-situ conditions are evaluated by mining experiences and model calculations with the aid of data from rock-mechanical, geodetical and geophysical monitoring measurements (stress, strain, temperature, etc.). Geomechanical data originate from laboratory measurements and in-situ-measurements (deformation measurements in shafts and galleries), as well as calculations of stresses and strains by model calculation.

4.1.2 Geotechnical data

Basically, the geotechnical data are needed to perform the safety assessment, the long-term safety assessment as well as the operational safety and regarding radiological as well as conventional safety aspects. Geotechnical data must be sufficiently known to support this task. The data necessary to design a radioactive waste repository in salt rock are given below.

4.1.2.1 Repository mine

Based on the site characterisation and the geologic information the repository mine is planned, the geometric structure of the repository mine is adapted to the geologic structure. The geometry of the repository mine is an important input parameter, affecting repository performance significantly. The geometric data of the repository mine inclusive of boreholes are collected in the mine surveyors documentation. In this documentation some more important information repository specific information is available. The date of excavation of individual sections of the mine as well as the date of backfilling. In the case of a repository mine the position of the the waste respectively the waste container is also documented.

As a by-product of the site characterisation and the planning of the repository mine the primary stress state is determined as well as the initial temperature state depending on depth.

4.1.2.2 Host rock

Considering the host rock geotechnical data must be available covering the following aspects:

It has to be regarded that anhydrite layers or blocks are inherent parts of salt rock. However, in contrast to salt, anhydrite shows elastic/brittle behaviour. Thus, in the following, those geotechnical data respectively engineering properties of salt and anhydrite are summarized that are essential to the design of a radioactive waste repository in salt rock. Knowledge must be present on

- Stress strain relations – to describe the deformation behaviour
- The dilatancy boundary – to guarantee an undisturbed, effective rock salt barrier
- The failure boundary – to guarantee the stability of mining excavations
- Thermal properties as well as quantities describing thermo-mechanical coupling – if heat-generating radioactive waste is to be disposed

Remark: Permeability and porosity of intact rock salt are determined, however, they are extremely low forming a tight barrier if the dilatancy boundary is not exceeded. Anhydrite is assumed to be a porous medium containing joints. If anhydrite layers are connected to water-bearing overburden they are not regarded as a barrier as a rule. Anhydrite is tight in combination with salt when forming isolated blocks inside the salt structure.

Deformation behaviour

Basically, salt rock shows viscoplastic or creep deformation mechanisms. Generally, three phases of creep are distinguished, i.e. primary, secondary and tertiary creep. To describe creep behaviour of salt mathematically, several approaches for stress-strain relations have been developed.

All these models are based on an additive split of strains (small strains) or strain rates (large strains) in elastic parts ε_e, viscous parts ε_v, and plastic parts ε_p, basically, i.e.

$$\varepsilon = \varepsilon_e + \varepsilon_v + \varepsilon_p$$

All these constitutive models comprise at least the elastic and the viscous part. Often primary creep can be neglected due to its short duration while tertiary creep should be reduced to be negligible in a well-designed repository because it is coupled with cracking. To conserve the salt rock barrier, tertiary creep should be restricted to the contour of mining excavations where it is unavoidable. Thus, it can be controlled by classical mining safety measures, e.g. re-ripping.

If emplacement of heat-generating waste is considered the constitutive model must be able to reproduce thermally activated creep. In the WIPP and BGR models, the thermal influence on creep rate is covered by an additional Arrhenius function.

Depending on the salt structure and its age, the creep rate of natural rock salt differs even under identical load conditions. For classification purposes, so-called creep classes were introduced. The creep classes are defined with respect to the BGR reference creep laws. Different creep classes are coupled to the reference creep laws by a multiplicative prefactor. The creep classes cover a range of –1 to 9 subsequently doubling or halving the prefactor. The reference creep laws are equivalent to creep class 5. In general, intergranular/bound water leads to increased creep rates. For practical purposes, this effect is included in the creep class when regarding intact rock salt.

The deformation behaviour of anhydrite is described as purely elastic before failure and elastoplastic beyond the failure boundary. In a well-designed repository conditions beyond the anhydrite failure boundary should also be restricted to small zones close to the contour of mining excavations.

Dilatancy and micro-cracking

To prove the integrity of the salt rock barrier, the dilatancy criterion on the micro-cracking limit is applied. Barrier integrity is checked by comparing the existing octahedral shear stress state to the tolerable octahedral shear stress state on the dilatancy boundary. Thus, the dilatancy criterion is related to the stress. As the dilatancy boundary depends on the method of experimental evaluation, the dilatancy criterion on the micro-cracking boundary is applied in order to check the intact salt rock barrier at present. The micro-cracking boundary is the most conservative dilatancy criterion. It is based on acoustic emission measurements as a significant increase of acoustic emissions characterizes the beginning of micro-cracking.

A complementary criterion relying on the strain state is the so-called Aversin criterion. It states that the barrier integrity of protective salt rock layers is lost if the accumulated inelastic principal strain limit is exceeded. Alternatively, an equivalent strain limit may be used if the direction of principle strain is changing.

Recent research results indicate that both the aforementioned criteria must be revised if very low principal stress amounts are acting especially with regard to tensile stress amounts. For this reason tensile stresses are evaluated additionally.

As anhydrite is assumed to be a porous medium containing joints, the micro-cracking boundary of anhydrite is not of interest.

Failure

The failure boundary of rock salt and anhydrite is given by the Mohr-Coulomb failure criterion with tension-cut-off or by its Drucker-Prager approximation. As a main difference, anhydrite has a failure boundary which is independent of time whereas the failure boundary of rock salt shows time-dependent behaviour due to increasing damage as a consequence of creep beyond the dilatancy boundary.

The failure boundary is of interest when rating the load bearing capability of structural elements, e.g. pillars and stopes or contour zones close to mining excavations, which are not part of the salt rock barrier. The failure boundary represents the upper limit of short-term strength. In practice, pillars and stopes often bear uniaxial loads. For this reason the uniaxial compression strength and the tensile strength determined by the Brazilian test method are also included when evaluating the stability of mining excavations. The time-dependent stability of pillars, stopes, and contour zones exceeding the dilatancy boundary or the uniaxial compression or the above mentioned tensile strength is monitored by geotechnical measurements. If a structural element approaches its stability limit, state-of the-art engineering actions are taken, e.g. backfilling, re-ripping, rock bolting etc.

Thermal behaviour and thermo-mechanical coupling

When disposing heat-generating radioactive waste in salt rock thermal behaviour has to be taken into consideration. The influence of a rising temperature on deformation and thus acceleration of the creep rate was already mentioned. Additionally, the time-dependent temperature field has to be evaluated to check the thermal impact on the salt rock barrier. When calculating the evolution of the temperature field, heat capacity and heat conductivity of salt rock are relevant salt-specific input parameters. While the heat capacity can be assumed to be constant for practical issues, the heat conductivity is a nonlinear function depending on temperature. Heat conductivity decreases as temperature increases. This nonlinearity has to be taken into account when rating the results of temperature calculations against the permissible temperature limit. In the case of thermal loads, the stress state is indirectly affected by thermo-mechanical coupling and has to be included when rating barrier integrity and structural stability. The thermal expansion coefficient acts as a coupling parameter. It can be assumed to be constant in the range of practical application when designing a final repository for heat-generating waste in salt rock.

4.1.2.3 Backfill

For a well-designed radioactive waste repository in salt rock dry crushed salt is provided as backfill material because of its favourite sealing capabilities in the long-term, when it is highly compacted. According to rock salt for the backfill the following constitutive relations must be available

- Stress strain relations – to describe the deformation/compaction behaviour
- Thermal properties as well as quantities describing thermo-mechanical coupling – if heat-generating radioactive waste is to be disposed

Because of its potential barrier function the permeability of the backfill is regarded depending on the compaction state of the backfill. The compaction state is related to the current porosity. As a consequence the following relationship is available

- Permeability porosity relations – to describe the increasing barrier function of the crushed salt backfill depending on its decreasing porosity.

Deformation behaviour

Basically, crushed rock salt shows viscoplastic or creep deformation mechanisms similar to rock salt. To describe creep behaviour of crushed salt mathematically, several approaches for stress-strain relations have also been developed. All these models are based on an additive split of strains (small strains) or strain rates (large strains) in elastic parts ε_e and viscous parts ε_v, basically, i.e.

$$\varepsilon = \varepsilon_e + \varepsilon_v$$

In contrast to rock salt, however, the volumetric deformation/compaction is the predominant deformation process at high porosities. For this reason some models are restricted to volumetric creep. With decreasing porosity deviatoric creep becomes more and more important.

If emplacement of heat-generating waste is considered the constitutive model crushed salt must be able to reproduce thermally activated creep as well as rock salt.

Thermal behaviour and thermo-mechanical coupling

When disposing heat-generating radioactive waste thermal behaviour of crushed salt has also to be taken into consideration. The influence of a rising temperature on deformation and thus acceleration of the creep rate was already mentioned. Additionally, the time-dependent temperature field has to be evaluated to check the thermal impact. When calculating the evolution of the temperature field, heat capacity and heat conductivity of crushed salt are relevant backfill-specific input parameters. While the heat capacity increases with decreasing porosity, the heat conductivity is a nonlinear function depending on temperature and porosity. Heat conductivity decreases as temperature increases and increases as porosity decreases. This nonlinearity has to be taken into account when rating the results of temperature calculations against the permissible temperature limit. In the case of thermal loads, the stress state is indirectly affected by thermo-mechanical coupling and has to be included. The thermal expansion coefficient acts as a coupling parameter.

Permeability porosity relationship

The permeability of the backfill depends on its compaction state. In a wide range down to k = 10-16 m² the permeability of crushed rock salt can be described as a nonlinear function of porosity in agreement with classical approaches, which couple permeability and effective porosity. Beyond that limit a relationship of permeability and porosity is not evident.

4.1.2.4 Shaft and drift seals

Shaft and drift seals are designed individually depending on the repository structure as well as the geologic conditions and the scenarios affecting the integrity of the seals. In salt rock shaft and drift seals are designed using the following building materials as main components

- bentonite,
- salt concrete,
- magnesium oxide concrete.

The seals are designed according to national and European guidelines in civil engineering. Additionally, special attention must be paid to the durability respectively long-term stability of the seals because their working life exceeds working lives typically regarded in the guidelines significantly.

Often the EDZ of the salt rock is assigned to be part of the seal. Thus, some geotechnical data must be available for the EDZ, i.e. permeability, porosity and stress state. The stress state is of importance because in the EDZ damaged rock salt must be assumed. In damaged rock salt, however, permeability is a function of the least principal stress respectively the effective least principal stress.

4.1.3 Other data

Though the geological and geotechnical data are the most substantial part of the data acquisition process for a PA exercise, there are other groups of data that have to be established with equal accurateness. In the following, the typical selection procedures are described for the most important types of data.

4.1.3.1 Waste data

The radionuclide inventories of the repository are essential for the results of dose calculations. Since in Germany there is still no final concept for a repository for heat-generating waste, it is not clear how much waste it will contain. For estimation, three main sources of waste have to be taken into account:

- Spent Fuel (SF) Elements that are to be directly disposed of. Direct disposal is foreseen for a number of existing SF elements, especially from old Russian-type reactors. According to the valid German legislation, it is also the only option for the future. As the remaining quantities of electricity to be produced by each nuclear power plant have been prescribed, one can calculate the amounts of waste of this kind that will occur until the projected end of the use of nuclear power. This requires precise knowledge of the types of individual SF elements, their initial compositions, their burn-ups and the dates of their removal from the reactor. Some of these data can only be estimated today. The radionuclide activities and heat power are calculated for a given reference date, which is assumed to be the end of the operational phase of the repository.
- Vitrified waste from reprocessing. German Spent Fuel used to be reprocessed in France or in the UK. Since this is no longer admissible, the final amounts of waste originating from this source are in principle known. The inventories and the thermal data can be derived from the specifications of the reprocessing facility. By decay calculations they have to be projected to the reference date for the repository.
- Intermediate-level wastes (ILW), originating from the reprocessing or directly from the power plants. They comprise vitrified reprocessing water, compacted fuel element casings, structural parts and technological wastes. It is difficult to determine the radionuclide activities of these wastes exactly, the more as it is not yet known which amounts of them will accumulate until the reference date for the repository. Moreover, it is not quite clear which of these wastes will at all be disposed of in the repository, because an independent repository will be available for low- (LLW) and intermediate-level waste.

A completely different situation is given for the existing German LLW/ILW repositories ERAM and Asse. Their inventories cannot be calculated but have to be derived from the files of the waste deliverers, which stem from different decades and are sometimes inaccurate or incomplete. Therefore, there is some uncertainty about the real inventories and the values for use in PA calculations have to be chosen conservatively.

4.1.3.2 Physical data

Some of the physical data needed for PA calculations, such as brine or rock densities, viscosities, or the coefficients of their temperature dependence, can be taken from widely available and well-established databases. This results in well-founded parameter values with low uncertainties. Others, such as diffusion constants or dispersion lengths, are poorly known under the relevant in-situ conditions and can only be estimated. Some physical parameters, however, are rather specific to the applied models and cannot be easily derived from values documented in the literature. This may relate, for example, to the parameters of the phenomenological laws used for describing bentonite resaturation, rock salt compaction, or the relation between permeability and porosity of a porous medium. For cases like the latter one, a number of investigations exist, but they lead to widely spread results. In other cases, few or no experimental investigations are available, and one is urged to derive parameter values from analogue situations or to make an estimation. Physical parameters determined in this way are subject to a high degree of uncertainty, which should be adequately considered in an uncertainty analysis.

4.1.3.3 Chemical/geochemical data

Geochemical data of relevance for PA are, above all, sorption data and solubilities. Sorption is normally sufficiently well-described by a linear model using fixed distribution coefficients. These values are element-specific and depend on the sorbing material as well as on the geochemical conditions. In general, they have to be measured under in-situ conditions. If no measured data are available, one has to use estimated values, which can be derived, for example, from known values for chemically similar elements or from other analogies. Since sorption is always an advantageous effect in PA, uncertain distribution coefficients should principally be rather under- than overestimated.

Although, in many cases, fixed element-specific solubility limits are assumed in PA models, this is a rough simplification, which is often inadmissible. The maximum element concentrations in the brine depend, to a large extent, on each other, and it is a challenging task to determine the real equilibrium composition of the brine in a specific part of the repository system. Geochemical equilibria can be calculated with the code EQ3/6, which itself needs a comprehensive thermodynamical data basis. While some of the coefficients can be found in the literature, others have to be determined by means of extensive investigation programmes. A comprehensive thermodynamical reference data basis (THEREDA) is currently being elaborated in collaboration between five organisations from Germany and Switzerland, including GRS. The data in this database are verified and quality-assured [www.thereda.de].

4.1.3.4 Model-specific data

Some models used for PA need specific data that can neither be derived from general databases nor be provided by the operator. Where the performance assessor applies such models, it is his or her own responsibility to use adequate data. For example, in the ERAM repository seals are used, which can be disintegrated by magnesium-containing brine. For this process, a specific model has been developed, which needs to know the dissolution capacity of the brine as well as the maximum relative increase of permeability through this process. While the dissolution capacity can, with some uncertainty, be estimated by theoretical considerations, the maximum relative increase of permeability is a model parameter with no realistic meaning, as in reality, the process will most probably not stop after the permeability has increased by a given factor. Parameters like this one have to be chosen with care, and it has to be made sure that their choice does not lead to an underestimation of consequences.

4.1.3.5 Probability density functions (pdf)

Uncertainty analysis and sensitivity analysis are important parts of the safety case and are normally performed by applying probabilistic methods. These require appropriate pdfs for each uncertain parameter. To determine the pdf, the uncertainty of the parameter itself has to be estimated properly, which is not an easy task. Some simple rules for determination of pdfs are given in the GRS contribution on the topic “uncertainty analysis”. A more detailed systematic procedure has been elaborated within PAMINA WP 2.2.A [10].

4.2 Related topics

As already mentioned, the topic of criteria for input and data selection is related to the PAMINA topics “uncertainty analysis” and “sensitivity analysis”. A sensitivity analysis can trigger the process of data selection by identifying input parameters that have a high influence on the model results and therefore have to be determined with specific care. On the other hand, it can prevent putting too much effort in data that are more or less irrelevant for the model results.

Another related PAMINA topic is “biosphere”. A proper calculation of the dissemination of radionuclides in the biosphere requires a sophisticated data generation process, which is described in the relevant topic paper.

4.3 Databases and tools

There are no specific databases or tools in use for PA data selection in Germany.

4.4 Application and experience

Some application examples and experiences have been described in chapter 4.

4.5 On-going work and future evolution

At the German repository sites Morsleben and Konrad, where abandoned mines are used for repository purposes, a lot of knowledge about the site's geology already exists from the operational phase of the mines. In the other existing repository project in Germany, the Gorleben project, most of the geological exploration and data collection work was done in an early phase of the project. In all repository projects it was aspired to firstly achieve a largely comprehensive data set to have the basis available for a site specific safety assessment. The recent development appears to tend towards a partly interchange in the sequence of data collection and safety assessment. Instead of firstly trying to collect a data set which should be as comprehensive as possible, a safety assessment is already required in an early project phase regardless of the current grade of completeness of the collected geological data set. Those data, which are needed to be fed into the safety assessment but which are still to be determined, have to be soundly estimated for the safety assessment and reasonably varied. The benefit from the earlier safety assessment before exploration is completed is to be aware of the significance of the different geological data for the safety and furthermore the knowledge, with which degree of exactness the geological data have to be explored.

5. Lessons learnt

Input and data selection for PA calculations is a very important part of the process of long-term safety assessment for repositories. It will be critically checked by the licensing authorities as well as by the public. Experiences have shown that questionable data used in PA studies will be identified by critical checkers and can lead to a challenge of the total investigation. Therefore, it is essential to maintain the following rules:

- All relevant data should be determined carefully and according to the state of the art.
- Less relevant data that might be chosen with less care should be justified by means of a sensitivity analysis.
- It has to be made sure that uncertainties are covered either by choosing pessimistic values or by performing a qualified uncertainty analysis.

- The data determination process has to be traceably documented.
- It should never be tried to hide databases or parts of them from the public.

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In Germany three formations have been under discussion for final disposal of heat-generating and high level radioactive waste, namely rock salt, claystone and granite. Integrated performance assessment models for long-term safety assessment have been developed for all three formations. The description here is restricted on safety assessments for disposal in rock salt, which has been the preferred option for several decades.

There is no recent safety case for a repository with heat-generating and high level radioactive waste. The information presented is based on the study SAM for a repository with HLW, SF and ILW from 1991 [BUH 91] and the safety case for the repository for LLW and ILW in Morsleben, ERAM [STO 04].

2. Regulatory requirements and provisions

The guideline ‘safety criteria for the final disposal of radioactive wastes in a mine’ from 1983 requires that the effective dose to a single human individual is below the acceptance level of 0.3 mSv/a given in the German Radiation Protection Ordinance. This has to be shown by consequence analyses with integrated models for relevant scenarios. Currently, revised safety criteria are under development.

In order to allow for the inherent uncertainties in the long-term safety assessment it is the expectation of the regulator that the calculated dose rates are significantly below the acceptance level. Data uncertainties have to be addressed, e.g. in probabilistic calculations.

Programs have to be used, which comply with the state of the scientific and technical knowledge. These codes and the underlying models have to be verified and validated (cf. section 0).

The application of the biosphere model in long-term safety assessment is mandatory under the German government regulations.

3. Key terms and concepts

An overall definition for a model is given by the ICRP: A **model** is a conceptual description of the disposal system or parts of this system, a mathematical description of the concept, and the implementation of the mathematical description in a computer program, and **modelling** is the process of generating a model and applying it to a specific problem [ICR 98].

Usually it is distinguished between a conceptual, a mathematical and a numerical model. A **conceptual model** is a description of a repository system or subsystem and its behaviour in the form of qualitative assumptions regarding aspects such as the geometry of the system, boundary conditions, time dependence, and the nature of any relevant physical, chemical and biological processes, whereas a **mathematical model** is a set of mathematical equations designed to represent a conceptual model. A **numerical model** is a computer code designed to solve the problem defined by the mathematical model.

4. Treatment in the Safety Case

4.1. Methodology

Models used in the safety case are developed and applied on two different levels:

- detailed models to characterise the evolution of sub-systems, or the impact of specific processes, or to generate input data for the integrated models;
- integrated models to perform consequence analysis for selected scenarios of the repository system.

4.1.1. Detailed models

Such models are used to simulate laboratory and in-situ experiments and to better understand specific processes or the performance of subsystems as a whole. In some cases such modelling approaches are directly implemented in integrated models for consequence analyses. However in most cases, when identified as relevant, the respective process is implemented in a simplified form (cf. section 0). Some of the detailed models are only used to generate input data for integrated models.

Examples for detailed models used for the near field in rock salt are

- Rock-mechanical model for calculation of convergence of residual volumes: Convergence is one of the most important processes for a repository in rock salt. Detailed rock-mechanical calculations are performed to describe this process taking into account the impact of important parameters, e.g. fluid pressure, backfill, or humidity.
- Model for corrosion-induced processes in the near field (coupled): A model has been developed, which describes the coupled processes occuring with container corrosion in the case of water intrusion into the emplacement area. The processes taken into account are volume increase, water consumption, precipitation of salt, gas generation, pressure balance, and the impact on convergence.
- Model for source term, geochemical evolution in the near field, precipitation/sorption processes of radionuclides and dissolution/precipitation of different salt minerals: Models are developed to claculate the mobilisation of radionuclides from the waste matrix observed in laboratory experiments. Geochemical codes are used to describe the development of the geochemical conditions in the near field and to calculate element-specific solubility limits. The same codes are used to calculate dissolution/precipitation processes and their impact on changes in porosity/void volumes.
- Model for the long-term behaviour of an excavation disturbed zone (EDZ) around a sealing or backfilled drift: Modelling of compaction processes considering creep and viscoplasticity of the rock salt, which lead to a sealing of the EDZ after return to a normal stress state.
- Model for gas generation and pressure build-up: A specific programme can be used to perform calculations on gas generation in detail including corrosion, radiolysis and

different microbial reactions.

Examples for other detailed models are:

- Model for burn-up and activation calculations of the radionuclide inventory in the spent fuel elements and in the vitrified glass matrix: These models are only used to generate input data for the radionuclide inventory and for the distribution of radionuclides in the different fractions of the spent fuel elements: the spent fuel matrix, the zircaloy cladding and the other metal parts.
- Model for calculation of temperature distributions: These calculations are also performed to calculate input data for the integrated model, i.e. the temperature distributions and its temporal changes in the repository.
- Biosphere model: By the biosphere model dose conversion factors (DCFs) for each radionuclide are calculated assuming today climatic conditions. These DCFs provide the annual dose (Sv/a) to a member of a critical group assuming a unit concentration in the near-surface water (1 Bq/m^3). The dose rates are calculated by the integrated model by multiplication of the radionuclide concentration in the near-surface aquifer and the respective DCFs.

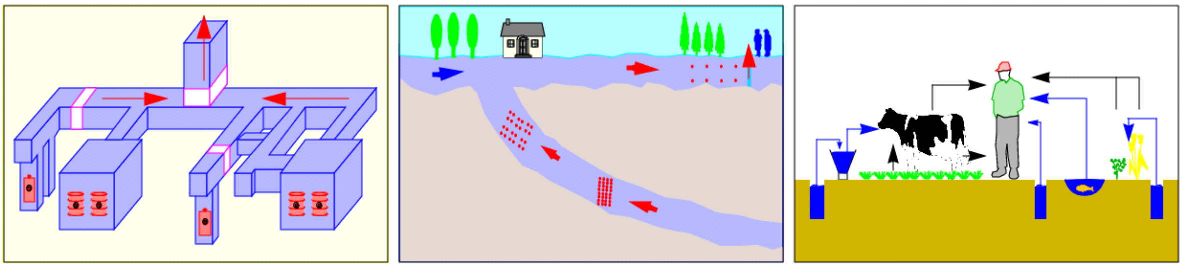
4.1.2. Detailed modelling of the far field

Far field modelling is only of relevance for scenarios, where waste forms get into contact with brine and a radionuclide release from the near field occurs. In current long-term safety analyses for repositories in rock salt only the overburden of the salt dome is considered as the far field. Far-field modelling is done in three phases:

- Modelling of the density driven water flow (2D, 3D)
- Transport modelling (2D, 3D, particle tracking) to identify the transport pathways from the top of the salt dome to the biosphere
- Abstraction of the results from the 2D/3D transport model to a 1D model for performance assessment

4.1.3. Integrated models for consequence analysis

When modelling the disposal system it is advantageous to divide the global system into different parts that can be treated separately, as long as the interfaces between compartments are properly considered. For a repository in salt formations these compartments are the near field (with emplacement boreholes / drifts and infrastructure), the far field (overburden) and the biosphere as schematically shown in Figure 1.



near field **far field** **biosphere**

Figure 1: Schematic representation of the different compartments of the repository system considered for integrated modelling

However, for a repository in rock salt scenarios for normal evolution and altered evolution need to be distinguished. In case of a normal evolution all open voids in the salt dome will be closed after distinct time by convergence. Thereby all potential water pathways will be closed and no radionuclide realease from the salt dome occurs, i.e. the waste is completely confined in the host rock formation. The calculation of this scenario includes the convergence of void volumes, the permeability change of backfill and sealings back to values of undisturbed rock salt and the impact of gas built up by corrosion/radiolysis due to residual water content of the salt formation. All calculations are performed by the near-field model only.

In case of an altered evolution scenario at some point in time, water will get into contact with the waste and radionuclide mobilisation and release will occur. For modelling of altered evolution scenarios the water pathway and the gas pathway are currently distinguished. Processes considered for the water pathway are:

- Temperature distribution and temporal change
- Flooding of the mine by groundwater and water from brine inclusions
- Convergence including spatial heterogeneity and impact of fluid pressure, backfill and humidity of backfill
- Brine displacement by convergence
- Pressure build-up by gas production
- Gas release after increase above external pressure
- Brine displacement by gas storage
- Porosity dependent flow resistance
- Container failure
- Radionuclide release from waste matrix
- Radionuclide retardation by precipitation (solubility limits) and sorption
- Radionuclide transport by advection and diffusion
- Instantaneous mixing in each model segment
- Transport through the overburden (geosphere)
- Exposition in the biosphere

4.1.4. Probabilistic versus deterministic approaches

Deterministic parameter variations are performed for basic safety demonstration, to examine the influence of a single parameter and to improve system understanding. Since the impact of a parameter can be completely different under different conditions (non-linearity of the system), deterministic variation of single parameters is, however, not sufficient.

Probabilistic Monte Carlo simulations (simultaneous variation of all parameters) are carried out to calculate the variability of the calculated dose due to parameter uncertainty and to identify the sensitive parameters according to the correlation between parameter value and calculated dose. This approach is preferred to the practice of a deterministic calculation with a "conservative" parameter set because

- different processes may compete and compensate each other, so that for many parameters it is not evident which choice is "conservative"
- combinations of conservative values for several parameters are weighted with their low probability of occurrence
- sensitive parameters can be identified by their degree of correlation between the parameter value and the calculated dose.

Model calculations are also performed to demonstrate the robustness of the repository system, i.e. when it can be shown that even for pessimistic assumptions for initial states and for the evolution of the repository system the acceptance level for the radiation exposure is not exceeded. However, a systematic investigation of the robustness of the applied models itself has not been performed so far. This issue is currently addressed in a national project.

4.1.5. Simplification / abstraction to PA

In some cases complex models are included into the integrated PA models. An example is the coupled model for corrosion in the near field (c.f. section 0). But in most cases models used on process level are simplified for application in integrated codes. The motivation for simplification is either

- very long computing times due to high complexity or large domains regarded,
- enough data for complex models are not available, or
- the complexity is not needed for description of the process, which, of course, has to be shown.
- A special case is that the model is prescribed by legislation.

Examples for each of these simplifications are given in the following.

Geosphere model: The detailed modelling of the transport in the far field is briefly described in section 0. It is necessary to use a simple 1D model for the integrated PA calculations. The main reason for this simplification is the extremely long computing time needed for 2D/3D calculations of large and complex regions. For the PA calculations, however, many parameter variations and hundreds of runs for statistical Monte-Carlo simulations are needed to assess the influence of the data uncertainties on the result of the calculation and the significance of certain parameters. The model and the input parameters needed to set up a simulation with a 1D code have to be determined by abstraction from the 2D/3D simulations. This can be achieved in different ways. So far particle tracking has been used in the 2D/3D model to determine the main transport pathway and to set up the 1D pathway accordingly. The hydrological units are represented by a small number of different transport sections in the 1D model. This approach can lead to notable differences compared to the 2D/3D model due to the different transport pathways of the different radionuclides. An alternative approach would be the use of a multi 1D model to account for different transport pathways for the different fission products and decay chains.

Mechanistic sorption models: Currently, a lot of studies are performed to develop thermodynamic sorption models. The advantage of these models is that they are able to describe the dependence of sorption coefficients from the geochemical conditions. The direct application of surface complexation models instead of constant Kd-values in the transport codes is only necessary, if changes of geochemical conditions occur and are coupled to the transport, i.e. their application is not necessary for scenarios without temporal changes of geochemical conditions.

However, also for scenarios with temporal changes in geochemical conditions by far not enough data for all radioelements and potential substrates in the overburden of the salt host rock are available. Therefore, these models are only used to back-up Kd-values for important elements for different geochemical conditions and to derive bandwith for these values.

Biosphere model: In Germany, the biosphere model is prescribed by legislation and is specified in the rules for the assessment of the radiological impact of nuclear facilities. This approach is kind of a stylised approach, since only one biosphere model – reflecting the today´s situation and standardised German exposure pathways – is applied and no uncertainties or future changes of the biosphere are taken into account.

4.1.6. Time scales

Usually the same integrated model is used for the calculation of the normal evolution and altered evolutions of the repository over the time scale of 1 million years. However, in case of the normal evolution of the repository at very late time scales beyond 1 million years it is a question to what extent the process of subrosion (the process of salt dissolution from the top of the salt surface connected to the uplift of the salt dome) might lead to a mobilisation of radionuclides when the rock salt is dissolved down to the repository area and cause consequences to exposed individuals. For this hypothetical, very unlikely scenario a different, highly simplified, conceptual model is used, where the activity inventory is distributed homogeneously over the volume of the disposal mine. Thus, the release rates of activity are proportional to the subrosion rate. This simplified approach seems to be justified due to the long period of time (release starts much later than 1 million years), where the detailed information about the geometry of the mine is questionable.

4.1.7. Validation / verification

Due to IAEA the model verification is the process of determining whether a computational model correctly implements the intended conceptual model or mathematical model [IAE 03]. Codes are usually verified by comparison with other qualified codes of similar type or if available for the respective test cases with analytical solutions.

For radioactive waste management IAEA defines validation as the process of building confidence that a model adequately represents a real system for a specific purpose [IAE 03]. Therefore, confidence in the codes is increased by application to as many test cases as possible. Typical test cases for model validation are

- simulation of laboratory experiments and field tests,
- simulation of paleo-systems / natural or anthropogenic analogues,
- comparison with process level models (which is only possible for subsystem models).

4.2. Related topics

Related topics are uncertainty analysis, sensitivity analysis, and criteria for input data selection.

4.3. Databases and tools

For deterministic and probabilistic integrated performance assessment calculations the programme package EMOS is used. It consists of different modules for the compartments near field, far field and biosphere (s. Figure 2). The interfaces of all modules are identical. Thus it is possible to directly connect each of the models with each other, e.g. to investigate the barrier effect of the far-field by one integrated calculation with and one without a far-field module.

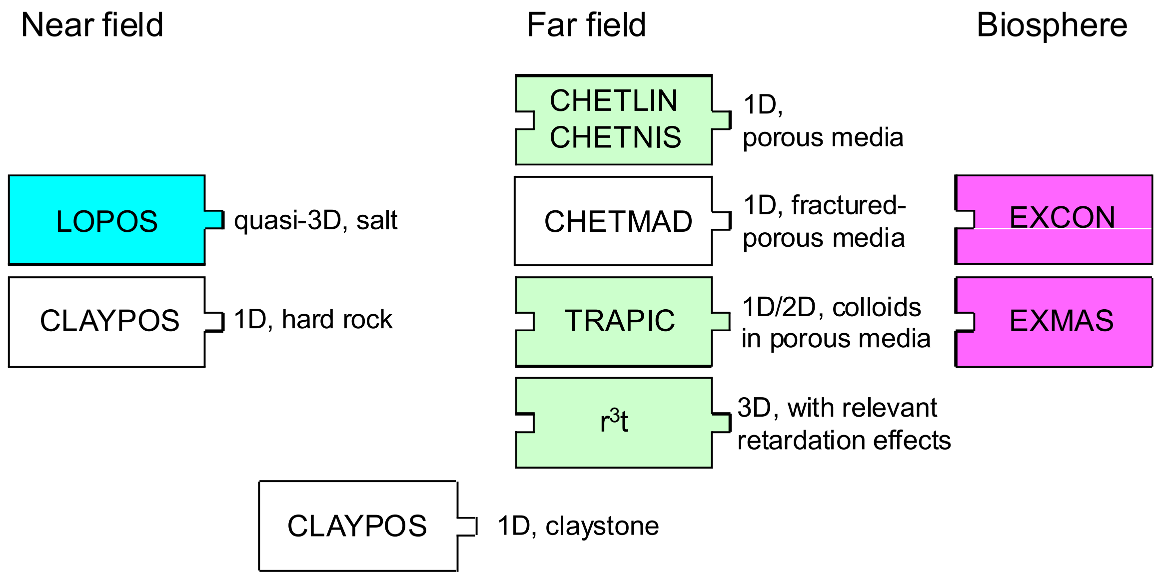


Figure 2: Programme package EMOS with modules for the different compartments. The coloured modules are used for consequence analysis of a repository in rock salt

For detailed modelling several other codes are used like

- the codes OREST and GRS-AKTIV for burn-up and activation calculations
- the codes TOUGH and Code Bright for two phase flow: Currently Code Bright is

further developed to describe the sealing processes in the excavation disturbed zone

- the codes Chemapp, EQ3/6, PHREEQC and GWB for geochemical calculations
- the code d^3f for density driven flow and the code r^3t for transport calculations in the overburden of the salt dome

4.4. Application and experience

The modelling approaches described in section 4.1 have been applied in the long-term safety assessment for a generic repository with all kind of waste in rock salt [BUH 91] and are currently applied in the frame of licensing applications for real repositories with intermediate and low level waste in Morsleben [STO 04, NOS 05] and in the Asse mine.

4.5. On-going work and future evolution

The following topics are currently under development:

- Improvement of source term models based on actual R&D results, e.g. to include the Si release from the waste matrix, the impact of the Si concentration on the radionuclide mobilisation rates and its transport out of the disposal areas.
- Development of a consistent and quality assured German thermodynamic database
- Investigation of the impact of climate changes on flow and transport in the overburden and on biosphere processes
- Adaption of codes to calculate additional indicators, which are currently discussed within the revision of the German safety criteria, to demonstrate the isolation of the waste.

Furthermore GRS is involved in PAMINA WP 4.2, where methods will be developed to transfer geosphere information from detailed codes to PA transport models (cf. section 0).

5. Lessons learnt

The application of the models in current implementation processes for the repository for low and intermediate level waste in Morsleben and in the Asse Mine has shown that the basic structure of the integrated model is suitable. During the application the necessity was recognised to further improve models in order to simulate specific processes, which might have not been identified by analyses of a generic repository. Examples are the implementation of gas storage processes and brine flow through an EDZ.

Another lesson learnt is that a quality assurance and consequent documentation of the codes is vital, in particular for longer lasting repository projects, in which knowledge might get lost by experts leaving before finalisation of the project.

The participation in international projects dealing with performance assessment modelling is also very valuable. It represents a good platform for code intercomparisons which is usually not possible on national level, due to a limited accessibility of suitable codes.

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A5 GRS-K (Cologne, Germany)

Peter Jürgen Larue, GRS

Revision: 1

30 January 2009

Contents

1. Background/ Introduction

In Germany, the present regulatory requirements for the disposal of radioactive wastes in geological formations date to 1983 /BMI 83/ (“safety criteria”). Since then, regulatory expectations have advanced, now reflecting the international standards set out by ICRP /ICRP 98/, NEA /NEA 04/ and IAEA /IAEA 06/. On this account, GRS drafted “Safety requirements for the disposal of high active wastes in deep geological formations” /BAL 07/ on behalf of BMU, which is expected to serve as a sound basis for a new regulation.

Based upon the GRS proposal /BAL 07/, BfS workshop’s results /BRE 07/ and BfS recommendations as of June 2007 as well as the evaluation of the GRS proposal prepared by BMU’s (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety) advisory bodies “Reaktor-Sicherheitskommission (RSK)” and “Strahlenschutzkommission (SSK)”, BMU carries out the final elaboration of the Safety Requirements. A draft Version of the Safety Requirements of BMU was presented on web in 2008 /BMU 08/.

Criteria for input and data selection are not mentioned in the safety criteria /BMI 83/, hence the existing regulatory requirements in Germany do not demand data selection explicitly. At the most, it could be stated, that there is an implicit requirement for application of input and data selection, which results from the general demand to perform safety assessments according to the state of the art of science and technology.

Therefore, the main focus of this contribution is on the safety requirements in their draft format /BAL 07/ and /BMU 08/, which comprises the present regulatory expectations with regard to input and data selection.

2. Definition of terms and used concepts

In the definitions and explanations of terms of /BMU 08/ input and data selection is general required for the “Safety case”:

“The safety case comprises data, measures, analyses and arguments documenting compliance with these Safety Requirements and hence the safety of the final repository, together with the testing and evaluation thereof.”

3. Regulatory context

Quantitative data is required in order to be able to conduct meaningful safety assessments. But the later the period in SA for which data is given, the greater the uncertainties become when calculating the repository’s impacts. If the uncertainties rise to such a degree that almost any result could be produced, such calculations will have very little documentary value. Quantitative observations and analyses may be replaced with qualitative ones, provided adequate containment of the pollutants can be assumed on the basis of long-term geoscientific forecasts and adequate empirical data.

When performing deterministic calculations as evidence of long-term safety, the admissible test values (e. g. corrosion rate of waste containers, age of groundwater, transport speed of any pore water contained in the isolating rock zone, risk of serious health damage) must be complied with. Deterministic calculations should be based on as realistic as possible modelling (e.g. by use of median values as input parameters) /BMU 09/. Additional calculations should be carried out with parameter and (where applicable) scenario / model variation, in order to analyse the uncertainty of the results of deterministic calculations /BMU 08/

3.1 Regulations and guidance

At present, no legal regulation exists in Germany which demands a specific data selection in the framework of a safety case (SC) respectively safety assessment (SA).

In /BMU 08/ only general requirements for input and data selection are mentioned for the safety case, the safety analysis and its review:

“During exploration, the applicant shall ascertain the principal site data relating to safety of the repository in an adequate level of detail as required for the safety cases. Where this requires the quantitative determination of site data, the accuracy / range of and any potential changes in such site data under emplacement conditions should be ascertained. The applicant must prove the validity of such data to the licensing authority. Where data obtained from other sites is to be used, the transferability of such data must be justified.” (Section 8.10. in /BMU 08/)

“For long-term forecasts, where applicable, reference data and reference models should be used for periods during which the uncertainty of the input data and calculation models is so high as to cast doubt on the validity of the results. Qualitative evidence should additionally be used for such periods”. (Section 8.6. in /BMU 08/)”

“In order to review the safety assessments for emplacement operations, decommissioning and the post-closure period, a measurement programme should be carried out which can be used to analyse the input data, assumptions and statements of these safety assessments. In particular, this measurement programme should record the impacts of thermo mechanical rock reactions to heat-generating waste, geotechnical measures, and rock-mechanical operations. For evidence purposes, such measurements should continue to include the initial status and the development of activity concentration in spring water and groundwater, soil, water bodies and the air within the repository’s sphere of influence. Significant deviations from the relevant data, statements and assumptions in the cited safety cases should be notified to the competent authority immediately, and evaluated with regard to their safety relevance. If necessary, counteractive measures should be carried out by the operator in order to avoid any impairment to important safety functions. Where approval is needed for such counteractive measures, this should be obtained by applying to the competent authority. The competent authority shall also decide on discontinuation of the measurement programme.” (Section 8.8. in /BMU 08/)

3.2 Requirements and expectations

As mentioned in the introduction, regulatory expectations have advanced since 1983. They are set out in /BAL 07/ and /BMU 08/, which is expected to serve as a draft for a updated guideline for safety requirements for geologic disposal and – as such – is outlined in Section 3.4.

3.3 Experience and lessons learned

GRS Cologne works as TSO for licensing bodies in the framework of the review of safety analyses performed by the implementer by own expertises. GRS is not responsible for evaluation data which are selected for SA ore measurements or laboratory experiment to get this data. Up to now these evaluations were done by the Geological Survey of the land, where the repository is licensed.

3.4 Development and trends

The safety requirements draft /BAL 07/ comprises both, the international developments of the past decade (mainly /ICRP 98/, /NEA 04/ and /IAEA 06/) and the national trends emerging from expert group discussions.

The draft guidelines /BAL 07/ and /BMU 08/demand input and data selection in the framework of site specific safety analyses as basis for the lay out design of the repository system. The requested procedure and process of input and data selection are not prescribed in detail. This will be done in guidelines which are under development.

4. Analysis and synthesis

Input and data selection are not subject to existing legal regulation in Germany. To-day's regulatory expectations are set out in the "Safety requirements" /BAL 07/ and the draft Version of "Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste" /BMU 08/, which are expected to serve as in draft for a new regulation. This safety requirements draft general demand site specific input and data selections as basis for the lay out design of the repository system as well as an in the safety case. The request for input and data selections as a part of the performance assessment to demonstrate long-term safety in the safety case reflects the IAEA standard /IAEA 06/.

It can be stated that no details are prescribed on how to perform input and data selection and which methods and processes to be used. This underlines the general strategy in the 1983 regulations as well as the 2007 draft, to set state-of-the-art standards for input and data selection to demonstrate safety, but to leave the final details of how to provide evidence up to the implementer (and their appraisal up to the regulatory body).

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A6 NDA (United Kingdom)

1. Introduction

This document gives an overview of the NDA's approach to data gathering which contributes to the radiological performance assessment, the environmental impact assessment, the engineering design and the scientific understanding to the support the different stages in the development of a geological disposal facility in the UK. The data are derived from a number of studies: an assessment of the current (2007) radioactive waste inventory of the UK; data from a proposed site characterisation project to identify key site information; data from an ongoing research programme.

2. Regulations and guidelines

The piece of UK regulation that would apply to radioactive discharges from a closed repository is the Radioactive Substances Act 1993 (RSA93) [1]. This legislation is quite general, and applies to a great variety of situations where there may be discharges of radioactivity to the environment. In October 2006, Government announced that higher activity wastes would be managed in the long-term through geological disposal and that the NDA would be the implementers. Relevant agencies published new guidance in February 2009, known as the 'Guidance on Requirements for Authorisation' (GRA) [2], which outlines how an application for an RSA93 authorisation would be judged in the specific case of land based disposal of solid radioactive waste. This GRA updated the previous Guidance, published in 2007 [3]. The new GRA has been split into two documents, one dealing with near-surface disposal and another dealing with deep geological disposal.

In terms of specific recommendations on data the GRA requires assurance of the adequacy of a developer's proposals for collecting information and data to support a decision to start underground operations and to support a decision to move to each stage of development. The GRA outlines requirements for the developer to have procedures for documentation and record keeping, quality management of data, and to be alert to possible future changes to standards and to basic data. In circumstances where there is uncertainty due to lack of relevant data it recommends the use of expert judgement and states that where "*few or no relevant data can be gathered, a 'stylised ' approach may be adopted, in which arbitrary assumptions are made that are plausible and internally consistent but tend to err on the side of conservatism*".

In June 2008, as part of the Government's "*Managing Radioactive Waste Safely*" (MRWS) programme, a White Paper was published entitled "*A Framework for implementing geological disposal*" [4] which includes the framework for selection of a candidate site or sites at which detailed investigations will be carried out. The UK geological disposal facility programme is being conducted in the context of this White Paper.

3. Terminology

NDA's approach to terminology is to try to avoid the use of jargon wherever possible. Where specialist terminology is required, NDA tries to use existing terms wherever possible, for example terms that are defined in national regulations or which are defined internationally, for example by the IAEA or NEA. In these ways NDA seeks to avoid introducing 'new' terminology.

4. Treatment

Performance assessment begins with a wide-ranging consideration of all the features, events and processes (FEPs) that could affect long-term performance of a disposal facility. Having identified relevant FEPs, we consider the potential interactions between them, for example through the development of a FEP interaction matrix diagram. The process of developing the matrix diagram leads to the specification of conceptual models that require development and representation within the performance assessment, and hence the highlighting of areas for data collection and further research.

The remainder of this section considers the broad areas in which data are required, namely inventory, site-specific data from site characterisation activities and other research data.

4.1 Inventory

4.1.1 Background

The Department for Environment, Food and Rural Affairs (Defra) and the NDA have commissioned the 2007 UK Radioactive Waste Inventory to provide information on the status of radioactive waste at 1 April 2007 and forecasts of future arisings in the UK [5]. The UK Radioactive Waste Inventory is updated periodically to capture the impacts of changes in plant operating lifetimes, decommissioning programmes and waste management strategies.

The UK Radioactive Waste Inventory includes information on the quantities, types and characteristics of wastes for each of the main organisations producing wastes. It also presents information on the radioactivity and the material content of the wastes including high, intermediate, low level wastes and high volume very low level wastes. The Inventory addresses radioactive waste materials produced from uranium enrichment, nuclear fuel manufacture, nuclear power production, spent fuel reprocessing, research and development, medical and industrial sources and defence activities.

4.1.2 Data compilation

Preparation of the 2007 Inventory has involved the compilation and assessment of detailed numerical and descriptive information for 1,269 waste streams produced in the UK. The data have been provided by the organisations that operate sites in the UK where there are radioactive wastes. Data relating to defence activities has been included on a voluntary basis. Information on these wastes was gathered by requesting the data in a standard form for each waste stream. Over 200 persons across all waste producing sites were involved in providing the data.

The following information is given for each waste stream:

- Name;
- Waste classification;
- The volume of waste at 1 April 2007;
- Radioactivity concentration;
- Material composition;
- The forecast total number of waste packages;
- Current or planned treatment and packaging.

4.1.3 Data assessment

Each waste stream in the inventory is allocated a unique identifier. Each site is identified, together with the site owner and waste custodian. For sites with operational and decommissioning wastes, the operational waste streams are listed first.

The authors of the 2007 inventory independently assessed all information supplied for each waste stream. The assessment included:

- Checking for internal consistency and completeness;
- Comparison of the information with data for related waste streams;
- Comparison of the information with that in the 2004 Inventory;
- Evaluation of the adequacy and validity of the information.

Feedback was provided, as a result of which some revisions to data were made by waste producers.

4.1.4 Uncertainty in inventory data

The precise timing of decommissioning and the procedures to be used are often yet to be finalised, so waste volumes, and the timing of their arising, are usually subject to greater uncertainty than for operational wastes.

For most existing wastes there is a high level of confidence in the volume, based on measurement. In general there is reasonable confidence in estimates of future arisings from operations over the next 5 years. Uncertainty increases the further that operational waste arisings are projected into the future. The greatest uncertainty rests with future arisings of waste from facilities decommissioning and site clean up. This is particularly the case for wastes at the lower end of the low level waste activity range, where uncertainty about regulatory requirements and disposal routes, lack of definition of site decommissioning and clean up plans, and the fact that much characterisation work remains to be carried out, make estimation of waste volumes difficult.

4.2 Site characterisation studies

4.2.1 Background

As the site and design for a geological disposal facility in the UK have not yet been chosen, the NDA is currently developing a 'generic' safety case to support the different stages in the implementation of a geological disposal facility. As we start to assess specific sites, we will be able to refine our approach to include site-specific parameters.

Once a site has been identified site characterisation will be needed to confirm that the candidate site has properties suitable for the geological disposal facility. The information acquired will be used as input to the development of a post-closure safety case to demonstrate that hazardous substances disposed in the facility will not be transported to the accessible environment in quantities that might lead to an unacceptable risk. The safety case therefore requires a wide range of different types of information from the site characterisation programme (e.g. geology, hydrogeology, geochemistry, repository design etc.) and provides feedback and guidance as to which parameters and processes should be being investigated and the level of detail or precision required. The site characterisation study will inform and interact with both engineering design and waste packaging through the need to demonstrate that the disposal system has been optimised. The safety case therefore requires the following:

- Information to demonstrate a good understanding of the current-day system and how the system might change in the future. This includes the consideration of how the properties of the geosphere might evolve over time in response to processes such as climate change or in response to the presence of the geological disposal facility;
- Information to support the scenarios that are developed for assessing the future evolution of the system;
- Detailed information on transport parameters along the potential transport pathways to support the numerical performance assessment models.

A sufficient understanding of the present state and the previous evolution of the site will therefore be dependent on the quality of both the available data and its interpretation. Nirex[†] produced a status report [6] on its geosphere and biosphere characterisation project in 2006.

4.2.2 Stages of site investigation

The process of site characterisation is comprised of five inter-related stages:

- Data acquisition – to obtain measurements and to collect data utilising a range of measurement techniques and surveys;
- Data processing – to transform measurement data into information that is meaningful in terms of the properties of the site;

[†] United Kingdom Nirex Limited (Nirex) was integrated into the NDA as the Radioactive Waste Management Division (RWMD) in March 2007

- Interpretation – to understand the significance of that information in terms of the individual aspects of the site (e.g. groundwater flow, geology, environmental processes, etc);
- Integration – to develop a self consistent understanding of the site as a whole which includes all the individual aspects;
- Communication – to communicate the understanding obtained to others (e.g. those involved in performance assessment, engineering design and key stakeholders) and to obtain feedback that could influence the ongoing process of site characterisation.

The overall site characterisation will be carried out in a series of stages. The approach which was adopted for the Sellafield investigations in the 1990's [7], was to organise the activities in a parallel manner. At discrete, pre-determined stages during the investigations there are 'data freezes' at which stage the interpretation activities commence followed by engineering design and safety assessment studies. However, during this time further investigations are progressing. At the next data freeze further information is fed into the interpretation, design and safety assessment teams such that they can maintain a rolling programme of work. Monitoring the progressive development of the engineering design and safety assessment through the stages following each of the data freezes may provide a means of evaluating progress towards completion of the surface-based investigations. It is envisaged that these reviews may need to be conducted by some form of independent review group in a manner that generates confidence with the key stakeholder groups. It is likely that any future UK site characterisation programme will be organised in a parallel manner to enable the opportunity for feedback.

4.2.3 Information needed for site descriptive models

The process of site characterisation is usually undertaken by the development and progressive updating of a series of discipline based 'Site Descriptive Models' [8]. The descriptive models are a convenient means for interpreting and presenting the results of investigations at a site. The various descriptive models do not exist in isolation and there is transfer of information between models. The descriptive models are also used as input to the performance assessment models and engineering designs for the facility at the site.

The descriptive models that may be developed for a UK site are likely to include the following:

- Geology
- Hydrogeology
- Hydrochemistry
- Geotechnical
- Transport properties
- Thermal properties
- Biosphere

The geology model provides the framework on which all the other models are built because it gives a basic understanding of the nature and distribution of the various rocks and soils that are present at the site. The information needed and the method of measurement for each of the descriptive models are given in [6] and [9].

Descriptive models may change significantly as new information on and understanding of site characteristics is obtained. However, as understanding develops during the later stages of the investigations, it is anticipated that the descriptive models will become stable and not change significantly as further information is obtained. Hence, the stability of site descriptive models is also a potential criterion for defining completion of the surface-based investigations.

4.2.4 Quality control of data

Documentation, record keeping and quality management are key requirements to the provision of information as outlined in the GRA [2]. A quality plan will be prepared to cover all activities related to the site characterisation programme. The intended use of the data will be documented as part of the planning, other uses of the data will be evaluated and justified. The quality plan will assure the compatibility of data derived from scientific investigations with any conceptual or mathematical models. The quality plan will also establish provisions for the evaluation of data quality to assure that the data generated are, as far as possible, complete, representative and accurate. Uncertainties in data and their analyses will be identified and documented. A data management system will be planned in advance of characterisation activities to ensure the highest standards of data access and storage. Peer reviews of methods and documentation will be employed to provide additional confidence in the data gathering and storage process.

The NDA has been working in collaboration with the British Geological Survey to develop a high-level data management strategy [10]. It will be essential that the systems are in place, tested and are fully operational before acquisition of investigation data commences. Such a system would ensure that the data are:

- Coherent and consistent through the application of scientific standards;
- Captured and processed using industry standard data capture systems;
- Provided with a clear audit trail to data sources;
- Managed in an environment that permits full version control and maintenance of archives;
- Accessible as and when required;
- Maintained in a secure and controlled environment.

4.3 Research data

All modelling work is underpinned by data. The NDA uses data from a variety of sources, including laboratory experiments, field tests and large-scale experiments, site investigation, literature searches and comparisons with natural phenomena. Not all data will be obtained in the format required by the models and it is unlikely that a complete data set will be available.

Some data will require processing prior to use in models. This is particularly true for geological and hydrogeological data obtained from field tests and site investigation. For example, initial data processing and upscaling take account of the fact that a rock layer may be non-uniform in its properties and that there will be variability on different length scales. Measurements taken on a relatively small length scale need to be 'upscaled' in order to represent a larger rock mass.

Some data will require extrapolation or interpolation because the actual data available are incomplete or do not relate to the exact conditions experienced by the repository system. For example, as it is not possible to conduct experiments over the very long timescales (thousands of years) for which it is required to assess the performance of the disposal facility, information concerning the evolution of the facility may need to be extrapolated from data obtained from much shorter timescale experiments. Expert judgement may be combined with the available empirical data to elicit a full data set or manage the consequences of uncertainty associated with the available data, in particular the selection of probability density functions (PDFs) for certain parameters [11].

In terms of data, there is the question of how much data will suffice. This is linked to the handling of uncertainty in performance assessments, which is discussed in [12]. The overall aim of data gathering is to build sufficient confidence in the safety case that it provides a sound basis to inform the decision being taken at that stage of the facility development process. The accuracy and reliability of the models is clearly an important part of that confidence, however the quantitative performance assessments results are only one component of the overall safety case. They should be complemented with evidence from other sources, for example comparison with data from natural analogues.

5. Applications and experience

A future site characterisation and data gathering programme in the UK is likely to take advantage of the knowledge and experience gained previously from site characterisation and research programmes, including:

- Experience gained by Nirex from the management of previous characterisation programmes at potential sites for near-surface facilities [13] and geological repositories [7] in the UK;
- Experience gained by sister organisations to the NDA through the management of characterisation programmes in other countries. In particular, fact-finding visits have been made to SKB in Sweden and Nagra in Switzerland, together with a review of documents and reports that have been published by these and other sister organisations related to the design and implementation of geosphere characterisation programmes;
- Two studies have been commissioned by Nirex and undertaken by the British Geological Survey dealing with the availability of data on the deep geology in the UK onshore area [14] and the requirements for the design and implementation of a database system [10].
- Discussions and workshop meetings have been held with a range of UK-based specialists in performance assessment, engineering design and project management to seek their input on specific aspects of site characterisation;
- The NDA research programme which covers a vast range of subjects involving scientists from many organisations, both in the UK and abroad.

6. Developments

The current and future activities related to data needs for site description and safety case models are to:

- Update the UK radioactive waste inventory to reflect changes in waste management strategies, decommissioning programmes, commercial, technological or regulatory reasons, and current information;
- Complete the study to develop a strategy for the development of a data management system to store and manage the information arising from a characterisation programme;
- Continue with the studies to develop an improved definition of discipline-based information requirements for a site characterisation project with peer review by a group of specialists;
- Continue to identify gaps in information in the models that would need to be addressed by site investigations;
- Further develop the procedures for addressing uncertainty in data;
- Develop a strategy for communication of information on the site geosphere characterisation to all interested stakeholders. This entails: organisation of data and information in a form that it is readily available to potential audiences ranging from a lay audience to technical specialists; the use of appropriate reports, brochures, and web sites together with a 'helpline' for requests for information;
- Maintain the research and development programme on: wasteform research; gas generation; near-field research; geosphere research; biosphere research and criticality safety research.

7. Conclusions

The 2007 UK Radioactive Waste Inventory is the latest public record of information on the sources, quantities and properties of radioactive waste in the UK at 1 April 2007 and predicted to arise after that date. Revision of the predictions, particularly of the long-term forecasts, may be necessary as plans change and estimates are refined.

The NDA believes, on the basis of the documented site characterisation project and past experience that, in principle, it is practicable to characterise a site for the development and implementation of a geological disposal facility in the UK, and a programme of site characterisation could be implemented by the NDA, if requested to do so.

8. References

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A7 NRG (The Netherlands)

note

to :	Topic coordinator 'Criteria for Data Selection'	
from :	J. Hart	Petten/015.017
copy :	J.B. Grupa, A. Poley, T.J. Schröder	
date :	24 February 2009	
reference :	21952/09.93897 RE/JH/MH	
subject :	NRG Contribution to topic 11 'Criteria for Data Selection'	

Section 1: Background/ Introduction

In the late 1980's the VEOS study (Safety evaluation of disposal concepts in rock salt) has been performed in the Netherlands [1, 2, 3, 4]. The aims of this study were the evaluation of the post-closure safety of some possible disposal concept and the determination of relevant characteristics. VEOS used a scenario approach followed by a deterministic consequence analysis and several deterministic sensitivity studies. The analyses resulted in a number of release scenarios with estimated exposure. For some scenarios with a relatively high exposure the probability of occurrence was also calculated. The resulting risk defined as the product of this probability and the health effect of the exposure was below the risk levels set in neighbouring countries and the IRCP.

In the early 1990's a generic probabilistic safety analysis (PROSA, [5]) of the Dutch generic reference disposal concept has been performed. The PROSA study had two equally important aims, viz. the determination of the radiological effects on humans and the derivation of safety relevant characteristics of a disposal concept for radioactive waste. These characteristics have been derived from sensitivity analyses of the radiological consequences of some disposal concepts in rock salt formations. The PROSA study was restricted to the safety in the post-closure period.

The methodology used for the scenario selection was based on the idea that a repository is a multi-barrier system which' evolution can be characterized by the state of its four barriers:

- the engineered barriers
- the isolation shield of salt around the repository
- the overburden, and
- the biosphere itself

In addition it was assumed that the first three barriers could have two possible states: i) present and ii) by-passed. This implies that there are 8 possible states of the multi-barrier system. For each barrier state a number of FEPs can then be found which are defining the state of the barrier. These primary FEPs were used to define the scenarios. The remaining FEPs were considered as "secondary" FEPs and described the transport of the nuclides. The

methodology implied that each FEP has to be judged carefully in order to establish whether it is of importance and if so how the role will be and in which part of the repository the FEP applies.

The PROSA study used a systematic approach to scenario selection that ultimately led to a set of representative scenarios that covered all aspects relevant for the long term safety. The method used a FEP catalogue to show comprehensiveness of the obtained set of scenarios.

Two different types of calculations were performed: a probabilistic analysis of the nuclide transport for the subrosion scenarios, and a deterministic analysis for the water intrusion scenarios. The sensitivity analysis aimed at finding the input parameters having the strongest influence on the exposure, whereas the uncertainty analysis aimed to quantify the output variability.

The PROSA study was carried forward and extended in the CORA program [6], in which the options for retrievable storage and disposal of radioactive waste in the Netherlands were investigated, both for a salt-based and clay based repository.

Section 2: Regulatory requirements and provisions

A central policy consideration of the Dutch Government is a stepwise approach to finding waste management options that are feasible, suitable and acceptable, in both technological and societal respects, is. Based on three policy documents, published respectively in 1984 [7], 1993 [8] and 2002 [9], the current strategy can be summarized as follows:

- long-term interim storage in purpose-built stores at COVRA, the Dutch site for surface storage of radioactive waste, for at least 100 years;
- ongoing research, preferably in international collaborative programs;
- eventually retrievable[13] deep geological disposal.

There are presently no regulatory requirements and provisions that directly relate to the topic of "human intrusion". Indirectly however several laws regulate the public against hazardous materials. For example, with regard to nuclear energy, the purpose of the Nuclear Energy Act [10] is to regulate (Article 15b) the protection of people, animals, plants and property. In addition a number of decrees have also been issued containing additional regulations. The most important of these in relation to the safety aspects of nuclear installations are:

- the Nuclear Installations, Fissionable Materials and Ores Decree (Bkse),
- the Radiation Protection Decree (Bs).
- the Transport of Fissionable Materials, Ores, and radioactive Substances Decree (Bvser).

[13] Retrievability means the deposition of radioactive waste in a way that it is reversible for the long-term by proven technology without re-mining.

The Nuclear Installations, Fissionable Materials and Ores Decree regulates all activities (including licensing) that involve fissionable materials and nuclear installations. The Radiation Protection Decree regulates the protection of the public and workers against the hazards of all ionising radiation. It also establishes a licensing system for the use of radioactive materials and radiation emitting devices, and prescribes general rules for their use. The Transport of Fissionable Materials, Ores and Radioactive Substances Decree deals with the import, export and inland transport of fissionable materials, ores and radioactive substances by means of a reporting and licensing system. The Nuclear Energy Act and the above mentioned decrees are fully in compliance with the relevant Euratom Directive laying down the basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation. This Directive (96/29/Euratom) is incorporated in the relevant Dutch regulations.

Section 3: Key terms and concepts

The Dutch concept for an underground facility for disposal of radioactive waste is still being developed. In the Netherlands attention mainly has been focused on suitable salt domes in the northern part of the country and clay layers in the south. Since the Dutch radioactive waste will be stored in the COVRA (Central Organization for Radioactive Waste) surface interim storage facility for a long time (up to some 100 years) the determination of a suitable concept is at present not a critical issue. For the safety assessment of an underground repository for radioactive waste the PROSA methodology was developed for the determination of scenarios.

There are currently no actual plans to transfer this waste to a national deep geological repository. However there have been several options investigated in the Netherlands, mainly within the above-mentioned PROSA and CORA programmes. Both the options of disposal in rock salt (cf. Figure 1) and in Boom clay, which are both abundantly present in the Netherlands, were investigated.

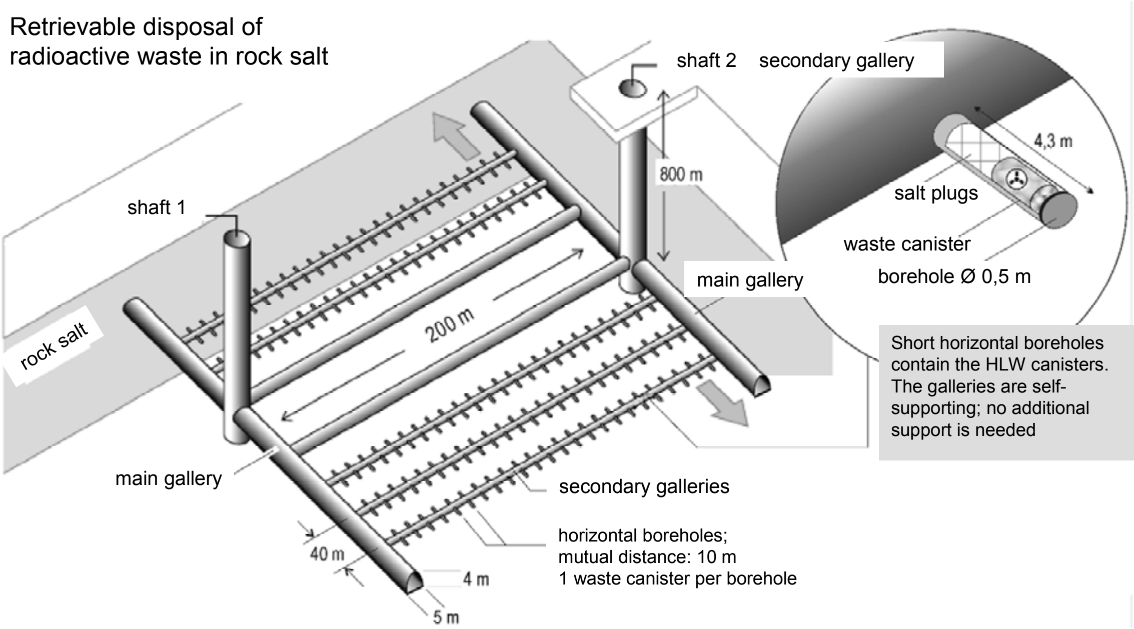

Figure 2 Rock salt based option for retrievable disposal of radioactive waste [6]

Section 4: Treatment in the Safety Case

Section 4.1.1: Methodology

The modelling strategy in the Dutch PROSA study has been described extensively in the PROSA Final Report [5], and summarized in NRGs contribution to the PAMINA WP1.1 Topic 7 "Modelling Strategy". In the present section the modelling of the human intrusion that has been carried out within the PROSA study is summarized.

<u>Overview of the PROSA Methodology</u>

In the PROSA study a scenario type of analysis has been followed by a probabilistic consequence analysis. This implied the following steps:

1. identification of FEPs which might influence the state of the barriers, the release, transport, and state of radionuclides. The list should be comprehensive and not be restricted to FEPs induced by nature or the waste but also contain human induced FEPs. An overview of the FEPs that were considered to play a role from the human intrusion point of view is given in the next section "FEPs – human induced phenomena - post-closure and sub-surface activities".

2. First screening of the list of FEPs. The first screening of this list was performed with respect to the type of host rock (repository in a rock salt formation) and the probability

of occurrence.

3. Classification into primary and secondary FEPs. A primary FEP directly attacks or bypasses one or more of the barriers from the multi-barrier system. The primary FEPs consequently define the state or evolution of the repository. In particular they lead to a change in the size or the short circuiting of the barriers. The remaining FEPs were defined as the secondary FEPs. These FEPs influence the transport and the state of the radionuclides. The secondary FEPs define the transport and the state of the nuclides for a given state or evolution of the repository and should be included in the transport model and/or code.

4. Definition of possible multi-barrier states (MBS). In the definition of the state or evolution of the barriers in the multi-barrier system a simple division into attacked or by passed was proposed. Here also a relatively small number of barriers was proposed to limit the number of possible MBS. The main reason for the use of the MBS was the simplification of the further screening prior to the combination of primary FEPs.

5. Assignment of the primary FEPs to each of the multi-barrier states taking into account that some processes attack more than one barrier.

6. Screening of the FEPs for each of the multi-barrier states. In this screening a classification of FEPs with respect to time was considered very helpful.

7. Definition and selection of the scenarios to be analyzed further. This step also included the selection of the processes to be taken into account in the consequence analysis.

8. Determination of the secondary FEPs for each of the multi-barrier states.

9. Scenario selection, (see Topic 6 'Evolution of the Repository System')

10. Determination of the probability of the scenarios,

11. Determination of the calculation model,

12. Determination of the parameters and their probabilities,

13. Dose calculation,

14. Reliability assessment (see Topic 7 'Modelling Strategy')

15. Sensitivity and uncertainty analysis.

The scenarios were screened on the basis of the results of the previous VEOS study and arguments related to the availability of detailed models. The remaining list of scenarios to be analysed consisted of 2 subrosion scenarios, 4 groundwater intrusion scenarios, and 1 human intrusion scenario.

To facilitate the consequence analysis of these scenarios for each compartment in the transport model a list of FEPs has been developed that were taken into account. These FEPs have been accounted for in the three compartments of the transport and exposure model or in the data and resulted in a set of calculated dose rates for the different cases. One set of FEPs related to human induced phenomena and it listed below for the post-closure and sub-surface activities. This list covers step i) of the afore-mentioned list of steps of the PROSA methodology.

Section 4.1.2: Data Selection

A principal criterion for the selection of model data that have been applied in the VEOS, PROSA, and CORA studies was that the data must be generic, but representative of the conditions that are met in the underground and biosphere of the Netherlands.

The next sections provide an overview of the data that have been applied in the mentioned studies, and, in some cases, the reasoning behind the utilization of these data.

The performance assessment of the Dutch safety case was done using the EMOS computer program [11]. The computer program EMOS (Endlagerbezogene MOdellierung von Szenarien) has been developed by GSF, Germany, for assessing the consequences of the release of radionuclides from a repository in a salt formation, the subsequent nuclide transport through the geosphere, and the release of the nuclides into the biosphere EMOS is a so-called lumped-parameter code which means that within a chosen control volume, spatial differences of thermal hydraulic variables, like fluid density, concentration, and temperature, are neglected.

The code package can be used for a deterministic as well as a probabilistic consequence analysis. The original code contains three separate modules representing the three different compartments in a repository system:

- REPOS; In REPOS (REPOSitory) a complete disposal mine with all technical barriers can be modelled. REPOS has models for the release of radionuclides from different types of containers and waste forms.
- MASCOT - MASCOT analyses the nuclide transport in the geosphere. The code calculates the time dependent two or three dimensional nuclide transport in an infinitely extended porous and homogeneous continuum. The groundwater flow field is obtained separately from the METROPOL simulations. This was done since the groundwater flow model in MASCOT is only represented by a uniform vertical velocity. In order to apply MASCOT in PROSA it was combined with the models for the repository (REPOS) and the biosphere (EXPOS).
- EXPOS calculates the radiation ExPOSure in terms of maximum dose rates for individuals or groups based on dose-conversion factors.

Each of these modules as well as their respective sub-modules requires their own set of input parameters. A summary of these parameters will be given in the subsequent paragraphs.

REPOS Module – General data of physical and chemical quantities

In the PROSA study best estimate values of most parameters were applied to models in the REPOS-code. These data refer to the properties of the main materials rock/crushed salt, brine and waste with their related properties. The numerical values were obtained by studies previously performed before the PROSA study, from experiments done in the Asse mine, or engineering judgment.

- Rock salt related properties
  - Rock salt temperature
  - Petrostatic pressure
  - Density
  - Young's modulus
  - Coefficient creep/convergenee relation
  - Exponent convergence-pressure relation
  - Exponent pemeability-porosity relation
- Coefficient permeability-porosity relation
  - Activation energy salt
  - Coefficient of diffusion
  - Permeability of dams
  - Permeability-factor for in- and throughflow phase
  - Porosity of dams

REPOS Module – Waste Mixture

The foreseen radioactive waste originates from reprocessing of the spent fuel elements from nuclear power plants, reactor operation and decommissioning, and from hospitals and laboratories. The majority of both the radioactive fission and activation products as well as actinides contained in the spent fuel is concentrated at the reprocessing plant in the High Level Waste (HLW). The remainder of the activity is treated and conditioned using methods appropriate to medium (MLW) and low level waste (LLW) with low concentrations, but large volumes. The HLW is conditioned at the vitrification facility into borosilicate glass matrix. In addition to the waste from reprocessing and reactor operation also waste from hospitals and laboratories has been considered.

The detailed inventory and properties of the reprocessing waste were derived from COGEMA specifications by NAGRA. The COGEMA specifications are based on the reprocessing of low enriched uranium fuel with a bum-up of 33 GWd/ton uranium three years after discharge from the reactor. The inventory and properties of the other wastes, from reactor maintenance and decommissioning and hospitals and laboratories, were also taken from the NAGRA study [summarized in Ref.4].

REPOS Module – Element Data

The concentrations of the nuclides in brine are restricted by the solubility limits of the corresponding elements. The transport of radionuclides out of a conceptual model segment is limited to the radionuclides in solution and the surplus of the radionuclides precipitates in the segment under consideration. In the PROSA study the best estimate values of the element specific solubility limits for High- and Medium Level Wastes in the respective segments were applied. The data originated from earlier studies (e.g. [1] to [4]).

REPOS Module – Geometrical Data

The specific segment and canister data concerns the geometrical and volumetrical data of galleries, sealings,-dams and excavations for disposal. These sets of data were determined in the phases preceding the PROSA study [4].

REPOS Module – Glass Dissolution Rate

By many experiments the glass dissolution rate has been shown to be time-dependent. This experimental evidence is limited because the measurements are short-term laboratory results. Extrapolations of experimental data over more than hundred thousand years may not adequately consider the differences in environmental conditions such as temperature, the surface area/water volume ratio, and the geochemical interactions between the glass and the type of solution. For purpose of modelling glass dissolution in waste repositories, the experimental data must be extrapolated over long periods of time. The requirements of verification of those extrapolations have lead to the use of natural analogues. So, for the PROSA modelling, not merely an extrapolation of the Arrhenius relation is used, but the dissolution rate has been modelled as a distributed variable, with the average value based on natural analogue studies.

Geological Parameters – Internal Rise Rate

The Geological Survey of The Netherlands has made an inventory of values of average internal rise rates which are present in the German and Netherlands literature. These values were derived from geological observations. They represent averages for the whole salt dome and for the total geological time span which was considered in the literature studied. Fourty individual values of internal rise rates have been collected for various salt domes and for various geological periods in Germany, the Netherlands and the Netherlands sector of the North Sea.

The values of the gathered average internal rise rate range from 0.0002 to 0.6 mm/a, In 36 cases the values are smaller than or equal to 0.1 mm/a; in the interval from 0.1 to 0.4 mm/a no values were found; a very modest peak of 3 observations is present at a value of 0.4 mm/a and 1 observation was available of the maximum value of 0.6 mm/a. It was not possible to show whether the absence of values between 0.1 and 0.4 mm/a is realistic or an artefact in the available data set. In the PROSA study the internal rise rate was one of the variables that have been modeled as a probabilistically distributed parameter.

Geological Parameters – Subrosion Rate

In the PROSA study several values of average subrosion rates have been compiled on the basis of literature data on salt domes present in Germany and the Netherlands. The values refer to average rates of subrosion during the, geologically spoken, most recent period, most often Holocene and Pleistocene and sometimes Cenozoic. They provided the possibility to study the relation between the depth of the salt dome and the subrosion rate. This relation is thought to exist on the basis of subrosion phenomena, theoretical considerations, and finite element analyses. From these analyses the subrosion rate was fitted by an exponential equation. In addition, it was assumed that this relation would have a probabilistic distribution t account for the uncertainties in the involved processes that determine the subrosion rate.

Geohydrological Parameters

Average values of geohydrological parameters such as the porosity and permeability of the geohydrological units, the hydraulic gradient the earths surface, etc were advised by the former Dutch Geological Survey. These values were samples taking into account statistical distributions to obtain a set of distributed input parameters for the MASCOT code, a module solving the nuclide transport equations in the geosphere.

Transport Parameters in the Geosphere

The 4 processes taken into account in the MASCOT module which describes the transport geosphere are:

- advection
- dispersion
- sorption
- decay

Advection is one of the main processes for the transport of radionuclides and is characterized by the groundwater velocity. This parameter has been modeled as part of the geohydrological parameters (see previous paragraph). Decay and ingrowth is governed by the properties of the nuclides. The decay rates are not treated as random variables. Dispersion and sorption are the remaining processes in MASCOT that needed to be specified by additional data.

Dispersion

In general data on the dispersivity are scarce and on the type of sediments dealt with in the PROSA study no data were available. Therefore, concerning the dispersivity it was only intended to estimate the order of magnitude. An additional complicating factor was that a relation exists between the dispersivity and the scale where it relates to. This scale effect is caused by an additional dispersion due to heterogeneities in the system that are not explicitly taken into account in the model. Therefore, the dispersion was also related to the size of the units in the model. In the PROSA study the dispersion refers to the dispersion caused by heterogeneities inside the layers.

For the dispersivities in the PROSA study a triangular distribution has been chosen, that varies 5 m and 15 m with a maximum for 10 m. These values were based on a typical salt layer thickness of 100 m and a ratio between dispersivity length and scale length varying from 0.05 to 0.15.

Sorption

Sorption was recognized as one of the key processes in retarding the transport of radionuclide through the geosphere. Nevertheless, reliable experimental data were still sparse. Sorption depends on the surface characteristics of the solid phase (grain skeleton) and the chemistry of the aqueous phase. Therefore, a wide diversity of sorption databases exist. For the PROSA study a database has been used, which was previously used in a PAGIS study [12]. That study refers to a disposal site in Germany and had many similarities with the PROSA project. For the PROSA study a log-uniform distribution for the distribution coefficient was assumed taking into account the values reported in the PAGIS study.

Biosphere Parameters

In the PROSA study the radiation dose to humans was calculated with the computer codes EMOS-ECN and PANTER using the biosphere module EXPOS. The dose rate was calculated multiplying the flux of a radionuclide to the biosphere by the appropriate dose conversion factor. The parameters required in EXPOS were therefore the nuclide-dependent dose conversion factors. As probabilistic calculations were performed in PROSA, distributions of the dose conversion factors were determined for each nuclide.

In the case of the conditions analyzed in the PROSA study, two types of biospheres could be distinguished in the various selected scenarios for the safety assessment.

- In the first, where the radionuclides were assumed to move gradually with the groundwater through the geosphere, the radionuclides enter the biosphere via discharge into a river. Exposure of humans to radionuclides occurs in this type of biosphere via the use of the river water (ingestion).
- In the second biosphere type, the radionuclides can reach the biosphere through the uplift of the repository field due to the diapirism process. Here, clearly different exposure pathways are relevant as, for example, the growth of crops is not very likely in a dry salt desert. In this case the exposure of humans to radionuclides by inhalation and external radiation.

For these reasons two distinct sets of dose conversion factors were calculated for the biosphere module EXPOS. The individual dose rates were calculated for various exposure pathways from the concentrations in the surface water and surface soil compartments. The dose due to ingestion includes the intake of drinking water, milk, cereals, leafy vegetables, root vegetables, meat, freshwater fish and seafood. Inhalation pathways include the inhalation of re-suspended soil or beach sediment and sea-spray. External exposure is due to gamma emissions of contaminated soil, beach sediment and fishing gear.

Ingestion

The values of the ingestion dose conversion factors were determined using the environmental transfer model MiniBIOS [**¡Error! Marcador no definido.** and refs therein]. MiniBIOS was used to determine the distributions of the dose conversion factors for radionuclides transported via groundwater. MiniBIOS is a biosphere transport model developed to calculate the dose to individuals due to the release of radionuclides from the disposal of radioactive waste. The model incorporates a linked chain of terrestrial compartments, each comprising river water, sediments, soil boxes and biota and a simple ocean model. Activity is interchanged between these boxes through a variety of processes.

The river is subdivided into sequentially connected compartments and flows towards a sea compartment. The code calculates the radionuclide concentrations in the various compartments as a function of time. Processes included in the MiniBIOS transfer coefficients between the different model compartments are:

- river flow
- irrigation with river water
- sediment flow
- infiltration of rain and irrigation water, bioturbation and diffusion
- infiltration of rain and irrigation water, diffusion
- diffusion and bioturbation
- diffusion and upwards groundwater flow
- groundwater flow towards the river
- sediment transport to land by flooding and dredging
- erosion
- sedimentation, diffusion and bioturbation
- diffusion and bioturbation
- diffusion and (only in a lake) burial by continued sedimentation
- diffusion
- burial by continued sedimentation (only in a lake)

MiniBIOS uses 134 input parameters. The four types of data are shown in Table 1. In the calculations some input parameters were used stochastically (indicated in bold in Table 1) and some in a deterministic way.

Table 1 Input parameters of MiniBIOS (stochastic parameters in bold)

nuclide-specific	decay constant, dose per unit intake or per unit exposure, **concentration factors** (soil → crop, pasture → animal, water → fish), **sedimentation factor, distribution coefficient** in soil and sediment, gamma energies, weathering rate
biosphere data	**depth** and **volume** of the various compartments, release position, **flow** of fiver and sediment, interception factors, cropping rate, **sediment transfer to land, erosion rate, irrigation, rainfall**, groundwater velocity, **diffusion coefficients** in soil, sediment and water, **bioturbation coefficient** in soil and sediment, **suspended sediment load**, density and **porosity** of soil and sediment, crop yield, dust level
human data	human consumption rates, inhalation rate, occupancy time
release data	time-dependent flux

The parameters used deterministically were:

- parameters specific to an exposure pathway, not included in the dose calculations.
- well-known parameters, like the decay constant.
- parameters related to the human consumption pattern. These were chosen to be deterministic to minimize the effect of human behaviour.

The values of the input parameters were based on several values found in the literature, and on the expertise of the former Geological Survey in The Netherlands. For the deterministic parameters the best-estimate value was used, and for the stochastic parameters a distribution between the various values found in the literature. If the distribution type was not found in literature a log-uniform distribution between the minimum and maximum values has been applied.

When for a particular nuclide-specific parameter only one or two parameter values were available, a distribution was selected based on the distribution of a similar element. The stochastic parameter values were sampled from the assumed distributions using Latin Hypercube Sampling. Correlations between the parameters were taken into account.

Inhalation and external radiation

The dose conversion factors for inhalation and external radiation were calculated for an adult living continuously on the repository field without protection against radiation or dust, and assuming that there is no protective layer on the repository field as a result of deposition of uncontaminated particles from outside. Further, a uniform distribution of the nuclides in the repository field and an equal resuspension rate of glass and salt particles have been assumed.

The dose conversion factors for inhalation and external radiation were calculated for an adult living continuously on the repository field without protection against radiation or dust, and assuming that there is no protective layer on the repository field as a result of deposition of uncontaminated particles from outside. Further, a uniform distribution of the nuclides in the repository field and an equal resuspension rate of glass and salt particles have been assumed. Table 2 summarizes the Parameters included in the external radiation and inhalation pathways.

Table 2 Parameters included in the external radiation and inhalation pathways

external radiation	gamma and X-ray energies, dose factor per unit exposure, residence time
inhalation	dust level, dose factor per unit intake, inhalation rate, residence time

The dose conversion factors for inhalation and external radiation were calculated in a deterministic way, as opposed to the methodology used for the DCF's for ingestion. The reason was that the calculation methodology for the effects due to inhalation and external radiation was straightforward and the effects of less conservative assumptions could easily be estimated.

Section 4.2: Related topics

Main related topics are, "Uncertainty Management and Analysis", "Sensitivity Analysis", and "Modelling Strategy".

Section 4.3: Databases and tools

- FEP database and the information included in the procedure for FEP analysis [5].
- REPOS - In REPOS (REPOSitory) a complete disposal mine with all technical barriers can be modelled. REPOS has models for the release of radionuclides from all type of containers and waste forms. The important physical and chemical effects influencing the transport of radionuclides are modelled. These processes are: temperature distribution, convergence of excavations, permeability of backfilled excavation, damms, seals, gas production by radiolysis and corrosion, diffusion, sorption, and radioactive decay and ingrowth. The models for the transport of radionuclides include: transport by density differences, gas transport, transport by a pressure gradient, and transport by diffusion.
- METROPOL – The METROPOL code is capable to perform a detailed 2-dimensional groundwater flow model. The METROPOL analyses were done stochastically in order to account for the large uncertainties of groundwater flow paths and geohydrological conditions.
- MASCOT - MASCOT analyses the nuclide transport in the geosphere. The code calculates the time dependent two or three dimensional nuclide transport in an infinitely extended porous and homogeneous continuum.
- EXPOS - EXPOS calculates the radiation EXPOSure in terms of maximum dose rates for individuals.
- MiniBIOS, a computer program used to determine the distributions of the dose conversion factors for radionuclides transported via groundwater.
- UNCSAM, developed to conduct sensitivity and uncertainty analyses of mathematical models [13].

As described in the previous section the actual data collection was a tedious process that required significant engineering judgment. Sources of the actual numerical values were wide-spread.

Section 4.4: Application and experience

The extended PROSA method [14] has been applied for the safety study underlying to the license application for the closure of the Asse (D) salt mine including the experimental disposal facilities (29. January 2007 [15]) and for a review on behalf of the Ministry of Agriculture and Environment of Sachsen-Anhalt (MLU) of two supporting reports issued in 2002 in preparation of the licensing process for the Morsleben Repository for radioactive waste (Endlager für radioaktive Abfälle Morsleben - ERAM) [16].

Section 4.5 On going work and future evolution

We expect that the PROSA procedure for identifying scenarios will be extended by the application of 'safety functions' for future safety studies.

At present there is no ongoing work in the Netherlands on the topic of the evolution of the repository system. Research on climatic changes is however a main topic.

Section 5: Lessons learned

A principal criterion for the selection of model data that have been applied in the VEOS, PROSA, and CORA studies was that the data must be generic, but representative of the conditions that are met in the underground and biosphere of the Netherlands.

The actual data collection in the PROSA study was a tedious process that required significant engineering judgment. Sources of the actual numerical values were wide-spread.

The methodology for the data collection is closely linked to the methodology of the safety/performance assessment of the repository. The SA/PA determines which data are needed for the modelling assumptions, the calculations, and probability functions (if applicable).

The PROSA data included all details of the nuclide inventory, the repository lay-out, near field characteristics, the groundwater compartment and biosphere compartment. For the analysis of the subrosion scenarios the uncertain parameters have been given a probability density function to take into account the uncertainty. These parameters were the leaching rate of the nuclides from the glass matrix, the depth dependent subrosion rate, the internal diapirism rate, the groundwater velocity, the element specific ka factor and dose conversion factors.

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A8 NRI-RAWRA (Czech Republic)

Reference: 1

Version: 1

16/01/2009

1. Introduction

This document describes the strategy for selection of data needed for demonstration of safety of Deep Geological Repository in the Czech Republic. Czech concept is similar to KBS 3 concept of disposal of spent fuel assemblies in granite in a vertical or horizontal position. The repository layout in granite host rock consists in spent fuel waste packages surrounded by bentonite bricks and located in the tunnels at least 500 m under the surface. Instead of copper based canisters in KBS 3 concept, carbon steel canisters were proposed for assemblies from VVER reactors, but this concept is going to be reviewed in a new project initiated recently by RAWRA. In the current stage only generic data are available since no site has been selected for DGR.

This document is based primarily on requirements of Degree of State Office for Nuclear Safety (SUJB) on Radiation protection [1], guide documents of SUJB for elaboration of the safety reports for DGR siting and construction permit [2,3] and data acquired during preparation of initial safety report for “Reference design” of DGR [4].

2. Regulatory requirements and provisions

The limits and conditions for safe radioactive waste disposal are according to Czech Atomic Law based on safety analyses that include data and admissible parameters, which ensure nuclear safety and radiation protection and methods and terms for measurement and evaluation thereof. These limits and conditions shall include appropriate waste acceptance criteria, specifying conditions and limits for characteristic of radioactive waste, such as radionuclide content, the maximum admissible quantity of radionuclide sources, structure stability, leachability, heat and radiation effects, possibility of gas generation , possibility of microbial decomposition and origination of critical state, content of corrosive substance, etc.

These acceptance criteria shall be established by State Office for Nuclear Safety in the operating licence for particular repositories, subject to an assessment of safety reports submitted by Radioactive Waste Repository Authority.

According to guides of SUJB, safety reports must contain data describing comprehensively all components of site and DGR design (topography, geology, hydrology, geochemistry, demography, design of repository, waste packages, etc.). Primarily following data are needed to judge criteria for siting according to Degree of SUJB 215/2007 e.g.:

- The occurrence of karstic phenomena in the extent endangering the stability of the rock massif in the bedrock and in the rock cover of the land selected for the siting.
- The manifestation of post-volcanic activity such as the escapes of gases, thermal, mineral and mineralised waters, found on the lands or area of the supposed siting and in their site vicinity zones.
- The achievement or exceeding of the value of intensity of the maximum calculated earthquake 8 °MSK (scale of Medvedev-Sponheuer-Karnik for estimation of the macroseismic effects of earthquakes) on the lands of supposed siting.

- The occurrence of the capable and seismogenic faults with the recent surface deformations of area and with the possibility of origination of secondary faults, found by a geological survey on the land of supposed siting.

All the data needed for evaluation of impact of radionuclides on the environment must be gathered. Modelling of transport of radionuclides shall be based on detailed knowledge of site for DGR. A list of parameters, their substantiation a possible change of parameters in space and time and their maximal and minimal values must be given. A list of reports with data and information not directly given in the safety report must be included at the end of safety report and must be given their availability.

3. Key terms and concept

Key term and concepts used in Czech safety approach corresponds to the terminology used in IAEA documents [7].

4. Treatment in the safety case

Data generation for the preliminary safety case in the Czech Republic

The preliminary safety case [4] was based on information and data acquired during project coordinated by NRI in years 1993 – 1998. The gathering of data and information was divided into the following areas:

- Source term including near field interactions
- Far field interactions
- Safety case
- Siting
- Design activities
- Public relation activities
- Coordination

The main purpose of this project was to gather information available to prepare program for DGR development and to perform the first estimate of DGR cost. The main tool of obtaining data was an informal expert judgement from subject-matter experts. Generalists from the coordination group of NRI identified the issues and tasks related to safety analyses, design or siting of DGR. Reports were focused mainly on acquiring the following data:

1. Inventory of wastes
2. SF and other waste form properties
3. Sealing and construction materials properties

4. Criticality
5. Waste package materials degradation properties including gas generation
6. Sealing materials degradation processes
7. Heat transfer properties and heat transport calculations
8. Migration properties of barriers
9. Hydrogeology transport calculations
10. Contaminant transport calculations
11. Underground laboratory studies
12. Natural analogues studies
13. FEPs and scenario derivation
14. Formal safety case procedure preparation

More than 130 reports were prepared. Generalists from the NRI coordination group and then independent peers reviewed the reports prepared by subject-matter experts. The data and information acquired during this period were used then for initial safety report of Czech design of repository in granite structure [4].

Data generation for safety assessment models

Data for safety assessment models, which will be utilized in the preparation of second safety report being now prepared in NRI, are now divided into the following sections:

Inventory

For inventory the data are generated mainly by calculations using computer codes such as ORIGEN or SCALE. Inventory data for instant release fractions are taken from literature search.

Decay constants

Uncertain decay constants of some radionuclides (e.g. Se-79) are checked out with data reported in Laboratoire National Henri Becquerel Atomic & Nuclear Data [8].

Spent fuel matrix and other waste forms degradation rates

Data on degradation rates of spent fuel matrix and other waste form are taken from literature reviews, but laboratory experiments are also performed to get a deeper understanding of the problem and to verify literature data for Czech concept.

Canister lifetime

Data for lifetimes of carbon steel canisters are based of 4 sources:

- Literature reviews
- Laboratory experiments in simulated repository conditions
- Modelling
- Experiments in–situ (under preparation)

Only preliminary data from experiments are now available so that only preliminary estimates of canister lifetimes and canisters lifetime distribution are used in performance assessments.

Migration parameters of radionuclides in bentonite

Most of bentonite migration parameters are based on literature reviews, but a systematic research program started for Czech type bentonite in the project supported by RAWRA and Ministry of Trade and Industry. Most for experiments were performed to verify methodologies and determine uncertainties of sorption and diffusion measurements [10]. Experiments are focused primarily on soluble, mobile elements (Cs, Sr, I, Tc). No experiments are planned to be performed for actinides, which are limited by very low solubilities.

Solubilities of radionuclides

Data for solubilities of radionuclides are based primarily on literature reviews and own modelling using geochemical codes, such as PHREEQE or MINTEQ. Data for geochemical modelling are based on reliable chemical thermodynamic databases [10,11].

Geosphere data

The main sources of Czech specific data concerning geosphere are from 200 – 400 m deep boreholes at testing sites “Melechov” and testing site “Potucky”. Testing was performed by Czech Geological Survey [e.g. 12] . For preliminary performance assessments also some literature data from abroad granite sites are taken. (e.g. SKB data [13]).

Biosphere data

Biospheric factors were calculated for stylised biospheres farmstead, highlands area and fishponds area. The data were based primarily on IAEA and NRC recommendations [e.g. 14, 15, 16].

Role of QA in the data generation process

Quality assurance system must be implemented according to Regulation of the SÚJB 214/1997 Coll. on Quality Assurance [17] for all activities concerning preparation of deep geological repository including data gathering. The quality assurance system and quality assurance programmes must be documented before the start of relevant activities. All organizations participating in the development of deep geological repository must have established a quality assurance system. No templates for data gathering from R&D groups are available. Database of data for safety case is under preparation for second safety report, which should be prepared until 2011. For deterministic calculations conservative, best-estimate values or range of values are used. For probabilistic calculations usually triangle distribution, i.e. minimum, best-estimate, maximum values, are used.

5. Applications and experience

There is only limited experience concerning preparation of DGR safety cases in the Czech Republic. The preliminary safety case for a hypothetical site was prepared already in 1999 [4] as a part of reference, conceptual design of a repository, but Czech geological disposal program can be still characterised as to be under conceptual stage including preparation of safety approach and safety strategy. The main objectives of current safety related activities are to establish scientific basis for evaluating safety functions of a geological repository. The important part of currently running projects is to develop and implement conceptual and mathematical models, and experimental and analysis methods for preparation of the safety report (safety case) for permission of including candidate sites for land use planning documentation in about 2017.

6. Conclusions

It is well known that proving and demonstrating long-term safety of deep geological repository strongly depends on available data. Even if the Czech disposal program started already in the beginning of nineteen's, it can be still considered to be in concept phase, because no real data, except inventories of spent fuel assemblies, are available. A lot of experimental and analytical procedures have been developed in NRI and other research institutions in recent years. This and also cooperation with other abroad research organizations provides a significant prerequisite for acquiring in future reliable data needed for evaluation of safety of deep geological repository.

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A9 POSIVA (Finland)

16th January 2009

1. Introduction

Spent fuel from the Finnish nuclear power reactors is planned to be disposed of in a KBS-3 type repository to be constructed at a depth between 400 and 600 metres in crystalline bedrock at the Olkiluoto site (Southwestern Finland).

In 2001 the Parliament ratified the Government's favourable Decision in Principle on Posiva's application to locate the repository at Olkiluoto, being the milestone prior to entering the phase of confirming site characterisation. The next step of the nuclear licensing of the repository is the application for a construction license in 2012.

The required documentation of studies and conclusions on the long-term safety will be published in a step-wise approach with an increasing level of detail. A plan for a synthesis of evidence, analyses and arguments that quantify and substantiate the safety and the level of expert confidence in the safety, i.e. the safety case, was prepared in 2004 (Vieno & Ikonen 2005) and updated in 2008 (Posiva 2008). The planning report introduces the Posiva Safety Case Portfolio as the documentation management approach, facilitating flexible and progressive development of the safety case. In the portfolio the Models and Data Report summarises the models and key input data used in the safety case for describing evolution, radionuclide transport and dose assessment. It includes models and data related to the spent nuclear fuel, the EBS and the site including external conditions (i.e. climate).

2. Regulatory requirements and provisions

The regulatory requirements are set forth in the Government Decision on the safety of the disposal of spent nuclear fuel (STUK 1999) and, in more detail, in the regulatory Guide YVL 8.4 issued by STUK (2001). The safety regulations and guidance will be updated periodically.

Modelling and input data

In STUK (2001) it is stated that in accordance with Section 29 of the Government Decision, the computational methods shall be selected on the basis that the results of the safety analysis, with high degree of certainty, overestimate the radiation exposure or radioactive release likely to occur.

In order to assess the release and transport of disposed radioactive substances, conceptual models shall first be drawn up to describe the physical phenomena and processes affecting the performance of each barrier. Besides the modelling of release and transports processes, models are needed to describe the circumstances affecting the performance of barriers. From the conceptual models, the respective calculational models are derived, normally with simplifications.

Simplification of the models as well as the determination of input data for them shall be based on the principle that the performance of any barrier will not be overestimated but neither overly underestimated.

The modelling and determination of input data shall be based on the best available experimental knowledge and expert judgement obtained through laboratory experiments, geological investigations and evidence from natural analogues.

The models and input data shall be appropriate to the scenario, assessment time window and disposal system of interest. The various models and input data shall be mutually consistent, apart from cases where just the simplifications in modelling or the aim of avoiding the overestimation of the performance of barriers implies apparent inconsistency.

3. Key terms and concepts

Posiva uses as most the terminology in the IAEA glossary of 2007. Whenever any term is adapted from other sources its definition is specified in detail. Comparisons and correlation with the terminology used by the Finnish regulator is also specified in order to avoid misunderstandings.

4. Treatment in the Safety Case

4.1 Methodology

4.1.1 Data handling and modelling

The *handling of critical data and modelling* process creates the main link between the *safety case* process, the *engineering design and planning of implementation* processes and the *site characterisation* process. It starts from the definition of the primary input for the safety case (the "critical" data, models and assumptions used in the safety assessment) and sees to it that all the steps needed to produce that input are described in a way that enables the control and assessment of its quality (Figure 1).

The process consists of the following activities (Posiva 2008):

<u>1. Identification of the critical input data</u>

The first step is to identify the parameters and data sets that are needed as input to the safety assessment. Identification is based on prior safety assessments and the needs defined by the *safety assessment*. However, the final definitions of the actual parameters and data sets are formulated as a clearinghouse activity (see Figure 1) in liaison with the supply processes (engineered barrier system design and development; site characterisation): the clearinghouse activity ensures that the input requirements are defined in a way that makes it possible for the supply processes to produce the input within the required time frames. A document containing the current list of data, parameters and models considered as critical input is prepared and maintained.

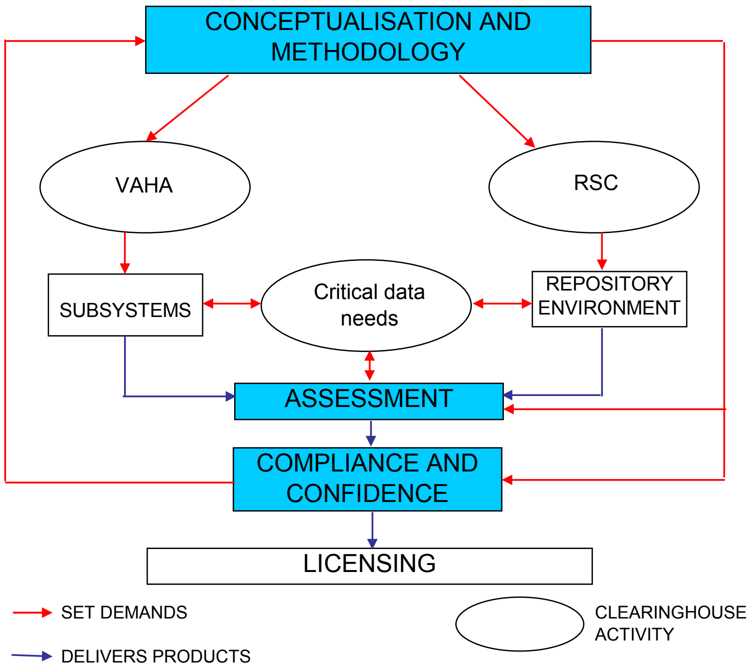

Figure 1. Main activities of the safety case production process (Posiva 2008). VAHA = Requirements for the EBS system; RSC = Rock suitability criteria

2. Description of the production processes for the assessment input data

The chain of activities that is needed to produce the input in the form needed by the safety assessment is described and documented. In most cases, this means the specification of the initial EBS and site conditions at the time when the control of the emplacement process ceases (e.g., after the emplacement of the buffer). For the site data, the chain of production activities starts with observations and measurements, continues with primary interpretations and necessary abstractions (inference, upscaling, expert judgement) and ends with the derivation of effective parameters or datasets that can be used in safety assessment models and calculations. Models and theories are used for interpretation and abstraction. For the EBS data, the production process is divided into two steps: the design stage and the implementation stage. The production process for assessment input data takes account of the reasoning behind the design requirements that led to the choice of the design parameters (specification). It also considers design justifications in terms of performance studies and practical demonstrations that show how the specification meets these requirements. Repository implementation procedures are relevant to the extent that they may affect the actual "as-built" values of the parameters and their associated uncertainties.

3. Quality review of the safety assessment input data

The description of the production processes for the most significant assessment input data (Step 2) is needed for their quality review. The responsibilities for the definition and implementation of the quality control and assurance measures for the supporting processes that produce the input data are defined within these supporting processes themselves. The quality review at this step consists of checking that a continuous chain of quality control has been applied to the production of the input and the prescribed quality assurance measures have been taken. The results of the review are summarised in the *Models and Data Report*, together with the references on which the review is based.

4. Clearance

At this step, the collected input data is either validated for further use in the safety case, further proofs and justifications are requested from the data suppliers, or the data is released for restricted use. All restrictions and caveats on the use of input data are documented in the *Models and Data Report*.

5. Improvement

The reporting of the data selection process in the Models and Data report is to include the following (Posiva 2008):

- Source of information (e.g. from laboratory or in situ tests, and related modelling). Specific emphasis is put on the conditions for which data are supplied with respect to their intended use.
- Impact of information on assessment results, including any sensitivity analyses or bounding calculations that may have been performed to evaluate how the system evolution and ultimately the radiological consequences are affected by the data at hand.
- Data uncertainty, including spatial variability (e.g. scaling issues, discrete features) and temporal variability (e.g. variation of groundwater composition over time).
- Correlations among parameters used in the safety assessment (e.g. influence of water-rock interaction on groundwater composition).
- Quantification of the parameter values, considering the most likely values and ranges or distributions of the values. Whenever possible, probability distributions for certain parameters will be given in case there is a sufficient basis to support them; otherwise best estimate values and ranges of variation covering the most “pessimistic” values consistent with current scientific understanding will be given. The quantification process takes into account uncertainty related to data (assessed by the technical experts) and scenarios considered in the safety assessment (assessed by the safety assessment team).
- Description of the quality assurance and quality control activities.

Data will be organised according to the system component to which they relate: spent fuel, cast iron insert and copper canister, buffer, backfill, geosphere and biosphere. Implementation related data covering engineering and residual materials and including relevant information related to excavation and operation will also be included. These various groups of data are discussed individually, below.

Spent fuel data, insert and copper canister

Examples of data related to spent fuel, the copper canister and the canister insert to be included in the *Models and Data Report* include:

- Copper and cast iron physical and mechanical data.
- Copper and cast iron corrosion parameters under different physico-chemical

conditions expected during canister evolution.

- The dimensions and evolution with time of possible or hypothetical canister defects, which are needed for radionuclide release and transport calculations.
- Radionuclide inventories: The existing repository plans have been made for the disposal of three different fuel types (BWR, VVER 440 and EPR) from five nuclear power reactors: Loviisa 1 and 2, Olkiluoto 1, 2 and Olkiluoto 3 using. Based on the current planned operational lifetimes of Loviisa 1 and 2 and of Olkiluoto 1, 2 and 3, and with the current maximum discharge burnup, this corresponds to approximately 5 500 tU in 2 840 canisters (Chapter 3 in Miller & Marcos 2007).
- Radionuclide partitioning between fuel matrix, instant release fraction, zircaloy and other metallic parts.
- The fractional dissolution rate of the fuel matrix and the corrosion rates of the zircaloy cladding and other metal parts.
- Criticality data.
- Solubilities of radionuclides relevant to the safety case.

Some background information related to canister and insert data is given below.

Canister and insert data

Much of the current information about the canister and the insert is presented in the Canister Design Report (Raiko 2005), an update of which will be published by the end of 2008. Key issues for the safety assessment are the probability, characteristics and evolution of canister defects. Posiva is currently developing manufacturing and inspection technologies to estimate the probability of initial canister defects. Reports describing inspection and manufacturing technologies, including seal weld technology, will be published by the end of 2009.

A related issue is the data required for modelling radionuclide release from a canister with a penetrating defect. Release involves several interacting processes (including the evolution of the defect over time, water intrusion, corrosion of the cast iron insert, gas generation and release, and the thermo-hydro-mechanical-chemical evolution of the system of the defective copper-iron canister and buffer).

Buffer

Examples of buffer data to be discussed in the *Models and Data Report* include:

- Physical and chemical properties.
- Thermal properties.
- Hydraulic properties.
- Mechanical and rheological properties.
- Transport data.
- Geometrical dimensions.

MX-80 sodium bentonite from Wyoming, USA has been the reference buffer material in Posiva's previous safety assessments. The properties of MX-80 are well known, based on extensive and thorough national and international studies. However, another potential buffer material, calcium bentonite DEPONIT CA-N from Milos, Greece, is also currently under consideration for the reference.

Backfill

A description of the backfill including physico-chemical information, volumes and masses as well as their location in the repository will be included in the *Models and Data Report*.

The types of data presented for the backfill will be similar to those presented for the buffer. However, different types of backfill (e.g. crushed rock/bentonite mixtures, swelling clays) and different possible physical forms (e.g. pellets, blocks) will be taken into account. Posiva is currently developing a site-specific backfilling concept within the Coordination Programme for the Olkiluoto-Specific Backfilling (OBA).

Implementation-related data

Implementation-related data are data not only about materials but also about repository construction and operation. Implementation-related materials are referred to as engineering and residual materials. Engineering materials for which data will be compiled include:

- Structural materials, associated, for example, with iron-bearing structures outside the canister, such as the supercontainer shell and compartment plugs used in KBS-3H.
- Sealing materials, such as cementitious materials or colloidal silica (Silica-Sol) used for groundwater control and for construction purposes.
- Plugs, such as structures made of cement, rock, bentonite (or a combination of the above) used to isolate the deposition tunnels, the central tunnel, ramps and other entrances from the surface and to plug boreholes.

Residual materials from construction and disposal operations (e.g. organic additives in cement grouts, organic materials from vehicles and human waste and oxidising by-products from drilling and blasting) may also be left in the repository after closure.

Engineering and residual materials are important to long-term safety because of their potential to influence the near-field chemical environment, and hence affect important barrier functions and/or near-field conditions, such as radionuclide solubility and sorption behaviour, concentrations of corrosive species, and the abundance of nutrients for microbial activity.

Data concerning repository construction and operation include design dimensions and tolerances, dimension and nature of the gaps between the different barriers and nature of the interfaces between different barriers. Potential implementation mishaps involving more than one barrier (e.g. buffer damage during installation) will also be discussed, while potential implementation mishaps specific to one barrier will be discussed in the barrier-specific sections of the report (e.g. canister defects during welding).

Because the plans for closing and sealing the repository are still under development, the first *Models and Data Report* focuses mostly on information used in the most recent KBS-3V and

KBS-3H safety assessments. It is expected that the 2012 update will contain more detailed information on the engineering and residual materials, as the design develops further.

Geosphere

The current conditions of the Olkiluoto site, described in terms of geological, rock mechanics, hydrological, hydrogeochemical and transport models, are given in the Olkiluoto Site Descriptions (e.g. Posiva 2005, Andersson *et al.* 2007), which are regularly updated. The evolution of the site conditions has been discussed by Pastina & Hellä (2006). The *Models and Data Report* focuses on data applied in the models for describing the main processes relevant to the safety case, especially those affecting canister integrity, buffer behaviour and radionuclide transport. The data discussed include those related to:

- Groundwater composition, including the presence of gases and microbes.
- Thermal properties.
- Fracture data, including impact of fracture minerals on the buffering capacity and retention properties of the rock.
- Rock mechanics.
- Groundwater flow.

The currently ongoing excavation of ONKALO, the construction of the repository and its subsequent operation will disturb the natural properties of the rock. Examples of these disturbances include e.g. the introduction of engineering and residual materials which will affect groundwater composition, and the formation of the excavation damaged zone (EDZ), which will affect the hydraulic properties of the rock / buffer interface. The impact of construction and repository operation on the properties of the geosphere will be considered in defining the parameter values to be used in the safety case.

Biosphere

The biosphere assessment aims at describing the relevant past, present and future conditions of the surface systems of the Olkiluoto site, track the fate of any radionuclides released from the repository to the biosphere, and assess possible radiological consequences on humans and other biota. From a modelling and data point of view, the biosphere assessment can be divided into three main components: *deriving terrain and ecosystem (landscape) forecasts*, *radionuclide transport modelling in the landscape*, and *assessing radiological consequence*. The *Biosphere Description* is an important background process feeding these components with information. The most important data sets (and related models) of each component are:

Terrain and ecosystem forecasts:

- Topographic model.
- Post-glacial land uplift data and model.
- Climate scenario, especially regarding sea level and hydrological balance.
- Sedimentation and erosion data and model.

Landscape modelling:

- Geometrical properties of and connections between contaminated objects.
- Sorption properties of soils and sediments.
- Biological cycling of elements - mainly root uptake and subsequent translocation.
- Water balance in contaminated objects.

Radiological consequence analysis:

- Anatomical and physiological properties of humans and dose-response data for both humans and other biota (these are, however, taken as given in the biosphere assessment, since international standards and recommendations e.g. from ICRP and the FREDERICA database are utilised).
- Geometrical properties and habitation data of representative fauna.
- Productivity of various food items in the contaminated objects.
- Food and water intake by humans and representative fauna.

4.2 Related topics

- Biosphere: For a more detailed description on the selection process of input data for the biosphere, please see the corresponding topic.
- Modelling strategy: models, data and modelling are closely connected. See please the topic of Modelling strategy.

4.3 Databases and tools

Technical working environment and streamlined workflow incorporating good means of communication within the persons involved are essential for transparent, effective and highly qualified modelling. The information infrastructure for the overall safety assessment consists of the following databases:

- the POTTI research database for the site investigation data,
- the GIS database for spatially bounded data,
- The VAHA system for long-term safety and design requirements
- the Biosphere Assessment Database for the assessment data, and
- external databases (national and international: e.g. NEA-TDB).

In addition to the databases, several tools are developed or customised for Posiva's assessment team, e.g.:

- UNTAMO GIS tools for terrain and ecosystem development modelling.
- Modelling and simulation environment PANDORA on Matlab/Simulink engine for biosphere transport calculations.
- MARFA, PORFLOW, REPCOM, FTRANS, GoldSIM for radionuclide transport in near

and far field

- Sensitivity and uncertainty analysis tool EIKOS.

4.4 On-going work and future evolution

For 2009, a first Model and Data report is to be issued that comprises the data used in the recent safety assessments for KBS-3H (Smith et al. 2007) and KBS-3V (Nykyri et al. 2008).

For the future, and to submit the construction license application for the repository in 2012, an updated Model and Data report will include overall data used not only in the safety assessment, but also in the broader safety case.

5. Lessons learned

As shown in Figure 1, the safety case production process relies on the input from two principal Posiva processes: the *site characterisation process* and the *engineering development and design process*. In addition, it provides the necessary input for the *requirements management process* and the *rock suitability criteria (RSC) programme*.

The quality management of site investigations and the processing of the primary data from measurements and observations is based on the ISO 9000:2000 standard and covered by Posiva's management system. The system also covers aspects of the subsequent modelling and interpretation activities, including the responsibilities of the suppliers, supplier audits, application of computer codes, and use of data sets, documentation and product control. However, the quality achieved also relies on the application of scientific principles, such as the critical use of data and information, open publication policy, repeatability of the experiments and traceability of the information used.

The quality management of the engineering development and design process is based on system-specific quality manuals as will be the quality management of implementation. Such manuals will be produced for all the main components of the engineered barrier system: the canister, the buffer and the backfill and the sealing systems.

Expert elicitation

The purpose of the *handling of critical data and modelling* process is to describe the whole chain of activities that are needed to produce the input data and models for safety assessment. Ideally, the description should provide a logical and theoretically sound derivation of the input data and models from empirical observations, measurements and experiments. In some cases, however, there may be conflicting data sources, alternative theoretical assumptions or simply a lack of relevant data. In such cases, the input data and models are selected on the basis of expert judgement. To make the judgements as transparent and unbiased as possible, a formal expert elicitation process is introduced as a part of the data production (Posiva 2008).

The process is based on the interaction and collaboration between safety analysts and domain experts and aims at developing a joint understanding of the issue at hand and, consequently, a consensus view on the input data and models to be used in the assessment. The background and details of how this process could be implemented are described in a research report (Hukki 2008).

The process may consist of the following phases:

- selection of the issue,
- selection of the forum of elicitation,
- selection of experts,
- selection of the shared conceptual frameworks,
- preparatory work of safety analysts,
- training of experts,
- instruction of experts,
- independent work of experts,
- iterations,
- validation of expert judgments for later use,
- treatment of possible controversies, and
- final documentation of the process.

While it is important that the participating experts are highly qualified and that their expertise covers the issue at hand, it is not realistic to set formal rules for their selection. The basis of selection of the experts, as well as the qualifications of the experts selected, will be fully documented.

Conceptual tools will be used to facilitate joint understanding of the issue. There are different types of tools: *elicitation forms* for each party (safety analysts and domain experts) and *structural and contextual descriptions* that serve as shared conceptual frameworks for both parties. The safety analysts formulate a preliminary view of input data and model uncertainties and document this view and the underlying assumptions and grounds in a *Safety Analysts' Elicitation Form*. The form guides the analysts in formulating, justifying and documenting their view in an explicit way.

The function of the *Experts' Elicitation Form* is to support the experts in the production of expert judgments.

After being informed by the safety analysts on the course of action foreseen for the elicitation and validation process, the experts are provided with an explanation of the purpose and idea of the form. The experts are instructed on what is required from them and on the format in which the judgment(s) must be presented. The instructions focus on how to address uncertainty and on the importance of making the reasoning process as explicit as possible. In the case of probabilistic judgments, special training may be useful.

Structural descriptions are intended to build a common understanding of the issue at hand and a comparison of the safety analysts' and the experts' views in a structured way. The descriptions provide shared frames of reference for describing and discussing uncertainties and possible inter-relationships between different uncertainties. Contextual descriptions are prepared to present the context of the production of the input and the intended use of the input in the safety assessment.

What follows is the provision of the requested input and subsequent discussions and iterations, with the aim of reaching a sufficient consensus to provide recommendations on the use of input data and models in safety assessment. If the safety analysts and the experts are unable to reach sufficient consensus, the resolution of the issue is left with Posiva's Safety Committee consisting of chosen experts involved tighter in the evaluation of the overall programme. The whole process will be fully documented.

In general, the functions and responsibilities for the process are assigned according to Table 1. Here "X" means major contribution, "x" a supportive contribution, and "[x]" means optional supportive contribution.

Expert reviews

All the reports of the safety case portfolio will be subject to expert review before publishing and special reviews may also be requested for intermediate progress reports. In particular, expert reviews will be carried out of all reports that do not carry disclaimers of Posiva's responsibility. These include reports such as the Olkiluoto site descriptions and the main reports on EBS performance.

Table 1. Roles and responsibilities of participants in the expert elicitation process. "X" means major contribution, "x" a supportive contribution, and "[x]" means optional supportive contribution

Phase	QA Manager	Safety analysts	Domain experts	Safety Group
Selection of issue	x	X		
Selection of forum_		X		
Selection of experts	X	x		
Selection of shared conceptual frameworks	X	x	[x]	
Preparatory work of safety analysts	x	X		
Instruction/training of experts	x	X	X	
Independent work of experts	x		X	
Iterations	x	x	X	
Validation of expert judgments for later use	x	X	X	
Treatment of possible controversies	x	X	X	X
Final documentation of the process	X			

To ensure consistency, a special expert panel will be nominated to review the final portfolio reports that are intended to support the license application. The outcome of the reviews will be documented, together with the actions taken in response to the review comments.

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1. Introduction and background

The collection of input data for the SAFIR 2 (ONDRAF/NIRAS, 2001) calculations was started in 1997 and finalised during the first months of 1999. As the Belgian research programme on geological disposal of high-level and long-lived radioactive waste in the Boom Clay formation started already in 1976, many results of the site and waste characterisation programmes were already available in 1997. Further characterisation of the Boom Clay as well as the cemented environment of the supercontainer is going on for the preparation of the Safety Case 1 (SFC 1). The methodology for the data selection used in SAFIR 2 is currently improved for its future application in the frame of the SFC 1 preparation.

2. Regulatory requirements and provisions

Regulatory requirements and guidelines concerning long-term safety of high-level radioactive waste disposal are still in preparation in Belgium.

3. Key terms and concepts

The Belgian RD&D Programme is organised in three broad axes of work: technology, phenomenology and safety assessments defined as:

- *Technology* concerns the development of a repository concept and design and the means for their implementation, including feasibility assessment.
- *Phenomenology* concerns the development of scientific understanding of the disposal system and the events and processes that affect its evolution and performance.
- *Safety assessment* concerns the identification and quantitative evaluation of safety-relevant phenomena and uncertainties.

Through their RD&D programme the two poles technology and phenomenology develop a description of the system and its evolution. They contribute for a large part to the development of the assessment basis and are therefore referred as the *assessment basis group*. The assessment basis group strives for both completeness and realism. It gathers different research teams specialized in specific fields of expertise which develop the knowledge and the associated uncertainties over particular features, events or processes (e.g. steel corrosion, migration in clay). For this reason scientists from the assessment basis group are called *experts* in the following paragraphs. The assessment basis group does not consider in the first place the evolution of the whole repository, what is the role of the safety assessors. Through evolution, safety and performance models the *safety assessors* from the *safety assessment group* consider the repository as a whole (see the contribution of ONDRAF/NIRAS and SCK•CEN on “Modelling strategy”). They evaluate the impact of the phenomenological uncertainties on long-term safety and seek the different broad-brush evolutions of the repository system from the safety impact point of view.

In the methodology developed for SFC 1, the assessment basis group expresses parameter data under the form of a source range and an expert range defined as:

- *Source range* of a parameter is the range of values outside of which the parameter value is unlikely to lie, considering the current knowledge.
- *Expert range* of a parameter is the range of values within which experts expect the parameter value to lie; the expert range is thus a subset of the source range.

4. Treatment in the Safety Case

4.1 Methodology

The safety evaluations require a large number of input data, which have not all been the subject of specific measurements. The scarcity of measured data for a large number of input data necessitated the introduction of a pragmatic approach instead of an approach based on sound statistical methods.

The safety evaluations presented in the SAFIR 2 report consist in best estimate calculations, complemented by stochastic "Monte Carlo" simulations, the results of which are used for sensitivity and uncertainty analyses. Therefore, it was necessary to select for each input parameter a best estimate value and a probability distribution function.

For each group of parameters of a certain field of expertise an expert and a safety assessor were appointed. The expert collected the available data; these can be results of measurements, results of calculations, and literature data. The collected data were then discussed between the expert and the safety assessor in the so-called *interaction meetings; for the SAFIR 2 data collection the number of people participating in these meetings was limited to 2 to 4 persons*. During this interaction period the safety assessor met in turns the experts of the different fields of expertise of the assessment basis group.

When different data sets were available, the first aspect to be discussed was the relevance and representativeness of the available data sets in order to identify the most relevant data. The expert then proposed a best estimate value on the basis of the most relevant data set. The reliability of the selected value was discussed between the expert and the safety assessor. If the available data were considered as sufficiently reliable and representative, they were directly used to determine the best estimate value. However, if the representativeness or reliability of the available data were considered questionable, the "best estimate" value was conservatively adjusted.

The next step was the determination of a probability density function (pdf). In a very few cases sound statistical techniques for identification of a pdf and calibration of its parameters could be applied. For the biosphere conversion factors, which result from calculations with the biosphere model, this approach could be applied. A log-Weibull distribution was identified and its parameters were calibrated on the basis of the results of stochastic calculations of the biosphere model. However, for most input parameters a pragmatic approach had to be used. On the basis of the available data sets the expert estimated a minimum and a maximum value. The reliability and conservatism of the selected range of possible parameter values was discussed between the expert and the safety assessor. Then, the first topic to be considered was the scale of the distribution: linear or logarithmic. When the range of possible values was larger than a factor 5, a logarithmic scale was used. The next topic to be discussed was the statistical weight that has to be given to values close to the best estimate. If it was considered necessary to give a higher statistical weight to the values around the best estimate value, a (log)triangular distribution was selected. When this was not considered necessary, i.e. the real value is expected to be somewhere between the minimum and maximum, a (log)uniform distribution was selected.

A particular process can have impact on processes studied by other research teams (e.g. the impact of the alkaline plume on the host rock, the impact of climate change on the corrosion of the overpack), and therefore the uncertainties in a particular process can affect other particular processes. Therefore, there is a need to have iterative interaction meetings and a necessity for the safety assessor to meet in turns each team of experts in order to develop step by step a coherent understanding of the repository evolution and to determine which of all the identified phenomenological uncertainties will really play a safety role. This intensive interaction period requires important care for a transparent and traceable transfer of the parameter values and the associated uncertainties from the assessment basis group to the safety assessors.

The safety models considering the whole repository system and its environment require substantial simplifications with respect to the phenomenological evolution of the repository system. Therefore a number of parameters used in such models must be seen as “lumped parameters” representative of different concurring processes (e.g. the retardation parameter). *Interaction meetings* are also essential so that the experts and the safety assessors acquire a common understanding of the processes, features and events influencing a particular parameter which will be used in safety calculations.

4.2 Available data

Near field data

Results of the waste characterisation programme allowed for an estimation of the glass matrix lifetime. The lifetime of the uranium oxide matrix in the case of spent fuel disposal was estimated on the basis of literature data. No research had been done on sorption of radionuclides on near field materials; consequently, sorption in the near field was conservatively neglected. A limited number of measured solubility limits were available; most solubility limits were based on results of thermodynamic calculations with Phreeqc.

Clay data

The effective thickness of the clay barrier was estimated on the basis of results of the site characterisation programme, such as geophysical borehole loggings, grain size analyses and measurements of hydraulic conductivity. The effective hydraulic conductivity was estimated from measurements of hydraulic conductivity. The hydraulic gradient over the clay layer was derived from piezometric observations in the aquifers overlying and underlying the host clay formation. Parameters related to diffusive transport through the host clay formation were largely based on results of the migration research programme. The parameters on some non-studied elements were derived from results available for chemically analogue elements.

Aquifer data

The dilution factor for a water well and the river sections that might be contaminated by natural discharge of the overlying aquifer were determined on the basis of results of the hydrogeological models.

Biosphere data

The biosphere conversion factors were calculated with the biosphere model that has been developed for the Mol site. The parameters used in the biosphere model were based on literature data.

4.3 Documentation

In order to ensure the traceability of the data collection process two types of forms were introduced. The first form is the *data collection form*, which gives a one-page overview of the selected values for the input parameters (both best estimate value and pdf), the main references and the names of the experts (at least one) from the assessment basis group and of the safety assessor involved with the data collection.

The second form is called the *annex* which can give much more detailed information on the data that were available, a (short) discussion on their relevance, the reasoning applied to derive a best estimate value, and the distribution and its parameters.

The data collection forms as well as the annexes have been collected in a report (Marivoet et al., 1999).

5. Lessons learned and future programme

The method for the data selection followed in SAFIR 2 was successfully applied despite some shortcomings: The “best estimate” value selected by the experts and the safety assessor for the safety assessment calculations tended to lie systematically on the conservative side and was not always representative of the best estimation of the parameter as formally defined. This resulted in a loss of information regarding the “true” value expected for a particular process and a difficulty to evaluate the degree of conservatism of a certain value assigned to a parameter. In order to reinforce the traceability and transparency of the data collection in SFC 1 a refinement of this approach is under development.

The major modification lies in the fact that the parameter is rather expressed as a range of values rather than as a best-estimate. The expert is requested to provide two ranges of values for a specific parameter, the so-called “source range” and “expert range”.

The source range of a parameter takes account of the uncertainties due to the simplifications inherent to the conceptual modelling but also of those stemming from hypotheses of the conceptual model which are less well supported and remain to be confirmed. This range rests on little expert judgment since all possible values of the parameter induced by the poorly-supported hypotheses of the conceptual model are covered.

The expert range is meant to be a more realistic range of parameter values than the source range and is arrived at by making expert assumptions regarding the poorly-supported hypotheses. Therefore the expert range implies much more expert judgment than the source range. The expert range is a subset of the source range: it is equivalent to the source range less the impact of the uncertainties on parameter value. Whereas the source range is defined by a minimum and maximum value representative of the conservative and optimistic case, the best estimate of the expert range represent the value expected by the expert for a particular parameter.

The level of confidence in the expert range depends on the quality of the justifications for the assumptions:

- if there are enough indications available (multiple lines of evidence) or if it can be expected that the range will be confirmed in the future, for instance on the basis of the results of the ongoing experimental and/or modelling work, the level of confidence in the expert range will be considered high;
- if justifications for the assumptions are weak, for instance because there is no research going on or even foreseen, the level of confidence in the expert range will be considered low.

Using the two-range approach, the safety assessor will select the minima, maxima or best estimates to represent a conservative or realistic calculation case. The uncertainties covered by the source range are discussed within the interaction meetings, together with the hypotheses behind those uncertainties and the way the hypotheses are treated for defining the expert range.

As uncertainties are progressively reduced by the RD&D programme, a particular expert range becomes more and more supported until it can be considered as the new source range in the next RD&D programme.

As part of the *treatment of the uncertainty*, the parameter data are expressed according to three categories of uncertainties:

1. *Upscaling* - the degree to which observations and measurements made over relatively short intervals of space and time may be assumed to apply over the larger spatial and temporal scales of interest in safety assessment.

2. *Transferability* - the degree to which observations and measurements made at one location in the host formation (e.g. in the Mol-Dessel area) may be assumed to apply at another location (the actual repository site, which may be elsewhere in the potential siting area).

3. *Evolving conditions* - the impact of phenomena, such as climate change and geological events, that may affect the disposal system occurring over time in a given scenario and assessment case.

This categorization originates from the specificities of the Belgian RD&D programme. The SFC 1 is a safety case dedicated to the study of a zone in which a reference site is selected. The reference site is not intended to be the future site for the geological repository, but is rather taken as the site of reference to perform the experimental studies and subsequently the safety assessments.

Most of the data used in safety calculations come from experiments carried out in the underground research laboratory or in surface laboratories on clay cores taken at the reference site. The adaptation of these data to the *in situ* conditions of the reference site may require spatial and temporal extrapolations which increase the uncertainty range on these data: This operation is called the upscaling. The applicability of the parameters and processes from the reference site to the whole assessment zone contributes also in most cases to an increase of the uncertainty of the parameter. The evaluation of the uncertainties arising from the applicability of the parameter data from the reference site to the whole assessment zone is called the transferability. Due to the timescales considered in the safety assessment of a geological repository, it is recognized that the uncertainties linked to the phenomenological evolution of the repository are usually the most important factors contributing to the uncertainties on the parameters. The uncertainties linked to the evolving conditions of the repository are considered in the third category of uncertainties. Note that this third category includes also the uncertainties linked to upscaling and transferability. For each of these categories a source and an expert range is provided (along with best estimates and, if possible, probability density functions).

This categorization in three different types of uncertainty allows to trace the increase of the uncertainty from the minimum range (based on measurements valid for the reference site) up to its maximal range after spatial and temporal extrapolation. It helps the safety assessors to consider these uncertainties in (altered) evolution scenarios and assessment cases.

During the interaction phase between the experts from the assessment basis and the safety assessors, the uncertainties will be discussed on the basis of this categorization. In general, safety assessors and experts will discuss first the impact of the upscaling for which the uncertainties are mostly known and managed. The discussion will then be carried out following the two categories for which uncertainties are more difficult to handle.

A database system equipped with a versioning and reviewing system is currently implemented in order to guarantee the traceability of the selection of the parameter ranges from evaluations, based on experimental, process modelling or literature studies, performed by the assessment basis group up to their use in the safety calculations.

6. References

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