OPERA

RESEARCH PLAN

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Section I: THE SAFETY CASE

1. Introduction

1.1. Background

The five-year research programme for the geological disposal of radioactive waste – OPERA [1] – will start in June 2011. As the radioactive waste disposal process in the Netherlands is at an early, conceptual phase and the previous research programme has ended more than a decade ago, in OPERA a first preliminary or initial safety case will be developed to structure the research necessary for the eventual development of a repository in the Netherlands. The safety case is conditional since only the long-term safety of a generic repository will be assessed.
The Meerjarenplan serves as guideline for the execution of the research. This OPERA Research plan is a complement to the OPERA Meerjarenplan [1]. The OPERA Research plan elaborates the research programme description in the Meerjarenplan. It describes:
- the structural elements of the Safety Cases upon which the needs for R&D are based
- the research necessary to develop two initial, conditional Safety Cases for national repositories concepts for radioactive waste in rock salt and in Boom Clay

1.2. Objectives

The OPERA Research plan contains a comprehensive description of the individual research tasks for which proposals can be submitted and will serve as the basis for the Calls (for the proposal procedure and organisation of the Calls see the Meerjarenplan). The objective of the research is to collect and develop evidence and arguments to evaluate the long-term safety. The research therefore involves both technical as well as societal aspects.
The tasks described in the plan reflect the components in the initial, conditional safety case. Starting point for execution of the tasks is the use of exiting national and international literature and transfer of the information to the generic repository in the Netherlands. Only where necessary, literature survey and comparison should be complemented by experimental research.
In the plan, research background, scope, and rationales, as well as relevant interactions between the tasks are described. The planning of the research activities is presented and possible areas for collaboration with the Belgian research programme on radioactive waste disposal are identified.

1.3. Realization of Research plan

The OPERA Research plan is developed by NRG in close collaboration with COVRA. It is based on discussions from the NORA [2] meeting in November 2009, three task leader meetings that were held in February, April and June 2010 and the NORA workshop in June 2010. The task leader meetings were attended by Dutch research institutes such as NRG, ECN and TNO and Dutch universities such as Delft University of Technology, Utrecht University and Wageningen University and Research Centre. The Research plan in the developing stage was discussed in the NORA workshop with the Belgian agency for the management of radioactive waste ONDRAF/NIRAS. This Research plan is reviewed by Charles McCombie from MCM Consulting.

1.4. Explanation of contents of Research plan

Chapter 2 contains a general overview of the main elements of a Safety Case. In Chapter 3, the basic structure of the OPERA Safety Cases is presented. This chapter contains a condensed summary of relevant boundary conditions for the OPERA Safety Cases and

[1] OPERA is the Dutch acronym for research programme into geological disposal of radioactive waste
[2] NORA is the Dutch acronym for network into geological disposal of radioactive waste

presents the safety strategy that has to be supported by the research programme. Chapter 4 describes briefly the structure of the OPERA research programme and summarizes the contents of the different work packages. In Chapter 5, an overview of the time planning is given that reflects considerations on how to facilitate the collaboration with the Belgian research programme on radioactive waste disposal OPERA aims at. In Chapter 6, a detailed time planning as well as the assignment for funding of the tasks in the work packages are shown. In Section II, the content of the tasks are discussed in more detail.

2. General set-up of a Safety Case

The development of geological disposal facilities for radioactive waste will take place over decades. At various stages in the lifecycle of these facilities, decisions are needed to proceed through the lifecycle and move towards the next stage. These decisions are supported by a safety case. The Safety case means a collection of arguments in support of the long-term safety of the repository. A safety case comprises the findings of a safety assessment and a statement of confidence in these findings. For a disposal facility, the safety case may relate to a given stage of development. In such cases, the safety case should acknowledge the existence of areas of uncertainty or of any unresolved issues and should provide guidance for work to resolve these issues in future development stages.
Safety assessments are carried out periodically throughout repository planning, construction, operation, and prior to closure, and are used to develop and progressively update the Safety Case. The resulting Safety Case report provides an evaluation of safety at a point in the stepwise procedure to develop a repository[3], with the level of detail and the complexity of the analysis varying substantially from an early assessment, focusing on general concepts and feasibility, to a late assessment addressing the optimization of the system or compliance with regulatory requirements. The development of the Safety Case methodology is also a powerful tool for structuring and conducting research programmes for the disposal of radioactive waste and this tool will be applied in the present study.

2.1. Elements of a Safety Case

The methodology of the 'Safety Case' that has been developed significantly over the last decade, is a substantial step forward towards a systematic approach integrating all relevant aspects of the safe disposal on radioactive waste. Nevertheless there is no completely agreed approach and different national disposal programmes use slightly different definitions of a Safety Case. The approach used here is based directly on the publications on the NEA [2]. Elements that contribute to the Safety Case may include the following (Figure 1):

- The safety strategy: the safety strategy is the approach for achieving a safe disposal. This includes an overall management strategy, an assessment strategy and - depending on stage of the disposal process - also a siting and design strategy.
- The assessment basis: the assessment basis is the collection of information and analysis tools supporting the safety assessment. This includes an overall description of the disposal system, the scientific and technical data and understanding relevant to the assessment of system safety, and the assessment methods, models, computer codes and databases for analysing system performance.
- Evidence, analyses and arguments: most national regulations give safety criteria in terms of dose and/or risk, and the evaluation of these indicators using mathematical analyses, for a range of evolution scenarios for the disposal system, appears prominently in all safety cases that are intended for regulatory review. In addition, it is common to use other lines of evidence, including qualitative comparisons, to give a perspective on the risks and to enhance confidence in the results of mathematical analyses.
- Synthesis: to substantiate the claim of safety, a synthesis of the available evidence, arguments and analyses is made. This should highlight the grounds on which the authors of the Safety Case have come to a judgment that the proposed disposal system can provide the required level of safety and hence the planning and development of the disposal system should continue.

[3] Beside safety-related information, the Safety Case reports often also contain other information, like cost, resources, timing etc.

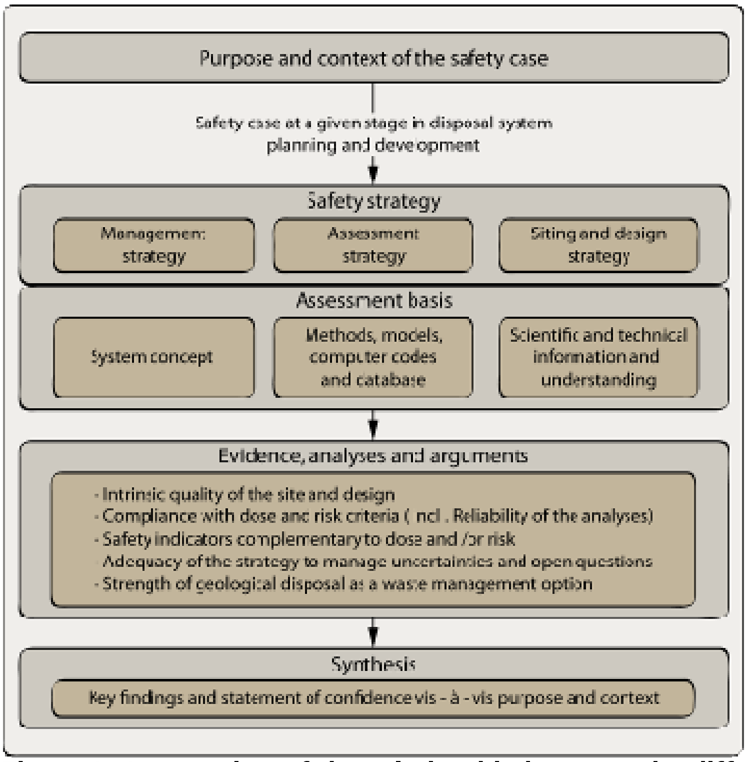


Figure 1: An overview of the relationship between the different elements of a Safety Case [2].

2.2. Elements of the OPERA Safety Cases

The main objective of the OPERA research programme is to provide tools and data for the development of Safety Cases for national repository concepts for radioactive waste disposals in two host rocks present in the Netherlands, salt rock and Boom Clay. In the OPERA Meerjarenplan, the purpose and context of the OPERA Safety Case have been described in more detail. This Research plan describes the content and structure of the OPERA research programme that forms the core of the OPERA programme. In the next sections, the safety strategy and the outline of the assessment basis will discussed as it will apply to the OPERA Safety Cases. This forms the basis for the elaboration of the programme structure in the next Chapters.

As noted in the OPERA Meerjarenplan, much work has been done earlier in the Netherlands on disposal concepts for rock salt and, accordingly, only limited efforts within OPERA are performed to develop a Safety Case in rock salt. Consequently, the major part of the OPERA research programme is dedicated to the development of the OPERA Safety Case for Boom Clay. For better readability of the Research plan, all descriptions and discussions apply to the Boom Clay Safety Case in the first instance, except if stated differently. However, part of the work on the OPERA Safety Case for Boom Clay, in particular methodological aspects and safety case context, can also be used for development of the Safety Case for rock salt. For a description of the work related to rock salt see Task 2.2.1 in Section II: WP 2.

3. Safety strategy

A ‘safety strategy’ as part of a Safety Case describes the overall approach to demonstrating safety, and includes strategies for the management, assessment, siting and design.

3.1. Management strategy

In the Netherlands, the national policy lays down that all radioactive waste will be stored above ground in engineered structures allowing retrieval at all times for a period of at least 100 years. After this period of long-term storage, geological disposal is foreseen. The policy is based on a step-wise decision process in which all decisions are taken to ensure safe disposal in a repository, but without excluding unforeseen alternative solutions in the future. An important decision to be taken after the period of interim storage is whether to continue with above ground storage or to start the development of a repository. During interim storage, research is to be conducted into the development of a repository, either in a national or a multinational context. A detailed description of the management strategy can be found in the OPERA Meerjarenplan.

3.2. Siting strategy

The selection of a location for a radioactive waste disposal facility is a sensitive topic that should be prepared carefully. Since the early 1980s, siting radioactive waste repositories has proved immensely difficult in every country. Lessons have been learned in the last decade from successful national programmes and advanced processes have emerged that address this aspect. Currently, the disposal of radioactive waste is defined as a multi-step approach that aims to ensure that any chosen site provides demonstrably sufficient safety during the operational phase and in the long term.

A central element of successful siting strategies is cooperation with local communities that may be interested in hosting a disposal facility and wish to become actively involved in its development. Experience in some countries has shown that a community-level and national-level discussion and evaluation process can be employed to find sites that are both technically suitable and supported by common consent. Considering the actual stage in the decision-making process in the Netherlands, the efforts within OPERA on the development of a siting strategy will be limited to one aspect: it is generally acknowledged that it is important to build up confidence in the technical feasibility and radiological safety of radioactive waste disposal in an early stage. Trust and confidence in the safety of the disposal system, the implementing process and the implementer will be necessary to facilitate future decisions on siting. This trust can only be reached when stakeholder and public are involved already in an early phase of a disposal programme; accordingly, efforts will be devoted within OPERA to investigate how to involve stakeholders and assessing what determines the level of public trust and confidence.

3.3. Assessment strategy

The assessment strategy defines the approach adopted to perform safety assessments and evaluate evidence and arguments for the long-term safety of a repository. An initial definition of the assessment strategy for the OPERA Safety Case is part of this Research plan and will be worked out in more detail during the OPERA research programme (see Task 2.1.1 in Section II). A condensed description of the assessment basis used to implement the assessment strategy is given in the next section.

4. Assessment basis

The assessment basis consists of descriptions of the disposal concept, of the scientific and technical information and data that are needed to understand the functioning of the safety system, and tools and methods used to translate this understanding into quantitative safety and performance assessments. The following three sections describe these elements of the assessment basis for the OPERA Safety Case.

4.1. System concept

The system concept represents the repository design under consideration. Besides providing a description of the engineered barrier system (EBS) and the geological barriers, it explains how these barriers are expected to provide safety over the required long timescales. [e.g. 3]. Such a system of multiple barriers (MBS) is intended to perform a number of functions relevant to long-term safety, called safety functions. In general, the safety functions relied on are "to contain the radionuclides associated with the radioactive waste and to isolate them from the biosphere" in order to prevent radionuclides and other toxic species reaching the surface in such concentrations that they could present an unacceptable risk. The entire MBS is can be subdivided into the following subsystems [4,5,6]:

- The near-field - including
    - i) wastes packages (waste matrix, container, overpack if used)
    - ii) further engineered barriers (buffer materials if used, seals, cap or cover) and
    - iii) zone disturbed by the presence of any excavations (excavation disturbed zone, EDZ);
- The far-field –the host rock and surrounding geological formations (or overburden);
- The biosphere - the physical media (atmosphere, soil, sediments, and surface waters) and the living organisms (including humans) that interact with them.

The near field comprises, in addition to seals, backfills and plugs, also supporting materials like concrete lining in case the host rock itself cannot provide sufficient support to prevent collapse of the excavated volume for a sufficient period. This period is usually defined by the required time to emplace the waste but can also be defined for a larger period for example in case of the retrievability of waste in the Dutch policy [7].

The far field comprises the host rock that is not damaged during excavating of volumes and the geological media surrounding the host rock. Another term for the far field is "geosphere". Within OPERA, this region is also labelled the "geological environment".

The potential host rock formations that are considered within OPERA are Zechstein rock salt and Boom clay formations. As shown in the description of the research tasks, experimental research is limited to Boom clay formations. Therefore, the following paragraphs are attributed to the Boom clay formations.

4.1.1. Safety functions

A methodology to assess safety throughout the development of the repository is using safety functions [2,3]. Safety functions can be defined as actions or roles that the natural and engineered barriers must perform to prevent the radionuclides present in the disposed waste posing an unacceptable hazard to humans or the environment [8]. The barriers are selected and designed so as to ensure that safety is provided by means of multiple safety functions and that the overall performance of the repository is not unduly dependent on a single safety function. Some are latent safety functions that come into play at different times or under different scenarios (e.g. leach resistance during physical containment phase). Different safety functions can be defined dependent on type of host rock and EBS design. In Safety Assessment and Interim Feasibility Report (SAFIR) 2, the safety functions for a repository in the Belgium Boom Clay are described [3]. This approach is also used in

OPERA. Figure 2 gives an overview of the relevant safety functions, as presented in the SAFIR study and as will be used for the OPERA disposal concept for the disposal of HLW in Boom Clay. Outlines of this concept are described in a complementary report [9].

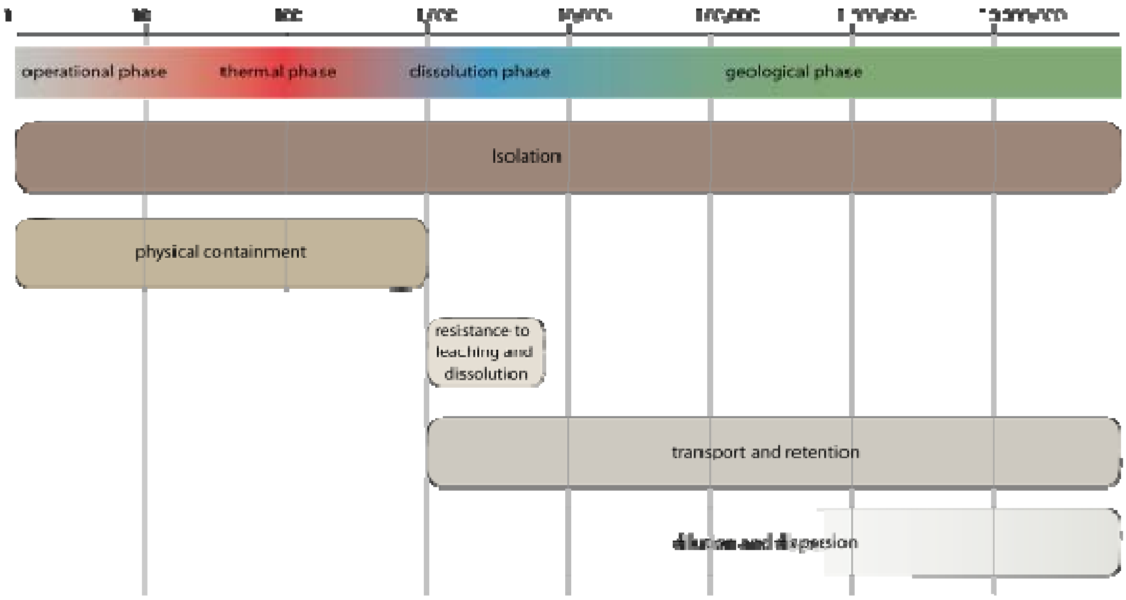


Figure 2: Safety functions of the OPERA disposal concept for HLW adopted from SAFIR-2 [3].

For the safety assessment of the OPERA disposal concept, four relevant phases were identified: the ‘operational phase’ defines the phase from the moment the first waste containers are emplaced in the facility until the moment when all disposal galleries and other open volumes are backfilled and sealed. During the ‘thermal phase’, the temperatures of the surrounding host rock are significantly increased by the heat released by the HLW. The ‘dissolution phase’ describes the time interval where the waste is being increasingly dissolved and the ‘geological phase’ describes the time interval when the engineered barrier system (EBS) is assumed to have no relevant protective function anymore.

The OPERA reference concept is based upon five safety functions:

1. The safety function ‘isolation’ describes the limitation of (unwanted) access to the facility, either by human intrusion (deliberate and inadvertent) or natural processes (e.g. erosion). This safety function applies in all phases and must be guaranteed by management of the access during the operational phase and a proper design of the repository and a suitable geological setting during all other phases.
2. The safety function ‘physical containment’ describes the isolation of the radionuclides from their immediate environment (i.e. water) by the waste container. According to the safety strategy chosen in the disposal concept, the design should ensure that this function applies throughout the thermal phase.
3. The safety function ‘resistance to leaching’ describes the slow release of radionuclides from the waste matrix. This safety function is relevant once the ‘physical containment’ function fails and waste comes into contact with water.
4. The safety function ‘transport and retention’ describes the slow transport of radionuclides through the host rock due to diffusion, retention and retardation processes. During the dissolution phase, it works in parallel with the safety function ‘resistance to leaching’. Based on model calculations, it is expected that the ‘resistance to leaching’ has only limited influence on the overall safety compared to the slow transport through the host rock.

5. The safety function ‘dilution and dispersion’ is not a safety function in the sense that it can be optimised by improvements in design. This function describes the dilution and dispersion of radionuclides in the geosphere that surrounds the host rock and in the biosphere. This safety ‘function’ applies from the dissolution phase on, but it is expected that this function is relevant only after more than 10.000 years because the slow transport out of the host rock formation is expected to take longer than this.

One rationale for this system concept is to simplify the assessment basis by creating the possibility to assess some of the safety functions independently from others. By using a container that isolates the waste for longer than the duration of the thermal phase, the migration of radionuclides is easier to assess and has fewer uncertainties, because thermal effects on radionuclide migration can be neglected. In other words, if the isolation of radionuclides during the thermal phase is guaranteed by the container and the surrounding EBS, the assessment of radionuclide migration can be performed under condition where the host rock can be assumed to behave similarly to undisturbed Boom Clay[4]. As consequence, both safety functions will be assessed independently from each other: in a performance assessment, the integrity of the container during the thermal phase can be established, and in a safety assessment - starting after the interval that is marked by the minimum life expectancy of the container - the migration of radionuclides can be calculated with more confidence.

For low and intermediate level wastes (LILW) waste, the same approach can be used. Figure 3 shows this overview for the OPERA reference concept for the disposal of LILW in Boom Clay. It only differs in the absence of the thermal phase since the generated heat during decay is not expected to cause any rise in temperature for which additional measures in the design are required.

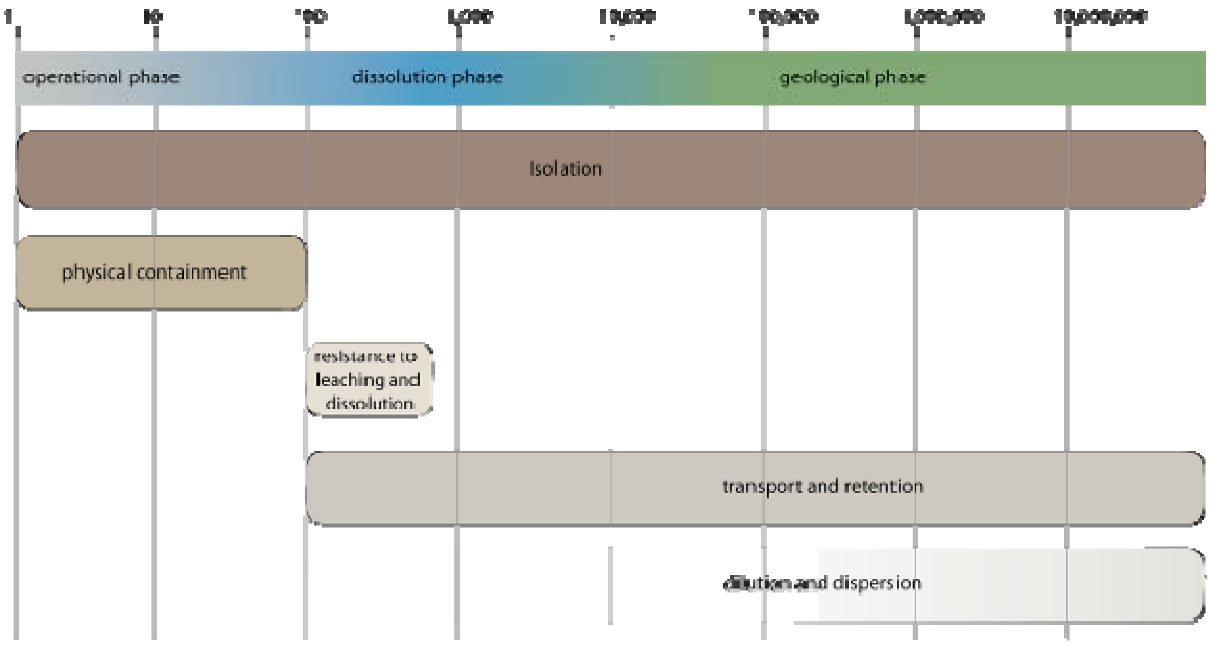


Figure 3 Safety functions for the OPERA reference concept for LILW adopted from ONDRAF/NIRAS [3].

[4] Disturbance made by excavating disposal galleries and boreholes is expected to have disappeared after the thermal phase. As temperatures have also returned to ambient at the given depth, the safety functions “transport and retention” and “dilution and dispersion can be analysed in Boom Clay without taking into account thermal or mechanical disturbance.

An overview of the objectives of the safety functions is shown in Table 1. It also shows to which compartments or barriers these safety functions apply as well as an indication of a period in time.

Table 1. Overview of safety functions, objectives, components and barriers adopted from ONDRAF/NIRAS [3]

Safety function	*Objectives*	*Component and/or barrier*	*Indicative time [1] [years]*
Physical containment	Protection from groundwater for the required period	Waste package	1.000 (HLW) 100 (LILW)
Resistance to leaching and dissolution	Delay and spread the release into the rest of the EBS and the host rock	Waste Form	< 10.000 (HLW) 100 (LILW)
Transport and retention	Prevent and spread the release into the biosphere	Host rock (Boom Clay)	> 100.000
Dilution and dispersion	Natural processes that bring a reduction in concentrations	Surrounding rock formations (Aquifer)	10.000
		Biosphere	500
Isolation	Limit the likelihood and impact of human intrusion or of erosion exposing the wastes	Geology (erosion)	> 1000.000
		Institutional control / memory (intrusion)	100 - 5000

[1] Period of time over which a scientifically correct and convincing assessment of the action of the safety function is assumed to be possible.

The OPERA specific outline [9] of a disposal concept is available the start of the OPERA research projects.

4.2. Scientific and technical information and understanding

The development of scientific and technical understanding, data and arguments to support the Safety Case is the main objective of the OPERA research plan. The safety functions defined in the previous section leads to clear requirements for the assessment of the given concept and can be translated into specific research questions. The following six main research topics related to the safety functions of the disposal concept in Boom Clay can be distinguished:

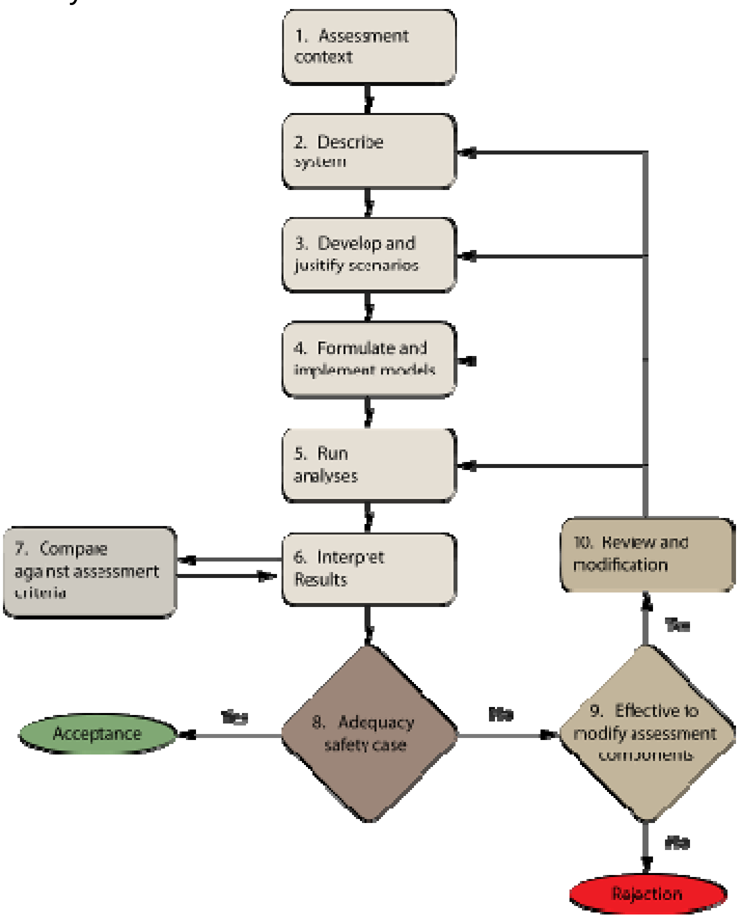
- Future evolution of the geosphere (isolation)
- Integrity of the container/EBS system during the thermal phase (physical containment)
- Source term HLW/ILW/LLW (resistance to leaching)
- Radionuclide migration in Boom Clay (transport and retention)
- Radionuclide migration in surrounding rock formations (dilution and dispersion)
- Radionuclide migration and uptake in the biosphere (dilution and dispersion)

To address all aspects of these main questions, a multidisciplinary approach is necessary, involving different kinds of contributions and arguments and often covering more than one area of expertise.

4.3. Methods, models, computer codes and databases

A ‘safety assessment’ can be defined as: “the process of systematically analysing the hazards associated with the facility and the ability of the site and designs to provide the safety functions and meet technical requirements of a disposal system [10]. In a safety assessment, the potential hazard or harm can be measured and may be evaluated in the course of making a safety case [11]. A potential hazard is the dose to which people may be

exposed. This indicator, the dose, is calculated and compared with the criterion dose limit or constraint: the reference value.
Although both terms are often used synonymously with each other, a distinction can be made between 'performance assessment' (PA) and 'safety assessment' (SA)[5]: the latter term is used when safety (or health) related indicator (e.g. the dose rate) is compared with a reference value. The term performance assessment then is used for the comparison between the calculated performance (e.g. 'period of physical containment') and the performance (or design) criterion (also reference value). In the calculation of the performance or safety, assumptions have to be made. The normal (or reference) scenario is based on processes that have a high probability to occur and, therefore, represents the most likely evolution of a repository; human actions on repository development are neglected. The safety of a repository may evolve differently e.g. in case of human intrusion, malfunctioning of a safety function or a not forecasted seismic activity. In a scenario analysis, the impact on safety on these processes with a low probability is addressed.
An important aspect in the assessment of the different safety functions is the completeness of the assumed set of features, events and processes (FEPs) that can influence the behaviour of the repository system since the safety functions must perform adequately for all of these cases and combinations of them. A common approach to test if all relevant aspects attached to the safety functions under consideration are addressed in the assessment is the use of a so-called 'FEP-list'. The structured list of FEP's [12] and the more detailed descriptions are valuable for the evaluation of the comprehensiveness of contributions to the OPERA research programme and of the completeness of the OPERA Safety Case [6].



[5] note that '*safety assessment*' is often used in literature as a synonym for the combination of SA and PA
[6] The definition of a comprehensive list of FEP's specific for the OPERA Safety Case is defined as task in the OPERA research plan.

Figure 4 Safety Assessment methodology [4]

4.3.1. Safety assessment methodology

The methodology of any safety assessment consists of a number of steps as shown in Figure 4. The first step, the assessment context, includes definition of the assessment purpose and criteria. In OPERA, the purpose is the assessment of the feasibility of a potential, generic repository design. Siting is excluded. The second step, the system description, characterises, as quantitatively as possible, the components of the disposal system and their interfaces. The development of the repository is considered in different scenarios in step 3. In a normal evolution scenario, the potential migration pathway for radionuclides is to pass all components. The transport of this potential migration pathway can be calculated using a number of interconnected models, as shown in Figure 5. Two types of models are formulated and implemented in this step. On the left side of the figure models are descriptions of the system and how it acts. On the right side are the calculational models which development requires understanding and input data from the left side. For modelling of radionuclide migration, a compartmental approach will be followed. The modelling of the three compartments (the host rock (Boom Clay), the formation (aquifer) surrounding the host rock and the biosphere) may differ in order to analyse the different safety functions that apply in the three compartments and to take into account the differences in the processes involved, their relevance and their degrees of uncertainties.

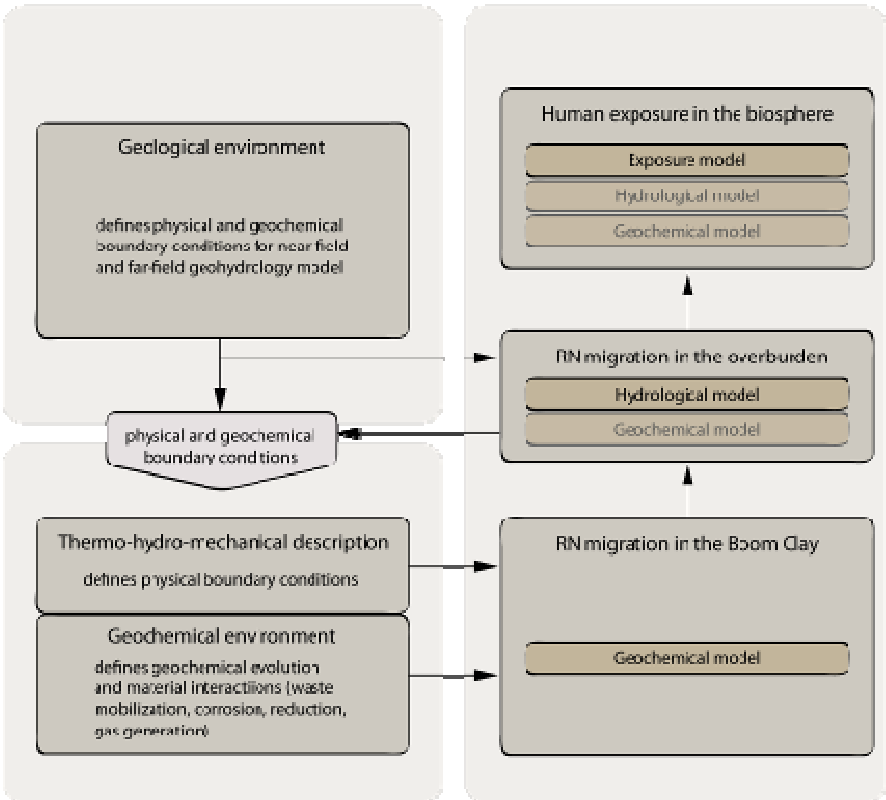


Figure 5: Overview of the different, interconnected models used in step 4 of the safety assessment methodology

The safety assessment is concluded with interpretation of the results and comparison of calculated safety and performance with their reference values (the assessment criteria, steps 6-8). Based on this comparison, the disposal concept can be accepted or rejected (step 8). In case of rejection it is considered in steps 9 and 10 whether modifications to the system, data or analyses will alter this conclusion.

4.3.2. Interrelationship between different tasks within OPERA

Conducting a safety assessment and developing a Safety Case involves coordinating a variety of interrelated tasks and disciplines. Figure 6 shows interrelated set of tasks that are to be performed within OPERA. From defining the logistic, legal (e.g. reference values) and societal boundary conditions for the disposal concept under consideration, via defining the disposal concept and scenarios to the calculation of the safety and performance of the system. The final task is the integration of all evidence and arguments into an overall safety statement that will be communicated to stakeholders and the interested public.

Safety statements can be used to organise and document available information according to its safety relevance and to steer research tasks. The safety statement approach, developed by ONDRAF/NIRAS, is a structured, hierarchical method to divide the top-level safety requirements into increasingly specific statements that can be supported by research tasks [13]. As such safety statements can provide valuable tools for communicating between safety assessors, geoscientists and stakeholders and for assessing the propagation of uncertainties in a bottom-up manner, (i.e. from the most specific to the most general statements).

Higher-level statements, such as the statements that define the safety concept, being more general in nature, can be formulated, early in the programme. Other more detailed statements gradually emerge as the programme proceeds, that is as the concept and design become better defined and more firmly established, and geoscientific evidence and arguments and other elements of the assessment basis are developed. At the end of OPERA, these statements will be used for the definition of topics in a research programme.

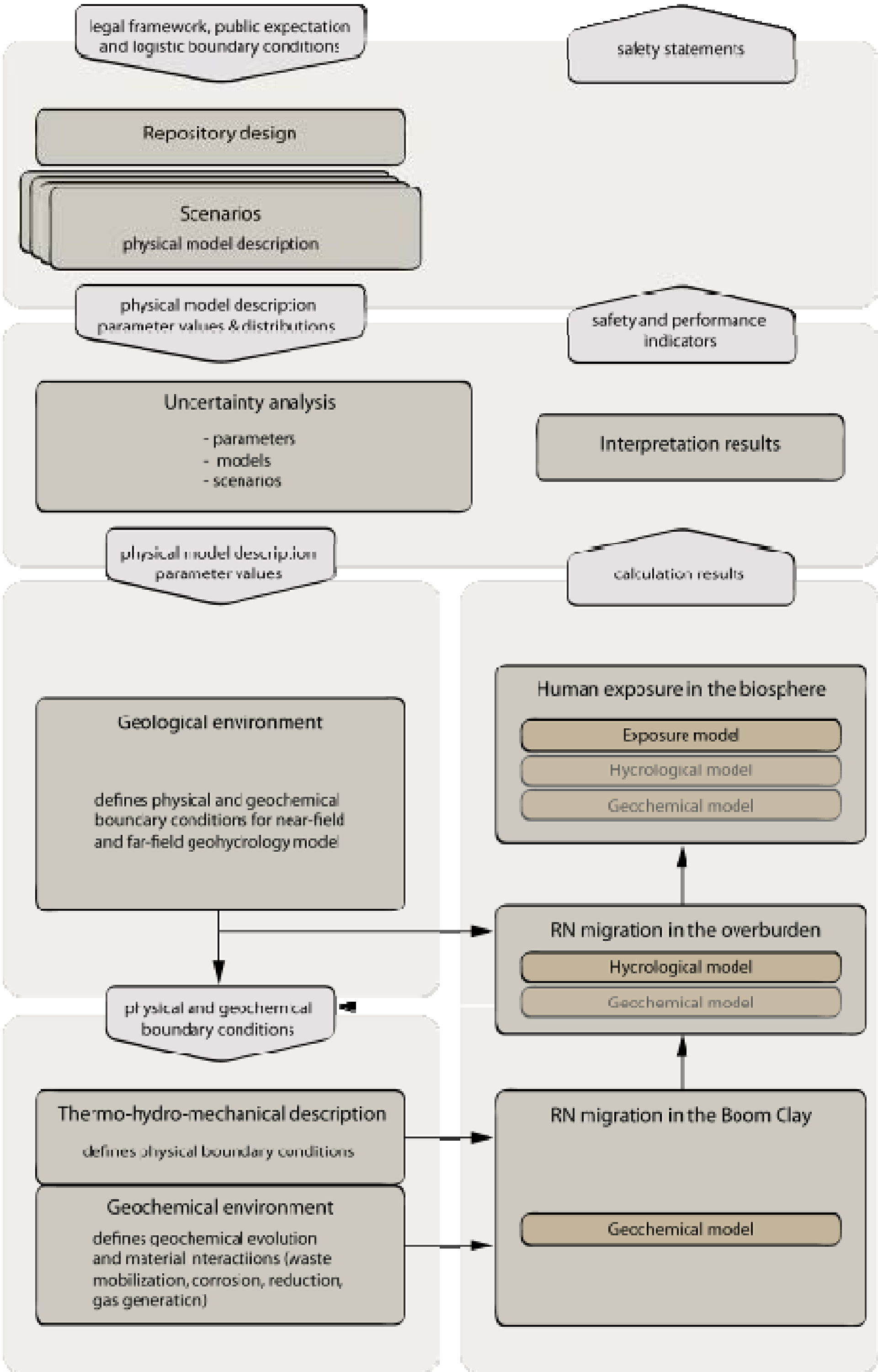


Figure 6: Interrelationship of different tasks within OPERA.

5. Structure of the OPERA research programme

The tasks are organized in a work package structure that reflects the different fields of work or disciplines.

5.1. Modularity of programme elements

The programme is organized in a modular way, containing a larger number of separate tasks with well defined content and clear interfaces with other tasks. This gives OPERA the flexibility to work on (fundamental) research questions without losing track of where the results can contribute to the main goal of assessing the repository concept. It also enables OPERA and future research programmes to evaluate, refine or replace contributions on a very detailed level. In addition, the modular structure facilitates the transferability of the knowledge gained in OPERA to other (argillaceous) host rocks.

5.2. From fundamental knowledge to the final safety statement

Every task defines a topic that needs to be considered with regard either to the expected implications on relevant safety functions of the OPERA reference concept or to the safety functions itself. The result of every task that is related to the study of physical or chemical processes must address all relevant processes, discuss the relevance of these and it should contain a conservative estimation on the parameters that are considered and the uncertainties that are attached to them. The conclusions drawn from a task should be based on sound experimental evidence and fundamental process understanding rather than 'educated guesses' or 'rule-of-thumbs'. The status of the scientific arguments presented and remaining uncertainties need to be discussed.
The integration and simplification of fundamental process understanding into a form that enables the performance of safety assessment calculations is defined as a separate task and all arguments and analyses that lead to the model description should carefully be documented. In this manner, at the end of OPERA, a full documentation will be available describing all steps from fundamental processes to the overall safety assessment model. The final report of every task should be presented in a way that it can be integrated in the final Safety Case reports.

5.3. Open for collaboration

The OPERA Research plan gives some indication of the depth to which every task has to be worked out, but contributors should indicate in more detail the scope and nature of the work that they want to conduct. This approach is chosen to keep the programme open for the intended collaborations with (parts of) the Belgian research programme on radioactive waste disposal. Some aspects of the proposed work may be unnecessary when cooperation can be arranged in a particular field of work, e.g. because sufficient experimental results are already available. Other proposed topics may already be part of the Belgian research plan. However, by structuring the programme in a modular, task-based way, both the general outline of the OPERA research programme and the individual task definitions should not have to be adapted although some contributions may change in scope but without changing the principal nature of the contribution.

5.4. Collaboration with Belgian programme

The Boom Clay is an argillaceous clay formation named after the Belgian village of Boom, where this formation reaches the surface. Boom Clay is present in the north-eastern part of Belgium and can be found almost everywhere in the Netherlands. Because of its properties that make it a suitable candidate host rock for the disposal of radioactive waste, both Belgium and the Netherlands are performing research on the potential use of this host rock for their national facilities.

To increase the efficiency and to avoid duplication of work, the OPERA research programme aims at a close cooperation with the Belgian research programme on radioactive waste disposal. For both countries, the host rock considered and many elements of the repository design are very similar. The Belgian research organization SCK·CEN has more than 30 years of experience with research on radioactive waste disposal in the Boom Clay formation. This has resulted - besides detailed knowledge on Boom Clay as a host rock - in considerable experience in both the performance of applied experimental work and the integration of the results into performance assessment (PA). Furthermore, the Belgian HADES underground research laboratory enables the Belgian research programme to perform in-situ experiments and to demonstrate the validity of assumptions and models used in PA.
Given the differing stages of both national programmes, for OPERA the advantages of a close cooperation with the Belgian research programme are obvious. But the Belgian research programme may benefit from OPERA as well: the strong consortium of leading experts in their fields that is represented in the OPERA research programme may add to the existing expertise of the SCK·CEN and their partners in certain areas of work. Common parts of the work foreseen in the Belgian research programme may be performed within OPERA, enabling SCK·CEN or other organizations involved in the Belgian research programme to use their capacities for other topics. Critical exchange of expert opinions and experience may stimulate and improve the quality of both programmes. Finally, a complementary approach of both programmes using - where applicable - the same methods, assumptions and parameter values will increase the confidence of public and stakeholders in the safety statement and arguments that support the long-term safety of the geologic disposal of radioactive waste in Boom Clay in Belgium and the Netherlands.

The set-up of the OPERA research programme is designed to enable and stimulate this cooperation. Without defining the scope and target of cooperation for each individual contribution, OPERA's scheme for the evaluation and funding of proposals reflects the following principles:

1. where possible, existing knowledge from the Belgian research programme should be used
2. if necessary, this knowledge will be translated to the Dutch disposal concept
3. if necessary, additional work will be performed within OPERA, either to fill gaps in the joint programme or else to address Netherlands-specific topics

5.5. General work package outline

The tasks to be undertaken in the OPERA research programme are allocated to one of seven work packages (WP).

- In WP1, "Safety Case Context", all contextual and logistic boundary conditions for the OPERA Safety Case will be defined. This includes the definition of waste characteristics (WP1.1), the determination of political requirements and societal expectations with regard to reference values, retrievability aspects, and the involvement of stakeholders and the public (WP1.2), as well as questions related to the effective communication of Safety Case outcomes to stakeholders and the public (WP1.3).
- WP2, "Safety Case", is the overall integrating work packages of OPERA including the definition of the Safety Case structure and methodology (WP2.1) and the limited efforts within OPERA to evaluate the current state of the art on the repository design in rock salt (WP2.2).
- In WP3, "Repository design", the principal feasibility of a disposal concept in Boom Clay in the Netherlands at 500 m depth is evaluated (WP3.1), and possible design modifications can be investigated that may reduce uncertainties with respect to safety assessment calculations (WP3.2).
- In WP4, "Geology and geohydrology", all relevant geological and geohydrological features of the geosphere at present and their expected future evolution(s) are

investigated (WP4.1), and to be used to define the boundary conditions for the near-field (WP4.2).

- In WP5, “Geochemical and geomechanical behaviour of the repository”, all aspects related to the geochemical behaviour of the materials introduced into the Boom Clay (WP5.1), the natural evolution of the host rock and potential interactions of the host rock with the materials introduced to it (WP5.2) are investigated.
- In WP6, “Radionuclide migration”, all relevant processes that describe the migration of radionuclides from the waste through the different compartments to the biosphere are studied. This work package is divided into three parts related to the migration of radionuclides in the repository and the host rock (WP6.1), in the surrounding geosphere (WP6.2), and the migration and uptake of radionuclides in the biosphere (WP6.3).
- In WP7, “Scenario development and performance assessment”, all methods and tools necessary to perform safety assessment calculations are established. In WP7.1, all relevant scenarios that need to be considered in the Safety Case are identified and worked out in detail. In WP7.2, the modelling tools necessary to perform the safety assessment calculations are developed, including the derivation of all parameter values from the input of WP4 - WP6. In WP7.3, the methods used for the safety assessment are defined and the safety assessment calculations are performed and documented.

Figure 7 shows all elements of the OPERA Safety Case and how the work packages are related to them.

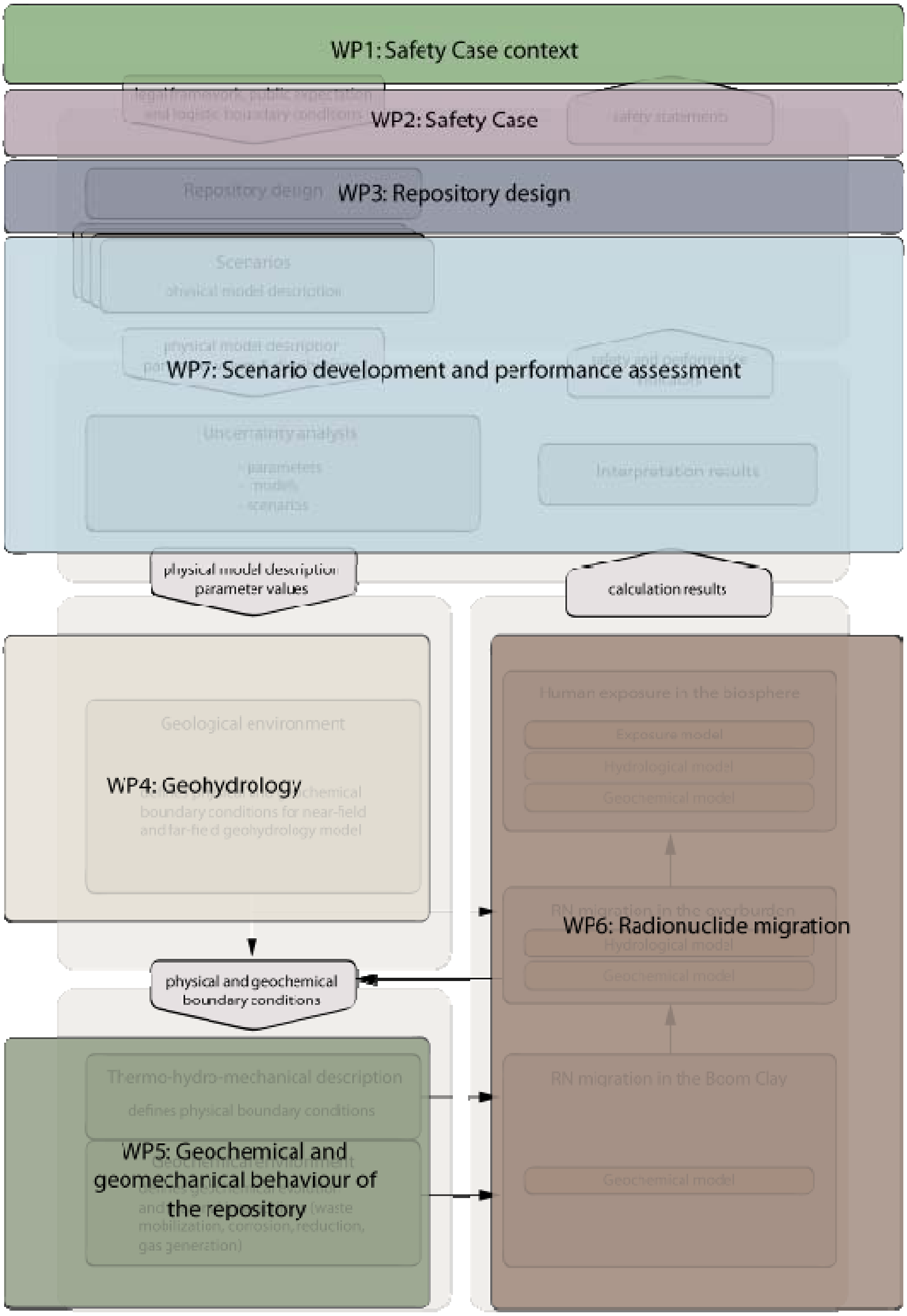


Figure 7 Elements of the Safety Case and their coverage by the work packages.

6. Planning

In Table 2, a general overview of the time planning for the different tasks of the research programme is given. Table 2 is based on considerations on the nature and relevance of the individual tasks and the interactions between several programme parts.

Table 2: Time schedule for the different tasks

research activities: low medium high

Time table of research activities	2011	2012	2013	2014	2015
WP1: Safety Case context					
WP1.1: Waste characteristics					
Task 1.1.1: Definition of radionuclide inventory and matrix composition	high	medium		low	low
Task 1.1.2: Alternative waste scenario's	medium	medium	medium		
WP1.2: Political requirement and societal expectations					
Task 1.2.1: Arena or stakeholder analysis	high	medium			
Task 1.2.2: Legal requirements	high	medium			low
Task 1.2.3: Retrievability and staged closure		medium	medium	medium	
Task 1.2.4: Public & stakeholder involvement	high	medium			
WP1.3: Communicating the Safety Case					
Task 1.3.1: Communicating Safety Case results	medium	low			medium
WP2: Safety Case					
WP2.1: Definition of the Safety Case					
Task 2.1.1: Structure of the Safety Case	high	medium			
Task 2.1.2: Safety assessment methodology	high	medium	low	low	low
WP2.2: Repository design in rock salt					
Task 2.2.1: Evaluation of current knowledge for building the Safety Case		medium	medium	medium	
WP3: Repository Design					
WP3.1: Feasibility studies					
Task 3.1.1: Principal feasibility of reference design	high	medium	medium	medium	high
WP3.2: Design modification					
Task 3.2.1: Design modifications (o)		low	low		
WP4: Geology and geohydrology					
WP4.1: Geology and geohydrological behaviour of the geosphere					
Task 4.1.1: Description of the present geological and geohydrological properties of the geosphere	medium	medium			
Task 4.1.2: Future evolution of the geological and geohydrological properties of the geosphere		medium	medium		
WP4.2: Geohydrological boundary conditions for the near-field					
Task 4.2.1: Definition of boundary conditions for near-field model		medium	medium		
Task 4.2.2: Favourable geohydrological settings (o)			low	low	low
WP5: Geochemistry and geomechanics					
WP5.1: Geochemical behaviour of EBS					
Task 5.1.1: HLW Waste matrix corrosion processes		medium	high	high	
Task 5.1.2: LLW/ILW degradation processes and products			high	high	medium
Task 5.1.3: Metal corrosion processes		medium	medium		

Time table of research activities	2011	2012	2013	2014	2015
Task 5.1.4: Cementitious material degradation					
Task 5.1.5: Microbiological effects on the EBS and Boom Clay					
WP5.2: Properties, evolution and interactions of the Boom Clay					
Task 5.2.1: Geochemical properties and long-term evolution of Boom Clay					
Task 5.2.2: Geochemical interactions in Boom Clay					
Task 5.2.3: Geomechanical properties and thermo-hydro-mechanical evolution of Boom Clay					
WP6: Radionuclide migration					
WP6.1: Radionuclide migration in Boom Clay					
Task 6.1.1: Fundamental aspects of sorption processes					
Task 6.1.2: Modelling of sorption processes					
Task 6.1.3: Modelling of diffusion processes					
Task 6.1.4: Mobility and presence of colloidal particles					
Task 6.1.5: Non-diffusion related transport processes of solutes in Boom Clay					
Task 6.1.6: Gas migration in the EBS and in Boom Clay					
WP6.2: Radionuclide migration in the surrounding rock formation					
Task 6.2.1: Modelling approach for hydraulic transport processes					
Task 6.2.2: Modelling approach for radionuclide migration					
WP6.3: Radionuclide migration and uptake in the biosphere					
Task 6.3.1: Modelling approach for transport & uptake processes					
WP7: Scenario and performance assessment					
WP7.1: Scenario					
Task 7.1.1: Scenario development					
Task 7.1.2: Scenario representation					
WP7.2: PA model development and parameterization					
Task 7.2.1: PA model for radionuclide migration in Boom Clay					
Task 7.2.2: PA model for radionuclide migration in the geosphere					
Task 7.2.3: PA model for radionuclide migration and uptake in the biosphere					
Task 7.2.4: Integrated modelling environment for safety assessment					
Task 7.2.5: Parameterization of PA models					
WP7.3: Safety assessment					
Task 7.3.1: Safety and Performance Indicators methodology					
Task 7.3.2: Definition of methods for the uncertainty analysis					
Task 7.3.3: Safety assessment calculations					

As stated in a previous chapter, the OPERA research plan intends to facilitate and stimulate a close cooperation with the Belgian research programme. The realization of the intended cooperation between the Belgian and Dutch research programmes is however not a trivial task, since it must fit in both research programmes and should not interfere with any national contexts. Besides, detailed bilateral consultations on project-level will be necessary to define the scope of any of the individual collaborations and the conditions under which the collaborations will take place.

To enable the start of the OPERA research programme without (undue) delay, time was reserved in the planning for reaching an agreement between about terms and conditions of collaboration at programme level and for concluding bilateral consultations at project level. Hereto, the proposed time schedule in Table 2 was evaluated with respect to the required degree of collaboration in the individual tasks. Not all elements necessary for a Dutch Safety Case were found to be dependent on the intended cooperation with the Belgian research programme: although for some topics input or possible collaboration is recommended, other topics may be related to specific Dutch subjects. With regard to the intended Dutch - Belgian cooperation four types of tasks were identified:

1. 'specific Dutch topics': these tasks describe topics that can be worked out independent from cooperation with the Belgian research programme and thus can start up independent from a cooperation agreement. A proposal for these tasks can be granted without prior matching with the Belgian research programme. It should be noted that a classification as "specific Dutch topic" not necessary means that collaboration with the Belgian research programme is not wanted or may not be useful.
2. 'possible collaboration on methodological aspects': these tasks describe topics where only a minor input from the Belgian research programme is needed on methodological aspects. A proposal for these tasks can be granted without matching this with the Belgian research programme, because the relation with the Belgian research programme will be limited.
3. 'possible collaboration on technical aspects': these tasks describe topics where collaboration with the Belgian research programme on technical aspects is recommended but not essential. The quality and scope of a proposal can be judged without a prior cooperation agreement with the Belgian partners and the project can be performed with only limited inputs by partners of the Belgian research programme.
4. 'close collaboration recommended': for these tasks, a close collaboration with the Belgian research programme is recommended to avoid massive overlap and repetition of work.

Based on the considerations above, four phases for granting funds (Calls) to proposals are defined, with indicative time steps in parenthesis[7]:

- phase I: granting of proposals as soon as possible. PhD proposals should preferably belong to this group; however it should be noted that not all ambitions for PhD projects can be foreseen in advance (June 2011)
- phase II: expected granting six months after phase I(2012)
- phase III: in a third phase, proposals can be granted, that are not scheduled for the first year and where sufficient time is available to identify the relevance of this topic and to plan the potential collaborations with the Belgian research programme (June 2012 / February 2013)
- phase IV: in the fourth phase proposals will be granted that are foreseen for a later stage of the programme. Proposals here should also address the results gained in the OPERA programme at that moment (December 2013)

Table 3 shows the resulting timetable for funding of the different phases. In the first phase, no task needs to be started where cooperation with the Belgian research programme is found to be strongly recommendable.

[7] The exact dates of the individual calls will be announced by the Programme Directorate (see *Meerjarenplan*)

Table 3: Timetable for assignment of funding

kinds of collaborations:	specific Dutch topic	possible collaboration on methodological aspects	possible collaboration on technical aspects	close collaboration recommended

Scheduling of the work packages	phase I	phase II	phase III	phase IV
WP1: Safety Case context				
WP1.1: Waste characteristics				
Task 1.1.1: Definition of radionuclide inventory and matrix composition	X			
Task 1.1.2: Alternative waste scenario's	X			
WP1.2: Political requirement and societal expectations				
Task 1.2.1: Arena or stakeholder analysis	X			
Task 1.2.2: Legal requirements	X			
Task 1.2.3: Retrievability and staged closure		X		
Task 1.2.4: Public & stakeholder involvement	X			
WP1.3: Communicating the Safety Case				
Task 1.3.1: Communicating Safety Case results	X			
WP2: Safety Case				
WP2.1: Definition of the Safety Case				
Task 2.1.1: Structure of the Safety Case	X			
Task 2.1.2: Safety assessment methodology	X			
Task 2.1.3: Review of ongoing OPERA programme (o)		X		
WP2.2: Repository design in rock salt				
Task 2.2.1: Evaluation of current knowledge for building the Safety Case		X		
WP3: Repository Design				
WP3.1: Feasibility studies				
Task 3.1.1: Principal feasibility of reference design	X			
WP3.2: Design modification				
Task 3.2.1: Design modifications (o)		X		
WP4: Geology and Geohydrology				
WP4.1: Geology and geohydrological behaviour of the geosphere				
Task 4.1.1: Description of the present geological and geohydrological properties of the geosphere	X			
Task 4.1.2: Future evolution of the geological and geohydrological properties of the geosphere		X		
WP4.2: Geohydrological boundary conditions for the near-field				
Task 4.2.1: Definition of boundary conditions for near-field model		X		
Task 4.2.2: Favourable geohydrological settings (o)				X
WP5: Geochemistry and geomechanics				
WP5.1: Geochemical behaviour of EBS				
Task 5.1.1: HLW waste matrix corrosion processes		X		
Task 5.1.2: LLW/ILW degradation processes and products			X	
Task 5.1.3: Metal corrosion processes		X		
Task 5.1.4: Cementitious material degradation		X		
Task 5.1.5: Microbiological effects on the EBS and Boom Clay		X		
WP5.2: Properties, evolution and interactions of the Boom				

Scheduling of the work packages	phase I	phase II	phase III	phase IV
Clay				
Task 5.2.1: Geochemical properties and long-term evolution of Boom Clay	X			
Task 5.2.2: Geochemical interactions in Boom Clay		X		
Task 5.2.3: Geomechanical properties and thermo-hydro-mechanical evolution of Boom Clay		X		
WP6: Radionuclide migration				
WP6.1: Radionuclide migration in Boom Clay				
Task 6.1.1: Fundamental aspects of sorption processes	X			
Task 6.1.2: Modelling of sorption processes		X		
Task 6.1.3: Modelling of diffusion processes		X		
Task 6.1.4: Mobility and presence of colloidal particles		X		
Task 6.1.5: Non-diffusion related transport processes of solutes in Boom Clay		X		
Task 6.1.6: Gas migration in the EBS and in Boom Clay		X		
WP6.2: Radionuclide migration in an aquifer				
Task 6.2.1: Modelling approach for hydraulic transport processes		X		
Task 6.2.2: Modelling approach for radionuclide migration		X		
WP6.3: Radionuclide migration and uptake in the biosphere				
Task 6.3.1: Modelling approach for transport & uptake processes			X	
WP7: Scenario development and performance assessment				
WP7.1: Scenario				
Task 7.1.1: Scenario development	X			
Task 7.1.2: Scenario representation	X			
WP7.2: PA model development and parameterization				
Task 7.2.1: PA model for radionuclide migration in Boom Clay	X			
Task 7.2.2: PA model for radionuclide migration in an aquifer			X	
Task 7.2.3: PA model for radionuclide migration and uptake in the biosphere			X	
Task 7.2.4: Integrated modelling environment for safety assessment			X	
Task 7.2.5: Parameterization of PA models		X		
WP7.3: Safety assessment				
Task 7.3.1: Safety and Performance Indicators calculation methodology	X			
Task 7.3.2: Definition of methods for the uncertainty analysis	X			
Task 7.3.3: Safety assessment calculations	X			

depends on the proposal

7. References

[1] Verhoef E, *Meerjarenplan*, OPERA-PG-COV002, 2011, 1-28

[2] Nuclear Energy Agency, *Post-closure Safety Case for Geological repositories: Nature and Purpose*, NEA report 3679, OECD, Paris, 2004, 1-53.

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[4] International Atomic Energy Agency, *The Safety Case and Safety Assessment for radioactive waste disposal*, IAEA Safety Standard Series, No DS 355 Draft Safety Guide, 2008, page 18,22/65.

[5] *Understanding and Physical and Numerical Modelling of the Key Processes in the Near Field and their Coupling for Different Host Rocks and Repository Strategies (NF-PRO)*, Nuclear Science and Technology, European Commission, 2008, Contract FI6W-CT2003-002389, EUR 23730, page 7/217.

[6] International Atomic Energy Agency, *Safety Assessment methodologies for near surface disposal facilities, IAEA Results of a co-ordinated research project*, Volume 1: Review and enhancement of safety assessment approaches and tools, 2004, page 21/408.

[7] Joint convention safety of spent fuel management and on the safety of radioactive waste management. Ministry of Housing, Spatial Planning and Environment, October 2008, 3rd National report of the Netherlands, pages 15-17/132.

[8] ONDRAF/NIRAS*, Multi-criteria analysis on the selection of a reference EBS design for vitrified high level waste*, NIROND 2004-03, page 119/120.

[9] Verhoef E, Neeft E, Grupa J, Poley A, *Outline of a disposal concept in clay*, OPERA-PG-COV008, 2011, 1-17.

[10] IAEA 2007 Geological Disposal of Radioactive Waste DRAFT SAFETY GUIDE DS 334, page 14.

[11] *Safety indicators for the safety assessment of radioactive waste disposal*, Sixth report of the Working Group on principles and criteria for radioactive waste disposal, IAEA-TECDOC-1372, 2003, 1-36.

[12] Mazurek M, Pearson FJ, Volckaert G, Bock H, *Features, Events and Processes Evaluation Catalogue for Argilleous Media*, NEA4437, 2003, Section I.3.

[13] Smith P, Dierckx A, Capouet C, van Geet M, *Safety statements as a tool to incorporate geoscience in the safety and feasibility case*, AMIGO-3, 2009, 255-263.

Section II: DESCRIPTIONS OF TASKS IN WORK PACKAGES

Introduction

In this section, all tasks of the OPERA research programme are defined and their content, context and relation to other tasks are described. As stated in the OPERA Meerjarenplan, the main focus of the OPERA research programme lies on the disposal concept in Boom Clay. Except for Task 2.2.1, all tasks are related to the Safety Case in Boom Clay, and no further specification is given in the other tasks. Note that all tasks marked as 'optional' are not necessary to realize the main objective of OPERA, the development of Safety Cases, but are linked to other objectives of the OPERA programme.

WP1: Safety Case context

In this work package, all contextual and logistic boundary conditions for the OPERA Safety Case should be defined. This work package is split up in three parts:

- in WP1.1, "*Waste characteristics*", the waste characteristics in terms of radionuclide inventory and matrix composition will be characterized;
- in WP1.2, "*Political requirement and societal expectations*", three tasks are defined for the determination of political requirements and societal expectations with regard to reference values, retrievability aspects, and the involvement of stakeholders and the public;
- in WP1.3, "*Communicating the Safety Case*", topics related to an effective communication of Safety Case outcomes to stakeholders and the public are addressed.

The work packages WP1.2 and WP1.3 should be performed in close cooperation between social scientists and technical experts to be able to place the specific questions and challenges of the geological disposal of radioactive waste in a broad societal context.

WP1.1: Waste characteristics

Task 1.1.1: Definition of radionuclide inventory and matrix composition

To define a model representation of the repository for safety assessment, a proper physico-chemical description of the waste properties, the 'source term' is necessary.

In this task, a source term should be defined, both in terms of the radioactive inventory and the waste matrix. This should include all fractions, i.e. vitrified HLW, spent fuel, other HLW residues (claddings, filters, etc.) and ILW/LLW. Based on the current scenario for nuclear energy use in the Netherlands, existing uncertainties on the future inventory should be discussed and quantified.

It should be noted that the definition of 'source term' used here does not include any process description (e.g. mobilization) but is limited to an overview of the waste composition (for waste degradation processes see WP5). The definition of the matrix might be more complex in case of the low-level and intermediate level waste fractions and should therefore be performed together with Task 5.1.2 to define the degree of details necessary and the parameters that need to be reported.

<u>Product:</u>

- M1.1.1.1: Reference list of waste inventory and matrix composition
- M1.1.1.2: Report on determination of the inventory

Task 1.1.2: Alternative waste scenario's

A reduction of the source term by a) transmutation b) improvements in the fuel cycle or c) immobilization techniques may be advantageous for the long-term safety. In this task interesting techniques can be proposed and their potential influence on the inventory can be evaluated.

Proposed techniques should consider the relevance of the different radionuclides for the long-term safety of a geologic disposal concept. Proposed immobilization techniques should cover a relevant time interval (>>10.000 years).

<u>Product:</u>

- M1.1.2.1: Report on alternative waste scenario's

WP1.2: Political requirement and societal expectations

Task 1.2.1 Arena or stakeholder analysis

Decision-making processes about waste management facilities have to address the views of a broad range of interested stakeholders. Defining the circle of affected stakeholders and other legitimate participants in the decision-making about radioactive waste facilities is increasingly an issue. Typically, the number of involved stakeholders has become greater over the course of the decision processes. This task should identify the stakeholders in the

decision-making about geological disposal in Netherlands and indicate which stakeholders are influential.
This task should identify relevant stakeholders. In some many countries, this stakeholder identification has taken place in a way regulated by law. Some overlap may exist with concepts developed in Tasks 1.2.2 and 1.2.4 and a close interaction with this Task is therefore recommended.
<u>Product:</u>

- M.1.2.1.1: Report identifying relevant stakeholders

Task 1.2.2: Legal requirements
Due to the lack of explicit legislation in the Netherlands, potential legal requirements that may influence the conceptual background of the OPERA Safety Case must be derived from international guidelines, other national legislations and expert or stakeholder opinions. In any safety assessment, a comparison is made between health related calculated results (e.g. dose) and safety criteria (e.g. accepted reference values for dose limits or constraints). Safety Indicators and their reference values will thus be an essential part of the OPERA Safety Case and the proposed indicators and reference values must be justified by the evaluation of international guidelines, other national legislations and public and stakeholder expectations.
In this task, potential legal requirements for a geologic disposal in the Netherlands should be defined by evaluation of national and international guidelines and recommendations. This should include the derivation of reference values for the Safety Indicators (developed in close interaction with Task 7.3.1) that form the basis for the quantitative safety evaluations. These reference values should be based on national and international guidelines and recommendations including an analysis of the underlying argumentation and the derivation of the proposed values. The proposed legal requirements defined in this work package should be compared with national and international stakeholder visions and it should be evaluated whether these requirements answer public expectations and concerns sufficiently. In a synthesis, open topics as well as a (potential) framework of legal requirements, including Safety Indicators and reference values that can be used for the OPERA Safety Case, should be derived. The overall results of this task should integrate both social and natural scientist views on this matter.
This task should address both the definition of Safety and Performance Indicators (in discussion with Task 7.3.1) and their reference values. The definitions should reflect technical, legal and societal aspects as well as relevant cross-disciplinary visions on this question (e.g. from (environmental) ethics or radioecology). For the specific topic of 'retrievability' and the definition of a staged disposal process, see Task 1.2.2.
<u>Product:</u>

- M.1.2.2.1: Reference list of recommended values as assessment criteria for a safety and performance assessment
- M.1.2.2.2: Report on legal requirements

Task 1.2.3: Retrievability and staged closure
The retrievability of waste is an important prerequisite for the geologic disposal in the Netherlands since more than 15 years. Whereas in the Netherlands no explicit legislation or guidelines with regard to the exact technical content of the term 'retrievability' is developed, the general concept is discussed internationally and worked out in last decade to greater detail by developing principles like 'retrievability', 'reversibility', geological disposal as a 'staged process' and the utilization of 'pilot facilities'. Although some of these concepts are already integrated in general terms within the OPERA disposal concept for a disposal in Boom Clay, the 'retrievability' as an essential aspect of the Dutch policy on radioactive waste disposal needs to be worked out in greater detail.
In this task, the principle of "retrievability" as an essential aspect of the Dutch policy on radioactive waste disposal should be worked out in more detail. The system concept that is

part of the OPERA reference concept should be evaluated in light of recent international developments regarding the retrievability of radioactive waste, with particular attention to the definition of a realistic timeline and structure for the staged operation and closure of the repository. This includes also the definition of potential criteria's staging decisions should be based on and the actors that should be involved in these decisions. The French concept of staged closure of a repository, as outlined in the '*Dossier 2005 Argile*' [8] could serve as a basis for this evaluation. A critical evaluation should be performed whether the procedure proposed will result in a robust process and answers the political and public expectations in the Netherlands.
This task should address the current state-of-art on this topic. This task should address technical, legal and societal aspect. All analysis should be based on the Dutch management strategy as described in the paragraph 2.1 of OPERA *Meerjarenplan. Some overlap may exist with Task 1.2.1 and Task 1.2.3 with regard to the risk perception and the definition of the public and stakeholder expectation.*

Product:

- M.1.2.3.1: Report on state-of-the-art of the retrievability concept

Task 1.2.4: Public & stakeholder involvement

The disposal of radioactive waste is a political sensitive issue. Communication with and involvement of stakeholders and public is essential to create confidence in future disposal plans. The way in which public and stakeholders can get involved successfully will depend on the national context and the stage of the radioactive waste disposal programme.
In this task potential expectations of stakeholders and the public with regard to their involvement in the process of the implementation and realization of a radioactive waste disposal should be investigated. It should be analysed if and how this expectation can be met. Based on the national context as outlined in Task 1.2.1 and international experiences, strategies for the public and stakeholder involvement and communication should be developed.
It should be noted that due to the Dutch policy of long-term interim storage no pressing need exists to realize a repository in the near future. In the current management strategy (see OPERA *Meerjarenplan), siting is not foreseen in this century. Furthermore, due to the large abundance of Boom Clay in the Netherlands, siting is not a critical issue. It is expected that within the next decade the first radioactive waste repository for HLW will be realized in Europe, which may influence the public perception. Emphasis should be given on current options for involvement and communication. Some overlap may exist with concepts developed in Task 1.2.2 and a close interaction with this Task is therefore recommended*

Product:

- M1.2.4.1: Recommendations for the OPERA programme with regard to public and stakeholder involvement
- M1.2.4.2: Report on public and stakeholder involvement and communication

WP1.3: Communicating the Safety Case

Task 1.3.1: Communicating Safety Case results

Within the OPERA research programme, a safety assessment will be performed that evaluates all safety relevant aspects of the disposal concept (design of repository) and should demonstrate the long-term safety of such a facility. The results will be published in public accessible Safety Case reports, containing a clear safety statement supported by a full set of arguments. However, the presence of a well-documented in-depth review that satisfies independent national or international experts does not necessarily mean that the public will be convinced about the safety of a geological disposal concept, too.

[8] Chapter 10 in Architecture and management of a geological repository, Argile Dossier 2005, ANDRA Report Series.

In this task, it should be investigated how the Safety Case outcome can be communicated effective and successful with the public. This task should address all aspects of project presentation, presentation of the Safety Case outcomes, the use of several formats and channels and may propose other potential supporting activities.
Some overlap may exist with Task 1.2.3.
Product:

- M1.3.1: Report on communicating the Safety Case results

WP2: Safety Case

This work package has a central role in the set-up and definition of both Safety Cases. Based on the elements and the framework described in this Research plan and the OPERA *Meerjarenplan*, it should works out the structure and methodology of the OPERA Safety Cases in more detail. WP2 consists of two parts:

- in WP2.1, the Safety Case structure and methodology will be defined
- in WP2.2, all efforts on the Safety Case in rock salt within OPERA are combined

WP2.1: Definition of the Safety Case

Task 2.1.1: Structure of the Safety Case

The term “Safety Case” describes a complex, multidisciplinary approach to perform and evaluate the safety of a radioactive waste disposal. Although some conceptual aspects or elements of the Safety Case in general and for the specific OPERA Safety Case in Boom Clay in particular are already described in this Research plan and the OPERA *Meerjarenplan*, the function of the Safety Case as a guideline through the OPERA research programme and later phases asks for a more specific and detailed definition to warrant a feasibility of the OPERA Safety Case and to ensure the completeness and consistency of the programme. An important task with regard to the overall consistency of the research programme is the translation of the safety functions into more specific research safety statements that must be substantiated in the individual tasks and will form the input for the safety and performance assessments in Task 7.3.3. This task has therefore an important role in organizing and structuring the research efforts performed within OPERA.

Development of the Safety Case is the responsibility of the OPERA Programme Directorate. Hereto the Directorate establishes a Safety Case group with national and international experts. This task provides all of the necessary groundwork for the Safety Case group that compiles the Safety Case report(s). In this task, the structure of the OPERA Safety Case and all related elements should be defined in such a way that it can serve as general guideline for all contributions and defines the programme priorities in detail. Based on international approaches for the Safety Case, logistic boundary condition as defined in Task 1.1.1, legal requirements (Task 1.2.1) and public and stakeholder aspects (Tasks 1.2.2 and 1.3.1), a general framework must be developed that is suitable for the specific Dutch needs and satisfies the objectives of OPERA and the framework defined by the Dutch management strategy (see OPERA *Meerjarenplan*). The Safety Case structure should include the definition of internal evaluation and decision points and should propose a detailed set-up for the reports necessary to document the outcomes of the OPERA Safety Case. Special attention should be given to retrievability aspects and how they will be reflected in the current system concept and management strategy. Although the host rock Boom Clay will be examined in more detail within OPERA than the host rock Zechstein rock salt, the safety case structure should preferably be applicable to rock salt as well. *For rock salt some overlap may exist with task 2.2.1.*

<u>Product:</u>

- M2.1.1.1: Report on the OPERA Safety Case structure
- M2.1.1.2: Hierarchy of safety statements derived from the safety functions

Task 2.1.2: Safety assessment framework

A central aspect of the Safety Case is the execution of a safety assessment. This requires the definition of a sound and consistent methodology, a critical evaluation of assumptions used in the Safety assessment calculations, the evaluation of relevant evolution scenarios and safety functions, the identification and classification of relevant FEPs, the evaluation of uncertainties, and the interpretation of the calculated results.

In this task, the overall methodology and strategic framework for the safety assessments that will be performed within OPERA WP7 (Scenario Development and Performance Assessment) should be defined. Together with the system design, this will form the assessment basis. The methodology defined in this task will serve as general guideline for the way the different tasks within OPERA WP7 will be performed and how the results of all contributions will be documented. Furthermore, in this task the different evolution scenarios defined in Task 7.1.1 will be evaluated with respect to their consistency and if the set of scenarios will answer the needs defined in WP1. Finally, in this task the completeness of the arguments and analyses of the OPERA programme will be evaluated and documented in a structured way by the use of FEP's.

Product:

- M2.1.2.1: Report on the safety assessment methodology
- M2.1.2.2: Guideline for reporting of OPERA contributions to the Safety Case
- M2.1.2.3: Report on OPERA FEPs

WP2.2: Repository design in rock salt

Task 2.2.1: Evaluation of current knowledge for building the Safety Case

In the last 35 years much work is performed in the Netherlands on the geologic disposal of radioactive waste in rock salt. As discussed in the OPERA *Meerjarenplan, t*he OPERA research programme is strongly focusing on the disposal concept in Boom Clay. However, part of the management strategy in the Netherlands is to develop and maintain the knowledge about the disposal of radioactive waste in rock salt, too. A large number of safety assessments was performed for repository designs in rock salt in the past, but so far the results were not integrated according to the recently developed methodology of the Safety Case that will used within OPERA for the repository concept in Boom Clay.

In this task, the knowledge on the safety and feasibility of the geologic disposal of radioactive waste in a rock salt formation in the Netherlands should be analysed and integrated according to the methodology of the Safety Case. International experiences on the waste disposal in rock salt should be accounted for, too (i.e. from Germany and the USA). It should be evaluated if the current state of knowledge is sufficient to support a Safety Case for rock salt. Possible gaps in understanding or lack of experimental support should be worked out in detail. Although no calculation will be performed within this task, all elements of a Safety Case should be defined in way that enables the evaluation of the state-of-the-art on the repository concept in rock salt within the methodology of the Safety Case[9].

The work should be based on the critical evaluation of current knowledge and existing information and should not include any new research activities. The documentation of this current state should preferably be according to the structure developed in task 2.1.1.

Product:

- M2.2.1: Report on the current support for a Safety Case for a repository design in rock salt

[9] see *Nuclear Energy Agency. Post-closure Safety Case for Geological repositories: Nature and Purpose. NEA report 3679, OECD, Paris, 2004* and the previous section of this Research plan

WP3: Repository Design

In this work package, the principal feasibility of a disposal concept in Boom Clay in the Netherlands at 500 m depth is evaluated (WP3.1). In WP3.2, possible design modifications can be investigated that may reduce uncertainties with respect to the safety assessment of the system concept.

WP3.1: Feasibility studies

Task 3.1.1: Principal feasibility of reference design

The outlines of the current disposal concept is a generic repository concept based on experiences and data of the Belgian HADES URL at 225 m depth. Although some extrapolations and analysis of existing data have been performed in the past, the composition and geomechanical behaviour of the Boom Clay present at the (yet unknown) future location of a Dutch repository is not elaborated in sufficient detail to support the principal feasibility of the repository design. In this task, the feasibility of the OPERA disposal concept, including the retrieval of the waste, will be evaluated, based on generic assumptions on the clay composition of a future location and taking into account the uncertainties in the current knowledge on the clay properties and behaviour.

This Task should clarify if - and under which conditions- the current OPERA disposal concept is feasible and if relevant modifications of the design - i.e. modifications that may influence the outcome of the safety assessments relevantly - are necessary.

Product:

- M3.1.1: Report on the feasibility of a generic Dutch repository concept in Boom Clay

WP3.2: Design modification

Task 3.2.1: Design modifications (optional)

Although the specific layout and realization of the EBS or other elements of the OPERA reference concept is not expected to have a relevant influence on the long-term safety, the uncertainties attached to material degradation and corrosion behaviour may have an impact on the efforts necessary to support the safety assessment and to deliver convincing arguments to the Safety Case.

In this task, possible design modification may be defined that reduces or avoids uncertainties in the safety and performance assessments.

A contribution to this task should be related to proven obstacles in the safety assessment.

Product:

- M3.2.1: Report on design modifications for the generic OPERA reference concept in Boom Clay

WP4: Geology and geohydrology

In the current OPERA reference concept for a disposal in Boom Clay, three safety functions can be related to the geosphere (that is the host rock and the surrounding rock formations) the '*isolation'* to the waste, the '*dilution and dispersion'* of radionuclides in the geosphere and the '*transport and retention'* through the Boom Clay layer. Thus the geosphere can influence the long-term safety in three ways: 1) any radionuclides that eventually enter the biosphere first must pass the geosphere at least in a normal scenario and 2) the properties and long-term stability of the host rock depends on the future evolution of the surrounding rock formation. To evaluate the long-term safety of the geologic disposal it is therefore important to understand past and possible future evolutions of the geosphere.

WP4.1: Geology and geohydrological behaviour of the geosphere

Task 4.1.1: Description of the present geological and geohydrological properties of the geosphere

In this task, a generic description of the present geological and geohydrological characteristics and features in the geological environment enclosing the host-rock and of the host-rock itself should be given (stratigraphy, lithology, tectonics, seismic characteristics, hydrologic features, etc.). Although at present no preference exists for the location of a repository in the Netherlands, areas with shallow Boom Clay layers (depth < 400 m) or of limited layer thickness (<< 100 m) can be excluded from this analysis. The features considered should be related to the safety functions '*isolation'*, *'dilution and dispersion'* and *'transport and retention'* and should provide the necessary input for the calculation of the radionuclide migration through the geosphere in Task 6.2.1 and Task 6.2.2 (e.g. hydrostatic and lithostatic pressure, expected permeability's and pressure gradients etc.), the assessment of the role of advective transport processes in Task 6.1.5 and the definition of the boundary condition for the near-field in Task 4.2.1. Existing uncertainties should be addressed explicitly and considerations should be presented that can serve as guideline for a realistic representation of the geosphere in the safety and performance assessment. Factors that may be of relevance for the long-term safety should be highlighted.

All works should be performed in close cooperation with the referred Tasks, because for these contributions, the definition of a research or modelling approach can not be delivered in advance but is intrinsic part of the content of these Tasks. Note that this contribution is of a generic nature, since siting is not a topic in the current programme or near future (see OPERA Meerjarenplan*).*

<u>Product:</u>

- M4.1.1: Report on the geological and geohydrological characterisation and properties of the geological environment

Task 4.1.2: Future evolution of the geological and geohydrological properties of the geosphere

In this task, a generic description of the expected future changes of the geosphere as described in Task 4.1.1 should be worked out. Beside the definition of the most likely ('normal') evolution, future uncertainties should be discussed explicitly. Eventually, relevant altered evolutions that can not be excluded should be distinguished by the definition of altered scenarios (e.g. earth quakes). Relevant features with respect to the safety functions '*isolation*', *'dilution and dispersion'* and *'transport and retention'* should be described in a way that it can serve as input for the calculation of the radionuclide migration through the geosphere in Task 6.2.1 (i.e. hydrostatic and lithostatic pressure, expected permeabilities and pressure gradients etc.), the assessment of the role of advective transport processes in Task 6.1.5 and the definition of the boundary condition for the near-field in Task 4.2.1. Considerations should be presented that can serve as guideline for a realistic representation of the geosphere in the safety and performance

assessment. Factors that may be of relevance for the long-term safety should be highlighted.
A condensed overview on the past evolution should be integrated to support the consistency with the used methodologies and arguments.
Product:
- M4.1.1: Report on the geological and geohydrological evolution of the geosphere

WP4.2: Geohydrological boundary conditions for the near-field
Task 4.2.1: Definition of boundary conditions for near-field model
In order to define the model representation of the clay layer in which the repository is situated, the boundary conditions that are superposed by the geologic environment (the host rock and the surrounding rock formations) need to be defined (e.g. pressures, groundwater composition, etc).
In this task, the boundary conditions for the near-field should be defined, based on the analysis performed in Task 4.1.1. Furthermore, the influence of future evolution on the boundary condition as elaborated in Task 4.1.2 should be worked out. Besides a general description of the future evolution, this contribution should describe all relevant parameters necessary to assess of the role of advective transport processes in Task 6.1.5, including an overview of the existing uncertainties. Factors that may be of relevance for the long-term safety should be highlighted.
Product:
- M4.2.1: Report on the geospheric boundary conditions for the near-field

Task 4.2.2: Favourable geohydrological settings (optional)
Although the retention capacities of the Boom Clay may be quite comparable in large areas of the Netherlands, the surrounding rock formations might be more or less favourable.
In this task favourable or less favourable settings for the long-term safety of a future repository in the Netherlands should be defined. Based on the analysis performed in the previous tasks and other parts of the OPERA programme, location specific features or condition that are less favourable for a repository should be identified, either due to their influence on the safety functions or due to an increased uncertainty with respect to the future evolution of the host rock.
Product:
M4.2.2: Report on unfavourable geohydrological settings for a repository in the Netherlands.

WP5: Geochemistry and geomechanics

In this work package, the geochemical and geomechanical properties of the Boom Clay are defined. Based on the properties, analyses will be performed to investigate the future evolution of the Boom Clay: the natural evolution of this host rock and the potential interactions with the man made materials. WP5.1 is dedicated to the most relevant degradation and corrosion processes of materials that are part of the EBS or waste fraction. It is expected that the degradation products may generate a chemically disturbed zone (CDZ) in Boom Clay. A close collaboration between the different tasks is therefore expected. The same is true for WP5.2: here, the collaboration should aim to develop a combined, consistent model representation of the Boom Clay that can be used for the performance assessment of the host rock.

WP5.1: Geochemical behaviour of EBS

Task 5.1.1: HLW waste matrix corrosion processes

Although at the present state of knowledge the relevance of the safety function *'resistance to leaching and dissolution'* for the long-term safety is limited, reliable estimations of the waste matrix dissolution rate and a proper experimental support is relevant for two reasons: first, to support the 'multi barrier' concept that requires that failure of one barrier should not impair the overall safety and second because it is necessary to understand the possible interactions that may occur between the waste matrix and other components of the repository. Furthermore, for certain altered scenario's, the dissolution behaviour might be of some relevance for the overall safety in case the uncertainty of this process is not sufficiently quantified.

In this task, information on the corrosion processes of the waste matrix of vitrified waste and spent fuel from the research reactors should be investigated that can be used to assess and quantify the safety function *'resistance to leaching and dissolution'*.

The contributions should explicitly include interaction with degradation products of the surrounding EBS components.

Product:

- M5.1.1.1: Report on the corrosion behaviour of vitrified waste
- M5.1.1.2: Report on the corrosion behaviour of spent fuel

Task 5.1.2: LILW degradation processes and products

Together with the disposal of LILW, large amounts of non-radioactive materials are introduced into the host rock (i.e. container, shielding, non--radioactive waste constituents, air). Chemical interactions of these waste components and their soluble and gaseous degradation products need to be known to be able to estimate the influence on the host rock structure and to be able to perform a safety assessment for this waste fraction.

In this task, a general estimate of degradation processes in the waste matrix of LILW should be performed. The uncertainty of the waste matrix composition must be addressed explicitly and the distribution of possible safety-relevant parameters must be quantified. Possible interactions with the host rock or elements of the EBS should be analysed. A proposal for the safety assessment of this waste fraction should be presented.

This task should interact closely with Task 1.1.1 to define meaningful parameters to describe the characteristics of the LLW/ILW waste fraction.

Product:

- M5.1.2: Report on the degradation of LLW/ILW

Task 5.1.3: Metal corrosion processes

In the current safety strategy it is assumed that the safety function *'physical containment'* covers the thermal phase of the system design. To assess this safety function, the corrosion rate of the waste container and the overpack must be estimated. Although at the present state of knowledge the relevance of the safety function *'physical containment'* for the long-term safety is limited, the introduction of this safety function simplifies the performance of radionuclide calculations. Besides, reliable estimations of the steel corrosion rates and a proper experimental support of this rates is relevant for two reasons: first, to support the 'multi barrier' concept that requires that failure of one barrier should not impair the overall safety and second because it is necessary to understand the possible interactions that may appear between the waste matrix and other components of the repository. Examples of possibilities are hydrogen gas production during metal corrosion and sorption of dissolved iron complexes in Boom Clay becoming competitive with radionuclide sorption. In this task, a description of corrosion processes of the steel in the container or EBS of HLW should be made and a simplified estimate on corrosion rate should be delivered. The contribution should consider the influence of the specific environmental condition present in the disposal (e.g. pore water composition, heat, redox aspects, degradation products of other EBS components, etc.).

Product:

- M5.1.3: Report on the metal corrosion processes

Task 5.1.4: Cementitious material degradation

Cementitious materials in a disposal are used as gallery support, plug, shielding, backfill etc. or are present in the waste containers. Although at the present state of knowledge the relevance of the corrosion behaviour of cementitious materials for the long-term safety is limited, reliable characterization of corrosion products and rates based on proper experimental support is relevant for a number of reasons: massive amount of alkaline fluids from cementitious products may alter the overall safety concept by interactions with other repository component (safety function '*physical containment*') or the host rock (safety function '*transport and retention'*). The dissolution rate of vitrified waste can increase due to elevated pH values and impair the safety function '*resistance to leaching and dissolution*'. Corrosion products may alter the host rock in the EDZ, eventually supporting the formation of preferential pathways. Finally, to enable the retrievability of the waste, the evolution of the mechanical properties of cementitious EBS components need to be known.

In this task, a general description of degradation processes of cementitious materials in the EBS of HLW should be performed and possible implications for the repository design should be pointed out. The results should lead to a generalized quantitative description of all safety-relevant processes and should include a discussion on parameter uncertainties and distributions.

Product:

- M5.1.3: Report on cementitious material degradation

Task 5.1.5: Microbiological effects on the EBS and Boom Clay

Microbiological processes can lead to relevant geochemical alterations that may influence the safety function '*physical containment*', '*transport and retention'* and '*resistance to leaching and dissolution*'. Redox processes may be controlled by microbiological processes. Besides the alteration of the chemical composition by oxidation and reduction processes, micro-organisms may alter the speciation of radionuclides (e.g. alkylation of Se) or may change the transport properties of porous media (e.g. biofilm formation, colloidal oxidation products).

In this task, possible microbiological effects on either the EBS or in the EDZ of the Boom Clay should be investigated and quantified.

Product:

- M5.1.5: Report on microbiological effects on the EBS and Boom Clay

WP5.2: Properties, evolution and interactions of the Boom Clay

In this work package, the geochemical and geomechanical properties of the Boom Clay layer will be described. Furthermore, the future evolution of the Boom Clay layer will be investigated, both the expected evolution of the Boom Clay due to the evolution of the enclosing (natural) environment and by interactions with components of the radioactive waste repository (geochemical and thermo-hydro-mechanical). In essence, in WP5.2 it will be defined what Boom Clay is and how it will react to the evolution of the enclosing geosphere en perturbation induced by the presence of the waste disposal facility. The results will form the basis for several analyses and models used for the safety assessment and contributors should cooperated with the concerning tasks. The migration of radionuclides through the host rock is expected to be the most relevant contributor to the long-term safety of a repository concept in Boom Clay. Proper knowledge on clay properties in their specific geological setting and the future evolution of the Boom Clay properties is essential to support the assessment of the safety function '*transport and retention*'.

Task 5.2.1: Geochemical properties and long-term evolution of Boom Clay
In this task, the geochemical behaviour of the Boom Clay and evolution thereof as result of future evolution as defined in Task 4.2.1 should be described. The results of this task will serve as input for WP6.1. The work performed within this work package should be performed in close cooperation with the contributors to WP6.1 to guarantee that all relevant features that affect the migration of radionuclides in the Boom Clay will be covered. The results should lead to a generalized quantitative description of all processes that can effect the safety function 'transport and retention' and should include a discussion on parameter uncertainties and distributions.
This task is limited to the behaviour of undisturbed Boom Clay. For interactions with corrosion and degradation products from repository components see next task.
<u>Product:</u>

- M5.2.1.1: Reference list of Boom Clay properties
- M5.2.1.2: Report on the geochemical behaviour of Boom Clay

Task 5.2.2: Geochemical interactions in Boom Clay
In this task, the geochemical interaction of the Boom Clay with corrosion and degradation products as described in WP5.1 should be analysed. The analysis should cover processes that may impair the retrievability of the waste on the short term (about 100 years). The results should also lead to a generalized quantitative description of all processes that can effect the safety function 'transport and retention' on the long term. The results should include a discussion on the distribution of the values of the parameters.
It should be noted that the safety function 'transport and retention' applies after the thermal phase. With respect to the integration of thermo-mechanical effects, cooperation with Task 5.2.3 is necessary.
<u>Product:</u>

- M5.2.2: Report on the geochemical interaction of Boom Clay

Task 5.2.3: Geomechanical properties and thermo-hydro-mechanical evolution of Boom Clay
The migration of radionuclides through the host rock is expected to be the most relevant contributor to the long-term safety of a repository concept in Boom Clay. Proper knowledge of the mechanical alteration of clay properties or induced solute movements as a result of the construction of a repository in the Boom Clay and the disposal of waste is essential to perform a safety assessment. Although the safety function '*transport and retention*' applies after the thermal phase, it is important to address structural changes that may impair the retrievability of the waste on the short term or the host rock on the long term.

In this task, the thermo-hydro-mechanical behaviour and evolution of the Boom Clay as result of the construction of the repository and the disposal of radioactive waste should be analysed. Based on the geological boundary conditions defined in Task 4.2.1, both the evolution of parameters relevant for radionuclide migration (porosity, permeability, temperature) and the potential presence of solute transport within the Boom Clay (others than by molecular diffusion) should be analysed. Possible (permanent) geochemical alterations of Boom Clay properties in de EDZ should be addressed as well as alterations by the heat production of HLW. The work performed within this work package can build on the work performed within the European 6th framework project TIMODAZ [10] and should be performed in close cooperation with the contributors WP6.1 to guarantee that all relevant features that affect the migration of radionuclides in the Boom Clay will be covered.

Product:

- M5.2.3: Report on the thermo-hydro-mechanical behaviour of Boom Clay

[10] http://www.timodaz.eu

WP6: Radionuclide migration

This work package addresses the migration processes responsible for the transport of radionuclides from the waste container into the biosphere. The migration of radionuclides through the Boom Clay, described by the safety function '*transport and retention*' is expected to be the most relevant contributor to the long-term safety of repository concepts in clay. Besides that, the safety function "dilution and dispersion' that is related to the migration of radionuclides in surrounding rock formation and biosphere is expected to contribute significantly to the overall safety. WP6 has thus an essential role in the safety assessment of the disposal concept for Boom Clay.

The work package is divided into three parts, each related to migration processes in one compartment.

It should be noted that the safety function 'transport and retention' applies after the thermal phase. Due to the relatively small relevance of the EDZ on the long-term safety, the study should focus on the sorption behaviour of the unaltered parts of the Boom Clay.

WP6.1: Radionuclide migration in Boom Clay

Task 6.1.1: Fundamental aspects of sorption processes

A good understanding of the fundamental processes behind the sorption of radionuclides in the clay is essential for the safety assessment since sorption seems to be the dominant mechanism for retention of many radionuclides.

In this task, the fundamentals aspects of sorption behaviour of radionuclides in Boom Clay should be investigated. The contribution should address the specific properties and composition of the Boom Clay. An approach should be developed that enables the experimental characterization of relevant features of the Boom Clay and the modelling of complex multi-elemental sorption and ion-exchange processes in the host rock. This includes an evaluation of the pH-dependency of the sorption behaviour and the influence of the variability of ionic strength and the composition of Boom Clay pore water in different regions in the Netherlands. All relevant aspects that need to be considered for the quantitative evaluation of radionuclide migration processes should be addressed and a general approach for the quantitative assessment of sorption and ion-exchange processes in Boom Clay should be derived.

<u>Product:</u>

- M6.1.1: Report on fundamental aspects of sorption processes

Task 6.1.2: Modelling approach for sorption processes

In this task, the results of Task 6.1.1 should be translated into a geochemical model description for radionuclide sorption in Boom Clay. The model representation should account for pH, Eh, ionic strength, pore water composition, pressure, temperature and the interaction of different surfaces present in Boom Clay. A database should be compiled that includes the sorption properties of all relevant radionuclides.

This task should be performed in close cooperation with Task 6.1.1. Because diffusion and sorption processes can not be studied independently from each other, this task should also be performed in close cooperation with Task 6.1.3.

<u>Product:</u>

- M6.1.2.1: Model representation of radionuclide sorption processes in Boom Clay
- M6.1.2.2: Reference database with sorption properties
- M6.1.2.3: Report on radionuclide sorption in clay

Task 6.1.3: Modelling approach for diffusion processes

In this task, a critical evaluation of the features behind radionuclide diffusion in Boom Clay should be performed, including effects of spatial heterogeneity (large- and small-scale), the electrostatic properties of the clay and exclusion effects at the interface to other

phases. A general approach for the quantitative evaluation and modelling of this process should be derived. A database should be derived for the diffusion properties (apparent diffusion coefficient, apparent porosity) of all relevant radionuclides.
Because sorption and diffusion processes can not be studied independently from each other, this task should be performed in close cooperation with Task 6.1.2. Due to the relatively small relevance of the EDZ on the long-term safety, the study should focus on diffusion processes in the unaltered parts of the Boom Clay.
Product:

- M6.1.3.1: Report on radionuclide diffusion in clay
- M6.1.3.2: Reference database with diffusion properties

Task 6.1.4: Mobility and presence of colloidal particles
The presence of suspended colloidal particles can potentially increase the migration of radionuclides in Boom Clay. Radionuclides can sorb to charged colloidal particles (e.g. fulvic and humic acids, iron(hydr)oxides) or can be present as colloid themselves (Eigencolloids, nanoparticles). Because the presence of colloids in Boom Clay may impair the safety function '*transport and retention*', it is important to assess the presence of colloids and quantify possible interactions with radionuclides.
In this task, the relevance of colloids for the migration behaviour of radionuclides in Boom Clay should be assessed. All potential sources of colloids and possible interactions between colloids and radionuclides should be mapped. The solubility of the colloids and the processes behind it should be worked out for the given system. Based on experimental results, an estimation of the relevance of colloids for the migration of radionuclide should be presented. The results should lead to a generalized quantitative description of all processes that may alter the safety function "transport and retention" and should include a discussion on parameter uncertainties and distributions.

Product:

- M6.1.4: Report on presence and mobility of colloidal particles

Task 6.1.5: Non-diffusion related transport processes of solutes in Boom Clay
In this task, a critical evaluation of non-diffusion related transport processes in Boom Clay should be performed, including convective transport by hydraulic gradients, by temperature gradients, by gas pressure and displacement by compaction of the Boom Clay material. A generic approach for the quantitative evaluation of these processes in safety assessments should be derived and the relevance for the safety function "transport and retention" should be discussed.
It should be noted that the safety function 'transport and retention' applies after the thermal phase. Gas related transport processes should be analysed in close cooperation with Task 6.1.6.
Product:

- M6.1.5: Report on non-diffusion related transport processes in Boom Clay

Task 6.1.6: Gas migration in the EBS and in Boom Clay
In this task, a critical evaluation of fundamental processes behind gas-related transport in Boom Clay should be performed, including pressure and temperature dependent gas penetration, two-phase flow, pathway dilation and the occurrence and relevance of preferential pathways in the EBS. A clear overview should be given on the experimental support behind these processes and a general approach for the quantitative evaluation of these processes in safety assessments should be derived. The relevance for the safety function "transport and retention" should be discussed. Attention should also be given to processes that may impair the retrievability of the waste.
Some overlap may exists with Task 6.1.6.
Product:

- M6.1.6: Report on gas migration in the EBS in Boom Clay

WP6.2: Radionuclide migration in the surrounding rock formation

The migration of radionuclides in the rock formations surrounding the host rock is an important link between the mobilization of radionuclides, their transport through the host rock and the assessment of potential exposure to humans. Although assumed to be less relevant than the safety function '*transport and retention*', it is expected that the safety function '*dilution and dispersion*' that is attached to the radionuclide migration in the surrounding rock formation and biosphere will significantly add to the overall safety of the repository concept. The radionuclide transport through the geosphere is connected with the same uncertainties of the future evolution as the geosphere in general (see Task 4.1.1 and 4.1.2). Any approach to assess the radionuclide migration through the geosphere need to address these uncertainties therefore explicitly.

Task 6.2.1: Modelling approach for hydraulic transport processes

In this task, a generic, simplified hydrological model representation of hydraulic transport properties of the geosphere should be defined, including the uncertainties with regard to the future evolution. Dependent on the results, the contribution should include either a set of transfer functions or a modelling code that can be used within Task 6.2.2. The proposed model description should be supported by uncertainty analysis, and the factors that give rise to the largest uncertainties should be highlighted.

Product:

- M6.2.1: Report on hydrological transport properties in the rock formations surrounding the host rock
- M6.2.2: Hydrological modelling code or set of transfer functions

Task 6.2.2: Modelling approach for radionuclide migration

In this task, a modelling approach for the radionuclide migration through the geosphere should be defined, based on the hydrological model description defined in Task 6.2.1. The migration model should be simplified in a way that it can be integrated in a PA code. The proposed model should be supported by uncertainty analysis, and the factors that give rise to the largest uncertainties should be highlighted.

Product:

- M6.2.2: Report on modelling of radionuclide migration in the rock formations surrounding the host rock

WP6.3: Radionuclide migration and uptake in the biosphere

The migration of radionuclides in the biosphere is an important link between the mobilization of radionuclides, their transport through the geosphere and the assessment of potential exposure to humans. Although assumed to be less relevant than the safety function '*transport and retention*', it is expected that the safety function '*dilution and dispersion*' that is attached to the radionuclide migration in the geosphere and biosphere will significantly add to the overall safety of the repository concept.

Task 6.3.1: Modelling approach for transport & uptake processes

In this task, a generic migration and uptake model for radionuclides that enters the biosphere from predefined pathways, as defined in Task 6.2.2, should be developed. The model should describe all relevant biospheric features and compartments and should include all processes necessary to quantify the migration of radionuclides between the compartments. All relevant pathways to human exposures should be evaluated, and the uncertainties with regard to the future evolution should be discussed. The results should be used to define generic dose conversion factors.

Product:

- M6.3.1: Report on radionuclide migration and uptake in the biosphere
- M6.3.2: Reference list of dose conversion factors

WP7: Scenario development and performance assessment

WP7.1: Scenario
The safety assessments of a Safety Case are based on several scenarios. Next to the 'normal evolution scenario', that represents a conservative estimate of the most likely evolution, altered scenarios can be defined, e.g. human intrusion scenarios or abandonment scenarios.

Task 7.1.1: Scenario development
In this task, all scenarios relevant for the assessment of the long-term safety of a repository in Boom Clay should be evaluated and a general outline of the features and the resulting altered evolutions of these scenarios should be defined.
This task should integrate results of Task 4.1.2.
<u>Product:</u>
- M7.1.1: Report on the description of relevant scenarios for a repository in Boom Clay

Task 7.1.2: Scenario representation
In this task, the scenarios defined in Task 7.1.1 should be translated into physical and geochemical model representations used for the safety assessment. The relevant processes should be defined and parameterization for each scenario should be derived on basis of the input of other WP's.
<u>Product:</u>
- M7.1.2.1: Report on scenario model representation
- M7.1.2.2: Reference list of model parameter for all scenarios

WP7.2: PA model development and parameterization
Task 7.2.1: PA model for radionuclide migration in Boom Clay
The migration of radionuclides through the Boom Clay (safety function 'transport and retention') is expected to be the most relevant contributor to the long-term safety of a repository concept in clay. In Task 6.1.1, Task 6.1.2 and Task 6.1.3, the fundamental processes behind the migration will be evaluated and a model description will be formulated.
In this task, a model to compute the radionuclide migration in the undisturbed Boom Clay formation and including all relevant processes described in WP6.1 should be developed. This model should be based on a suitable geochemical modelling code and should serve in other tasks related to geochemical processes as an integrated tool for detailed process studies as well as for sensitivity analysis and safety assessment. The modelling code should have the potential for flexible coupling with other models that either define certain internal model parameters (e.g. porosity, temperature) or use the calculated output for further computations (e.g. hydraulic model).
<u>Product:</u>
- M7.2.1.1: Modelling code for the migration of radionuclides in Boom Clay
- M7.2.1.2: Report on migration model in Boom Clay

Task 7.2.2: PA model for radionuclide migration in the rock formations surrounding the host rock
The migration of radionuclides through the Boom Clay is expected to be the most relevant contributor to the long-term safety of a repository concept in clay. Although assumed to be less relevant than the safety function '*transport and retention*', it is expected that the safety function '*dilution and dispersion*' that is attached to the radionuclide migration in the rock formations surrounding the host rock and biosphere will significantly add to the

overall safety of the repository concept. However, in case of a generic approach that will be used in OPERA, the relevance of the migration of radionuclides from the host rock to the biosphere for the long-term safety is not clear at the present moment. This depends mainly on the uncertainties that must be attributed to the geospheric evolution and that will be investigated in Task 4.1.2 and Task 4.2.1. Based on this result, and the modelling approach defined in Task 6.2.2, the degree of detail and the processes that need to be integrated in such a model will be defined.
In this task, a modelling code should be developed to compute the transport of radionuclides from the host rock to the biosphere. The modelling code will be part of the OPERA integrated SA model (Task 7.2.4) and will be used for sensitivity analysis and safety assessment. The model should have the potential for flexible coupling with other models that either define certain internal model parameters (e.g. porosity, temperature) or use the calculated output for further computations (i.e. biospheric transport model).
<u>Product:</u>

- M7.2.2.1: Model for the migration of radionuclides in the rock formation surrounding the host rock
- M7.2.2.2: Report on migration model in the rock formations surrounding the host rock

Task 7.2.3: PA model for radionuclide migration and uptake in the biosphere
The estimation of radionuclide transport through the biosphere and the distribution over different compartments is an important element for the evaluation of the potential exposure of the population to radionuclides originating from a radioactive waste disposal.
In this task a model description for computing the transport of radionuclides within different compartments of the biosphere should be developed and realized on a suitable software platform. Together with an uptake model that accounts for all relevant routes for exposure, this model will be used to couple the radionuclide flux out of the geosphere with the potential exposure of the population. Although it is likely that for SA purposes only predefined dose conversions factors will be used, the model should be structured and documented in a clear way. The representation of this model in a software code should enable the access to all relevant model parameters to enable modifications and analyse specific situations later on.
<u>Product:</u>

- M7.2.3.1: Model for the migration and uptake of radionuclides in the biosphere
- M7.2.3.2: Report on migration and uptake of radionuclides in the biosphere

Task 7.2.4: Integrated modelling environment for safety assessment
For the safety assessment calculations performed within OPERA, several models as described in Task 7.2.1 to 7.2.3 need to be coupled together with the subroutines for the uncertainty analysis of Task 7.3.2.
In this task, an integrated modelling environment need to be developed that couples the different sub-models that are used in OPERA. It should enable the repeated calculation of predefined scenarios (Task 7.1.2) using the subroutines for uncertainty analysis developed in Task 7.3.2. The outcome will be transformed in the same units in which the reference values for the Safety and Performance Indicators are expressed. These assessment criteria are defined in Task 1.2.2.
<u>Product:</u>

- M7.2.4.1: Integrated modelling environment for the safety assessment
- M7.2.4.2: Report on model integration

Task 7.2.5: Parameterization of PA models
The safety assessments of a Safety Case are based on several scenarios. Next to the 'normal evolution scenario', that represents the most likely evolution, altered scenarios can be defined, e.g. human intrusion scenarios, or abandonment scenarios. The safety

assessments will be performed for all scenarios in the integrated safety assessment environment developed in the Tasks 7.2.1 to 7.2.4. To be able to perform the calculations, all models may have to be simplified and parameterized, considering both the distribution of the values in parameters used in the models that are defined in WP4 to 6 and the necessary simplifications of the complex processes that were developed.
In this task, the scenarios defined in Task 7.1.2 should be translated into parameterized model representations in the modelling codes developed in Task 7.2.1 to 7.2.4. Based on the input of several WP's and the determined distribution of parameter values, sensitivity analysis should be performed to extract relevant processes and to simplify the model representation as far as possible. The result should be a set of model representations of relevant processes, the accompanying parameter values and their distribution. The models, parameters and their distributions must be defined for each scenario, and a detailed report should contain arguments for the chosen model parameterizations.
Product:

- M7.2.5.1: Report on model parameterization
- M7.2.5.2: Reference set of model parameter

WP7.3: Safety assessment
In addition to a number of arguments supporting the used approach, a Safety Case relies on a set of safety assessment calculations addressing all relevant scenarios.

Task 7.3.1: Safety and Performance Indicators calculation methodology
To analyse and communicate the extensive results of the safety assessment calculations, a set of suitable Safety and Performance Indicators is necessary, that gives a comprehensive overview of the expected repository behaviour and the long-term safety.
In this task, the calculation methodology Safety and Performance Indicators defined in Task 1.2.2. for the OPERA Safety Case is established.
Note that the reference values will be defined in Task 1.2.2 because they should be based on technical aspects as well as normative aspects such as moral standards, beliefs or political opinions.
Product:

- M7.3.1.1: Report on Safety and Performance Indicators development
- M7.3.1.2: Safety and Performance Indicators calculation methodology

Task 7.3.2: Methods for uncertainty analysis
The several sources of uncertainties in a safety assessment are broadly categorized in three categories: scenario uncertainty, model uncertainty and data/parameter uncertainty. In this task, the arguments for the approaches chosen to address these uncertainties as well as subroutines and methods are developed. The work performed in this task could build on the IAEA's standard safety series[11]. The developed model routines will be used as 'plug-in' in the integrated modelling environment for safety assessment (Task 7.2.4).
Product:

- M7.3.2.1: Report on methods for uncertainty analysis
- M7.3.2.2: Model subroutines for analysis of calculation outcomes

Task 7.3.3: Safety assessment calculations
In this task, the necessary performance and safety assessment calculations should be initiated, performed, and analysed, based on the input of several other tasks. The initiation starts with the description of the assessment context and ends with the comparison of the calculated Safety and Performance Indicators in Task 7.2.4 with the reference values in Task 1.2.1. The comparison, using the uncertainty analysis in task 7.3.2, should be calculated and presented for each scenario. This comparison, for each safety

[11] The Safety Case and Safety Assessment for radioactive waste disposal, IAEA Safety Standard Series, No DS 355, Draft safety guide, 2008.

function as well as the complementary performance of the different safety functions, is the essential part of the groundwork for substantiation of the safety statements defined in Task 2.1.1. The outcome of each comparison should preferably be supported by multiple arguments and the level of understanding of the (combination of) processes. The gaps in knowledge as well as (possible required) simplifications in modelling and other computational measures should be clearly expressed as well as the impact of these gaps and measures for assessing the safety function in question as well as the complementary performance of the different safety functions for the disposal system.

Product:

- M7.3.3.1: List of calculated comparisons for all scenarios
- M7.3.3.2: Report on safety assessment calculations

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