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The French R&D Programme on Deep Geological Disposal of Radioactive Waste

An International Peer Review of the "Dossier 2001 Argile"

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 to assess work accomplished. The review reports' comments on issues of general relevance may also be of interest to other member countries.

The French government requested that the NEA organise an international peer review of the *Dossier 2001 Argile* produced by the French National Agency for Radioactive Waste Management (Andra). The scope and objectives of the review were laid out in the terms of reference. According to these terms, the NEA Secretariat established an International Review Team (IRT) made up of eight international specialists, including one member of the NEA Secretariat. The experts were chosen to bring complementary expertise to the review. The peer review should help the French government and the institutions, organisations and companies involved in waste management to decide on the future work programme and its priorities.

This report presents the consensus view of the IRT. It is based on a review of the *Dossier 2001 Argile* and supporting documents, on information exchanged with Andra in answers to questions raised by the IRT, and on direct interactions with staff from Andra during a week-long workshop in France.

In keeping with NEA procedures for independent reviews, neither the French government nor Andra have commented on this report - Andra has only had the opportunity to check for factual correctness. The IRT has made its best effort 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 Andra staff for their hospitality during the brief visits to France, and for their excellent organisational support, which facilitated the work of the IRT. The IRT would also like to thank the staff of Andra for the helpful and open way they responded to the review.

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HIGH-LEVEL SUMMARY OF THE REVIEW

Background

A review has been conducted of documentation developed by Andra, collectively known as the Dossier 2001 Argile, by an international review team of independent specialists covering all relevant aspects of research, safety assessment and the geological sciences. As described below, the Dossier represents a key milestone in the programme of work, for which Andra is responsible, to assess the feasibility of the deep geological disposal of high-level and long-lived radioactive waste in France. An important objective of the review was to make recommendations on developments or improvements that would maximise the contribution of Andra's work programme to a national decision on waste management solutions in 2006. This report presents the consensus view of the international review team. It is based on the Dossier 2001 Argile and supporting documents, on information exchanged with Andra in answers to questions raised by the review team, and on direct interactions with staff from Andra during a week-long workshop in France.

The Dossier 2001 Argile represents one step in a process of studies and research work leading up to the submission of a report due in 2005 containing Andra's conclusions on the feasibility of a repository in the Callovo-Oxfordian clay formation of Eastern France. In this respect, the Dossier 2001 Argile has the status of an interim progress report and a test of methodology:

- It presents the knowledge and results available in 2001, acquired during the research work completed by that time at the Meuse/Haute-Marne laboratory site.
- It describes the state of progress of the research programmes conducted by Andra, presenting the design data acquired, with an underlying logic of reversibility and safety analysis, and setting out the prospects for future research work.

- It represents a first test of the analysis methods used, presenting these methods for critical review with the aim of preparing sufficiently in advance for the report due in 2005.
- This means that the Dossier 2001 Argile is in no way conclusive and not a document submitted for licensing purposes. In particular, it does not refer to regulatory compliance.

The Dossier 2001 Argile is the first scientific progress report delivered by Andra. It is the wish of the French Government that the Dossier 2001 Argile should be a widely read and discussed document with the general aim of improving its methods and the rigour of its approach. Therefore, the French Government considered as essential a review of this first report by an independent panel of international experts. Positive experience from earlier NEA reviews led the government to ask the NEA to organise an International Review Team (IRT) to provide a peer review of the Andra Dossier 2001 Argile. The members of the IRT were chosen to bring complementary areas of expertise to the review.

An orientation meeting was held on 14-15 November 2002 to ensure that the IRT would be able to fulfil the Terms of Reference. This was followed by a review of documents identified under the Terms of Reference and of further, explanatory documents provided by Andra at the request of the IRT. As a result of this process, the IRT generated two main rounds of written questions – all of which were answered in writing by Andra on an agreed timescale. A workshop was then held over the period 3-7 February 2003 comprising presentations and discussions on specific topics identified by the IRT and culminating in an oral presentation of the preliminary key findings. During this time, the review was greatly facilitated by the framework of openness and transparency established by Andra management, who made a comprehensive commitment to the review at all times through the availability of high-quality staff with the necessary knowledge and experience to respond to technical and strategic questions.

The present report documents the IRT findings, and was written during the period 8 March to 8 April 2003. In keeping with NEA procedures for independent reviews, neither the French Government nor Andra have commented on this report – Andra has only had the opportunity to check for factual correctness. The IRT has made its best effort to ensure that all information is accurate and takes responsibility for any factual inaccuracies. The IRT wishes to confirm that sufficient information was made available such that it was able to fulfil its Terms of Reference. In particular, the IRT was able to test the available knowledge and processes.

Overall evaluation from an international perspective

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

General observations

- A solid research and development base exists in all areas and the quality is high, although this is not always clear in the documentation available. The only significant research and development omission is on gas issues.
- Safety-relevant design factors are clearly identified and the proposed design options appear reasonable. The modular design approach has the potential to produce designs that are robust against current uncertainties.
- The Dossier 2001 Argile provides a test of the safety analysis methodology. The APSS provides an innovative method for achieving a desirable systematic formalism as a basis for the safety analysis. It successfully integrates science and safety assessment and it provides a valuable platform for communication with the scientific community. In principle, it ensures exhaustive traceable analysis, but further development of some of its procedures is required for this to be realised.
- Although the Dossier 2001 Argile is not a comprehensive analysis at this stage, the information it provides is consistent with its conclusion that the safety analysis reveals no factors ruling out a repository. More importantly, the Dossier 2001 Argile provides a suitable methodological basis for the expected, fuller analysis in the time horizon of 2005.
- The documented Scientific Programme for 2002-2005 is well-informed by the Dossier 2001 Argile and future research and development needs are clarified. All significant research requirements identified in the Dossier 2001 Argile are addressed by proposed work programmes that have the potential to deliver the required information by 2005.
- The current status of the project and the important issues to be addressed are identified, although they could be communicated more effectively in the Dossier 2001 Argile. The totality of information

and the methodologies developed provide Andra with a sound platform to support their forward programme, and in particular to progress to a deeper and more comprehensive analysis in 2005.

- The Andra approach to "reversibility" has merit in terms of providing a basis for maintaining technical flexibility during the operational phase of the repository. This technical flexibility could be integrated with a process of stepwise decision making that is yet to be identified. The relevant documentation does not define the basic principles and hierarchy of values that underlie the selection of a reversible repository design and there is no discussion on the trade-offs required to achieve greater or lesser degrees of reversibility.

Soundness of basis and competence of implementation

The Dossier 2001 Argile rests on a sound technical basis and has been, in general, competently implemented. The IRT views this as being due, in part, to Andra's openness to, and inclusion of, the wider scientific community in its programme. Andra's links with public research institutions are very apparent through its policy supporting postgraduate and postdoctoral research, and its long-term contractual relationships with over 100 laboratories through partnership agreements that foster the formation of research groups or laboratory networks. The way Andra has established and sustained networks with the academic and research institutions in France promotes:

- bringing together the best available teams and expertise;
- development of innovative techniques and advances in fundamental understanding; and
- sharing of the objectives of the programme.

These links provide a strong scientific foundation for the present work as well as for pursuing future activities.

Consistency with international standards and practices

With regard to the overall scientific bases, modelling capabilities, and the safety approach, Andra's efforts are seen as being *in line* with international standards and practices.

In some domains, such as the systematic consideration of all waste types as source terms (e.g., bitumen, hulls/ends), the multibarrier design approach for B-type waste forms, the use of archaeological and industrial analogues to support materials choices, and the assessment of geological stability, the IRT views Andra as being *in the forefront* of international efforts.

In yet other areas, such as the phenomenological description and APSS methodology, consideration of the operational phase (reversibility), and modularity of repository design, Andra is viewed as being *innovative.*

Planned work or trends

With regard to the future work planned by Andra and the trends evident in its ongoing work, the IRT is impressed and complimentary of the plans presented in the Scientific Programme for 2002-2005. The IRT agrees with the priorities established to obtain a firmer picture of key aspects of the disposal system by 2005. The planned Scientific Programme matches these priorities and evidences a systematic process for obtaining the desired information. Andra displays a realistic view of the current status of science, which is informed by a continual audit process within and between the relevant functional departments. The IRT obtained clear evidence of the commitment to this process which was not overly dependent upon numerical sensitivity analysis and took due account of the need for a fundamental scientific understanding. The only major omission pertains to the impact of gas on repository design and performance. The IRT also notes that any further development of numerical models, which are already quite strong, should be balanced against the availability of the required data/knowledge.

Recommendations

The IRT has made a number of suggestions concerning ways the Dossier 2001 Argile might be improved. The three most notable recommendations concern the clarity of the documentation, the consideration of gas issues in repository design and performance, and further clarity regarding the concept of reversibility and how it will be justified and implemented.

The Dossier 2001 Argile suffers from failing to identify (and write for) the intended audience(s), inconsistency in the level of detail provided in different technical areas, and incomplete presentation of important information, which results in a lack of transparency, albeit unintentional. The IRT notes that this may prompt criticism of the contents of the Dossier 2001 Argile, which

would not be justified in respect of the technical work. These problems are attributable, in large part, to the immense scope of the Dossier 2001 Argile, the uneven state of advancement of the research in different areas at the time the Dossier 2001 Argile was prepared, and the fact that Andra is necessarily on a "learning curve" with respect to the preparation of documents of this nature. The IRT recommends a concerted effort to overcome these limitations when the time comes to prepare the Dossier 2005.

Generation of gas in repositories is internationally recognised as an issue with both design and performance implications. The IRT understands that insufficient information was available at the time of completion of the Dossier 2001 Argile to incorporate gas issues appropriately. As Andra moves forward, however, the IRT recommends that gas issues be treated fully in both qualitative and quantitative safety analyses.

Given the central role that Andra is expected to play in the national debate in France on options for the long-term management of radioactive waste, it appears advisable for Andra to undertake work to clarify the basic principles and hierarchy of values related to reversibility and retrievability. Noting the societal context of this topic, it would also be beneficial to present this work for promoting a broad-based discussion to inform any further development of design concepts.

Overview

The IRT was impressed with the progress made by Andra, in partnership with research institutes and universities, on its deep geological disposal programme since 1991. A sound methodological basis exists to evaluate the safety of disposal of high-level and long-lived radioactive waste in argillaceous formations. A substantial body of research results and site-specific information has been established, and the priorities for its enhancement by 2005 are well-justified. There is clear evidence of carefully thought-out management procedures to integrate safety assessment, research and engineering design: this should ensure that the decision to be taken in 2006 on proposed solutions will be well-informed in this area. The IRT recommends that careful thought is given to the structure of the documentation to be produced in 2005, and to the presentation and traceability of the information that it will contain. It is essential that the scientific and technical basis is communicated effectively to all relevant audiences.

1. INTRODUCTION

1.1 Background

Radioactive waste management has been a technical issue in France since 1960, when the first reactors were built and began operation. From the beginning, deep geological disposal has been considered as a potential solution to the long-term management of the waste. Construction of underground facilities for *in situ* characterisation of the potential host geology was envisioned as the best method of evaluating the feasibility of geological disposal.

Following unsuccessful attempts by the French Atomic Energy Commission (Commissariat à l'énergie atomique, CEA) to start preliminary geological surveys at four sites to assess different geological media (clay, granite, salt, schist), the French Government decided in 1989 to involve the Parliament in the decision-making process, at first through hearings, and then through the passage of the Law on "Research in Radioactive Waste Management" at the end of 1991 [17].[1]

The 1991 Waste Act defines the general frame of research and development and identifies three avenues of research concerning the management of high-level and long-lived radioactive waste, as well as a 2006 milestone for a decision by the Parliament about the possible implementation of proposed solutions. Within this legal frame, the French National Radioactive Waste Management Agency (Agence nationale pour la gestion des déchets radioactifs, Andra) was created as an independent public body for radioactive waste management and made specifically responsible for the second avenue of research, "assessing the feasibility of the deep geological disposal of this radioactive waste, notably with underground laboratories". Options for retrievable or non-retrievable disposal are to be studied under the 1991 Act; however, in 1998, the French Government indicated that emphasis should be given to a "logic of reversibility".

1. Bracketed numbers (e.g., [17]) refer to reviewed documents listed in Annex 2.

The CEA is in charge of the two remaining R&D avenues foreseen by the Waste Act:

- partitioning and transmutation;
- waste conditioning and long-term interim storage.

The Waste Act foresees a comprehensive assessment of all the avenues of research in the year 2006. To that effect, the Act also created an Independent National Review Board (Commission nationale d'évaluation, CNE) to inform and advise the government on the interim progress at the technical and scientific levels.

In furtherance of the avenue of research related to deep geological disposal and underground research laboratories, a siting phase initiated in 1993 through a consultation mission led by MP Bataille identified four candidate sites: the area of Marcoule in the Gard department (clay formation), the area near La Chapelle Bâton in the Vienne department (granitic formation beneath sedimentary layers), and two areas in Eastern France belonging to the Meuse and the Haute-Marne departments (clay formation), joined in one single site in 1995. Beginning in 1994, Andra started preliminary geological and geophysical surveys (including 2D seismic profiles) and drilled exploratory boreholes in these three different areas of France.

In 1996, three applications, backed by these preliminary studies, were filed by Andra to obtain construction and operating licences for underground laboratories so that *in situ* R&D programmes could be pursued. By the end of 1998, the French Government took a twofold political decision concerning the Andra projects:

- it authorised the construction and operation of an Underground Research Laboratory at the Eastern site;
- it did *not* authorise work at the other sites and started a new siting process with another consultation mission in order to find a new site with outcropping granite.

After the decree formalising the Eastern site decision (August 1999), Andra began its *in situ* R&D programme for the Meuse and Haute-Marne area. The construction of the Underground Research Laboratory (URL) facility, near the village of Bure, started in September 2000, after a 3D seismic campaign and some additional boreholes aimed at characterising the geological formations to be investigated by the URL (in particular the potential host formation, the Callovo-Oxfordian argillite) were completed, and after the authorization to sink

the shafts was granted by the Government on 7 August 2000. The potential host formation is horizontal with a lateral extension of the order of tens of kilometers, is 130 metres thick at the URL site, and lies at an average depth of 500 metres.

The Andra R&D programme for investigating the feasibility of deep geological disposal of high-level and long-lived radioactive waste in the Callovo-Oxfordian argillite of Eastern France is denominated “Projet HAVL Argile”. To prepare for the 2006 comprehensive assessment by Parliament required by the Waste Act, Andra set out to produce an intermediate milestone report in 2001 for the project HAVL Argile, the “Dossier 2001 Argile”. That Dossier is the subject of the current review.

1.2 The Dossier 2001 Argile

The Dossier 2001 Argile represents one step in a process of studies and research work leading up to the submission of a report due in 2005 containing Andra’s conclusions on the feasibility of a repository in the Callovo-Oxfordian clay formation.

In this respect, the Dossier 2001 Argile has the status of an interim progress report and a test of methodology:

- it presents the knowledge and results available in 2001, acquired during the research work completed by that time at the Meuse/Haute-Marne laboratory site;
- it describes the state of progress of the research programmes conducted by Andra, presenting the design data acquired, with an underlying logic of reversibility and safety analysis, and setting out the prospects for future research work;
- it represents a first test of the analysis methods used, presenting these methods for critical review with the aim of preparing sufficiently in advance for the report due in 2005.

This means that this Dossier 2001 Argile is in no way conclusive and not a document submitted for licensing purposes; it does not refer to regulatory compliance. Nevertheless, it is being statutorily reviewed by both the French Nuclear Safety Authority (Autorité de Sûreté Nucléaire, ASN) and the CNE.

Its methods will, by definition, be critically assessed so the approach can be improved and made as thorough as possible. It would be premature to draw

any definitive conclusions at this stage, but it is essential to recognise that the Dossier 2001 Argile was intended to provide a test of the methodology.

The Dossier 2001 Argile has had a threefold effect on future activities:

- The Dossier 2001 Argile has set in motion a critical assessment of all the existing research programmes, shaping their development and assessing their relevance. In particular it has steered the precise definition of requirements for knowledge relating to the underground laboratory.
- It has helped identify the key scientific issues that need to be investigated in the research programmes. This includes identifying components with a particularly sensitive role in the robustness of a repository.
- It has guided the choice, in 2002, of the repository concepts to be studied. A fairly wide range of repository concepts had been considered up to 2001, without particularly attempting to optimize the concepts. During 2002, a number of concepts were selected for studying up to 2005 and these will be the subject of more definition.

Beyond the experience acquired, it is also important to emphasize the limits of the work accomplished in the Dossier 2001 Argile:

1. The Dossier 2001 Argile does not claim to establish feasibility, but restricts itself to showing that at this preliminary stage no factor ruling out feasibility has been identified.
2. The safety evaluation is deliberately limited in scope:
    - the number of scenarios has been voluntarily limited to two scenarios: the normal evolution scenario and one altered scenario (seal failure), and
    - the radionuclide-release computations have been limited to 15 radionuclides by waste package type.

This is because the main objective of the Dossier 2001 Argile aims at developing and testing methodologies. The safety evaluation to be conducted for the 2006 milestone will encompass more scenarios, such as canister failure, a borehole intercepting disposal vaults, etc.

3. The safety calculations and, specifically, the radiological consequences presented in the Dossier 2001 Argile are rough estimates and are not claimed to be a faithful reflection of a physical reality. They have all been based on systematically pessimistic and unfavourable assumptions. The values calculated provide orders of magnitude whose sole virtue is that they allow Andra to identify the important components and to direct the analysis towards the most sensitive issues. Thus, for example, the values obtained for dose calculations cannot meaningfully be compared to the benchmark regulatory limits. The uncertainty analysis is preliminary and needs to be developed thoroughly.
4. The Dossier 2001 Argile is based on preliminary repository design information that has been revised in 2002 in the light of this work. It cannot therefore be considered to represent or give advance notice of the technical options that will be proposed in the feasibility report to be submitted in 2005.

The Dossier 2001 Argile includes two synthesis documents: a report intended for a wide audience (Synthesis Report – Part A) [1], and a longer scientific report (Synthesis Report – Part B) [2] that expands on the information in the Part A report. Part B presents technical details in four principal areas: acquiring knowledge, studying repository design concepts, understanding and modelling the repository system, and analysing operational and long-term safety. In addition to the synthesis documents, the Dossier 2001 Argile includes reference documents on waste packages, materials, the biosphere, and geology. Andra has also prepared numerous supporting reports.

1.3 Terms of reference

It is the wish of the French government that the Dossier 2001 Argile should be a widely read and discussed document with the general aim of improving its methods and the rigour of its approach. Therefore, the French government considered as essential a review of this first report by an independent panel of international experts. Positive experience from earlier NEA reviews led the government to ask the NEA to organise an International Review Team (IRT) to provide a peer review of the Andra Dossier 2001 Argile. The members of the IRT were chosen to bring complementary areas of expertise to the review. Annex 1 to this report lists the IRT members and provides brief biographical sketches.

As laid out in the Terms of Reference (ToR), the objective of the review was to check that the Dossier 2001 Argile is soundly based and competently implemented. The consistency of Andra's methodological approach was to be assessed in the light of international standards and practices. Finally, the review was intended to assess that the planned work or trends envisioned by Andra are consistent and that priorities are well addressed. The French authorities were particularly interested in the provision of detailed recommendations for specific improvements that could be implemented.

The peer review should inform the French authorities (Ministère de l'Industrie and Ministère de la Recherche) whether the R&D programme at this intermediate step is consistent with (i) other national disposal programmes, in particular the ones considering argillaceous formations, and (ii) international practices.

Basically, the peer review should assess:

- the clarity of the documentation, through its structure and its synthesis (Parts A and B);
- the consistency of the applied methodologies for assessing the long-term safety and performance of a potential repository, and its adequacy with the main objective of identifying components with a particularly sensitive role in the robustness of a repository;
- the internal consistency between the scientific and technical knowledge base (collected and bibliographical data) and the assumptions used in the report at different levels: the basic knowledge, the phenomenological descriptions, the selected values of parameters, and the conceptual models;
- the pertinence of the conclusions, in particular those linked with the main objective of the Dossier 2001 Argile.

The preliminary design of the repository and its implication on safety during the construction and operation phases of the repository life are not to be considered in the review since the different design options were established only in 2002.

In the context of the general objectives previously indicated, the peer review should focus specifically on:

- The assumptions on the lifetime of the canister and its possible overpack, in particular those considered for the vitrified waste and spent fuel, linked with the behaviour of metallic materials and in particular their corrosion.
- The radionuclide release due to the alteration of either the waste matrix or the waste content itself.
- The methodology used in modelling, from site data, the Callovo-Oxfordian formation on a regional basis.
- The way reversibility is defined and then analysed.
- The methodological approach denominated Phenomenological Analysis of Repository Situations (Analyse Phénoménologique des Situations de Stockage, APSS) which aims at an exhaustive spatial and temporal inventory and description of the phenomena thought to take place in the repository.
- The approach and methodology developed for the safety assessment: instead of using a FEPs (features, events, processes) data base, the APSS is a base for a Qualitative Safety Assessment (Analyse Qualitative de Sûreté, AQS); both approaches (FEPs and APSS/AQS) lead to the definition of reference and altered scenarios.
- The management of different time scales. Safety assessments of deep geological repositories usually consider periods of millions of years. An important issue is to balance information devoted to the different time scales as mentioned in the French Basic Safety Rule RFS III.2.f [18].
- The management of uncertainties. Two kinds of uncertainties have to be considered in a safety case. Uncertainties related to the future evolution of the repository and uncertainties related to the lack of knowledge, insufficient data, and assumptions used. The peer review should examine how the Dossier 2001 Argile considers these uncertainties.
- The documents that were the subject of the review by the IRT are listed in Annex 2. The IRT recognises that the technical work reported in the Dossier 2001 Argile was completed in 2001, and that further significant progress has been made since. This subsequent work was sometimes described in the face-to-face discussions, and

the planned Scientific Programme for 2002-2005 [14] was reviewed, but the Dossier 2001 Argile remained the focus of the review.

1.4 Conduct of the review

The IRT met for the first time in Châtenay-Malabry at the Andra offices on 14 and 15 November 2002. During these two days, Andra staff presented an overview of the Dossier 2001 Argile. A representative of the French ministries also presented the government view of the Dossier 2001 Argile and the purpose of the IRT review. The IRT also discussed the Terms of Reference (ToR) for the review, and the division of the review work among the review team.

During the first meeting in Châtenay-Malabry, it was agreed that the IRT review would focus on technical details only in the area of radionuclide release from waste packages and, to a lesser degree, metallic corrosion – the balance of the Dossier 2001 Argile being viewed as a demonstration of procedures and methodology, not as a finished, comprehensive technical product suitable for detailed technical review. In addition to the key areas outlined in the ToR, Andra made specific requests that the IRT comment on:

- their approach to constructing the geologic conceptual model;
- how to define the appropriate degree of focus to be given to different factors over different time periods.

The IRT was also asked to address the manner in which Andra is presenting information.

During the ensuing weeks, members of the IRT examined the main and supporting documents listed in Annex 2, focusing on those sections of the reports closest to their expertise. During the review, the IRT sent two sets of questions to Andra for clarification. Andra provided written responses to all these questions.

The IRT met for a second time, for a week-long workshop, from 3 to 7 February 2003. Andra staff gave presentations addressing a number of key issues raised by the IRT. These discussions included presentations on the method of analysing safety, the evolution of the Andra design, the hydrogeological model, and management of uncertainties. Detailed questions were also asked by the IRT to the appropriate French experts, and answers were provided. In a number of cases, additional briefing notes were prepared by Andra for the IRT.

At the close of the workshop on 7 February 2003, the IRT Chairman, Alan Hooper, orally presented the initial collective opinion of the IRT to Andra and the representatives of the French government and authorities. Each member of the IRT prepared written views and comments that were compiled into a draft report. This was reviewed by the 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 Andra for fact checking, but not for comment. The IRT takes, however, full responsibility for any factual inaccuracies.

1.5 Organisation of the report

Introductory material on the background, the Dossier 2001 Argile, terms of reference, and the conduct of the review has been given in the preceding sections of this chapter.

Section 2 is structured around the fundamental aspects of the review as laid out in the Terms of Reference.

Section 3 is aimed at the more technically interested reader, and presents detailed observations on specific aspects of the Dossier 2001 Argile. Its subsections are organised around the different disciplines that contributed to the Dossier 2001 Argile, particularly those regarding the quality of the technical and scientific basis of the work undertaken.

Section 4 provides general conclusions.

The review presumes that the reader is generally familiar with the aims and content of the Dossier 2001 Argile, but not necessarily with all the details of the documentation.

2. REVIEW OF FUNDAMENTAL ASPECTS

The Terms of Reference describe four fundamental aspects that the peer review should assess:

- the clarity of the documentation, through its structure and its synthesis (Parts A and B);
- the consistency of the applied methodologies for assessing the long-term safety and performance of a potential repository, and its adequacy with the main objective of identifying components with a particularly sensitive role in the robustness of a repository;
- the internal consistency between the scientific and technical knowledge base (collected and bibliographical data) and the assumptions used in the report at different levels: the basic knowledge, the phenomenological descriptions, the selected values of parameters, and the conceptual models;
- the pertinence of the conclusions, in particular those linked with the main objective of the Dossier 2001 Argile.

The IRT's assessment of each of these aspects is given below.

2.1 Clarity of the documentation

The clarity of the documentation presented in the Dossier 2001 Argile is variable. Some of this variability can be attributed to the immense scope of the Dossier, the uneven state of advancement of the research in different areas at the time the Dossier 2001 Argile was prepared, and the fact that Andra is necessarily on a "learning curve" with respect to the preparation of documents of this nature. But in some areas, such as hydrogeological modelling, the Dossier 2001 Argile simply does not reflect the excellent and extensive work performed by Andra presented during technical interactions with the IRT, and the supporting information that a technical reader in particular might want is lacking. This under-representation of the work that has been performed may lead to negative criticism of the Dossier 2001 Argile that could have been

avoided. In other areas, notably corrosion and geologic stability, the information and arguments are clearly and completely presented and can easily be traced to the appropriate supporting documents.

Given the preliminary nature of the Dossier 2001 Argile, a complete, consistent level of documentation was probably not possible. Certain factors/ considerations, however, could have been implemented in the Dossier 2001 Argile that would have improved its readability, and these should definitely be borne in mind during preparation of the Dossier 2005. These factors include:

- Definition of the intended audience of each element of the Dossier 2001 Argile, and careful tailoring of the level of detail to the needs of that audience. The two parts (A and B) of the Synthesis report [1, 2] were intended to respond to the needs of different audiences for different levels of detail, but it is not clear how well defined the audiences for the two parts were and, consequently, how successful the Dossier 2001 Argile was in meeting different needs. If synthesis documents are planned for the Dossier 2005, they might be prepared with the different needs of decision makers, highly technical reviewers (possibly including regulators), and the interested public in mind. Similarly, Volume 5 of the Geological Reference Document [4] appeared to be intended for a technical reader, but did not provide the level of detail needed for such a reader.
- Clear presentation at an early stage of how the various components of the Dossier 2001 Argile fit together. A flow chart or information tree might be used to show the relationships among the numerous documents associated with the Dossier 2001 Argile.
- Individual documents (e.g., APSS Objective and Methodology [10]) better able to be understood on their own, even when that involves some degree of duplication of material presented in other documents. Few people are going to read all of the documents, so individual documents need to be as complete as possible.
- Providing a more comprehensive view of the entire Dossier 2001 Argile in the Synthesis. For example, elements of the Context chapter in the Safety Approach document [11] should be included in the Synthesis to provide a clearer understanding of the aims and methods of the Dossier 2001 Argile.
- Providing a better justification/rationale for the overall approaches that have been followed for data acquisition and modelling. This would help put the presented information in perspective (objectives,

limitations, etc.). The way the future scientific programme has been documented by Andra [14] provides a good example of such a justification.

- Much more extensive referencing of statements and conclusions to the more detailed documents from which they were derived. In many areas, little direct referencing was provided in the Dossier 2001 Argile, including its supporting documents, making it difficult for the interested reader to know where to look to find additional information on specific points.
- More extensive use of figures and illustrations in support of the written text. Figures such as flow charts and cross sections can facilitate understanding of complex and/or spatial relationships. These figures could, in some cases, be simplified versions of figures contained in the supporting documents, showing only those things needed to support the point(s) being made. Many of the figures presented in the Synthesis documents were extracted directly from more detailed supporting documents, and included superfluous information and/or elements that could not be understood outside of the context of the original source.

The Dossier 2001 Argile was not intended as a presentation of a safety case. Nevertheless, demonstrating the development of a research and assessment basis for waste disposal in the Callovo-Oxfordian might have benefited from taking a more argumentative focus. This could be achieved by:

- Providing a concise discussion of the overall disposal concept and the functions served by the different barriers. With the functions of the barriers defined, the performance expected or needed from each barrier could be discussed, followed by the lines of available evidence showing that the desired/expected performance is realistic.
- Paying close attention to providing a balanced overall discussion of phenomena, avoiding undue weighting of minor factors or exceptions (e.g., oxidation of spent fuel).
- Statements about confidence building.

Other elements that need to be included are:

- discussion and justification of conceptual models; and
- discussion of numerical models/codes used for calculations, including details of their implementation (discretisation, boundary conditions, parameterisation, time-stepping, etc.) and development, providing references.

2.2 Consistency of the applied methodologies for assessing the long-term safety and performance of a potential repository

The IRT was asked to evaluate the consistency of the methodologies applied to assess the long-term safety and performance of a potential repository, and its adequacy with the main objective of identifying components with a particularly sensitive role in the robustness of a repository.

The IRT found that all key methodological elements needed for a comprehensive safety assessment are present in the Dossier 2001 Argile. Generally speaking, adequate consistency was noted in the application of methods for different elements of the safety assessment, but consistency between the methods described and their application was not always transparently documented. For example, the procedure for selection of cautious but reasonable parameters was not easy to trace in many examples. Detailed questioning revealed that there was consistency, but it was not clearly documented.

In the application of methods, the IRT found that the consistency between the elements of the safety analysis was generally adequate, but recommends that the propagation of uncertainties needs improvement. This would be partly met by an analysis of a more comprehensive set of scenarios, but it must also be demonstrated how data uncertainties and, in particular, uncertainties affecting the fixation of time frames in the APSS will be managed and propagated to other parts of the assessment methodology.

The methods developed allow identification of key sensitive components of the repository at the present stage, but they will need development for future assessments. Some of the newly developed elements (APSS and AQS), in particular, are potentially useful but need further development. The application of the APSS method requires development regarding, e.g., documentation and transparency. There are also needs for methodological improvements regarding such things as flexibility in the fixation of time frames and coupling to other

parts of the safety assessment. Regarding the AQS methodology, Andra is recommended to develop procedures for making the subjective elements more transparent and traceable, and to address the issue of taking the temporal evolution of the system into account.

The methods employed to identify key sensitive components of the repository (e.g., deterministic sensitivity analyses) are appropriate at the present stage of Andra's programme. The analyses were, by intention, not exhaustive and need additional development for future assessments. A more strict and comprehensive implementation of a carefully selected methodology for sensitivity analyses would be in line with what other organisations are currently developing or implementing.

2.3 Internal consistency between the scientific and technical knowledge base and the hypotheses used in the report

The IRT was asked to evaluate the internal consistency between the scientific and technical knowledge bases and the hypotheses used in the Dossier 2001 Argile. The IRT found that a cautious approach has been adopted to ensure that hypotheses can be supported by data. Considerable basic scientific knowledge is available to Andra that was not used in the Dossier 2001 Argile, but can be applied in future analysis as appropriate. In some areas, such as the radionuclide-retention properties of the Callovo-Oxfordian, the IRT believes that more systematic use of the basic knowledge available would support significantly greater confidence than asserted by Andra.

Phenomenological descriptions were clearly traceable to existing scientific and technical knowledge, but a finding on the APSS methodology is that in the future there will be a need to demonstrate that comprehensive account has been taken of this knowledge. Selected values for parameters used in safety evaluation are found to be consistent with scientific and technical knowledge, although often this is in the sense of sound identification of a pessimistic value. The use of scientific and technical knowledge in the development and linkage of conceptual models is often impressive, for example in the groundwater flow and radionuclide transport model or in certain radionuclide-release models, although this was only fully appreciated following presentations by Andra staff on the flow and transport model.

2.4 Pertinence of the conclusions

The IRT was asked to assess the pertinence of the conclusions reached in the Dossier 2001 Argile, particularly with respect to the main objectives laid out for the Dossier 2001 Argile. Andra presented its conclusions in Section VII of Part A of the synthesis [1] under the following headings:

- a wealth of knowledge already gained under the project;
- firm design solutions for the feasibility studies;
- testing the analysis, evaluation, and interpretation methods;
- lessons for future research; and
- an important stage in the feasibility evaluation process due for completion in 2005.

2.4.1 A wealth of knowledge already gained

The Dossier 2001 Argile summarises extensive work carried out in a wide range of areas that supports evaluation of the feasibility of the repository. Andra claims a solid, high-quality R&D base in all areas due, in part, to the contributions of many different scientific partners. The IRT finds that this is clearly the case in a great many areas, although it is not always clear in the Dossier 2001 Argile. The only significant R&D omission the IRT has noted is related to gas issues (see Section 3.4).

2.4.2 Firm design solutions for the feasibility studies

Andra states that it has developed a comprehensive approach that identifies the key elements in repository design. This approach demonstrates that viable designs can be achieved involving processes and parameters that can be controlled. Both the design factors and realistic preliminary design approaches have been identified.

The IRT agrees that design factors have been clearly identified and the proposed design options appear reasonable. However, the potential impacts of gas generation on repository design remain to be evaluated. The modular design approach adopted by Andra has potential to produce designs that are robust against current uncertainties. It allows the source term represented by each module to be modelled with confidence that conditions would remain within bounds for which there are reliable data and that time-variant thermal and

chemical perturbations from wastes in other modules do not have to be taken into account. Clearly, this does not represent design optimisation at this stage, but provides a good baseline for optimisation studies that may be performed in the future.

2.4.3 Testing the analysis, evaluation and interpretation methods

Andra asserts that the APSS and AQS presented in the Dossier 2001 Argile provide a methodological basis for a fuller evaluation of repository performance in 2005. The IRT agrees that the APSS and AQS provide essential elements of a methodological basis, but that both tools need further development.

The APSS is presented as an innovative way of reducing system complexity to a set of variables that are easier to address flexibly and reproducibly. The IRT agrees that the APSS is a structured approach to handling the temporal evolution of the system. The flexibility of the method, however, remains to be demonstrated in an application to a more comprehensive set of scenarios. Reproducibility certainly seems achievable, but requires more developed documentation procedures than in the example shown in the Dossier 2001 Argile.

The APSS is also presented as a useful tool for integrating knowledge, providing a basis for understanding the way the phenomena that take place in the repository are interwoven. The IRT agrees that the APSS integrates science and its schematisation for safety assessment purposes, and provides a useful platform for communication with the scientific community.

The AQS is presented as a method for identifying the scenarios that need to be evaluated quantitatively from the results of the APSS analysis. One stated advantage of the AQS is that it is exhaustive and traceable. The IRT agrees that this is possible, but notes that further development of the method is necessary to provide a comprehensive demonstration that this is the case.

2.4.4 Lessons for future research

Andra states that sensitivity analyses have identified the areas in which more accurate information could allow the use of more realistic, less pessimistic parameter values that will improve the modelled performance of the repository. The safety analysis has allowed the different repository components to be classified in order of importance, and has clarified future R&D requirements.

The IRT concurs that the future scientific programme has been well-informed by the Dossier 2001 Argile and by additional information available to Andra. The scientific programme for 2002-2005 [14] is based on a clear and realistic evaluation of the current state of knowledge and well-justified proposals as to the necessary developments and how they can be made.

2.4.5 An important stage in the feasibility evaluation process

Andra concludes that "no factor ruling out a repository has been identified at this stage in the feasibility study process." The IRT finds the information provided in the Dossier 2001 Argile to be consistent with this conclusion. However, as explicitly recognised by Andra, the Dossier 2001 Argile does not provide a comprehensive analysis at this stage.

Andra also states that the Dossier 2001 Argile provides a platform for selecting repository design concepts, identifying uncertainties to be addressed, and updating research programmes to concentrate on key objectives. The IRT agrees that the current status and important issues are identified, although they are not always communicated effectively in the Dossier 2001 Argile. The totality of information available to Andra at this time provides a sound platform for the future programme.

3. REVIEW OF SPECIFIC ASPECTS

The Terms of Reference for the review identified specific, technical aspects of the Dossier for review. The aspects that eventually received an appropriately detailed review were identified following discussions with Andra on 14-15 November 2002. The results of the review are presented.

3.1 Corrosion

Vitrified wastes from fuel reprocessing are contained in a thin-walled canister made of stainless steel 309S. Present concepts for the vitrified wastes call for a metallic overpack with an intended lifetime of about 1 000 years, to allow for the temperature of the waste form to drop below 50°C by the time groundwater may come in contact with the vitrified waste matrix. For modelling purposes, the corrosion resistance of the thin steel canister is not taken into account.

Present concepts for spent fuel include a metallic overpack with an intended lifetime of about 10 000 years to allow for the temperature of the spent fuel to drop below 80°C by the time groundwater may come in contact with the fuel. For modelling purposes, the breaching time of the fuel cladding is not taken into account.

For both vitrified waste and spent fuel, the corrosion resistance of the metallic overpack is a key consideration in the overall assessment of the performance of the disposal system.

The Dossier 2001 Argile document entitled “Materials Baseline – Volume 4” [3] summarises the knowledge acquired by Andra on the corrosion of metallic materials relevant to geologic disposal of high-level wastes. Three classes of materials are considered:

1. Low- and non-alloy steels.
2. Nickel-chromium-based steels.
3. Copper and titanium.

A significant body of knowledge exists on the corrosion behaviour of low- and non-alloy steels and nickel-chromium-based steels, which is well captured in the Andra document. In particular, the chapter dealing with the corrosion of low-alloy and non-alloy steels provides a thorough discussion of the corrosion mechanisms of interest to geologic disposal. The document also includes a review of the durability of buried industrial objects (piping) and archaeological analogues, which can be of value in validating predictions of the durability of non-alloy steels over periods of time significantly longer than those typical of laboratory studies.

The chapter on austenitic steels is also well developed, although not to the same extent as the one treating low- and non-alloy steels. Finally, a more abbreviated review of the corrosion of titanium and copper is presented for completeness, because of the proposed use of these metals by the U.S. and Swedish programmes, respectively.

The emphasis on low- and non-alloy steels is a reflection of the predisposition of the Andra programme to rely on these materials for vitrified waste and spent-fuel applications, as confirmed by the choice of designs made in 2002. Low- and non-alloy steels are "corrosion-allowance" materials, and require significant quantities of metals due to their readily measurable corrosion rates, especially under oxidizing conditions. The main reason for Andra's choice of these materials is that their long-term behaviour is, in principle, more straightforward to predict compared to nickel-chromium alloys, the corrosion resistance of which rests on the stability of a highly protective chromium-rich surface layer. Other reasons for Andra's choice include ease of fabricability (such as welding), cost, etc.

For safety assessment purposes, the main source of uncertainty derives from the limited knowledge of the environmental conditions, especially water chemistry, which will prevail during the repository operational and closure phases. In particular, for vitrified waste and spent-fuel, the ability to predict the durability of the overpack depends on the knowledge of the environmental conditions that exist at the interface between the overpack and the corroding environment, taking into consideration the mechanical stresses that may exist in the overpack. Given (i) Andra's choice of low-alloy steels and the design features deriving from using this class of materials (specifically, overpack thickness) and (ii) the technical bases presented in Chapter IV (Corrosion of Low and Non-Alloy Steels), reasonable upper bounds of corrosion rates can be reliably estimated as long as the following conditions prevail:

- Nominal parameters for the interstitial water present in the Eastern argillites (as documented in Chapter III).

- Ability to rule out large uncertainties that would be introduced by phenomena such as (i) boiling heat transfer at the overpack/aqueous solution interface (leading to solute concentration effects), (ii) excessive radiation fields (leading to a more aggressive water chemistry due to the formation of species such as H_2O_2), and (iii) stresses in excess of yield (for example, by deformation of the overpack due to local swelling pressure).

These limitations are generally well identified in the Dossier 2001 Argile.

A major problem in evaluating the behaviour of low- and non-alloy steels is identified in the Dossier 2001 Argile as the potential for cracking due to hydrogen embrittlement. Trapping of the hydrogen released by the corrosion reaction at the metal/water interface, followed by pickup of the trapped hydrogen by the metal, could lead to mechanical failure of the overpack. *A more complete analysis of expected hydrogen partial pressure in the repository environment in relation to the possibility of hydrogen embrittlement should be performed for the proposed materials specifications of the carbon steel overpack.*

Potential limitations in the understanding of the evolution of the overpack-clay system have also been identified, specifically with regard to iron/clay interactions, as documented in "Scientific Programme, HLLW Clay Repository Project, 2002-2005" [14]. As stated in that document, it is recommended that the programmes under way be continued with the objectives "to strengthen the hypotheses adopted and provide supporting evidence".

In summary, the Dossier 2001 Argile document "Materials Baseline – Volume 4" [3] provides a sound technical basis for making informed decisions about the designs selected for the Dossier 2005.

3.2 EBS design concepts

The Dossier 2001 Argile represents an early stage of development of design concepts for the repository and the Engineered Barrier System (EBS). A clear set of criteria is given in the Synthesis Report – Part B [2] for evaluating these design concepts. Nonetheless, some of the most critical factors underlying evaluation of these concepts are not clearly brought out in the report. In particular, the significance of fundamental limitations in process understanding in contributing to such decisions is touched on too briefly. For example, the option of using a cementitious backfill as an alternative to bentonite as an EBS around spent-fuel canisters is discussed. Limited information is presented to

support its consideration in the Dossier 2001 Argile. Furthermore, the balance of information in the literature on spent-fuel performance (e.g., leaching studies and thermodynamic data) casts considerable doubt on this option (as compared to the depth of relevant information for a near field conditioned by bentonite). This is an example of an area in which the fundamental research needs to support a design decision are not clearly represented in the documentation. *It is recommended that the information supporting selection of design options be more comprehensively treated, in particular, the identification of the most critical limiting factors.*

3.3 Waste package source terms

In the Dossier 2001 Argile, Andra has dealt with repository design and performance assessment studies for a wide variety of waste types. For each of these waste types, including the various B waste groups (ILW), C waste (vitrified waste), and various types of spent fuel, reference waste types and packages are clearly described.

The scientific understanding of the B wastes and the derived source-term models are presented in a clear and comprehensive fashion. The bitumen degradation model is quite sophisticated and the presentation illustrates a significant improvement in understanding relative to previous models. It is common to see very conservative immediate release/mixing tank type models typically used for this and other ILW types, which tends to convey an impression that ILW barriers are completely ineffective. The further development of this model is thus strongly encouraged. In a similar fashion, the understanding of, and model development for, hulls and ends type wastes is impressively laid out. Again, this represents a considerable improvement in treating these wastes in performance assessment and clarifies the nature of potential improvements in understanding and modelling. The proposed rates appear very reasonable and consistent with scientific understanding as summarised in CEA and international studies. The systematic identification of the uncertainties and the clear definition of achievable goals in research for these types of wastes and the move towards more realistic models is strongly encouraged.

The summary of scientific issues for vitrified waste performance is well balanced, although, considering the importance of waste durability, rather brief, compared to, for example, the very comprehensive treatment of canister materials. A more detailed presentation on the foundation of the alternative models is recommended in support of future safety assessment calculations.

Reasonable conclusions appear to have been reached regarding possible rates of dissolution and the potential for improved understanding by 2005.

The section on spent fuel source terms does not adequately capture the depth of understanding available in CEA studies and the international literature (Poinssot *et al*., 2001, Shoesmith, 2000). Some statements are inadequately supported and leave an unfavourable impression regarding the state of knowledge, for example:

1. The discussion of Zircaloy cladding certainly would leave a non-specialist with a very poor impression of Zircaloy ("…hydrided and embrittled. They display cracks…"). In spite of some hydriding and embrittlement, <1 in 1 000 rods have defects at exit from the reactor and IAEA studies have confirmed the considerable durability of Zircaloy fuel cladding in wet and dry storage, i.e., the absence of development of further defects. Although credit for cladding as a barrier to release of radionuclides from spent fuel under disposal conditions may not be a realistic target, the scientific evidence for and understanding of its durability over interim storage time frames is considerable and is worthy of note.
2. The lack of clarification regarding which aspects of fuel source term are reasonably well studied and understood versus those in which understanding is much more limited has the unfortunate effect of suggesting that there is overall a rather weak scientific foundation for developing source-term models. For example, the suggestion that all or part of the fuel might be oxidised before the arrival of water (because in high burnup fuel some traces of U_4O_9 exist, an observation that is unimportant with respect to dissolution) is highlighted in the scientific discussion at the same level of uncertainty as radiolysis or fission product segregation, both of which have been actively studied for almost twenty years and for which dozens of references exist.

It is recommended that these issues be resolved by ensuring a more balanced and comprehensive treatment of the scientific understanding of spent-fuel dissolution, with a clear presentation of the relative importance of the specific uncertainties, including maximum use of data from international studies especially in those cases in which French data are limited.

In spite of the above concerns, the suggested source term rates appear to be justifiable at this stage, although it would have been useful to propose an alternative rate significantly different from the 10^{-4} per-year value to explore the

effect of different matrix dissolution rates, given that much lower rates are implied by some literature studies. The contribution of labile fission products, the dominant dose contributors, of 20% appears to be a suitably conservative choice at this stage of studies. Possible reduction in this rather conservative value may be possible, as it is based on rim effects at high burnup, a phenomenon of little significance below 45-50 GWd/t. Thus, some indication of the expected burnup distribution of spent fuel may lead to a more realistic model.

3.4 The absence of treatment of gas in the safety analysis

The IRT understands that insufficient information was available at the time of completion of the Dossier 2001 Argile to incorporate gas issues into the repository safety analysis. Nonetheless, a broad conclusion is drawn in the Dossier 2001 Argile that "research does not reveal any factors that rule out a repository". Since it is implicit that there is no reason to believe that full incorporation of gas issues would change this view, it would be useful to see the qualitative arguments listed for why this is so. Elements of the arguments are mentioned (e.g., the observation from GAMBIT studies (Swift *et al*., 2001) that gas breakthrough does not impair the function of the bentonite barrier). These arguments, even without quantification, would provide support for the strong statement that has been made. Such an approach is consistent with the notion that a safety case should include a variety of quantitative and qualitative arguments.

In order to inform design choices and the need for further waste characterisation, and considering the very limited capacity for gas to diffuse out of comparably tight formations studied abroad, it is recommended that boundary conditions for the far-field gas transport be evaluated as soon as possible. For design purposes and for preliminary input to identification of scenarios, scoping calculations (gas generation and accumulation versus diffusion capacity in the host formation) and further consideration of the internationally available experience (NEA, 2001; Rodwell *et al*., 1999) appear to be necessary.

3.5 Characterisation and modelling of the Callovo-Oxfordian and its surroundings

3.5.1 Overall geological characterisation

The documentation presented in Tomes I-IV of the Référentiel Géologique (Geological Reference Document) is, from a geological sciences point of view, extensive and impressive. The quality of the scientific foundations of the French programme regarding the characterisation of the host formation and its surroundings is regarded as high.

As a preparatory exercise to a future safety case, it would have been of interest to collect in one place the key arguments that support the current and long-term barrier performance of the host formation. These arguments are spread throughout the reports and rarely highlighted as such.

The RFS III.2.f [18] establishes the basic criteria to be met by a potential repository site. It was not the objective of the Dossier 2001 Argile to demonstrate compliance of the Bure site with these siting criteria, as this was the subject of the licensing procedure of the Bure URL. During this licensing procedure, it was systematically checked that the Bure site possessed no disqualifying characteristics according to the RFS.

The confinement roles given to the host formation in the overall safety approach of the Dossier 2001 Argile imply the following general characteristics ("Safety Approach" [11]):

- low permeability;
- minimum depth to limit the intrusion risk;
- sited far away from aquifers.

These characteristics seem to be met by the Callovo-Oxfordian argillites.

Generally speaking, the material presented in the Geological Reference Document confirms the overall favourable characteristics of the Callovo-Oxfordian argillites as a potential host formation for a repository.

The initial and general orientations of the programme of geological knowledge acquisition as reported in the Geological Reference Document should have been further explained in the Dossier 2001 Argile synthesis documents. In particular, a better justification of the current R&D programme

on the basis of, on the one hand, the uncertainties derived from the preliminary safety analyses carried out for the URL licensing procedure, and, on the other hand, the safety functions and roles devoted to the host formation in the global safety approach would have been welcomed to understand better the focus and objectives of the documented work. This would have avoided the impression that the Geological Reference Document is somehow decoupled from the Dossier 2001 Argile.

It should be noted that the presentations given during the review week allowed the IRT to get an adequate overview of the issues at hand after the completion of the Bure URL licensing procedure and therefore of the general orientations mentioned above.

The presentations also allowed clarification of the stepwise approach that has been chosen in the characterisation and quantification of the migration parameters of the host formation, with primary focus given to a detailed mineralogical analysis and to the definition of a reference porewater chemistry to support future modelling exercises.

The IRT notes that a systematic justification of the future priorities and objectives has been followed in defining the scientific programme for 2002-2005 [14]. This approach also considers the limited time available before the next iteration of the Dossier in 2005, and the way it has been documented is commendable. An example of such justification is the work to be carried out on the characterisation of the Oxfordian aquifer around the Bure site. Even though retention (e.g., sorption) of radionuclides in this formation could potentially provide an adequate barrier to their release (see Section 3.5.5), better definition of the low-permeability zone in the Oxfordian, which reduces the hydraulic transfers towards the overlying aquifers, is considered as a priority for the Dossier 2005 because it can more practicably be accomplished in the time available than could the development of fully defensible quantitative information on retention.

The overall geological characterisation of the host formation, which is based, on the one hand, on a thorough description of the current situation and, on the other hand, on a detailed understanding of the diagenetic evolution of the host formation and its surroundings, is very detailed and at the forefront of such studies. It allows inference notably of the lateral continuity of the favourable parameters and the overall stability and buffering capacity of the host formation and its surroundings. In this domain, the Andra scientific programme is certainly more advanced than many other national programmes.

The approach used to define an "equivalent geological area" (Chapter IV of Volume 5 of the Geological Reference Document [4]), where the results to be acquired at the level of the Bure URL could be transposed, is to be commended as it allows assessing the representativeness of the latter and, therefore, helps upscaling from URL scale to repository scale.

The IRT recommends that the extent of the "equivalent geological area" should be frequently reassessed in the light of newly acquired knowledge in order to maintain its representativeness. Andra might in particular consider whether some criteria related to the local low-permeability zone could be included in the definition of this area.

3.5.2 Transfers in Callovo-Oxfordian argillites

The conceptual model for the solute transfers in the Callovo-Oxfordian argillites is based on the dominance of diffusion over long periods of time. The Dossier 2001 Argile presents multiple arguments supporting this hypothesis, e.g., low permeabilities, overpressurisation, natural tracer profile, absence of hydraulic role of the faults. These arguments cover various temporal and spatial scales.

The IRT is of the opinion that efforts should be pursued in order to build further confidence in these arguments as key support to host-formation performance. In particular, clarifications are needed concerning:

- the interpretation of the natural chloride profile (and potentially of other natural tracer profiles);
- the potential hydraulic role of faults intersecting the host formation (at the regional scale) in order to support upscaling of the low permeability values measured on samples or in boreholes (It should be noted that current hydrogeological model calibration does not require any hydraulic role of the faults.);
- the origin of the overpressurisation and its maintenance through geological time (understanding of driving phenomena). In this framework, it is important to (i) compare (and, as appropriate, explain differences) with other national approaches and (ii) ensure consistency of arguments concerning the roles of Onsager processes in solute transfers.

Precipitation in, and sorption on, the Callovo-Oxfordian argillites are considered in the safety assessment calculations as processes that could retard

radionuclide transfers through the host formation. The Dossier 2001 Argile in general, and the Geological Reference Document in particular, could have taken further advantage from the overall confidence that exists at the international level on the efficiency of such processes in clays. Furthermore, the discussions held with Andra experts have demonstrated that such a confidence is shared for the Callovo-Oxfordian argillites.

The efficiency of these processes and their quantitative evaluation for safety assessment purposes should be further supported by, in particular.

- defining *a reference Callovo-Oxfordian porewater chemistry;*
- *assessing the representativeness of the analogies used for defining K_d data for the Callovo-Oxfordian clays;*
- *assessing the representativeness of batch sorption experiments vis-à-vis repository conditions;*
- *assessing the potential consequences of sorption competition between radionuclides and other solutes migrating in the geosphere (through scoping calculations);*
- *a better understanding of sorption processes.*

It should be noted that Andra has clearly acknowledged (in the Dossier 2001 Argile or during the discussions with the IRT) the need to increase efforts on porewater chemistry and retention issues. Andra, in accordance with its stepwise approach towards characterisation of retention properties of the host formation, has already established an extensive R&D programme to investigate this issue further.

The IRT encourages these efforts. Furthermore, considering the time needed to characterise such retention properties experimentally, it is recommended to explore further the possibilities of transferring data acquired in foreign countries to the specific case of the Callovo-Oxfordian argillites.

Considering the importance of the geological barrier, the argumentation that supports the characterisation and understanding of the radionuclide retention properties and processes in the argillites, as reported in the Dossier 2001 Argile, is too sketchy compared to that provided for other geoscientific issues.

3.5.3 Induced perturbations

The discussions concerning the different zones affected by the excavation of the underground facilities and the properties of the argillites under different saturation conditions are more mature than in many other programmes. However, the documentation gives the impression that the damages and perturbations induced by the underground work will have long-term detrimental consequences on water and solute transport. This might be overconservative. The potential and conditions for self-healing or self-sealing of the argillites should be further analysed.

Considering the potential use of concrete in the design (e.g., overpacking of the B waste, lining), the impact of an alkaline front on the geochemical and retention properties of the Callovo-Oxfordian argillites is considered to be an issue in the Dossier 2001 Argile. Information provided during interactions with Andra suggests a limited perturbation created by the concrete. In this field, any further work should be driven by a global assessment of the extent of this perturbation vis-à-vis other repository-induced perturbations.

Generally speaking, a more formal feedback mechanism should be established between the characterisation of the host formation and the design development. Up to now, feedback seems to have been mostly focused on mechanical aspects (extension of the Excavation Disturbed Zone (EDZ)).

3.5.4 Hydrogeological framework

Generally speaking, the hydrogeological situation is rather favourable: e.g., poorly exploitable surrounding aquifers due to their low permeabilities, the availability of other water resources, the high level of chloride in the Dogger; etc. But the IRT found the discussion in the Dossier 2001 Argile synthesis documents [1 and 2] and Volume 5 of the Geological Reference Document [4] concerning the hydrogeological framework and modelling to be inadequate and incomplete. Face-to-face discussions revealed that considerably more work (of high quality) had been done in this area than was acknowledged or taken credit for in the Dossier 2001 Argile.

The IRT would also have liked further justification of the simplifications that were used to "move" from the phenomenological hydrogeological model towards the "safety model". The latter is not explicitly documented in the Dossier 2001 Argile. *In particular, the conservative assumptions that have been made should be clearly stated, e.g.:*

- *the simulated pumping wells used to estimate doses to future populations are located upstream of the modelled natural outflows and in the middle of the calculated radionuclide plume;*
- *the low-permeability zone of the Oxfordian aquifer is extended the minimum amount needed for calibrating results of the hydro-geological model against hydraulic heads; its actual extent could be considerably larger.*

The scientific programme for 2002-2005 concerning hydrogeological characterisation and modelling is well informed by the Dossier 2001 Argile (uncertainties to sort out, location of new drillholes, choice of natural tracers to be used, etc.) and should help test current results of the model. In this framework, the move towards a unified coherent hydrogeological model is seen as a necessary step forward (use of a regional-scale model with successive mesh refinements at the local and site scales).

3.5.5 Safety reserves

Several phenomena with a potential to improve the barrier performances of the host formation and its surroundings are not considered in the safety assessment calculations, which is conservative. Among these are:

- radionuclide retention in the formations that surround the Callovo-Oxfordian argillites (especially in the overlying marls);
- self-healing of the EDZ with partial recovery of the barrier properties of the argillites.

These phenomena and their impact on radionuclide migration could be considered as a kind of "safety reserves or margins".

The quantification of these phenomena is not seen as a priority for Dossier 2005. *It is, however, recommended to assess their potential role in the fulfilment of the functions attributed to the geosphere further (e.g., through qualitative arguments or scoping calculations). The presence of such reserves*

or margins could be used to build further confidence in the long-term performances of the disposal system.

3.6 Reversibility

To inform the national debate to be held in France in 2006 with regard to the selection of the reference options for the long-term management of radioactive waste, the Law of 1991 [17] calls for Andra to carry out studies on options for "retrievable" and "non-retrievable" geological disposal. In a December 1998 statement, the French Government (Prime Minister, 1998) indicated that emphasis should be given to a "logic of reversibility". This Government statement had been informed by a June 1998 report provided by the CNE (1998).

The Law of 1991 does not define what constitutes an "irreversible" repository, nor does the Dossier 2001. This would be of interest, in order to define better what distinguishes a "reversible" repository. The CNE terms "irreversible" a repository from which waste can be retrieved only by mining techniques, i.e., a closed and sealed repository (CNE, 1998). Reversibility is thus associated, by the CNE, to an open or partially open repository. Consistent with this view, a repository that is reversible is described, by the CNE, to be a "geological interim storage facility convertible into a geological repository".

The concept of "reversible repository" presented by Andra appears to conform to that of the CNE in that:

> "A reversible repository is one which, by its design and the quality of understanding available, allows waste management choices to be made at any time, as for an interim storage." [9]

Andra states in addition that:

> "A reversible repository must be robust in the long term, with respect to the basic objectives of personal and environmental protection (it must be possible to close the repository when the decision to do so is taken)."[9]

Degrees of reversibility can then be associated with different degrees of closure of the repository.

Ultimately, the Dossier 2001 Argile addresses the "retrievability" of waste packages in a repository that is progressively shut down and sealed. The

choices that can be made at each stage of progressive closure are to maintain the present configuration, to reverse the previous stage, or to proceed to the next one. The nearer one is to final closure, the more complex the operations for retrieval are, and the lower the level of reversibility/retrievability is considered to be. Once the repository is closed, "reversibility" – meaning retrievability – "is no longer a question of stages to complete in terms of managing the repository". The distinction amongst the two terms "retrievability" and "reversibility" is made in the Dossier 2001 Argile but it is not used consistently. This may be due to translation error into English. We recommend that Andra should be more specific in the use of these terms in the future. In the context of the Dossier 2001 Argile, reversibility is about assuring that the conditions to retrieve the wastes do exist during the operational phase.

The Dossier 2001 Argile presents, for each closure stage, the physical phenomena that need to be taken into account for assuring that retrieval is possible while preserving the robustness of the system vis-à-vis its long-term performance. The linking of each different closure state of the repository to the possibility of reversing from that state back to the retrieval of the waste package is examined in a systematic fashion. The approach is convincing and effective in that it provides an internally consistent and systematic frame that does not require pre-determined timings of closure operations for examining the technical issues connected to retrieval and for identifying management solutions. The analysis benefits much from the description of phenomena given by the APSS. Indeed, the analysis is very much an example of application of the APSS and demonstrates, in one more setting, the usefulness of the APSS.

The Dossier 2001 Argile provides a good exploration of how it could be possible to manage the progressive closure of a repository in a manner that assures flexibility. It also provides a solid methodological basis to the statement that is often made in international programmes that retrievability can be assured during the pre-closure phase of a repository. The Dossier 2001 Argile, however, does not provide a complete picture of how the whole retrievability case can be made based on safety, economical, and ethical considerations. In particular, the safety of the "reversible" repository has not been studied, nor have social and economic considerations, such as loss of know-how or availability of funds, been brought into the analysis as constraints in the managing process for a repository and their implications on safety.

The estimates for how long any specific repository stage can be maintained are order-of-magnitude and come from current knowledge on the kinetics of major processes, or from industrial practice (e.g., lifetime of concrete structures). The document mentions only qualitatively some specific processes that may have an impact on the evolution and performance of the repository in

the longer term, such as ventilation-induced desaturation and oxidation of the argillite in the near field. Andra plans to make improvements in some of these areas, e.g., by further developing a proposal for a monitoring programme. Such new analyses and considerations are, of course, important to the acceptability of the concept and need to be pursued.

Andra has opted not to set a preconceived duration either for specific stages of repository operations or for the whole length of the reversibility/ retrievability period. Any such periods are deemed to be the result of societal negotiation based on trust building and compatibility with the continued safe operation and maintenance of the repository while keeping the long-term goal of protection of man and the environment. This is the sense of Andra's statement that "the decision to move to a phase of lesser reversibility must be based on sufficiently strong conviction" [2, p. 175] – as the IRT learnt in the face-to-face discussions. Initially, the IRT had found this statement to be ambiguous. That is, it could be interpreted to mean that waste could be emplaced underground before there was strong confidence in the safety of the facility and, therefore, that retrievability could be considered as a safety-relevant measure, which, of course, would be against the principles of geologic disposal. To counter this impression, it is recommended that Andra state clearly that retrievability is **not** a feature required for safety and that reversibility is a management tool/concept to maintain flexibility during the operational phase of the repository. Connected to this aspect is the important issue of the financial provisioning for costs that may have to be borne to address concerns other than safety of disposal, e.g., for exercising some alternative management process for recovered waste.

More generally, it would be useful if Andra presented in the future updates of the Dossier 2001 Argile the underlying principles to be adhered to in the area of reversibility/irreversibility, as well as a greater range of possible reversible designs and irreversible designs. Other reversible designs or approaches are possible:

- In Sweden, a demonstration phase with only about 5-10% of the waste is to be carried out. Upon evaluation of this phase, either the waste (spent fuel) is retrieved or a full repository is built and closed. In the latter case, long-term retrievability is favoured by the robust design of the spent fuel canisters and by the keeping of appropriate records (Olsson, 2001). Other less-reversible disposal concepts are also being considered in Sweden (SKB, 2001).
- In Switzerland, a combination of a test facility and final facility, similarly to Sweden, is envisioned. In addition, a small pilot facility

can be used in connection with a monitoring system to check the performance of the underground repository for as long as it is desired (Nagra, 2002; Wildi, 2000).

Vis-à-vis other international approaches, including the one to be implemented in the USA, the French Government statement of 1998 (Prime Minister, 1998) appears to place the principle of control and freedom for future generations as high as that for safety, whereas it ranks second in other national programmes (e.g., Wildi, 2000). The Dossier 2001 Argile is unclear in this ranking of principles. Although discussions with the Andra management demonstrated an objective of reversibility consistent with operational and long-term safety, it appears important that the above aspects be clarified in the future.

The approach to reversibility presented in the Dossier 2001 has merit in terms of providing a basis for maintaining technical flexibility during the operational phase of the repository. This technical flexibility could be easily adapted to a process of stepwise decision-making that is yet to be identified. To date the approach appears to have been developed with relatively little guidance from the French authorities. In effect, this is a first step that should provide a basis for stakeholders, including the French authorities, to develop guidance or trigger debates on this topic. *However, given the central role that Andra is expected to play in the national debate in France, it appears advisable for Andra to undertake work to clarify the basic principles and hierarchy of values related to reversibility and retrievability, for example, based on the questions posed earlier in this section. This clarification could also lead to the identification of a spectrum of choices.* Once a stand-alone document is produced, it would also be beneficial to have a broad-based discussion in order to refine the concepts further. An early debate with key stakeholders on the meaning of reversibility and retrievability would also be beneficial in preparing for the debate on options that will be undertaken in France in the year 2006.

3.7 Approach and methodology developed for the safety assessment

3.7.1 General

The methodology applied in the Dossier 2001 Argile contains the essential components that can, in one form or the other, be expected in an assessment of long-term safety. It contains:

1. a comprehensive description of the system to be analysed;

2. an analysis of the temporal evolution of the system broken down into relevant spatial components;
3. an analysis of the safety functions of the system;
4. an evaluation of how the safety functions could become impaired;
5. a structured derivation, from the understanding of safety functions and the temporal evolution of the system, of scenarios for the quantification of radiological consequences;
6. a derivation of models for consequence calculations;
7. examples of consequence calculations for two important scenarios; and
8. deterministic sensitivity analyses.

The above steps are informed by results from ongoing research and development work. Considerable efforts seem to have been made in both the development and the application of the methods used in the various parts of the Dossier 2001 Argile analysis.

3.7.2 APSS

In the Dossier 2001 Argile, Andra introduces the so-called APSS method ("Analyse Phénoménologique des Situations de Stockage" or, in English, "Phenomenological Analysis of Repository Situations" (PARS)) to handle the temporal evolution of the system under study.

In the APSS method, the system is spatially broken down into a number of components determined by the structure of the repository and the host rock. The temporal evolution for each component is divided into a number of "situations", or rather epochs during which a fixed set of phenomena (processes) dominate as driving forces for the evolution of the system. For high-level waste, there is, e.g., a thermal phase during which heat load from the waste and related phenomena have a significant influence on the situation evolution. A data sheet is associated with each situation, where the time frame of the situation, the repository components involved, and overall assumptions regarding the situation are described. Then the thermal, hydraulic, mechanical, chemical, and radiological (T, H, M, C, R) phenomena relevant to the situation are described verbally and as a number of "conceptual models" showing visually the main features of the evolution during a "situation". Finally, recommendations regarding (further) modelling of the relevant phenomena are given.

The starting point of the APSS is the situation prior to the construction of the repository. The construction period, the operational phase, and the post-closure phase are then included in the analyses, each phase as a number of different “situations”.

Any method used to evaluate the long-term safety of a deep repository for radioactive waste must be able to handle the temporal evolution of the system under study. The APSS method is in many basic aspects in line with methods used or being developed by other organisations.

The APSS methodology is an adequate tool for the characterisation of “situations” in space and time. The “situations” are based on features and processes to be taken into account whereas the time segmentation of the “APSS General Situation Table” depends on the assumed occurrence of events. Thus, the APSS methodology requires a procedure with many elements in common with a FEPs (Features, Events, and Processes) analysis. In addition, every attempt to achieve comprehensiveness of the situations to be taken into account will benefit from a comparison with FEP analyses performed and databases produced elsewhere. Therefore, APSS is not an alternative to FEP-based methods but rather an instrument to apply such a method effectively by deriving a structure based on location and time.

The method seems to work well when it supports the description of the normal evolution scenario. However, its usefulness remains to be demonstrated when applied to altered evolutions that might be based on the assumption of occurrences of uncertain, especially disruptive events and sequences of such events. Since the APSS is not flexible in time and the subsequent failure tree processing does not account for the timing of such events, it is necessary to test the method against the needs for the development (rather than the description) of such altered scenarios.

The identification of processes for a given situation needs to be better motivated and documented. A contribution to this effort would be the comparison to international FEP data bases that is planned by Andra. Also, modelling efforts underlying the description of situations need to be better documented. There is also room for improving the transparency and systematic approach of the treatment and propagation of uncertainties within the APSS and between the APSS and other parts of the safety assessment.

The APSS also seems to be appropriate with regard to the traceability of decisions, choices, assumptions, and research progress. However, the data sheets used for the description of situations should be expanded to support this

by recording e.g. decisions, references, names of experts involved, etc. This applies also to the formalised scenario descriptions.

The inclusion of the construction, operational, and post-closure phases in the methodology promotes consistency in the analyses of the different phases and is thus a strength of the methodology. Here, the APSS methodology seems to be more systematic than most comparable methods.

The application of the APSS method requires development regarding e.g. documentation and transparency. There are also needs for methodological improvements regarding propagation of uncertainties, flexibility regarding the fixation of time frames and coupling to other parts of the safety assessment. In summary, the IRT finds that the APSS methodology, after these developments has the potential of becoming a useful tool for its intended purposes. It appears resource demanding, but also seems to provide a valuable forum for the integration of scientific work and safety assessment efforts and a useful platform for communication with the scientific community outside the waste-disposal arena.

3.7.3 AQS

Together with the APSS, the so-called qualitative safety assessment, AQS, forms the basis for the safety assessment methodology in the Dossier 2001 Argile. An important input to the AQS is a description of the safety-bearing functions of the repository components and the host rock (Internal Functional Analysis, Analyse Fonctionnelle Interne AFI). This takes the form of a so-called function tree with the ultimate purpose of protecting man and the environment at the highest hierarchical level and which uses input from the description of the repository design and from an analysis of what requirements the external environment puts on the repository system.

The results of the APSS are used to judge whether and when the desired functions of the system as described by the functional tree could be jeopardised in a so-called Failure Mode and Effects Analysis (Analyse de modes de défaillance et de leurs effets, AMDE). The outputs of this analysis are elementary failures (i.e. possible causes for a function not to be performed properly), associated with an indication of their relative likelihood.

For the further processing of the failure modes, the function tree is “inverted” into a failure tree in a straightforward manner. The elementary failure causes (with their associated likelihoods) are then attached to the corresponding functions. A semi-automatic processing of the tree provides the

critical failure modes (comprising combinations of failures) with their relative rankings (derived from their likelihood). The ranked list of failure modes is then the basis for the selection of a number of scenarios for further processing in the safety assessment.

The AQS is a systematic way of describing the safety functions of the system and developing scenarios for consequence calculations. The description of the AQS methodology in the Dossier 2001 Argile is, however, insufficient. It occurs at too low a level in the hierarchy of reports and lacks clarity and completeness.

The time at which a failure occurs is not taken into account in the failure tree processing. Hence, an early failure is not treated as being more severe than a late failure in the **ranking** of failure modes that is the basis for selecting scenarios. A related weakness regarding the processing of the failure tree concerns the difficulty of handling the gradual deterioration of components of the repository, leading to a gradual loss of a function.

Also, the method is sensitive to the highly uncertain, partly subjective relative probabilities for different failures that also influence the ranking of failure modes and, hence, the subsequent selection of scenarios.

In all safety assessments, the construction of scenarios and their selection for further treatment, e.g., by means of numerical consequence calculations, strongly depends on subjective decisions and choices. These need to be recorded in a traceable manner to promote quality assurance. This allows both revisiting them at later stages of the Safety Case development and presenting them in a transparent way to various audiences. In the AQS, this inevitable subjective factor is introduced via the decisions made during the construction of the function tree as well as in the derivation of failure probabilities using the APSS. The subsequent automatic processing of the failure tree by means of which the scenarios are derived and ranked for further treatment implies a danger to hide the subjective character of the underlying decisions. *Thus, it would be useful to derive a mechanism for the identification of the major factors that contributed to the construction and choice of scenarios in order to trace them back to their origins.* The suggestion made earlier concerning the recording of decision processes in the APSS data sheets would support such a development. The FMEA charts are a good starting point for this.

In conclusion, the IRT notes that the AQS is a systematic and rather complex method for the derivation of scenarios in a safety assessment. Like other internationally available methods, it necessarily depends on subjective judgements. *If it is to be applied in future assessments, it is recommended that*

Andra develop procedures for making the subjective elements more transparent and traceable, and to address the issue of taking the temporal evolution of the system into account.

3.7.4 The management of different timescales

The IRT notes that the methodology presented by Andra in the Dossier 2001 Argile has the potential of managing the different time scales relevant to deep geological disposal in accordance with the French Basic Safety Rule RFS III.2.f [18].

3.7.5 The management of uncertainties

The Dossier 2001 Argile recognises the different kinds of uncertainty that must be taken into account in developing a safety assessment for a repository in a deep geological formation. In view of the stage reached by the programme, Andra did not feel it was appropriate to explore each kind of uncertainty in detail, but this is explained clearly and the reasons given are justified in the view of the IRT. In particular, the "normal evolution" of the geosphere in the long term was not propagated from its description in the phenomenological analysis to the safety assessment, and just one "altered evolution scenario" was evaluated. Nevertheless, the IRT believes there is a sound methodology in place to address uncertainties about the future evolution of the repository system. In order to allow an assessment of the feasibility of deep geological disposal in argillaceous formations, this methodology must be comprehensively applied in the relevant safety assessment in the future.

Uncertainties related to a lack of knowledge and/or data, and to representation of the system, are identified in the relevant documents dealing with these subjects, but more systematically in some cases than in others. Knowledge reference documents contain this information but not in a readily identified, specific part of the document, whereas a highly systematic approach has been adapted in the phenomenological analysis. There, the uncertainties connected with each phenomenon within a situation are listed in a dedicated section of the report and the means of addressing the uncertainties are itemised (e.g., design measures, targeted research, etc.).

The IRT was impressed by the quest for a consistent management of uncertainties. The approach has been designed to ensure that the acquisition of further knowledge would support the selection of different models and parameter values in the future such that the evaluated system performance

would improve in consequence. For example, a pessimistic model of the leaching of vitrified waste is currently adopted because there is currently insufficient confidence to adopt an alternative, more favourable model for the leaching process.

In the review, the methodology documented for the selection of cautious but reasonable parameter values was examined thoroughly. When there were sufficient data, the method was applied as would be expected, but for many important parameters a decision had been taken that, in view of the prevailing uncertainty, a pessimistic value would be adopted. This is not inconsistent with the procedure laid down for the selection of cautious but reasonable parameters but led the IRT to conclude that the process has limitations for use in the safety assessment. Nevertheless, the existence of such a process would have benefits in imposing a discipline on the transfer of scientific data into the assessment. *During the review, it was clear that Andra recognises the limitations of this approach to parameter selection and has in hand a suitable evaluation of methods that would improve the situation in the future. That evaluation should be of value in its own right and would ideally be presented for discussion with Andra's international counterparts.*

The IRT was particularly impressed at the management of uncertainty in the design process. At the current stage of the programme, design choices are being made in order to be robust against prevailing uncertainties. For example, the design concepts for the disposal cells for heat-generating waste are intended to ensure that temperatures of various components of the system remain below certain thresholds. These thresholds are set as upper bounds of temperature at which there is confidence in the behaviour of the component under the relevant conditions. Such an approach should lead to robust design concepts for evaluation in 2005. Andra confirmed the IRT's view that this does not correspond to optimisation of design. Optimisation would be expected to be carried out at a later stage of an ongoing development programme.

3.7.6 Sensitivity analyses

At this specific state of the French programme, the Safety Assessment naturally has to deal with diverse variables and uncertainties. Amongst others, these are variables amenable to decisions to be made either by the waste producers or by Andra such as fuel-cycle scenarios to consider, waste packages to be chosen for the different waste types, and repository design options for each package type. In addition, the Dossier 2001 Argile had to deal with uncertainties concerning the assessment calculations related to scenarios, models, and parameters. Several of these variables and uncertainties, namely

those concerning waste packages, design options, and parameter choices, have been tackled by means of variant calculations. Others like the question of fuel-cycle scenarios were covered using conservative assumptions.

The deterministic sensitivity analyses were, by intention, not exhaustive but sufficient for the present state of knowledge and appropriate in that they inform Andra with regard to further research and development by identifying major sources of uncertainties. In particular, they have highlighted major factors requiring attention in the development of the concept, such as the potential role of the excavation disturbed zone and the associated need for control, or the required performance of sealing arrangements.

The approach also informs about the role of several waste packages with regard to potential long-term consequences.

However, the use of simplified models and mostly conservative parameters does not provide Andra with valuable information concerning the choice of design options by this particular method (although other methods have been used effectively to inform design studies, as noted in 3.2). The models are rather insensitive to design alterations.

It is difficult to track the several calculation variants in the Dossier 2001 Argile. They could have been presented in a more systematic and informative way.

4. CONCLUSIONS

The IRT has been able to present its findings in response to each of the points identified in the Terms of Reference.

4.1 Presentation of the documentation

The IRT had considerable comments on the presentation of the Dossier 2001 Argile and recommendations on how this can be improved in the future. A clear presentation is needed of how the various components fit together. Not all the information that is relevant is documented, or easy to find. In the Dossier 2001 Argile, the information presented is highly variable in quality and completeness, but this can be explained by the current stage of the overall programme. The documentation did not always reflect the excellent and extensive work that the IRT found had been performed, for example in the area of hydrogeological modelling. The IRT notes that this may prompt criticism of the contents of the Dossier 2001 Argile which would not be justified in respect of the technical work performed. The objectives of Parts A and B of the Dossier Synthesis Report to communicate to a rather broad and general audience and to a technical audience, respectively, were not met successfully. Part A is still overly technical and does not establish key achievements. Part B does not satisfy the technical expert who would wish to gain an overall view of the scientific and analytical content of the Dossier 2001 Argile, and should be supported by more extensive references to underlying documents to allow the arguments to be traced. *More illustrations are needed to support and clarify the written text in both Parts A and B, and these should be at an appropriate level for the audience – dealing with concepts rather than technical detail in Part A in particular. It is recommended that Andra uses modern research on the visual presentation of information for improvements in this area.*

The documents underpinning the Synthesis Report are recommended to be more complete in terms of not being reliant upon context and information documented elsewhere, and again there should be more extensive referencing to underlying information. The IRT recommends that the Dossier 2005 documents should be written to fit a pre-designed hierarchical structure.

4.2 Consistency and adequacy of applied methodologies

The IRT concludes firmly that all key methodological elements required for a safety assessment are presented in the Dossier 2001 Argile. Some newly developed methods, the APSS (Analyse Phénoménologique des Situations de Stockage) and AQS (Analyse Qualitative de Sûreté), have good potential but need further development. The application of the APSS method requires development regarding, e.g., documentation and transparency. There are also needs for methodological improvements regarding, for example, flexibility in the fixation of time frames and coupling to other parts of the safety assessment. Regarding the AQS methodology, Andra is recommended to develop procedures for making the subjective elements more transparent and traceable, and to address the issue of taking the temporal evolution of the system into account. The consistency between method descriptions and applications is not always evident. For example, the procedure for selection of cautious but reasonable parameters was not easy to trace in many examples. Detailed questioning revealed that there was consistency, but it was not clearly documented.

In the application of methods, the IRT found that the consistency between the elements of the safety analysis was generally adequate, but recommends that the propagation of uncertainties needs improvement. This would be partly met by an analysis of a more comprehensive set of scenarios, but it must also be demonstrated how data uncertainties and, in particular, uncertainties affecting the fixation of time frames in the APSS will be managed and propagated to other parts of the assessment methodology. The methods developed allow identification of key sensitive components of the repository at the present stage; they will need development for future assessments. *A more strict and comprehensive implementation of a carefully selected methodology for sensitivity analyses would be in line with what other organisations are currently developing or implementing.*

4.3 Internal consistency between the knowledge base and the hypotheses

The IRT believes it is very important to note that a cautious approach has been adopted. Considerable basic scientific knowledge is available to Andra that was not used in the Dossier 2001 Argile, but can be applied in future analysis as appropriate. Phenomenological descriptions were clearly traceable to existing scientific and technical knowledge, but a finding on the APSS methodology is that in the future there will be a need to demonstrate that comprehensive account has been taken of this knowledge. Selected values for parameters used in safety evaluation are found to be consistent with scientific

and technical knowledge, although often this is in the sense of sound identification of a pessimistic value. The use of scientific and technical knowledge in the development of conceptual models is often impressive, for example in the groundwater flow and radionuclide transport model or in certain radionuclide release models, although this was only fully appreciated following presentations by Andra staff on the flow and transport model.

The IRT examined specific topics in the Dossier 2001 Argile in particular detail, in line with the Terms of Reference, viz: lifetime of metallic materials; waste package source terms; the description of the Callovo-Oxfordian formation and its surroundings; reversibility; and safety assessment methodology. The overall scientific basis, modelling capabilities, and safety approach were found to be in line with international best practice and equivalent work in other national programmes. In some areas, the Dossier 2001 Argile revealed work at the international forefront, including:

- systematic consideration of all waste types as source terms (e.g., bituminised B-waste or hulls/ends);
- multibarrier design approach for B-wastes;
- use of archaeological/industrial analogies to support material choices; and
- assessment of geological stability.

In some other areas, Andra's approaches are innovative, in particular the phenomenological description and associated APSS methodology, consideration of the operational phase (in relation to reversibility), and modularity of repository design.

The IRT paid particular attention to the scientific basis for the Dossier 2001 Argile. It found Andra's links with public research institutes to be very apparent. It commends the policy of supporting post-graduate and post-doctoral research and appreciates the value of long-term contractual relationships with over 100 laboratories through partnership agreements and promotion of research groups or laboratory networks.

The IRT was particularly impressed by the information presented in the document, "Scientific Programme: HLLW Clay Repository Project, 2002-2005", and agrees with the priorities identified to lead to a firmer picture on key aspects of waste disposal in clay by 2005. The only major omission is the impact of gas evolution from the wastes and specific recommendations are made as to how this should be addressed as soon as possible. *The IRT believes*

that the project has already established a strong numerical modelling capability to meet its needs and urges that careful consideration be given to balance any further development against the availability of the required knowledge and data.

4.4 Pertinence of conclusions

The IRT was required to comment on the pertinence of the conclusions drawn in the Dossier 2001 Argile and used the key conclusions in Part A of the Synthesis, listed below, as a framework.

1. A solid research and development base exists in all areas and the quality is high.

   This is clearly the case in a great many cases, although it is not always clear in the documentation available. The only significant research and development omission is on gas issues.

2. Both the design factors and realistic preliminary design approaches have been identified.

   Safety-relevant design factors are clearly identified and the proposed design options appear reasonable. The modular design approach has the potential to produce designs that are robust against current uncertainties.

3. The Dossier 2001 Argile provides a test of the safety analysis methodology.

   The APSS provides an innovative method for achieving a desirable systematic formalism as a basis for the safety analysis. It successfully integrates science and safety assessment and it provides a valuable platform for communication with the scientific community. In principle, it ensures exhaustive traceable analysis, but further development of some of its procedures is required for this to be realised.

4. The safety analysis reveals no factors ruling out a repository.

   The information provided in the Dossier 2001 Argile is consistent with this conclusion but, as Andra recognises, this is not a comprehensive analysis at this stage. The Dossier 2001 Argile provides a suitable methodological basis for a fuller evaluation in 2005.

5. Future research and development needs are clarified.

   The documented Scientific Programme for 2002-2005 is well-informed by the Dossier 2001 Argile. All significant research requirements identified in the Dossier 2001 Argile are addressed by proposed work programmes that have the potential to deliver the required information by 2005.

6. The report communicates a platform for the future.

   The current status of the project and the important issues to be addressed are identified, although they could be communicated more effectively in the Dossier 2001 Argile. The totality of information and the methodologies developed provide Andra with a sound platform to support their forward programme, and in particular to progress to a deeper and more comprehensive analysis in 2005.

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Annex 1

MEMBERS OF THE INTERNATIONAL REVIEW TEAM

Alan Hooper

Alan Hooper is Chief Scientific Advisor at United Kingdom Nirex Limited, the UK organisation responsible for developing safe and publicly acceptable concepts for the long-term management of radioactive materials. He is responsible for advising on the overall science and engineering programme of Nirex and its key deliverables, and on communicating the programme to scientific institutions.

Alan Hooper was awarded a first class honours degree in chemistry from Nottingham University in 1968 and a Ph.D. for research into complex oxide systems by the same University in 1971. He worked in the Research Division of the Central Electricity Generating Board for seventeen years, initially studying the safety of operation and maintenance of advanced power reactor systems. In 1980, he joined the Nuclear Decommissioning Project and was responsible for research into the safety implications of decommissioning strategies for the UK's first generation of gas-cooled Magnox reactors. From 1985 he was responsible for the specification and implementation of the research programme to support the retrieval and conditioning of the CEGB's intermediate-level wastes for eventual geological disposal.

Since joining Nirex in 1988, Alan Hooper has held a number of senior management positions. He was responsible for the research and assessment programme for a number of years, and, for some time, for the specification and implementation of the site characterisation studies at Dounreay and Sellafield. He gave extensive evidence to the public inquiry into the siting of an underground "rock characterisation facility" at Sellafield and has also given evidence to various parliamentary select committees. He is the named inventor of the specially formulated backfill material proposed for use in the Nirex Phased Disposal Concept for intermediate-level wastes.

Alan Hooper is currently a member of the UK delegation to the NEA Radioactive Waste Management Committee and its Integration Group for the Safety Case. Previously he was Chairman of the NEA' Site Evaluation and Design of Experiments Co-ordinating Group for seven years, playing an active role in promoting initiatives such as The Clay Club, GEOTRAP Project, and workshops on specialist topics such as conceptual modelling. He has also chaired various technical specialist groups for the IAEA working on the scientific and technical basis for radioactive waste management and the associated safety requirements. He currently serves on the Programme Development Board for the Environmental Protection Programme of the British Geological Survey.

Richard Beauheim

Richard Beauheim is a Principal Member of Technical Staff at Sandia National Laboratories, and is currently Lead Hydrologist for the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, USA. From 1984 to 1996, he was the Principal Investigator for the hydrogeological characterisation of the WIPP site. During preparation of the WIPP license application, he was responsible for integration and consistency of field information and performance assessment models. After the licensing of WIPP in 1998, he was responsible for the hydrology components of the WIPP monitoring system. He is now coordinating and directing hydrogeologic field studies and performance assessment activities related to the recertification of WIPP.

Mr. Beauheim received his B.A. in anthropology from the University of Wisconsin-Madison (USA) in 1974. In 1980, he received M.S. degrees in geology and water resources management from the same university. Prior to joining Sandia in 1984, he spent four years as a hydrogeological consultant to the mining and nuclear-waste industries. During this time, he was a member of the U.S. Office of Nuclear Waste Isolation review team evaluating seven candidate salt sites for high-level radioactive waste repositories. Mr. Beauheim is the author of 20 journal and conference papers and over 30 technical reports. His particular technical expertise is in the areas of performance and interpretation of hydraulic and tracer tests and site characterisation.

In 2000-2001, Mr. Beauheim took a one-year leave of absence from Sandia to serve in the Radiation Protection and Waste Management Division of the NEA in Issy-les-Moulineaux, where he oversaw the completion of the GEOTRAP project and prepared a number of reports and documents. On behalf of Sandia and the WIPP project, he was actively involved in the INTRAVAL and GEOTRAP projects, and is currently on the Steering Groups of the recently

initiated NEA International Projects on Engineered Barrier Systems (EBS) and Approaches and Methods for Integrating Geologic Information in the Safety Case (AMIGO).

Allan Hedin

Allan Hedin is a senior company specialist on safety assessments at the Swedish Nuclear Fuel and Waste Management Company (SKB). His responsibilities include the management of SKB's safety assessment projects for deep repositories for high-level waste.

Allan Hedin received a M.S. in Engineering Physics from the University of Uppsala in 1983 and a Ph.D. in Ion Physics from the same university in 1987. His thesis concerned theoretical and experimental work on interactions between fast heavy ions and solids with applications in mass spectrometric techniques. After four years of further academic research in the fields of laser-induced desorption and scanning tunnelling microscopy, he was employed by the Swedish National Chemicals Inspectorate in 1991 to work with risk assessments of chemical substances and products.

Allan Hedin has been working with SKB since 1994. He was originally employed to work with probabilistic radionuclide transport calculations and has gradually obtained more general responsibilities for safety assessment methodology issues. He has a particular interest in developing simplified mathematical models that capture the essential properties of more complex representations in the field of safety assessment. He was a senior author, editor and assistant project manager for SKB's latest safety assessment SR 97 and is now the manager for the safety assessments to be carried out during SKB's site investigation phase.

Allan Hedin was a member of NEA's former Performance Assessment Advisory Group (PAAG) and is currently a member of the Integration Group for the Safety Case (IGSC). He has taken active part in several international projects organised within PAAG and IGSC.

Lawrence Johnson

Lawrence Johnson is a senior scientist at Nagra (the Swiss National Cooperative for the Disposal of Radioactive Waste), where he has worked since 1999 on various aspects of engineered barriers performance, including waste

form behaviour, canister design, and development of models for near-field performance assessment.

Lawrence Johnson received his B.Sc. in Chemistry from the University of Lethbridge in 1977 and joined AECL at Whiteshell Laboratories in 1978. After several years studying the dissolution of spent fuel and vitrified high-level waste, he became manager of engineered barrier studies in the Canadian Nuclear Fuel Waste Management Program, leading the group responsible for research and development for engineered barriers for disposal of nuclear fuel, including engineering studies, as well as the development of a source-term model for spent fuel, corrosion models for nuclear fuel waste containers, transport models for clay-based buffer and backfill barriers, and integration of near-field models. In addition, he managed the studies of durability of spent fuel in interim wet and dry storage. He is senior author of two comprehensive performance assessment studies of engineered barriers, one detailing borehole emplacement of spent fuel in Ti containers and the other on in-room emplacement of Cu containers. The two studies played a central role in the federal review of AECL's Environmental Impact Statement under the Environmental Assessment and Review Process conducted from 1994-1997. He is the author of over 80 reports and journal papers on spent fuel dissolution, spent fuel storage and near-field performance assessment.

In 1997, he was a member of the NEA International Review Group for the SKI SITE-94 performance assessment study, and during 1997-98 was a member of the USDOE Expert Panel on Waste Form Dissolution and Radionuclide Mobilization.

Philippe Lalieux

Philippe Lalieux is a geologist and geophysicist with 15 years' professional experience in the field of radioactive waste disposal. He graduated from the University of Brussels (Belgium) in 1983 with a B.Sc. in Geological Sciences and obtained a Masters Degree (M.Sc.) in Geophysical Sciences from the same university in 1984. From 1986 to 1994 he was staff member of the Belgian Agency for the Radioactive Waste and Enriched Fissile Material (ONDRAF/NIRAS). His responsibilities included the co-ordination and defense of the Safety Assessment and Feasibility Interim report (SAFIR) as well as the supervision of geoscientific characterisation of potential sites for deep and near-surface disposal, and natural analogue studies.

He joined the OECD Nuclear Energy Agency Secretariat in 1995. He has been in charge, within the Radiation Protection and Waste Management

Division, of the Agency's programmes on deep disposal site characterisation and evaluation. In particular he was responsible for the Scientific Secretariat of the Co-ordinating Group on Site Evaluation and Design of Experiments for Radioactive Waste Disposal (SEDE), the GEOTRAP Project on radionuclide transport in the geosphere, and the Clay Club. He was a member of the joint NEA/IAEA international peer review of the 1996 Performance Assessment of the US Waste Isolation Pilot Plant (WIPP) and of the NEA international peer review of the SKI SITE-94 Project (Sweden).

In 2000, he went back to ONDRAF/NIRAS to ensure the coordination and the defense of the second Safety and Feasibility Interim Report (SAFIR 2), which was presented to the authorities in 2001. He is now in charge of the coordination of the Belgian deep disposal programme for HLW and MLW in poorly indurated clays.

He also chairs the NEA Working Group on the Characterisation, Understanding, and Performance of Argillaceous Rocks as Repository Host Formations (usually known as the "Clay Club").

Albert Machiels

Albert Machiels is a Senior Technical Manager at the Electric Power Research Institute (EPRI), where he is responsible for several R&D programmes related to the back-end of the fuel cycle, materials corrosion, and risk- and reliability-based applications. Present activities are focused on developing a better understanding of environmentally assisted corrosion (including stress corrosion cracking and irradiation-assisted stress corrosion cracking) and other materials degradation phenomena for applications to spent fuel storage, transportation and disposal, and to PWR and BWR environments.

Albert Machiels holds Ingénieur Civil Chimiste and Ingénieur en Génie Nucléaire degrees from the University of Liège, Belgium; and a M.S. and a Ph.D. in Engineering from the University of California, Berkeley.

Before joining EPRI, he was an Associate Professor at the University of Illinois, Urbana-Champaign. Prior to moving to the U.S.A., he spent four years at the University of Liège (Belgium), including one year at the EUROCHEMIC Reprocessing Plant, teaching and working on issues related to spent-fuel reprocessing.

Albert Machiels previously served as a member/reviewer in several Panels on the "Scientific Needs of the Technology of Nuclear Waste

Containment", "Glass Leaching", and "Engineered-Related Issues in the U.S. Nuclear Waste Repository Program". He also served as co-chairman for the Third International Symposium on "Ceramics in Nuclear Waste Management", American Ceramic Society, Chicago (1986) and as the U.S. Technical Chairman for the International Topical Meeting on "LWR Fuel Performance", American and European Nuclear Societies, France (1991).

Klaus-Jürgen Röhlig

Klaus-Jürgen Röhlig graduated as a mathematician in 1985 at the Mining Academy (Bergakademie) in Freiberg, Saxony. In 1989, he received his Ph.D. degree (Dr. rer. nat.) in the field of mathematical bifurcation theory and its application to fluid flow problems from the Mining Academy.

From 1989 to 1991, Klaus-Jürgen Röhlig was employed by the Institut für Energetik (IfE), Leipzig, Saxony. He developed and applied computer codes for the numerical simulation of fluid flow and contaminant transport. During this time, he became increasingly involved in environmental questions and, amongst others, in the field of radioactive waste management.

In 1991, Klaus-Jürgen Röhlig joined the Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH in Cologne (Köln), initially working on hydrogeological modelling and on numerical simulation of fluid flow and contaminant migration in the near field and the far field of final repositories for radioactive waste. During the following years, the scope of his work broadened towards other fields linked to the post-closure Safety Case for radioactive waste repositories such as the methodology of Safety Cases and Safety Assessments, scenario development, quality assurance for computer codes used in assessments, and probabilistic methods. He is especially interested in the utilisation of geostatistical methods for probabilistic Safety Assessments. Being the project manager for the technical advice to the German regulator BMU (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety) in the field of post-closure Safety Cases, he is involved in the development of safety criteria and regulatory guidelines for radioactive waste disposal.

Klaus-Jürgen Röhlig worked in NEA's Performance Assessment Advisory Group (PAAG) and is now a member of the Integration Group for the Safety Case of Radioactive Waste Repositories (IGSC). He was and is involved in several activities of these groups such as PSAG, IPAG, and GEOTRAP. He chairs the Steering Group of the recently initiated OECD/NEA International Project on "Approaches and Methods for Integrating Geologic Information in

the Safety Case" (AMIGO). In 2000, he served as a consultant at NEA's headquarters in Issy-les-Moulineaux.

Claudio Pescatore

Claudio Pescatore holds a Ph.D. in nuclear engineering from the University of Illinois, Urbana-Champaign (USA). He has over 20 years' experience in the field of nuclear waste covering low-level waste, high-level waste, and spent-fuel storage and disposal.

Claudio Pescatore joined the Brookhaven National Laboratory in 1982 and was involved in the study of high-level waste and spent-fuel disposal concepts in basalt, salt, and tuff formations. His work covered reliability and modelling studies of waste package materials during storage and disposal, analyses of gaseous and aqueous pathways for radionuclide migration, and peer reviews of environmental impact assessment studies and site characterisation plans. At Brookhaven, he was group leader for Radioactive Waste Performance Assessment. Until 1995, he was also adjunct Professor of Marine Environmental Sciences at the University of New York, Stony Brook.

Claudio Pescatore joined the OECD/NEA in 1992 in the Division of Radioactive Waste Management and Radiation Protection, where he is the Deputy Head for Radioactive Waste Management. He has been at the centre of several recent international initiatives such as the ASARR and GEOTRAP projects, and the IPAG studies, and co-author of several NEA reports on the status of and issues in radioactive waste management worldwide. He is a co-author of the NEA Confidence Document. He serves as the technical secretariat of several NEA committees: the Radioactive Waste Management Committee (RWMC), the RWMC Regulators' Forum, the Working Party on Decommissioning and Dismantling, and the Forum on Stakeholder Confidence. On behalf of the NEA, he has organised numerous international peer reviews of national safety studies. These include: SKI's Project-90 (Sweden), AECL's Environmental Impact Statement of the Disposal of Canada's Nuclear Fuel Waste, the 1996 Performance Assessment of the US Waste Isolation Pilot Plant (WIPP), SKI's SITE-94 project (Sweden), the Nirex methodology for scenario and conceptual model development (UK), the JNC's H-12 Project to establish the technical basis of HLW disposal in Japan, the SR 97 study by SKB (the Swedish spent fuel and waste management company), and the SAFIR 2 report produced by the Belgian Agency for Radioactive Waste and Fissile Materials (ONDRAF/NIRAS).

Annex 2

DOCUMENTS REVIEWED

The main documents reviewed were:

1. Dossier 2001 Argile, Synthesis Report, Part A – a 157-page overview report, available in French and English.

2. Dossier 2001 Argile, Synthesis Report, Part B, Supporting Scientific and Technical Data – a 332-page overview report providing more detail than Part A, available in French and English.

3. Materials Baseline, Volume 4, Corrosion of Metallic Materials (C.RP.AMAT.01.060, 219 p.).

4. Geological Reference Document of the Meuse/Haute-Marne Site, Volume 5, State of Progress in Modelling (A RP ADS 99-005, 67 p.).

5. High-level, Long-lived Waste Repository Project, Normal evolution scenario in post-closure phase, Definition (SUR NT ADSU 00-041, 70 p. plus appendices).

6. High-level, Long-lived Waste Repository Project, Normal evolution scenario in post-closure phase, Justification and traceability of hypotheses considered (SUR NT ADSU 01-014, 43 p.).

7. High-level, Long-lived Waste Repository Project, Scenario for seal failure and/or transfer through the damaged zone around seals and engineered barrier plugs, Definition (SUR NT ADSU 00-038/B, 67 p.).

8. High-level, Long-lived Waste Disposal in Clay Project, Qualitative Safety Analysis Methodologies for Repository Operating and Post-Closure Phases (1st safety verification) (C NT ADSU 01-106, 31 p.).

9. High-level, Long-life Waste Repository Project – Clay, Analysing Levels of Reversibility in Preliminary Concepts (C RP A HVL 01-078, 84 p.).

10 Phenomenological Analysis of Repository Situations (APSS), Objective and methodology (C DO AHVL 00-138, 17 p.).

11. Safety Approach devised for the feasibility study of the high-level long-lived waste repository project (SUR NT ADSU 99-052/B, 35 p.).

12. 2001 Safety Calculations, Waste Packages Source Term Proposals (Status as of 31/12/2000) (C.NT.AMAT.99.069, 78 p.).

Supporting documents in English reviewed included:

13. HAVL Project, Preliminary concepts, Comparison of RFS.III.2.f and the Andra approach, Packages, engineered barriers and seals (SUR.NT.ADG.01.190, 15 p.).

14. Scientific Programme, HLLW Clay Repository Project, 2002-2005 (C PE ADS 02-039, 131 p.).

15. Procedure: Choice of Cautious but Reasonable Data for Processing Safety Scenarios (QUA MO ADSU 01-4223, 7 p.).

16. Analysis and management of uncertainties within the context of research into repositories in deep geological formations (14-p. note).

17. Research in Radioactive Waste Management, Law of December 30, 1991 (Andra reprint of French Law n^{o} 91-1381 of December 30, 1991).

18. Ministère de l'Industrie et du Commerce Extérieur. Basic Safety Rule, Rule N^{o} III.2.f, Disposal of Radioactive Waste in Deep Geological Formations.

19. Ministry of Research, Technology Division. Research Strategy and Programmes on the Management of Long-Lived High-Level Radioactive Waste, 2002-2006, Status Report & Executive Summary, 2002 Edition.

Supporting documents in French reviewed included:

20. Référentiel Géologique du Site de Meuse/Haute-Marne, Tome 4, Le Callovo-Oxfordien (A RP ADS 99-005, 154 p.).

21. Analyse Phénoménologique des Situations de Stockage (APSS), Arborescence matérielle (C SH AHVL 99-106, 7 p.).

22. Analyse Phénoménologique des Situations de Stockage (APSS), Processus de stockage: hypothèse de travail (C NT ASTE 00-0805).

23. Analyse Phénoménologique des Situations de Stockage (APSS), Définition des situations (C NT AHVL 99-038).

24. Analyse Phénoménologique des Situations de Stockage (APSS), Chronogramme "Période d'Exploitation d'un Stockage" (C PN AHVL 00-0139).

25. Analyse Phénoménologique des Situations de Stockage (APSS), Fiches de situation (C DO AHVL 01-001).

26. Analyse Phénoménologique des Situations de Stockage (APSS), Fiche de situation 14, État naturel du Callovo-oxfordien dans contexte géodynamique initial (0-100 000 ans) (C NT AHVL 00-070).

27. Analyse Phénoménologique des Situations de Stockage (APSS), Fiche de situation 68, Module et alvéoles de stockage de combustibles usés UOX pendant la phase thermique (100-5 000 ans) (C NT AHVL 00-114).

28. Analyse Phénoménologique des Situations de Stockage (APSS), Fiche de situation 77, Module et alvéoles de stockage de combustibles usés UOX pendant la phase de resaturation des modules (5 000-10 000 ans) (C NT AHVL 00-115).

29. Analyse Phénoménologique des Situations de Stockage (APSS), Fiche de situation 81, Evolution après 100 000 ans des formations géologiques (C NT AHVL 00-135).

Andra also made other supporting documents available in French as requested by the IRT. The review also drew on information given in answers to questions from the IRT, and the extensive discussions with Andra staff (see Section 1.4).

Annex 3

DEFINITIONS OF ACRONYMS

French abbreviation	French	English	English abbreviation
AEN	Agence pour l'énergie nucléaire	Nuclear Energy Agency	NEA
AFI	Analyse fonctionnelle interne	Internal Functional Analysis	IFA
AMDE	Analyse de défaillance et de leurs effets	Failure Mode and Effects Analysis	FMEA
Andra	Agence nationale pour la gestion des déchets radioactifs	National Agency for Radioactive Waste Management	
APSS	Analyse phénoménologique des situations de stockage	Phenomenological Analysis of Repository Situations	PARS
AQS	Analyse qualitative de sûreté	Qualitative Safety Assessment	
ASN	Autorité de sûreté nucléaire	Nuclear Safety Authority	
CEA	Commissariat à l'énergie atomique	Atomic Energy Commission	
CNE	Commission nationale d'évaluation	National Review Board	

GPD	Groupe permanent déchets auprès de l'autorité de sûreté nucléaire		
HAVL	[Déchets à] haute activité et à vie longue	High-level long-lived [wastes]	LL-HLW (or HLLLW, as in some translations)
RFS III.2.f	Règle fondamentale de sûreté iii.2.f	Basic Safety Rule III.2.f	
THMCR	[Phénomènes] thermiques, hydrauliques, mécaniques, chimiques et radiologiques	Thermal, Hydraulic, Mechanical, Chemical, and Radiological [phenomena]	THMCR
		Features, Events, and Processes	FEPs
		International Review Team	IRT
		Research and Development	R&D
		Terms of Reference	ToR
		Underground Research Laboratory	URL

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