OPERA

Towards a safety strategy

Developing a long-term Dutch research programme into geological disposal of radioactive waste

OPERA-PG-COV014

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Safety strategy: boundary conditions, strategic choices, aims and objectives
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Date of publication 26 March 2014
Keywords: radioactive waste, safety, Dutch policy, geological disposal, OPERA, safety case
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Contents

Summary

The implementer of a facility for disposal of radioactive waste has the responsibility to develop and maintain a safety case. The safety case is an integration of arguments in support of the safety of the disposal of radioactive waste. According to IAEA and NEA guidance documents, one of the components of the safety case should be a safety strategy. A safety strategy is a high-level approach for achieving safe and acceptable disposal of radioactive waste. For the Netherlands, this strategy should provide for a systematic process for developing, testing and documenting the understanding of a disposal facility and building and maintaining the necessary knowledge and competences through successive research programmes. As a formal safety strategy is not yet available, the aim of this document is to start its development and documentation. Considering the policy of long-term interim storage period (at least 100 years), the safety strategy should focus of the research in the successive programmes. It has been chosen to focus research using requirements. These requirements should provide a general orientation for long-term research programmes. Following the Belgian safety strategy, these requirements are formulated as working hypotheses. Boundary conditions are requirements derived from relevant Dutch and international regulatory framework and policy. Strategic choices are preferences of the implementer for geological disposal of radioactive waste.

The boundary conditions are:

- *The ICM criteria (isolate, control and monitor) form the basis of the radioactive waste management policy.*
- *Radioactive waste is stored above ground for a period of at least 100 years.*
- *A single organisation has been established for management of all steps of the radioactive waste management process.*
- *In addition to a national geological disposal facility (GDF), the option of a multinational GDF is not excluded.*
- *All radioactive waste is intended to be disposed of in a single, deep GDF operating in 2130.*
- *The GDF has to be designed, operated and closed such that the process is reversible and the waste is retrievable.*
- *Both rock salt and clay formations are being considered as potential host rocks for geological disposal in the Netherlands.*
- *Specific regulatory criteria for the siting or the performance of a geological disposal facility have not yet been defined.*
- *The public has to be given the necessary opportunities to participate effectively in the decision-making process regarding radioactive waste.*

The strategic choices are:

- *The GDF will be constructed at sufficient depth to take into account the impact of surface phenomena.*
- *The GDF will be constructed within a Tertiary Clay formation or Zechstein rock salt formation.*
- *For a GDF in Boom Clay in the Netherlands: the research should build on the ONDRAF/NIRAS disposal concept and their research on Boom Clay.*
- *The materials and implementation procedures will not unduly perturb the safety functions of the host formation, or of any other component.*
- *In the case of heat-generating waste, the engineered barriers will be designed to provide complete containment of the wastes at least through the thermal phase.*
- *Waste types will be divided into groups to be emplaced in separate sections of the geological disposal facility.*

- *The different disposal galleries and sections, and the geological disposal facility as a whole, will be closed (access routes backfilled and sealed) following a progressive, step-wise closure procedure.*
- *Geological disposal planning will assume that surveillance and monitoring will continue for as long as deemed necessary.*
- *There are preferences for using shielded wastes packages that minimise operations and consequent operational radiation doses in the underground.*
- *There are preferences for materials and implementation procedures for which broad experience and knowledge already exists.*

1. Introduction

1.1. Background

The development of a geological disposal facility for radioactive waste will take place over a century in the Netherlands. It requires at least 100 years to collect sufficient radioactive waste to make a disposal facility economically viable. A choice between a national facility or disposal of radioactive Dutch waste in a multinational facility has not yet been made. A technical aspect is that the post-closure safety of a geological disposal facility is easier to predict with a cooling time of several decades for heat-generating High Level Waste. This long period of interim storage allows enough time to make the necessary financial, technical and social preparations to implement a geological disposal facility. At various stages in the lifecycle of the geological disposal facility, decisions are needed to proceed through the lifecycle and move towards the next stage. These decisions are to be supported by a safety case. It is the responsibility of the implementer of a geological disposal facility to develop and maintain a safety case [IAEA,2011:p.19].
Figure 1 shows the common elements in the decision-making processes on geological disposal in different countries and the key stakeholders [IAEA, 2009]. Added on the left is the planned timing for the Netherlands that follows from the current Dutch policy. Indicated on the right is the nature of the decision that has to be taken e.g. the element 'Operation' is drive by two decisions: the decision to "Operate" taken by the operator and the decision of issuing a license for operation taken by the regulator.

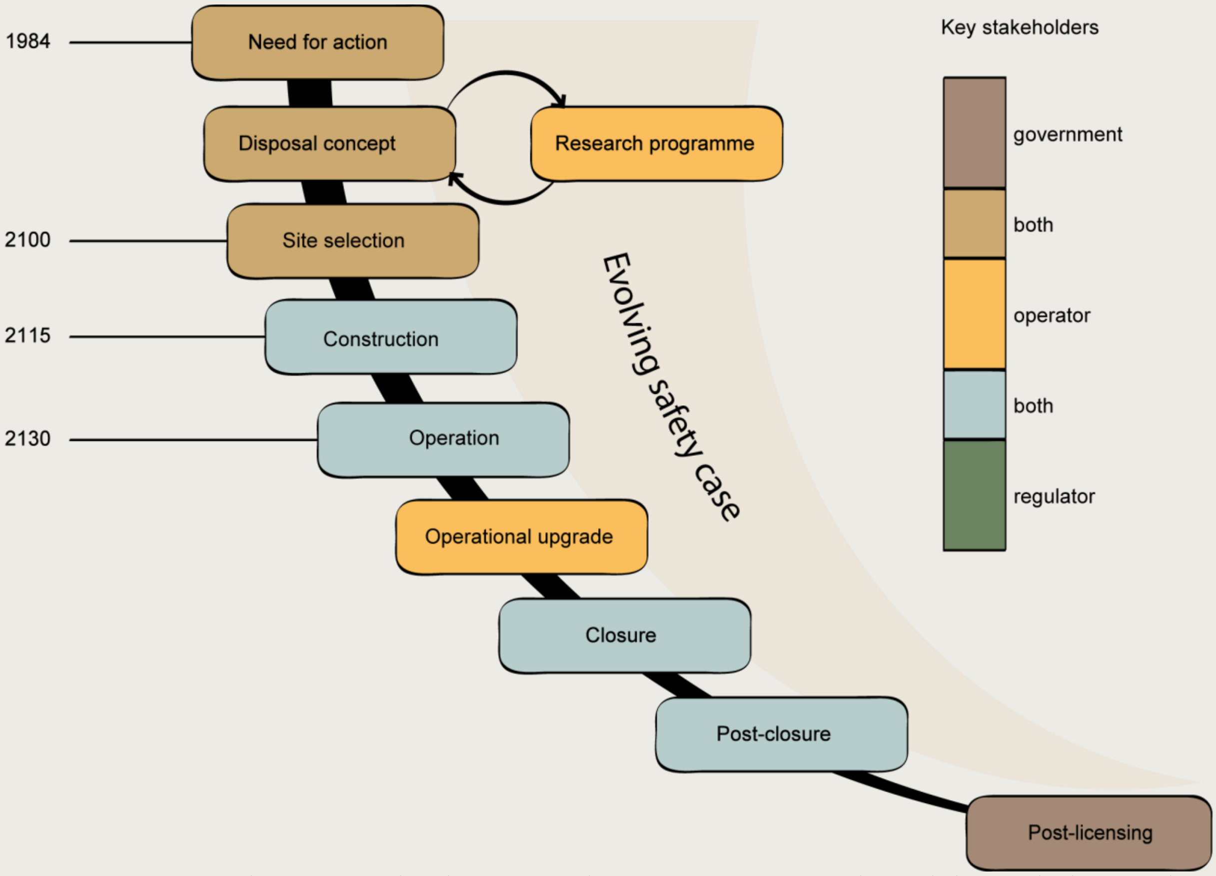

Figure 1 Common elements in the decision-making processes on geological disposal identified in an IAEA meeting and added on the left the timeline for the Netherlands.

The goal is to progressively develop the safety case in order to provide a sufficient basis for a decision to move forward to the next phase in 2100: site selection. From now until then in 2100, preliminary safety cases relying on rather generic assumptions about the properties of the host rock, are expected to be compiled at the end of each research programme. The last preliminary safety case should support the decision that adequate information is available to make a site selection. All other preliminary safety cases should structure the research necessary to get to that point.

One of the components of the safety case is the safety strategy [IAEA, 2012; NEA, 2013]. The safety strategy is a high-level approach for achieving safe and acceptable disposal of radioactive waste. The IAEA recommends defining this strategy at as early a stage as possible [IAEA, 2012:p.24]. In the Netherlands, this strategy should provide for a systematic process for developing, testing and documenting the understanding of a disposal facility and building and maintaining the necessary knowledge and competences through successive research programmes. It is important to note that the safety strategy is a living document; it as well as the disposal concepts will develop iteratively over a period of at least 100 years.

OPERA [1] is the third national research programme on geological disposal of radioactive waste in the Netherlands. This five-year research programme has started 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 two initial safety cases will be developed for generic repositories in the Netherlands either in Zechstein rock salt or in Boom Clay. An important result of OPERA will be a long-term R&D roadmap for geological disposal in the Netherlands.

1.2. Objectives

The objective of this document is to start the development and documentation of a formal safety strategy within OPERA. Considering the Dutch policy with an interim storage period of at least 100 years, this formal safety strategy will be limited to the approach for the definition of the research necessary. It has been chosen to focus the research by requirements, specified either as boundary conditions or as strategic choices. These requirements should provide a general orientation for long-term research programmes. Following the Belgian safety strategy [Smith, 2009], these requirements are formulated as working hypotheses. Boundary conditions are requirements derived from relevant national and international regulatory framework (IAEA, EU (Euratom), ICRP) and policy. Strategic choices are preferences of the operator (implementer of geological disposal e.g. waste management organisation) with the aim to define further the requirements for a GDF in the Netherlands.

The aims and ambitions are to define the desired outcomes of an on-going research programme (i.e. at this moment the five-year programme OPERA) and are constrained by the time and resources available.

1.3. Realization

The strategic choices and boundary conditions have been compiled from different sources, starting with official documents that describe Dutch radioactive waste policy and complemented with international recommendations and other international documents together with information from current advanced disposal programmes.

[1] OPERA is the Dutch acronym for research programme into geological disposal of radioactive waste. Previous programmes were OPLA (1974 – 1993) and CORA (1996 -2001).

Following IAEA recommendations [IAEA,2012:p.99] the document has been set up to enable the traceability of assumptions of choices and conditions, by e.g. referring to primary references as well as documents that report on the historical context of the rationale for these choices. Often these references are available only in the Dutch language, however. The sources from which conditions and choices have been compiled can be lengthy. Therefore, the page(s) in the sources where the described choice, assumption or parameter value can be found are specified in order to facilitate traceability of the referred information.
The document has been reviewed by the OPERA Safety Case group and discussed with representatives from the Dutch Ministry of Economic Affairs to ensure consistency with the previous national research programmes, international practice and Dutch radioactive waste policy.

1.4. Explanation contents

This is a ‘stand alone’ document describing the strategic choices and boundary conditions that are intended to be used as input in the Dutch safety strategy. The boundary conditions and strategic choices are described in Chapter 2 and Chapter 3, respectively. The aims and objectives of OPERA have been described in English and Dutch documents such as the OPERA Meerjarenplan [Verhoef,2011a]. These published aims and objectives of the third Dutch research programme OPERA have been compiled in Chapter 4 in order to facilitate monitoring by international experts. Chapter 5 lists definitions of the used specific terminology employed to enable consistent use throughout the research programme. The definitions are, as far as possible, compatible with international usage. Chapter 6 lists referred sources.

2. Boundary conditions

The boundary conditions to provide a general orientation for long-term research programmes are derived from the relevant international and national regulatory framework (IAEA, EU (Euratom), ICRP) and national policy. Research activities are required on the basis of Article 8 of the EC Directive on radioactive waste as a way to obtain, maintain and develop necessary expertise and skills for the management of radioactive waste [EU,2011:p.54]. The boundary conditions for geological disposal of radioactive waste in the Netherlands include:

1. The ICM criteria (isolate, control and monitor) form the basis of the radioactive waste management policy.

Since 1984, the policy in the Netherlands is that all hazardous and radioactive waste must be isolated, controlled and monitored [2] [VROM,1984:p.10].

2. Radioactive waste is stored above ground for a period of at least 100 years.

In 1984 the decision-in-principle has been taken to dispose of the Dutch radioactive waste in a geological disposal facility after interim storage above ground for a period of at least 100 years [EL&I,2011a:p.16-18; VROM,1984:p.10; EL&I,2012:p.5; EZ, 2013:p.8].

3. A single organisation has been established for management of all steps of the radioactive waste management process.

The different steps in radioactive waste management are closely interrelated [EU,2011:p.50] and can be structured and interpreted as a set of interacting processes [IAEA,2006a:p.2]. Decisions taken in one individual step may affect a subsequent step. As a consequence the interdependencies between all steps in spent fuel and radioactive waste generation and management need to be managed [EU,2011:p.53].

The policy in the Netherlands is that all radioactive waste[3] produced in the Netherlands is managed by a single organisation, namely COVRA. Transferral of the radioactive waste to COVRA includes transferral of the ownership and liabilities. COVRA is responsible for the management of the different interfaces and interdependencies between all steps of the radioactive waste management process [EL&I,2011a:p. 21; VROM,1984:p.4]. [4]

4. In addition to a national geological disposal facility (GDF), the option of a multinational GDF is not excluded.

During the next 100 years, an international or regional solution may become available. The option of sharing a geological disposal facility (GDF) with one or more countries is also being considered in the Dutch 'dual track' policy [EL&I,2012:p.2; EL&I,2011a:p.20; EL&I,2011b:p.4-5]. A national research programme on geological disposal for radioactive waste is an essential element for both tracks of the policy [EU,2011:p.53].

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[2] How monitoring can be applied to geological disposal is described in a strategic choice (No 8).

[3] An exception is radioactive waste with a half-life less than 100 days. This is allowed to decay at the sites where it is generated.

[4] Only for research reactors, spent fuel is regarded as radioactive waste. For nuclear power plants, spent fuel is reprocessed in contracts between the producer of spent fuel and the (foreign) reprocessing facility [EL&I, 2011a, p.16].

5. All radioactive waste is intended to be disposed of in a single, deep GDF operating in 2130.

For the national disposal option, no separate facilities for Low and Intermediate Level Waste (LILW) and High Level Waste (HLW) are envisaged. Because of the relatively small waste volume expected to be collected in a period of 100 years, separate facilities are economically not feasible [EL&I,2011a:p.24]. Consequently, deep geologic disposal will be required for all waste categories as a final solution [EL&I,2011a:p.17; EL&I,2011b:p.4].
The policy in the Netherlands is that during the interim storage period the geological disposal is prepared financially, technically and socially in such a way that it can be implemented in practice. After the storage period (around 2100), a decision is foreseen, with the options being to continue the storage, to realise the GDF, or to use new techniques or management options that may become available during the period of interim storage [EL&I,2011a:p.18]. In all cases after 2130, a geological disposal route should become operational [EL&I,2011a:p.82].

6. The GDF has to be designed, operated and closed such that the process is reversible and the waste is retrievable.

In 1993 the government adopted, and presented to parliament, a position paper on the long-term underground disposal of radioactive and other highly toxic wastes [VROM,1993]. This forms the basis for further development of a national radioactive waste management disposal policy, which now requires that any GDF be designed in such a way that each step of the process is reversible. This means that retrieval[5] of waste, if deemed necessary for whatever reason, would still be possible for decades up to more than a century after closing the geological disposal facility, leaving the possibility to future generations to apply other management techniques, if available [EL&I,2011a:p.19].

7. Both rock salt and clay formations are being considered as potential host rocks for geological disposal in the Netherlands.
Because the Netherlands has adopted the strategy of storage in dedicated surface facilities for at least 100 years, there is no immediate urgency to select a specific host rock. Both rock salt and clay formations would qualify as potentially suitable host rocks for a geological disposal facility [EL&I,2011a:p.18; VROM,2003:p.9].

8. Specific regulatory criteria for the siting or the performance of a geological disposal facility have not yet been defined.

Because the Netherlands has adopted the strategy of storage in dedicated surface facilities for at least 100 years and potentially suitable host rocks are available, there is no immediate urgency to develop specific regulatory criteria for the geological disposal of radioactive waste.
There are general international guidelines (IAEA) on the siting and safety of geological disposal facilities. Furthermore, in principle the same radiation safety requirements that apply to the licensed nuclear facilities in the Netherlands would also apply to the GDF, at least during the operational phase [6]. This is consistent with the principle that the GDF has to be designed, operated and closed in order to ensure that future generations are not less

[5] A brief history of the studied disposal concepts and the discussion in the Dutch parliament concerning retrievability of waste is described in the Annex.
[6] These radiation safety requirements are 0.1 mSv per year and 10^{-6} deaths per year for people outside the nuclear facility see Annex.

protected than the current generation under the internationally and nationally endorsed radiation protection criteria and standards [IAEA,2006b:p.41].

There are no regulatory criteria for the siting of a geological disposal facility in the Netherlands developed yet, neither at national nor European level[7]. In the previous research programme, assumptions have been made to investigate the feasibility of a geological disposal facility in the Netherlands, such as depth. The results of this programme identified clay and salt as potentially suitable geological formations in the Netherlands. These results, however, do not exclude in any way that other disposal concepts based on different assumptions could also be feasible.

9. *The public has to be given the necessary opportunities to participate effectively in the decision-making process regarding radioactive waste*.

All EU Member States have to ensure that necessary information on the management of spent fuel and radioactive waste is made available to workers and the general public [EU,2011:p.55]. Transparency is important to build confidence in the regulator, the implementer, and the safety of radioactive waste management routes; to enable a dialogue among stakeholders and/or public debate on the geological disposal [EL&I,2011a:p.18]. Transparency should be provided by ensuring effective public information and opportunities for all stakeholders concerned, including local authorities and the public, to participate in the decision-making processes in accordance with national and international obligations [EU,2011:p.50].

[7] A brief history of this investigation in European projects is described in the Annex.

3. Strategic Choices

Strategic choices are high-level preferences made on the basis of existing knowledge and understanding that aim to further define the requirements for a GDF in the Netherlands. These choices are constrained by the boundary conditions.

1. The GDF will be constructed at sufficient depth to take into account the impact of surface phenomena.

The host rock and geological environment should provide an effective containment of the emplaced waste and isolation from the biosphere. The depth of GDF should be sufficient to take into account impact of surface phenomena such as ice ages [Verhoef,2011b:p.3].

2. The GDF will be constructed within a Tertiary Clay formation or Zechstein rock salt formation.

The geological conditions in the Netherlands, with large salt formations in the Northern part of the country and clay formations at varying depth in the whole country, are in principle favourable from the perspective of disposal of radioactive waste [see e.g. for clay Boisson,2005:p.3; e.g. for rock salt Storck,1988:p.20]. For OPERA, the rock salt from Zechstein formation and Boom Clay from Rupelian formation are considered as potential host rocks [Verhoef,2011a:p.2-3].
OPERA has its main focus on Boom Clay, as more information is already available on rock salt formations in the Netherlands. The Dutch research programme OPLA (1982-1993) was devoted to disposal in rock salt in the Zechstein formation and in CORA (1996-2001) rock salt as well as Boom Clay was considered. Experimental results for disposal of radioactive waste in rock salt are available [Hamstra,1981; Prij,1985; Vons,1993; BAMBUS, 2000/2004]. The distribution and available knowledge concerning properties of other tertiary clay formations [Simmelink,1996; Rijkers,1998] were investigated in the previous research programme CORA. The available knowledge of measured properties of these clays at representative depth for a GDF is scarce but two tertiary clays formations namely Oosterhout and Breda may have a too large hydraulic conductivity i.e. larger than 1×10^{-7} m/s. Asse and Ypresian clay appear to be more homogeneous in lithology e.g. more uniform in grain size than Rupel (Boom) clay while Asse and Ypresian are present in the Netherlands usually at depths below 800 metres.

3. For a GDF in Boom Clay in the Netherlands: the research should build on the ONDRAF/NIRAS disposal concept and their research on Boom Clay.

The Belgian programme has developed extensive knowledge of disposal of radioactive waste in Boom Clay since 1974. The Belgian programme includes an Underground Research Laboratory in Mol where experiments have been and still are performed to validate models. The next strategic choices described in this chapter have been adapted from the Belgian safety strategy to fit the Dutch situation[8].

[8] Except for the first three choices, all choices in this document are derived from this Belgian strategy [Smith,2009]. A notable difference in formulation is the usage of the word “shall”. Considering that “shall” may have a formal connotation as it is used in documents such as the IAEA Safety Fundamentals and Standards, it was decided to use “will” instead of “shall”. As the context of the choices may differ between Belgium and the Netherlands a short explanation is given with each strategic choice.

4. The materials and implementation procedures should not unduly perturb the safety functions of the host formation, or of any other component.

Robust disposal systems are characterised by simple, well-understood or easily characterised features and phenomena. In the disposal concept the host rock that contains and isolates the waste, together with its surrounding geological environment, have to be stable and with predictable behaviour over long periods of time. The design of the GDF, construction, operational and closure should minimize perturbation of the host rock in order to preserve its safety functions.

5. In the case of heat-generating waste, the engineered barriers will be designed to provide complete containment of the wastes at least through the thermal phase.

In case of heat-generating waste, the safety assessment is more robust when the waste package contains the radionuclides for a thousand to a few thousands of years. This initial phase is the so-called 'thermal phase' during which the temperature in the surrounding clay is increased such that the potential effect on radionuclide migration becomes more difficult to quantify [NEA,2008:p.38].

6. Waste types will be divided into groups to be emplaced in separate sections of the geological disposal facility.

Investigation of a generic disposal concept for all types of radioactive waste is one of main differences between OPERA and the previous programmes OPLA and CORA that considered only part of the waste inventory for disposal (mainly vitrified HLW). The generic GDF design investigated contains separate sections for each group of waste in a single facility in order to prevent or minimize the influence of the products generated by degradation of waste matrices and packages on other types of waste.

7. The different disposal galleries and sections, and the geological disposal facility as a whole, will be closed (access routes backfilled and sealed) following a progressive, step-wise closure procedure.

The aim of the disposal concept is to ensure passive safety, and to remove the need for active controls after closure. It has to be assured that any provision for retrievability does not have an unacceptable adverse effect on safety or performance. This implies that the emplacement of the waste in the GDF would ensure a sufficiently safe situation in case of neglect or social disruption, e.g. leading to flooding. In order to create an effective barrier from the biosphere the GDF should be closed as soon as practically possible following the emplacement of waste. This will considerably complicate the post-closure retrieval of waste that demands accessibility of the waste in a GDF for a prolonged period. A possible way to take both objectives into consideration is a progressive, step-wise closure procedure.

After emplacement, an observational period is foreseen in which recovery of the waste or waste packages is possible. In the OPERA disposal concept [Verhoef,2011b:p.11] the sections in which waste are emplaced contain dead end drifts to prevent circulation in the unlikely case of flooding during the observation period, pre-closure and sealing. During this period, monitoring is needed as well as regular maintenance of access ways and emplacement/retrieval systems. On a regular basis it could be decided whether to extend the post-operational phase, or retrieve the waste, or to close the facility. This decision process could be guided by a legally established procedure, which must be transferred from government to government or even over generations.

8. Geological disposal planning will assume that surveillance and monitoring will continue for as long as deemed necessary.

Although waste retrievability allows future generations to make their own choices, it is dependent upon the technical ability and preparedness of society to keep the facility and site accessible for surveillance and monitoring over a long period, even after closure. Retrievability requires long-term arrangements for maintenance, data management, monitoring and supervision e.g. systems to facilitate retrieval of waste [Verhoef,2011b:p.6]. Post-closure surveillance and monitoring is assumed to be continued until adequate assurance has been obtained concerning the safety of the geological disposal of waste. It important to understand, however, that the post-closure performance and safety does not depend in any way on the ability to continue monitoring.

9. There are preferences for using shielded wastes packages that minimise operations and consequent operational radiation doses in the underground.

At COVRA, only solid waste is accepted for storage and conditioning of waste is always with the intent of deep geological disposal. LILW is stored in shielded (concrete) packages. The aim in waste treatment and storage is to keep operations simple and reduce the number of operations required. Fewer operations mean smaller radiation doses for workers and less risk. In the Boom clay disposal concept shielded disposal packages are foreseen in order to minimise operations and to ease handling of waste packages in the underground. For rock salt, the shielding in the HLW disposal package may be removed after emplacement of waste.

10. There are preferences for materials and implementation procedures for which broad experience and knowledge already exists.

The ability to show that adequate levels of containment and isolation are provided over the necessary time frames requires that the disposal concepts are robust with respect to potentially perturbing phenomena and to uncertainties that may arise over the long time frames involved. Thus, as far as reasonably possible, events and processes that could be detrimental to isolation and containment, as well as sources of uncertainty that would hamper the evaluation of how the systems evolve over time, are avoided or reduced in magnitude, likelihood or impact by means of siting or design choices. In general, the introduction of more foreign materials leads to more difficulties with the prediction of possible effects of these materials on the host rock and/or other EBS materials and thus increases uncertainties.
Similarly the processes and procedures for the development, construction and operation of the GDF need to be robust, i.e. simple, reliable, and effective. Therefore there is a preference for above ground construction, assemblage and quality assurance of waste packages and for the usage of technologies where possible that have been proven in related fields of work, such as mining, tunnel construction (concrete support) and the oil and gas industry.

4. Aims and objectives of OPERA

4.1. Studying the safety and acceptability of geological disposal in the Netherlands

Because the Netherlands has adopted the strategy of storage of radioactive waste in dedicated surface facilities for at least 100 years, there is no immediate urgency to select a specific disposal site for this waste. However, further research is required to resolve outstanding issues, to develop and preserve the expertise and knowledge, and to be prepared for site selection in case of any change to the current timetable, arising by way of future European directives, for example [EL&I,2011a:p.20].

The result of OPERA will be to detail a first roadmap for the long-term research on geological disposal of radioactive waste in the Netherlands, based initially on a re-evaluation of existing safety and feasibility studies conducted more than ten years ago, making use of present international and, wherever possible, national knowledge. This will be done by developing *initial* and *conditional* safety cases for generic GDFs in Zechstein rock salt and Boom Clay formations in the Netherlands. The goal in OPERA is to develop *initial* safety cases that are intended to mark the start of the research development process and to iterate these as knowledge grows to new developed insights. The safety case is *conditional* since plausible assumptions must later be confirmed in a safety case e.g. for site selection.

The primary objectives are firstly to make a structured assessment of the post-closure safety of a generic GDF in the Dutch Boom Clay formation, and secondly to investigate the retrievability of waste from the facility and the technical feasibility of the proposed design. Societal and ethical processes that influence the acceptance and the required safety levels are considered to be an essential part of the framework for this assessment.

As in the previous national research programmes much work has been done on disposal concepts for rock salt, only limited efforts within OPERA are performed to develop a safety case in rock salt. It is expected that 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 Zechstein rock salt. Neither siting nor the choice of a geological formation will be a topic in OPERA.

Specific OPERA objectives are to:

1) conduct a study of the societal aspects and processes concerning decision-making on geological disposal;
2) perform an evaluation of the technical-scientific knowledge concerning geological disposal in both host rocks that has been gained in the last decades (nationally and internationally) and transfer the information to the generic geological disposal facility in the Netherlands;
3) identify and conduct research to reduce uncertainties;
4) compile an initial, conditional safety case for a Boom Clay disposal facility;
5) apply the methodology using the existing knowledge about Zechstein rock salt disposal.

4.2. Building knowledge and competences

A further aim of the programme is building and maintaining the knowledge and competences to run a geological disposal research programme and manage the interfaces between all steps of the radioactive waste management process from generation to disposal.

Ambitions are to reactivate research on geological disposal and to involve a broad group of (new) researchers in the field, as well as to provide access to previous research on geological disposal in the Netherlands, communicate transparently about the results and embed the (developed) knowledge in an academic curriculum.

5. Definitions

Consistent usage of definitions throughout OPERA is important for both internal communication (between the different projects) and external communication. Definitions should be as far as possible compatible with international usage and where different clearly defined. In the definitions below special care was given to comprehensible formulation and avoiding introduction of new terms where possible.

Disposal concept

is the description of the envisaged repository system to contain the waste and is based on the boundary conditions and strategic choices. Isolation of the radionuclides from the radioactive waste from the biosphere is provided by a multi-barrier system. Barriers are natural (geological) and man-made (engineered) - namely the waste form, the waste package (container), the backfill, the host rock and the formations surrounding the host rock. For OPERA, the outline of the disposal concept adapted from ONDRAF-NIRAS for the type, volume of radioactive waste to be disposed in the Netherlands is described [Verhoef et al, 2011].

Geological disposal

is the containment of waste and the isolation of waste from the accessible biosphere. The containment of waste takes place via a system of multiple barriers. The barriers contain or inhibit, reduce, delay migration of the radionuclides in/from the waste. These barriers are natural (geological) and man-made (engineered). The facility for the disposal of solid radioactive waste is located at least a few hundred metres below ground level in a geological formation. Disposal refers to the emplacement of waste with no intention to retrieve the waste. It does not mean that retrieval of waste is not possible. This definition reflects the IAEA description of geological disposal [IAEA, 2006b; p.1-2; IAEA, 2011; p.3,5].The implementation of the EU Directive [EU, 2011] has resulted in the revision of the definition of final disposal in the Decree on radiation protection of the Nuclear Energy Act [EZ, 2013: p.4,16].

Geological disposal facility

is the man-made (engineered) part of the multi-barrier system.

Safety case

is an integration of arguments, at a given stage of geological disposal development, in support of the safety of the disposal of radioactive waste. A safety case comprises the findings of a safety assessment. It should acknowledge the existence of any unresolved issues that may have an impact on safety of the GDF and provide guidance for work to resolve these issues in future development stages. The definition adapted from [NEA,1999:p.22] is slightly different than used in the OPERA Research Plan [Verhoef,2011d:p.5] and OPERA Meerjarenplan [Verhoef,2011a:p.4]; "geological disposal" and "disposal of radioactive waste" is used instead of "repository", 'long-term' has been removed since the other stages of the GDF should also be safe and 'statement of confidence' has been removed since the concept is vague. This definition reflects the description of the safety case in the most recent IAEA publication [IAEA,2006b:p.5,23] on geological disposal and disposal in general [IAEA, 2011:p.30].

Safety strategy

is the high-level approach adopted for achieving safe and acceptable disposal of radioactive waste. This is almost the same definition as used in the OPERA Research Plan [Verhoef,2011d:p.7] except that 'and acceptable' is added to emphasize that disposal should be social based and that "overall" used instead of "high-level". The same definition can be found in [NEA, 2013:p.21] and [IAEA, 2012:p.24] apart from the addition "and acceptable".

Storage

is the containment of waste and the isolation of waste from the accessible biosphere. The facility for the containment of waste is designed with the intention to retrieve the waste. Storage is a temporary measure following which some future actions planned e.g. disposal. This definition reflects the IAEA description of storage [IAEA, 2011; p.3]. The distinction between storage and disposal with respect the intention to retrieve the waste has been adopted [EZ, 2013: p.6] following the implementation of the EU Directive [EU, 2011].

System / safety concept

is the description of how the barriers in the disposal concept are integrated to provide safety after closure of the GDF. Safety functions with assigned time frames are used for this description. This definition and methodology is used in the OPERA Research Plan [Verhoef,2011d:p.8-11] except that 'on the long-term' is replaced by ' after closure of the GDF (Geological Disposal Facility)'. This definition reflects almost the definition of the safety concept from the Belgian agency ONDRAF/NIRAS [Smith,2009:p.8]. The Belgian safety strategy is by far further developed than the Dutch one and allows further detailing of the definition of the safety concept. It has been chosen to limit the definition to the items that are used within OPERA.

Safety function

is the action or role that the natural and/or engineered barrier(s) performs after closure of the GDF to prevent the radionuclides present in the waste posing an unacceptable hazard to humans or the environment. This definition is almost the same as used in the OPERA Research Plan [Verhoef,2011d:p.7] and is taken from an ONDRAF/NIRAS publication [NIROND,2004: p.119]; 'after closure' has been added in order to comply with the IAEA description [IAEA,2012:p.73].

6. References

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Annex – Retrievability of waste

The reasons for the boundary condition for retrievability of waste in the Dutch policy are [VROM,1993:p.7]

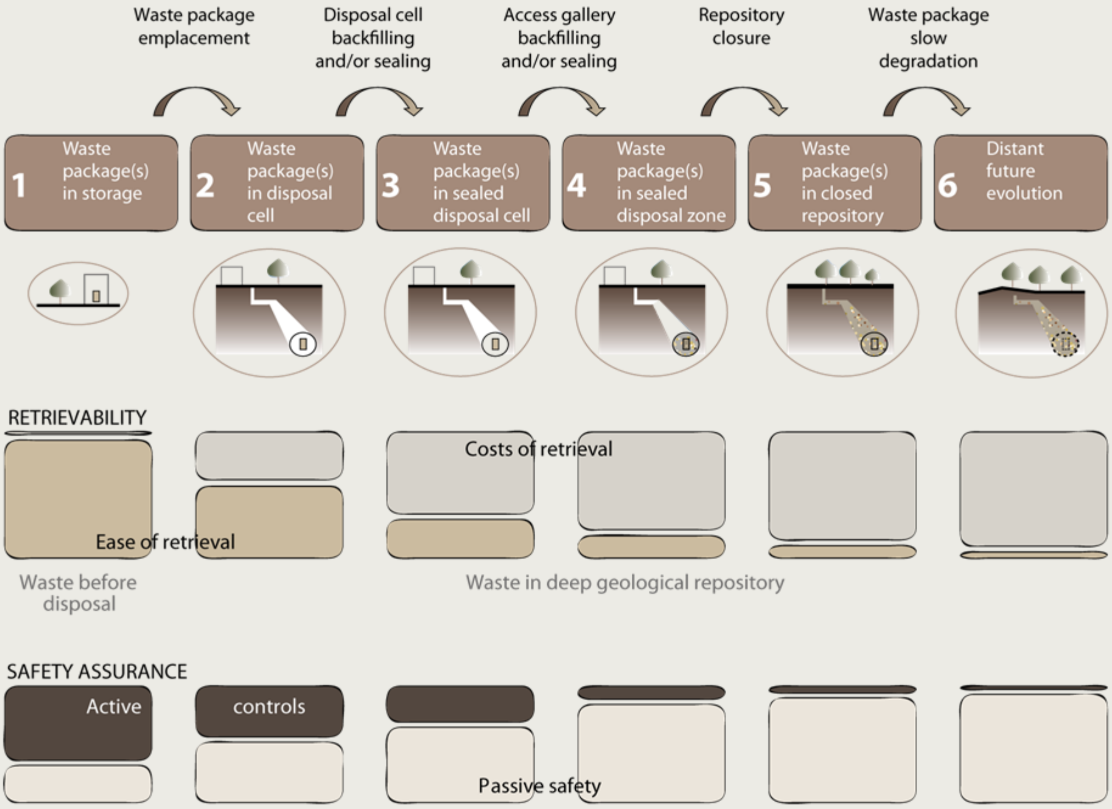
1) The disposal facility should be organized in such a way that a maximum in safety can be achieved under normal and exceptional or unexpected circumstances. Therefore, isolation and control by human intervention should be optimal;
2) The waste should be available when an acceptable management technique has emerged by which the waste can be reused again.

Many disposal concepts in rock salt were studied in the Dutch research programme OPLA but research was focussed on disposal of HLW (vitrified) waste in deep (vertical) boreholes. For this concept, deep boreholes up to 1800 meters below the surface are drilled from the earth surface. These boreholes would be filled with a fluid. The waste is emplaced by sinking the waste (contained in canisters) in the fluid. The fluid, brine, should after the emplacement of waste be removed as far as possible [Van Hattum and Blankevoort,1986:p.52-71]. The isolation of the waste is provided by enclosure of rock salt by creep. The possibility to retrieve the waste for reasons of control and/or recycling is limited in this disposal concept. Therefore one of the (main) studied disposal concepts in OPLA was rejected by the Dutch parliament in 1993 [VROM,1993:p.7].

In the next research programme on geological disposal, CORA, the possibility of retrievable disposal was studied. In this programme, the disposal concept contained small horizontal disposal drifts; 5 meter maximum in length for the disposal of one canister in each drift. The canister is contained in an overpack. The overpack is expected to remain intact for hundreds or even more than 1000 years. After emplacement of this waste package, the drift would be backfilled. The start of retrieval of waste is the removal of the backfill [EZ,2001:p.40,41,60]. The Dutch parliament was convinced that the retrievability of waste was technically possible with this disposal concept [VROM,2002:p.12].

In the latest safety standards specific for disposal of radioactive waste, the IAEA distinguishes geological disposal from borehole disposal. Borehole disposal has not been adopted for a disposal facility by any State [IAEA,2011;p.5].

A description of the implementation of retrievability of waste for the Dutch case has been published for OPERA in Outlines of a disposal concept in clay. A fail-safe situation was envisaged by backfilling and sealing of disposal galleries after emplacement of waste but leave other galleries e.g. access open for a certain period to facilitate recovery of the waste or waste packages [Verhoef, 2011:p.6,12]. Such a description can be graphically depicted. The following figure shows this graphical depiction made by the Nuclear Energy Agency to elaborate communicating the relationship between retrievabilility and the development phase of a geological disposal facility.



Annex – Safety requirements for nuclear facilities in the Netherlands

The European radiation protection criteria and standards have been established in Council Directive 96/26/Euratom [EU,1996] on the basis of article 30 of the EURATOM-treaty from 1957 and apply to all practices. The radiation protection criteria and standards are derived from ICRP publication 60 from 1991 [ICRP,1991]. In March 2007 the ICRP made new recommendations, however, these have not led to new legislation yet.

The provisions of the directive have been implemented into the Dutch legislation, in particular in the Decree on radiation protection [SZW,2001] of the Nuclear Energy Act. All nuclear facilities in the Netherlands consequently require a permit in accordance with the Nuclear Energy Act. The relevant radiation protection criteria and standards for such permit can be found in the Decree on radiation protection which has been in force since March 1, 2002. This includes among others a legal location limit of 0.1 mSv effective dose per year for people outside the nuclear facilities as described in Article 48.1 of this Decree [SZW,2011:p.21].

As the basis for a permit, the radiation dose that members of the public receive as a consequence of (possible) emissions of radioactive material (into the atmosphere or surface water) or as a consequence of external irradiation have to be calculated. The rules for calculation can be found in an annex of a Ministerial Order on the assessment of consequences of ionising radiation [VROM,2002].

IAEA has safety-based requirements for GDFs that involve optimisation of protection, including social and economic factors, and reasonable assurance that the safety criteria will be met over the long term, a dose criterion of 0.3 mSv per year and a risk constraint in de order of 10^{-5} deaths or serious hereditary diseases per year [IAEA,2006b:p.10-11]. The requirements are based on the ICRP publications 77 and 81 [IAEA,2006b:p.8]. The dose criterion of 0.3 mSv is derived from ICRP 77 [ICRP,1997:p.16;NEA,2008:p.81] and corresponds to a risk equivalent of about 10^{-5} per year [ICRP,1998:p.17;NEA,2008:p.81]. These criterions have not been changed with the new IAEA Safety standard for disposal in general [IAEA,2011:p.13] neither with the new ICRP publication. As clearly indicated by ICRP [ICRP,2013:p.12], in the very long-term (for post-closure), dose and risk criteria should be used for the comparison of options rather than a means of assessing health detriment. The current Dutch maximum permissible additional risk for individuals is per installation 10^{-6} deaths per year [EL&I,2011a:p.36-38;VROM,1989:p.13].

In the 80's an EC project was carried out to make an inventory of potential options for siting geological disposal facilities in the European Union [EU,1980:p.15-16]. The criteria used, such as thickness and depth, were defined solely for the purpose of the inventory, were based on the knowledge and available information of that time, and were neither exhaustive nor definitive [EU,1980:p.23]. EC publications that followed concluded that the safety requirements for geological disposal should be fulfilled rather than comply to a quantification of a depth or a thickness of a host rock [EU,1990:p.30; EU,1992:p.7].

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