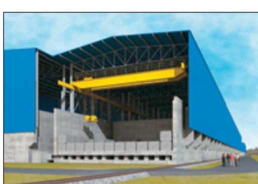
Radioactive Waste Management
2012

The Long-term Radiological Safety of a Surface Disposal Facility for Low-level Waste in Belgium

An International Peer Review of Key Aspects of ONDRAF/NIRAS' Safety Report of November 2011 in Preparation for the License Application



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NEA No. 7086

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The mission of the NEA is:

- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as
- to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information.

The NEA Data Bank provides nuclear data and computer program services for participating countries. In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

Cover photos: Surface disposal model and aerial view of the proposed disposal facility, Belgium (ONDRAF/NIRAS).

Foreword

An important activity of the OECD Nuclear Energy Agency (NEA) in the field of radioactive waste management is the organisation of independent, international peer reviews of national studies and projects. The NEA-organised peer reviews help national programmes to assess the work accomplished. Other institutions, organisations, companies, and generally interested parties involved in waste management also benefit from the NEA peer review reports.

In 2011, the Belgian Federal Public Service of Economy and Energy, following approval by the Energy Minister, requested the NEA to organise a peer review of key aspects of the safety case being developed by the Belgian Agency for Radioactive Waste and Enriched Fissile Materials, ONDRAF/NIRAS, for the license application to construct and operate a surface disposal facility for low- and intermediate-level radioactive waste in the municipality of Dessel in Belgium.

Terms of Reference (ToR) for the review were developed and agreed. The objective of the peer review was to provide a statement, from an international perspective, on the credibility and robustness of ONDRAF/NIRAS' long-term safety strategy and assessment as part of the safety case to be submitted to the Belgian Federal Agency for Nuclear Control.

To carry out an independent review, the NEA Secretariat assembled an International Review Team (IRT) comprising seven international specialists, including two from the NEA, all of whom were free of conflict of interest. During the review, all communications between ONDRAF/NIRAS and the IRT were managed through the NEA.

This report presents the consensus view of the IRT based on the experts' review of key long-term safety aspects of the ONDRAF/NIRAS Safety Report of November 2011.

In accordance with NEA procedures for independent reviews, neither the Belgian Federal Public Service of Economy and Energy nor ONDRAF/NIRAS has commented on this report. Both parties have, however, had an opportunity to check it for factual correctness.

Acknowledgements

The IRT would like to thank the Belgian Federal Public Service of Economy and Energy for its assistance in facilitating the review. The IRT would also like to thank ONDRAF/NIRAS and its staff for their help and openness in responding to the review. Finally, the NEA gratefully acknowledges the organisations that provided the experts to the IRT.

High-level findings

Background

In 2011, the Belgian Federal Public Service of Economy and Energy, after approval by the Energy Minister, requested the OECD Nuclear Energy Agency (NEA) to organise a peer review of key aspects of the safety case being developed by the Belgian Agency for Radioactive Waste and Enriched Fissile Materials, ONDRAF/NIRAS, for preparing the license application for the construction and operation of a surface disposal facility for short-lived low- and intermediate-level radioactive waste (category A waste) in the municipality of Dessel (the cAt Project).

This review was carried out by an International Review Team (IRT) comprising seven international specialists, including two from the NEA, all of whom were free of conflict of interest and chosen to bring complementary expertise to the review as specified in the Terms of Reference (ToR).

The main objective of the peer review was to provide a statement, from an international perspective, on the credibility and robustness of key aspects of the ONDRAF/NIRAS' safety case. Namely, on the long-term safety strategy and the long-term safety assessment parts of the safety case that ONDRAF/NIRAS plans to submit to the Belgian Federal Agency for Nuclear Control. Additional important roles for the peer review were:

- To provide ONDRAF/NIRAS with information to help it ensure that its future licence application file will be in line with international best practice.
- To provide all observers of the review process with an overview of ONDRAF/NIRAS' work in preparation of the licence application.

The IRT reviewed all the documents identified in the ToR as well as other relevant documentation provided by ONDRAF/NIRAS during the review process. In addition it had oral and written exchanges with ONDRAF/NIRAS.

This document presents the consensus view of IRT based on the experts' review of the key aspects of the ONDRAF/NIRAS safety case of November 2011 (version for the peer review) relating to long-term safety. The NEA has made its best effort to ensure that all information is accurate and takes responsibility for any factual errors. The IRT wishes to confirm that enough information was made available to enable it to fulfil the ToR.

Key findings

The purpose of the review is to assist the Belgian Federal Public Service of Economy and Energy, the public and relevant organisations by providing an international view on the maturity of ONDRAF/NIRAS low- and intermediate-level waste disposal programme *vis-à-vis* international recommendation and best practices, and the state of the art of other national programmes. According to the ToR the peer review should provide the Belgian Federal Public Service of Economy and Energy with a statement, from an international perspective, on the credibility and robustness of key aspects of ONDRAF/NIRAS' safety case of November 2011 in preparation for the application for construction and operation of a surface disposal facility for short-lived low and intermediate-level radioactive waste facility in the municipality of Dessel.

In performing the review and developing its final statement, the IRT was asked to consider international best practice in the following areas:

- The long-term safety strategy as defined and applied.
- The proposed disposal system design.
- The quality of the scientific and technical bases for the safety assessment, especially in the area of concrete phenomenology.
- The long-term safety assessment methodology and results.

Statement to the Belgian Federal Public Service of Economy and Energy

From an international perspective, ONDRAF/NIRAS' long-term safety strategy and safety assessment methodology are, in the main, credible and robust. The disposal programme implements international recommendations and best practice, takes into account the conditions stipulated by the Federal Government and the local communities, and is technically mature.

The IRT also notes that there has been a good, structured dialogue between ONDRAF/NIRAS and the safety authority (FANC) during the pre-licensing phase

The IRT considers that the safety case documentation is well structured with different levels of reports aimed at different audiences, both technical and non-technical. In the areas of the safety report that the IRT has reviewed, the documentation is generally clear and traceable.

The IRT is pleased to learn that the safety case would be updated and reviewed by the regulator prior to commencing disposal operations.

The safety of the proposed surface disposal facility concept relies importantly on the engineered barrier system, as do similar modern facilities for short-lived radioactive wastes in other countries.

With respect to the scientific basis for the safety assessment described in the Safety Case, version for the peer review, the IRT considers that the research, development and demonstration (RD&D) work performed so far has identified and investigated the relevant processes. ONDRAF/NIRAS has a reasoned plan for future RD&D to address remaining uncertainties and a demonstration test programme is already under way.

The IRT notes that an Integrated Management System is being developed including organisational aspects, safety culture, and quality assurance principles to be applied to all aspects of disposal facility implementation.

The IRT considers, however, that the breadth of ONDRAF/NIRAS' work relevant to the safety case is not fully represented in the relevant chapters of the Safety Report of November 2011. This became even more evident during the process of the review, e.g. during the written and oral exchanges with ONDRAF/NIRAS' staff.

Overall, ONDRAF/NIRAS has a team of competent and well-motivated staff with good evidence of safety culture and capable of taking the cAt Project forward.

The above statement is supported by the following high-level review findings regarding the specific focus questions identified in the ToR for the peer review. More detailed review findings, suitable for more specialist audiences, are provided in Chapters 2 and 3 of the present report, respectively.

The long-term safety strategy as defined and applied

The long-term safety strategy developed and implemented by ONDRAF/NIRAS is well founded: it considers defence in depth, optimisation and passive safety principles, and takes into account international guidelines, recommendations and best practice.

The safety arguments are developed, structured and analysed systematically using a set of safety functions based on isolation, containment and retardation, linked to the main system components and to define time periods.

The staged approach for disposal facility construction, operation, closure and, later, institutional control is based on a staged licensing process. It implies continuous feedback from monitoring and RD&D results, which is in line with international best practice, guidelines and recommendations.

The IRT notes that the on-going and forward RD&D programmes should further contribute to improving knowledge, understanding system performance, reducing uncertainty, increasing confidence in safety margins, and optimising the system.

Specific observations and suggestions are provided in the body of this review.

The proposed disposal system design

The proposed system design is in accordance with the long-term safety strategy, the waste inventory and the characteristics of the local environment.

The safety of the proposed design relies importantly on the engineered barrier system, as do similar modern facilities for short-lived radioactive wastes. In this case, given the characteristics of the Dessel site, the engineered barrier system is even more substantial.

The technical design of the disposal facility is detailed enough to allow long-term safety assessment. The proposed barrier system is composed of materials for which there is a good knowledge of their properties.

Demonstration tests and trials have led to improvements in the construction techniques and have provided valuable information that may be used to further improve the system design and further enhance the various construction techniques, construction sequences and inspection equipment. Construction of the caisson, monolith and module has been shown to be feasible.

The IRT has made specific suggestions on possible design improvements.

The quality of the scientific and technical bases

Concrete plays a prominent role in the proposed disposal system performance. ONDRAF/NIRAS' description of the phenomenological issues of concrete performance offers suitable and relevant support for the long-term safety assessment. A novel approach is presented for evaluating the durability of the concrete structures based on the use of durability indicators.

The scientific knowledge presented on concrete is state of the art and is correctly presented. The scientific basis of other components, such as the earth cover, is also state of the art. Technical limitations (e.g. the development of concrete permeability, cracking issues) are being evaluated in the current RD&D plan and a forward RD&D programme will be conducted.

Specific observations and suggestions are provided in the body of this review.

Long-term safety assessment methodology and results

ONDRAF/NIRAS' methodology for long-term safety assessment is sound: it closely follows the IAEA supported approach and will be implemented iteratively as the project progresses.

ONDRAF/NIRAS has considered a large number of scenarios and assessment cases including human intrusion, normal and altered evolution. The set of scenarios is, in principle, adequate, but it is complex to fully comprehend the relationships between the scenario types.

The IRT could not review all of the details of the safety assessment results as many were presented only during the course of the review. The IRT observes that the results of the safety assessment suggest that the calculated safety of the disposal system is not very sensitive to variations in the values of numerous parameters. The IRT also observes that the reported, calculated radiological impacts are within the ICRP allowed ranges for the various different scenarios, including the "penalising scenario". The IRT, however, has questioned some assumptions made by ONDRAF/NIRAS and has suggested additional calculations, which may or may not confirm the results of the current assessment.

Detailed observations and suggestions are provided in the body of this review, in particular, on the need to present the results from the many assessment cases in an integrated and transparent manner.

Table of contents

List of acronyms

AES	Alternative Evolution Scenario
ARS	Alternative Reference Scenario
BAT	Best Available Technology
BDBE	Beyond Design-Basis Earthquake
CSH	Calcium-Silica-Hydrate
DBE	Design-Basis Earthquake
DiD	Defence-in-Depth
EBS	Engineered Barrier System
EES	Expected Evolution Scenario
EIA	Environmental Impact Analysis
FANC	Belgian Federal Agency for Nuclear Control
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IMS	Integrated Management System
IRT	International Review Team
K_d	Distribution Coefficient
LES	Likely Evolution Scenario
MONA	Dutch acronym for "Mol consultation on nuclear waste", a partnership between the municipality of Mol and ONDRAF/NIRAS
NEA	Nuclear Energy Agency
ONDRAF/ NIRAS	Belgian Agency for Radioactive Waste and Enriched Fissile Materials
PS	Penalising Scenario
PVC	Polyvinyl Chloride
QA	Quality Assurance
QC	Quality Control

RD&D	Research, Development and Demonstration
RS	Reference Scenario
SSCs	Systems, Structures and Components
STORA	Dutch acronym for "Study and consultation on radioactive waste in Dessel"; a partnership between the municipality of Dessel and ONDRAF/NIRAS. Before 2005, it was known as STOLA.
TAW	Tweede Algemene Waterpassing
ToR	Terms of Reference

1. Introduction

1.1 Background to the Belgian category A waste disposal programme

ONDRAF/NIRAS, the Belgian Agency for Radioactive Waste and Enriched Fissile Materials, is a public entity created by a Belgian Law of 8 August 1980. ONDRAF/NIRAS is responsible for the safe management of all radioactive waste in Belgium. Part of the inventory of radioactive wastes in Belgium is classed as "category A waste". These wastes have low- or intermediate-levels of radioactivity and contain mostly short-lived radionuclides.

The development of a long-term management solution for category A waste in Belgium started in mid-1980s. Initial RD&D activities focused on scientific and technical aspects. Societal aspects were taken into account at a later stage as the scientific and technical studies continued to progress. In 1998, the Belgian Council of Ministers endorsed the development of integrated disposal projects within a framework of societal participation between interested municipalities and ONDRAF/NIRAS.

Interests expressed by the municipalities of Mol, Dessel, Fleurus and Farciennes led to the creation of 3 partnerships: STOLA in Dessel, MONA in Mol, and PaLoFF in the municipalities of Fleurus and Farciennes.

In 2006, the Council of Ministers decided to select the STOLA-Dessel surface disposal proposal and authorised ONDRAF/NIRAS to further develop the integrated disposal project.

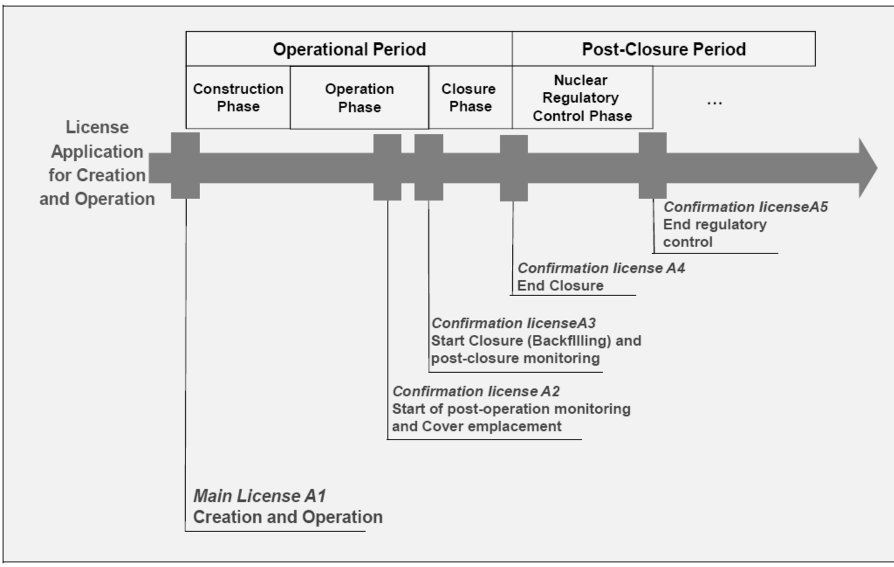
The Council of Ministers subsequently commissioned the Federal Agency for Nuclear Control (FANC) as the Belgian safety authority with the task of developing a licensing procedure for radioactive waste disposal facilities and conducting formal, evidence-based reviews of ONDRAF/NIRAS' activities in preparing the license application Safety Report.

1.2 Licensing process

The FANC, the Belgian Federal Agency for Nuclear Control, or nuclear safety authority, has developed a specific licensing procedure for radioactive waste disposal facilities (FANC 2007), which is currently being transposed into an official regulation for issue as a Royal Decree.

The Belgian stepwise licensing process is illustrated in Figure 1.1. A "*creation and operation*" license, or main license (A1), is necessary for the construction and operation of the disposal facility. The A1 licence authorises the start of construction and stipulates the operational conditions. An A2 confirmation license is required for the construction of a multilayer cover. Following the construction of the multilayer cover, an A3 confirmation license is required for authorising backfilling of the drainage systems, inspection rooms and galleries, and setting the facility into its final closure configuration. An A4 confirmation license is then required for commencement of the nuclear regulatory control phase. In the final stage, an A5 license is envisaged for consenting to the ending of nuclear regulatory control.

Figure 1.1: Different licenses, periods and phases in the lifetime of a disposal facility as based on FANC (2007)



The current draft of the Royal Decree indicates that the FANC approval of the start of operations would take the form of a confirmation license (FANC 2010b; Minon 2012b). The exact and final definitions of the confirmation licences required and the steps for their approval may change in the future (ONDRAF/NIRAS 2011a, 2012a), depending on the precise details of the Royal Decree.

Amongst other requirements, the licensing regulation demands a Safety Report that addresses the radiological safety of the facility. The Safety Report is an essential part of the documentation of the license application.

The licensing process also requires an Environmental Impact Analysis (EIA) a result of various legal instruments, including European Directives, Article 37 of the Euratom Treaty, and Belgian Federal and Regional Legislation (ONDRAF/NIRAS 2010a; 2011a, 2012a; Berckmans 2012). The EIA must be conducted before applying for a building and environmental permit from the Flemish regional authority. The EIA also forms part of the application for a creation and operation licence.

1.3 The role of partnership and the cAt Project

A partnership approach has been put in place in Belgium to develop proposals for facilities for the long-term management of low-level and short-lived intermediate-level waste (LILW). This means that the local community is directly involved in developing both the facility design and a socio-economic package for their area along with ONDRAF/NIRAS. Initially, three such partnerships were set up, leading eventually to two neighbouring municipalities (Dessel and Mol in the province of Antwerp – Flemish region) expressing an interest in hosting a disposal facility. In June 2006, the Federal government decided on surface disposal in Dessel as the final destination for Belgian short-lived LILW. Since that decision, the remaining partnerships (STOLA, now STORA, in Dessel and MONA in Mol) have both been closely involved in the development of the integrated repository project (NEA 2005c, 2010).

The community partnerships are structured as not-for-profit organisations. Such organisations have a sound legal basis and long-standing tradition in Belgian civil society and local community life. The framework offers a relatively flexible structure with which many people are familiar. In practice the community partnerships consist of:

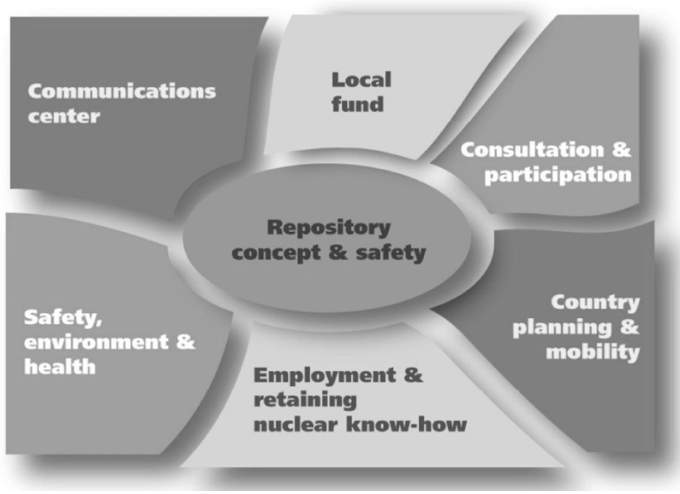
- General Assembly (GA) – made up of representatives of all interested local organisations, the GA acts as guardian of the decision-making process. Members decide on/approve the main framework within which the other bodies of the partnership work and the final concept for the project that is recommended to the municipal council.
- Executive Committee (EC) – takes intermediate decisions on budget, co-ordinates working groups, supervises project co-ordinators. They co-ordinate the day-to-day management of the partnership.
- Project Co-ordinator(s) – look after administration and communication tasks, organise and support working groups. This has been a full time role.
- Working Groups – made up of independent individuals on voluntary basis – discuss different aspects of the project in detail. In the siting phase, they considered current research, commissioned extra research and talked to experts. Each working group had an assigned contact person from ONDRAF/NIRAS who attended working group meetings to discuss proposed options and suggested alterations by the local participants.

After the siting decision, new working groups were set up to continue the active involvement of the local partners in the development of the project. In both the Dessel- and Mol-based partnerships, three working groups have been active: one focusing on matters related to the totality of the nuclear activity in the Mol-Dessel area; two others following closely the development of various aspects of the integrated project which is nowadays known as the "Integrated cAt Project". The IRT received a presentation from the two partnerships during their site visit. The partnerships impressed upon the IRT their strong support for the project, which they consider as also theirs (Claes and Sannen 2012).

Recognising the importance of partnership in the development of disposal facilities for radioactive wastes, the cAt Project (Figure 1.2) currently integrates seven sub-projects that address various aspects of work aimed at the disposal of Belgian category A waste at Dessel (ONDRAF/NIRAS 2010a, 2011a):

- Consultation and participation.
- Disposal facility concept and safety.
- Safety, environment and health.
- Local fund.
- Communication centre.
- Employment and retention of nuclear know-how.
- Country planning and mobility.

Figure 1.2: The seven building blocks of the cAt Project (ONDRAF/NIRAS 2010a)



In addition to consultation and participation, safety has an over-riding influence on the development of the disposal facility concept and the partnership have themselves proposed technical features that would enhance the safety of the facility, such as the inspection rooms underneath the disposal modules, the fixed steel roof to protect the modules against weather conditions during the emplacement of the waste, and the use of concrete disposal packages or monoliths (ONDRAF/NIRAS 2011l, Claes and Sannen 2012).

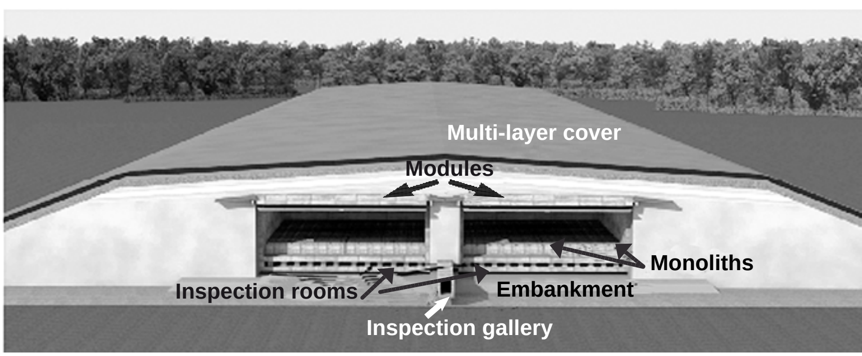
The main objective of the current phase of the cAt Project is to obtain the A1 license for the construction and operation of the surface disposal facility.

1.4 The disposal facility concept

The disposal facility being proposed for construction at Dessel would be a highly-engineered, above-ground, vault-type facility, similar to two other modern and fully-licensed operating LLW disposal facilities: the Centre de l'Aube in France and El Cabril in Spain.

The disposal concept consists of a set of engineered barriers. With reference to Figure 1.3, these barriers include reinforced-concrete waste disposal containers or "caissons" that, when filled with waste and a cement-based grout, provide a monolithic wasteform known as a "monolith"; disposal modules, also made of reinforced concrete into which the monoliths are placed; and a multi-layer cover. A series of inspection rooms and an inspection gallery beneath the modules completes the disposal concept. The modules will be covered with a fixed steel roof during the entire operation period to protect them against weather conditions. The whole system rests on a foundation, consisting on a 0.6 metre thick drainage layer and a 2 metre-thick sand-cement embankment, to minimise the risk of water entering the disposal facility from below. The average depth of the water table at the site ranges between 1 and 2 metres both in winter and summer. Further details and discussion of the proposed facility design are given in Sections 2.3.2 and 3.3.

Figure 1.3: Overview of the disposal concept (ONDRAF/NIRAS 2011a)



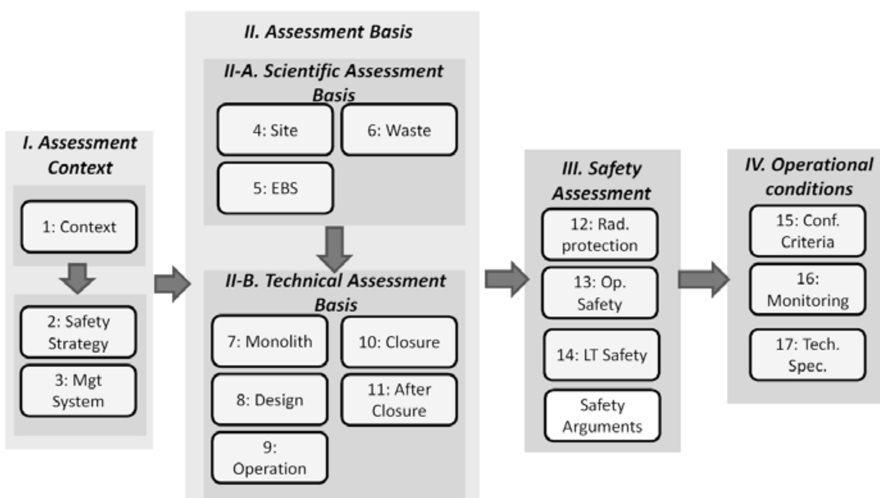
1.5 The structure of the safety case

As illustrated in Figure 1.4, the safety case being developed by ONDRAF/NIRAS consists of a set of reports and documents at different levels:

- Two Level 1 Safety Reports provide syntheses of the key safety arguments for technical and non-technical audiences, respectively.
- One Level 2 Safety Report supports the Level 1 reports and contains the safety arguments and their associated supporting elements.
- Several Level 3 and 4 documents provide further support for the upper level reports, for example by describing the scientific and technical basis, the methodologies for developing the design of the disposal system, and the conduct of safety assessments.

Figure 1.4: Structure of the safety case (ONDRAF/NIRAS 2011a)

Figure 1.5: The structure of the Level 2 Safety Report of November 2011 (version for the peer review) showing how information flows between its different parts and chapters (ONDRAF/NIRAS 2011a)



The Level 2 Safety Report of November 2011 (version for the peer review), which is the main document considered during this review, comprises 17 chapters, grouped into the following four inter-related parts:

Part I Assessment Context.

Part II Assessment Basis.

Part III Safety Assessment.

Part IV Synthesis of Safety Arguments, Results and Operational Conditions.

The structure of the Level 2 Safety Report is illustrated in Figure 1.5. Figure 1.5 also shows how information flows between the different parts and chapters of the report. More details on the individual chapters are given in Chapter 3 of the present document.

1.6 Remit of the international review

In 2011, the Belgian Federal Public Service of Economy and Energy requested the NEA to peer review key aspects of the safety case being developed the Belgian Agency for Radioactive Waste and Enriched Fissile Materials, ONDRAF/NIRAS, for the license application for construction and operation of a surface disposal facility for low- and intermediate-level radioactive waste in the municipality of Dessel.

As defined in the ToR, the objective of the peer review was to:

- Provide a statement, from an international perspective, on the credibility and robustness of ONDRAF/NIRAS' long-term safety strategy and long-term safety assessment as part of the safety case to be submitted to the Belgian Federal Agency for Nuclear Control in view of obtaining a licence for the construction and operation of a surface disposal facility for low- and intermediate-level short-lived radioactive wastes.

The peer review should also:

- Provide ONDRAF/NIRAS with information to help it ensure that licence application file will be in line with international best practice.
- Provide observers of the review process with an overview of ONDRAF/NIRAS' work in preparation of the licence application, especially the part that is within the scope of the international peer review, identifying elements that are amenable to improvement.

As stated in the ToR, the peer review should focus on:

- The "well-foundedness" and soundness of:
  - The long-term safety strategy as defined and applied.
  - The proposed disposal system design.
  - The methodology for long-term safety assessment.
  - The long-term safety assessment results.
- The quality of the scientific and technical basis supporting the long-term safety assessment, particularly on the topic of long-term concrete phenomenological behaviour.

The IRT notes that judgments on compliance with Belgian regulations are the responsibility of the Belgian Safety Authority, FANC, and were not within the scope of this international peer review.

The primary documents provided to the IRT for review were the following chapters of the Safety Report:

- ONDRAF/NIRAS (2011b) Chapter 2: Safety approach, safety strategy and safety concept, NIROND-TR 2011-02 E V1, Document ready for peer review, November 2011.
- ONDRAF/NIRAS (2011d) Chapter 5: Knowledge of the phenomenological issues of the engineered barriers in their environment, NIROND-TR 2011-05 E V1, Document ready for peer review, November 2011.
- ONDRAF/NIRAS (2011f) Chapter 7: Monoliths, NIROND-TR 2011-07 E V1, Document ready for peer review, November 2011.
- ONDRAF/NIRAS (2011g) Chapter 8: Design and construction, NIROND-TR 2011-08 E V1, Document ready for peer review, November 2011.
- ONDRAF/NIRAS (2011h) Chapter 14: Long-term safety assessment, NIROND-TR 2011-014 E V1, Document ready for peer review, November 2011.

Some other chapters of the Safety Report (Chapters 1 and 6; ONDRAF/NIRAS 2011a,f in the version for the peer review) and certain supporting documents were also provided and examined by the IRT (see Annex 1).

1.7 Organisation and conduct of the review

The peer review was organised in accordance with the NEA guidelines for international peer reviews for radioactive waste management (NEA 2005a).

An International Review Team (IRT) was assembled by the NEA. In order to ensure independence of the review and avoid conflict of interest, the experts chosen by the NEA had not over the past five years been involved (e.g. as consultants, employees or experts) either for ONDRAF/NIRAS or FANC in developing the disposal programme or the safety case for the Belgian cAt Project. Details of the criteria for assessing independence are described in the ToR.

The IRT was chosen to provide expertise in long-term safety assessment, expert knowledge of concrete degradation and phenomenology, safety and regulatory authority experience, and operational experience of surface disposal sites. The IRT had a broad international spectrum of competencies, a balance of academic researchers and other experts with vast knowledge of radioactive waste management and safety assessment. Annex 2 to this report lists the IRT members and provides brief biographical information.

An initial two-day peer review meeting was held on 19 and 20 December 2011 in Brussels, Belgium, at which the IRT met for the first time with ONDRAF/NIRAS in the presence of observers from the FANC and the Belgian Federal Public Service of Economy and Energy. During the meeting, ONDRAF/NIRAS described the cAt Project and the anticipated licensing steps. The safety strategy and safety assessment were also explained. The IRT reviewed and discussed the information provided, and review tasks were assigned to review team members according to technical areas of expertise.

During the ensuing review period, the IRT sent two sets of written questions to ONDRAF/NIRAS. The first set of questions comprised a set of standard peer review questions developed for NEA-organised peer reviews (NEA 2005b). The second set of questions comprised more specific questions raised by members of the IRT following their initial review of key parts of ONDRAF/NIRAS' Safety Report (version for the peer review) and supporting documents. In total, the IRT submitted over 300 written questions. ONDRAF/NIRAS provided written answers to both sets of questions (ONDRAF/NIRAS 2012a,d).

A five-day peer review meeting was held in Brussels, Belgium, from 4 to 8 June 2012. In addition to the IRT and ONDRAF/NIRAS, the meeting was attended by various observers, including staff from the FANC and the Belgian Federal Public Service of Economy and Energy. During this review meeting, the IRT met with the partnerships in Dessel and visited the site of the proposed disposal facility. The IRT presented preliminary review findings at the end of the meeting on 8 June 2012.

The peer review was conducted taking into consideration relevant national and international legislation, guidelines and recommendations, international best practices, and state-of-the-art knowledge from other radioactive waste management programmes.

This report documents the findings of the IRT. These findings are based on review of relevant chapters of the November 2011 Safety Case Report, version for the peer review, and examination of supporting documentation as well as the information provided by ONDRAF/NIRAS in response to the IRT's questions and during the two peer review meetings.

1.8 Organisation of this document

The main audiences for this report are the Belgian Federal Public Service of Economy and Energy, ONDRAF/NIRAS, and observers of the review process, such as the FANC and the communities participating in the partnerships. Other institutions and organisations, technical specialists involved in waste management and interested parties within and outside Belgium may also benefit from this report.

The present document starts with high-level review findings for an audience of policy makers.

- Chapter 1 provides a general introduction, including brief information on the Belgian category A waste disposal programme, the licensing process, the role of partnership and the cAt Project, the design of the proposed surface disposal facility, the safety case and Safety Report of November 2011, and the scope, aims and conduct of the peer review.
- Chapter 2 begins with a statement to the Belgian Federal Public Service of Economy and Energy based on the IRT's findings with respect to the specific questions identified in the Terms of Reference. It represents a more detailed version of the high-level findings that are presented earlier on in the review report. Chapter 2 is written for an audience of decision-makers and interested publics.

- Chapter 3 provides detailed reviews of key aspects of ONDRAF/NIRAS' safety case (version for the peer review). This chapter is intended for the more technically-oriented readers, in particular the ONDRAF/NIRAS staff.
- Annex 1 lists the documents reviewed and examined by the International Review Team.
- Annex 2 identifies and provides summary biographical information on the members of the International Review Team.

2. Findings *vis-à-vis* the remit of the review

2.1 Introduction

The purpose of the peer review was to assist the Belgian Public Service of Economy and Energy, public and relevant organisations by providing a statement, from an international perspective, on the credibility and robustness of key aspects of the ONDRAF/NIRAS' safety case of November 2011 in preparation for the application for construction and operation of a surface disposal facility for short-lived low and intermediate-level radioactive waste facility in the municipality of Dessel. Additional important roles for the peer review were:

- To provide ONDRAF/NIRAS with information to help it ensure that its future licence application file will be in line with international best practice.
- To provide all observers of the review process with an overview of ONDRAF/NIRAS' work in preparation of the licence application.

Accordingly, a ToR was developed for the review that states that the peer review should provide the Belgian Federal Public Service of Economy and Energy with an international perspective on the credibility and robustness of key aspects of the safety case, including the safety strategy and the long-term safety assessment.

In performing the review and developing its final statement, the IRT was asked to consider international best practice and to focus on "*the well-foundedness and soundness*" of:

- The long-term safety strategy as defined and applied. The long-term safety strategy includes both passive and active elements to support long-term safety.
- The proposed disposal system design taking into account the long-term safety strategy, and taking due account of the provisional radionuclides inventory.
- The methodology for long-term safety assessment and its application, taking into account the system design, waste types and the environment.
- The long-term safety assessment results.

The IRT was also asked to focus on *"the quality of the scientific and technical bases supporting the long-term safety assessments and especially the phenomenology of concrete behaviour over time"*.

The ToR identifies specific questions under each of the focus areas. In addition to presenting the IRT's Statement, this chapter summarises the review findings of the IRT *vis-à-vis* the remit of the review and the specific questions identified in the ToR.

The findings of the IRT are based on review of the relevant chapters of the Safety Report of November 2011 and an examination of supporting documentation as well as the information provided by ONDRAF/NIRAS in response to the IRT's questions and during two peer review meetings.

The peer review was conducted with the understanding that this review is one step in the stepwise development and licensing of a disposal facility in Belgium. Judgements on the compliance of the Safety Report with Belgian regulations are the responsibility of the FANC and fall outside the scope of the international peer review.

The IRT used the specialist knowledge of its members and its collective understanding of international best practice to evaluate the information provided and to make findings and recommendations.

2.2 Overall statement to the Belgian Federal Public Service of Economy and Energy

From an international perspective, ONDRAF/NIRAS' long-term safety strategy and safety assessment are, in the main, credible and robust. The disposal programme implements international best practice, takes into account the conditions stipulated by the Federal Government and the local communities, and is technically mature.

The IRT also notes that there has been a good, structured dialogue between ONDRAF/NIRAS and the safety authority (FANC) during the pre-licensing phase.

The IRT considers that the safety case documentation is well structured with different levels of reports aimed at different audiences, both technical and non-technical. In the areas of the safety report that the IRT has reviewed, the documentation is generally clear and traceable.

The IRT is pleased to learn that the safety case would be updated and reviewed by the regulator prior to commencing disposal operations.

The safety of the proposed disposal facility relies importantly on the engineered barrier system, as do similar modern facilities for short-lived radioactive wastes in other countries.

With respect to the scientific basis and the safety assessment described in the Safety Report (version for the peer review), the IRT considers that the research, development and demonstration work performed so far has identified and investigated the relevant processes. ONDRAF/NIRAS has a reasoned plan for future RD&D to address remaining uncertainties and a demonstration test programme is already under way.

The IRT notes that an Integrated Management System is being developed including organisational aspects, safety culture, and quality assurance principles to be applied to all aspects of disposal facility implementation.

The IRT considers, however, that the breadth of ONDRAF/NIRAS' work relevant to the safety case is not fully represented in the relevant chapters of the November 2011 Safety Report. This became even more evident during the process of the review, e.g. during the written and oral exchanges with ONDRAF/NIRAS' staff.

Overall, ONDRAF/NIRAS has a team of competent and well-motivated staff with good evidence of safety culture and capable of taking the cAt Project forward.

The above statement is supported by the following high-level review findings regarding the specific questions identified in the ToR for the peer review. More detailed review findings, suitable for more specialist audiences, are provided in the rest of Chapter 2 and in Chapter 3 of the present report, respectively.

2.3 Summary of review findings

The ToR includes a series of more detailed questions, which the IRT has addressed. The following sections present the findings and recommendations of the IRT with respect to these more detailed questions.

2.3.1 Long-term safety strategy

With respect to the questions:

- *Is the proposed long-term safety strategy well founded?*
- *Does the proposed long-term safety strategy consider the defence in depth, optimisation and passive safety principles?*
- *Does the long-term safety strategy conform with international best practices?*

The IRT considers that:

- The long-term safety strategy is in accordance with internationally accepted safety principles [e.g. optimisation and Best Available Technology (BAT), Defence-in-Depth, passive safety, radiation protection].
- The long-term safety strategy is based on isolation, containment and retardation, which is consistent with international best practice and guidelines.
- The safety arguments have been developed structured and analysed systematically using a set of safety functions linked to the main system components and to defined time periods.
- The safety strategy takes into account the requirements of the Government, the partnerships and national and international guidance.
- The staged approach for disposal facility construction, operation, closure and, later, institutional control is based on a staged licensing process. It

implies continuous feedback from monitoring and RD&D results, which is in line with international best practice, guidelines and recommendations.

- The on-going and future RD&D programmes should further contribute to improving knowledge, understanding system performance, reducing uncertainty, increasing confidence in safety margins, and optimising the system.

With respect to the question:

- *Is the phased approach for system construction, operation, closure and post-closure control in line with international guidelines, recommendations and best practice?*

The IRT considers that:

- ONDRAF/NIRAS is following a phased approach to disposal facility development with local partnerships and in line with the Belgian process for governmental decisions.
- The proposed phases for disposal system construction, operation, closure and post-closure control are in line with national regulations and international practices and recommendations.
- The timescales foreseen for institutional control (~350 years) are in line with international practice.

In conclusion, the safety strategy is well founded. It takes account of the defence in depth, optimisation and passive safety principles, and is in accordance with international best practices. ONDRAF/NIRAS has described the disposal concept to an adequate level of detail for the current stage of the disposal programme and has clearly identified the safety functions of the various repository components. The design strategy adopted by ONDRAF/NIRAS develops the system based on principles that incorporate multiple barriers and safety functions. The iterative process described by ONDRAF/NIRAS for disposal system design, development and safety assessment, suitably controlled by a suitable management system is appropriate and should allow the incorporation of new knowledge, while maintaining flexibility in the development process. ONDRAF/NIRAS is preparing an Integrated Management System for the construction and operation of the disposal facility according to international recommendations. In particular, ONDRAF/NIRAS is planning for the organisational structure that will carry out the implementation of the project. This should help ensure that the construction, operation and evaluation of safety are done efficiently and reliably. ONDRAF/NIRAS has identified and prioritised the future RD&D needs in an appropriately structured manner in order to reduce identified uncertainties and increase the confidence in the robustness of the disposal system. Overall, ONDRAF/NIRAS's phased approach for system construction, operation, closure and post-closure oversight is in line with international guidelines, recommendations and best practice.

The IRT recommends that ONDRAF/NIRAS should explain clearly to stakeholders the potential for monitoring information to confirm disposal system performance, and to work with stakeholders towards an agreed process for the periodic review of facility status and the closure decision.

2.3.2 Proposed disposal system design

With respect to the question:

- *Is the development of the proposed disposal facility design coherent and conforming to the long-term safety strategy, taking into account the types and quantities of waste and the environment?*

The IRT considers that:

- The design strategy follows a logical structure and integrates all of the specific design requirements deduced from the safety functions, the government and partnerships.
- The proposed disposal facility design is modular and can be adapted to the waste volumes.
- The proposed disposal facility design takes account of the characteristics of the site and environment (e.g. rainfall, settlement, groundwater table, seismicity, flooding).
- In summary, the proposed disposal facility design conforms to the long-term safety strategy, the provisional waste inventory and the environment.

The IRT recommends that:

- ONDRAF/NIRAS should consider including a water collection system in the sand layer under the clay layers of the cover so that the performance of the cover as an infiltration barrier can be monitored and proper drainage of the cover verified.
- ONDRAF/NIRAS should continue research into the possibility of backfilling the inspection rooms with alternative materials in order to add further defence-in-depth to the design.

With respect to the question:

- *Is the technical design of the disposal facility and its planned implementation sufficiently credible and robust, taking into account the specificities of the Dessel site, to justify the ONDRAF/NIRAS assessment of the long-term, expected evolution of the disposal system?*

The IRT considers that:

- The technical design of the disposal facility takes into account the specificities of the site. It is detailed enough to enable long-term safety assessment – links are made in the Safety Report (November 2011 Safety Case version for the peer review) between the safety functions and the expected evolution, and uncertainties have been assessed.
- The materials of the engineered barrier system are generally well known.
- The facility would be implemented in accordance with best engineering practices. Implementation of rigorous Quality Assurance (QA) and Quality Control (QC) will be important.

- The construction of the caisson, monolith, module and cover has been shown to be feasible.

The IRT recognises the demonstration tests and trials conducted by ONDRAF/NIRAS have led to improvements in the construction techniques and have provided valuable information that may be used to further improve the system design, and further enhance the various construction techniques, construction sequences and inspection equipment.

The IRT considers that the accumulation of water inside the disposal module base should be avoided and recommends that ONDRAF/NIRAS consider including a water collection system in the sand layer under the clay layers of the cover so that the performance of the cover as an infiltration barrier can be monitored and proper drainage of the cover verified.

ONDRAF/NIRAS is considering the possibility of filling the inspection rooms with a zeolite-based material at the time of closure. The IRT recommends that ONDRAF/NIRAS continue research into the possibility of backfilling the inspection rooms with alternative materials in order to add a further defence-in-depth layer to the design.

In summary, ONDRAF/NIRAS follows a sequential and iterative design process that started with a generic design developed with the Partnership and which later evolved into an improved and detailed design, including implementation procedures. The design takes into account the waste inventory and the specificities of the site. During the design process ONDRAF/NIRAS has demonstrated that it took into account international experience, as well as the application of the BAT and optimisations principles favouring the robustness of the design. This has resulted in a highly-engineered design. The design of the disposal facility is detailed enough to allow long-term safety assessment. Construction of the caisson, monolith and module has been shown to be feasible. The facility would be implemented in accordance with the best practices.

Overall, the proposed disposal facility design is in accordance with the long-term safety strategy, the provisional waste inventory and the environment. The proposed disposal concept relies importantly on the engineeered barrier system, as do similar modern facilities for short-lived radioactive wastes in other countries. In this case, given the characteristics of the Dessel site, the engineered barrier system is even more substantial to limit water flow and radionuclide releases. Implementation of a rigorous QA programme and QC measures will be important.

2.3.3 The quality of the scientific and technical bases

With respect to the question:

- *Does the description of the scientific and technical basis (and in particular the phenomenological issues of concrete performance and degradation) offer suitable and relevant support for the long-term safety assessment? Is this scientific and technical basis state of the art and are the scientific and technical limitations correctly taken into account?*

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The IRT considers that:

- Concrete plays a prominent role in the performance of the proposed disposal system.
- ONDRAF/NIRAS has taken a sensible scientific approach to the consideration of concrete performance, supported by an on-going programme of research, development and demonstration. The descriptions of the many processes considered demonstrates a good scientific understanding of how the complex system may behave over the long-term.
- ONDRAF/NIRAS' description of the phenomenological issues of concrete (e.g. carbonation, cracking, de-calcification, corrosion of reinforcement) offers suitable and relevant support for the long-term safety assessment.
- The scientific knowledge presented on concrete (chemical behaviour, carbonation, degradation) and on other engineered components, such as the earth cover, is state of the art.
- Technical limitations (e.g. the development of concrete permeability, cracking issues) are being evaluated and will be taken into account.

The IRT recommends that:

- ONDRAF/NIRAS should address degradation of concrete by carbon dioxide from organics in the wastes and consider biological activity.
- Because cracking will occur over different timescales, ONDRAF/NIRAS should show to what degree through-going cracking may be acceptable in the first 350 years, rather than assuming that through-going cracking does not occur.
- System heterogeneity and partial saturation call for further RD&D on coupling of chemical reactions with water and gas transport at the drum/caisson scale.
- ONDRAF/NIRAS should consider the possible effects of varying water saturation on the chemical degradation of the monoliths.

In conclusion, ONDRAF/NIRAS' description of the phenomenological issues of concrete offers suitable and relevant support for the long-term safety assessment. Specific RD&D studies and literature reviews have been conducted to gather pertinent information to improve the understanding of concrete behaviour and enhance the design of the engineered barriers. The quality of the scientific knowledge presented on concrete is state of the art and is correctly presented. The descriptions of the many processes demonstrate a good scientific understanding of how the complex system may behave over the long term. Most conceivable detrimental processes have been addressed to a sufficient level of detail. Technical limitations (e.g. the development of concrete permeability, cracking issues) are acknowledged and are being evaluated; proportionate solutions will be proposed. Uncertainties that need further consideration have been identified. A novel approach is presented for evaluating the durability of the concrete structures based on the use of durability indicators. Reasonable design measures and implementation procedures have been proposed for limiting adverse effects of potentially detrimental processes. The IRT has identified various observations and detailed recommendations for further improvements in Chapter 3 of the present report.

2.3.4 Long-term safety assessment method and results

With respect to the question:

- *Does the long-term safety assessment methodology accord with international best practice?*

The IRT considers that:

- The long-term safety assessment methodology closely follows the IAEA approach and is in accordance with international best practice.
- In specific areas (e.g. safety functions) ONDRAF/NIRAS' methodology is at the forefront of development.
- ONDRAF/NIRAS plans to apply the safety assessment methodology in an iterative way as the project progresses – this is good practice.

With respect to the question:

- *Are the presented scenarios (human intrusion, normal and altered evolution) adequate to assess potential evolutions of the disposal and its long-term safety?*

The IRT considers that:

- There is no single "best" way for scenario development – the approach may necessarily be country – and facility-specific.
- ONDRAF/NIRAS has considered a large number of scenarios and assessment cases including human intrusion, normal and altered evolution.
- The set of scenarios is, in principle, adequate, but it is complex to comprehend all the relationships between the scenario types.
- Although it could not review the details of all of ONDRAF/NIRAS' assessment scenarios and assessment cases because many of these were only presented to the IRT in summary form in June 2012, the IRT observes that there are benefits in including both the conservative Reference Scenario and the more realistic Likely Expected Scenario.
- Some scenarios and cases (in particular, the Reference Scenario) include a mix of conservative and non-conservative assumptions; this can obscure understanding of system performance.
- The IRT could not review all of the details of the safety assessment results as many were presented only during the course of the review. The IRT observes that the results of the safety assessment suggest that the calculated safety of the disposal system is not very sensitive to variations in the values of numerous parameters. The IRT also observes that the reported, calculated radiological impacts are within the ICRP allowed ranges for the various different scenarios, including the "penalising scenario". The IRT,

however, has questioned some assumptions made by ONDRAF/NIRAS and has suggested additional calculations, which may or may not confirm the results of the current assessment.

- The on-going and future RD&D programmes should contribute to improving knowledge, reducing uncertainty, increasing confidence in safety margins, and optimising the system.

The IRT recommends that:

- ONDRAF/NIRAS should include further, more-detailed information on the nature of the wastes and the waste inventory in the Safety Report. ONDRAF/NIRAS should monitor changes in the waste inventory and maintain sufficient flexibility in its programme so that it can accommodate the wastes.
- ONDRAF/NIRAS should in the Safety Report explain and justify the selection of parameter values for the disposal facility components and the rationale for mixing different assumptions related to the "intact" or "degraded" characteristics of the components.
- ONDRAF/NIRAS should identify in the Safety Report the set of parameters values and associated assumptions that it considers represent the best-estimate of disposal system performance.
- ONDRAF/NIRAS should explain clearly the achievable performance of the disposal system based on current knowledge of concrete permeability for large engineered structures.
- ONDRAF/NIRAS should consider an assessment case in which infiltration is controlled by the clay infiltration barrier instead of the impervious concrete top slab.
- ONDRAF/NIRAS should examine the sensitivity of assessed disposal system performance to the selected times at which the engineered components are assumed to degrade.
- ONDRAF/NIRAS should present a stronger justification for the claim that bath-tubbing will not occur, taking into account the uncertainties that exist associated with the hydraulic characteristics of the concrete components over time, as discussed above. ONDRAF/NIRAS should consider the possibility of exposure to contaminated water that has overflowed from the facility (by "bath-tubbing") and entered surface soils and waters (e.g. streams).
- ONDRAF/NIRAS should explain the rationale for the penalising, or "what if", scenarios considered, making sure that they are based on logically consistent assumptions regarding engineered barrier performance and associated uncertainties.
- ONDRAF/NIRAS should document the uncertainty and sensitivity analyses that have been undertaken, and describe the significance of the parameters and assumptions considered.

- ONDRAF/NIRAS should highlight the key parameter(s) that ensure the safety of the disposal concept, and explain the phenomenological reasons for the parameter sensitivities.
- ONDRAF/NIRAS should consider carefully how to present, integrate and synthesise all of the results from the many assessment scenarios and cases in a way that allows the reader to understand the likelihood and importance of each of the cases.
- As the disposal programme progresses, the safety assessments should better reflect the reasonably achievable properties of the engineered components in order to provide better guidance on optimisation of the engineered barrier system and waste acceptance, and increase confidence in safety assessment results.

With respect to the question:

- *Is the method for the calculation of the maximum allowable radionuclide waste inventories robust and credible?*

The IRT considers that:

- ONDRAF/NIRAS' approach for the calculation of the maximum allowable radionuclide waste inventories:
  - Is based on the Human Intrusion and Reference Scenarios which are designed to be more conservative than the Expected Evolution Scenario.
  - Takes account of both specific activities of radionuclides in the waste and total activities in the facility.
  - Is consistent with the IAEA *"sum of fractions"* approach.
- The method for calculating the maximum allowable radionuclide waste inventories is in principle credible and robust.

The IRT recommends that:

- ONDRAF/NIRAS should consider the practicalities of waste characterisation and the possible benefits of grouping radionuclides when setting waste acceptance criteria.

In conclusion, ONDRAF/NIRAS's methodology for long-term safety assessment is sound and in accord with international best practice. ONDRAF/NIRAS has considered a large number of scenarios and assessment cases including human intrusion, normal and altered evolution. The set of scenarios is, in principle, adequate, but it is complex to comprehend all of the relationships between the scenario types.

The IRT could not review all of the details of the assessment cases or safety assessment results that have been developed since November 2011. Some scenarios and cases (in particular, the Reference Scenario) include a mix of conservative and non-conservative assumptions; this can obscure understanding of system performance. On the other hand, there are benefits in including both the conservative Reference Scenario and the more realistic Likely Expected Scenario in the analysis.

The IRT considers that the hydraulic conductivity of the concrete disposal facility components is a key parameter governing the potential for release and transfer of radionuclides from the disposal facility to the aquifer. The IRT recommends, therefore, that ONDRAF/NIRAS should carefully justify the selection of the hydraulic conductivity values used in the modelling. It may be that the hydraulic conductivity of concrete components ought to be higher than currently selected.

The IRT also considers that due to uncertainties related to the long-term hydraulic conductivity of concrete structures at larger scales, it would be more convincing to address the possible hydraulic conductivity of the disposal facility cover by relying on the characteristics of the clayey layer in the cover. Such a layer should be able to protect the concrete roof during the regulatory control phase and efficiently limit possible water infiltration into the disposal modules. The IRT recommends, therefore, that ONDRAF/NIRAS should consider an assessment case in which infiltration to the facility through the cover is controlled by the clay infiltration barrier in the cover instead of the impervious concrete top slab.

The IRT notes that the on-going and future RD&D programmes should contribute to improving knowledge, reducing uncertainty, increasing confidence in safety margins, and optimising the system.

3. Detailed review findings

3.1 Introduction

This section of the report presents detailed reviews by the IRT of the key aspects of ONDRAF/NIRAS' Safety Report of November 2011 (version for the peer review) identified in the ToR.

The structure and chapters of the Safety Report of November 2011 is as follows:

- Part 1 – Assessment Context.
  - Chapter 1 on context/organisation.
  - Chapter 2 on safety strategy and safety concept.
  - Chapter 3 on the Integrated Management System (IMS).
- Part 2 – Assessment Basis.
  - Chapter 4 on the site characteristics.
  - Chapter 5 on the phenomenology of the Engineered Barrier System (EBS).
  - Chapter 6 on the waste characteristics.
  - Chapter 7 on the design and construction of the monoliths.
  - Chapter 8 on the design and construction of the disposal facility and the auxiliary buildings.
  - Chapter 9 on the operation of the disposal facility.
  - Chapter 10 on the closure of the disposal facility.
  - Chapter 11 on the measures after closure of the disposal facility.
- Part 3 – Safety Assessment.
  - Chapter 12 on radiation protection.
  - Chapter 13 on the operational safety assessments.
  - Chapter 14 on the long-term safety assessments.
- Part 4 – Operational Conditions.
  - Chapter 15 on the monitoring and surveillance programme.
  - Chapter 16 on waste conformity criteria.
  - Chapter 17 on the technical specifications for the disposal facility.

The peer review was organised in the following broad areas according to the principal documents reviewed:

- The assessment context (in particular Chapters 1 and 2), focusing on safety strategy.
- The scientific and technical basis for the assessment in the area of the phenomenology of concrete engineered barriers (Chapter 5).
- The proposed design of the disposal facility and the plans for the implementation/construction of the engineered barrier system (Chapters 7 and 8).
- The long-term safety assessment (Chapter 14).

Documents supporting the chapters of the Safety Report were also reviewed as necessary (see Annex A1.2). The detailed reviews presented in this chapter also take account of ONDRAF/NIRAS' answers to the IRT's questions (ONDRAF/NIRAS 2012a,d) and the presentations given during the peer review meetings (see Annex A1.3).

The findings from the detailed reviews are consistent with, and fully support, the review conclusions summarised in Chapter 2 of this report, although the text in this chapter is more detailed and contains additional detailed recommendations that may be more relevant to specialists and safety assessors.

3.2 Safety approach and strategy

3.2.1 Documents reviewed

The IRT's review of long-term safety approach and strategy is based on relevant parts of ONDRAF/NIRAS (2011a,b,i,j,l), as well as on ONDRAF/NIRAS' responses to the IRT's questions (ONDRAF/NIRAS 2012a,d), and ONDRAF/NIRAS' presentations provided during the peer review meetings and site visit.

In assessing ONDRAF/NIRAS' safety approach and safety strategy, the IRT reviewed Chapters 1 and 2 of the November 2011 Safety Report (ONDRAF/NIRAS 2011a,b). Chapter 1, "Organisation of the safety report and general information" (ONDRAF/NIRAS 2011a) was reviewed in an attempt to seek information on the key elements important to safety case development.

Specifically, Chapter 1 provides an overview of the category A waste disposal project (the cAt Project), including developmental details of how the long-term management solution for category A waste was derived in Belgium and detailing the decisions of the Council of Ministers and the integration of the societal dimensions into the Project. The principal elements of the Belgian regulatory framework as well as the framework of ONDRAF/NIRAS are also described. General information on the site and the disposal facility is also presented, as well as on the organisation of the Safety Report.

Chapter 2 of the November 2011 Safety Report (ONDRAF/NIRAS 2011b) describes ONDRAF/NIRAS' safety approach, safety strategy and safety concept, and the boundary conditions to development of the disposal facility. The chapter explains that ONDRAF/NIRAS is following an iterative overall approach to the development of a safe disposal facility and also addresses ONDRAF/NIRAS' management strategy as well as design strategy and the assessment strategy. A large part of Chapter 2 focuses on the safety concept and the major long-term safety functions provided by the disposal system and its Systems, Structures and Components (SSCs) over various timeframes. The final part of the chapter analyses possible effects on the implementation of the safety concept of potential changes to the boundary conditions and the scientific basis.

3.2.2 Detailed review findings

The following topics were considered in detail during the peer review:

- Overall safety approach.
- Boundary conditions and constraints on facility development.
- Safety strategy.
- Management system.
- Design strategy.
- Safety concept, timeframes and safety functions.
- Plans for monitoring and facility control.
- Research, development and demonstration plan.
- Knowledge management and preservation.

The following sub-sections address each of these topics.

3.2.2.1 Overall safety approach

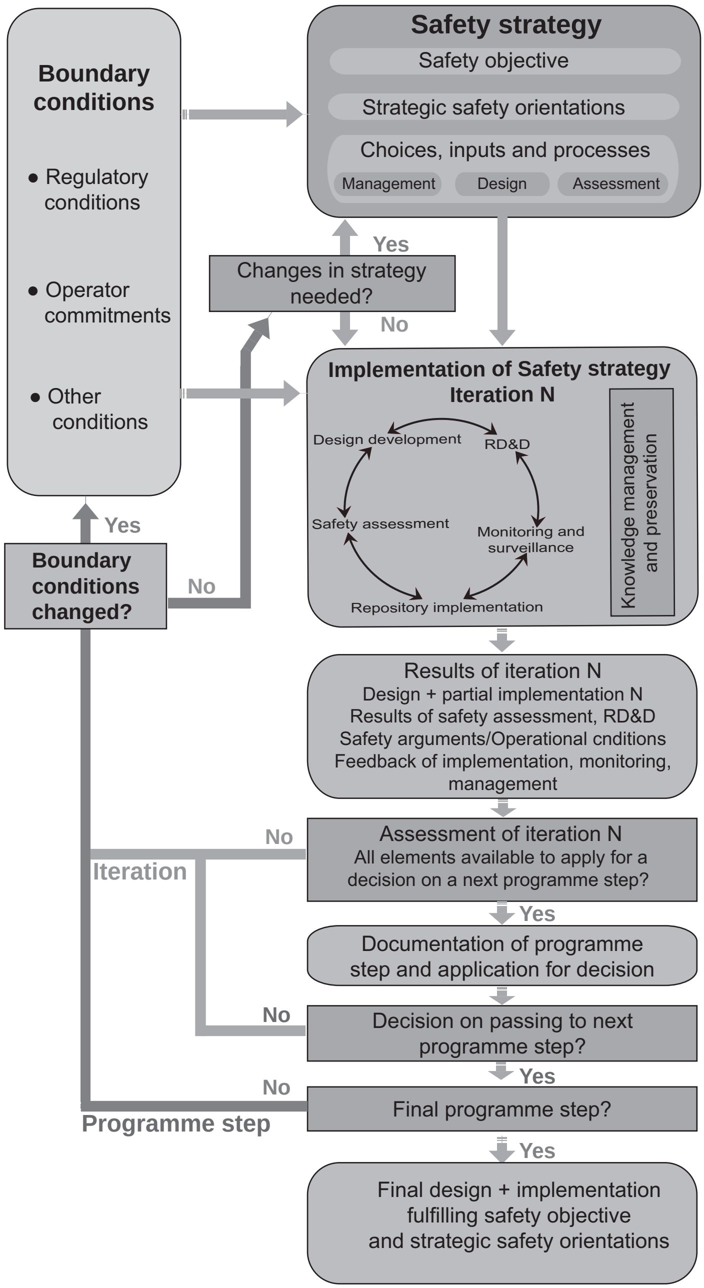
ONDRAF/NIRAS is following a stepwise approach to disposal facility development as illustrated in Figure 3.1. The approach involves an iterative management process, the "*overall safety approach*", which includes periodic safety assessment and takes account of the prevailing regulatory and technical socio-political boundary conditions, or constraints, on disposal facility development.

The main elements of the safety approach during each programme step are:

- The documentation of the boundary conditions affecting the disposal facility.
- The development of the safety strategy, including the safety concept.
- The implementation of the safety strategy.
- The documentation of safety assessment results.

Documentation of the results serves to inform the decision-making process on whether to pass to the next step of the programme.

Figure 3.1: Overview of ONDRAF/NIRAS' safety approach and its relation to safety strategy (ONDRAF/NIRAS 2011b)



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The implementation of the safety strategy encompasses the parallel and interrelated activities of:

- Design development.
- Research and development, including site characterisation, and demonstration.
- Safety assessment.
- Monitoring and surveillance.
- Design implementation.

Programme steps are demarcated by formal decisions such as government decisions and regulatory decisions and licenses.

The IRT considers that the iterative process described by ONDRAF/NIRAS for disposal system development and implementation, suitably controlled by an appropriate management system, is appropriate and should allow the incorporation of new knowledge, while maintaining flexibility in the decision making process according to the international recommendations and practices (NEA 2004).

3.2.2.2 Boundary conditions and constraints on facility development

The boundary conditions and constraints, listed in Chapter 2 (ONDRAF/NIRAS 2011b), are described in more details in Chapter 1 (ONDRAF/NIRAS 2011a) and in the supporting report "Contextual framework of the safety strategy for near surface disposal of category A waste at Dessel" (ONDRAF/NIRAS 2011i).

The boundary conditions and constraints on disposal facility development include the legal and regulatory framework, the requirements by the local partnerships and the Belgian Government, as well as inputs from previous programme steps:

- The Governmental decisions of 16 January 1998 and 23 June 2006, beside the selection of the Dessel site and the type of disposal based on the preliminary STORA design, demand a flexible stepwise approach, allowing for retrievability and controllability.
- The partnerships' main requirements include safety as the key driver, and other technical requirements, e.g. building inspection rooms and galleries under the modules, a fixed roof structure, the use of monoliths, an active control period after closure, and other demands such as the preservation of nuclear expertise in the local area and memory of the site

The IRT considers that Chapter 2 of the November 2011 Safety Report (ONDRAF/NIRAS 2011b), in conjunction with Chapter 1 and the supporting report (ONDRAF/NIRAS, 2011i), presents a sufficiently complete and transparent view of the prevailing contextual factors for the development of the selected near surface disposal concept (i.e. an above-ground, vault-type disposal facility), including those characteristics of proposed site at Dessel (e.g. hydrogeological, seismic and climatological conditions) that may affect the design requirements.

The IRT notes that during this period (2007-2011), the FANC has developed a set of regulatory guidance documents on various aspects applicable to the safe development of the disposal system (FANC 2007; 2009a,b; 2010a,b,c,d; 2011a,b).

The IRT also notes that ONDRAF/NIRAS has been involved in open and constructive dialogue with the regulatory authority (FANC) during the project development phase (2007-2011), based on a formal and structured procedure agreed between the FANC and ONDRAF/NIRAS, according to the governmental decision of 23 June 2006. The IRT considers that this kind of interaction, allowing the involvement of the regulator in the pre-licensing phase, is beneficial for development of the disposal project and contributes to building confidence in the disposal project.

The IRT notes that the specific stepwise licensing process developed by the FANC, and currently being transposed into an official regulation, will include a first confirmation of the main construction and operation license before commencement of waste emplacement in the disposal facility. The IRT also notes that periodic assessments and reviews will be performed in order to take account of results from the monitoring and RD&D programmes.

3.2.2.3 Safety strategy

ONDRAF/NIRAS' safety strategy is to isolate the wastes from people and the biosphere, contain the radionuclides within the wasteform and the disposal facility, and delay and attenuate any releases that eventually occur. The safety strategy is founded in the high-level radiological objective of the disposal facility which aims to protect people and the environment now and in the future. The use of appropriate Waste Acceptance Criteria (WAC) derived in part from safety assessments should ensure compliance with regulatory limits and guidelines on radiological impacts. This broad approach is in accordance with international requirements, guidance and best practice.

In developing its approach, ONDRAF/NIRAS has identified the relevant international recommendations (e.g. ICRP 2000, 2006; 2007; NEA 2004; IAEA 2006, 2011) and has consulted with reputable international experts and other national waste disposal programmes.

The safety strategy addresses important internationally-accepted safety principles, including optimisation and Best Available Technique (BAT), Defence-in-Depth (DiD), robustness, passive safety and radiation protection (e.g IAEA 2006a).

In accordance with the international recommendations, ONDRAF/NIRAS' safety strategy encompasses the following three components: management system, design strategy and safety assessment strategy – these are discussed in the following sub-sections.

3.2.2.4 Management system

Section 2.5 of Chapter 2 of the November 2011 version of the Safety Report briefly addresses the scope and organisation principles of the Integrated Management System (IMS) that ONDRAF/NIRAS is developing for the construction and operation of the disposal facility. Chapter 1 provides additional information regarding ONDRAF/NIRAS' organisation for the construction activities and co-ordination with the contractors, as well as on the interaction process between ONDRAF/NIRAS and the waste producers that will be necessary in order to ensure compliance with requirements on waste disposal.

During the review, the IRT asked ONDRAF/NIRAS to provide further information on the management system that applied during the project phase (2006-2012). In its response to the IRT´s question, ONDRAF/NIRAS (2012d) indicated that:

- The disposal project has been developed within a Total Quality Management System set up by ONDRAF/NIRAS and certified ISO 9001-2008, and internal and external audits are held with the aim of improving its performance.
- Approved quality assurance systems and procedures are being applied to the management of ongoing activities, such as site characterisation and monitoring, detailed design, waste characterisation and safety assessment.
- Specific peer reviews of key aspects of the disposal facility development were also performed in order to build confidence in the design.

The presentation on the Integrated Management System, given by ONDRAF/NIRAS during the second review meeting (Minon 2012a), explained how the various activities comprising disposal facility development and implementation are being managed, and included additional information on the relationships between the various organisations involved in the waste management process and the flow of information, the organisation within ONDRAF/NIRAS and the elements of the quality management programmes for the design construction and operation of the disposal facility.

The IRT considers that ONDRAF/NIRAS is fully aware of the relevance (and main elements) of the management system in providing assurance of the safety processes being applied in the development and implementation of the disposal facility. ONDRAF/NIRAS is preparing an Integrated Management System for the construction and operation of the disposal facility according to the international recommendations (e.g. IAEA 2006b, 2008). The IRT considers that in particular, the creation and organisation of the Operational Start-up Group, the Coordination Committee, the Plant Operation Review Committee, and the Safety Assessment Committee should be helpful in ensuring that the construction and commissioning of the disposal facility are undertaken in ways that will comply with the applicable requirements.

The IRT notes that it is ONDRAF/NIRAS' plan to further develop its QA/QC programme. The aims of the proposed plan include:

- Controlling all activities during the construction and commissioning phases with pre-approved procedures and test programmes.
- Applying waste management constraints and waste acceptance criteria to ensure waste conformity with disposal requirements during operation phase.

These aims are considered adequate for ensuring the disposal project is implemented with suitable quality assurance and control. The IRT emphasises, however, that an effective QA programme should be prepared before implementation begins and should include planning and management efforts to clearly communicate the importance of QA policies to staff and to enforce conformance with QA procedures throughout the organisation.

3.2.2.5 Design strategy

ONDRAF/NIRAS' design strategy is described in Chapter 2 of the November 2011 Safety Report (ONDRAF/NIRAS 2011b) and detailed in the supporting document (ONDRAF/NIRAS 2011i). The design strategy involves following an iterative process of design refinement and optimisation. The process begins with the development of the safety concept taking into account the characteristics of the site and the requirements derived from government decisions and the local partnerships, as well as inputs from previous stages of the project. The process leads to the definition of the design requirements that serve as the basis for the development of the technical design of the disposal facility.

In an initial iteration, a reference design "T0" was developed, based on the safety concept and consideration of alternative design and implementation options. Based on feedback gained as the programme progressed, analyses of the various features, events and processes in the disposal system (e.g. climatic phenomena and the high level of the water table in the vicinity of Dessel), and consideration of the Best Available Technology (BAT) and feedback from international experiences, the "T0" design was later refined and a "T1" design was developed, as detailed in Table 5 of ONDRAF/NIRAS' answers to the 2nd questionnaire (ONDRAF/NIRAS 2012d). For example consideration of the climate and the proximity of the water table led to optimisation of the thickness of individual layers within the cover, the addition of a gravel layer between the monoliths and the module wall, as well as the addition of a 2 metre-thick embankment below the modules. This design strategy has led to a design that aims at favouring robustness of the system (e.g. NEA 1998, IAEA 2003; ICRP 2006).

Overall, the IRT considers that the iterative design strategy adopted by ONDRAF/NIRAS, based on the principle of optimisation, is in accordance with international recommendations and best practices.

3.2.2.6 The safety concept, time frames and safety functions

- The safety concept

As described in Section 1.4 of this report, the surface disposal facility proposed for construction at Dessel would be a highly-engineered, above-ground, vault-type facility, similar to other fully licensed and operating disposal facilities for short-lived radioactive wastes in other countries.

The local geology is characterised, to a depth of approximately 190 m, by various permeable sand layers of Quaternary and Tertiary age, underlain by a layer of the Boom Clay that, due to its thickness and low hydraulic conductivity, forms a basement for the overlying aquifer system (ONDRAF/NIRAS 2011a). The average depth of the water table at the site ranges between 1 and 2 metres both in winter and summer (ONDRAF/NIRAS 2012b).

The proposed disposal concept would include a set of engineered barriers, including reinforced concrete waste disposal packages or "caissons" that when filled with waste and cement-based grout provide a monolithic wasteform, "monoliths", reinforced concrete disposal modules, and a multi-layer cover. A series of inspection rooms beneath the modules and an adjacent inspection gallery completes the disposal concept. The whole system rests on a foundation which includes a 2 metre-thick embankment placing the modules and the inspection structures above the water table, which is very close to the surface and above the maximum flood level.

ONDRAF/NIRAS defines the safety concept as the integrated description of the major safety functions provided by the system and the SSCs that ensure that each of the safety functions will be fulfilled over at least the assigned timeframes.

- Time frames and safety functions

The November 2011 version of the Safety Report describes six expected post-construction phases of disposal facility development (Phases I to VI) as illustrated in Figure 3.2. Figure 3.3 indicates the safety functions defined by ONDRAF/NIRAS and the phases over which they are expected to be fulfilled (ONDRAF/NIRAS 2011b). A detailed breakdown of the safety functions assumed to be provided by each of the Systems, Structures and Components (SSCs) is given in Section 2.8.4 of Chapter 2 of the November 2011 version of the Safety Report (see e.g. Table 2-1 of ONDRAF/NIRAS 2011b).

Figure 3.2: Time frames and phases defined in the Safety Report (November 2011, version for the peer review) (ONDRAF/NIRAS 2011a)

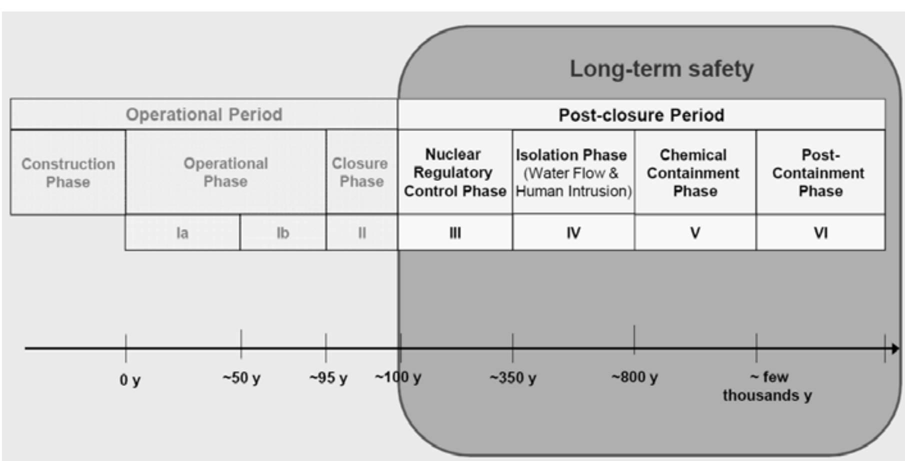
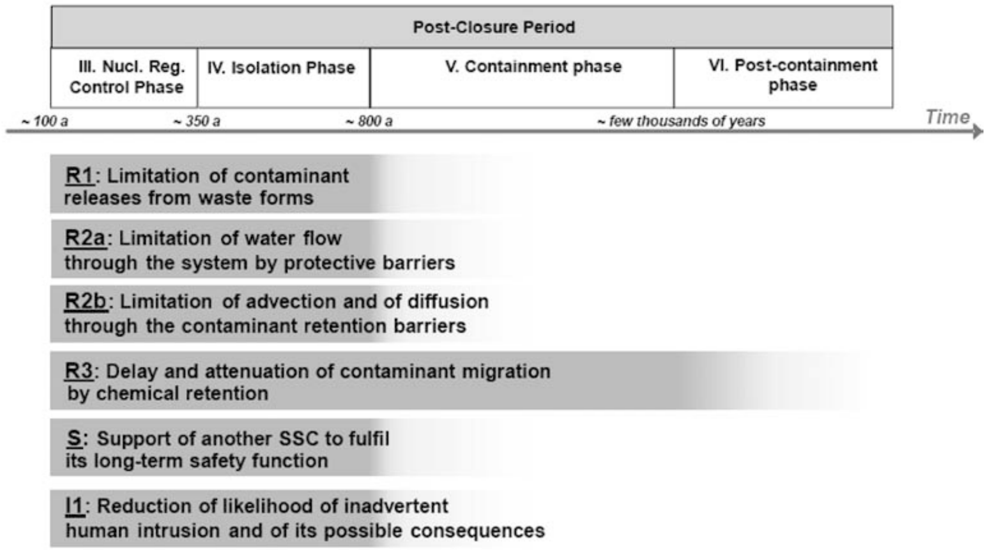


Figure 3.3: Long-term safety functions provided by the disposal system and the phases over which they are expected to be fulfilled (ONDRAF/NIRAS 2011b)



The IRT notes that the proposed phases for disposal system construction, operation, closure and post-closure Nuclear Regulatory Control (phases I to III) are in line with national regulations, in particular with the national licensing system, and international practices and recommendations (e.g. IAEA 2011).

During the review, the IRT asked ONDRAF/NIRAS to clarify the plans for, and timing of, facility closure. In its response to the IRT's questions on this topic (ONDRAF/NIRAS 2012a), ONDRAF/NIRAS noted that:

- Facility closure would involve backfilling of the drainage system in the support slab and backfilling of the inspection rooms and galleries. Facility closure would occur in Phase II after construction of the facility cover. Facility closure is currently planned to occur in between 95 and 100 years' time.
- The decision to close the facility will need to balance the desire to close the facility as soon as possible, in order to reduce the risk of human intrusion and place the disposal system in its final passive configuration, with the desire to have confirmation of disposal system performance through monitoring.

Additional information provided during the review week (Bastiaens 2012c) on *plans for operational monitoring and closure* indicates that:

- Periodic evaluations will be undertaken to decide whether or not to proceed to the closure phase.

- The procedure for obtaining the closure license includes involvement of all stakeholders.

The IRT recommends that ONDRAF/NIRAS should explain clearly to stakeholders the potential for monitoring information to confirm disposal system performance, and to work with stakeholders towards an agreed process for the periodic review of facility status and the closure decision.

The IRT notes also that the timescales foreseen for Phase III, the Nuclear Regulatory Control Phase (~350 years), are in line with international practice and assumptions regarding active institutional control (e.g. in France, Spain, the Czech Republic, the United Kingdom).

In Phase IV, ONDRAF/NIRAS assumes that the disposal facility will (ONDRAF/NIRAS 2012b, page 41):

- Continue to limit water infiltration and radionuclide release and migration.
- Continue to reduce of the likelihood of inadvertent human intrusion and its possible consequences.

The IRT notes that during phase IV (350-800 years) the facility is gradually degrading. Therefore, the assumption that the installation can reduce human intrusion after the end of the regulatory control phase involves growing uncertainties, even in the case that a system of markers is in place at the site.

ONDRAF/NIRAS' Phase V, the "*chemical containment phase*", was described as the period from ~800 to "*a few thousand years*" time, during which delay and attenuation of radionuclide releases would be achieved by chemical retention only. Phase VI, the "post-containment phase" was described as being the period after "a few thousand years" for which judgemental uncertainties on system evolution are so high that assessments of residual contamination are illustrative. In view of these descriptions, the IRT notes that the assessments probably become illustrative at an earlier time than the start of Phase VI. It is also possible that Phase VI might not start until later than a few thousand years – i.e. the chemical containment phase might last longer than was assumed in the November 2011 Safety Report (see e.g. NEA 2012a).

Section 2.8.4 of the November 2011 Safety Report (ONDRAF/NIRAS 2011b) discusses the long-term safety functions that ONDRAF/NIRAS assumed will be provided by the facility components at different stages of disposal facility evolution.

Section 2.8.4.2 of the November 2011 Safety Report (ONDRAF/NIRAS 2011b) suggested that the gravel inside the module middle would provide a support safety function by limiting damage to the monoliths in an earthquake. The IRT noted that this gravel might also direct any water to flow around rather than through the monoliths and, thereby, provide additional support to the safety function R2b. In its response to the IRT (ONDRAF/NIRAS 2012a) ONDRAF/NIRAS agreed with this observation.

Section 2.8.6.3 of Chapter 2 (ONDRAF/NIRAS 2001b) on "Robustness of the system of DiD layers" addresses the failures considered in designing the disposal system with regard to its "delay and attenuate releases objective". As the safety functions R2a, R2b, R3 and in some extension R1 rely on the basic material (i.e. concrete), the IRT questioned how the disposal system can be designed without considering common failure mode may occur. During the review week a presentation was given (Vermariën and Cool 2012c) that provided detailed information on the independence of degradation of safety functions R2 and R3 with respect to water flow, the effect of water flow through cracks on R2 and R3 and the set of cases considered in enhancing assessment robustness. The IRT suggests that ONDRAF/NIRAS should document these aspects more fully in Chapters 2 and 14 of the Safety Report.

The IRT considers that it is appropriate for ONDRAF/NIRAS to define the long-term safety functions based on an overall "isolate, contain and retard" strategy (i.e. reduce the risk of human intrusion, limit contaminant releases from the waste, etc). Such an approach is consistent with international best practice and guidelines and the manner in which it was developed is at the forefront internationally (NEA 2009; IAEA 2011).

Overall, the IRT considers that ONDRAF/NIRAS has described the disposal concept to an adequate level of detail for the current stage of the disposal programme and has clearly identified the safety functions of the various repository components. Notwithstanding this, the IRT notes that the assumed durations of the phases, particularly in the post-closure period, can only be indicative and that, in reality, the engineered barriers will degrade gradually, rather than "failing" at specific times. In Section 3.4 below, the IRT suggests that that ONDRAF/NIRAS should examine the sensitivity of assessed disposal system performance to the selected times at which the engineered components are assumed to degrade.

3.2.2.7 Plans for monitoring and facility control

The IRT requested more information on the relationships between ONDRAF/NIRAS' safety arguments and the plans for monitoring and control of the disposal facility over the coming years, and how the control plans may be influenced by monitoring activities. In its response to the IRT's questions on this topic (ONDRAF/NIRAS 2012d), ONDRAF/NIRAS:

- Described the range of monitoring activities and parameters foreseen and indicated that monitoring of the cover will include visual inspection and topographic surveys.
- Noted that the drainage system beneath the modules will remain active for about 50 years after cover installation and that this would give an indication of cover performance.
- Noted that lessons learned from the test cover, which will be studied for at least 30 years, will determine the means and necessity for internal monitoring.
- Noted that at present it has no plans to install a water collection system inside the cover because such systems might affect cover performance.

Overall, the IRT considers that ONDRAF/NIRAS should in general plan to review and update its safety arguments, assessments and plans for facility control in light of monitoring data. In more detail the IRT considers that ONDRAF/NIRAS should consider including a water collection system in the sand layer under the clay layers of the cover so that the performance of the cover as an infiltration barrier can be monitored and proper drainage of the cover verified (the rationale for this latter recommendation is discussed in Sections 3.3 and 3.4).

3.2.2.8 Research development and demonstration plan

The Safety Report (November 2011, version for the peer review) briefly addresses some of the objectives of the future RD&D programme. During the review, the IRT asked ONDRAF/NIRAS for additional information regarding the proposed contents and priorities of the RD&D programme, especially in addressing identified uncertainties. The second review meeting, therefore, included a presentation by Cool and Van Geet (2012) on ONDRAF/NIRAS' RD&D plan. ONDRAF/NIRAS indicated that its future RD&D activities will be aimed:

- To further confirm the assumed performance of the disposal system.
- To further optimise the system by both increasing performance and robustness of performance of the disposal system in cases of failures.

The major axes of the forward programme will be:

(i) To confirm the performance of the engineered barrier system, including the earth cover, monoliths/modules, and the backfilling for the inspection room.

(ii) To improve current knowledge of waste characteristics.

(iii) To stay abreast of international developments and best practices on safety cases and safety assessments.

(iv) To reduce uncertainties in hydrogeology and biosphere modelling.

The IRT considers that ONDRAF/NIRAS has identified and prioritised its RD&D needs in an appropriately structured manner in order to reduce identified uncertainties and increase the confidence in the robustness of the disposal system. The IRT also considers that ONDRAF/NIRAS management process of RD&D programme, based on the integration of various disciplines, is well defined.

3.2.2.9 Knowledge management and archiving

During the review, the IRT noted the need to make plans and arrangements for knowledge management and preservation, as well as for recording and archiving information from each step of the programme, and asked ONDRAF/NIRAS to describe its plans for knowledge management and preservation. In its response to the IRT's questions on this topic (ONDRAF/NIRAS 2012d), ONDRAF/NIRAS noted that:

- Knowledge of the site will be "embedded" in the local and regional communities through education initiatives, a communication centre, and close collaboration with local stakeholders.

- The Integrated Management System would be used during the operational phase to sustain nuclear expertise (see also Minon 2012b).
- Master documents such as as-built plans will be kept in different locations printed on specific (acid free) archival paper.
- Regular meetings with stakeholders would keep the memory of the project alive.

The IRT considers that ONDRAF/NIRAS is clearly aware of the need for knowledge management and recording and archiving of information associated with the project. The IRT recommends that ONDRAF/NIRAS should continue to develop and implement its plans for knowledge management and preservation and archiving. The IRT notes that ONDRAF/NIRAS is a contributing member to the NEA project on the Preservation of Records, Knowledge, and Memory across generations.

3.2.3 Summary of IRT conclusions

The disposal facility proposed for construction at Dessel in Belgium would be a highly-engineered, above-ground, vault-type facility, similar to other modern, fully licensed and operating disposal facilities for short-lived radioactive wastes in other countries.

On safety approach and strategy

ONDRAF/NIRAS' stepwise approach to disposal facility development involves an iterative management process, the overall safety approach, which includes periodic safety assessment and takes account of the prevailing regulatory and technical socio-political boundary conditions. The IRT considers that the iterative process described by ONDRAF/NIRAS for disposal system development and implementation, suitably controlled by an appropriate management system, is appropriate and should allow the incorporation of new knowledge, while maintaining flexibility in the decision making process according to the international recommendations and practices.

ONDRAF/NIRAS' safety strategy is to isolate the wastes from people and the biosphere, contain the radionuclides within the wasteform and the disposal facility, and delay and attenuate any releases that eventually occur. This approach is in accordance with international requirements, guidance and best practice. The IRT considers the safety strategy to be well founded and credible.

ONDRAF/NIRAS' design strategy involves following an iterative process of design refinement and optimisation based on feedback gained as the programme progresses, analyses of the various features, events and processes in the disposal system, and consideration of the Best Available Technology (BAT). Overall, the IRT considers that the iterative design strategy adopted by ONDRAF/NIRAS, based on the principle of optimisation, is in accordance with international recommendations and best practices.

The boundary conditions and constraints on disposal facility development include the legal and regulatory framework, the requirements provided by the local partnerships and the Belgian Government, as well as inputs from previous programme steps. The IRT considers that the November 2011 Safety Report presents a sufficiently complete and transparent view of the prevailing contextual factors for the development of the selected near surface disposal concept.

The IRT notes that ONDRAF/NIRAS has been involved in open and constructive dialogue with the regulatory authority (FANC) during the project development phase (2007-2011). The IRT considers that this kind of interaction, allowing the involvement of the regulator in the pre-licensing phase, is beneficial for development of the disposal project and contributes to building confidence in the disposal project.

ONDRAF/NIRAS is preparing an Integrated Management System for the construction and operation of the disposal facility according to the international recommendations

On the safety concept, timeframes and safety functions

The IRT considers that ONDRAF/NIRAS has described the disposal concept to an adequate level of detail for the current stage of the disposal programme and has clearly identified the safety functions of the various repository components.

The Safety Report (November 2011, version for the peer review) describes six post-construction phases of disposal facility development (Phases I to VI). The IRT notes that the proposed phases for disposal system construction, operation, closure and post-closure Nuclear Regulatory Control (Phases I to III) are in line with international practices and recommendations (e.g. IAEA 2011).

The IRT notes that the timescales foreseen for Phase III, the Nuclear Regulatory Control Phase (~350 years) are in line with international practice and assumptions regarding active institutional control.

The IRT considers that ONDRAF/NIRAS' approach to define the long-term safety functions based on an overall "isolate, contain and retard" strategy (is consistent with international best practice and guidelines and was developed in a manner that is at the forefront internationally. Notwithstanding this, the IRT notes that the assumed durations of the phases, particularly in the post-closure period, can only be indicative and that, in reality, the engineered barriers will degrade gradually, rather than "*failing*" at specific times. The IRT recommends that that ONDRAF/NIRAS should examine the sensitivity of assessed disposal system performance to the selected times at which the engineered components are assumed to degrade.

On the implementation of the safety strategy

The IRT recommends that ONDRAF/NIRAS should explain clearly to stakeholders the potential for monitoring information to confirm disposal system performance, and to work with stakeholders towards an agreed process for the periodic review of facility status and the closure decision.

ONDRAF/NIRAS' future RD&D plan, focusing on confirming the assumed performance of the disposal system will help to reduce remaining uncertainties increasing the confidence on the robustness performance of the disposal system.

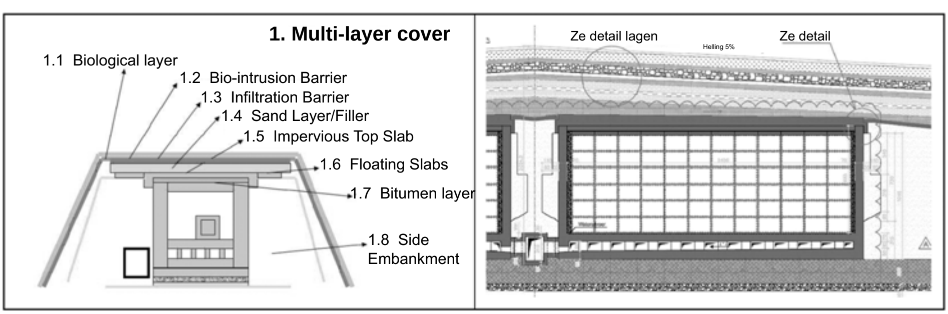
The IRT considers that ONDRAF/NIRAS is clearly aware of the need for knowledge management and recording and archiving of information associated with the project. The IRT recommends that ONDRAF/NIRAS should continue to develop and implement its plans for knowledge management and preservation and for archiving. Overall, the IRT considers that Chapters 1 and 2 of the November 2011 Safety Report provide a good description of the safety approach and safety strategy being used in the cAt Project. As Chapter 2 addresses fundamental concepts of ONDRAF/NIRAS overall safety approach for development and implementation of the disposal system, the IRT considers that it should be accompanied by a glossary that include the various terms used.

3.3 Proposed disposal system design

The disposal facility being proposed for construction at Dessel would be a highly-engineered, above-ground, vault-type facility, similar to two other fully-licensed and operating disposal facilities for short-lived radioactive wastes: the Centre de l'Aube in France and and El Cabril in Spain.

The disposal concept consists of a set of engineered barriers. With reference to Figure 3.4, these barriers include reinforced-concrete waste disposal containers or "caissons" that provide a monolithic wasteform when filled with waste and a cement-based grout, "monoliths", disposal modules, also made of reinforced concrete into which the monoliths are placed, and a multi-layer cover. A series of inspection rooms beneath the modules and an adjacent inspection gallery completes the disposal concept. The whole system rests on a foundation which includes a 2 metre-thick sand-cement layer. The average depth of the water table at the site ranges between 1 and 2 metres both in winter and summer.

Figure 3.4: Schematic view of the disposal system and the multi-layer cover components (ONDRAF/NIRAS 2011f)



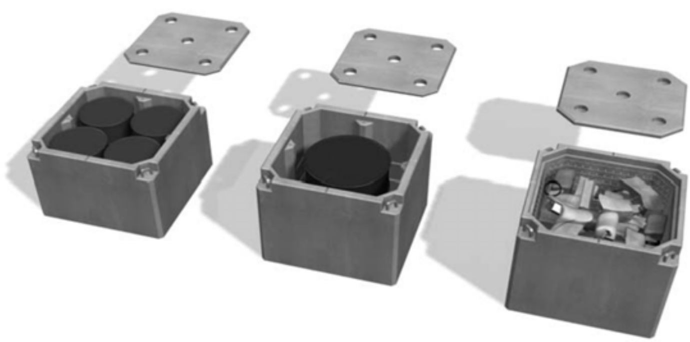
3.3.1 Documents reviewed

The IRT's review of the proposed disposal system design is based on relevant parts of ONDRAF/NIRAS (2011a,f,g,h,m,n; 2012b), as well as on ONDRAF/NIRAS' responses to the IRT's questions (ONDRAF/NIRAS 2012a,d), and ONDRAF/NIRAS' presentations provided during the peer review meetings and site visit.

Chapter 7 of the November 2011 Safety Report (ONDRAF/NIRAS 2011f) describes the caissons and monoliths and their safety functions. Information is provided on the detailed design of the caissons and on the production of the monoliths, as well as on possible defects and corrective actions. In more detail, Chapter 7 begins with a brief description of the three types of caissons (Figure 3.5). The design and safety functions of both the caissons and monoliths are then explained, and a brief description is given of the safety factors applied to the caisson design. Also covered are the production processes for the caissons and monoliths, and the elements that are being considered for inclusion in the future QA/QC programme for caisson and monolith production.

ONDRAF/NIRAS also gave presentation on how it plans to develop the QA/QC programme for the waste packages and for waste acceptance criteria during the second peer review meeting (Coppens 2012; Cosemans 2012).

Figure 3.5: Schematic view of the Type I (left), Type II (centre) and Type III (right) caissons containing different waste types (ONDRAF/NIRAS 2011f)



Chapter 8 of the November 2011 Safety Report (ONDRAF/NIRAS 2011g) provides a description of the design of the proposed disposal facility (Figure 3.5), its construction and the various standards and QA and QC measures that would be applied. In more detail, Chapter 8 describes the design and construction of the proposed disposal facility and summarises the design strategy, including the specific requirements requested by the Belgian regulatory bodies and the local partnership (containment of the radionuclides, radiological protection, protection of the environment, waste retrievability, provision of inspection rooms, etc.) that ONDRAF/NIRAS has considered in developing the design requirements for the facility. Events and accidents that could affect the safety of the disposal facility are discussed; plausible events considered in the design process included earthquakes, floods and the effects of extreme weather conditions (e.g. snow cover, wind, tornado and temperature). Chapter 8 also contains a brief description of the elements to be included in the future QA/QC programme for facility construction.

More information on QA/QC requirements for facility construction and the construction sequence were presented during the second peer review meeting (Bastiaens 2012e; Coppens 2012).

3.3.2 Detailed review findings

The following topics were considered in detail during the peer review:

- Caissons and monoliths.
- Modules.
- Roof and cover.
- Inspection gallery and inspection rooms.
- Events considered in the facility design process.
- Construction sequence.
- Feasibility and demonstration tests.
- Quality assurance and quality control.
- Robustness of the design.

The following sub-sections address each of these topics.

3.3.2.1 Caissons and monoliths

The caisson is essentially a cubic box that would be used to contain the waste (Figure 3.5). The caisson body is a rectangular container made of reinforced concrete with a thickness of approximately 120 mm. The caisson lid is also made of reinforced concrete. Three types of caisson would be used depending on the wastes to be disposed of. For example, the wastes include solidified/supercompacted ashes, evaporator concentrates, construction materials, filters, metals, resins and sludges (ONDRAF/NIRAS 2011e). The thickness of the caisson lid is approximately 80 mm for Type I and Type II caissons, and 120 mm for Type III caissons. The reinforcement cages for the caisson bodies and lids are made of carbon steel. The IRT considers that Chapter 7 provides adequate design information on the waste disposal packages.

Once wastes have been placed into the caissons, the remaining space inside the caissons would be filled with a cement-based grout to form a monolithic wasteform or disposal package. The monoliths would subsequently be positioned and stacked within concrete modules (see below).

The long-term safety functions of the caissons include restricting the release of contaminants from the wasteform, limiting water infiltration, and providing chemical retention (e.g. sorption) properties that retard the migration of contaminants. The IRT considers that the safety functions of the caissons and the monoliths are clearly defined.

The detail provided in Chapter 7 on the production of the caissons and monoliths shows that ONDRAF/NIRAS has considered the various situations that may occur during the production process. For example, Section 7.5.2.4 discusses how immobilisation mortar would be injected to limit radioactive contamination.

Section 7.4.3 lists the various safety factors used in the load calculations for the caisson components. The IRT notes that some loads were not explicitly taken into account in the model used to help design the caissons and monoliths, including thermal loads resulting from hydration of the immobilisation mortar, loads resulting from the effect of the increased volume of the mortar undergoing expansive reactions, and dynamic loads resulting from drop from height.

The IRT notes that simply stating the values of the safety factors used/assumed without explaining how the safety factors were selected would not allow readers to understand how much safety margin has been allowed for in the calculations. A similar comment may also be made on Section 7.4.4, which discusses the loads on the caissons and monoliths, and the different situations that have been considered in the designs. The various loads and situations are listed, but no justification or reference to supporting documentation is provided. Although the lack of such explanations may have no implications for the designs of the waste packages, explanations should be provided in the Safety Report to allow readers to understand why the particular situations and safety factors were considered (e.g. why is 0.85 used to assess the long-term effect of the load, or why a dynamic load of 1.15 is considered?).

Section 7.4.3.4 discusses the potential for metal loss from the caisson lifting anchors over a 300-year period as a result of corrosion and concludes that the estimated loss would not jeopardise the retrievability of the monoliths. The IRT notes that the 0.03 to 2.2 mm wall loss was estimated based on consideration of atmospheric corrosion and that no additional corrosion allowance will be provided in the design of the lifting anchors. The IRT notes that surface damage or scratches may occur during loading or stacking of the monoliths. Dents or scratches on the surface may create sites for localised corrosion, especially in the presence of chloride, in which case the lifting anchors may corrode at a higher rate. The IRT recommends, therefore, that ONDRAF/NIRAS should address the potential effects of localised corrosion on the caisson lifting anchors.

The IRT also recommends that Chapter 7 (in the November 2011 Safety Report) should be subject to further editorial checks and proof reading to improve consistency. For instance, Section 7.2.3 refers incorrectly to Phase IV as the "insulation phase", Phase V as the "*confinement phase*", and Phase VI as the "phase after confinement". These phases have been referred to as the "isolation phase", the "containment phase", and the "post-containment phase" in other parts of the November 2011 Safety Report.

3.3.2.2 Modules

The concrete modules (see Figure 1.3) would be built of reinforced concrete and would be approximately 11 metre high, 25 metre wide and 27 metre long. The modules would comprise a double bottom slab (the foundation slab and the support slab), 0.7 metre-thick walls and a roof including a structural top slab. The base of the modules would include inspection rooms and a drainage system for monitoring leachate (see below).

The modules would be built on a foundation comprising general filling material covered by a 0.6 metre-thick layer of gravel for drainage and an approximately 2 metre-thick layer of sand and cement. The foundation is designed primarily to ensure that the modules remain above the water table and above the maximum flood level at all times.

The base of the module has been designed to provide structural support for the emplaced monoliths and includes:

- A 0.7 to 0.9 metre-thick reinforced concrete support slab, which is structurally attached to the side walls of the module.
- A total of 156 concrete columns, each with horizontal dimensions of 0.75 metre x 0.75 metre; one located under each stack of monoliths to limit bending of the support slab.

The design for the module roof consists of a 0.4 metre-thick structural top slab, pre-cast concrete shielding slabs and an impervious top slab. The impervious top slab is a fibre-reinforced concrete component designed to prevent or limit the inflow of water to the modules. The method for constructing the impervious top slab is, therefore, designed to avoid the formation of shrinkage cracks. “Floating” concrete slabs would be placed along the perimeter of the impervious top slab with the aim of supporting and protecting the overlying cover from stresses originating in the underlying structures. These slabs are also designed to divert infiltrating water away from the module walls. A bitumen layer would be emplaced across the top of the structural top slab before removal of the steel roof (see Section 3.3.2.4). The bitumen layer would provide a temporary impervious cover and limit the formation of cracks in the impervious top slab. Unlike grouting, the use of sand or gravel to fill voids inside the modules would ease the retrievability of monoliths if this was ever required. The IRT considers that in conjunction with Chapter 1, Chapter 8 provides adequate information on the design of the modules.

The long-term safety functions of the module components include preventing water from accessing the waste and limiting releases from the wasteform, for example by contributing to retardation. The impervious top slab, walls and backfilled inspection rooms (see below) are also designed to reduce the probability of inadvertent human intrusion. The gravel layer between the monoliths and the module walls is designed to limit the effects of earthquakes on the monoliths. The IRT considers that the safety functions of the modules are clearly defined.

In total, 34 disposal modules are planned. Each module would be structurally independent in order to limit the effects of differential subsidence. The 34 modules are divided into two zones comprising 20 modules and 14 modules. The IRT considers that the proposed disposal facility design is modular and can be adapted to the waste volumes that are actually created.

3.3.2.3 Roof and cover

During the operational phase, the modules would be protected from precipitation and extreme temperature changes by a fixed steel roof. The steel roof comprises an array of roof sections that would be anchored to the walls of the modules and supported by concrete pedestals. The roof sections for each module would be structurally independent. The roof to be placed over the set of 20 modules would be 60 metre wide, 300 metre long and 24 metre high. Water collected on the roof would be directed into an infiltration basin.

After the operational phase, the steel roof would be replaced by a multi-layer cover. The final design of the cover will be determined in future based on results from the test cover and international experiences. At present the reference design for the cover comprises four functional layers (ONDRAF/NIRAS 2011g, page 55):

- A ~1 metre-thick "biological layer" designed to decrease erosion and to promote plant growth. The "biological layer" comprises a 0.2 metre-thick upper layer of soil material mixed with gravel to decrease erosion and organic matter to promote plant growth, an 0.8 metre-thick lower layer of sandy material, and a 0.3 metre-thick transition layer of un-compacted sand to limit mixing of upper and lower layers.
- A 1 to 1.5 metre-thick "bio-intrusion layer" designed to prevent animal intrusion and root penetration. The *"bio-intrusion* layer" comprises a 0.7 metre-thick layer of stony gravel forming a barrier to deep digging animals, a 0.3 metre-thick layer of compacted sand forming a barrier against flora and fauna, and a 0.4 metre-thick layer of uncompacted sand to drain water laterally.
- A 1 to 1.5 metre-thick "infiltration layer" designed to direct water away from the module. The "infiltration layer" comprises a 0.6 metre-thick layer of compacted clay to protect the underlying clay from desiccation, a 0.3 metre-thick layer of un-compacted clay on top of a geosynthetic clay liner, and a 0.6 metre-thick layer of compacted clay.
- A 0.25 metre-thick sand layer to discharge water to the lateral side embankment.

The IRT considers that it would be helpful, in due course, to provide additional information on the expected performance of each of the cover components over time and on any (e.g. physical, chemical) interactions between them; this would improve confidence in estimates of the long-term performance of the cover. Disposal facility construction and operation would precede cover emplacement and so there would be time to conduct tests on the cover and its components as the disposal programme progresses.

The IRT notes that as the proposed design does not include a water collection system in the cover, it might be sensible at the very least to monitor the drainage water flowing through the sand layers in the cover, particularly in the first few decades after cover emplacement. The IRT recommends, however, that ONDRAF/NIRAS should consider including a water collection system in the sand layer under the clay layers of the cover so that the performance of the cover as an infiltration barrier can be monitored and proper drainage of the cover verified. Otherwise, monitoring of the state of the cover would largely be limited to visual inspection, and the condition of cover in terms of an infiltration barrier would not be known. Poor drainage could affect the mechanical stability of the cover leading to increased infiltration. The IRT considers that, if well-engineered, such a water collection system need not introduce premature degradation of the cover, but would allow the performance of the infiltration layer to be confirmed through monitoring.

3.3.2.4 Inspection gallery and inspection rooms

The proposed design includes an inspection gallery and inspection rooms beneath the disposal modules. The inspection gallery would be equipped with three water collection drains for each module for monitoring purposes. The inspection rooms could be accessed from the inspection gallery by inspection equipment (e.g. robots). The height of the inspection rooms and the size of the inspection room openings in the proposed design would, however, prevent access by humans.

The IRT considers that the November 2011 Safety Report could have provided more information on the benefits and detriments of including the inspection rooms and galleries in the design. Further information on this topic was provided during the second review meeting in the form of a presentation (Bastiaens 2012a); the IRT recommends that some of this additional information could be included in an updated version of the Safety Report. It is understood that the requirement for the inspection rooms and galleries derives largely from the local partnerships.

The IRT notes that, in accordance with the proposed design, it is ONDRAF/NIRAS' intent to monitor the integrity of the cover and the filled modules via the drainage system and the inspection rooms and galleries in the base of the modules. The IRT notes that the drains in the base of the modules might only provide an indirect indication of cover performance – this is part of the reason for the recommendation to consider including a water collection system in the cover (see above).

The IRT also notes that ONDRAF/NIRAS intends to undertake any necessary repairs to the drainage system during the operational phase; it would be helpful to provide further information on the repair methods that might be used and their feasibility.

The IRT notes the need for the facility to include multiple safety functions and defence-in-depth. The IRT considers that the possibility of backfilling the inspection rooms with a zeolite-based material at the time of closure is promising (because zeolite phases, such as chabazite, are known to occur and may be stable over the long term within degrading cementitious materials, and because zeolites are known to have good sorption properties) and might add further defence-in-depth to the design. The IRT recommends that ONDRAF/NIRAS should continue research into the possibility of backfilling the inspection rooms with alternative materials in order to add further defence-in-depth to the design. The feasibility of methods to emplace such backfill materials and the possible interactions between them and the wastes and concretes of the disposal facility would need to be considered as part of ONDRAF/NIRAS' RD&D programme.

More generally, although during the review ONDRAF/NIRAS provided some information on the possible interactions between the concrete barriers and the wastes and between the concrete barriers and other materials present in the disposal system (ONDRAF/NIRAS 2012d; Gens 2012), the IRT considers that the topic of interactions between materials should be assessed in further detail.

3.3.2.5 Events considered in the facility design process

The IRT notes that ONDRAF/NIRAS has undertaken a broad-ranging analysis of internal and external events that might contribute to loads on the components of the disposal facility. Based on this analysis of events, the following external events were considered in the design of the disposal facility components:

- Earthquakes (monolith, module, steel roof).
- Floods (water collecting building, drainage system, embankment level).
- Extreme climate conditions (steel roof).

With regards to earthquakes, the disposal system is designed to resist certain reference levels of seismicity. Three reference seismic events have been considered:

- A Design Basis Earthquake (DBE) during the operational phase 1a (~50 years).
- A DBE in the period until the end of the nuclear regulatory control phase (~350 years).
- A Beyond Design Basis Earthquake (BDBE) in the period until the end of the isolation phase (~800 years).

With regards to floods, ONDRAF/NIRAS has assessed the frequency of flooding at the site to be less than 10^{-7} per year for both the current climate state and potential future climate states. The maximum simulated water level near the site which might occur as a result of breaching of the dike is 25.2 metre TAW (Tweede Algemene Waterpassing – see Chapter 8 of the November 2011 Safety Report), which is significantly lower than the proposed level of the disposal facility. The flood risk probability of 10^{-7} year equates to a value of 24.75 metre TAW.

With regards to extreme climate conditions, the following initiating events have been considered:

- Loads imposed on steel the roof by snow.
- Loads imposed on the steel roof by winds and tornadoes.
- Loads created by temperature differences between the outdoor air and the steel and concrete components.

With regards to settlement, after filling a maximum total vertical displacement of the modules of 153 mm is calculated. Along the transverse axis of the disposal facility, maximum differential settlements are calculated of between 22 mm and 35 mm over the 25.4-m width towards the central gallery. Along the longitudinal axis of the disposal facility, a maximum differential settlement of between 21 mm and 33 mm is calculated for the outer modules over the 27.4-m length. After construction of the multi-layer cover, total settlements of the modules are between approximately 252 mm and 326 mm.

With regards to bearing capacity the assessed capacities are:

- Module walls: 235 kPa.
- Filled modules (no cover): 300 kPa.
- Modules with cover: 400 kPa.

The IRT considers that the design analysis process has considered the most relevant features, events and processes.

3.3.2.6 Construction sequence

Module construction is briefly described in Section 8.7 of the November 2011 Safety Report (ONDRAF/NIRAS 2011g). A specific presentation on the construction sequence was given by ONDRAF/NIRAS during the review meeting (Bastiaens 2012e).

The disposal modules would be constructed in several phases. The construction sequence has been derived based on modelling of several possible sequences. A key aspect is that in order to maximise radionuclide containment and retention, there should be no joints in the walls of the facility.

Filling of the modules using a four-by four pattern has been adopted in order to minimise the potential effects of settlement (Bastiaens 2012e).

In closing the disposal facility, all voids between the modules would be filled and a lateral side embankment would be created to provide a gradual transition from the multi-layer cover to surrounding ground level. This would contribute to the drainage of water from the earth cover away from the modules.

The IRT considers that ONDRAF/NIRAS has presented appropriate information on the construction sequence for the proposed facility.

3.3.2.7 Feasibility and demonstration tests

To test and further substantiate the technical feasibility of the proposed design, ONDRAF/NIRAS has prepared a number of prototypes caissons, conducted a demonstration test that involved constructing part of the module including the inspection gallery and inspection rooms, undertaken a test to monitor the subsidence of the ground under a weight comparable to that of a filled module, and will construct a test cover to study the behaviour of the cover layers over a period of several decades (e.g. ONDRAF/NIRAS 2010a).

The demonstration test involving the disposal module includes the drainage layer at the bottom, the embankment of sand and cement, the foundation slab, the columns beneath the monoliths and the floor of the inspection area, as well as part of the module walls and the inspection gallery and rooms. The demonstration test was aimed at evaluating the construction techniques and their phasing, and monitoring a number of construction parameters to substantiate the design in detail.

As fractures usually develop in cement-based materials, limiting shrinkage-related cracks and construction joints was of significant importance. A defined construction sequence was followed. The walls were constructed first and then a non-traversing formwork was used. Measures were taken to limit friction at the bottom of the walls and the internal formwork was loosened shortly after pouring the walls. The slabs and columns were constructed after the walls; coupler systems were used to connect the rebars and, thus, limit the development of cracks at the joints between the slabs and the walls.

The demonstration test also provided an opportunity to trial an on-site concrete plant. Detailed construction techniques evaluated during the demonstration test included the sliding enhancing elements underneath the walls, the use of teflon elements and steel plates, the construction of connections between the walls and the slabs, the concrete compaction method, i.e. the use of internal concrete vibrators and external formwork vibrators. With regard to concrete mixture preparation, tests were performed on the mixing sequence, the control of the water content, the concrete composition, the type of super-plasticizer, aggregate provenance, and concrete curing. Sampling and testing were also part of the concrete properties assessment.

The module demonstration test provided various positive observations with regard to the concrete mixture and its production, and in terms of temperature and compressive strength requirements. In addition, no cracks were observed in the columns or slabs. Some negative observations were identified in the tests, however:

- Cracks were found on the upper parts of the walls.
- The workability of the concrete was low during wall construction and, locally, the compaction of the concrete in the walls was insufficient.
- Minor amounts of secondary concrete phases were observed to form.
- The high density of concrete reinforcements complicated the compaction of the concrete.

One effect of cracking of the module base might be to reduce the likelihood of bath-tubbing. However, solid concrete will always contain a certain non-negligible amount of water (e.g. NEA 2012a). Even under partially-saturated conditions, diffusion could cause transport of radionuclides to other parts of the barrier system. The IRT recommends that the forward programme of RD&D should consider and investigate the development of saturation and permeability within the different waste stacks (columns), with the aim of better quantifying the potential for radionuclide transport.

The effects of poor construction and poor closure may also need to be evaluated, and this analysis could be started using data from the demonstration tests at the site. For example, the effects of loading on the structures will need to be followed in order to assess the effects of the possible seismic hazard. Another example would be an analysis of the potential effects of poor construction leading to inadequate drainage of the cover.

As a result of the observations made during the tests and trials, ONDRAF/NIRAS undertook further work to tackle the observed problems and improve curing conditions on top of the wall. External formwork vibrators were used in conjunction with internal compaction, and the super-plasticizer was changed to prolong and improve the workability of the concrete. The result was that the workability of the concrete was improved and no fractures occurred on top of walls (i.e. the feasibility of constructing modules with walls 11 m-high was demonstrated). The compaction is now sufficient, with limited visible flaws, and interfaces between concrete phases are not visible. However, the high density of reinforcement still complicates compaction and additional consideration may be warranted.

In summary, ONDRAF/NIRAS has demonstrated the technical feasibility of constructing the caissons, monoliths, modules, inspection gallery and rooms by conducting various tests and trials at the proposed disposal facility site. These tests and trials have led to improvements in the construction techniques. The IRT considers that the tests and trials have provided valuable information that may be used to further improve the system design and enhance the various construction techniques, construction sequences and inspection equipment (e.g. the inspection robot for use in the inspection rooms). The IRT also considers that the full-scale demonstration tests at Dessel are an effective means of communicating information on the disposal facility to stakeholders.

3.3.2.8 Quality assurance and quality control

The facility would be designed and constructed following best engineering and international practices, and in accordance with a QA/QC system. Chapters 7 and 8 of the November 2011 Safety Report identify and describe the elements that ONDRAF/NIRAS expects to include in the future QA/QC system.

The IRT considers that ONDRAF/NIRAS has developed sensible plans for how to handle, process, and store the waste packages (i.e. carry out production tests in an accredited facility, design special equipment to ensure that waste deposition into the monoliths will not damage the caissons, protect the monoliths during transportation to the module, etc.).

Section 8.9.2 of the November 2011 Safety Report indicates that certificates would be required verifying the quality of raw materials, and that future contracts would include various requirements on contractors to work in accordance with defined procedures:

- Hold points and controls would be established to allow ONDRAF/NIRAS to verify the quality of work and products.
- In addition to a mandatory ISO 9001-certified quality management system, the Section 8.9.2.2 of the November 2011 Safety Report indicates that a technical file containing organisational and technical details for product manufacture would have to be developed and maintained.
- In addition to detailed information on product manufacture, ONDRAF/NIRAS would require contractors to provide records of any non-conformances.

Chapter 8 also describes a "self-controlling programme" that ONDRAF/NIRAS foresees using as a means of monitoring, and gaining confidence in, contractors' products and services. Chapter 8 indicates that ONDRAF/NIRAS plans would include unannounced inspections or visits.

More details on the QA/QC programme for the construction of the caissons, monoliths and modules were provided during the review week (Coppens 2012). As concrete is a major component in the disposal system, ONDRAF/NIRAS has planned to test the quality of the caissons and concrete specimens periodically using both destructive tests and non-destructive tests.

The IRT notes that ONDRAF/NIRAS proposes to develop the QA/QC programme in a progressive manner and that so far, only initial planning work has been carried out. Nevertheless, the IRT considers that ONDRAF/NIRAS' planning efforts seem generally adequate and thorough.

The materials of the engineered barrier system are generally well known, but the properties of the engineered barriers affecting long-term safety will need to be monitored through rigorous application of the QA/QC programme. The IRT considers that concrete shrinkage will be a key parameter to consider.

3.3.2.9 Robustness of the design

The IRT notes that the design of the disposal system is based on the multi-barrier concept and that the design has been developed taking into account the characteristics of the site and local environment; this is evidenced, for example, by ONDRAF/NIRAS' settlement test and the research programmes carried out to measure groundwater levels and assess the potential for seismic activity.

The proposed disposal facility would be highly-engineered and constructed in accordance with best engineering practice. The proposed design is similar to, and in some sense is derived from, two other fully licensed and operating disposal facilities for short-lived radioactive wastes: the Centre de l'Aube in France and El Cabril in Spain.

The IRT notes that, in detail, the design proposed for implementation at Dessel in Belgium includes barriers with increased thicknesses and/or strengths as compared with some of the similar operating disposal facilities. For example:

- The amount of steel re-enforcement.
- The thickness of the sand layers beneath the modules.
- The thicknesses of the module walls.

The IRT notes also that the proposed engineered barrier system would be composed of materials for which there is good knowledge of their properties and behaviour. This allows the long-term performance of the engineered barriers to be assessed with more confidence. For instance, the modules are constructed using reinforced concrete, which is a versatile construction material. Concrete also provides a highly alkaline environment that tends to limit the corrosion of embedded steel reinforcement. ONDRAF/NIRAS has described its understanding of the potential behaviour and degradation of the cementitious engineered barriers in Chapter 5 of the November 2011 Safety Report (see Section 3.4).

The IRT considers, therefore, that ONDRAF/NIRAS' design process has led to a design that clearly aims at favouring robustness of the system and of the safety assessment (NEA 1998, IAEA 2003).

3.3.3 Summary of IRT conclusions

The proposed disposal facility would be highly-engineered and constructed in accordance with best engineering practice.

The proposed design concept accords with the long-term safety strategy (i.e. it should provide the required safety functions), and has been adapted to the waste inventory and the characteristics of the site and the local environment. The proposed design also takes account of the contextual requirements on the disposal system (e.g. for monitoring and retrievability).

The IRT notes that the proposed engineered barrier system would be composed of materials for which there is good knowledge of their properties.

The IRT notes the particular importance of the multi-layer cover in minimising water percolation into the modules over long time periods, and recommends, therefore, that the mechanical stability of the cover should be further assessed, particularly for the situation of poor drainage of the cover.

The IRT considers that the accumulation of water inside the disposal module base should be avoided and, therefore, recommends that ONDRAF/NIRAS should consider including a water collection system in the sand layer under the clay layers of the cover so that the performance of the cover as an infiltration barrier can be monitored and proper drainage of the cover verified.

The IRT notes the need for the facility to include multiple safety functions and defence-in-depth. The IRT considers that the possibility of backfilling the inspection rooms with a zeolite-based material at the time of closure is promising and might add further defence-in-depth to the design. The IRT recommends that ONDRAF/NIRAS should continue research into the possibility of backfilling the inspection rooms with alternative materials in order to add further defence-in-depth to the design.

The IRT notes that ONDRAF/NIRAS has undertaken a broad-ranging analysis of internal and external events that might contribute to loads on the components of the disposal facility. The IRT considers that the design analysis process has considered the most relevant features, events and processes. The IRT considers that ONDRAF/NIRAS has presented appropriate information on the construction sequence for the proposed facility.

ONDRAF/NIRAS has demonstrated the technical feasibility of constructing the caissons, monoliths, modules, inspection gallery and rooms, roof and cover by conducting various tests and trials at the proposed disposal facility site. These tests and trials have led to improvements in the construction techniques. The IRT considers that the tests and trials have provided valuable information that may be used to further improve the system design and enhance the various construction techniques, construction sequences and inspection equipment (e.g. the inspection robot for use in the inspection rooms). The IRT also considers that the full-scale demonstration tests at Dessel are an effective means of communicating information on the disposal facility to stakeholders.

The facility would be designed and constructed following best engineering and international practices, and in accordance with a QA/QC system. The IRT notes that ONDRAF/NIRAS proposes to develop the QA/QC programme in a progressive manner and that so far, only initial planning work has been carried out. Nevertheless, the IRT considers that ONDRAF/NIRAS' planning efforts seem generally adequate and thorough.

In terms of the documentation, the IRT considers that in general the November 2011 Safety Report (version for the peer review) contains adequate information on the design of the disposal facility. For example, the design information provided is detailed enough to enable long-term safety assessment. The IRT considers, however, that it would be helpful, in due course, to provide additional information on the expected performance of each of the cover components over time and on any (e.g. physical, chemical) interactions between the materials to improve confidence in estimates of long-term performance.

3.4 Scientific and technical basis for the safety assessment

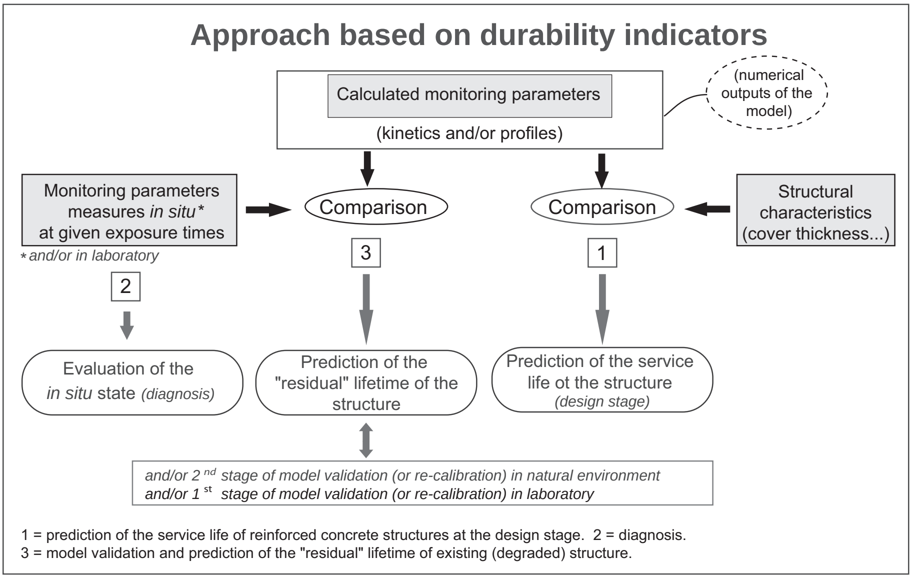
3.4.1 Documents reviewed

The IRT's review of the scientific and technical basis for the safety assessment is based on relevant parts of ONDRAF/NIRAS (2010b; 2011d; 2012f), as well as on ONDRAF/NIRAS' responses to the IRT's questions (ONDRAF/NIRAS 2012a,d), and ONDRAF/NIRAS' presentations provided during the peer review meetings and site visit.

Chapter 5 of the November 2011 Safety Report (ONDRAF/NIRAS 2011d), "Knowledge of the Phenomenological Issues of the Engineered Barriers in their Environment" starts with descriptions of the role of the cover as a protection system for the underlying cementitious structures and of its long-term evolution. Potential cover erosion processes caused by water, flora, fauna, sliding, earthquakes, etc., are discussed. The chapter then describes the cementitious materials and the various physical and chemical processes that may potentially affect the proposed barriers.

The next section of Chapter 5 covers the "service life" of the concrete barrier system. Cracking, carbonation and decalcification are identified as the major potentially detrimental processes. A novel approach, based on the use of durability indicators, is presented for evaluating the durability of the concrete structures (Figure 3.6) (Baroghel-Bouny 2006). Figure 3.6 illustrates the text provided in Section 5.5.7.2 of Chapter 5. Simple, but particularly relevant measurable/observable parameters (durability indicators) had been defined (e.g. water accessible porosity, gas permeability, water permeability, portlandite concentration, etc.). Depending on individual issues, including their constituting processes and models, the durability indicators offer a way to easily compare "what is" and "what is not expected" during the period of institutional control. Differences in predicted and observed/measured (*in situ* and in lab) parameter values will help adapting/re-calibrating the underlying models. The IRT notes the approach proposed by ONDRAF/NIRAS and encourages ONDRAF/NIRAS to continue to develop and apply it in order to confirm the service life estimates.

Figure 3.6: Schematic of ONDRAF/NIRAS' proposed approach to estimating the "service life" of concrete components, as developed by LCPC (Baroghel-Bouny 2006)



The next section of Chapter 5 discusses the long-term (chemical) evolution of the concrete system. This section also summarises the long-term evolution of radionuclide retention based on a K_d concept, presents K_d values as a function of concrete degradation state, and discusses the uncertainties in the light of solutes potentially present.

Finally, the conclusion to Chapter 5 includes a list of key uncertainties that might impact on the long-term evolution of the engineered barrier system.

3.4.2 Detailed review findings

The following topics were considered in detail during the peer review:

- Cover erosion rates.
- Concrete dissolution.
- Concrete cracking.
- Concrete carbonation.
- System heterogeneity and partial saturation.
- Radionuclide sorption.
- Monitoring engineered barrier system performance.

The following sub-sections address each of these topics.

3.4.2.1 Cover erosion rates

Page 5-5 of the November 2011 Safety Report suggested that in the absence of vegetation on the cover, the average erosion rate would increase, but would not exceed 10 mm per year. The IRT noted that the source of this data was unclear. In its response to the IRT's questions on this topic (ONDRAF/NIRAS 2012d), ONDRAF/NIRAS noted that:

- Long-term erosion rates had been calculated using the WATEM-SEDEM model, as described in NIROND-TR 2010-03 (ONDRAF/NIRAS 2010b).
- The erosion rates were calculated for a system consisting of the cover on top of the module with a 10% slope and consisting of the biological layer, bio-intrusion layer and infiltration barrier, and a side slope with a slope of 1:2 or 1:3 consisting of a biological layer and bio-intrusion layer.
- Erosion rates of between 0.35 metre and 0.5 metre in 10 000 years were calculated for 1:2 or 1:3 side slopes. These rates correspond to rates of ~5 x 10^{-2} mm per year.
- The value assumed in the safety assessment corresponds more or less to the assumed erosion rate for NE Belgium (about 1 metre in 10 000 years).
- The current facility design has a slope for the top of the cover that is lower than the 10% slope used in the calculations (5% instead of 10%).
- Bare soils are very rare in the climatological conditions for NE Belgium and the materials in the cover will be chosen in such a way that it can support vegetation.

The IRT considers that the assumed erosion rates seem traceable and reasonable, but that further data from the test cover should also be considered as it is collected. In addition, the IRT recommends that the possibility of localised more severe erosion of the cover should be considered.

3.4.2.2 Concrete dissolution

Section 5.6 addresses the long-term evolution of the cementitious barrier materials. The evaluation is based on a state-of-the-art batch-type model of cement degradation and considers the four well-established states of cement degradation (e.g. NEA 2012a). In its analysis, ONDRAF/NIRAS considers various types of leaching solutions. The large variability of literature experimental and model data was investigated with a series of models to bound the uncertainties and the final rate of leaching was selected by a sensible combination of pessimistic assumptions. The IRT concludes that the resulting leach rates are sensible under the given assumptions and considering the available thermodynamic data for cementitious materials. The IRT, however, notes the following points:

- The potential neo-formation of clay-type and zeolite-type materials is not considered. Such new mineral formation could substantially change the evolution and quality of the porosity and subsequently the disposal facility water saturation characteristics.

- The report does not deal with the long-term chemistry of silicon. This is probably related to the fact that siliceous aggregates are not used because of the potentially adverse alkali-silica reactions. However, dissolved silica is unavoidable in leaching solutions and is also released when calcium-silica-hydrate (CSH) gel degrades. At least a semi-quantitative discussion on the long-term mass balances of silicon seems necessary.
- As pointed out by ONDRAF/NIRAS, the coupling between water transport as both gas and liquid with geochemical changes is under development (ONDRAF/NIRAS 2011e). It is a matter of fact that difficulties in dealing with coupled systems arise from local system heterogeneities. In the long-term, localised chemically-induced changes in transport pathways could become relevant. At least a prospective discussion, relying on the scientific findings obtained so far, shedding some light on these issues, seems necessary.

3.4.2.3 Concrete cracking

Cracking is an issue that is also considered very important by ONDRAF/NIRAS. The importance of cracks is indicated by a several page long and very well written high-quality discussion on cracking in Chapter 5 of the November 2011 Safety Report (Section 5.5.3.2). This discussion provides very valuable information on the expected behaviour of the system concerning cracking. The IRT notes the detailed discussion provided on the interplay between cracking and self-healing. The text acknowledges that it is good practice to rigorously control design, curing conditions and construction sequences to prevent the system from building up a potentially connected network of transport pathways with enhanced transport properties. The conclusion to the section in the November 2011 Safety Report is that cracks likely to form “should” remain relatively limited and shallow. This may be the expected case; however, ONDRAF/NIRAS does not demonstrate convincingly that cracks cannot penetrate fully through the EBS with time. The IRT recommends that ONDRAF/NIRAS should indicate the potential consequences of a system malfunction (i.e. when part of the cracked network really penetrates fully through the structures). In summary, the IRT notes that cracking will occur over different timescales, and recommends that ONDRAF/NIRAS should attempt to quantify to what degree through-going cracking may be acceptable in the first 350 years, rather than assuming through-going that cracking does not occur.

3.4.2.4 Concrete carbonation

Carbonation has been identified as a major process leading to adverse effects, particularly in the short term.

In the November 2011 Safety Report ONDRAF/NIRAS discusses the possible extent of “external” carbonation (i.e. carbonation caused by carbon dioxide from outside the wastes). ONDRAF/NIRAS has indicated that carbonation of concrete results in reduced porosity because the calcite precipitated has a molar volume greater than that of portlandite. The IRT asked if carbonation could cause cracking as well as porosity reduction. In its response to the IRT’s questions on this topic (ONDRAF/NIRAS 2012d), ONDRAF/NIRAS cited several published research papers (e.g. Glasser and Matschei 2007) that support the assumptions that carbonation will not cause cracking because the pore space available and the potential for recrystallisation are sufficient to accommodate calcite formation.

The IRT notes that the wastes will include organic materials in the form of resins, ion exchangers, etc., that may degrade. It is presently unclear, on which path such degradation will proceed. It is conceivable that, under strongly reducing conditions, only methane will be produced; but it is also conceivable that the degradation will produce carbon dioxide (or a mixture of carbon dioxide and methane). The kinetics of such processes and the potential impact of biological activities are not yet understood in great detail. This potential for "internal" carbonation was not discussed by ONDRAF/NIRAS in Chapter 5 (in the November 2011 version for peer review) reviewed by the IRT.

The IRT asked if sources of carbon dioxide within the modules (e.g. in the wastes) had been considered in ONDRAF/NIRAS' evaluation of the extent of carbonation. In its response to the IRT's questions on this topic, ONDRAF/NIRAS noted that carbon dioxide sources within the modules had not been considered in the evaluation of the carbonation process, but that (ONDRAF/NIRAS 2012a):

- Burnable wastes, in particular cellulosic wastes, are incinerated.
- Temperatures and radiation dose rates will be too low to induce degradation of the organic fraction of the wastes to such extent that they will contribute to carbonation.
- As long as the engineered barrier system keeps its integrity, the absence of free water in the waste packages will limit any microbial activity and, thereby, minimise the generation of carbon dioxide from biodegradation of cellulosic waste.
- Other organics present (e.g. ion exchange resins embedded in polymer matrices or cement, PVC) are not easily metabolised by microorganisms.
- In the long term, the high pH of percolating water is not an appropriate environment for sustaining microbial activity (even if local niches might to some extent eventually develop).
- The small amount of carbon dioxide which should eventually be produced in the waste package will react with the cementitious matrix used for the immobilisation of the waste in the primary packages.

The IRT notes these points, but recommends that the arguments in the Safety Report should be further strengthened by adding discussions of what the consequences might be if particular assumptions in the preceding bullet points were not achieved in practice.

The IRT considers that sources of carbon dioxide within the modules (e.g. in the wastes) should be considered in evaluating the possible maximum extent of carbonation and that the evaluation should be kept up to date by using information on the wastes actually accepted for disposal. This could, for example, be done on the basis of simple overall mass balance considerations to bound maximum achievable impacts.

The IRT notes that the monoliths will include a variety of other chemicals whose reactions with the cementitious barriers are not mentioned in Chapter 5 (in the November 2011 Safety Report). Of particular interest are corroding metals. Apart from producing hydrogen, the resulting hydroxides react with cement constituents and may lead to internal degradation. Such reactions should at least be discussed and estimates of their potential extent should be provided.

The potential for microbial activity in the wastes leading to carbon dioxide production may be limited by controlling the free water content of the waste packages as pointed out by ONDRAF/NIRAS. Even so, the IRT recommends that the ongoing research programme should probably have as one of its aims better quantification of the potential for microbial activity and gas generation in the disposal facility.

3.4.2.5 System heterogeneity and partial saturation

Various chemical reactions within caissons and drums filled with waste and backfilled with grout (e.g. corrosion of metals, degradation of organic matter, reactions with salts, and reactions of iron corrosion products with cementitious constituents) may proceed if they are thermodynamically and kinetically favoured. Such chemical reactions may produce gas (e.g. hydrogen or methane) or consume water (e.g. metal corrosion). Within the caissons and waste drums, the distribution of materials will be spatially heterogeneous, potentially also including voids. This may lead to situations where the porosity is partly filled with aqueous solution and partly filled with gas, and this could potentially lead to spatially distinct reaction zones within the caissons and drums. The IRT notes that such issues are not addressed by ONDRAF/NIRAS in Chapter 5 of the November 2011 Safety Report. The IRT considers that these are not critical issues within the first 350 years, but that it would be sensible to acknowledge and address them in ongoing RD&D studies or plans for future studies. In summary, the IRT considers that system heterogeneity and partial saturation call for further RD&D on the coupling of chemical reactions with water and gas transport at the drum/caisson scale.

Humidity within the monoliths will be controlled by the surrounding natural system and by the roof construction which is designed to protect the monoliths from water. However, a "bath-tubbing" effect in which the wastes are partially saturated with water cannot be completely ruled out. The kinetics of degradation reactions at the water table level might increase due to potentially intensive evaporation and condensation processes, leading to enhanced solute transport at this particular position. The IRT recommends, therefore, that ONDRAF/NIRAS should consider the possible effects of varying water saturation levels on the chemical degradation of the monoliths. Such effects may also impact on the evolution of redox conditions.

3.4.2.6 Radionuclide sorption

Section 5.7 of the November 2011 Safety Report describes the distribution coefficient (K_d) values assumed for the changing chemical environment in concrete degradation states I to IV. ONDRAF/NIRAS provides K_d values that have already been reviewed by an international expert panel and associates substantial uncertainty ranges to these values. The IRT has no further comments on these data (some specific questions were raised in the 2nd questionnaire – see ONDRAF/NIRAS 2012d). Sub-section 5.6.7.2 of the November 2011 Safety Report discusses the impact of chloride on these K_d values and classifies the elements as being subject to high, medium or low impact. Although such a type of discussion is necessary and highly welcomed, the IRT found that the argumentation presented is often unclear and difficult to follow. The IRT recommends that the clarity of the arguments in this section of the Safety Report should be reviewed.

3.4.2.7 Monitoring engineered barrier system performance

In several places, Chapter 5 mentions monitoring and *in situ* experiments as active measures that would be used to corroborate the hypotheses made regarding the assumed service life of the facility. Examples are the humidity measurements, the sampling of drainage fluids and, in particular, an RD&D program focusing on cracking and its potential impact on carbonation and reinforcement corrosion. It is not clear what would/could sensibly be measured from a chemical perspective or what actions would be taken if a measurement or observation was to differ from the expected result. Chapter 5 (in the November 2011 Safety Report) suggests that chemical changes will most likely occur very slowly, such that they would probably not be significant and may not even be observable before the end of the regulatory control phase (~350 years). For the expected case, therefore, monitoring would probably only show up potentially adverse chemical changes after long observation periods. The IRT notes that such long observation periods pose both technical and organisational questions for monitoring. Although ONDRAF/NIRAS recognises these issues, the IRT, nevertheless, recommends that further consideration should be given to developing plans for monitoring and remedial action strategies that are logical and feasible to implement over the ~350 years period during the nuclear regulatory control period.

3.4.2.8 Remaining uncertainties

Chapter 5 of the November 2011 Safety Report (ONDRAF/NIRAS 2011d, page 48) identifies the following "major uncertainties in the long-term evolution of the concrete components":

- Initial conditions of the cementitious engineered barriers determined by construction and closure activities.
- Degree of saturation of the cementitious engineered barriers and its time evolution.
- Effects on concrete components of a beyond design basis earthquakes sooner than expected.
- Time for initiation of major cracks impacting the performance of the engineered barriers.
- Characteristics of the cracks (aperture, pattern) and the time-evolution of the cracks.
- Effect of cracks on water flow in cementitious components.

- Effect of cracks on heterogeneity of chemical conditions in cementitious components.
- Influence of physical properties of cementitious components on rate of leaching.
- Physical properties porosity, tortuosity, diffusivity, dispersivity, permeability of partially degraded cementitious barriers.
- Amount of water needed to leach state III and evolution of pH and Ca concentrations during state III.
- Coupling between water flow evolution and chemical evolution of cementitious barriers.
- Radionuclide sorption values onto cementitious barriers, in particular sorption values for state III, impact of chloride and of cellulose.
- Effects of chlorides in some specific waste streams on radionuclide retention and on performance of reinforced concrete barriers.
- Effects of cellulose on radionuclide retention onto cementitious engineered barriers.

The IRT considers that ONDRAF/NIRAS has identified the major uncertainties that need to be considered (e.g. through one or more of scoping studies, performance and/or safety assessments, and further research). The IRT has focussed in particular on the degree of saturation, the hydrological effects of cracking, and interactions within the EBS including with the wastes.

3.4.3 Summary of IRT conclusions

Chapter 5 of the November 2011 Safety Report (ONDRAF/NIRAS 2011d) provides a lot of sound and relevant technical information and gives a very comprehensive summary of the phenomenological issues of the engineered barrier system.

ONDRAF/NIRAS has taken a sensible scientific approach to the consideration of concrete performance, supported by an on-going programme of research, development and demonstration. The descriptions of the many processes demonstrate a good scientific understanding of how the complex system may behave over the long term. The IRT considers that ONDRAF/NIRAS' description of the phenomenological issues of concrete (e.g. carbonation, cracking, decalcification, corrosion of reinforcement) offers suitable and relevant support for the long-term safety assessment. The IRT notes that specific RD&D studies and literature reviews have been conducted to gather pertinent information with which to improve the understanding of concrete behaviour and enhance the design of the engineered barriers. Reasonable design measures and implementation procedures have been proposed for limiting adverse effects of potentially detrimental processes.

The structure of Chapter 5 is appropriate; starting with the earth cover, demonstrating that the system will most likely "survive" the envisaged service lifetime and, finally, describing the long-term (chemical) evolution and the impact of chemical changes on radionuclide retention.

Processes that have potentially the most significant impacts on disposal system performance are identified to be carbonation, decalcification, cracking and the development of humidity. All these processes are addressed in sufficient detail. Processes that may potentially disturb the system under given and future environmental conditions are discussed. It is demonstrated that none of these unfavourable processes would affect the safety functions even under conservative or extreme parameter assumptions. The IRT concludes that most conceivable detrimental processes have been addressed to a sufficient level of detail – a small number of exceptions are noted above in Section A3.4.2.

The present state of the art in scientific and technical knowledge on concrete (e.g. chemical behaviour, carbonation, degradation) is correctly presented. For example, the approach to representing the long-term dissolution of concrete and the chemical evolution of cement pore waters is considered to be state of the art. The conclusions drawn by ONDRAF/NIRAS in the November 2011 Safety Report regarding the key processes that may occur in the concrete barriers and their importance seem appropriate, but some assumptions remain uncertain (e.g. relating to cracking and water flows). These technical limitations (e.g. the development of concrete permeability, cracking issues) are being evaluated and will be taken into account.

Uncertainties that need further consideration have been identified and a RD&D programme is in place.

ONDRAF/NIRAS has presented a novel approach for evaluating the durability of the concrete structures based on the use of durability indicators, as developed by LCPC (Baroghel-Bouny 2006).

The analysis presented by ONDRAF/NIRAS in Chapter 5 suggests that the service life of the concrete engineered barriers ought to be at least 350 years. The IRT notes the approach proposed by ONDRAF/NIRAS and encourages ONDRAF/NIRAS to continue to develop and apply it in order to confirm the service life estimates. The IRT notes that concrete will crack, which may change the characteristics of potential transport pathways, but that at the same time it may well be that the concrete barriers retain some of their beneficial properties (e.g. chemical properties) for much longer than 350 years.

Generally, Chapter 5 of the November 2011 Safety Report is well written and is at a high scientific level. In particular, Sections 5.5.3 to 5.5.7 provide good discussions on concrete cracking, leaching, and carbonation and on the approach to service life estimation based on durability indicators. It was found that carbonation, generally described by a square root of time law, and subsequently the corrosion of reinforcement when carbonation proceeds, are the main phenomenon influencing the service lifetime of the concrete structures.

On documentation, the IRT notes that the November 2011 Safety Report includes significantly shortened summaries from various supporting reports. There are several cases where the supporting information and the parameters evaluated appear somehow to have been taken out of their original context and where the reader would wish to see more information from the supporting report. Many of these cases have been addressed in ONDRAF/NIRAS' answers to the second NEA questionnaire (ONDRAF/NIRAS 2012d). The Safety Report chapter would, however, certainly benefit from including some of the additional information contained in the answers to the questionnaire.

An example is that ONDRAF/NIRAS' answers to the second questionnaire (ONDRAF/NIRAS 2012d) include additional design details such as the material requirements of the different barriers (i.e. soil, clay, sand, etc) or the construction sequence which, although maybe tentative, are already available and would be good to include in the Safety Report. This would allow readers to better understand the arguments used in drawing certain conclusions (e.g. that the chloride content in the clay is to be limited to between 10^{-2} to 10^{-3} mol, in order to reduce risk of de-passivation of concrete reinforcement).

The IRT notes that the chapter might also be improved by providing more defined plans and measures for handling uncertainty in cases where unexpected or undesired situations may arise. For example, Section 5.5.6 notes an assumption that the modules will only be exposed to the air for 50 years. In reality, it is possible that the operational period may be extended beyond 50 years. The Safety Report might be improved if it addressed such uncertainties in order to provide added assurance to regulators and other stakeholders.

3.5 Long-term safety assessment methodology and results

3.5.1 Documents reviewed

The IRT's review of long-term safety methodology and results is based on relevant parts of Chapter 14 of the November 2011 Safety Report (ONDRAF/NIRAS (2011h; 2012e), as well as on ONDRAF/NIRAS' responses to the IRT's questions (ONDRAF/NIRAS 2012a,d), and ONDRAF/NIRAS' presentations provided during the peer review meetings and site visit (e.g. Vermariën and Cool 2012a,b,c).

Chapter 14 of the November 2011 Safety Report summarises a series of safety and performance assessment calculations that were undertaken with the aims of (i) demonstrating that the Category A disposal facility would comply with the relevant safety criteria (ii) evaluating the possible performance of the disposal system and (iii) providing inputs to the setting of appropriate limits on the types of wastes that can be accepted for disposal in the facility. On the other hand, In Sections 14.10 and 14.12 related to "performance analysis" and to "lines of reasoning for establishing confidence in long-term safety of disposal", respectively, were not available for peer review. The IRT got insights on these topics during the peer review week (Vermariën and Cool 2012b; Cool 2012). Consequently, the IRT's assessment of, in particular, the uncertainty analysis and the safety margins that would be provided by the proposed disposal facility is limited.

3.5.2 Detailed review findings

ONDRAF/NIRAS is applying a systematic methodology for assessing the long-term safety of the proposed disposal facility for Category A radioactive wastes. ONDRAF/NIRAS's safety assessment methodology includes six main steps:

- Definition of the assessment context.

- Development of the assessment basis.
- Scenario development.
- Model formulation (models, assumptions and data).
- Conduct of safety analyses.
- Interpretation and presentation of results.

The assessment methodology would be applied in an iterative fashion as the disposal programme and the facility are developed, and the assessment results would be used to inform operational criteria and decisions on waste acceptance.

The IRT notes that, in broad terms, ONDRAF/NIRAS's safety assessment methodology includes all of the principal components expected of such assessments and is consistent with safety assessment methods used internationally (e.g. within relevant IAEA and NEA projects – IAEA 2002b; NEA 2012b). The IRT considers that ONDRAF/NIRAS' overall safety assessment methodology is sound, although some detailed questions and observations were identified in the following areas of the safety assessment:

- Assessment context and assessment basis.
- Scenario development.
- Models, assumptions and data.
- Assessment modelling.
- Interpretation and presentation of results.

The following sub-sections address each of these topics.

3.5.2.1 Assessment context and assessment basis

It is clear that in defining the assessment context, ONDRAF/NIRAS has taken account of the relevant the requirements of the Belgian government and regulators (e.g. FANC 2007; 2009a,b; 2010a,b,c,d; 2011a,b[1]), the partnerships and national and international guidance.

The assessment basis is discussed in Sections 3.3 and 3.4 of this report.

3.5.2.2 Scenario development

- Evolution in scenario categorisation

The categorisation of scenarios has changed during the process of the review.

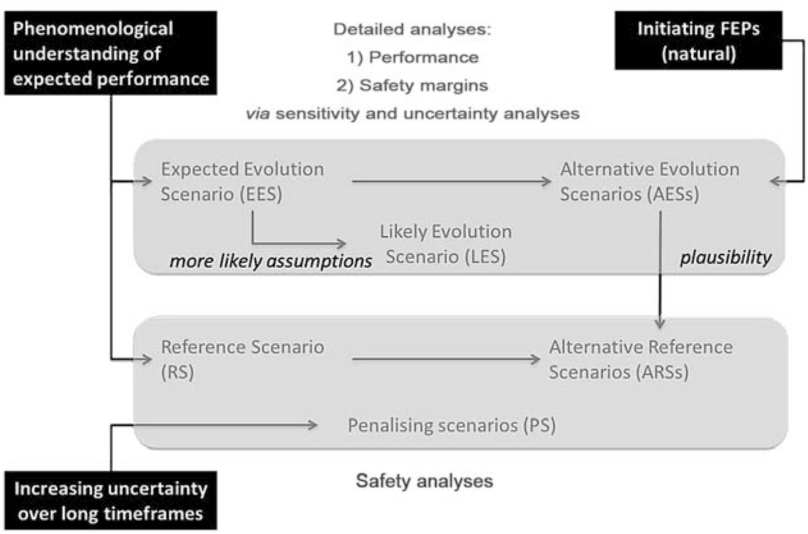
Chapter 14 of the November 2011 Safety Report (ONDRAF/NIRAS 2011m) introduced the Reference Scenario (RS), Alternative Reference Scenarios (ARSs), the Expected Evolution Scenario (EES), Alternative Evolution Scenarios (AES), Human

1. The IRT did not assess the compliance of ONDRAF/NIRAS' Safety Report with the FANC documents. It only satisfied itself to observe that these were taken into account.

Intrusion Scenarios (HIS), and Penalising Scenarios (PS). The Reference Scenario was to be used for demonstrating compliance with regulatory targets, while the Expected Evolution Scenario was intended to be more realistic. The IRT noted, however, that ONDRAF/NIRAS' assessments of both the RS and the EES included a mixture of conservative and optimistic assumptions which meant that the results of the assessments were potentially difficult to understand. Based on review of the November 2011 Safety Report, the IRT was not able to understand clearly whether ONDRAF/NIRAS had considered an assessment case that presented a true "best estimate" of the expected disposal system performance. For example, it was not clear why in the assessment of the EES, the river and associated wetlands were not receptors for radionuclides as well as the water well.

During the peer review week, ONDRAF/NIRAS provided additional information including, a presentation by Vermariën and Cool (2012b) that introduced a new categorisation of scenarios (Figure 3.7). The new scheme, presented in Figure 3.7, includes a Likely Evolution Scenario (LES), which appears to be considered somehow "more likely" than the Expected Evolution Scenario.

Figure 3.7: ONDRAF/NIRAS' scenarios (Vermariën and Cool, 2012b)



- Complexity of the scenario analysis

It is clear from the presentations at the peer review week (e.g. Vermariën and Cool, 2012a,b) and ONDRAF/NIRAS (2012b) that ONDRAF/NIRAS has considered a large number of scenarios and assessment cases, that span the range of scenarios that are usually considered in such safety assessments (human intrusion, normal and altered evolution scenarios) and that address the possible effects of future climate change. The IRT could not review all of the details of the assessment cases described during the second peer review meeting, but considers that the set of scenarios is, in principle, broad enough.

The IRT recognises that there is no single "best" method for scenario development and that the approach may necessarily be country-specific.

The IRT considers, however, that it is complex to comprehend the relationships between the various scenario types defined by ONDRAF/NIRAS. For example, the relationship between the AES and ARS type scenarios. It is also noted that ONDRAF/NIRAS (2012d) only addresses the AES scenario type and does not address ARS type scenarios.

The IRT considers that there are benefits in including both the conservative Reference Scenario and the more realistic Likely Expected Scenario in the safety assessment. The IRT also notes, however, that ONDRAF/NIRAS will need to explain and more fully justify the definition of the scenarios in the Safety Report. The IRT recommends that ONDRAF/NIRAS should identify in the Safety Report the set of parameters values and associated assumptions that it considers represent the best-estimate of disposal system performance.

With regard to the penalising scenario, the IRT notes that this scenario considers "intact" properties for the engineered barrier components up to 2 000 years, followed by a sudden loss of containment thereafter. The IRT recognises that it may be valid to assess a penalising scenario reflecting very unlikely conditions with the view to testing the robustness of the safety of the disposal system. Even in this perspective, however, fixing a time for engineered barrier failure or degradation *a priori* introduces a mixture of hypotheses (optimistic and pessimistic) that makes the rationale for the penalising scenario unclear. In the end, knowing that there are significant uncertainties associated with concrete behaviour and the performance of the multilayer cover system even before 2 000 years, the approach may reduce confidence in the representativeness of the whole assessment. For instance, this leads to the unusual situation in which some radionuclides (e.g. Sr-90 and Cs-137) contribute to calculated potential dose for the EES or the RES, but not for the penalising scenario. The IRT recommends that ONDRAF/NIRAS should explain the rationale for the penalising, or "what if", scenarios considered, making sure that they are based on logically consistent assumptions regarding engineered barrier performance and associated uncertainties.

3.5.2.3 Analysis of climate related effects

Chapter 5 of the November 2011 Safety Report (ONDRAF/NIRAS 2011d, e.g. page 5-34) identifies the possibility that the site of the disposal facility might be inundated by the sea within the next 10 000 years, but this possibility does not appear to have been fully addressed in the safety assessment. The potential exposure pathways considered during the radionuclide screening process were discussed in Section 14.4 of the November 2011 Safety Report, but this section did not appear to address the possibility of disposal facility inundation. The IRT recommended, therefore, that there was need for further clarification of the Safety Report to show that the range of scenarios and potential exposure pathways considered in the safety assessment does indeed "capture" or bound the consequences of future climate change, including events such as marine inundation and glaciation.

In its response to the IRT's questions on this topic (ONDRAF/NIRAS 2012d), ONDRAF/NIRAS noted that:

- Possible future climate evolutions and their consequences on near field, geosphere and biosphere behaviour are described in ONDRAF/NIRAS (2012c).
- Based on a literature review and discussions with climate experts, estimations of future climate changes are summarised in ONDRAF/NIRAS (2012c) for the near future (up to AD 2100), the long term (within the next 10 000 years) and the very long term (10 000 to 200 000 years).
- Marine inundation of the site within the next 10 000 years under warmer climate is one of the two extreme cases considered. The other extreme event consists of an early glaciation (after ~53 000 years).

During the peer review week, ONDRAF/NIRAS provided further information on the treatment of future climate change in the safety assessment (Jacques 2012a,b).

On the basis of all of the information provided, the IRT considers that climate-related effects have been properly taken into account; the IRT recommends that this is made clearer in the Safety Report.

3.5.2.4 Assumed timing of earthquakes

With regards to earthquakes, the disposal system is designed to resist certain reference levels of seismicity. Three reference seismic events have been considered:

- A Design Basis Earthquake (DBE) during the operational Phase 1a (~50 years).
- A DBE in the period until the end of the nuclear regulatory control phase (~350 years).
- A Beyond Design Basis Earthquake (BDBE) in the period until the end of the isolation phase (~800 years).

During the review, the IRT noted that the documentation did not address the possibility of a Beyond Design Basis Earthquake occurring in Phase III (i.e. during the Nuclear Regulatory Control Phase), as this could cause cracking and, therefore, affect the permeability of the disposal facility components.

During the peer review week, ONDRAF/NIRAS provided additional information including, in particular, a draft report entitled "Model assumptions for the cementitious near field of the Dessel near surface disposal facility" (ONDRAF/NIRAS 2012e). This report details a large number of assessment cases that have been considered, including Alternative Evolution Scenario 4 case 3, which assesses the consequences of a major earthquake affecting the facility, including the monoliths, after 350 years (i.e. at the end of the Nuclear Regulatory Control Phase – Phase III). This case therefore assesses the impact of a BDBE at an earlier time than the ~800 years considered in the Expected Evolution Scenarios. The IRT considers that AES4 does go some way to addressing its question, but the

IRT has not seen the results from the safety assessment calculations for AES4; these will presumably be included in an updated version of the Safety Report. In raising this issue, the IRT was seeking reassurance that if the facility were to be damaged by a large earthquake and then for whatever reason not be repaired, the potential consequences would be within an acceptable range.

3.5.2.5 General assumptions and data

- Barrier evolution

ONDRAF/NIRAS has represented the gradual degradation of the engineered disposal facility components using "snapshots" of their properties at specific times. The IRT considers that this approach is valuable as it provides some insight regarding the possible evolution of the disposal system. However, the IRT also considers that ONDRAF/NIRAS should examine the sensitivity of assessed disposal system performance to the selected times at which the engineered components are assumed to degrade.

- Inventory

The IRT's remit did not include making a detailed review of the waste inventory. The IRT notes that the safety assessment presented in the November 2011 Safety Report is based on the waste inventory from 1st January 2008. The IRT requested more detailed information on the estimation of the waste inventory and its radionuclide content. The requested information was provided during the peer review week (Wacquier 2012). The IRT recommends that ONDRAF/NIRAS should include further, more descriptive information on the wastes in the Safety Report.

The IRT notes that the waste inventory will change over time and observes that ONDRAF/NIRAS will monitor changes in waste inventory and plans to maintain sufficient flexibility in its programme so that it can accommodate the wastes.

Determination of the projected inventory of wastes for disposal in the facility (the source term) and the acceptability of particular wastes are addressed in Section 3.5.2.9.

- Near-field hydraulic conductivities

ONDRAF/NIRAS has based the selection of effective hydraulic conductivity values for the concrete components of the disposal facility on results from small scale experiments and inverse calculations performed by IETcc, SCK and CEA (ONDRAF/NIRAS 2012d).

  - From the IETcc experiments, the direct measurement of hydraulic conductivity on cylindrical samples is approximately 4.58×10^{-11} m/s. The IRT notes that no variation or uncertainty is associated with this value.
  - From the SCK inverse calculation, ONDRAF/NIRAS derives a value is of 5.67×10^{-13} m/s and notes that this value lies within a range of 1×10^{-11} to 1×10^{-13} m/s reported for similar concrete in the literature. The IRT notes that uncertainty associated with the selected value is not considered in the assessment and that this value is at the low end of the range cited from the literature.

- ONDRAF/NIRAS indicates that CEA experiments and calculations resulted in values ranging from 2.06 x 10^{-15} m/s to 3.5 x 10^{-15} m/s.

On the basis of this set of data, ONDRAF/NIRAS indicates that the nominal value for the hydraulic conductivity of the concrete matrix for large scale (several metres) objects is 5.67 x 10^{-13} m/s. The values used in safety assessment range from 1.31 x 10^{-12} m/s to 3.41 x 10^{-12} m/s in order to account for a fracture network assumed to be present after manufacturing of the modules. A transition from the nominal values to a degraded value of 3.32 x 10^{-6} m/s is assumed to occur progressively over the period from 350 years to 850 years after disposal facility closure.

With regard to the representation of heterogeneities in the concrete components, the IRT notes that ONDRAF/NIRAS has considered zones of higher hydraulic conductivity that aim at representing the propagation of cracks into the concrete after construction. The assumption that cracks will form and cause zones of higher hydraulic conductivity is sound, but the IRT notes that ONDRAF/NIRAS assumes that initially the cracks will not be connected through the entire thickness of the concrete components ("no through-going cracks") (ONDRAF/NIRAS 2011m, Chapter 14, page 39).

- Hydraulic conductivity of the roof system

The IRT questioned the realism of the initial value of effective hydraulic conductivity assumed for the roof, which in the EES ONDRAF/NIRAS set to 3.41 x 10^{-12} m/s. In its response to the IRT's questions on this topic (ONDRAF/NIRAS 2012d), ONDRAF/NIRAS indicated that that the hydraulic conductivities presented for the cover in the November 2011 Safety Report were based on a cautious assessment of permeability that involved up-scaling matrix properties to the disposal facility scale by assuming a postulated network of fractures. ONDRAF/NIRAS considers this to be a very severe hypothesis for a fibre reinforced concrete of which the impervious top slab within the cover is made. The IRT notes, however, that the nominal selected values are lower than those obtained from experiments on some samples, and considers that this choice seems to be optimistic, particularly considering the larger scale of the disposal facility components as compared to the experimental samples, and the general lack of data on the hydraulic conductivities of initially low permeability components over long timescales (centuries). The IRT notes that there are also uncertainties associated with construction defects, "natural" heterogeneities in the concrete and the presence of interfaces between the disposal facility components. The IRT recommends, therefore, that ONDRAF/NIRAS should carefully justify the selection of the hydraulic conductivity values used in the modelling. It may be that the nominal hydraulic conductivity of concrete components ought to be higher than currently selected.

The IRT notes that the hydraulic conductivities presented in the November 2011 Safety Report and associated reports for the roof system (3.4 x 10^{-12} m/s) and module basis/foundations (1.75 x 10^{-12} m/s) suggest that the hydraulic conductivity of the module base could be lower than that of the roof (e.g. ONDRAF/NIRAS 2012d, page 115). If the roof system was really to be more permeable than the module basis/foundations, then there might be conditions in which the facility could accumulate water, particularly if there was any failure or clogging of the drains, and this might create a "bath-tubbing" effect. ONDRAF/NIRAS is aware of this situation and indicates (ONDRAF/NIRAS 2012d, page 15) that, by design, the cover is not expected to have a higher permeability than the module base. ONDRAF/NIRAS (2012d) also notes that when all components are functioning as intended, the module base is a weaker component than the roof. However, ONDRAF/NIRAS does consider an Alternative Reference Scenario (ARS1) that simulates a transient situation in which the cover is partly degraded but the module base is not degraded. During the peer review week, ONDRAF/NIRAS provided additional information including, in particular, a draft report entitled "Model assumptions for the cementitious near field of the Dessel near surface disposal facility" (ONDRAF/NIRAS 2012e). This report details a large number of assessment cases that have been considered, including AES1-1 case 6 (see pages 147 and 157) which assesses the potential consequences of bath-tubbing and assumes a higher initial value of effective hydraulic conductivity for the roof of 4.73×10^{-12} m/s. The overall peak impact calculated for this scenario is a potential dose of approximately 2.9 mSv/yr; ONDRAF/NIRAS considers this calculated impact to be acceptable because of the low likelihood of the scenario occurring.

▪ Parameter combinations

With regard to page 167 of Chapter 14 in the November 2011 Safety Report (ONDRAF/NIRAS 2011m), the IRT notes that the reference leaching model considers "degraded" values for bulk density, porosity and effective diffusion coefficient for concrete and mortar components, but that initially at least "intact" hydraulic conductivity values are used. The IRT considers that this strategy of mixing "degraded" and "intact" properties makes it difficult to clearly understand whether models simulate behaviour that is likely to occur or behaviours that are more conservative or pessimistic. The IRT recommends that ONDRAF/NIRAS should in the Safety Report explain and justify the selection of parameter values for the disposal facility components and the rationale for mixing different assumptions related to the "intact" or "degraded" characteristics of the components.

3.5.2.6 Modelling assumptions

ONDRAF/NIRAS' safety assessment methodology has been applied in a way that includes several assumptions. Examples are as follows:

- An important assumption is that bath-tubbing will not occur. The IRT considers that assessing the potential impacts of bath-tubbing is a positive point, but considers that ONDRAF/NIRAS should present a stronger justification for the claim that bath-tubbing will not occur, taking into account the uncertainties that exist associated with the hydraulic characteristics of the concrete components over time, as discussed above.
- The assessment of the Reference Scenario:
  - Does not account for radioactive decay of the wastes prior to disposal.
  - Assumes complete and instantaneous dissolution of wastes.
  - Assumes that potentially exposed groups obtain all of their food and water from the contaminated area around the facility.

Overall, the IRT notes the presence of conservatisms, but also considers that some assumptions, e.g., regarding the permeability of the concrete components (e.g. relating to cracking and permeability) may be optimistic – meaning that water flows through the disposal facility might, in reality, be greater than modelled in some of the assessment cases.

The IRT recommends that as the disposal programme progresses, ONDRAF/NIRAS should present safety assessments that better reflect the reasonably achievable properties of the engineered components in order to provide better guidance on optimisation of the engineered barrier system and waste acceptance, and increase confidence in safety assessment results.

3.5.2.7 Biosphere analysis

Based on review of the November 2011 Safety Report, the IRT recommended that further consideration might be given to representing certain biosphere environments (e.g. wetlands) in a more realistic way. The IRT notes that more realism appears to be included in the Likely Evolution Scenario.

At the peer review week, ONDRAF/NIRAS presented some details of the way in which bath-tubbing is modelled, including a slide (Slide 15 of Vermariën and Cool, 2012a) that indicates that in the assessment model, the potential exposure pathway considered involves contaminated water overflowing from the facility and entering the groundwater. The IRT recommends that ONDRAF/NIRAS should consider the possibility of exposure to contaminated water that has overflowed from the facility (by "bath-tubbing") and entered soils and surface waters (e.g. streams).

3.5.2.8 Interpretation and presentation of results

Sections 14.5 to 14.9 of the November 2011 Safety Report (ONDRAF/NIRAS 2011h) summarise a series of safety assessment calculations and results for the Reference Scenario, Alternative Reference Scenarios, the Expected Evolution Scenario, Human Intrusion Scenarios, and a Penalising Scenario. On the other hand, Sections 14.10 and 14.12 related to "performance analysis" and to "lines of reasoning for establishing confidence in long-term safety of disposal", respectively, were not available for peer review. The IRT got insights on these latter topics during the peer review week (Vermariën and Cool 2012b,d). Consequently, the IRT's assessment of, in particular, the uncertainty analysis and the safety margins that would be provided by the proposed disposal facility is limited.

The IRT could not review all of the details of the safety assessment calculations and results because they were presented only in the course of the review. The IRT considers, therefore, that it will be important for ONDRAF/NIRAS to:

- Fully document the calculations and the uncertainty and sensitivity analyses that have been undertaken, and describe the significance of the parameters and assumptions considered.
- Highlight the key parameter(s) that ensure the safety of the disposal concept, and explain the phenomenological reasons for the parameter sensitivities.

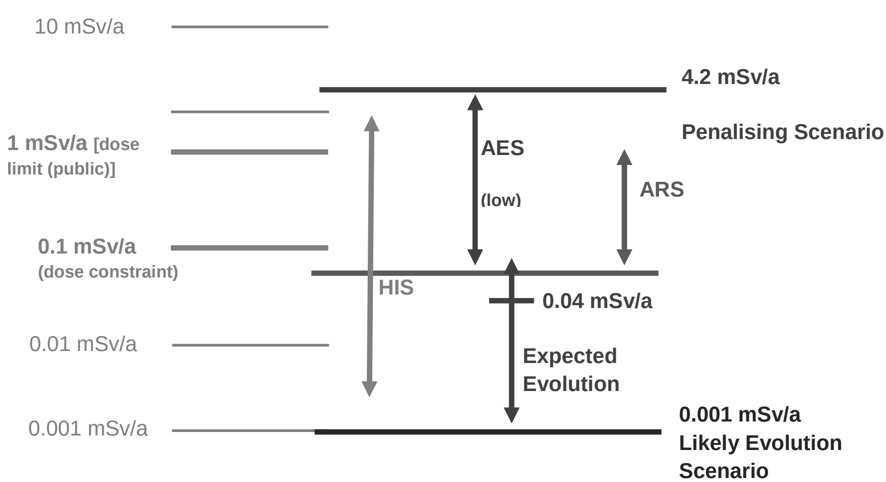
The IRT recommends also that ONDRAF/NIRAS should:

- Consider carefully how to present, integrate and synthesise all of the results from the many assessment scenarios and cases in a way that allows the reader to understand the likelihood and importance of each of the cases.
- Explain clearly the achievable performance of the disposal system based on current knowledge of concrete permeability for large engineered structures.

Based on the results that have been seen by the IRT, it is noted that the calculated safety of the disposal system does not appear very sensitive to variations in the values of numerous parameters. However, the IRT notes that some assessment cases have a higher sensitivity to key parameters and that those cases seem to be linked to the characteristics of the cementitious components e.g. the hydraulic conductivities of the concrete barriers. The IRT notes that on-going RD&D programmes should contribute, in due course, to improving knowledge, understanding system performance, reducing uncertainty, increasing confidence in safety margins, and optimising the system.

The IRT observes also that, in the safety assessment, ONDRAF/NIRAS has made reference to the international ICRP recommendations (ICRP-103) for radiological impact calculations. The calculated radiological impacts in the safety report, as well as other later calculations, are within the ICRP allowed ranges for the various different scenarios, including the "penalising scenario", and are illustrated in Figure 3.8. The IRT, however, has questioned some assumptions made by ONDRAF/NIRAS and has suggested additional calculations, which may or may not confirm the results of the current assessment.

Figure 3.8: ONDRAF/NIRAS' synthesis of calculated radiological impacts for different scenarios (Minon, 2012b)



3.5.2.9 Source term and waste acceptance criteria

The IRT asked for additional information on the determination of the projected source term. The requested information was presented during the review week meeting (Wacquier, 2012). The IRT notes that ONDRAF/NIRAS is following a step by step approach to identify the long-term safety relevant radionuclides. The IRT considers that the method proposed by ONDRAF/NIRAS for calculation of the maximum allowable radionuclide waste inventories is in principle credible and robust.

Section 14.11 of the November 2011 Safety Report (ONDRAF/NIRAS 2011m) described ONDRAF/NIRAS' approach to setting operational criteria on the basis of long-term safety assessment results.

ONDRAF/NIRAS' approach is based on applying the IAEA "sum of fractions" approach (IAEA 2003b) to derive limits on the activity concentration of key safety relevant radionuclides and to evaluate the radiological capacity of the disposal facility.

The IRT considers that the method proposed by ONDRAF/NIRAS is appropriate, but that consideration will need to be given to which scenarios and assessment cases ought to be used to derive the quantitative disposal limits.

The IRT recommends that further consideration may also need to be given to the practicalities of implementing the results of such *"sum of fractions"* calculations to control waste acceptance. For example, there may be benefits of grouping some of the radionuclides considered in the calculations. It will also be necessary to consider the scale over which activity concentration limits are specified and the degree of spatial variability in waste activity that can be accepted.

3.5.3 Summary of IRT conclusions

On the safety assessment methodology and results

Sections 14.5 to 14.9 of the November 2011 Safety Report (ONDRAF/NIRAS 2011m) summarise a series of safety assessment calculations and results for the Reference Scenario, Alternative Reference Scenarios, the Expected Evolution Scenario, Human Intrusion Scenarios, and a Penalising Scenario. On the other hand, Sections 14.10 and 14.12 related to "performance analysis' and to "lines of reasoning for establishing confidence in long-term safety of disposal", respectively, were not available for peer review. The IRT got insights on these latter topics during the peer review week (Vermariën and Cool 2012c,d). Consequently, the IRT's assessment of, in particular, the uncertainty analysis and the safety margins that would be provided by the proposed disposal facility is limited.

Overall, the IRT concludes that ONDRAF/NIRAS' safety assessment methodology is in accord with international best practice, as the methodology follows closely the methodology developed under the aegis of the IAEA (IAEA 2002b).

ONDRAF/NIRAS has considered a large number of scenarios and assessment cases including human intrusion, normal and altered evolution. The categorisation of scenarios has changed during the process of the review. The set of scenarios is in principle adequate, but it is complex to comprehend all of the relationships between the scenario types. ONDRAF/NIRAS should strive to improve on this matter in the final version of the Safety Report.

The IRT recommends that ONDRAF/NIRAS should consider carefully how to present, integrate and synthesise all of the results from the many assessment scenarios and cases carried out in a way that will allow the reader of the Safety Case to understand the likelihood and importance of each of these cases.

The IRT also considers that ONDRAF/NIRAS should examine the sensitivity of assessed disposal system performance to the selected times at which the engineered components are assumed to degrade.

The IRT considers that the method proposed by ONDRAF/NIRAS for setting operational criteria (WAC) on the basis of long-term safety assessment results is appropriate, but that consideration will need to be given to which scenarios and assessment cases ought to be used to derive the quantitative disposal limits.

On the selection of important parameters and on assessment cases

The IRT considers that the hydraulic conductivity of the concrete disposal facility components is a key parameter governing the potential for release and transfer of radionuclides from the disposal facility to the aquifer. The IRT notes that ONDRAF/NIRAS has selected values for the initial hydraulic conductivity of concrete based, in part, on results from small-scale experiments. The IRT considers, however, that the effect of construction defects, "natural" heterogeneities in the large concrete components and the presence of interfaces between the disposal facilities components will necessarily lead to higher hydraulic conductivity values than those from small-scale experiments. The IRT recommends, therefore, that ONDRAF/NIRAS should carefully justify the selection of the hydraulic conductivity values used in the modelling.

The IRT also considers that due to uncertainties related to the long-term hydraulic conductivity of concrete structures at larger scales, it would be more convincing to address the possible hydraulic conductivity of the disposal facility cover by relying on the characteristics of the clayey layer in the cover. Such a layer should be able to protect the concrete roof during the regulatory control phase and efficiently limit possible water infiltration into the disposal modules. The IRT recommends, therefore, that ONDRAF/NIRAS should consider an assessment case in which infiltration to the facility through the cover is controlled by the clay infiltration barrier in the cover instead of the impervious concrete top slab.

The IRT considers that assessing the potential impacts of bath-tubbing is a positive point, but considers that ONDRAF/NIRAS should present a stronger justification for the claim that bath-tubbing will not occur, taking into account the uncertainties that exist associated with the hydraulic characteristics of the concrete components over time, as discussed above. The IRT recommends that ONDRAF/NIRAS should consider the possibility of exposure to contaminated water that has overflowed from the facility by bath-tubbing and entered soils and surface waters (e.g. streams).

The IRT notes that on-going and future RD&D programmes should contribute to improving knowledge, understanding system performance, reducing uncertainty, increasing confidence in safety margins, and optimising the system.

Annex 1. Documents reviewed and examined

A1.1 ONDRAF/NIRAS November 2011 Safety Report chapters

ONDRAF/NIRAS (2011a) The Safety Report for the Surface Disposal Disposal facility for Category a Waste at Dessel, Belgium, Chapter 1: Organisation of the Safety Report and General Information, NIROND-TR 2011-01 E, V1. Document Ready for Peer Review, November 2011.

ONDRAF/NIRAS (2011b) The Safety Report for the Surface Disposal Disposal facility for Category a Waste at Dessel, Belgium, Chapter 2: Safety Approach, Safety Strategy and Safety Concept, NIROND-TR 2011-02 E, V1. Document Ready for Peer Review, November 2011.

ONDRAF/NIRAS (2011c) The Safety Report for the Surface Disposal Disposal facility for Category a Waste at Dessel, Belgium, Chapter 4: Characteristics of the Site and its Environment, NIROND TR 2011-04 E, V1. Document Ready for Peer Review, November 2011.

ONDRAF/NIRAS (2011d) The Safety Report for the Surface Disposal Disposal facility for Category a Waste at Dessel, Belgium, Chapter 5: Knowledge of the Phenomenological Issues of the Engineered Barriers in their Environment, NIROND-TR 2011-05 E, V1. Document Ready for Peer Review, November 2011.

ONDRAF/NIRAS (2011e) The Safety Report for the Surface Disposal Disposal facility for Category a Waste at Dessel, Belgium, Chapter 6: Waste, NIROND-TR 2011-06 E, V1. Document Ready for Peer Review, November 2011.

ONDRAF/NIRAS (2011f) The Safety Report for the Surface Disposal Disposal facility for Category a Waste at Dessel, Belgium, Chapter 7: Monoliths, NIROND-TR 2011-07 E, V1. Document Ready for Peer Review, November 2011.

ONDRAF/NIRAS (2011g) The Safety Report for the Surface Disposal Disposal facility for Category a Waste at Dessel, Belgium, Chapter 8: Design and Construction, NIROND-TR 2011-08 E, V1. Document Ready for Peer Review, November 2011.

ONDRAF/NIRAS (2011h) The Safety Report for the Surface Disposal Disposal facility for Category a Waste at Dessel, Belgium, Chapter 14: Long-term Safety Assessment, NIROND-TR 2011-14 E, V1. Document Ready for Peer Review, November 2011.

A1.2 Other ONDRAF/NIRAS reports

ONDRAF/NIRAS (2010a) The cAt Project in Dessel: Master Plan, A Long-term Solution for Belgian Category A Waste, NIROND 2010-02 E, March 2010.

ONDRAF/NIRAS (2010b) Long-term Evolution of the Multi-layer Cover, NIROND-TR 2010-03 E V1, September 2010.

ONDRAF/NIRAS (2011i) Contextual Framework of the Safety Strategy for Near Surface Disposal of Category A Waste at Dessel, NIROND-TR 2007-04E, V2, April 2011.

ONDRAF/NIRAS (2011j) The ONDRAF/NIRAS Safety Approach and Safety Strategy for Near Surface Disposal of Category A Waste at Dessel, NIROND-TR 2007-06 E, V2, June 2011.

ONDRAF/NIRAS (2011k) Long-term Radiological Safety Assessment Methodology and Uncertainty Management (Assessment Strategy), NIROND-TR 2007-08 E, V2, June 2011.

ONDRAF/NIRAS (2011l) Development of the Safety Concept and Status mid-2011 of the Disposal Facility Design, NIROND-TR 2007-03 E, V3, October 2011.

ONDRAF/NIRAS (2011m) Detailed Design – Modules, NIROND-TR 2011-55 E, V1, 2 November 2011.

ONDRAF/NIRAS (2011n) Detailed Design – Monoliths, NIROND-TR REF E, V1, 30 November 2011.

ONDRAF/NIRAS (2012a) Project Category A – NEA Peer Review - Answers to First NEA Questionnaire – ONDRAF/NIRAS' Surface Disposal Facility Safety Case Peer Review, ONDRAF/NIRAS Ref: 2012-0064, Rev. 0, 13 January 2012.

ONDRAF/NIRAS (2012b) Detailed Design – Steel structures, NIROND-TR 2011-61 E, V1, 31 January 2012.

ONDRAF/NIRAS (2012c), Long-term Climate Change and Effects on Disposal Facility, Geosphere, and Biosphere, NIROND-TR 2009-07 E V1, 31 January 2012.

ONDRAF/NIRAS (2012d) Answers to Second Questionnaire of NEA – ONDRAF/NIRAS" Surface Disposal Facility Safety Case Peer Review, NIROND-TR 2012-03 E V1, 30 March 2012.

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Bosselaers, R. (2011) The cAt Project: General Description: NEA Peer Review Introductory Seminar, 19 December 2011.

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Cool, W. (2011b) Chapter 2: Safety Strategy and Safety Concept: NEA Peer Review Introductory Seminar, 20 December 2011.

Cool, W. (2011c) Chapter 2: Phases – Safety Functions – SSCs: NEA Peer Review Introductory Seminar, 20 December 2011.

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Demarche, M. (2011) Objective of the Peer Review: NEA Peer Review Introductory Seminar, 19 December 2011.

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Bastiaens, W. (2012d) Technical Details of the Remote Inspection Equipment: NEA Peer Review Week 04-08 June 2012.

Bastiaens, W. (2012e) Sequence of the Construction of the Modules: NEA Peer Review Week 04-08 June 2012.

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Claes, J. and Sannen, H. (2012) Siting, Designing and Implementing in Partnership. MONA&STORA Peer Review Week 04-08 June 2012.

Cool, W. (2012) Robustness of the Disposal System with Regard to Uncertainties and Long-Term Stability: NEA Peer Review Week 04-08 June 2012.

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Coppens, E. (2012) QA/QC of Waste Packages, QA/QC During Construction: NEA Peer Review Week 04-08 June 2012.

Cosemans, Ch. (2012) The Waste Acceptance Criteria: NEA Peer Review Week 04-08 June 2012.

Gens, R. (2012) Chemical Compatibility of Waste with Cementitious Materials: NEA Peer Review Week 04-08 June 2012.

Gens, R. (2012) The Possible Use of Zeolites: NEA Peer Review Week 04-08 June 2012.

Gens, R., Vermariën, E. and Cool, W. (2012) Technical Details of the Cementitious EBS and their Assessments: NEA Peer Review Week 04-08 June 2012.

Gens, R. (2012) Estimation of Hydraulic Conductivities for the Engineered Components and How These Vary Over Time: NEA Peer Review Week 04-08 June 2012.

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A1.4 FANC guidance notes and documents

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FANC (2009b) Near Surface Disposal, on Belgian Territory, of Short-Lived Low and Intermediate Level Radioactive Waste. Earthquakes Guidance. FANC Note No. 007-125-E, Rev. 4, 17 December 2009.

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FANC (2010d) Safety Assessment: Biosphere. FANC Note No. 008-217-E, Rev. 3, 19 August 2010.

FANC (2011a) Surface Disposal of Short-Lived Low and Intermediate Level Radioactive Waste on Belgian Territory. FANC Note No. 007-228-F, Rev. 3, 17 January 2011.

FANC (2011b) Technical Guide Radiation Protection Criteria for Post-Operational Safety Assessment for Radioactive Waste Disposal. FANC External Note No. 2011-06-28-CAD-5-4-3-FR, 27 June 2011.

A1.5 International reports

IAEA (2001), Technical Considerations in the Design of Near Surface Disposal Facilities for Radioactive Waste, IAEA TECDOC-1256, International Atomic Energy Agency, Vienna.

IAEA (2002a) Scientific and Technical Basis for the Near Surface Disposal of Low and Intermediate Level Waste. IAEA Technical Report Series No. 412, International Atomic Energy Agency, Vienna.

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IAEA (2003b) Derivation of Activity Limits for the Disposal of Radioactive Waste in Near Surface Disposal Facilities, IAEA TECDOC 1380. International Atomic Energy Agency, Vienna.

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Annex 2. Members of the International Review Team and observers

Reviewers

RUIZ LÓPEZ, Maria del Carmen (IRT Chair)

BSc in Chemical Engineering from the University of Granada, Spain, and a Ph.D. in Chemical Sciences from the Complutense University of Madrid, Spain.

Carmen Ruiz has over 30 year experience in spent fuel and radioactive waste management, in particular in its safety and regulation. She has also a broad research experience characterisation of vitrified high-level waste and cemented low- and intermediate-level waste, conducted while in the Spanish Nuclear Research Centre (former JEN now CIEMAT) and in the Nuclear Research Centre of Kalsruhe (Germay).

Carmen Ruiz is presently Head of the High Level Waste (HLW) Department in the Consejo de Seguridad Nuclear (CSN), the Spanish nuclear safety authority. In this position, she has led the reviews for the licensing of spent fuel storage systems as well as the studies and research related to the safety of the long-term management and disposal of HLW. Previously she has been Project Manager for a number of multidisciplinary projects, including the review of the safety cases for the construction authorisation and the operation permit of the Spanish Short-Lived L&ILW Disposal Facility (El Cabril).

At international level Carmen Ruiz has actively participated in many international and European Commission programmes, acting as expert member, chair and vice chair, and contributing to numerous initiatives on the long-term safety of disposal facilities. She is the CSN's representative to the NEA/OECD Radioactive Waste Management Committee (RWMC) since 1999, and member of the RWMC Bureau. She has been member of the IAEA Working Group on Principles and Criteria for Radioactive Waste Disposal as well as member of the IAEA Waste Advisory Safety Standards Committee (WASSC). She has also participated in several peer reviews including the review of Short-lived Waste Management in France focused on the centre de L'Aube experience and the Integrate Regulatory Review Mission IRRS in Spain and its Follow-Up, convened by the IAEA at request of the government. She is also a member of the Standing Group of Experts that advise the French Nuclear Safety Authority in the field of waste disposal.

BENNETT, David

BSc in geology from the University of Nottingham, UK., PhD in geochemistry and water rock interaction from the University of Southampton, UK. Fellow of the Geological Society, London, UK.

David Bennett has over 20 years of experience in radioactive waste management and its regulation and has contributed to over one hundred published papers and reports in the area. His experience has included detailed research and modelling of cement-based materials. In addition to his expert knowledge on cementitious materials, his expertise also include undertaking and managing complex projects related to radioactive waste disposal facility authorisation and licensing, risk and safety assessment, safety cases, engineered barrier systems, waste immobilisation, geochemistry and radionuclide behaviour.

David Bennett is director of TerraSalus Limited an independent consultancy company that provides high-quality, professional advice on a range of environmental issues, including conventional and radioactive waste management.

David Bennett has many years of experience in contributing to national and international research and assessment projects and reviews. He has contributed to radiological assessments and nuclear waste disposal programmes in Belgium, Finland, France, Germany, Korea, Japan, Sweden, the UK and the US, and he has also contributed to several international programmes run by the European Commission, the IAEA and the NEA. He has extensive experience of managing and/or contributing to formal review panels. This has included chairing and coordinating the independent peer review panel for the UK's Low-Level Waste Repository (LLWR), leading an independent peer review of the UK Nuclear Decommissioning Agency's work aimed at developing a geological repository for radioactive wastes, contributing to the Swedish government's review of proposals for the deep geological disposal of spent fuel, and contributing to international peer reviews of plans for radioactive waste disposal in South Korea.

BERNER, Urs René

Diploma in Chemistry and PhD in Inorganic Chemistry from the Swiss Federal Institute of Technology (ETH) in Zürich, Switzerland.

Starting as a researcher in the cement industry, Urs Berner has over 25 years of experience in the field of radioactive waste management. His major areas of work include thermodynamic descriptions of cement-water interactions, the evaluation of concentration limits for hazardous elements in radioactive waste disposal systems, and critical evaluation of corresponding thermodynamic data. He works on model development and model application in long-term safety assessments in the framework of the Swiss disposal system. Currently, he works on the development of applicable thermodynamic models for clay systems and on the coupling of such models with transport codes. He has contributed to several performance assessments for the Swiss disposal system.

Urs Berner is team leader of the Geochemical Modelling Group in Paul Scherrer Institute's Laboratory for Waste Management. The PSI is the largest research centre for natural and engineering sciences within Switzerland. It performs world-class research in three main subject areas: Matter and Materials; Energy and the Environment; and Human Health. By conducting fundamental and applied research, PSI works on long-term solutions for major challenges facing society, industry and science.

Since 1997 Urs Berner has been a member of the international scientific committee and of the review group of the MIGRATION conferences. He made contributions to the Japanese H-12 project and participated in various scientific committees in workshops related to cementitious/concrete materials. Recently, he contributed as a co-author to the "Iron" issue of the NEA Chemical Thermodynamic Database report series and occasionally he has acted as Referent/ Reviewer/Opponent in cement/concrete-related PhD work in France and Sweden.

KONOPASKOVA, Sona

Sona Konopaskova graduated at the Czech Technical University, Faculty of Nuclear and Physical Engineering and she obtained Ph.D from the Faculty of Chemical Technology in Prague.

She joined Nuclear Research Institute in Řež (NRI) in 1975 where she worked in a number of technical areas, including environmental monitoring, environmental impact assessment, waste operational safety issues and waste disposal technology and safety. She was a head of radioactive waste disposal department and manager of deep geological repository programme. She started her work for RAWRA-CZ (Radioactive Waste Repository Authority) in 1998. She began working in the area of geological disposal safety, but later transferred to radiation protection and radiation safety issues. At present, she is working as a head of licensing and safety department in RAWRA and is continuously working on operational documents for Czech repositories for radioactive waste and on safety reports, including safety assessment, both operational and long term. She is responsible for safety assessment and safety reports of operated repositories and for preparation of documents supporting licensing processes. She is the author of more than ten safety cases submitted for licensing and/or re-licensing of repositories in the Czech Republic, and is cooperating in safety assessment of repositories operated in other countries. She has an Environmental Impact Assessment background as well, and is providing input to risk analysis concerning presence of hazardous materials in radioactive waste repositories.

RAWRA-CZ is a state organisation founded in 1997 with responsibility to operate radiactive waste repositories and also responsible for research and development of new repositories. RAWRA-CZ operates three subsurface repositories and makes an effort in technical activities concerning future geological repository.

International activities. Sona Konopaskova is a member of Integrated Group of Safety Assessment NEA OECD and she is involved in two NEA projects related to safety – the Sorption and TDB Projects. On behalf of IAEA she is participating in project on practical implementation of safety issues for surface repositories PRISM and in a similar project for geological repositories, GEOSAF.

KWONG, Gloria

PhD candidate in Materials Science from Imperial College, London,UK. Masters of Engineering in Chemical Engineering from the University of Toronto, Canada. Licensed professional engineer in Canada.

Gloria Kwong is a project manager at the OECD/NEA, supporting the Integration Group for the Safety Case (IGSC). She is responsible for projects and technical programmes that are related to safety cases and safety assessments for radioactive waste disposal within the OECD/NEA. Prior to joining the OECD/NEA, Gloria was a Senior Design Specialist in Canada, responsible for the design of the Canadian's used fuel container and corrosion related projects. She has over 12 years of experience in the field of radioactive waste management. Her contributions to this review include her design experience and knowledge of materials.

At the international level, Ms. Kwong is the technical Secretariat of the Integration Group for the Safety Case (IGSC), a main technical advisory body to the Radioactive Waste Management Committee (RWMC) of the OECD/NEA, and has the role of liaising members of the IGSC from 28 member countries. Such liaison provides a platform for international dialogues and technical expertise exchanges among the member states.

PESCATORE, Claudio (NEA Covenor)

MS and PhD in Nuclear Engineering (University of Illinois at Urbana-Champaign) and a Laurea cum laude in Applied Physics (University of Bologna, Italy).

He has over 30 years experience in the field of radioactive waste management. He is presently Principal Administrator in charge of the programmes of the Nuclear Energy Agency (NEA) of the OECD in the fields of decommissioning and radioactive waste management. Previously, he has been staff scientist and group leader for repository performance assessment at Brookhaven National Laboratory and adjunct professor of Marine Environmental Sciences at the University of New York at Stony Brook.

The OECD/NEA plays a lead role in helping the governments of the most industrialised countries and their specialists gain a shared understanding of the state of the art in radioactive waste management and decommissioning, and moving these fields forward.

At the international level Dr. Pescatore is well known for his role in the elaboration of the modern concept of a safety case for disposal, for launching and developing the NEA programmes on stakeholder confidence, and for helping open the field of regulation to wider discussion and review. He has organised 14 international peer reviews of national safety studies for disposal, four of which in Sweden. Overall, he is helping shape the profile of the modern waste management profession.

Claudio Pescatore regularly represents the Nuclear Energy Agency at national and international events and joint initiatives with other international institutions. He has participated as a member in the ICRP task group charged with developing updated international guidance on the application of the ICRP concepts and principles to geological disposal. He is also a member of the Standing Group of Experts that advise the French Nuclear Safety Authority in the field of waste disposal.

SERRES, Christophe

Christophe Serres obtained a PhD in 1992 in geosciences and modeling of oil reservoirs at the TOTAL research center in Pau.

He has 20 years of experience at IRSN (France) in performing research on geological disposal and review of safety case issued by french WMO in the framework of the French planning act on management of radioactive waste. He is currently head of the department in charge of safety assessment of radioactive waste disposal facilities (Andra Centre de la Manche, Centre de l'Aube, Bure) and natural radioactivity at the IRSN (Areva mining disposals).

IRSN is the French technical safety organisation in charge to developing research and performing technical expertise related to safety of nuclear activities and radiation protection.

He was involved in several Euratom Framework projects on waste safety (EVEREST, SPA, NFPRO, BENIPA, PAMINA, MICADO, FORGE…). He is also currently coordinator of the Euratom FP7 SITEX project on independent technical expertise for reviewing the safety case. He is the IRSN representative for the NEA/RWMC and IGSC and was chairman of the IAEA GEOSAF project on harmonisation of geological disposal safety assessment. He is involved in the European Pilot Study on the harmonisation of safety requirements on geological disposal and development of waste acceptance criteria.

Observers

DE HOYOS, Amélie

Masters degree in water engineering from EGID Institute (University of Bordeaux, France).

Amélie de Hoyos has been working at IRSN as a hydrogeological engineer since 2004, carrying out safety assessment reviews and technical evaluations for surface and geological disposal facilities in France, as well as for sites in Eastern Europe. In particular, she recently led IRSN's safety review of Andra's Dossier 2009 for geological disposal. She is presently the main IRSN safety engineer in charge of the Manche surface disposal site. She also performs research and development activities related to hydrogeological modeling of surface and geological repositories.

TICHAUER, Michael

Graduate engineer (Nantes School of Mines, France).

Michael Tichauer is presently Deputy Head of IRSN's Safety Assessment and Research Section for Radioactive Waste Disposal Facilities within the Radiation Protection / Waste and Geosphere Division. In this position, he is responsible for the safety assessment of the Centre de l'Aube surface disposal facility and he heads the Operational Safety Expert group for Geological Disposal facilities at the Institute of Radiation Protection and Nuclear Safety (IRSN).

His position allows him to carry on both expert and research activities for the appraisal of nuclear facilities. He has been involved in various international projects, ranging from IAEA harmonisation projects (member of PRISM and GEOSAF teams, co-chairman of GEOSAF II) to providing support to eastern European countries (e.g. safety assessment of disposal activities within the exclusion zone of Chernobyl). Prior to this position, he was involved in the decommissioning of Gen-1 reactors and operating laboratories in France.

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The Long-term Radiological Safety of a Surface Disposal Facility for Low-level Waste in Belgium

An important activity of the OECD Nuclear Energy Agency (NEA) in the field of radioactive waste management is the organisation of independent, international peer reviews of national studies and projects. This report provides an international peer review of the long-term safety strategy and assessment being developed by the Belgian Agency for Radioactive Waste and Enriched Fissile Materials, ONDRAF/NIRAS, as part of the licence application for the construction and operation of a surface disposal facility for short-lived, low- and intermediate-level radioactive waste in the municipality of Dessel, Belgium. The review was carried out by an International Review Team comprised of seven international specialists, all of whom were free of conflict of interest and chosen to bring complementary expertise to the review. To be accessible to both specialist and non-specialist readers, the review findings are provided at several levels of detail.

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