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SAFIR 2: Belgian R&D Programme on the Deep Disposal of High-level and Long-lived Radioactive Waste

An International Peer Review

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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FOREWORD

A major 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 peer reviews help national programmes in assessing the work accomplished. The review reports may also be of interest to others with their comments on issues of general relevance.

The NEA Secretariat established an International Review Team (IRT), on behalf of the Belgian Government, to perform a peer review of the SAFIR 2 report, produced by the Belgian Agency for Radioactive Waste and Enriched Fissile Materials (ONDRAF/NIRAS). The peer review should help the Belgian Government and the institutions, organisations and companies involved in waste management in Belgium to decide on the future work programme and its priorities. The IRT was made up of eight internationally recognised specialists, including two members of the NEA Secretariat. The experts were chosen to bring complementary expertise to the review.

This report presents the consensus view of the IRT. It is based on a review of the SAFIR 2 report and supporting documents, on information exchanged with ONDRAF/NIRAS in answers to questions raised by the IRT, and on direct interactions with staff from ONDRAF/NIRAS and their colleagues from SCK•CEN during a week-long workshop in Belgium.

In keeping with NEA procedures for independent reviews, neither the Belgian Government nor ONDRAF/NIRAS have provided comments on this report - ONDRAF/NIRAS has only had the opportunity to check for factual correctness. The IRT has made its best efforts to ensure that all information is accurate and takes responsibility for any factual inaccuracies.

Acknowledgements

All the members of the IRT would like to thank ONDRAF/NIRAS staff for their hospitality during the brief visits to Belgium, and for their excellent organisation of the visits, which facilitated the work of the IRT. The IRT would also like to thank the staff of ONDRAF/NIRAS, SCK•CEN and EURIDICE for the helpful and open way they responded to the review. Finally, the IRT appreciated the opportunity to visit the underground facility at Mol.

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SUMMARY

The Belgian Agency for Radioactive Waste and Enriched Fissile Materials (ONDRAF/NIRAS) has recently completed the SAFIR 2 report for the Belgian Secretary of State for Energy. The report covers the research, development and demonstration (RD&D) activities in the Belgian programme on the final disposal of high-level and long-lived radioactive wastes in a deep geological repository in Belgium since the earlier SAFIR study was issued (1989). It provides an integrated overview of the knowledge, experience and expertise developed within the programme using a template developed under the auspices of the European Commission for documenting long-term safety assessments. The ONDRAF/NIRAS Board of Directors has already had the report evaluated by a Scientific Reading Committee of Belgian experts while the report was being finalised. The Committee also made recommendations for the future work programme to be conducted by ONDRAF/NIRAS.

The Belgian Government asked the OECD Nuclear Energy Agency to organise an International Review Team (IRT) to provide a peer review of the SAFIR 2 report according to agreed Terms of Reference. In particular these state that "The peer review ought to help the Belgian Government and the institutions, organisations and companies involved in waste management to decide on the future work programme and its priorities". The Terms of Reference focus on:

(i) "the long-term safety assessment methodology, the well-foundedness of its results and the quality of its scientific and technical bases";

(ii) "the remaining key uncertainties and the RD&D programme that is proposed to deal with them in the next phase of the programme."

The review was undertaken in the period from June to December 2002 and was carried out bearing in mind the state of the art in other national programmes, the status of the Belgian programme, and the decisions that have to be taken in it.

This document represents the views of the IRT stemming not only from the review of the SAFIR 2 report itself and some supporting documents, but also from the extensive exchange, both orally and in writing, of questions and answers amongst the IRT members and their Belgian colleagues headed by ONDRAF/NIRAS. The IRT was thus able to get a comprehensive picture of the Belgian programme, which includes new information that has been developed since the completion of SAFIR 2.

Overall, the IRT has the following broad observations on the SAFIR 2 report:

- SAFIR 2 is the first attempt in Belgium to combine the knowledge accumulated to date into an integrated safety assessment format:
  - The document contains a large amount of information and gives a full picture of the progress made in the RD&D programme by the year 2000. At the same time much of the information is put into the framework of a safety assessment. The document is thus a hybrid of a status report and a safety assessment report and, because of this, it is, in parts, highly repetitive. The IRT recommends that in future these two aims should not be fulfilled by a single document. This would make the information more transparent, the decisions more traceable, and the document more user-friendly.
  - Some of the analyses, e.g., scenario analysis, date back to 1994; others are only slightly more recent. Important progress has been made both within the Belgian programme and world-wide since then, and the analysis needs to be developed further to take account of this.
  - The IRT acknowledges the fundamental role of the Boom Clay barrier in the performance of the overall disposal system. However, the IRT believes that more credit could be taken for the performance of the Engineered Barrier System (EBS) within the multi-barrier concept. The full effectiveness of the multi-barrier concept should be analysed and argued, including the interdependencies between the various components in the EBS, in order to give further support to claims of the robustness of the disposal concept.
  - The systematic management of uncertainty should be developed further and should play a central role in setting priorities and guiding future studies.

  - The transferability of information from laboratory and *in situ* experiments to models and their adaptation to different and changing *in situ* conditions is an important issue to bear in mind. In particular, a balance should be struck between building a predictive capability based on realism and mechanistic understanding and a capability to support safety through robust models and arguments.

  - Further safety assessment exercises should be carried out at regular intervals, e.g., every five to ten years or so. This should be in line with a stepwise decision-making process. This will enable the integrated team to be developed further, the safety assessment methodology to be applied more proactively, the points identified above to be improved upon, and the team to be ready for more in-depth discussions with all stakeholders, including the technical community at large, the regulators, the public, the waste producers, and the policy makers.

- The information provided indicates that a good basis exists for the future programme:

  - The studies made so far are relevant and provide an excellent platform for continuing with the programme on geological disposal of long-lived wastes. The information is very extensive and covers all relevant areas. The work done is in line with what is being done in other national programmes. It has also been possible to develop some novel and innovative methods and tools. The work is generally of high quality.

- The Boom Clay at Mol and the associated repository concept are a good focus for the RD&D phase, and it seems that siting flexibility exists:

  - Because of the geological situation in Belgium, poorly indurated clays are the leading candidates for repository host rocks, and as a consequence the work on the Boom Clay is relevant to the possible locations in Belgium.

  - The arguments provided in SAFIR 2 justify the choice of the Boom Clay at Mol as the focus for the phase of methodological research. However, the IRT believes that ONDRAF/NIRAS could have made more clearly the point that the studies on the system are relevant to the future programme, e.g., with regards to geological stability, the ability of engineering a repository, etc. In particular, the Boom Clay appears to have adequate properties for safety and construction, it occurs in adequate situations as regards depth and thickness, and its abundance suggests there is siting flexibility.

  - The Ypresian Clays have been studied as an alternative to the Boom Clay. They appear to have some advantages (there is no exploited aquifer beneath the potential host rock), but they also appear to have some disadvantages (such as lower geomechanical strength) when compared to the Boom Clay. There is great value in retaining flexibility of options and siting.
  - Good transferability of methodologies and designs is expected within the Boom Clay formation. ONDRAF/NIRAS recognises the importance of understanding whether methodologies and designs can be transferred to alternative formations or sites within the same formation.

- The SAFIR 2 report is a suitable basis for starting the dialogue with the regulators and policy makers in Belgium:
  - The SAFIR 2 report highlights the need for further support and clarification, at a policy level:
    - to enable the programme to move ahead beyond the methodological RD&D phase, and start consultations on siting;
    - to start the dialogue with the different stakeholders as a preparatory step on how to proceed with siting and with the associated decision making;
    - on what consideration needs to be given to monitoring and retrievability.
  - The SAFIR 2 report highlights the need for a regulatory framework, which includes guidance and criteria, on several issues such as:
    - criteria for judging safety and compliance with regulations;
    - the radiological and non-radiological protection of the relevant water resources of regional and national importance;

    - time frames for assessing regulatory compliance;
    - human intrusion.

  - One merit of the SAFIR 2 documentation is the extensive review of international guidance and the application of the information in SAFIR 2 when national guidance was missing.

- Because of their own internal reviews, and from the existing external reviews received, the Belgian programme is aware of the future RD&D needs. However, there is a need to develop a strategy for setting priorities and a structured approach for managing uncertainties.

- The Belgian programme for the disposal of high-level and long-lived radioactive waste is well developed and sufficiently advanced to address the siting issue:

  - The programme has built an important experimental capability and database of information regarding the performance of a potential repository for high-level and long-lived radioactive waste in Boom Clay. The programme has taken full advantage of a competent experimental team and of the HADES underground research facility. The latter is the longest operating such facility in Europe and, probably, world-wide. Its existence and operation demonstrates the technical feasibility of mining a repository in Boom Clay.

  - The programme has built an important capability in the area of safety assessment. Although questions remain about the detailed methods used for undertaking the analyses in support of a safety case, SAFIR 2 provides excellent and innovative additions to the safety case literature. Examples include the concept of using safety functions and the criteria for assessing confidence.

  - The Belgian disposal programme is at the forefront internationally in considering issues of stakeholder involvement. The SAFIR 2 companion booklet on radioactive waste management and sustainable development is innovative in this respect. It is understood, and very much appreciated, that this part of the programme will continue to be developed for B and C waste.

– The level of experience and information available is considered sufficient to move the programme on towards siting studies. During the siting phase, the RD&D programme should still continue in order to maintain and reinforce competence and to address the priority items that have been identified.

1. INTRODUCTION

1.1 Background

Work on radioactive waste management has been ongoing for many years in Belgium. In 1974 the SCK•CEN (Belgian Nuclear Research Centre) at Mol began investigating the possibility of geologic disposal for radioactive waste. Initially attention was focused on high-level and long-lived waste, and these wastes are the focus of SAFIR 2, where "high-level waste" is termed Category C waste, and "low- and medium-level long-lived waste" is termed Category B waste.

The foundation of the "*Organisme national des déchets radioactifs et des matières fissiles enrichies / Nationale instelling voor radioactief afval en verrijkte splijtstoffen*" or ONDRAF/NIRAS on 8 August 1980 was the result of a decision by the Belgian government to entrust the management of radioactive waste to one single institution under public control. This was in order to ensure that the public interest would play a crucial part in all decisions on the subject.

The Belgian Agency for Radioactive Waste and Enriched Fissile Materials (ONDRAF/NIRAS) is entrusted with developing and implementing a coherent and safe management strategy for all the radioactive wastes that exist in Belgium. This responsibility includes the development of a quantitative inventory of the radioactive wastes, the collection and transport of the wastes, their processing and conditioning, and their storage and long-term management. As well as this principal mission, ONDRAF/NIRAS has other responsibilities relating to decommissioning of closed nuclear facilities, the management of historical wastes, and the management of enriched fissile material.

In May 1989 ONDRAF/NIRAS submitted the first SAFIR report (Safety Assessment and Feasibility Interim Report) [1] to the Secretary of State for Energy. The main objective of this SAFIR report was to enable the national authorities to provide initial advice on the quality of the Boom Clay Formation located below the nuclear zone at Mol-Dessel as a potential host formation for final disposal of Belgian radioactive wastes with a long half-life and/or high activity. SAFIR also gave an overview of the information and results obtained in the research and development programme between 1974 and 1988.

On 22 May 1989, the Secretary of State for Energy formed the SAFIR Evaluation Commission. In its final report the Commission concluded that the choice of the Boom Clay located below the Mol-Dessel nuclear zone is appropriate for the study of an underground repository for high-level and long-lived waste. On the other hand, the Commission stated that there was a need for more extensive research into each of the aspects investigated. In accord with this decision, ten years after the publication of the SAFIR report, ONDRAF/NIRAS has produced an updated status report with an evaluation of the technical and scientific progress in the area of the deep disposal of high-level and long-lived waste in Belgium: the SAFIR 2 report [2]. This is the subject of the current review.

1.2 The SAFIR 2 report

The SAFIR 2 report [2] was prepared by ONDRAF/NIRAS for the Belgian Secretary of State for Energy, the supervising and regulatory authorities and all interested audiences. It describes the results obtained in the ten years (1990-2000) since the publication of the SAFIR report in 1989 in the field of geological disposal of high-level and long-lived low- and intermediate-level waste. It presents an evaluation of the progress made, and highlights the key remaining uncertainties. Future priorities are identified, and ways forward to address them are proposed. It shows that there is now sufficient knowledge available to move forward towards siting, although additional work in RD&D is still required.

The information compiled in the SAFIR 2 report is structured according to the table of contents of a safety report as proposed in the framework of an European Commission (EC) sponsored project [3]. The SAFIR 2 report is not a document to be submitted for licensing purposes, rather, it is an intermediate step in the long process towards establishing a safety case for licensing purposes and it should serve as a basis for a dialogue with the Belgian nuclear safety authorities regarding the preparation and content of such a safety case.

The ONDRAF/NIRAS Board of Directors has already had a preliminary version of the SAFIR 2 report reviewed by a Scientific Reading Committee while the report was being finalised. The Committee also provided suggestions on future priorities in the work programme. The final opinion of the Committee has been made publicly available by ONDRAF/NIRAS.

In addition to the full SAFIR 2 report, and to allow interested audiences to get a summary of the main achievements of the last decade of RD&D and of the main proposals for further work, a "Technical Overview Report" [4 – see also Annex 3] of the SAFIR 2 report has been issued. This document stresses particularly the methodological aspects and the qualitative arguments supporting long-term safety.

A further report "Towards the sustainable management of radioactive waste" [5 – see also Annex 3] provides background information to the SAFIR 2 report relating to the decision-making process in Belgium and the necessity to integrate the scientific and technical aspects of long-term waste management with societal considerations.

Subsequently, the Belgian Government asked the OECD Nuclear Energy Agency to organise an International Review Team (IRT) to provide a peer review of the SAFIR 2 study, which constitutes the subject of this report. The members of the IRT were chosen to bring complementary areas of expertise to the review. Annex 1 to this report presents the IRT members.

1.3 Scope, aims and conduct of the review

The Terms of Reference focus on:

(i) "the long-term safety assessment methodology, the well-foundedness of its results and the quality of its scientific and technical bases"

(ii) "the remaining key uncertainties and the RD&D programme that is proposed to deal with them in the next phase of the programme."

The main parts of the Terms of Reference of the peer review are given in Annex 2.

In considering the Terms of Reference, the IRT felt that it was more appropriate to comment on the main priorities for the future work programme, rather than on the detailed work packages that are under consideration.

The IRT also agreed with the Belgian authorities that the relevance of the work undertaken to date should also be discussed. This included considering whether the work was sufficiently representative for the siting possibilities in Belgium, and whether information gained could also be applied to other sites and relevant formations in Belgium.

The documents that were the subject of the review by the IRT are listed in Annex 3. The IRT recognises that the technical work reported in SAFIR 2 was completed in 2000, and that further significant progress has been made since then that is not reported in SAFIR 2. This subsequent work was sometimes discussed in the face-to-face discussions, but SAFIR 2 remained the focus of the review.

The IRT met for the first time in Brussels at the ONDRAF/NIRAS offices on 26 and 27 June 2002. During these two days, ONDRAF/NIRAS staff, along with contractors from SCK•CEN and EURIDICE, presented an overview of SAFIR 2. A representative of the Belgian government and observers from the safety authorities also attended this seminar. This meeting included a visit to the HADES Underground Research Facility (URF) and EURIDICE Demonstration Hall at Mol. The IRT also discussed the Terms of Reference for the review, and the division of the review work among the review team.

During the ensuing weeks, each member of the IRT examined the main and supporting documents, focusing on those sections of the reports closest to his or her specialist expertise. Subsequently, the IRT sent a set of more than 100 questions to ONDRAF/NIRAS for clarification. ONDRAF/ NIRAS provided written responses to all these questions.

The IRT met for a second time, for a week-long workshop, from 21 to 25 October 2002. There were presentations by ONDRAF/NIRAS staff, along with contractors from SCK•CEN and EURIDICE, addressing a number of key issues raised by the IRT. These discussions included presentations on "The Boom Clay as a barrier" and "The system of engineered barriers". Detailed questions were also asked by the IRT, and answers given by the appropriate Belgian experts. In a number of cases additional briefing notes, e.g., on geological stability, were prepared by ONDRAF/NIRAS for the IRT. A representative of the Belgian government and observers from the safety authorities also attended the discussion sessions with ONDRAF/NIRAS.

At the close of the workshop on 25 October 2002, the IRT Chair-person, Piet Zuidema, presented orally the initial collective opinion of the IRT to the representative of the Belgian government. The presentation was also attended by staff from ONDRAF/NIRAS, SCK•CEN, and by observers from the nuclear safety authority. Subsequently, each member of the IRT prepared written views and comments that were compiled into a draft report. This was reviewed by team members, and iteratively discussed and refined to the present report. When the report with the consensus views of the IRT was ready, it was submitted to ONDRAF/NIRAS and the Belgian Government for checking factual correctness, but not for comment. The IRT takes, however, full responsibility for any factual inaccuracies.

1.4 Organisation of the report

A summary of the review is given at the front of this document. It presents the main observations and recommendations from the review, and is designed to be "stand alone".

Introductory material on the background, terms of reference, and the conduct of the review has been given in the preceding parts of this section.

The main conclusions from the review are presented in Section 2. They expand on the conclusions presented in the summary.

More detailed observations are presented in Section 3 and are structured in five Subsections taking into account the objectives set for the review in the Terms of Reference. They are aimed at the more technically interested reader, and are organised around the different disciplines that contributed to the SAFIR 2 report, particularly those regarding the quality of the technical and scientific basis of the work undertaken.

The review presumes that the reader is generally familiar with the aims and content of the SAFIR 2 report, but not necessarily with all the details of the documentation.

2. CONCLUSIONS AND RECOMMENDATIONS AT AN EXECUTIVE LEVEL

Following a statement regarding the overall judgement, the main conclusions addressing the different areas of the Terms of References are summarised. These include the quality of the scientific and technical basis of the RD&D, the quality of the long-term safety assessment methodology, the well-foundedness of the results of the long-term safety assessment, the remaining key uncertainties and the conformance of the work of the Belgian programme on the disposal of long-lived wastes with international standards and practices in other national programmes.

2.1 Overall judgement

In the way it is written, the SAFIR 2 report is a combination of a status report and a safety case. In writing it, ONDRAF/NIRAS has produced a large body of valuable information, which provides a suitable platform for a dialogue towards further development of policy and regulations with respect to safety criteria and guidelines for implementation of a repository and for ensuring structured societal involvement in the project.

Besides the scientific and technical issues, the SAFIR 2 report addresses the importance of the societal dimension of repository development and has produced an important contribution on how to proceed in this area. This is considered to be a very important area for the future.

SAFIR 2 has produced many new results that are highly relevant to the disposal of long-lived wastes in Boom Clay. The RD&D covers all relevant areas of the engineered and natural system, as well as the methodology for undertaking the overall safety assessment. Despite the maturity of the RD&D programme, it is clear that there is a continuing need for RD&D and the SAFIR 2 report contains a comprehensive discussion on the future RD&D needs.

In addition to producing a large quantity of relevant results, the process of producing SAFIR 2 has also triggered ONDRAF/NIRAS to make many valuable and novel developments in their safety assessment methodology. Due to time constraints, however, it was not possible to develop these new areas fully, nor was it practicable to apply and document them comprehensively in the SAFIR 2 documentation. This has resulted in some incompleteness and inconsistencies in the report. However, it has resulted in an experienced team that is in a good position to develop these novel issues further, and to apply them in future studies. In some areas, e.g., safety functions and scenarios, there is a need to develop the new methodology and the corresponding tools further.

Based on all these considerations, and on the compilation of detailed observations in Section 3, the IRT comes to the following broad conclusions:

- The work conducted up to now is very valuable. The Belgian programme for the disposal of high-level and long-lived radioactive waste is well developed. The focus on the poorly indurated argillaceous formation, Boom Clay, is considered to be promising and justified. The programme undertaken to date provides a strong scientific basis for the future programme.
- The studies on the Ypresian Clays as an alternative to the Boom Clay are considered to be appropriate because there is great value in retaining several options for host rocks and for siting. It is also important to understand whether methodologies and designs can be transferred to alternative formations or sites.
- SAFIR 2 presents a strong platform for planning the future work, as it presents a comprehensive summary of the work done on methodological development. This development is extensive and of high quality (going back to the 70s). In addition, SAFIR 2 is a first attempt to combine the knowledge accumulated in the Belgian programme to date into an integrated safety assessment format.
- SAFIR 2 has led to novel and innovative developments and allowed a strong and skilled team to be put together; this will be of great value for the future programme. The underlying performance assessment (PA) methodology is well founded and is at the forefront in its ideas but still deserves further development.
- The current scientific basis of the Belgian programme is considered to be sufficiently strong to enable the programme to move from the methodological phase towards siting. A strong RD&D programme will still be needed during the siting phase.

- SAFIR 2 is comprehensive in its discussion of possible future RD&D work. However, the setting of priorities and the underlying strategy for managing uncertainties needs to be strengthened.
- In the absence of specific guidance from the Belgian authorities, ONDRAF/NIRAS has carefully considered and implemented international guidance.
- In order to focus future work, it is considered essential that the policy and the regulatory framework in Belgium be developed further. The views of ONDRAF/NIRAS on the societal dimension of developing a repository are innovative and very valuable. They will provide important input to policy development.

2.2 The relevance of the system studied

Belgium has decided to look at the option of deep disposal of their high-level and long-lived radioactive wastes in a geological repository with multiple barriers. This is in line with international practice.

The Boom Clay at Mol was selected in the 1970s for the methodological development phase, and the vast majority of the work has been undertaken on this formation. This review confirms that this formation has the potential to be suitable for deep geological disposal.

Because certain of the radionuclides have long half-lives, the repository will be required to perform over long timescales. To demonstrate adequate performance, it is important that the chosen site will be stable over the long term. The evidence collected to date suggests that this will be achievable. However, when a specific site is selected, it will be desirable to build further confidence in its stability.

One of the central themes of deep geological disposal is isolation through multiple barriers, some of which are engineered (the waste form, container, overpack, backfill and liner), and some of which are natural (the host rock and the geological setting). The barriers envisaged by ONDRAF/NIRAS fulfil this role. Further confidence, however, needs to be built in the performance of certain components, and more attention could be given to the contribution to safety provided by the engineered barriers.

The design and engineering seem in general to be technically feasible. The system is amenable to assessment, and the assessments undertaken to date suggest the performance will be acceptable.

Overall, the concept is in line with the accepted view of deep geological disposal. There appears to be flexibility in siting in the Boom Clay. The Ypresian Clays have been investigated as an alternative formation. The work undertaken at Mol appears to be relevant to a range of potential sites.

2.3 The quality of the current scientific and technical basis

The Belgian RD&D programme has a long history and is very broad. It has also the advantage of having an Underground Research Facility (the HADES facility since the 1970s) and over the years a strong experimental component was developed. The work undertaken is generally of high quality.

The management of such a large RD&D programme is a difficult task and the integration of science into the more applied disciplines, such as performance assessment and design, is challenging. In retrospect, some of the work does not seem to be sufficiently well focused. For example, the priorities seem to have been imposed at times by involvement in certain EC-sponsored projects. In addition, the overall balance was not always optimal, for example, in the balance of work between the EBS and the geosphere, in the balance between deterministic and probabilistic assessments, and between geochemistry and hydrogeology. The production of SAFIR 2 will now provide a good platform to reassess and focus the future RD&D programme. In particular, through SAFIR 2 many improvements have been achieved already, and these will come to fruition in the future, for example in the geochemical characterisation of the Boom Clay.

The IRT observes that different levels of maturity have been reached in different areas. Although the IRT acknowledges the efforts made by ONDRAF/NIRAS to provide a clear inventory and classification of all radioactive wastes, the IRT observes that in SAFIR 2 the work on Type C is more mature than the work on Type B wastes and spent fuel. The work on examining the barrier properties of the Boom Clay is more advanced than the work on radionuclide migration through the engineered barrier system. The studies of the feasibility of mining in the Boom Clay are more mature than work on some of the specific emplacement techniques.

Feedback between performance assessment and the other disciplines provides the basis to ensure that the repository development programme remains focused on the relevant areas. The way this will be achieved could be presented more clearly.

2.4 The quality of the long-term safety assessment methodology, and the representation of the scientific basis in the safety assessment

The approach taken in assessing safety has many novel aspects. It includes multiple lines of reasoning and the analysis of the system includes a comprehensive qualitative discussion (for example, a first analysis of the system by means of safety functions). For the quantitative analyses alternative safety indicators are used to help to get a more differentiated understanding of system performance.

Some of the analyses, e.g., scenario analysis, date back to 1994, however, and others are only slightly more recent. Important progress has been made both within the Belgian programme and world-wide since then, and the safety assessment analysis needs to be developed further to take account of this. Further safety assessment exercises should be carried out at regular intervals, e.g., every five to ten years or so. This should be in line with a stepwise decision-making process.

In the course of developing SAFIR 2, ONDRAF/NIRAS realised the importance of a "Safety Case" for the integral judgement of a repository project and started to develop the necessary framework and methodology. Through this, several novel and innovative ideas have been developed (safety functions, alternative safety indicators, the importance of qualitative arguments, etc.). However, due to time and resource restrictions it was not possible to develop all the necessary, more detailed methods and tools fully. Consequently, the methodology and corresponding toolbox need to be further developed. The IRT believes that this should include practical feedback on their use, perhaps through comparison with the approach of other organisations. This has the potential to enhance the traceability of the arguments for safety, as well as supporting communication with the different stakeholders.

In particular, the reporting structure of SAFIR 2 relies on the recommendations of the EC-sponsored project [3] on the documentation to be developed in the preparation for a licence application for an underground repository in clay. The IRT does not consider this to be the most suitable format for reporting of a "Safety Case". The mixture between "Status Report" and "Safety Case" in SAFIR 2 and the limitations with respect to completeness and consistency make some parts of the report difficult to digest. Indeed

ONDRAF/NIRAS, having taken the initial format for a safety report from [3], tried to incorporate novel ideas of producing a safety case [6], for example, in their approach to addressing the issue of confidence.

The transferability of information from laboratory and *in situ* experiments undertaken as part of the underlying RD&D programme to assessment models and to adapt them to different and evolving *in situ* conditions is an important issue. In particular, a balance should be struck between building a predictive capability based on realism and mechanistic understanding (as is appropriate as part of the RD&D programme) and an assessment capability to support safety through robust models and arguments.

The integration of the scientific basis for the performance assessment and repository design has not been always adequately documented. This leads to difficulties in reviewing the arguments underlying the decisions taken on the design and on the assumptions made in the performance assessment. This is part of a wider need to develop further the approach to the management of uncertainty. The IRT sees such management strategy as being very important in determining priorities for the future programme. It might also be valuable to consider using safety functions as a tool to guide repository design. In particular it would be valuable to develop this approach to define qualitatively and quantitatively the role of the various components of the system, and hence to develop the design requirements.

Even with a formal uncertainty management strategy, there is a clear need for some uncertainties to be further explored in some scenarios and conceptual models. The fundamental role assigned to the Boom Clay barrier in the safety of the whole disposal system needs a more comprehensive analysis of the uncertainties that might have the potential to perturb the geosphere. In addition the uncertainties in the conceptual models and parameters describing radionuclide transport through this barrier need a more thorough assessment.

The IRT feels that, in the SAFIR 2 report, the full credit for the quality of the EBS has not been exploited. Instead, the assessment places most importance on the barrier properties of the Boom Clay. By doing this, full advantage is not taken for the concept of the multi-barrier system.

2.5 The foundations of the results of the long-term safety assessment

The results of the long-term safety assessment are based on a large RD&D programme that covers all relevant areas. For many issues, both specific experiments and studies are available, although the level of detail differs. In general, however, it can be concluded that the results of the performance assessment are based on a sound body of RD&D.

The IRT acknowledges the substantial efforts of ONDRAF/NIRAS in using SAFIR 2 as a first exercise in integrating the results from the Belgian programme and the results presented indicate that the system under investigation has the potential to provide sufficient safety. However, the exercise presented in SAFIR 2 is far from being a complete "safety case" document, and it has not been possible to exploit all the new ideas developed (see, for example, [6]). However, the IRT recognises that this was not the aim of the project. As a consequence, the IRT recommends that in the next phase of work, ONDRAF/NIRAS should produce a comprehensive safety report, and that they should not in future combine a safety report with a status or state-of-the-art report. This should allow the foundations of the results to be better understood.

2.6 Technical feasibility

The extensive RD&D programme clearly indicates that it will be feasible to mine and construct the access tunnels and disposal galleries. However, there are some doubts about the reliability of the system chosen (disposal tube, hydration system) for emplacing the wastes and the associated engineered barriers. These doubts were confirmed in the discussion with ONDRAF/NIRAS and their experts, based on their findings from work completed since the finalisation of the SAFIR 2 report. Moreover, it will be important to identify not just a feasible design, but also one that will provide adequate reserves of safety.

This raises the importance of having alternative, fall-back designs and materials, which still need to be developed for certain parts of the system. Furthermore, detailed EBS concepts do not seem to exist for all the waste types.

2.7 Remaining key uncertainties

There is a considerable amount of information on the regional geological environment. However, the available information and the arguments on the description of the hydrogeological system, on long-term stability (given the proximity of the Roer Valley Graben) and on the consideration of future glaciations are still limited. These would need to be extended, were the region to be envisaged for a real site.

The extensive RD&D programme and the associated arguments clearly indicate the strengths of the Boom Clay as a barrier. However, there still remains some contradicting evidence with respect to the permeability of the clay, and clarification and additional evidence needs to be sought. This should include the potential role of discontinuities, work to reconcile the hydrogeological regimes in the upper and lower aquifers, and work to set better the regional hydrogeological regime into the context of the geological history. This should build confidence in the current hydrogeological conceptual model. In addition, the conceptual model for migration through a natural medium taking into account the range of geochemical processes still needs to be clarified. This clarification should include placing the concept of operational solubility on a sound technical and scientific basis.

As already indicated, the EBS is not yet fully analysed. The IRT believes that more credit could be taken for the role that is played by the EBS in contributing to the overall performance of the system. In addition, the IRT recommends that more attention be given to the detailed requirements of the EBS, and therefore to the details of its feasibility. Doubts remain on the feasibility of the SAFIR 2 concept for waste emplacement – there seems to be a need to develop an alternative emplacement concept (without using the disposal tube). These doubts are shared by ONDRAF/NIRAS.

In the assessments to date the analysis of high-level vitrified waste is on a firmer foundation than that of other wastes. Further work on the characterisation and assessment of Type B wastes and, to a lesser extent, on spent fuel is required to bring these assessments to a similar level. The IRT recommends that ONDRAF/NIRAS work closely with the waste producers to refine certain estimated inventories. For example the inventory of ^{129}I in vitrified waste is significantly higher than would be expected on the basis of the experience of other national programmes. The IRT also notes that the accepted estimate of the half-life of ^{79}Se in the technical community has increased significantly to a value higher than the one adopted in the SAFIR 2 report.

A peculiarity of the system under investigation, *vis-à-vis* those of other national programmes, is the relative proximity of the repository horizon to a major aquifer of regional importance. As a consequence, it is considered important to clarify, at the level of policy and regulation, the required level of protection to ensure the acceptability of the repository. This includes both radiological and non-radiological protection criteria.

2.8 Review of the proposed work programme

The SAFIR 2 report contains a very comprehensive list of RD&D issues. Although the critical issues are discussed in the report, the strategy for setting priorities is not presented and argued in depth. The IRT recommends that the setting of priorities should be more clearly linked to the reduction of the key uncertainties in the safety assessment and engineering feasibility, through a systematic approach to the management of uncertainties.

For some of the RD&D issues, policy input may be required. Examples are the importance that is attached by the Belgian authorities to the role of monitoring and retrievability, and the extent to which alternative host rocks should be investigated before the programme makes its final site selection.

2.9 Consistency with other national programmes and international practices

In many aspects the Belgium programme is in line with other national programmes and with international practice. These include:

- The concept of a geological disposal facility at depth relying on a system of multiple barriers in order to ensure passive safety is shared with other national programmes and is in line with international practice. Argillaceous formations are also being considered in several other countries (e.g.: France, Germany, Japan, Spain, and Switzerland).
- The stepwise approach and the phases of repository development are comparable to other programmes.
- The commitment of ONDRAF/NIRAS to societal dialogue is commended. Such commitment is being recognised internationally to be very important and essential to clarify relevant policy issues.
- The breadth and the extent of the RD&D programme are impressive, and full use has been made of the fact that the URF at Mol has been operating for over 20 years.
- The Belgian programme is open to international collaboration, and a very strong international co-operation is maintained in individual working areas through bilateral agreements, participation in EC-sponsored projects, and participation in

international *fora* and working-groups, e.g., at the NEA. This has contributed to a strong technical and scientific basis.

- The development of a methodology for making a "Safety Case", which started within the framework of the SAFIR 2 report, is in line with the international trend. Some of the work done in this area is novel and at the forefront. However, the application of this methodology has not yet been fully achieved.

There are, however, a number of aspects where the Belgian programme has a distinctive character. These include:

- The system being studied at Mol is distinctive because of its proximity to an aquifer of regional importance and because of the relatively shallow depth for geological repository for high-level and long-lived radioactive wastes. In addition, poorly indurated clay, as a host rock, is specific to the Belgian programme.
- The existence of alternative formations and how much flexibility is available for siting is less clear than in some other programmes.
- The national regulatory framework (criteria and guidance) is less well developed than in many other countries, and it is crucial that this is addressed in the near future. It is one of the key aims of SAFIR 2 to provide a platform for dialogue on this item. A regulatory framework would enable ONDRAF/NIRAS to put its analyses in a number of areas on a firmer foundation. This includes the treatment to be adopted for the analysis of human intrusion and the appropriate level of protection for water resources of regional importance. It would also be helpful to have guidance on the importance of monitoring and retrievabilty and on the role of alternative host rocks.
- The structure and content of the SAFIR 2 report are driven by the requirements defined by the SAFIR commission. A more appropriate reporting structure is needed in line with current trends in providing a "Safety Case" as part of the basis for decision making. This is also recognised by ONDRAF/NIRAS. The new reporting structure should help to ensure that the full picture of key issues and uncertainties is more easily available.

2.10 Experience of the review

Overall, the IRT found the experience of the review stimulating and productive. Members of the Belgian programme were very helpful, and the written answers to the questions and the face-to-face discussions were of high quality and very valuable in enabling the IRT to conduct the review effectively. At all times the Belgian team demonstrated a commitment and enthusiasm to produce a high quality product, and were constructively receptive to comments and advice.

3. OBSERVATIONS

3.1 The current technical and scientific basis

The understanding of the system is based on a RD&D programme that has been underway for almost three decades and has provided a vast amount of information. Through this programme, the understanding of key phenomena has developed significantly over the years and – together with the information from other programmes and from science in general – provides a good basis for the evaluation of system performance. However, the basis still needs improvements in some important areas and deserves further effort in the future RD&D programme, as is discussed below.

3.1.1 Understanding of the regional geological environment

The regional geological framework of the area under study for the Boom Clay at Mol has been derived from a general understanding of the geology of Belgium, a compilation of the scientific information available before ONDRAF/NIRAS started the high-level and long-lived waste disposal programme, and from specific research performed within the programme.

The understanding of the geological history at a regional scale is necessary for:

- the identification of large-scale and long-term stresses that may drive the future geological evolution of the area that needs to be considered in scenario development,
- the derivation of qualitative arguments for the stability of the site,
- building confidence in the conceptual models of the geosphere used for performance assessment, and for defining the boundary conditions for PA calculations.

Geological studies have continued at Mol since the first SAFIR report in 1990. Adequate descriptions of the geometry and the sedimentary history of the Cenozoic multi-layered system of the Campine Basin, to which the Boom Clay formation belongs, are included in SAFIR 2. Significant efforts have been put into studying the hydrogeology of this system at a regional scale providing an adequate framework for the local scale studies. Essential aspects of the future behaviour of the area (particularly climate and sea-level changes) have been studied as well, and interesting conclusions have been obtained recently. Preliminary results from the EC-PHYMOL project [7] looking at paleo-hydrogeological information have been presented to the IRT during the review, showing that different hydrogeological scenarios are being addressed appropriately.

Not all the aspects that are important in defining an adequate geological framework for the Mol area have been covered, however, to the same depth. Questions about the long-term stability of the Mol area may arise, because of its proximity to the Roer Valley Graben. The IRT believes that ONDRAF/NIRAS could have described the geometry and history of the Graben in more depth and could have presented a stronger line of reasoning on the role of the Roer Graben and its impact on the stability of this area, making use of information at a larger scale of study. This is also a key to enable a clearer strategy to be built to manage scenarios related to geological evolution.

The Roer Valley Graben is a major structure that belongs to the main European cortical rift (extending from the North Sea to the Gulf of Valencia) active from Oligocene to current time (characterised by large earthquakes in the Holocene [8]). This Variscan lithosphere suffers extensional stress due to the European-African collision. Earthquakes that may have most impact in the Campine Basin are related to the fault activity of the Roer Valley Graben.

ONDRAF/NIRAS is fully aware of the need for further work in this field. They have argued in SAFIR 2 that the area of Mol is far enough from the Graben not to be subjected to strong deformation, based on direct evidence collected during their studies (the nearest known fault is five kilometres to the east), as well as on indirect evidence derived from sedimentary, geochemical and hydrogeological considerations. However, the arguments in favour of geological stability could be made more strongly based on the available information of the past evolution of the graben, which may allow an assessment of the future stability of the graben. It may also be possible to include in the discussion information on crust rheology, thickness of the brittle layer of the lithosphere (crust plus upper mantle), seismogenic deep layer and fault geometry at depth.

Ongoing studies of ONDRAF/NIRAS for the reassessment of the seismic hazard of the area could be incorporated into the structural model in future studies. Seismic hazard has to be discussed in the assessment of long-term performance of the EBS and the geosphere barrier, but also in the assessment of operational safety of the repository.

Stronger support for the arguments could also be found from a literature survey on the issue. According to [9], the area of Mol is located in a zone showing a minimum amount of deformation, both compressive and distensive, whereas the Roer Valley Graben is classified as a zone suffering maximum distensive deformation. From regional structural studies of western and central Europe, there is no evidence of the Roer Valley Graben being associated with volcanic activity [10]. An analysis of this information, which could complement the argument for long-term safety of Mol, has not been presented in the SAFIR 2 report.

3.1.2 Understanding of the host rock

The extensive investigations to date allow clear statements regarding the geometry of the host rock (thickness/dip, lateral extension) and the absence of major regional fracture zones in the direct vicinity of the model site. The measurements indicate that the host rock is an excellent barrier with respect to flow and transport. The construction and operation of the URF at Mol have constituted a unique opportunity to take forward the characterisation of the Boom Clay, providing high-quality site-specific information.

The opportunity to have long-term and large-scale tests in the URF enhances confidence in characterisation and the performance of a number of aspects of the system. However, as discussed below, some of the detailed mechanisms and processes determining radionuclide migration in the host rock are not yet fully understood. This is also the case of perturbations in the host rock induced by a repository.

Hydrogeology of the host rock

a) Properties of the Boom Clay

The Boom Clay can be argued to be the most important barrier supporting safety in the SAFIR 2 report. Many radionuclides will decay either in the near field or in the clay close to the repository because of the very long migration times due to the tightness of the Boom Clay and its chemical reactivity. Only very long-lived poorly retarded radionuclides could potentially migrate through the Boom Clay by advection and diffusion.

The SAFIR 2 report presents evidence of the remarkable lateral continuity of the Boom Clay; this is shown by the perfect correlation of changes in grain size (clay/silt) and mineralogy (septarias). Consistent measurements of the permeability of the Boom Clay have been provided from hydraulic and tracer tests in core samples as well as in *in situ* tests in boreholes and the underground laboratory. Profiles of permeability values along the entire clay formation show an average of around 10^{-12} m/s with small deviations from this value. These observations have been used by ONDRAF/NIRAS to argue for the homogeneity of the Boom Clay and, also, to justify this average value for the larger-scale permeability for the performance assessment calculations.

However, ONDRAF/NIRAS has found that this value, obtained from measurements at the metre scale, is not consistent with that derived from regional hydrogeological modelling (dating back to 1984); the calibration of the hydrodynamic model resulted in a value of 10^{-10} m/s. In several other studies, an increase in the average conductivity with the scale of observation has been observed and attributed to a scale effect in heterogeneous media [11]. In low permeability environments, where there are limited methods available to measure conductivity, it has also been observed that fractures and sedimentary discontinuities that are effective on a regional scale may not be present in the small samples tested in laboratories [12]. Heterogeneities due to gradual changes in the grain size at a scale of several hundred metres are hardly detectable from single borehole measurements. Flexures present throughout the whole area of the Campine Basin, which may cause some heterogeneity, have been interpreted from seismic profiles.

The IRT believes that the future plan to build a model to address the homogeneity/heterogeneity in the geological barrier and the surrounding geosphere, as proposed by ONDRAF/NIRAS, is an appropriate next step, and one of the main developments needed in the future programme. This will demonstrate that due attention is being paid to treating uncertainties in the conceptual models for fluid flow and transport of radionuclides through the Boom Clay, and build confidence in the approach adopted in dealing with this key component of the safety assessment. It will also help to clarify the inconsistencies between the values obtained for the hydraulic conductivity of the Boom clay at different scales. The future use of the hydrogeochemical information in testing the groundwater flow models, as recognised by ONDRAF/NIRAS, will constitute another important step in this direction.

Different kinds of information (hard and soft) linked to permeability, such as direct measurements, lithostratigraphic facies and geophysical data, could be incorporated in such a model using a geostatistical approach for the geological medium. Such a model can also be used for upscaling to obtain the "regional" permeability of the clay. Appropriate geostatistical tools are readily available. They have the advantage that all the available information can be integrated in a systematic manner, and subjective "bias" is limited or avoided [13].

b) Modelling

ONDRAF/NIRAS has put substantial efforts into the calibration of a three-dimensional steady-state regional flow model. The main reason for this model is to have an independent check on the large-scale permeability of the Boom Clay. Such a model could also lead to a better understanding of the role of the aquitard (the Boom Clay) in the multi-layered system, and provide input to the more detailed transport models that are used in performance assessment.

The IRT considers that calibration of the regional hydrogeological model using new piezometric data from the underlying aquifer (lower Rupelian) and using data from transient conditions, as ONDRAF/NIRAS proposes, could be a complementary strategy to estimate the regional or large-scale hydraulic conductivity of the Boom Clay. The IRT recognises that such a model would have to rely on the description of a complex flow system having highly uncertain boundary conditions.

The local-scale hydrogeological model has been limited to the area between the two rivers Grote Nete and Kleine Nete, taking into account that groundwater discharges into them. These assumptions might be revisited after the calibration of the new regional model. The IRT believes that more attention should be devoted to the lower aquifer – there is the possibility that the model could show that there are pathways from the Mol area to the discharge wells.

ONDRAF/NIRAS could also take advantage in the future of other available modelling strategies, such as simple one-dimensional vertical profiles or representative vertical cross sections, that may help in understanding the water flow system and in deriving multiple lines of reasoning supporting the results of the hydrogeological models. The recent activities to build a "Supra-Regional Groundwater Modelling" (PHYMOL project, [7]) constitute an important contribution in this line, as well as in the management of scenarios. ONDRAF/NIRAS is proposing further attempts to test the groundwater flow models by using hydrogeochemical information, mainly in the form of vertical profiles of the concentration of natural tracers, which will constitute another important step.

The resolution of the difference between the two alternative values of hydraulic conductivity for the Boom Clay is important; with the lower value, diffusion dominates, with the higher value advection dominates, with the transition occurring around 10^{-11} ms^{-1} (at this value, the Péclet number is roughly unity).

The importance of this uncertainty is recognised by ONDRAF/ NIRAS, whose staff are confident that the lower value of permeability can be confirmed through further experimental work and improved modelling.

To summarise, the IRT feels it is important that a number of lines of argument are developed to justify the use of a low value for the vertical hydraulic conductivity for modelling flow and transport in the Boom Clay over the relevant spatial and temporal scales.

Geochemistry of the host rock

a) Mineralogy

The geochemical characterisation of Boom Clay is needed to understand the behaviour of radionuclides. Furthermore, a precise mineralogical description of the rock is the basis of this geochemical characterisation. From the SAFIR 2 report, it has not proved practicable to evaluate the level of understanding that ONDRAF/NIRAS has developed on this topic. Although there has been good work in this area, it was apparent that the methodology used has varied over the successive analytical campaign, and this makes the comparison of results from the different campaigns difficult. The major part of the analyses is conducted by X-Ray diffraction alone. However, this technique does not record phases present at a level of less than 5%, and trace minerals can play an important role in the control of some aqueous species. The IRT recommends that complementary measurements be undertaken using other techniques.

For simulating the perturbations to the system (for example, oxidation and alkaline plumes), it would be desirable to develop more precise estimates of the proportion of the minerals present, so that mass balance calculations can be undertaken.

Finally, the IRT recommends that the knowledge of the “crystalline state” of the minerals should be improved; this will enable the stability of the mineralogical phases to be better understood.

b) pCO_2

In the SAFIR 2 report, and after the face-to-face exchange with the Belgian experts, it appears that the partial pressure of CO_2 of the Boom Clay is a key parameter for deriving input parameters (solubilities, sorption) for performance assessment, and that it is not well understood. This parameter is important to constrain the carbonate system, the pH and the speciation of some important radionuclides. Only one direct measurement has been made and it is unknown how the value obtained originates. The IRT recommends that a study of this parameter be undertaken.

c) Modelling clay/water interactions

In the SAFIR 2 report, the Archimede project is presented. This interesting study ended in 1994 [14], and the IRT observes that no further work has been undertaken to improve the quality of the geochemical understanding since then. In particular, the Archimede project raised the question of the reactivity of the clay minerals and did not provide an understanding of how the obtained value for the pCO_2 originates. For modelling the solubility and the retention of radionuclides, a more detailed understanding of the interactions between water and minerals is recommended. As the clay minerals constitute the major part of the Boom Clay, it would be desirable to take into account the chemical behaviour of these minerals.

Moreover, the IRT notes that a mechanistic sorption model specific to the Boom Clay (for major elements and the significant radionuclides) is missing. This constitutes an important issue that the IRT recommends to be addressed in future work.

d) Impact of the thermal phase

The thermal phase would probably induce changes in the mineralogy of the Boom Clay, and calcite would be expected to precipitate. This precipitate would change the porosity of the rock and probably the diffusion coefficient of the radionuclides. This effect has not been studied to date in the SAFIR 2 project. During the face-to-face meeting with the IRT, ONDRAF/NIRAS concurred with the IRT on the importance of evaluating the impact of this phenomenon.

Transport processes in the Boom Clay

In the approaches used in other countries to understand radionuclide transport, special codes are often used to assess the different (partially coupled) phenomena. The development and use of corresponding tools has not been given prominence in SAFIR 2, nor is it clearly identified by ONDRAF/NIRAS as a priority for the future. The IRT recommends the use of such tools, so that a more mechanistic understanding of the processes can be developed and relied upon.

The analyses in the SAFIR 2 report rely extensively upon migration experiments. The IRT appreciates the commendable and significant effort that has been made to obtain experimental measurements for the apparent diffusion coefficients for a large number of radionuclides. This approach based on data gathered under specific conditions, however, has clear limitations as to whether the results can be extrapolated to different reference conditions (such as a different reference chemistry) and whether they can be extrapolated to long timescales. As an example, the IRT does not find the use of the concept of "operational solubility" (S_{op}) helpful in enabling the results to be extrapolated to different reference conditions. S_{op} is a concentration limit obtained by interpolation of the experimental data for some elements by using a linear, one-dimensional diffusion model based on linear reversible sorption. The value of the parameter "S_{op}" is thus dependent on the model of diffusion and sorption used and on the specific experimental setting. Other diffusion or sorption models would lead to other values and alternative interpretations, as would other experimental conditions. The IRT recommends that a more mechanistic approach be pursued to develop an adequate understanding. Alternatively, simplified robust models – rather than predictive, realistic ones – could be developed and relied upon.

The IRT also recommends that, when modelling radionuclide transport in the far field, the relevant species be assumed to be in chemical equilibrium with the Boom Clay rather than in an oxidised state.

Finally, it is observed that in the SAFIR 2 report the major transport process in Boom Clay is molecular diffusion, as is deduced from the low values of permeability obtained from laboratory tests. This hypothesis seems to be proved at the scale of core samples and at the scale of experiments (a few metres) made in the URF. At the scale of the Boom Clay formation, it will be interesting to examine whether the vertical profiles of the concentrations of natural tracers can be explained by the result of the diffusion of marine interstitial water towards the surrounding aquifers. From the face-to-face discussions, the IRT understands that the available data of natural tracers are not well understood at present and a complete profile of natural tracers across the Boom Clay is not available.

The IRT recommends that consideration be given to obtaining profiles of the concentration of some typical natural tracers. If these could be interpreted using a diffusion model with the measured values for the diffusion coefficients and the geochemical porosity, it would increase confidence that diffusion is indeed the dominant process at the scale of the host formation.

3.1.3 Understanding of the engineered barrier system (EBS)

The engineered barrier system described in the SAFIR 2 report is rather "complex" when compared to other national programmes, in that it includes a larger number of components: namely, the waste form, its overpack (for vitrified waste) or container (for spent fuel), an air "gap", a disposal tube, the backfill, a hydration system and a liner. In addition, the sealing materials of the galleries and disposal boreholes are also part of the EBS. The properties of all the materials involved and all interactions between components need to be sufficiently understood, and the consequences evaluated in the long-term assessment. A broad investigation programme has been carried out for the waste forms (Type C in particular), the overpack and the backfill, and demonstration tests have been carried out. As a consequence, on many issues, there is a strong scientific and technical basis to assess the technical feasibility and the performance of the proposed EBS. In recent time, this has also led the ONDRAF/NIRAS team to revise some of the choices made, as was learnt in the face-to-face discussions.

In general, a more detailed presentation of the understanding of the properties of the various components of the EBS would have been helpful. Furthermore, the near-field analysis is insufficient when compared to other national programmes. Indeed a better near-field analysis could provide higher levels of assurance of safety of the overall system, even if the host rock remains the main contributor to safety.

Backfill materials

The IRT asked for reasons for the choice of the FoCa Clay as a backfill material. The discussions revealed that this material was chosen because of its geomechanical properties. Compared to other backfill materials used in other programmes (e.g. MX-80 bentonite), however, it may be more complex, and as a consequence, it may be more difficult to model its sorption properties and its long-term evolution with confidence. The discussions also revealed that the FoCa clay has only been used as the reference material during the development phase, and that the final choice has yet to be made. Indeed the FoCa clay is unlikely to be considered further, which leaves open the question of what backfill material will be used in future. The IRT recommends that ONDRAF/NIRAS give priority to this issue and to take advantage of the substantial understanding available in other national programmes worldwide.

Overpack and container

The principal role played by the overpack container is to ensure the containment of vitrified waste and spent fuel during the thermal phase. An extensive research programme has been carried out from which ONDRAF/NIRAS have deduced a conservative overpack container lifetime.

It would have been helpful if, in the SAFIR 2 report, more details had been presented on issues such as:

- how workable is the material;
- will it be susceptible to localised corrosion;
- what overpack loads can be expected in the repository;
- what are the significant uncertainties over its behaviour;
- how significant is the overpack in the overall safety, and what safety margins are built into the overpack design;
- how will the overpack be sealed and what does the sealing technique mean for the corrosion performance;
- what is the probability for an early failure, and what would its significance be.

The arguments for the selection of the canister material seem to be retrospective. However, the basic criteria are that there should be no (or very little) gas production and that the corrosion lifetime of canisters should be at least 2000 years, but the walls should be thin, since space is limited. In the light of this, the selection of AISI 316 seems to be justified. The material is widely used and is reasonably priced.

Sealing materials

It would also be more helpful if more details were provided on the sealing materials. The seals are considered to be an important component in the concept, yet the SAFIR 2 documentation identifies no future work. As a result of this review (see also Section 3.2.3), the IRT is convinced that attention should be given to improve the assessments of the effects that might result from poorer than expected seal performance. Face-to-face exchanges between the

IRT and ONDRAF/NIRAS confirmed that studies of the sealing materials would continue.

Evolution of the EBS

The maximum temperature on the canister surface is reported to be 190°C, which means that there will be a substantial temperature gradient in the near field. This gradient will affect both the chemical and the mechanical properties of the EBS. The IRT encourages ONDRAF/NIRAS to evaluate the short-term thermo-hydro-mechanical evolution of the EBS.

Geochemical aspects

The geochemistry of the near field has not been extensively studied in the SAFIR 2 report. ONDRAF/NIRAS argues that the Boom Clay will impose, with time, its chemistry on the EBS. However, the introduction of a large quantity of new chemical components will perturb the *in situ* conditions, and therefore the final geochemical conditions may not be the same as before the perturbation, even after the system returns to equilibrium. This may affect the retention and migration of radionuclides. In addition, there will be a transient phase, while equilibrium is being established. Therefore more attention should be paid to the geochemical evolution of the EBS in order to develop a better understanding of the migration of the radionuclides.

Hydration system

Forced hydration is preferred by ONDRAF/NIRAS to natural hydration. However, it is recommended that the need for such a system be reconsidered. If it is indeed needed, then the question still remains about which is the best artificial method: immersion of blocks, hydration pipes or geotextiles. The remaining uncertainties concerning the feasibility of the hydration system are identified and highlighted in SAFIR 2. Research is also anticipated to understand better the kinetics of the process, to determine how much hydration is needed (to avoid vapour formation and to allow heat dissipation), and to define in which direction (to avoid solute concentration close to the disposal tube). The option selected for the saturation of the backfill may have strong implications for the evolution of the engineered barrier system.

It would be helpful to have a better understanding of the implications of a failed hydration system.

3.1.4 Understanding of the wastes

ONDRAF/NIRAS recognises the importance of an adequate treatment, characterisation and documentation of all wastes that are to be disposed of. This is reflected in the development of waste acceptance criteria and in the application of an appropriate QA regime. However, the reporting on the characteristics of the wastes (and the underlying understanding) in SAFIR 2 is rather unbalanced. Although the research programme on vitrified waste and the spent fuel stability needs to be continued, there is a strong need to have a closer look at some of the other Type B wastes.

The IRT also notes that, in general, the reported radionuclide inventories for vitrified waste and spent fuel are broadly consistent with information from other national programmes. For certain specific radionuclides, however, the inventory seems to be overestimated. An example of this is iodine in the vitrified waste. In the written answers and during the seminar meeting, ONDRAF/NIRAS acknowledged that the iodine inventory is unrealistic, and made it clear that they are committed to improve it. It is considered important that a capability should be developed to calculate and assess radionuclide inventories independently from the waste producers, in order to build confidence in these important data.

The IRT also notes that the instantaneous release fraction (IRF) for spent fuel is not discussed in the chapter on understanding the wastes, although this is a very important parameter in the migration calculations.

Finally, in section 2.1.5 of the SAFIR 2 report a simple, but adequate strategy is presented for the selection of relevant radionuclides for the assessment of safety. This strategy is not applied consistently, however. For example, the inventory calculations (Section 2.3) do not include all the identified radionuclides and the table in the assessment chapter (Section 11.3.2) is also different.

3.1.5 Understanding of near-field and far-field interactions

To understand the performance of the overall system, both the performance of the individual components and their interactions are important.

Coupled processes

A coupled THM model is presented in the construction chapter covering mechanical aspects of the interactions between the EBS and the host rock; this covers, for example creep and the effects of an increased porewater pressure. However, it is not clear how the results are, or will be, used in the long-term performance assessment.

It is stated in Chapter 4.3.3.1.2 that "An increase in temperature of the clay can also influence its mechanical properties (e.g. the degree of over-consolidation, rigidity, compression modulus) or can give rise to the formation of fractures and irreversible deformation". This fact is neglected in the thermal impact assessment (Chapter 11.3.7) and the whole analysis is based on observations from the CERBERUS experiment and is not convincing. In addition, a thermal analysis is presented in Chapter 5, but the results are not used in the assessment of performance. Additional work has been undertaken, however, in this area, as was reported in the face-to-face discussions.

The IRT encourages ONDRAF/NIRAS to continue to cover this area and to make sure the results are reported in the next phases of the programme.

Gas generation and migration

For the canister material chosen for spent fuel and high-level waste, it seems that it will be possible to avoid the formation of a free gas phase. However, a detailed evaluation of the effects of gas generated by the Type B wastes is still missing and is considered by the IRT to be a high priority item for future investigations.

The work performed on the release of gas through the Boom Clay is of high quality. The conclusion that the formation of a gas pathway will be a localised perturbation and will only displace a small amount of water is plausible.

The presentation of the scientific understanding on gas generation and transport is good. The issue is taken seriously by ONDRAF/NIRAS, and several models and approaches are given in the SAFIR 2 report. The experimental background is also of very high standard.

Thermal period

The thermal period in SAFIR 2 varies between 300 years (for vitrified waste) to 2 000 years (for spent fuel) with a period of 50 years storage for both vitrified waste and spent fuel before emplacement in the repository. This seems to be the basis used to derive the required period for complete containment, although there appears to be inconsistency in the assumptions made for the duration of containment in safety assessment. ONDRAF/NIRAS acknowledges that these periods were derived from qualitative arguments stating that complex interactions between components and radionuclide migration should be avoided during the thermal phase. The IRT recommends ONDRAF/NIRAS starts consultation with regulators on how to define an appropriate period of containment.

3.2 Quality of the performance assessment (PA)

3.2.1 Framework of performance assessment

The role and framework for the safety assessment is clearly described. The framework is based on a careful review of the work of, and views expressed by, the relevant international bodies, such as the IAEA and the ICRP.

To date the authorities in Belgium have not provided a regulatory framework or guidance on deep geological disposal. As a consequence, ONDRAF/NIRAS has developed a framework through a careful review of the work by international bodies. This is a sensible approach, and it provides a good starting point for assessing the results of the safety analyses. However, the maturity of the SAFIR 2 document suggests that a regulatory framework is now timely, and the document provides a suitable basis to start a dialogue with the regulators and policy makers in Belgium on a number of aspects, including the regulatory framework and guidance on how to deal with certain matters. This will enable the programme to move on to issues such as consultations on how to proceed with siting.

The IRT is pleased to note that ONDRAF/NIRAS recognises that a safety case is not simply a numerical comparison with a dose or risk-based criterion. Rather it is a multi-faceted analysis, where quantitative and qualitative arguments are brought together to build a safety case. ONDRAF/NIRAS is commended for its initial work on safety functions and alternative safety indicators (see below). These are useful tools to examine the role and quality of the different components of the repository system.

The importance of proper feedback and interaction between the different disciplines is clearly recognised by ONDRAF/NIRAS. The strategy followed in the Belgian programme to build periodic performance assessments is appropriate. Such a stepwise approach should facilitate feedback and interactions. However, the IRT believe that these ideas have not yet been fully implemented, and the resulting feedback is not yet apparent in certain parts of the programme. The input of performance assessment to the rest of the programme (design, RD&D) could have been stronger. ONDRAF/NIRAS has explained to the IRT that optimisation of the design is to be left until a site has been chosen, but this should not prevent iterative performance assessments being undertaken and interacting with design and research. The IRT believe that such a feedback from performance assessments to the rest of the programme would enable uncertainties to be managed in an appropriate manner, ensure that effort is focused, and as a consequence allow a more strongly founded assessment to be built.

3.2.2 Performance assessment methodology

In the SAFIR 2 report, ONDRAF/NIRAS recognises the appropriate foundations of a safety analysis, namely the multi-barrier approach, redundancy of barriers, and defence in depth. These foundations are held in common with assessments undertaken in other countries. It would be valuable to discuss these issues with the regulatory authorities in Belgium.

The building blocks of the safety assessment and the steps in a safety assessment are properly identified and described. The IRT notes that the implementation is not always complete, and some aspects are noted in Section 3.2.3.

The IRT has specific comments on a number of the elements of the performance assessment methodology.

Safety functions

The IRT considers the safety functions proposed by ONDRAF/NIRAS to be a valuable tool for aiding qualitative and quantitative understanding (see Chapter 13.D.1 of the SAFIR 2 report). The use of safety functions and in particular the identification of these safety functions for the main components is novel (introduced in 1999) and has proved a helpful tool in identifying priorities in the RD&D programme.

However, ONDRAF/NIRAS acknowledges that to date the approach of using long-term safety functions has only been applied *a posteriori*. It is expected that, on the basis of positive feedback on the SAFIR 2 report, ONDRAF/NIRAS will use this approach more proactively in order to help in the definition of the key design requirements. The approach will also aid in the traceability of decisions and choices made about the design to meet those requirements. This will be one of the priorities for the future programme. Through this exercise, progress is expected in:

- assessing redundancy and identifying whether there is the potential for common mode failure;

- identifying the "latent" functions (safety margins) – these are functions that are not thought to be required, but are available if another barrier performs poorer than expected (see Figure 13-7 of SAFIR 2).

Ideally, the considerations presented would be complemented by some simplified "insight calculations", see for example [15]. These can help illustrate the key features determining the performance of the system.

Alternative* s*afety* i*ndicators

ONDRAF/NIRAS is commended for the work on alternative safety indicators, for example radionuclide flux. The assessment of how many of the radionuclides decay to insignificant levels while still within the engineered system is very informative. The work on alternative indicators merits further development for both normal and altered scenarios – only dose rates are currently discussed for the altered evolution scenarios.

*"**Implementation of safety" and "Assessment of safety"***

The distinction of "implementation of safety" and "assessment of safety" and the discussion of both of them (based on the chosen safety strategy) in SAFIR 2 are considered to be very important. It is mentioned that the "implementation of safety" is mainly addressed in the chapters 2 to 9 of the SAFIR 2 report, whereas the "assessment of safety" is documented in Chapter 11. Unfortunately, Chapters 2 to 9 are not very specifically focused on a discussion of "implementation of safety"; this could be improved in future documentation.

Scenario development

The IRT supports the view of ONDRAF/NIRAS that scenario development is an appropriate way to deal with uncertainties in the way the system will develop. The requirements on the methodology are clearly described, and in general have been applied in an appropriate manner. The scenario methodology was developed through international projects (such as the EC EVEREST project [16]). As has been stated by ONDRAF/NIRAS, the scenario analysis dates from 1994 and is based on a NEA report of 1992.

The IRT is encouraged to see that ONDRAF/NIRAS has plans to implement a more up-to-date and systematic methodology for scenario development. The IRT notes that the strategy reported in SAFIR 2 mainly focused on the performance of the geological formation as the key component of the system. However, it also noted that a number of altered evolution scenarios, including the effects of poor sealing and the failure of the overpack, are being addressed.

Treatment of uncertainty and the management of uncertainty

The IRT is pleased to note that ONDRAF/NIRAS recognises the importance of treating uncertainty systematically in an assessment. The use of deterministic and stochastic calculations as complementary in the SAFIR 2 report is to be commended. However, the use of the stochastic approach in the SAFIR 2 report is limited to transport modelling and has not been updated recently. Ideally, the calculations presented would be complemented by some simplified "insight calculations", see for example [15]. These can help illuminate the key features determining the performance of the system. They can also help identify priorities for future work programmes.

The uncertainty analysis presented is broadly limited to the selection of parameter values. It does not cover conceptual model or scenario uncertainty in the same depth. The IRT recognises that ONDRAF/NIRAS has explored the use of alternative conceptual models. The spent fuel dissolution rate is taken from two different conceptual models; one uses a constant value, and the other is based on a linear dependence on alpha activity. ONDRAF/NIRAS is encouraged to pay increased attention to conceptual model uncertainty in the future.

In addition, it appears that the distributions used in the probabilistic calculations are considered to represent some sort of statistically based distributions, that is distributions based on the observed frequencies of events. The IRT considers that such distributions may not only be based on frequencies, but may rather represent "degrees of belief", representing genuine uncertainty.

In Section 11.2.7.4 the different approaches to treating uncertainty in deterministic and stochastic analyses is appropriately noted. This includes the use of "conservative" values in certain cases. The IRT notes that if such conservative values are applied to a significant number of parameters, then the approach may lead to an unrealistic description of the system, which may not be sufficiently close to its real behaviour. Because they are very conservative, such models may be useful if they predict that there is adequate safety, but it may be difficult to tell whether there is an excessive margin of safety. However, they may not be suitable for dealing with issues of optimisation of repository design and for focusing future research. There is value in trying to quantify the uncertainties in the parameters as realistically as possible. This provides a much better basis for optimisation of repository design, and provides an indication of the real margin of safety. Again it also contributes to the management of uncertainty.

This relates also to the concept of a “Robust Disposal System”, which has been introduced by ONDRAF/NIRAS. The parameters and the models used may support this, but a more realistic assessment is also needed to confirm that the robust system really is “robust”.

The interaction and feedback between performance assessment exercises and design of experiments and data gathering provide the basis to see how the understanding of repository performance is being enhanced. However, this could have been presented in a more systematic manner. A history of safety assessment exercises is given in Chapter 11, but how these assessments were used to guide RD&D is not provided. The EC-EVEREST study [16] was focused on determining the different sources of uncertainty and their relative importance for safety. It would have been useful to see the results of this study mapped onto the decisions made on future RD&D. Figures or flow diagrams or even simple lists of developments ordered in time would help to show the way these iterative processes have been taking place and would help to assess the “actual” progress made.

The biosphere

The methodology used for calculating radionuclide transfer in the biosphere and uptake by man, and for calculating resulting individual doses, is based on the concept of stylised situations. As a consequence, the calculated doses are to be considered as indicators of safety rather than predictions of actual doses. This is in line with the international practice. Indeed ONDRAF/NIRAS has applied the methodology developed as part of the IAEA BIOMOVS and BIOMASS programmes to the Mol site.

For certain long-lived radionuclides (e.g. ^{129}I), the current assessments suggest that much of the inventory will eventually be discharged into man’s environment albeit spread over very long times in the future. The aquifers play a significant role in diluting the radionuclides released, and in reducing the calculated doses (although other phenomena also affect these calculated doses). The calculated doses thus depend on the details of the model adopted. Although the modelling of the biosphere is in line with accepted practice internationally, it would be helpful to have a clearer picture of the key phenomena operating in the system. In particular, some attention should be given to whether alternative but equally justifiable assumptions could be made, which would lead to different results.

The choice of assumptions for the dose calculations is an important area where a dialogue with the regulator is needed in order to identify which quantities should be calculated, the way they are calculated, and how comparisons are to be made to assess regulatory compliance.

Human intrusion

ONDRAF/NIRAS recognises that it is appropriate to undertake assessments of future human intrusion. Two of the altered evolution scenarios considered in Section 11.5.2.2.2 of the SAFIR 2 report are concerned with intrusion. AES1 (Exploitation drilling) is concerned with sinking a well into the underlying (Lower-Rupelian) aquifer and the use of the extracted water for irrigation and drinking water supply. In AES8 (Exploratory drilling), it is assumed that an exploratory borehole is drilled through the repository. For this latter scenario, ONDRAF/NIRAS considers it appropriate to assess the impact on future inhabitants of the site, who come into contact with drilling sludge left on site, and also the consequences of a borehole being left open and water passing through the repository and coming into contact with radioactive waste. The calculations presented for AES8 are not complete, and ONDRAF/NIRAS is committed to undertaking them in future. The IRT encourages them to do this.

ONDRAF/NIRAS recognises the valuable advice given in ICRP Publication 81 [17], and they appropriately draw on paragraph 61 of that document, where it states that “Protection from exposures associated with human intrusion is best accomplished by efforts to reduce the possibility of such events”. This is captured in the safety function “Limitation of access” defined by ONDRAF/NIRAS. Internationally, it is generally recognised that this possibility is reduced by placing the repository deeper, and by avoiding natural resources that might be exploited in the future.

ONDRAF/NIRAS can only take the human intrusion assessment so far before the appropriate authorities give guidance on the regulatory framework. Such guidance could advise on what are the proper provisions for the protection of the relevant water resources, and how to weigh human intrusion considerations alongside considerations of the normal groundwater pathway.

The IRT believes that this is one of the issues that should be taken forward as part of a dialogue with the regulators and policy makers in Belgium and that such a dialogue is now timely.

3.2.3 Completeness of analysis and quality of incorporation of understanding into PA

In the Belgian programme, a number of performance assessment studies have been undertaken. This is consistent with a stepwise approach to repository development. Many of these have been in the framework of EC-sponsored projects. The nature of these assessments has changed from greatly simplified exploratory studies to more refined and better-founded studies.

In SAFIR 2, advantage has been taken from many of these studies without, however, updating all of the older information used to the current understanding. One consequence of this is that the results reported are not always consistent nor are they up to date. One example is the assessment for wastes other than spent fuel. The assessments for the different types of waste were carried out at different periods of time. For instance, for vitrified HLW, spent fuel and hulls and ends the reported calculations date from 1999 (references [4], [5] and [6] in Chapter 11, Section 11.5.3). The assessments for category B waste are older than 10 years. Thus the SAFIR 2 report is not properly comprehensive in this aspect. This should be borne in mind when drawing final conclusions, and identifying future priorities. In addition, the depth of the analysis is in certain areas incomplete or limited; examples include the effects of overpack failure and of poor seals.

Barrier performance

In the assessments presented in the SAFIR 2 report, the Boom Clay is the most important component in assuring the safety of the whole disposal system, and the analysis presented in SAFIR 2 focuses on this barrier. The EBS has received less attention, although the overpack has received some. To be consistent with the multi-barrier approach, further attention should be given to the contribution of the EBS as a whole.

It is stated in several places in the report that there is a high degree of redundancy in the safety case (e.g. Section 13.D.2.6). The IRT is not sure that this has been demonstrated. For the safety case presented, it is necessary for the Boom clay to perform as modelled, that is to have sufficiently low permeability that radionuclide migration through the Boom clay is dominated by diffusion, rather than advection being significant. If the Boom clay were not to perform as modelled, then it is possible that other parts of the system might have a more significant impact on the performance of the system. The importance of building confidence in the value of the permeability of the Boom Clay has been discussed already. There might be value in undertaking “What if …?”

calculations of migration and dose for a higher permeability value. This would aid in the understanding of barrier performance.

A phenomenon that could change the slow migration of radionuclides through the host rock is the transport of radionuclides in a gas phase. The formation of a gas phase is unlikely with vitrified waste and spent fuel, but not for Type B waste. The chemical form of ^{14}C is uncertain in spent fuel and Type B wastes, and its presence in a gaseous phase cannot be ruled out. This scenario is worthy of further attention.

Premature failure of (parts) of the engineered barriers

The scenario concerned with the premature failure of part of the engineered barriers is not fully discussed in the report. The overpack is correctly identified by ONDRAF/NIRAS as a crucial barrier during the thermal phase, and an important area for future reduction of uncertainty. The IRT strongly recommends further development of the failed-overpack scenario in an internally consistent manner. This should include consideration of the causes, nature, and the consequences of the time of the failure of the overpack and provide a clearer picture on the importance of these issues.

Poor-sealing scenario

The seals are an important barrier in the Belgian concept, since they will ensure that the host rock will be the main transport path. The scenario dealing with poor sealing is treated in the analysis. However, it is not clear that the poor-sealing scenario considered is necessarily the one that would have the highest consequences. In the scenario considered, the Boom clay still acts as a barrier to radionuclide migration to some extent, because its low permeability limits groundwater flow into the galleries and disposal tunnels. However, consideration could also be given to a "U-tube scenario" in which the seals between both shafts and the waste are ineffective. In this case, groundwater might be drawn through the repository by the difference between the heads in the aquifer at the locations of the shafts. In this case, the permeability of the backfill, rather than that of the Boom clay, would control the flow.

It might be argued that this scenario is very improbable because the likelihood of having more than one ineffective seal is negligible. However, this depends on the reason for the seals being ineffective. If simply the seals become less effective over time, then the likelihood of having more than one ineffective seal might not be much smaller than that of having one ineffective seal. This possible U-tube scenario assumes that the shaft lining in the aquifer has ceased to act effectively as a barrier to groundwater flow. However, it might be difficult to argue that the shaft lining will continue to act as a barrier in the long term. In addition, the effects of the excavation disturbed zone (EDZ) should be assessed. It may be that the consequences of this scenario are much smaller than those of the poor-sealing scenario considered. However, unless the scenario has been considered, this cannot be demonstrated.

Adequacy of the models used

In SAFIR 2 the adequacy of the tools available and the models used is not discussed in depth. The IRT feels that this should be done in future analyses. Such a discussion should also include issues like convergence for numerical models and the appropriateness of "equivalent" parameters such as dispersion length to model heterogeneity.

3.2.4 Data sets for performance assessment

The strategy followed by ONDRAF/NIRAS for the selection of the different parameters to be used in the performance assessment is described in a dedicated report "Data Collection Forms (DCF)" – a supporting document to SAFIR 2. The IRT had the opportunity to look at the files of this document during the review and discussed them with the ONDRAF/NIRAS staff. As a result of this, ONDRAF/NIRAS demonstrated that there have been strong interactions between experts and performance assessment managers throughout the project. However, the IRT found also that the arguments and supporting information behind the decisions taken on specific parameter values have not been incorporated in a complete and comprehensive way in the DCFs. The IRT encourages the development and implementation of a strategy in the future that improves the traceability of this process. Ways of recording important arguments in scenario development and modelling should link into this strategy and form an architecture that will facilitate peer review and the development of a dialogue with the regulators and other interested stakeholders.

However, in some areas the IRT feels that there are weaknesses in the way experimental evidence has been incorporated into performance assessment. This has arisen because the interpretation of the experiments has not been sufficiently focused on the needs of the performance assessment (for example, there is not enough emphasis on a sufficiently mechanistic understanding to extrapolate to long timescales, to large distances, or to alternative or evolving conditions).

One example is the modelling and assessment of the migration of radionuclides through the Boom Clay. Here, the concept of "operational solubility" is used as a variant model. The IRT has reservations on this approach, as mentioned earlier in this review. ONDRAF/NIRAS is encouraged to review and revise the approach, and to clarify the role of organic matter on radionuclide migration. Another example concerns the experimental numbers for the glass dissolution rate. These were taken from experiments and used directly, without assessing whether or not they were appropriate for the long time-scales involved.

3.2.5 Compliance with dose constraints

Given that there is currently no national guidance in Belgium on what dose rates will be acceptable for the post-closure phase, ONDRAF/NIRAS provisionally adopted a dose constraint of 0.3 mSv/yr for members of the public in SAFIR 2 – this is the value recommended by ICRP. This value is consistent with the value taken in other national programmes.

The results of the model calculations performed generally show doses below the envisaged constraint for all the waste streams considered and for most cases analysed. It is also worth noting that non-radiological effects have been addressed, namely the temperature rise in the aquifer and the potential for chemically toxic substances to return to the biosphere. The results suggest that the system will meet the safety targets. However, because the spectrum of calculations is not very extensive, it may well be possible that for some relevant situations the consequences are higher.

It is noted that the calculated doses for the three main waste streams analysed show some unexpected results, in that the maximum calculated dose is nearly equal for all of these waste streams. This is not consistent with the results from other national assessments and it may be due to the overestimated ^{129}I inventory in the vitrified HLW. ONDRAF/NIRAS acknowledges this problem and has already established contacts with waste producers to get a more accurate value.

In the assessment calculations, the Boom Clay provides excellent barrier properties. As a consequence, the contribution from the other components is limited; the calculated releases are essentially unaffected by their performance. However, these other components make a significant contribution in the multi-barrier concept. In addition, the assessments of the performance of certain components (e.g. glass matrix durability) are conservative. ONDRAF/NIRAS explained this through the concept of a "safety reserve", which means the difference between the functions actually performed by the system and the one taken into account in the safety assessments. The IRT encourages

ONDRAF/NIRAS to develop this notion further. It should contribute to providing "strong" arguments for the priorities for future RD &D studies.

For some of the altered evolution scenarios, significant doses are calculated (above the adopted constraint of 0.3 mSv/yr – see Section 11.5.4.2, Exploitation drilling). In order to put these results in context, it would be valuable if ONDRAF/NIRAS were to present a more extensive discussion on the "degree of belief" (or, if possible: "likelihood of occurrence") for such scenarios. It would also be valuable to put all the results in one place – currently the discussions are spread over different chapters. ONDRAF/NIRAS acknowledges that the analysis of altered evolution scenarios is not complete, and that the alternative safety or performance indicators need to be extended to cover these scenarios. The IRT encourages ONDRAF/NIRAS to continue to do this.

3.2.6 Quality and representation of understanding for key PA phenomena, "independent evidence"

For many of the issues critical to long-term safety, a large body of information is available. However, for some issues, the understanding and the "independent evidence" are still rather weak; this is acknowledged in the SAFIR 2 report.

The Belgian programme is well recognised internationally for its compilation studies on natural and archaeological analogues. The SAFIR 2 report gives general references to the use of such analogues as an independent line of reasoning to build confidence in the approach adopted and in the models used in assessing the safety of the disposal system. References given in the SAFIR 2 report to the potential of analogues include:

- The naturally occurring isotopes of the U, Th and Ra series present in the Boom Clay, and studied as analogues of the radioisotopes expected to be present at a disposal site for radioactive waste. This may help in further developing the understanding of migration processes.
- The thermal impact on the properties of the bentonite used as the buffer material and of the Boom Clay. Natural clays that have been subjected to such thermal perturbations in the past have been studied.
- Basaltic volcanic glasses are used as analogues to help in the understanding of long-term dissolution of vitrified wastes.

- Criticality – information from the natural nuclear reactor at Oklo is cited.
- The study of archaeological analogues for the waste containers to estimate the rate of corrosion and the identification of the relevant corrosion phenomena over long timescales.
- A number of comments are made on the potential to build confidence in the physical containment, retention and resistance to geochemical alteration of clays.

However, as ONDRAF/NIRAS recognises, natural analogues have not been used significantly in direct support of the performance assessment. Stronger interaction between experts and the performance assessment managers is recommended in order to make full use of this area, and also to guide new work in this area. The IRT also recommends discussions with the regulators, in order to clarify the role and the value they see in analogues and other observations of natural systems as independent lines of reasoning in demonstrating safety.

3.3 Technical feasibility

3.3.1 Mining feasibility

The construction and operation of the URF at Mol has constituted a unique opportunity to advance the characterisation of the Boom Clay, providing site-specific information of a high quality. The large body of experimental evidence that has been gathered to date, with the underground HADES facility being a key component, provides a demonstration of the feasibility of mining in the Boom Clay formation.

3.3.2 Construction feasibility

Construction feasibility has received a significant amount of attention in the SAFIR 2 report, with most of the attention being given to the excavation of tunnels and shafts. ONDRAF/NIRAS does recognise that a siting programme has not been performed yet, however, and that a more detailed characterisation of the potential emplacement areas will be needed to avoid structures that are active or susceptible of tectonic reactivation. Careful orientation of the emplacement galleries relative to the regional tectonic stresses and careful location of seals along these galleries will need to be considered in the design, in order to reduce the probability of some fractures affecting the total length of one of these galleries.

3.3.3 Logistics of emplacing EBS components

The description of the repository operation in the SAFIR 2 report assumes that the backfill and the disposal tube are in place. The requirements on the disposal tube are rather strict and it is doubtful that the current design will meet these criteria. This is also noted as an area where further research and development is needed. The backfill has been given very little attention in the programme up to the time when the SAFIR 2 report was finalised. On the other hand, in the identification of areas for further research this has been recognised. One area that is missing from the presentation of the operation is the detailed logistics; this should include answers to the questions such as “How many waste packages have to be emplaced each day?”, and “How much backfill needs to be taken down into the repository and how will this be done?” Two other important issues are handling waste packages and sealing of the repository, and it would be helpful to provide more discussion than is given in the SAFIR 2 report.

3.3.4 Safety during the operational phase

Safety during the operational phase is an important element of technical feasibility. Although the work documented on operational safety is only rudimentary, it is considered that operational safety will be achievable by adoption of a careful engineering approach fully consistent with a reference repository design. From a radiological safety point of view, practices in other nuclear facilities, and in particular storage facilities, will be transferable to the repository. Experience from other nuclear facilities should be transferable when performing a risk analysis during the operational phase. Typical risks include dropping packages during transport, criticality, fire, etc. Some aspects will need to be specifically developed, however, such as the risk of waste package drop in the shaft.

3.3.5 Weaknesses in the EBS design

Although the broad design, with multiple barriers (some engineered and some natural) is in line with international practice, the design chosen for the analysis of the SAFIR 2 report seems to have some significant weaknesses, which were confirmed in the discussions with staff from the Belgian programme. Although there is no doubt about the feasibility of excavation underground openings (including emplacement rooms), the chosen system of engineered barriers may not be feasible or appropriate for all waste types to be disposed. Some of the current concerns, e.g., on the backfill and hydration system, have been presented in Section 3.1.3.

The reason for existence (or creation) of discontinuities in the starting chamber and their potential role need to be clarified. This may imply the need to study the self-sealing of discontinuities (as was started in the EC SELFRAC programme). More in general, ONDRAF/NIRAS should aim at a better understanding in the area of thermo-hydro-mechanical (THM) behaviour.

Temperature evolution in the repository is discussed, but the most problematic wastes (MOX) are not discussed explicitly. The discussions clearly indicate that heat output of spent fuel is highly significant, and they indicate its importance for overall waste management planning (with the potential need for a prolonged period of interim storage). Thus, it may be worthwhile in future to clarify the acceptable maximum temperatures within the EBS and surrounding host rock.

3.3.6 Closure of the repository

Closure of the repository is well described in the SAFIR 2 report on the strategic level, as are repository monitoring and institutional control. This is to be commended, as no regulations exist in this area. Several of the components in the disposal system are designed to enable retrievability. The IRT recommends the anticipated role of monitoring be clarified with the appropriate authorities, particularly in the context of the retrieval of the radioactive wastes. In addition, the IRT recommends that ONDRAF/NIRAS observes the development of new technologies relevant for the long-term monitoring of the repository.

3.3.7 Environmental impacts

The construction and operation of the repository will have environmental impacts on the site where the repository is located, and the surrounding areas. One of the main reasons for this is the transport and storage of excavation and backfill materials and the transport of wastes and consumables during operation of the repository. This is outside the scope of the SAFIR 2 report, but should not be forgotten.

3.4 Relevance of the concept and the system

The selection of the Boom Clay in Mol goes back to the 1970s, and is based on an "*ad-hoc* screening process". The results of this process were confirmed by the findings of the "European Catalogue" [18, 19], and can still be considered to be a valid choice. The arguments provided in Chapter 3.1 of the SAFIR 2 report justify the choice of the Boom Clay at Mol as the focus for the phase of methodological research and development. However, the IRT believes that ONDRAF/NIRAS could have made more clearly the point that the system is relevant.

3.4.1 Long-term stability of the system

A stable geological environment is one of the most important aspects of safe geological disposal. In the course of the Belgian programme a significant emphasis has been placed on the evaluation of long-term stability. This has led to the conclusion that the site of Mol is likely to provide the needed stability. This point could have been made more clearly, however.

The inventory of siting possibilities shows that "soft clays" are extensive in Belgium, and it also seems possible that other siting areas with sufficient stability can be found. A deeper understanding of the range of feasible sites will be required as the programme moves towards a siting phase.

Ongoing projects (e.g. EC-PHYMOL [7]) examine the implications, of moderate glaciation for the normal evolution scenarios, and their results will have to be incorporated into future safety assessments in a structured way. Analogous work will need to be undertaken for altered evolution scenarios. The possibility of forming new fractures or re-activating existing discontinuities, in the case of the fault activation scenario, and the importance of erosion, for the case of the severe glaciation scenario, should be discussed in more depth. Other issues may also require more attention (e.g. changes in hydraulic gradients, subsidence, sea-level changes).

3.4.2 Isolation/retention capacity of the system

Overall, the system chosen is considered to have the potential to provide excellent isolation and retention of the radionuclides contained within the wastes for the long times that are needed. The time frames to be addressed are a matter of regulatory guidance to be agreed with the appropriate authorities.

In several areas, it will be necessary to extend the investigations in order to augment the current information base, enhance the understanding and confirm this overall conclusion. For instance, the SAFIR 2 report does not demonstrate or exploit the degree of redundancy provided by the EBS.

Although siting and design were chosen in order to minimise the likelihood of many potential perturbations and/or their effects on radionuclide retention, additional work is needed to build an adequate level of confidence that this actually is the case, or to enable an appropriate treatment in the assessments. This includes understanding whether perturbations affect differently alternative design and siting possibilities.

3.4.3 Technical feasibility and amenability to a reliable assessment

Taking into account the level of development of the Belgian disposal programme, the issue of technical feasibility is given a reasonable amount of attention in SAFIR 2:

- The feasibility of constructing shafts, transport and disposal tunnels is clearly demonstrated with the extensive experience from the HADES underground research facility.
- There is also a good presentation of the disposal techniques and equipment needed for disposing spent fuel and vitrified waste packages. However, there are some reservations about the EBS presented, see e.g. Section 3.1.3 of this review.

Not all parts of the disposal process are planned at this stage, however, nor are they presented in the same level of detail.

The chosen system seems to allow key properties related to "post-closure radiological safety" to be determined reliably as repository implementation progresses. This is due to homogeneity of the host rock, the use of fairly well understood materials for the engineered barriers, and a design that favours compatibility of the different components. However, for some key aspects the understanding that has been developed is not yet sufficient to draw any final conclusions.

The qualitative analysis of system performance using safety functions is considered to be very valuable. The concept of safety functions could be used to contribute to siting discussions besides being used simply as a tool for demonstrating the safety of a particular design or a particular site.

It is likely that there are reserves of safety in the engineered barrier system, which at this stage are not visible because of the strong emphasis on the natural barrier and its diffusive barrier function.

3.4.4 Siting flexibility and transferability of information and tools

The system chosen for the methodological development (the Boom Clay at Mol) is considered to be a good starting point for the Belgian programme, because this clay layer is present over a significant area of Belgium. The option seems very promising: it should provide long-term safety, and the technical implementation seems feasible. However, this review did raise the issues of the closeness of the repository to an aquifer of regional importance and the relatively shallow depth of the repository *vis-à-vis* other projects world wide.

As the programme moves to a siting phase, flexibility of siting is desirable. Alternative locations and formations appear to exist in Belgium; ONDRAF/NIRAS and the appropriate authorities will have to decide to what extent these alternatives need to be investigated. In particular, the flexibility available for the Boom Clay at locations other than Mol and the potential alternative locations in other formations should be clarified to understand as to how widespread genuine alternatives exist. These alternatives should be complementary and should avoid any potential weaknesses of the Boom Clay at Mol.

When considering alternative formations and locations it is important to understand whether the methods developed and the information obtained can be transferred from the present studies; this is recognised by ONDRAF/NIRAS. Developments in the PA methodology and the design for a repository are likely to be broadly transferable. The regional geological framework has been developed, and is relevant to both the Boom Clay and Ypresian Clay formations and to other areas. However, the geomechanical properties of the Ypresian Clays are not as good, and so the feasibility of construction has to be corroborated. Moreover, there are significant differences in the hydrogeological and geochemical properties.

3.5 The implementation process

3.5.1 Stepwise approach

The importance of the stepwise approach of repository implementation is clearly recognised within the SAFIR 2 report, and the proposals for future work are embedded within this framework. SAFIR 2 is part of a phased approach; its predecessor (SAFIR) has clearly defined the goals of SAFIR 2.

The SAFIR 2 report develops a clear framework for discussion of the justification for deep disposal of high-level and long-lived radioactive wastes. It also recognises the need for interaction and feedback between the different disciplines. In addition, it discusses the different steps in the process of site selection (Figure 1-7), although this is not discussed in depth in SAFIR 2; it is believed that this will be done in the next phase.

With SAFIR 2 a level of maturity has been reached that justifies considering in which areas there is a further need for purely methodological research. The IRT considers it worthwhile to start a discussion on siting with the appropriate authorities. In particular, the IRT strongly supports the proposal by ONDRAF/NIRAS to prepare a first *Safety and Feasibility Report* around 2010, and thus move away from the phase of purely methodological research. It is thus timely

- to explore the open policy issues with the appropriate authorities, and
- that the necessary regulatory framework will be established in Belgium.

It is also timely to think through the structure of the decision-making process, and in particular how and when to get wider stakeholder involvement in the process.

A number of waste streams have been considered in depth, and it would be useful to consider all types of waste in future work, and to develop a set of waste acceptance criteria to ensure that all wastes are compatible with future disposal facilities.

ONDRAF/NIRAS has recognised the importance of Quality Assurance, and has started to implement an adequate system. ONDRAF/NIRAS has also recognised the importance of "Knowledge Management" over the protracted timescales of repository development and operation. Taken together

QA and knowledge management will be key elements in the long-term programme of implementing a deep geological repository.

The need to consider monitoring and retrievability has been recognised and some initial work has been started. This should continue as it may be part of the approach to stepwise repository implementation, and should be consistent with the reference repository. However, to begin with, the future work needed in this area is mainly concerned with policy. Thus, in the planned societal dialogue these issues will need to be considered.

3.5.2 Reporting

A tremendous amount of information is made available through the SAFIR 2 report. The structure and content of the SAFIR 2 report is adequate for the requirement defined by the SAFIR commission. The "Technical Overview of the SAFIR2 Report" [4 – see also Annex 3] is of high quality, and proved a good starting point before reading the full report. The summary in Chapter 13 of the SAFIR 2 report is especially valuable, because it addresses all key issues in a very systematic and structured manner and is thus easy to follow.

The SAFIR 2 report tries to respond to several different objectives: presenting the phases of a repository development programme, the associated RD&D plans, a current status report, a feasibility study, a safety assessment, and a safety case. This leads to a complex report structure, and as a consequence, the reader is confronted with a multifaceted and, on occasions, repetitive report in which the main guiding theme can be difficult to follow. In places the work is up-to-date and fully reported (e.g. gas); in others it was undertaken some time ago (e.g. scenarios) or is incomplete (e.g. the EBS). It has also been challenging to present the work in a truly integrated manner.

An alternative presentation would be to develop several and complementary reports dealing separately with:

1. the overall strategy for radioactive waste management (principles, waste production forecasting scenarios);
2. the different phases of the repository development programme and their interdependencies;
3. a status report presenting the progress made in the various areas, including technical feasibility (alternative designs), safety assessment and confidence building (this third part is mostly given in Chapter 13 of the SAFIR 2 report);
4. a safety assessment and safety case.

This structure would help ensure that the full picture of key issues and uncertainties becomes available.

3.5.3 Role of and interaction between different stakeholders

The importance of interaction with the different stakeholders is clearly recognised by ONDRAF/NIRAS. The various issues of importance in such interactions are discussed and the significant conclusions are drawn. One of these conclusions is the need for a "platform" for dialogue and this platform should be provided by the SAFIR 2 documentation (including the short booklet "Towards a sustainable management of radioactive waste – background to the SAFIR 2 report" [5]). To help in the area of interactions with stakeholders, key requirements of the SAFIR 2 documentation are comprehensiveness, transparency and traceability. These requirements are not easy to fulfil. It is recommended that improvements be made to this effect in future documents.

The second objective of SAFIR 2 "to promote interaction with the Belgian regulatory authorities" has clearly conditioned the structure and content of the document. However, points of dialogue with the regulator are only highlighted in a rather short paragraph at the end of the document.

Different scenarios for radioactive waste management policy exist, including different possibilities for arising of the waste (types and amount) that have a clear impact on the repository development programme (design, RD&D programme and safety assessment). Although these are clearly recognised in the SAFIR 2 report, a clearer presentation of the impact of different waste management scenarios on repository development would be advisable when dealing with some of the non-technical stakeholders interested in the programme.

3.5.4 The existing RD&D basis

The need for a RD&D programme had been recognised early in the Belgian nuclear programme and was started under the auspices of SCK•CEN. After transfer of the responsibilities to ONDRAF/NIRAS the first status report was developed (SAFIR in 1990), which gave feedback on how to continue with the RD&D programme. The recommendations provided by SAFIR were largely followed, although progress in some of the areas has been slower than expected.

It might be helpful to find a way of presenting the scientific information derived from the most important RD&D developments in the

Belgian programme. The role and timing of the prestigious and well-known research projects performed within the Belgian programme as part of a history of RD&D development might be valuable.

It appears that the Belgian programme has been driven in certain areas by the fact that they were interacting with or part of various EC R&D projects. However, these projects are not put in a historical perspective. A road map of the more important projects and their input to design and safety assessment would help to assess the RD&D programme as a whole. It is not always clear whether the decisions have been driven by external requirements or by the needs of the Belgian programme itself.

3.5.5 Future RD&D

SAFIR 2 provides a good basis for re-evaluation of the future RD&D needs. The findings of SAFIR 2 need to be set alongside the experience in other programmes and by the discussions within the different relevant international *fora*. This has been largely done within the SAFIR 2 project.

The list of areas that might be considered for further RD&D is very extensive and seems to be "complete". Confidence, a key issue when dealing with a broad audience, is enhanced by the recognition of uncertainties and the need for further studies, and by the presentation of a programme to deal with them in the future. However, there is a need to decide on the priorities for the many different issues listed and to determine the level of ambition for each of them. There seem to be too many areas identified to investigate all of them in depth, where for some of them a broad-brush treatment might be sufficient. The rationale and approach for the decisions to be taken in the research and development programme is not presented in a clear and systematic way in the SAFIR 2 report.

One way to do this is through a systematic approach to manage uncertainties. In such an approach each of the areas with uncertainty is allocated to one of the following three major categories:

1. The uncertainty can be avoided or its effect mitigated to an acceptable level by changes in design or by siting.
2. Future RD&D is foreseen to decrease the level of uncertainty to an acceptable level.
3. The current level of uncertainty can be accepted.

This indicates that there is a strong need for a systematic analysis of "uncertainty importance", to a level that is more rigorous than that which is discussed in Section 13.D.2.7. However, it should be noted that there might also be a justification for RD&D just to confirm the current understanding without wanting to reduce uncertainty or just to improve scientific understanding.

The strategy for integration between design, performance assessment and RD&D is not clear in the report. It has been clarified partially in the answers to the IRT questions but, nevertheless, it would have helped if a strategy to set priorities and not only a list of open issues had been presented in Chapter 13. Moreover, a more detailed description of objectives, scope, methodology and working plan for a more reduced list of issues to be covered in the future RD&D programme, would reveal more clearly where ONDRAF/NIRAS believes it should go. Many of the ideas for the future are not developed enough in the report to allow for an assessment of their relevance and appropriateness. Such a systematic approach to managing uncertainty would aid the transparency of the programme for the various interested stakeholders.

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Annex 1

MEMBERS OF THE INTERNATIONAL REVIEW TEAM

Piet Zuidema, Chairperson

Piet Zuidema received his degree in civil and environmental engineering at Swiss Institute of Technology in Zürich where he also gained his PhD. In 1984 he joined Nagra and from the start has been heavily involved in safety assessments. In 1989 he became head of the “Nuclear Technology and Safety” Department; since 1998 he is Director for “Science and Technology”. He has been responsible for several major safety assessments in the Swiss programme and has broad experiences also in the management of RD&D, earth science issues and repository design. Dr. Zuidema has been involved in OECD/NEA Performance Assessment Advisory Group (PAAG) since the 80's and has for several years been the Chairman of PAAG. For several years he has been a member of OECD/NEA Radioactive Waste Management Committee (RWMC) and currently he also serves as a member of the Bureau to the RWMC. On several occasions he has also been expert to the IAEA.

Eric Gaucher

Eric Gaucher gained a PhD in geochemistry from the University of Paris VII in 1998 and a M.Sc. in earth sciences at the École Normale Supérieure of Lyon in 1993. During his doctoral research for the French Atomic Agency (CEA/Saclay, 1994-1997), he focused his experimental work on the study of the stability of clay minerals in connection with ion exchange processes.

He joined the French geological survey (BRGM Orleans) in 1998, where he is involved as a scientist and project leader on studies on “clay/water interactions” for the French Agency for Radioactive Waste Management (ANDRA). He is in charge of the BRGM project “Argilites”, a joint experimental and modelling study on the thermodynamical equilibrium between clays and water. Since 1999, he has managed the development of the use of the chemistry-transport coupled software PHREEQC for the EC-sponsored Ecoclay II project.

He is responsible of the internal consistency and quality of the geochemical data obtained during the construction of the Underground Research Laboratory at Bure (Meuse – France). In addition, he is a member of an international group of experts on the theme “modelling of the clay/porewater chemistry” on behalf of the Mont Terri Project (Switzerland) and is responsible for the BRGM team involved in the NEA Sorption Project.

Emmanuel Ledoux

Emmanuel Ledoux obtained his degree in mining engineering from École des Mines de Paris in 1970, and his PhD in Water Sciences in 1980 from both École des Mines and University Paris VI. His work is concerned with research and teaching on hydrogeological modelling applied to water resources, groundwater pollution, and waste disposal in deep and shallow geological formations. He is at present the head of Centre d’Informatique Géologique at the École des Mines in Fontainebleau, which is linked to the Centre National de la Recherche Scientifique (CNRS) through a joint research unit.

David Lever

David Lever gained a Ph.D. in applied mathematics from the University of Cambridge in 1979. He has over 20 years experience working in the field of radioactive waste disposal. He formerly supported Nirex as the Manager of the Nirex Safety Assessment Research Programme. He was a senior member of the team undertaking the Nirex 95 and Nirex 97 repository post-closure performance assessments. He also helped develop a scenario development methodology for Nirex. He was a member of the Secretariat of the international INTRAVAL project, and was also a member of the Editorial Committee of the Alligator Rivers Analogue Project. He is currently the Manager of Environmental Assessments Department at Harwell with Serco Assurance (formerly AEA Technology).

Claudio Pescatore

Claudio Pescatore is Principal Administrator for radioactive waste management at the OECD/NEA. He has 25 years experience in the field, and a multifaceted career as programme manager, consultant to industry, consultant to R&D agencies and safety authorities, university lecturer, and researcher. He oversees a broad programme of work covering technical, strategy, and policy areas in radioactive waste management. In particular, since the mid-1990’s, he is the organiser of all NEA peer reviews in the field of radioactive waste management.

His background is in the physical sciences. Dr. Pescatore holds a PhD degree in Nuclear Engineering from the University of Illinois at Urbana-Champaign.

Javier Rodríguez

Javier Rodríguez received his Ph.D. in geology in 1989 from the Complutense University of Madrid, Spain. His dissertation was a model of the origin and movement of pore water and solutes in a clayey aquitard in the surroundings of the Doñana National Park (Spain). Thanks to a grant by the Fulbright Programme for postgraduate students, he studied groundwater flow and transport modelling at the Department of Earth and Planetary Sciences at the Johns Hopkins University in Baltimore (Maryland, USA) during the period 1988-89. He served as Associate Editor of Hydrogeology Journal, the official journal of the International Association of Hydrogeologists (IAH), for the period 1997-2000.

Dr. Rodríguez joined the CSN in 1989 in the Branch of Siting and participated in the CSN review for the licensing of the construction and the operation of the "El Cabril" low-level radioactive waste disposal facility, and the dismantling and site restoration of the disused "Andújar" uranium mill. He also participated in studies on updating the characterisation of seven nuclear power plant sites. Since 1996 he has worked in the High-Level Waste Branch and has been directly involved in the CSN activities regarding the safety the geological disposal of high-level waste. Since 2002 he has worked at the Spanish Geological and Mining Institute, where he is Head of the Unit for the co-ordination of R&D and external relations.

Dr. Rodríguez has participated in several international activities of the European Union, the IAEA and the OECD Nuclear Energy Agency, being the CSN representative in the Co-ordinating Group for Site Evaluation and Design of Experiments (SEDE) of the Radioactive Waste Management Committee (RWMC) of the OECD/NEA. In 2000 he participated in the OECD/NEA Peer Review of the SKB performance assessment exercise SR-97.

Patrik Sellin

Patrik Sellin is a civil engineer from Chalmers University of Technology in Göteborg (Sweden). He joined Swedish Nuclear Fuel and Waste Management Company (SKB) in 1988. At SKB, his main responsibilities are performance assessment and research and development of buffer materials. Mr. Sellin was responsible for the analysis of the near field in the safety assessments SKB-91 and SR-97.

Sylvie Voinis

Sylvie Voinis graduated as a Chemical Engineer. After working as an R&D researcher on polymers for Philips for a few years, she joined the safety division of ANDRA (the French radioactive waste management agency) in 1986, where she concentrated particularly on near-field aspects of radioactive waste disposal. During her time at ANDRA, she was involved in HLW projects and participated in the development of a methodology for safety assessment, covering aspects such as functional analysis and qualitative analysis. Then she became head of the "safety methodology" team that was in charge both of near-surface and deep geological disposal. She also chaired the IAEA ISAM project for one year. Ms. Sylvie Voinis joined the OECD/NEA in 2000 where, as scientific secretary, she is in charge of the co-ordination of the activities carried out by the IGSC (Integration Group for Safety Case) and the Clay Club. She is also a member of the French "Permanent Group" concerned with nuclear facilities other than power plants.

Annex 2

THE TERMS OF REFERENCE FOR THE PEER REVIEW

The most relevant excerpts from the Terms of Reference are presented here. The general objectives were:

"The peer review should focus on:

(i) the long-term safety assessment methodology and the well-foundedness of its results and the quality of its scientific and technical bases;

(ii) the remaining key uncertainties and the R&D programme that is proposed to deal with them in the next phase of the programme.

Considering the decisions to be taken in the Belgian programme (i.e. the continuation of the methodological R&D), the peer review should inform the Belgian authorities whether the R&D programme on deep disposal in Belgium is coherent with:

(i) other national disposal programmes, in particular the ones considering argillaceous formations; and

(ii) international standards and practices.

The peer review should thus assess the results obtained so far as well as the on-going and planned work vis-à-vis their adequacy for achieving, in a period of time of 10 to 15 years, sufficient technical confidence regarding the safety and feasibility of the disposal of high-level and long-lived waste in a deep, poorly-indurated clay formation. As such, the peer review should also suggest amendments to the contents and structure of the proposed R&D work programme.

In other words the peer review ought to help the Belgian Government and the institutions, organisations and companies involved in waste management to decide on the future work programme and its priorities. In this respect, the peer review should also include in its work scope the review of the safety-related recommendations of the Scientific Reading Committee of the SAFIR 2 report and advise on how to handle and prioritise them."

More detailed objectives included:

"The peer review should be run at three levels. In decreasing order of importance these are:

- **Level 1:** the examination of all the important items for the long-term safety of the deep disposal solution that is being considered. This includes, in particular, the examination of the scientific knowledge basis and the methodologies used for the evaluation of the long-term safety. This also includes the remaining uncertainties and the prioritisation of further work according to these uncertainties. Being still in a methodological R&D phase, the site-specific characteristics should not be interpreted in a siting context. In order to help assess the internal consistency of the general approach towards disposal, this level of review also includes the review of the Technical Overview of the SAFIR 2 report.
- **Level 2:** the examination of the technical feasibility of the deep disposal solution that is being considered. This examination should be limited to those factors which have a direct influence on the long-term safety.
- **Level 3:** taking cognisance for information purposes only."

and

"In examining the long-term safety and the future R&D programme, the peer review should pay particular attention to the following points, which are of primary importance for the Belgian programme:

- the choice of the materials for the engineered barrier system, their compatibility with the disposal environment and their adequacy with regard to the required performances;
- the migration of the radionuclides through the clay host rock;
- the problem of gas production due to anaerobic corrosion and other processes, and the resulting perturbation of the clay host rock;
- the disturbance of the clay host rock (the development of fractures) due to geological phenomena and as a result of excavations during repository construction;

- the disposal – or naturally – induced geo-chemical perturbation/ evolution of the clay;
- the influence on the long-term safety of dramatic climatic changes (e.g. glacial ages, extreme humidity – flooding of the region – extreme drought).

Other points could be added to this list. For each of these points the review team should examine the critical elements of the obtained results, the remaining uncertainties and the proposed work to satisfactorily solve these issues.”

Annex 3

DOCUMENTS REVIEWED

The main documents reviewed were:

- SAFIR 2 report (Nirond 2001-06 E – December 2001) – the full report, made available as a CD-ROM and as a 4 volume paper-copy boxed set.
- Technical overview of the SAFIR 2 report (Nirond 2001-05 E, December 2001) – a 267 page overview report, available in English, French and Dutch.

A third short report was also made available:

- Towards a sustainable management of radioactive waste – background to the SAFIR 2 report (Nirond 2001-07 E, December 2001) – a short 17 page report giving the background to SAFIR 2.

ONDRAF/NIRAS also made other supporting documents available as requested by the IRT. The review drew further on information given in answers to questions from the IRT, and the extensive discussions with ONDRAF/NIRAS staff and their colleagues at SCK•CEN (see Section 1.3).

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