Evaluation of Current Knowledge for Building the Dutch Salt Safety Case - 16024

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ABSTRACT

This paper provides an overview of an evaluation for building the Safety Case of geological disposal of radioactive waste in rock salt in the Netherlands. The evaluation comprises the present knowledge about the safety and feasibility of geological disposal designs considered in the past, thereby classifying the information taking into account the methodology and structure of a Safety Case. The evaluation is performed as part of the Dutch research programme OPERA[1] by a consortium consisting of GRS from Germany, and TNO and NRG from the Netherlands. Basis of the evaluation is the available Dutch and international scientific-technical information about geological disposal in rock salt, especially from the German and US programmes.

The evaluations have shown that although much knowledge on the topic exists, the available information need to be integrated in order to develop a Dutch Safety Case on rock salt. For example, the characteristics of the Dutch radioactive waste investigated for disposal have changed considerably since the last Dutch research programme ended in 2000. This implies that the previously considered Dutch facility concepts for geological disposal in rock salt need to be adapted to the newly regarded waste types such as spent fuel from research reactors and large amounts of LLW, including depleted uranium. Introducing these aspects into the iteration towards a salt Safety Case would also require an update of the post-closure safety assessment.

INTRODUCTION

The Dutch five-year research programme for the geological disposal of radioactive waste, OPERA, started in June 2011. The main objective of OPERA is to provide tools and data for the development of Safety Cases for national repository concepts in two host rocks present in the Netherlands, Zechstein rock salt and Rupelian Boom Clay [1; p. 6]. Within the OPERA context, the Safety Case has been formulated as a collection of arguments in support of the post-closure safety of the repository [1; p. 5]. The Safety Case methodology is also a powerful tool for structuring and conducting research programmes for the disposal of radioactive waste. Additionally, the Safety Case can reveal areas of uncertainty and unresolved issues and provides guidance to resolve these issues in future development stages of the repository programme.

[1] OPERA: OnderzoeksProgramma Eindberging Radioactief Afval - Dutch acronym for Research Programme into Geological Disposal of Radioactive Waste

During the last 40 years, in the Netherlands much research effort has been devoted to the geologic disposal of radioactive waste in rock salt, for example in the framework of the ICK[2] [2], OPLA[3] [3], and CORA[4] [4] programmes. Additional work has been done in several European Framework projects like EVEREST, BAMBUS, PAMINA, and THERESA. In these programmes performance assessments and detailed analyses were carried out for generic repository designs in rock salt. The outcomes of all these programmes and projects have however not yet been integrated according to the recently developed and generally accepted methodology of the Safety Case, e.g. by NEA [5] and IAEA [6].

The present paper summarizes the results of the research performed for OPERA Task 2.2.1: *Evaluation of current knowledge for building the Safety Case*, as part of OPERA Work Package 2.2: *Repository design in rock salt* [1]. The OPERA Salt Safety Case (OSSC) project aimed to provide a roadmap to a first Safety Case for the geological disposal of radioactive waste in rock salt in the Dutch context. The roadmap is based on a review of the state of the art on geological disposal of radioactive waste in rock salt in the context of the Safety Case methodology, and a critical evaluation of the existing national and international knowledge base. The OSSC project identified and assessed possible gaps in the existing understanding in relation to the Safety Case and provides recommendations for guiding future activities in accordance with the radioactive waste management strategy in the Netherlands.

OVERVIEW OF DUTCH WASTE DISPOSAL PROGRAMMES ON ROCK SALT

During the last 40 years several national research programmes were executed in the Netherlands on the geologic disposal of radioactive waste in rock salt, which is abundantly available in the Netherlands:

ICK (1972-1979) – The first Dutch geological disposal programme focused on safety evaluations of a variety of generic conceptual designs for the deep disposal of radioactive waste in rock salt. Extensive analyses were performed on the temperature distributions in rock salt due to the heat output from heat-generating radioactive waste, and criteria for site selection were developed [2].

OPLA (1984-1989) – The central theme of the extensive OPLA programme [3] was “radiation safety” of salt-based repositories. It included research on a variety of topics: geology/geohydrology, host rock mechanics, radiation damage in rock salt, and mining engineering. In that period the Netherlands also participated in in-situ experiments in the German Asse II salt mine. Additionally, substantial efforts comprised the safety evaluations of disposal concepts in rock salt, viz. the VEOS[5] safety assessment.

[2] ICK: Interdepartementale Commissie Kernenergie (Interdepartmental Nuclear Energy Commission)
[3] OPLA: Opberging te Land - Dutch acronym for Onshore disposal
[4] CORA:Commissie Opberging Radioactief Afval -Dutch acronym for Commission on Radioactive Waste Disposal
[5] VEOS: *Veiligheids Evaluatie van Opbergingsconcepten in Steenzout* - Safety evaluation of disposal concepts in rock salt

OPLA-1A (1989-1993) – The follow-up programme of OPLA focused specifically on the safety assessment of geological disposal in rock salt. A methodology for the systematic development of scenarios, based on extensive evaluations of FEPs, was established. Additionally, development and application of probabilistic methods for the consequence analysis were developed and applied, viz. the PROSA methodology [7]. The in-situ research in the Asse II mine (demonstration techniques, heater experiments) continued, and further analyses on the radiation damage in rock salt were performed.

CORA (1996-2001) – The focus of the CORA programme concerned retrievable disposal of radioactive waste in rock salt and Boom Clay. Research was performed on geology/geohydrology, mining engineering and economics, radiation damage in rock salt, and, for the first time, societal aspects and ethics. Twenty research institutes, both from the Netherlands and abroad, participated in CORA [4].

During the period 2001 – 2011 no national programme on geological disposal was effective. However, Dutch participation in several in EU Framework projects, e.g. PAMINA, NF-PRO, BAMBUS-II, THERESA, and MoDeRn, assured to keep alive the previously developed knowledge about geological disposal in rock salt, although at a moderate level.

The presently running OPERA programme (2011-2016) [1] focuses on the implementation of the Safety Case methodology, which has been developed internationally after the end of the CORA programme. Most of the efforts in OPERA concentrate on geological disposal in Boom Clay, whereas limited efforts are performed to develop a safety case in Zechstein rock salt. The anticipated result of OPERA is a first roadmap for the long-term research on geological disposal of radioactive waste in the Netherlands. The timeline of the various Dutch programmes on geological waste disposal is shown in Fig. 1.

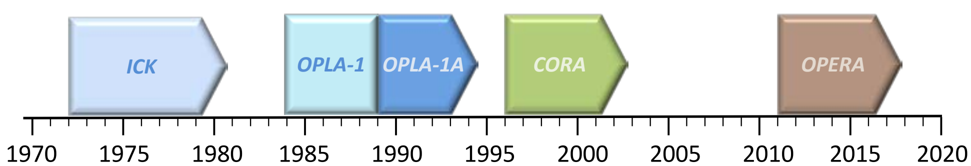


Fig. 1. Timeline of the Dutch programmes on geological waste disposal in rock salt.

The present paper summarizes parts of the work performed within OPERA WP2: “*Set-up and definition of Safety Cases for disposal in Zechstein rock salt and Boom Clay”*. The work was performed by a small consortium comprising specialists from GRS in Germany and the Dutch research and consultancy organizations TNO and NRG. The project OSSC, “*OPERA Salt Safety Case”*:

- evaluated the present knowledge about the safety and feasibility of a final disposal facility in rock salt in the Netherlands,
- analyzed available national (ICK, OPLA, CORA), and international (German and US) information about the final disposal in rock salt,
- integrated the information in the framework of a Safety Case,

- assessed the adequacy of the available information to build a Dutch Safety Case for the geological disposal in rock salt,
- Provided proposals to build the Dutch salt Safety Case.

APPLIED ETHODOLOGY

In the OSSC project the available knowledge on the safety and feasibility of the geologic disposal of radioactive waste in rock salt formations has been analyzed and integrated, coherent with the internationally accepted methodology of the Safety Case for final disposal of radioactive waste. The Safety Case for final disposal involves several principal elements, as depicted in Figure 1 (IAEA (left) [6, p.17]; NEA (right) [5, p.19]).

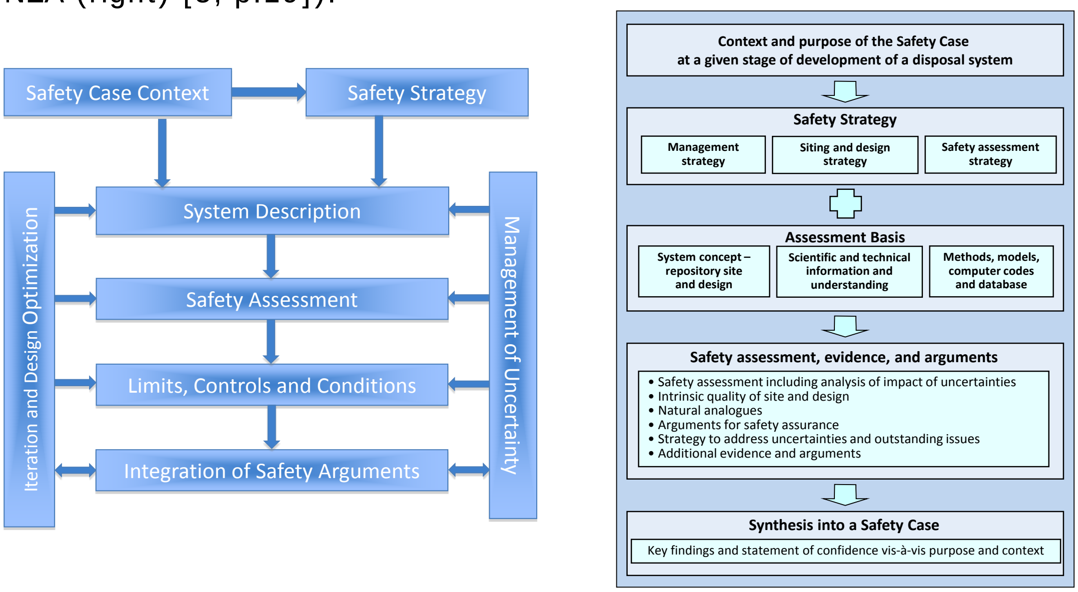


Fig. 2. General elements and structure of a Safety Case for final disposal of radioactive waste.

These elements have served as a basis to structure the evaluations of the abundant information available for the deep geological disposal of radioactive waste in rock salt. Main sources of information were the reports published as part of the Dutch waste disposal programmes and selected publications from the German programme for domal salt (e.g. ISIBEL [8], VSG [e.g. 9]), and the US waste isolation pilot plant (WIPP) in bedded salt (e.g. [10, 11]).

The following sections summarize the main outcomes of the evaluation of the various elements of the salt Safety Case.

SAFETY CASE CONTEXT

The *Safety Case Context* is an overarching element of the Safety Case, including a country's nuclear profile and legal framework. Throughout the last four decades the Dutch nuclear profile has changed considerably, mainly in terms of nuclear profile and characteristics of radioactive waste intended for disposal.

In the 1970’s and 1980’s the Dutch nuclear profile concerned two nuclear power plants (NPP), generating 500 MWe, and in those days it was anticipated that an additional 3000 MWe nuclear power generation would be deployed. In addition, six research reactors were foreseen, mostly utilizing highly enriched uranium (HEU).

At present, Netherlands operates a single, medium-sized NPP, i.e. the 483 MWe Borssele PWR, and two research reactors utilizing low enriched uranium (LEU): the High Flux Reactor (HFR) in Petten, and a small reactor in Delft intended for educational purposes. It is anticipated that the HFR in Petten will be replaced by another LEU-utilizing reactor in the next decade, the PALLAS reactor. Currently, no additional NPPs are foreseen. Another important nuclear facility in the Netherlands is the uranium enrichment facility in Almelo, generating large amounts of depleted uranium (DU), which is presently, unlike in the past, also considered for final disposal.

The characteristics of the radioactive waste generated by the present nuclear facilities differ significantly from those foreseen in the 1970’s and 1980’s. Consequently, results of extensive safety and performance assessments executed in the past are not representative for present day’s waste characteristics. The OSSC consortium therefore recommended to re-iterate previously executed safety assessment on the geological disposal in rock salt, based on updated waste characteristics.

Regarding the Dutch legal framework, OSSC concluded that the Dutch Nuclear Energy Act and the associated decrees are fully in compliance with the relevant Euratom Directive 96/29, laying down the basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation. However, it cannot be excluded that the future Dutch institutional framework may be subject to change and shifts of responsibilities. Consequently, the Dutch legal framework concerning radioactive waste and its disposal should be calibrated against new developments on a regular basis.

SAFETY STRATEGY

The *safety strategy* is a high-level approach for achieving safe disposal of radioactive waste, given a specific context as described in the previous section. Since the 1970’s and 1980’s the Dutch waste management strategy has altered. Important differences with the presently implemented strategy are:

- The adoption of long-term surface storage – whereas in the ICK and OPLA programmes the anticipated surface storage prior to geological disposal period was 10 to 50 years, nowadays this time period is at least 100 years [12; p.1];
- The requirement formulated in 1993 that radioactive waste emplaced in a disposal facility should be retrievable [13];
- The storage of spent research reactor fuel from Dutch research reactors. Prior to 2003 this SRRFF was returned to the US.

After the issuing of the 1993 retrievability requirement no further explicit legislation or (practical) guidelines for waste retrieval have been developed in the Netherlands. On the other hand, the general concept of retrievable disposal has been discussed internationally and worked out in recent years to greater detail by developing principles like ‘retrievability’, ‘reversibility’, geological disposal as a ‘staged process’ and the utilization of ‘pilot facilities’ [14].

At present the Dutch safety strategy for the disposal of radioactive waste is being elaborated [12], as part of the process of implementing Council Directive 2011/70/EURATOM of 19 July 2011. Additionally, the Netherlands is drafting the National Programme according to the definition provided by this Directive, and a Safety Strategy document establishing the Dutch strategy for the final disposal of radioactive waste.

An overview of the presently foreseen timeline of the Dutch Safety Case for geological disposal, and the anticipated roles of the various stakeholders in the decision making process to move forward from one phase to the next is shown in Fig. 3 [12; p.3].

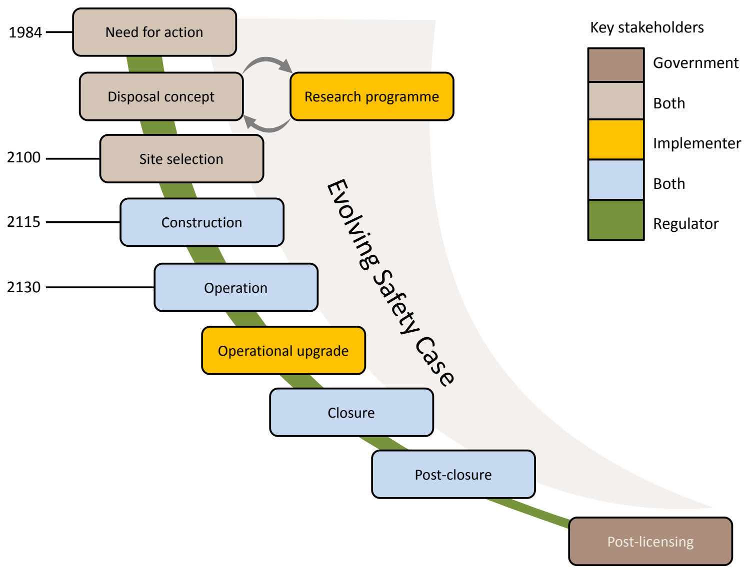
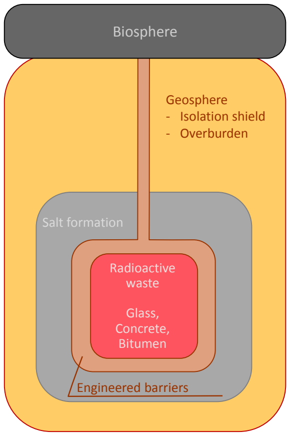


Fig. 3. Common elements in the decision-making processes on geological disposal including the timeline for the Netherlands.

At present, the Dutch safety concept for the geological disposal of radioactive waste in rock salt is less developed than the Boom Clay concept. The Boom Clay concept relies on the consideration of multiple barriers (see Fig. 4) and safety functions that can be attributed to the subsequent barriers [1; Section 4.1]. This safety concept would in principle also be applicable for the disposal in salt-based repositories. For salt-based repository concepts, developed in the past in the Netherlands, multiple barriers have been considered as well [3; p. 34]. However, the concept of safety functions for salt-based repositories in the Dutch context has not yet been established. The primary reason is that the consideration of safety functions emerged only after the previous Dutch national disposal programmes OPLA and CORA ended.



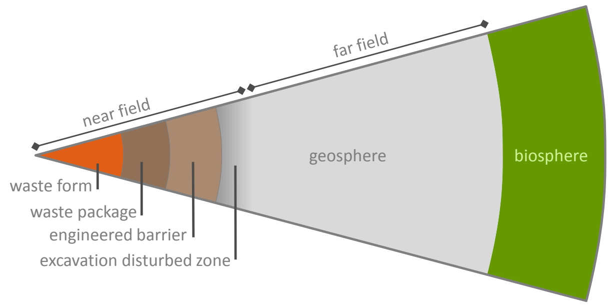


Fig. 4. Principle of a multi-barrier system in salt formations (OPLA, left), and in Boom Clay (OPERA, right).

Since 2001 no systematic activities have been performed on establishing a safety concept for the geological disposal in rock salt in the Netherlands. On the other hand, internationally there has been substantial progress in the development of safety concepts for geological disposal in general [6, 5], and in relation to the disposal in rock salt, notably in the US for bedded salt (e.g. [15]), and in Germany for domal salt [9].

The OSSC project concluded that the Dutch safety concept for the geological disposal in rock salt needs to be upgraded. Notably the detailing of safety-related features of the final disposal in rock salt such as the multi-barrier system, the designation and effectuation of the appropriate safety functions, and aspects related to the Dutch retrievability requirement, needs to be elaborated. These efforts should take into account recent international developments, especially in Germany and the US, and iterate with the most recently adopted Dutch strategy for the final disposal of radioactive waste.

SYSTEM DESCRIPTION

The Safety Case Component *System Description* presents the characteristics of the waste to be disposed of, the design of the facility in which the waste is disposed of, the salt formation wherein the facility is constructed, the surrounding and overlying sediments on the salt formations and the biosphere.

Waste Characteristics

The Dutch practice on the management of spent fuels from nuclear power plants is that the spent fuel is being reprocessed, and the remaining vitrified high-level wastes (HLW) and compacted hulls and ends are returned to the Netherlands. Spent fuel from the research reactors will be directly disposed of without reprocessing. Unlike in many other countries, where near-surface disposal for low and intermediate level waste (LILW) is a common practice, in the Netherlands this type of waste, including (Technically Enhanced) Naturally Occurring Radioactive Materials, (TE)NORM waste, is intended for deep geological disposal. An outline of the presently foreseen waste inventory intended for disposal around the year 2130 is given in [16].

Compared to the radionuclide inventories considered in the previous studies performed in VEOS, PROSA, CORA, and PAMINA, the following considerations apply:

- In the VEOS and PROSA studies consideration was given to future nuclear deployment scenarios including radioactive waste from NPPs that actually were never built; as a consequence, the assumed radionuclide inventories from waste produced by NPPs were considerably larger in the past compared to the presently foreseen inventory;
- Unlike in the past, the spent fuel from research reactors, including the future replacement of the HFR (PALLAS), is part of the present radioactive waste inventory;
- Unlike in the past, DU currently adds to the radioactive waste inventory intended for disposal. Although DU represents, in radiological terms, a relatively small fraction of the total inventory it comprises a significant volume (anticipated volume in 2130: approx. 35’000 m^3).

Since the waste characteristics provide the radionuclide source term for the safety assessment, the results of previously executed safety assessments performed in the Netherlands are not 1:1 representative for a future Dutch geological disposal facility in rock salt for hosting the presently foreseen types and amounts of radioactive waste.

Facility Designs

The conceptual facility designs for disposal in rock salt considered in the Netherlands so far are of a generic nature in three generic salt formations: a deep salt dome, a shallow salt dome and bedded salt. The disposal techniques in rock salt to accommodate the various considered types of waste studied in the OPLA research programme were [3; p. 27]:

- A conventional mine, consisting of boreholes for all heat-generating waste (vitrified HLW), and chambers or caverns for the remaining low and intermediate and level waste (LILW).
- Deep boreholes and caverns. The deep boreholes would be mined from the surface and meant for the heat generating high level waste. The caverns, leached from the surface, were meant for disposing all remaining waste. This disposal technique can be applied in all type of formations.

In order to accommodate the retrievability requirement formulated in 1993, a disposal concept has been developed as part of the CORA programme: the METRO-I design (see Fig. 5; [17]; p.13). That design comprises short horizontal boreholes for the disposal of vitrified HLW containers that would facilitate any retrieval. Another design measure to facilitate the retrieval of already emplaced waste canisters concerned a steel liner, which additionally would enhance the stability of the vitrified HLW disposal cells..

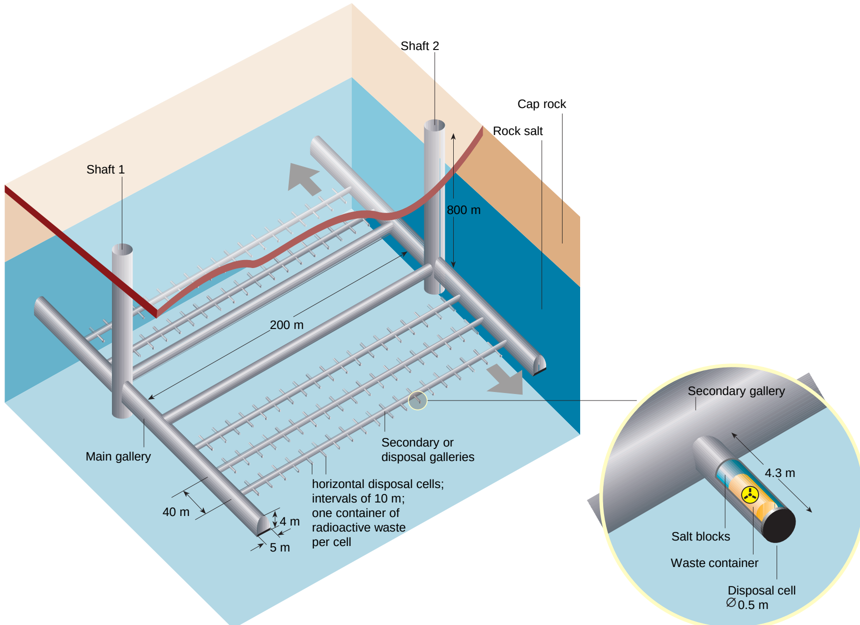


Fig. 5. Layout of the METRO-I disposal concept.

The METRO-I design did not include all Dutch waste fractions presently considered for disposal, hence there is a need to update the conceptual design that would accommodate the foreseen types and amounts of waste.

Salt Host Rock

Suitable host rocks for disposal in salt rock in the Netherlands include salt domes of the Zechstein Group in the Netherlands and consist of various rock types, including clay, carbonate, anhydrite and rock salt. At present, knowledge on salt domes is steadily increasing due to their use for salt extraction and possible gas storage.

As part of the OSSC project the depth maps of the top and base of the Zechstein Group have been constructed based on existing, but recently re-interpreted seismic data (2D and 3D) and borehole data. An example of the newly developed maps is depicted in Fig. 6, showing the lithostratigraphy of the Zechstein Group in the Netherlands [18].

Some topics have been identified which need additional efforts for reducing remaining uncertainties, such as e.g. acquiring detailed 3D seismic maps of the shape and internal structure of salt domes, improving knowledge on connectivity between aquifers and salt domes, and determining the structural position (bedded salt, domal salt) and shape of the salt structure (elongated, circular, overhangs etc.).

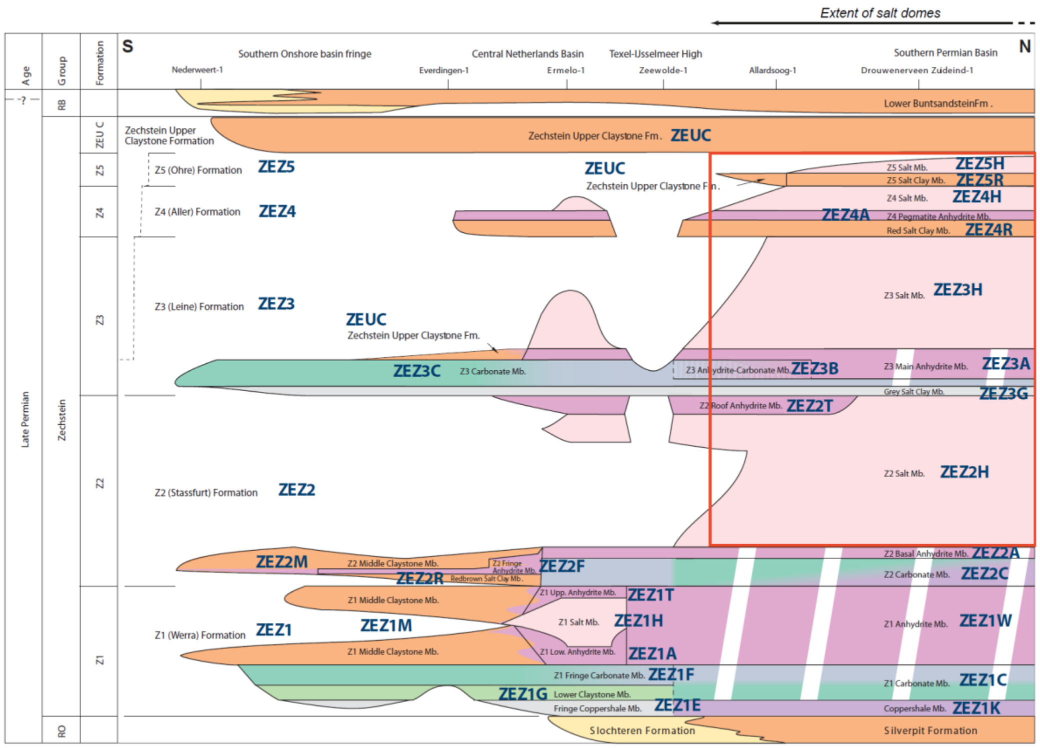


Fig. 6. Lithostratigraphy of the Zechstein Group in the Netherlands

Safety-relevant thermal, hydraulic, mechanical, and chemical processes

There is an abundance of data available about thermal, hydraulic, mechanical and chemical (THMC) properties of rock salt, much of which has been derived from exploration of the Gorleben and Asse sites in Germany, the Waste Isolation Pilot Plant (WIPP) in the US, and a variety of European Framework projects (e.g. BAMBUS I/II, THERESA). Extensive summaries of earlier studies, performed in the Netherlands during the last decades of the 20th century are available for further consultation.
The understanding of safety relevant processes is an essential prerequisite in the assessment of the post-closure safety of a geological disposal facility, and forms the scientific basis of a Safety Case on rock salt. On the basis of the information collected in the OSSC project, THMC-related aspects have been identified internationally as relevant to investigate further with respect to enhancing the understanding of salt THMC topics [19]. For illustration, Fig. 7 shows an example of the identified complex couplings between safety relevant THMC aspects relevant for the safety of salt-based repositories [20; Figure 1.3].

In order to identify potentially relevant aspects for enhancing the Dutch Safety Case, the OSSC partners utilized screening arguments for distinction between crucial aspects and features for reducing remaining uncertainties: (1) the extended surface storage period in the Netherlands, (2) the resulting limited heat output from disposed heat-generating waste, (3) the mild temperature effects on the surrounding host rock, (4) the delayed decision for siting a repository, and (5) expert judgement by authors familiar with the Dutch Safety Case. The identified issues have been categorized as follows and discussed in further detail in [19; Section 4.9.4]:

- Influence of Disturbed Rock Zone (DRZ)
- Compaction behaviour of crushed (granular) salt
- (T)HMC effects related to the dissolution of rock salt
- Corrosion of waste container and waste matrix
- Corrosion of cementitious barriers
- Solubility and transport of radionuclides

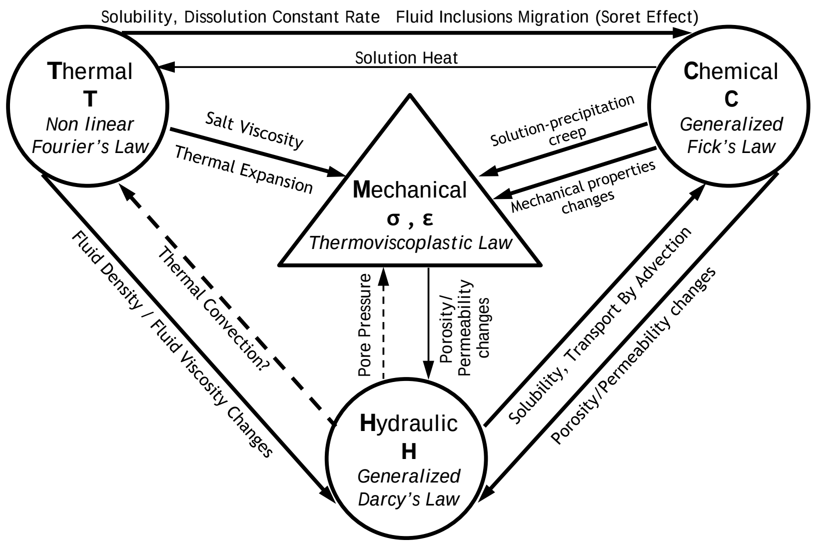


Fig. 7. Couplings between thermal, hydraulic, mechanical, and chemical processes [6].

Overlying Sediments and Biosphere

Considering the sediments overlying the salt formations and the biosphere, the OSSC project proposed the following topics to take forward in the next iteration of the Dutch Safety Case:

- The approach followed in the studies performed so far applied a generic model for the enclosing sediments and the biosphere. As the Dutch Safety Case for geological disposal progresses, the need will arise to adapt the modelling features to a specific site;
- Although a state-of-the-art representation of the geosphere is currently being developed as part of the ongoing OPERA programme, that model is related to the disposal in Boom Clay. Due to the greater depth of a disposal facility in rock salt, possible subrosion effects, and density effects of brine, a more detailed geosphere transport modelling approach need to be developed.

SAFETY ASSESSMENT

Safety assessment encompasses evaluating the performance of a disposal system and quantifying its potential radiological impact on human health and the environment [6; p.5]. Safety assessment is a major component of the Safety Case

[6] Dashed connections in this figure indicate processes that may not exist in undisturbed salt; fatter solid arrows indicate stronger relationships between processes.

for a disposal facility and should demonstrate whether the disposal facility complies with applicable regulatory requirements.

In the past, extensive safety assessments were performed in the Netherlands, encompassing a large variety of disposal concepts, waste characteristics, scenarios, and methodological aspects.

In the VEOS project [21, in Dutch] deterministic safety assessments were conducted on 21 different disposal concepts varying in: the nature of the salt layers (deep salt dome, shallow salt dome, bedded salt, the applied disposal technique (mine, borehole), the waste characteristics, and potential future evolutions (normal, altered, human intrusion scenarios). An example of the numerical results of the VEOS calculations is summarised in Fig. 8 [22; p.5], depicting the exposure calculated for different adopted scenarios.

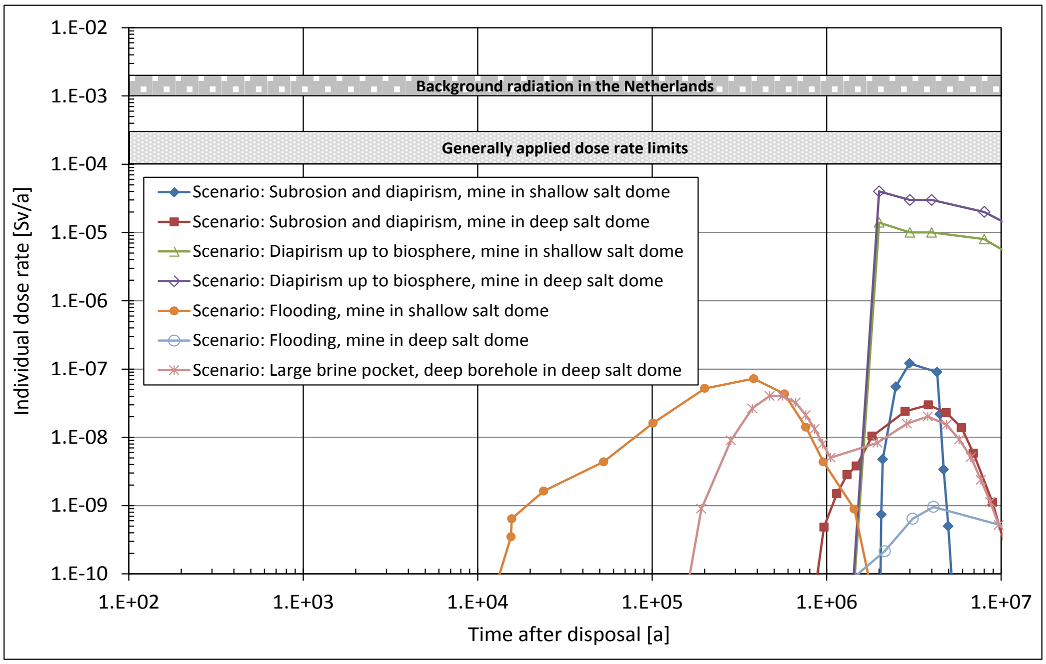


Fig. 8. Overview of VEOS results for leading scenarios.

From the results of the VEOS safety assessment calculations of disposed vitrified waste (HLW) it appeared that for almost all waste strategies and considered scenarios the dose rates are significantly below the natural background radiation in the Netherlands of maximally 3 10^{-3} Sv/a [3, p.92]. Only for the human intrusion scenario *Reconnaissance Drilling* a higher exposure was calculated, but judged extremely unlikely due to the very small probability of exposure and the conservative assumptions made for that scenario.

The follow-up PROSA probabilistic safety assessment comprised the elaboration of a systematic methodology for the development of scenarios for salt-based repositories, based on extensive evaluations of salt FEPs [7; Ch.3]. Additionally, probabilistic methods were developed and applied for the consequence analysis of several disposal concepts.

The results of PROSA confirmed the main conclusion of VEOS. The scenarios induced by natural FEPs resulted in a very low radiation exposure of future generations, whereas higher exposures can result from human intrusion scenarios. Due to the improved modelling of convergence and compaction of salt in PROSA the calculated exposure in the groundwater intrusion scenarios was reduced compared to the VEOS analysis to a negligible level.

A major conclusion of PROSA was that a probabilistic safety analysis can also help to identify parts of the disposal system that dominate the uncertainty, i.e. the less robust parts of the system. In the case of salt-based repositories it was found that in the investigated scenarios and with the assumed parameter bandwidths the internal rise rate of the salt dome was the parameter with the highest influence on the maximum dose rate.

The PROSA safety assessment was the last major, integrated safety assessment performed in the Netherlands on the geological disposal of radioactive waste in salt-based repositories. Subsequent projects conducted several performance assessments looking at specific aspects of the long-term safety, e.g.:

- CORA [4], where the focus was on the analysis of the neglect/abandonment scenario, assuming early flooding of an unsealed disposal facility in rock salt containing only vitrified waste;
- BAMBUS-II, a project funded by the European Community under the 'Nuclear Energy' Euratom Framework Programme (1998-2002), where the focus was on the behaviour of backfill in salt-based repositories [23];
- PAMINA, a project partially funded by the European Community (6th Framework Programme), where NRG and JRC Petten performed sensitivity and uncertainty analyses of the behaviour of compacted salt borehole plugs under both naturally dry and wet (flooding) conditions [24].

In addition to the safety assessments performed in the Netherlands, the OSSC Consortium also evaluated safety assessments performed in Germany and the US on salt-based repositories, and took notice of recent developments within the IAEA and NEA, mostly on methodological topics.

The results of the various safety assessments consequently and consistently demonstrate the good isolating and confining properties of rock salt as a host rock for the final, deep geological disposal of radioactive waste, for a large variety of normal evolution and alternative evolution scenarios. However, for human intrusions in a disposal facility substantial exposures have been calculated in some cases. These cases may be re-evaluated to see whether the sometimes conservative modelling assumptions are still valid, or whether the repository design may be adapted to reduce the risk of human intrusion.

An important observation was that, within the present Dutch context, the safety and performance assessments executed in the Netherlands need to be updated with respect to e.g. more recent inventories, biosphere models, and solubility data available. In a next iteration of safety assessment calculations should also consider an updated disposal concept, including updated FEPs and the further development of scenarios.

INTEGRATION OF SAFETY ARGUMENTS

The Safety Case Component *Integration of Safety Arguments* comprises a synthesis of the available evidence, arguments and analyses supporting the safety of a deep geological disposal facility in rock salt in the Netherlands. As no new safety assessment calculations have been performed in the OPERA OSSC project the safety arguments as obtained for OPLA and CORA have been reviewed and compared with current insights in process understanding of relevant safety features of the disposal design.

All the national and international efforts, together addressing safety-related aspects of salt-based geological disposal, resulted in sufficient confidence to construct and operate a dedicated repository for the disposal of radioactive waste, e.g. in the US (the WIPP). In Germany, there is also significant practical Safety-Case-experience with the ERAM and Asse facilities. Additionally, the Dutch and international efforts demonstrate that the option of geological disposal in rock salt can be pursued for isolating radioactive waste from the biosphere.

On the other hand, in the Netherlands there has been limited activity with regard to the development of a disposal facility in rock salt since the CORA programme, which ended in 2001. Moreover, at present there is no well-established Dutch concept in rock salt available for which a dedicated safety assessment, including all aspects and features (e.g. most recently identified waste characteristics, safety functions, complementary safety and performance indicators including reference values, many details of safety assessment parameterization, full probabilistic analysis, …) can be performed.

Considering the above, the integration of safety arguments within the Dutch context is necessarily partly based on generic considerations, and the Dutch Safety Case for the geological disposal of radioactive waste in a salt-based repository is still incomplete.

ITERATION OF THE DUTCH SALT SAFETY CASE

Although it was beyond the scope of the OSSC project to actually develop and build a Safety Case for rock salt or perform updated safety assessment calculations, the OSSC consortium judged that many elements necessary to do so are available, either from previous national and international research, or from the ongoing OPERA research programme for Boom Clay. Remaining uncertainties or gaps in knowledge could be narrowed down, and detailed guidance to develop the Dutch salt Safety Case was provided in two reports [19, 25]. An up-to-date Salt Safety Case, comparable to the Dutch OPERA Safety Case on Boom Clay currently under development, could be developed with reasonable effort over a period of 3 to 5 years. For achieving this, the OSSC Consortium recommended a stepwise approach:

Phase 1: Base model compilation and first safety assessment – this phase would include an update of previously executed safety assessments, utilizing the existing tools in the Netherlands.

Phase 2: Completion of process representation and refinement of the disposal concept – this phase would incorporate (updates of) process models which have been identified relevant for the long-term safety into the safety assessment tool.

Phase 3: Delivery of a rock salt reference model and the development of the initial Safety Case - the objective of the third phase is to develop further understanding of less well understood and possibly safety relevant processes - if necessary - and to deliver a fully integrated, up-to-date safety assessment model, on the basis of presently best available knowledge. After the execution of safety assessment calculations an initial Safety Case should be prepared.

CONCLUSIONS

The OSSC project has provided an evaluation of current knowledge for building the Safety Case for salt based repositories in the Dutch context. The evaluation has been based on the present knowledge about the safety and feasibility of a final disposal facility in rock salt in the Netherlands, and existing documents available from the US and German waste disposal programmes.

Based on previous efforts carried out in the Netherlands and abroad, the OSSC Consortium concluded that safety assessments performed in the past can be updated with reasonable efforts and integrated into the framework of a Safety Case.

The main recommendation to continue with the development of the Salt Safety Case in the Netherlands is to follow a three-step approach, making maximum use of existing knowledge, the outcomes of the OPERA programme, and international developments. That would lead to an increased understanding of safety-related aspects and an enhanced foundation of a Dutch salt Safety Case.

An important message from the work carried out in the OSSC project is that programmes for the geological disposal of radioactive waste, comprising many decades of activities, are subject to programmatic risks when the programme is maintained below a certain minimum level for a prolonged number of years. Important programmatic risks concern change of a nation’s context and/or regulations, the missing of relevant international developments, and loss of knowledge. In order to maintain a disposal programme’s Safety Case, activities should be executed on a continuous basis by performing national dedicated projects and/or by international cooperation.

ACKNOWLEDGMENTS

The research leading to these results has received funding from the Dutch research programme on geological disposal OPERA. OPERA is financed by the Dutch Ministry of Economic Affairs and the public limited liability company Elektriciteits-Produktiemaatschappij Zuid-Nederland (EPZ) and coordinated by COVRA.

REFERENCES

1 Verhoef E, Schröder TJ, OPERA Research Plan, OPERA-PG-COV004, COVRA N.V., 21 June 2011.
2 Hamstra J. et al., The Dutch geological waste disposal project, EUR 7151 EN, 1981.
3 Commissie Opberging te Land (OPLA): “Onderzoek naar geologische opberging van radioactief afval in Nederland. Eindrapportage Fase 1”, Ministerie van Economische Zaken, Den Haag, May 1989.
4 Commissie Opberging Radioactief Afval, “Terugneembare berging, een begaanbaar pad? Onderzoek naar de mogelijkheden van terugneembare berging van radioactief afval in Nederland” Ministry of Economic Affairs, The Hague, February 2001.
5 OECD-NEA, The Nature and Purpose of the Post-closure Safety Cases for Geological Repositories, NEA/RWM/R(2013)1, NEA No. 78121, OECD, Paris, 2013.
6 IAEA, The Safety Case and Safety Assessment for the Disposal of Radioactive Waste, Specific Safety Guide No. SSG-23, STI/PUB/1553, Vienna, September 2012.
7 Prij J, et al., PRObabilistic Safety Assessment, Final report, of ECN, RIVM and RGD in Phase 1A of the OPLA Programme, 1993.
8 DBE-TEC, Review and Appraisal of the Tools available for a Safety Assessment of Final Repositories for HLW ISIBEL (Status of the Total Performance Assessment for a Repository for HLW in Rock Salt), Joint report by DBE TECHNOLOGY GmbH, BGR, and GRS, Peine, April 2008.
9 Bollingerfehr W, et al., Status of the safety concept and safety demonstration for an HLW repository in salt - Summary report, TEC-15-2013-AB, Peine, December 2013.
10 US DOE, United States Department of Energy, Title 40 CFR 191 Subparts B & C Compliance Certification Application, 1996; Title 40 CFR 191 Subparts B & C Compliance Recertification Application. DOE/WIPP 2004-3231, March 2004; Title 40 CFR Part 191 Subparts B and C, Compliance Recertification Application 2014 for the Waste Isolation Pilot Plant, Appendix PA-2014, Performance Assessment, 2014; (and other relevant publications).
11 Hansen FD, Leigh CD,Salt Disposal of Heat-Generating Nuclear Waste, Sandia Report, SAND2011-0161, January 2011.
12 Verhoef E, Neeft E, Towards a safety strategy - Developing a long-term Dutch research programme into geological disposal of radioactive waste, OPERA-PG-COV014, 26 March 2014.
13 VROM, Ministry of Housing, Spatial Planning and the Environment, Opbergen van afval in de diepe ondergrond, Kamerstukken II, 1992-1993, 23163, nr. 1, 1-9.
14 OECD/NEA, Reversibility and Retrievability (R&R) for the Deep Disposal of High-Level Radioactive Waste and Spent Fuel - Final Report of the, NEA R&R Project (2007-2011), NEA/RWM/R(2011)4, 8 December 2011.
15 MacKinnon RJ, Salt Disposal Research, Development, and Demonstration (RD&D), 5th US/German Workshop on Salt Repository Research, Design and Operation Santa Fe, New Mexico, US, September 7-11, 2014.
16 Verhoef E, E. Neeft, J. Grupa, and A. Poley. OPERA. Outline of a disposal concept in clay. OPERA report OPERA-PG-COV008, COVRA N.V., July 2011, 1-17.
17 Van de Vate L, Retrievable disposal of radioactive waste in the Netherlands, TNO-NITG – Information, December 2001.
18 Van Adrichem Boogaert HA, Kouwe WFP, Zechstein Group. In: Stratigraphic Nomenclature of the Netherlands. (1993-1997), Retrieved 01-11-2013 from www.dinoloket.nl/Zechstein-group-ze.
19 Hart J, Prij J, Vis G-J, Becker D-A, Wolf J, Noseck U, Buhmann D, Evaluation of current knowledge for building the Safety Case for salt based repositories, OPERA-PU-NRG221A, 15 July 2015.

20 Kuhlman KL: Summary Results for Brine Migration Modeling Performed by LANL, LBNL, and SNL for the UFD Program. Sandia National Laboratories, SAND2014-18217 R, September 2014.
21 Prij J, Veiligheidsevaluatie van opbergconcepten in steenzout (VEOS), Eindrapportage Deelrapport 1, Samenvatting en evaluatie, ECN, Petten, January 1989.
22 Köster HW, de Jong EJ, Lembrachts JF, de Vries WJ, Dosisberekeningen – Eindrapportage, Deelrapport 10, Petten, April 1989.
23 Grupa JB, Hart J, BAMBUS-II - WP 7.3. The Safety Implications of Retrievability, NRG 20553/02.48069/P, Petten, February 2003.
24 Schröder TJ, Hart J, Costescu-Badea A, Bolado Lavin R, PAMINA Task 2.1.D, Techniques for Sensitivity and Uncertainty Analysis - Analysis of a repository design in a rock salt formation, PAMINA Milestone Report M2.1D.7, NRG-21952/09.95945, December 2009.
25 Hart J, Prij J, Schröder TJ, Vis G-J, Becker DA, Wolf J, Noseck U, Buhmann D, Evaluation of current knowledge for building the Safety Case for salt based repositories, OPERA-PU-NRG221B, 3 Augustus 2015.