AEN
NEA

OECD NUCLEAR
ENERGY AGENCY

INTERNATIONAL ATOMIC
ENERGY AGENCY

International Peer Review of the 1996 Performance Assessment of the US Waste Isolation Pilot Plant (WIPP)

April 1997

Report of the NEA/IAEA
International Review Group

AEN
NEA

OECD NUCLEAR ENERGY AGENCY

INTERNATIONAL ATOMIC ENERGY AGENCY

OECD/NEA - IAEA JOINT INTERNATIONAL REVIEW OF WASTE ISOLATION PILOT PLANT 1996 PERFORMANCE ASSESSMENT

NEA/IAEA Joint Secretariat:
c/o OECD/NEA, Le Seine Saint-Germain
12, Boulevard des Îles
F-92130 Issy-les-Moulineaux
Tel: +33 (1) 45 24 10 48 - Fax: +33 (1) 45 24 11 10
(Replies: For the attention of C. Pescatore)

Mr. G. Dials
Manager, Department of Energy
Carlsbad Area Office
P.O. Box 3090
Carlsbad, New Mexico 88221
United States of America

Ref. EN/S/5242

Issy-les-Moulineaux, 9 April 1997

Dear Mr. Dials,

Please find enclosed the final report of the international peer review of the 1996 Performance Assessment of the Waste Isolation Pilot Plant (WIPP) as documented in "Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant" (CCA). This technical review was commissioned by the Carlsbad Area Office of the United States Department of Energy (DOE) and jointly organised by the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development and the International Atomic Energy Agency as part of their routine services to their member Countries.

The review report is based on the best understanding obtained after several months of deep involvement of the Joint Secretariat and the experts of the International Review Group (IRG) which were especially set up and appointed for this purpose. It represents the combined views of the members of the IRG and is directed to the DOE and thus drafted for a technical audience familiar with contents of the CCA. It contains information which was considered useful and worth bringing to the attention of DOE. This cover letter highlights the main findings of the review in order to place them in a broad perspective, but it does not substitute for a thorough reading and interpretation of the actual report.

The primary focus of the review was on the technical soundness of the analyses and of the DOE approach to post-closure performance assessment, examined from an international perspective. The review report does not formally cover compliance aspects with the national regulations.

Not all parts of the CCA documentation were reviewed at the same level of detail, and specific points were looked at in greater depth according to the technical background, experience and judgement of each member of the IRG. The IRG also took into account additional information provided by the DOE in the course of the review, as well as their knowledge of the WIPP studies gained from previous international contacts. To preserve independence, the IRG did not examine reviews of the WIPP by other groups.

The IRG concluded that the performance assessment methodology is well-founded and has confidence in the majority of judgements and assumptions made in developing the calculational models. The quality of assessment codes and data handling is also generally good. Thus, the analyses reported in the CCA are, in the main, technically sound. The nature of the critical review has tended to identify and emphasise areas where improvements could be made, however, and comments and suggestions are also proposed for consideration by the DOE in future iterations of their assessments of the WIPP, e.g. during the re-certification phase of the facility. These should be considered within the context of the overall positive view of the IRG on the technical soundness and quality of the WIPP performance assessment as documented in the CCA. In particular, two areas are considered as deserving further attention by the DOE: (a) the implications, favourable and unfavourable, of the magnesium oxide backfill, and (b) the assumption of rapidly-reached, homogeneous conditions within the disposal rooms.

From the experience of the review, the IRG believes that, in the case of undisturbed performance, the WIPP facility would meet individual radiation dose standards typical of those used in other countries, even beyond the 10,000 years regulatory period. A judgement could not be reached for the case of disturbed performance, although supplementary analyses by the DOE indicated that a risk target, as internationally accepted, would be met in respect of a direct drilling scenario of the type specified in the regulations.

You will note that the review makes an overall judgement of the 1996 Performance Assessment of the Waste Isolation Pilot Plant rather than emphasizing views on specific aspects, and the report needs to be considered in its entirety. We trust that if the report is read from that perspective, it will prove valuable to the DOE.

On behalf of the IRG and the Joint Secretariat, we would like to take this occasion to thank you and your colleagues for your openness and assistance in the course of the review.

Yours sincerely,

Claudio Pescatore

Dr. Claudio Pescatore
On behalf of the IRG Chairman
and the Joint NEA/IAEA Secretariat

International Peer Review of the 1996 Performance Assessment of the U.S. Waste Isolation Pilot Plant (WIPP)

Report of the NEA/IAEA International Review Group

Preface

In January 1996, the United States Department of Energy (DOE) requested the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (NEA) and the International Atomic Energy Agency (IAEA) to jointly organise an international peer review of the 1996 post-closure performance assessment of the Waste Isolation Pilot Plant (WIPP). This assessment is described in the DOE document "Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant", issued in October 1996 and referred to as the CCA.

The NEA and the IAEA accepted the invitation and, in June 1996, Terms of Reference for the review were agreed between the DOE, the NEA and the IAEA .

The review was carried out, in the period October 1996 to March 1997, by a team of experts invited by the NEA and the IAEA, referred to as the International Review Group (IRG). The review included an examination of the relevant parts of the CCA, a visit to the WIPP site, and focused discussions between the IRG and DOE staff and contractors.

This report presents the combined, personal views of the members of the IRG, and offers the DOE an independent, international perspective on the 1996 performance assessment of the WIPP. The protocol for the review does not foresee further exchange between the DOE and the IRG and therefore the report is final.

This report has not been checked by the DOE. The IRG has made its best effort to ensure that all information in this report is accurate and takes responsibility for any factual inaccuracies.

International Peer Review of the 1996 Performance Assessment of the U.S. Waste Isolation Pilot Plant (WIPP)

Report of the NEA/IAEA International Review Group

Contents

Preface i
Contents ii
List of abbreviations iv

1. Introduction 1

1.1 Background to the Review 1

1.2 The International Review Group 2

1.3 The Review Process 2
1.3.1 Objective 2
1.3.2 Scope 3
1.3.3 Conduct of the review 3

1.4 Structure of the Report 4

2. The EPA Regulations and their Influence on the CCA 6

2.1 The EPA Regulations 6

2.2 The Influence of the EPA Regulations 7
2.2.1 Undisturbed and disturbed performance 7
2.2.2 The 10,000-year regulatory period 8
2.2.3 The containment requirement 8
2.2.4 Treatment of human actions 9
2.2.5 Results of performance assessment and treatment of uncertainty 10
2.2.6 Institutional controls 11
2.2.7 Terminology 12

2.3 Discussion 13
2.3.1 Overall implications for the CCA 13
2.3.2 Implications for the review 13

3. The 1996 Performance Assessment of the WIPP 14

3.1 The Compilation of Data 14
3.1.1 Site geology and hydrogeology 14
3.1.2 Natural resources 15
3.1.3 The underground facility 16
3.1.4 The waste inventory 17

3.2 Identification of Relevant FEPs and Scenarios 18
3.2.1 General procedure and documentation 18
3.2.2 Climatic and geologic FEPs 19
3.2.3 Future human actions 19
3.2.4 Waste and repository-related FEPs 20

3.3 Treatment of the Relevant Processes and Sub-system Models 21
3.3.1 Evolution of the geochemical environment 21
3.3.2 Processes related to the magnesium oxide backfill 22
3.3.3 Calculation of actinide solubilities 23
3.3.4 Two-phase-flow and coupled mechanical and hydraulic modelling 23
3.3.5 Modelling of the Culebra hydrology 24
3.3.6 Modelling of radionuclide transport 24

3.4 System Modelling and Calculations 25
3.4.1 The system model framework 25
3.4.2 Undisturbed performance calculations 26
3.4.3 Disturbed performance calculations 27
3.4.4 Supplementary radiological calculations 28

3.5 Documentation 28

4. Conclusions 30

4.1 Observations on the Specificity of the WIPP Case 30

4.2 Evaluation with Respect to the Terms of Reference 30
4.2.1 Appropriateness 30
4.2.2 Technical soundness 31
4.2.3 Conformity with international practices 31
4.2.4 Conformity with international guidance and standards 32

4.3 Overall Judgement 33

5. References 34

Appendix 1 The Members of the Review Group 35

Appendix 2 Terms of Reference for the Review 39

Appendix 3 Selected Paragraphs from the EPA Regulations 41

List of abbreviations

CCA	Title 40 CFR Part 191 Compliance Certification Application for the WIPP
CCDF	complementary, cumulative distribution function
CFR	Code of Federal Regulations
CH	contact-handled (TRU waste)
DOE	United States Department of Energy
DRZ	disturbed rock zone
EPA	United States Environmental Protection Agency
FEPs	features, events and processes
IAEA	International Atomic Energy Agency
IRG	International Review Group
LWA	Land Withdrawal Act
NEA	Nuclear Energy Agency of the Organisation for Economic Co-operation and Development
RH	remote-handled (TRU waste)
TRU	transuranic (waste)
US	United States (of America)
WIPP	Waste Isolation Pilot Plant

1. Introduction

This chapter outlines the background to the review, the composition of the International Review Group, and the process of the review, including the objective and scope. The structure of the report is also outlined.

1.1 Background to the Review

In the United States, the Department of Energy (DOE) is responsible for managing transuranic (TRU[1]) wastes generated by the production of nuclear weapons and other defence-related activities. The Waste Isolation Pilot Plant (WIPP) has been sited and designed to meet the criteria established by the US Environmental Protection Agency (EPA) for the safe, long-term disposal of such wastes. The facility is located near Carlsbad in south-eastern New Mexico and consists of above-ground and below-ground parts. The underground facility (repository) is located at a depth of 650 metres below the surface in a 600-metre-thick, bedded-salt formation.

The EPA regulations require, inter alia, that the DOE demonstrates a reasonable expectation that the WIPP repository will isolate the wastes placed in it from the accessible environment for 10,000 years. The DOE has developed an approach to demonstrating the long-term performance of the WIPP repository based on probabilistic performance assessment. This is designed to estimate how the WIPP disposal system[2] will perform during the 10,000-year regulatory period, taking account of uncertainties in events and processes which could affect the repository in the future.

Beginning in 1980, the DOE has carried out a series of iterative analyses of the long-term performance of the WIPP facility[3]. The latest, the 1996 performance assessment, is described in the DOE document "Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant" [DOE 1996], hereafter referred to as the CCA. The primary purpose of the CCA is to present the information required by the EPA to assess compliance with specific regulations (see Chapter 2). The CCA consists of Volume I plus over 50 appendices.

---

1 TRU waste is defined by the EPA as waste that contains more than 100 nanocuries (3,700 becquerels) of alpha-emitting transuranic isotopes, with half-lives greater than 20 years, per gram of waste, but excluding high-level radioactive waste and certain other wastes, c.f. 40 CFR 191 §191.02(i).

2 Disposal system means any combination of engineered and natural barriers that isolate the radioactive waste after disposal, c.f. 40 CFR 191 §191.12.

3 These earlier performance assessment documents have not been examined as part of this review.

1.2 The International Review Group

The International Review Group (IRG) assembled by the NEA and the IAEA included seven members actively involved in national radioactive waste management programmes - from waste management organisations, national regulatory bodies, universities and scientific consultancies. The IRG was completed by two representatives each from the NEA and the IAEA who provided a joint Secretariat and contributed technically to the review.

The names and summaries of experience of members of the IRG are provided in Appendix 1. Mr. Ken Bragg agreed to act as Chairman.

None of the members of the IRG had ever worked directly on the WIPP Project (or worked as a contractor or subcontractor to the DOE). All, however, had participated in international meetings, projects and comparison exercises in which the WIPP project had been represented, and had some prior knowledge of the project and of performance assessment as practised by the DOE. In some cases, this knowledge was extensive and detailed, and gained over many years in bi-lateral or multi-lateral exchanges.

1.3 The Review Process

1.3.1 Objective

The Terms of Reference for the review were negotiated between the DOE, the NEA and the IAEA, based on a first proposal by the DOE. The significant parts of the Terms of Reference are reproduced in Appendix 2. Therein, it is stated that:

> "The objective of the international review is to examine whether the post-closure performance assessment of the WIPP in the CCA is appropriate, technically sound and in conformity with international standards and practices."

The interpretation of this objective was discussed at length within the IRG, especially the phrase "in conformity with international standards and practices".

The IRG decided to conduct its examination to answer the following broad questions stemming from above statement.

Is the WIPP 1996 post-closure performance assessment:

1. appropriate ?

The IRG agreed that this should be interpreted as meaning appropriate in the context of the objective of the CCA, which is to satisfy the EPA regulations. The IRG also agreed that it should not undertake a formal comparison with the EPA regulations since this is the responsibility of the EPA. In this respect, it is emphasised that this review was organised to provide the DOE an independent, international perspective on the 1996 post-closure performance assessment of the WIPP.

2. **technically sound ?**

The IRG agreed that this item should be the primary focus of the review. For example, have adequate data and process information been used, are the conceptual models and their underlying assumptions scientifically-based or reasonable, have adequately tested mathematical and computer tools been applied ?

3. **in conformity with international practices?**

That is, are the scope of the assessment, methods of analysis and quality of application consistent with good practice in other countries ?

4. **in conformity with international guidance and standards?**

That is, are the calculated end-points consistent with international guidance[4] and standards in the manner these are formulated in other countries ?

1.3.2 Scope

The Terms of Reference identify the CCA Volume I as the primary material to be reviewed. After individual examination of this document, and joint discussions, the IRG made the following initial observations and decisions:

- The CCA has been prepared by the DOE to comply with the EPA regulations. These provide detailed guidance on how to demonstrate compliance, and are focused on the evaluation of specific performance indicators.

- The CCA Volume I does not constitute a self-contained or sufficient description of the 1996 performance assessment. Rather, it is necessary to examine many of the CCA appendices in order to find technical information at the level required by the IRG.

- The iterative programme of performance assessment of the WIPP has been the subject of a number of previous independent reviews, notably by the US National Academy of Sciences [NAS 1996]. These other reviews, several of which are summarised in Chapter 9 of the CCA Volume I, would not be examined as part of this review.

- In coming to a view on the four broad questions identified in Section 1.3.1, the IRG considered that it would also be able to examine and comment on other issues indicated by the Terms of Reference, such as the clarity and transparency of the documentation.

1.3.3 Conduct of the review

A summary of the history and conduct of the review is given in Box 1.

The IRG did not review the whole of the CCA at the same level of detail. The focus was on the DOE approach to post-closure performance assessment, technical soundness at a

4 A list of relevant international documents is annexed to the Terms of Reference, see Appendix 2.

conceptual level, and the performance of the disposal system. Specific points were identified and examined according to the technical background, experience and judgement of each reviewer. During the review, the DOE provided additional information orally, in some cases supported by overheads. This information has been taken into account by the IRG, but has not been formally reviewed.

In their work, the IRG identified technical issues of concern, both general and detailed, made specific comments to define the issues and, in many cases, made suggestions to the DOE on how concerns might be alleviated. It is for the DOE to decide if, or when, any of the suggestions will be implemented in their work[5].

1.4 Structure of the Report

The findings of the review are presented as follows:

- Chapter 2 introduces the EPA regulations which the CCA has been designed to satisfy, identifies and comments on the requirements which have had most influence on the assessment approach adopted in the CCA, and highlights points of interest from an international perspective. The aim of the chapter is to separate observations by the IRG on points related to the EPA regulations from the technical review of work by the DOE.

- Chapter 3 comments on the 1996 performance assessment mainly from a technical perspective. In particular, it examines the technical quality of the stages of post-closure assessment - compilation of data, identification of FEPs and scenarios, treatment of processes and sub-system modelling, system modelling and calculations. Comments are also made on the CCA documentation.

- Chapter 4 summarises the results of the review. This includes observations on the specificity of the WIPP case, the evaluation of the 1996 performance assessment of the WIPP facility against the Terms of Reference, and the overall judgement arising from the experience of the review.

The report assumes that the reader is familiar with the WIPP project and the CCA and presents a minimum of introductory material related to either.

[5] The Terms of Reference of the review do not ask for recommendations for the future programme of the DOE, and the future programme was not discussed during the review. It is understood, however, that the DOE has already taken action on some of the points raised by the IRG during the discussion meetings, and there are opportunities for further actions to be taken during the WIPP re-certification process.

Box 1: History and Conduct of the International Review

In January 1996, the Manager of the Carlsbad Area Office of the DOE approached the NEA and the IAEA to ascertain their willingness to organise a review of the 1996 performance assessment of the WIPP. In February and March, the NEA and the IAEA agreed, in principle, to carry out such a review, and formal agreement to carry out a jointly organised review was reached in June 1996. The NEA and IAEA formed a joint Secretariat and invited individual experts to participate in the review so that, by July 1996, a team covering the range of relevant expertise was identified - the International Review Group (IRG).

A copy of Volume I of the CCA was supplied to members of the IRG in October 1996. IRG members made a preliminary examination of the document and, in November 1996, met in Vienna to discuss the objectives and approach to conducting the review. The coverage of the various sections of the CCA by the IRG was discussed, and each member was assigned a selection of those CCA appendices and supporting references that he might need to examine. These documents were supplied to individual reviewers by the DOE, mainly by the end of November 1996.

Each reviewer then examined the CCA Volume I, selected appendices and references, and formulated a series of questions arising from the examination. These preliminary questions were compiled and submitted to the DOE in early January 1997 in order to have a more focused meeting between the IRG and DOE later that month. The compiled list included over 100 questions, organised into broad subject headings such as "presentation of safety assessment results", "FEP and scenario identification methods", "radionuclide inventory", etc.. Some of these questions were very specific, referring to particular data items and identified pages of the CCA; others were more general and were requests for clarification about DOE methods as described in the CCA; a few asked for supplementary information not included in the scope of the CCA, e.g. related to radiological consequences. Written answers were not provided, but the questions were used by the DOE to plan a set of focused presentations to the IRG, see below.

The DOE provided an electronic version of the CCA, including its appendices and references, to members of the IRG in early January. The reviewers were not able to take full advantage of these CD-ROMs in their main review work due to the late availability. The CD-ROMs, and the cross-references and search tools which they include, are undoubtedly useful, however, and were used later during the editing of the review report to check specific information in the CCA.

From 26 to 31 January 1997, the IRG met in Carlsbad, New Mexico. In this time, the IRG visited the WIPP facility, received focused presentations from DOE staff and contractors based on the questions previously submitted, and held meetings in closed session to review and confirm individual and joint views on the WIPP post-closure performance assessment. The presentations by the DOE were the starting point for detailed technical discussions which served to answer most of the questions originally raised by the IRG members. The visit to the WIPP facility, and associated discussions with DOE staff, were especially valuable to the reviewers in developing their understanding of the WIPP project and disposal system. During the meetings, information was provided orally, in some cases supported by overheads. This information has been taken into account by the IRG, but has not been formally reviewed.

On the final day of the week, a preliminary oral report was given to DOE representatives by the IRG Chairman.

A first draft report of the review was compiled and circulated to the IRG members for comment in February 1997. These comments were assimilated, and a second draft was produced and discussed at a meeting of the Secretariat, Chairman and consultant in Paris on 12 March 1997. A third draft was prepared and circulated to the IRG members for final comments. After incorporation of final comments, and unanimous approval by the IRG, the final report (this document) was submitted to the DOE on 9 April 1997.

2. The EPA Regulations and their Influence on the CCA

This chapter introduces the EPA regulations which the CCA has been designed to satisfy, identifies and comments on the requirements which have had most influence on the approach to performance assessment adopted in the CCA, and highlights points of interest from an international perspective. The aim of the chapter is to separate observations of the IRG on points related to the EPA regulations, from the technical review of work by the DOE, which is reported in Chapter 3.

In this chapter, factual and neutral observations are given in plain text. *Opinions of the IRG are given in italics.*

2.1 The EPA Regulations

The DOE was self-regulating until the Land Withdrawal Act (LWA) for the WIPP was promulgated in 1992. Amongst other provisions, the LWA designated the EPA as the regulator for radiological safety of the WIPP facility.

The design and operation of the WIPP are governed by a comprehensive set of US federal and state regulations. The regulations relevant to the post-closure radiological performance of the WIPP, which the CCA is designed to address[6], are contained in two EPA standards:

- **40 CFR Part 191** - Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes - which sets out general requirements for geological disposal systems in the US;
- **40 CFR Part 194** - Criteria for the Certification and Re-certification of the Waste Isolation Pilot Plant's Compliance with the 40 CFR Part 191 Disposal Regulations - which details the application of 40 CFR Part 191 to the WIPP.

In addition, the EPA has issued guidance on the interpretation of 40 CFR Part 194 in a Compliance Application Guidance document [EPA 1996].

40 CFR 191 was first issued in 1985, remanded in 1987 and re-issued in 1993. The regulation applies to spent nuclear fuel, high-level and transuranic (TRU) radioactive wastes, and sets out environmental standards for management and storage (Subpart A), disposal (Subpart B) and groundwater protection (Subpart C).

40 CFR 194 was issued in February 1996 and became effective two months later. The regulation sets out guidance specific to the WIPP project on the approach to performance assessment that the DOE should adopt and on the structure and content of the CCA. It provides detailed guidance on containment, assurance, and groundwater protection requirements, and includes paragraphs on, for example:

---

[6] Compliances with other regulations are dealt with in separate submissions by the DOE.

§194.14 Content of compliance certification application.

§194.22 Quality assurance.

§194.23 Models and computer codes.

§194.25 Future state assumptions.

§194.26 Expert judgement.

§194.27 Peer review.

§194.32 Scope of performance assessments.

§194.33 Consideration of drilling events in performance assessments.

§194.41 Active institutional controls.

§194.43 Passive institutional controls.

§194.45 Consideration of the presence of resources.

Appendix 3 reproduces extracts from 40 CFR 191 and 40 CFR 194 which are most pertinent to this review, including definitions of selected terms. In the following section, where paragraph numbers of 40 CFR 191 and 40 CFR 194 are referred to, the relevant paragraphs, or parts of paragraphs, can be found in Appendix 3.

2.2 The Influence of the EPA Regulations

The DOE designed the CCA to satisfy the requirements of 40 CFR 191 and 40 CFR 194. It is not surprising, therefore, that the structure and contents of the CCA, and the 1996 performance assessment, are strongly influenced by these regulations.

The IRG has not undertaken an analysis of the EPA requirements, nor attempted to systematically check whether the DOE has fulfilled these requirements. In many instances, however, the IRG found that points on which it wished to comment were a result of the requirements of the EPA regulations. This section identifies the more important of these points[7]. This is not intended as criticism of the regulations, nor of the DOE which is obliged to follow them, but to highlight points which are of interest from an international perspective.

2.2.1 Undisturbed and disturbed performance

The EPA regulations set requirements in respect of "undisturbed performance"[8] and "performance taking account of all significant processes" (disturbed performance). The disturbed and undisturbed performance are both judged relative to a "containment

[7] The implications of the the EPA regulations penetrate deeply into the technical details of the 1996 performance assessment. Some of the more detailed implications are perforce mentioned in Chapter 3.

[8] Term defined in 40 CFR §191.12, see Appendix 3. Note that the undisturbed performance includes the effects of human actions, potash mining and deep drilling, that may occur in the future outside the "controlled area".

requirement", based on collective dose considerations, which places a limit on the total release of radionuclides (40 CFR §191.13). The undisturbed performance is also judged relative to an individual dose limit (40 CFR §191.15) and groundwater protection requirements.

This separate consideration of disturbed and undisturbed performance is consistent with regulations in other countries. In several countries, for example, a distinction is made between expected events and processes or a normal scenario, and unexpected events and processes or altered scenarios. In most countries, the criteria applying to the two conditions are derived from the same basis - radiological risk to an individual. The EPA containment requirement, however, is based on collective dose considerations, and cannot be directly related to individual dose and radiological risk standards.

The IRG considers that it is appropriate to assess the undisturbed and disturbed performance separately, and this is in accord with practice in other countries. It is unusual, however, that a different basis for assessment should apply to each.

2.2.2 The 10,000-year regulatory period

The containment, individual dose, and groundwater protection requirements (see above and Appendix 3) all refer to a 10,000-year regulatory period. The EPA does not require any assessment beyond 10,000 years after closure, even in terms of qualitative arguments.

The reliability of performance assessment results declines at times in the far future because of the increasing uncertainty about future conditions, especially of the surface environment and human behaviour. For this reason, in most countries, it is considered that, in respect of performance in the far future, the requirement for quantitative assessments should be less stringent, with more qualitative arguments being allowed [IAEA 1994].

The Canadian, German and French regulations, for example, specify 10,000 years as the maximum time to which quantitative assessment needs be continued, but require qualitative arguments that releases will not increase dramatically beyond this time. In Switzerland, regulatory guidance indicates that calculations should be carried out at least until the estimated maximum of impacts has been reached, even if it is acknowledged that this may be beyond the limits of validity of the models.

The IRG was surprised that it did not find descriptions or arguments in the CCA indicating the possible performance of the WIPP facility beyond the end of the 10,000-year regulatory period. Such descriptions or arguments, including an indication of the mechanisms, likelihood, timing and possible maximum of impacts at longer times, would be an important element of performance assessment in most other countries.

2.2.3 The containment requirement

The major part of the performance assessment work presented in the CCA (Chapter 6 of Volume I) is to demonstrate compliance with the containment requirement (40 CFR §191.13).

The formulation of the containment requirement has several implications not already discussed:

- it is probabilistic and leads to the adoption of a probabilistic methodology to calculate the cumulative release (see also Section 2.2.5);
- it is only concerned with the total cumulative release to 10,000 years, not the timing or rates of release within this period;
- issues of individual dose and risk, as well as the biosphere, are not considered.

Results in the CCA are almost entirely probabilistic because of the focus of the CCA on compliance. The probabilistic systems modelling approach brings important benefits in investigating uncertainties in complex coupled systems and produces integrated measures of impact. Attention must be given, however, to presenting the results of the analysis in an accessible and transparent form. In particular, deterministic analyses may be useful to illustrate the model behaviour and support the probabilistic analyses[9].

Information on the temporal evolution of conditions and releases is important to understanding the physical evolution and performance of the disposal system, and can give confidence in the overall release results which are otherwise opaque. Such information is lacking in the CCA, although supplementary information was presented to the IRG during the meeting in Carlsbad[10]. Whereas the EPA requirements do not seem to exclude the presentation of results as a function of time, the focus of the DOE on compliance may have led to them not being presented.

The EPA containment requirement is based on consideration of collective dose and, moreover, relates to the total activity contained in the repository expressed in terms of EPA units (see 40 CFR 191 Table 1, reproduced in Appendix 3). The IRG found this difficult to relate to safety standards based on individual dose and radiological risk with which they are more familiar. The IRG therefore asked the DOE to provide supplementary information on doses that might be received. These are discussed in Section 3.4.4.

The IRG accepts the probabilistic approach, but found that the focus of the CCA on probabilistic estimates of total cumulative release, and lack of presentation of deterministic calculations or results as a function of time, hampered the understanding of the performance of the disposal system. It would have been helpful to present such results even if they are not required by the EPA.

2.2.4 Treatment of human actions

The EPA regulations give guidance on the assessment of future human actions at the WIPP site. They specify that:

[9] The relative merits of probabilistic and deterministic methodologies in assessments have been discussed internationally, for example within the NEA Integrated Performance Assessment Group [IPAG 1997].

[10] "Preliminary Summary of Uncertainty and Sensitivity Analysis Results Obtained in Support of the 1996 CCA for the WIPP", memo by J. Helton, 12/23/96.

- the characteristics of the future (at least in respect of human actions) are assumed to remain as they are at the present day (40 CFR §194.25);
- the assessment shall consider mining, deep drilling and shallow drilling (40 CFR §194.32a);
- in respect of mining, only the effects of changes in hydraulic conductivity of hydrogeologic units should be considered (40 CFR §194.32b);
- inadvertent intrusion by drilling for resources should be assumed to be the most severe scenario, and the method of estimating the future occurrence of drilling is specified, based on the frequency of drilling in the Delaware Basin in the last 100 years (40 CFR §194.33b);
- resource recovery activities, subsequent to drilling of a borehole, need not be considered (40 CFR §194.33d);

It is likely that mining of potash will occur within the controlled area at some time during the regulatory period. The only impact that the EPA asks the DOE to consider, however, is calculated to be beneficial for long-term performance (see Section 3.1.2).

The EPA specification of how to estimate a future drilling rate, plus the assumption of random occurrence in space and time, leaves little uncertainty in the inputs for the assessment of drilling. The actual situation is that there is a very large uncertainty concerning future human actions. Moreover, the case selected for analysis considers an activity that, based on knowledge of the resources in the Delaware Basin (see Section 3.1.2), is not sustainable for more than a few tens of years into the future.

The specification by the EPA on how to assess future human actions leads to a feeling that the performance assessment is arbitrary. The IRG accepts that, given the irreducible uncertainties associated with future human actions, it may be convenient from a regulatory standpoint to define reference events or scenarios that should be the basis of compliance calculations. The IRG, however, would have liked some discussion of the assumptions adopted and, in particular, why other human actions such as resource recovery need not be considered (see Section 3.2.3) and whether the assumptions adopted in representing mining and deep drilling can be considered to be conservative or sufficiently representative.

2.2.5 Results of performance assessment and treatment of uncertainty

The EPA requires that the results of the performance assessment are assembled into complementary, cumulative distribution functions (CCDFs), and that the uncertainty of disposal system parameters should be considered to generate a set of CCDFs (40 CFR §194.34). The regulations also set conditions on the statistical accuracy of results (see Section 3.4.3).

The CCDF is a generally accepted method of depicting uncertain outcomes commonly adopted in reactor safety studies. The DOE has developed the methodology to calculate the radionuclides releases from the controlled area[11] in the form of CCDFs that can be compared to the EPA containment requirement.

The DOE methodology adopts the Kaplan and Garrick [1981] definition of risk[12] and approach to the treatment of uncertainty. This leads to the generation of a single CCDF where each 'scenario' forms a single-point estimate of consequence and probability on the CCDF. The uncertainty incorporated in this single CCDF, which relates to uncertainty about what might happen in the future, is termed stochastic uncertainty. There is also uncertainty about starting conditions, or values of parameters that must be incorporated in the consequence models. Kaplan and Garrick refer to this as subjective uncertainty on the basis that the parameters do have some "true" or fixed value, but this is imprecisely known. Accounting for this uncertainty in disposal system parameters leads to a family of CCDFs.

The IRG observes that the separation of uncertainty related to disposal system parameters and uncertainty related to future events is presentationally useful and operationally convenient, but is to some extent misleading[13].

The above approach deals with parameter uncertainty. The EPA does not require, and the DOE does not consider, the uncertainty related to choice of features, events and processes, or choice of alternative models[14]. These sources of uncertainty are generally considered to be important internationally [IPAG 1997].

The lack of discussion of other uncertainties, not included through parameter uncertainty, would be considered a serious omission internationally when judging the results of performance assessment, although it is not required by the EPA for compliance calculations.

2.2.6 Institutional controls

The EPA regulations require the DOE to present descriptions of the active and passive institutional controls (defined in 40 CFR §191.12) that are proposed for the site. Further, the EPA allows the DOE to take credit, in terms of a reduced likelihood of human intrusion, for up to a maximum of 100 years after disposal in respect of active controls and "several hundred years"[15] in respect of passive controls (40 CFR §194.41 and 43).

---

11 Term defined in 40 CFR §191.12, see Appendix 3.

12 According to Kaplan and Garrick, risk is composed of three elements: what can happen, i.e. what scenarios can be identified; how likely is this, i.e. what probability should be assigned to each scenario; what is the consequence, i.e. what is the result, in terms of total release, for each scenario.

13 It supposes, for example, there is a true long-term rate of drilling applicable to the site, and that the uncertainty in time of occurrence is only a result of statistical variation. This is untrue - the future rate is highly uncertain and may not even be a physically meaningful parameter depending on the model adopted. In addition, the sampling of so-called subjective uncertainty is related, not just to present-day characteristics, but also to what those characteristics might be over the 10,000-year regulatory period.

14 The EPA does require descriptions of alternative conceptual models that are seriously considered but assumes that one model set, that "accurately portrays the performance of the disposal system", will be used in support of an application (see 40 CFR §194.23, not included in Appendix 3).

15 The guidance document [EPA 1996] further clarifies this point. It specifies that the EPA will allow up to approximately 700 years of credit (after closure), provided the applicant can support this assumption.

The prevailing international view is that, in the post-closure period, active institutional controls cannot be relied upon to exist for more than a few hundred years[16], which accords with the EPA regulations. Beyond this time, it is accepted that record keeping would be a useful precaution that might reduce the likelihood of future inadvertent human intrusion into the repository but cannot be relied on for long [NEA 1995]. There is no international consensus on the value of passive controls, such as markers, further in the future. Some experts consider that markers could attract unwanted interest in the site [Sumerling et. al. 1996; IAEA 1996], while others consider that markers could be effective in stimulating a search for records and are, overall, useful [SSI 1993].

The IRG observes that the EPA regulations <u>*require*</u> *the applicant to propose a system of passive institutional controls, including site markers, and* <u>*allow*</u> *the applicant to take some credit in performance calculations for the effect that these might have. To our knowledge, no other country formally allows credit to be taken for site markers in performance calculations. There is, however, no definitive position on this internationally.*

The DOE does take this credit offered by the EPA. The IRG observes that it would be more defensible to demonstrate compliance without attempting to take credit for passive site controls, the effectiveness of which must be uncertain[17].

2.2.7 Terminology

The terminology used in the WIPP performance assessment community, and in some cases formalised by the EPA regulations, is somewhat different from that used in other countries and familiar to the IRG.

The IRG was surprised, for example, that the CCA states that expert judgement is not used, whereas it is clear that the judgements of the project staff have had a very important influence on the performance assessment. This arises because the term 'expert judgement' has a specific meaning in the EPA regulations, indicating formal elicitation of experts independent of the project.

Another example is the DOE use of the term 'scenario' to mean a single simulation of the future (see Section 2.2.5), whereas internationally it is more often used to denote a general description of a possible future [NEA 1992].

The terminology in the CCA did pose some initial problems for the IRG in conducting the review, and also reduces the readability of the documents. The IRG is supportive, however, of the principle of maintaining a well-defined and consistent use of terminology between a regulator and applicant, and recognises that the prime requirement is that the CCA is unambiguous in relation to the EPA.

---

[16] The value assumed varies from country to country, usually 100 or 300 years.

[17] The Appendix EPIC, on which the DOE bases its claim to assume a reduced frequency of human intrusion up to 700 years after closure, presents a partial view of the archaeological evidence. The IRG believes that this view would not be generally upheld.

2.3 Discussion

2.3.1 Overall implications for the CCA

The EPA regulations provide detailed guidance and are prescriptive, not only in terms of the quantities that they require an applicant to calculate, but also in terms of the scope of assessment, presentation of results and even fixing of certain key assumptions. The goal of the EPA is to make judging compliance as straightforward as possible by setting out specific requirements. This can simplify the tasks of both the applicant and the regulator. It means, however, that important decisions relating to safety and what is a sufficient method and scope of assessment have already been taken.

Equivalent regulations in most other countries are written in a more general way. Principles and safety targets are set, but the responsibility of preparing a safety case in an appropriate form is left with the applicant. All relevant issues must be addressed, but the applicant has the flexibility to choose a suitable approach. In this case, some communication will usually take place between the applicant and the regulator to explore what might constitute an acceptable approach and scope of assessment.

The location of the WIPP site, in an area rich in mineral resources, requires that the focus of the performance assessment is on human intrusion. This is different from most other geologic environments considered for radioactive waste disposal, where assessments most often focus on an undisturbed case. Any quantitative assessment of future human actions is liable to be arbitrary to a large extent. Attention must therefore focus on the choice of assumptions underlying the analysis, e.g. whether they are reasonable, conservative and acceptable to stakeholders. This is not discussed in the CCA because the EPA specifies the assumptions that should be applied.

The IRG observes that the CCA is precisely designed to satisfy the EPA regulations, and these do not require the applicant to present a comprehensive argument related to safety. Thus, the analysis presented in the CCA appears somewhat arbitrary and does not represent a complete, self-standing, performance assessment as understood in other countries.

2.3.2 Implications for the review

The IRG was initially aware that the CCA is strongly influenced by the EPA regulations, but only became fully aware, during the review process, of the detail to which the regulations specify the technical approach of an applicant.

In preparing this report, the IRG has tried to distinguish between the decisions that have been determined by the EPA regulations (discussed mainly in this chapter), and the decisions made by the DOE, for which the DOE must take technical responsibility (discussed mainly in the next chapter).

3. The 1996 Performance Assessment of the WIPP

This chapter comments the 1996 performance assessment of the WIPP mainly from a technical perspective. In particular, it examines the technical quality of the various stages of post-closure assessment - compilation of data, identification of FEPs and scenarios, treatment of processes and sub-system modelling, system modelling and calculations. Comments are also made on the CCA documentation.

Although the detailed comments are aimed specifically at the CCA, the IRG has built its judgment on the technical soundness of the 1996 performance assessment, not only on its examination of the CCA, but also on the basis of prior knowledge of the WIPP project and work by the DOE and its contractors over a number of years.

In this chapter, factual and neutral observations are given in plain text. The views of the IRG and suggestions to the DOE are given in italics.

3.1 The Compilation of Data

3.1.1 Site geology and hydrogeology

The regional geology of the Delaware Basin is well known, because of the long experience arising from potash mining and hydrocarbon exploration in south-eastern New Mexico. This extensive regional knowledge has been compiled and well assimilated within the DOE programme. The stable focus of the WIPP on the currently selected site, over a period of more than 20 years, has allowed a very thorough investigation of the local and adjacent geology and hydrogeology.

The geological, hydrogeological and tectonic settings provide strong and multiple evidences of the natural long-term stability and isolation capacity of the Salado formation over time scales far in excess of the 10,000-year regulatory time frame. Due to these very favourable geological characteristics, most of the naturally occurring features, events and processes (FEPs) that could be thought of as having the potential to disrupt a geological repository can be screened out. A stronger reference in the CCA to these positive site-specific features could further support the intrinsic containment capacity of the Salado, and thus the safety case.

The existence of natural resources in the region highlights the possibility of human actions aimed at exploiting these resources. Thus, the presence of brine reservoirs in the Castile formation, which have been encountered during drilling for oil and gas mainly at the north-east margin of the Delaware Basin, is of concern. Apparently, no direct or indirect methodology exists to precisely characterise the extension and volume of these brine reservoirs. The lateral extent and volume of the brine reservoir encountered by the WIPP-12 borehole are not well known and the assessment calculations have to rely on a geostatistical approach covering the whole Delaware Basin.

The most recent investigation for the presence of Castile brine reservoirs underlying the facility was done, from the surface, about ten years ago. The possibilities for investigating brine reservoirs beneath, and local to, the WIPP site and, especially, for developing further methods to characterise their extent and volume from the underground, should be borne in mind during the construction phase of the underground facility.

The evidence for the very low permeability of massive salt beds such as the Salado is based on good physical arguments and on extensive measurements. Attention thus focuses on the anhydrite beds within the Salado. These constitute the only possible natural paths for gas, brine and contaminant transport away from the repository, and may also be a route for incoming brines that may react with waste components to produce gas. Hence, their properties are important in determining the pressure evolution of the repository.

A detailed characterisation of these beds has been performed, but it is not clear to the IRG, that the changes that will be induced in these units by repository excavation, subsequent salt creep movements, and gas pressure build-up are as well understood or characterised. The lack of complete understanding is handled by conservative choice of parameter ranges in the BRAGFLO calculations.

In the strata above the Salado most of the water is saline and is not potable, even by livestock, without substantial dilution. This is especially true for the Culebra dolomite, which is the most transmissive unit at the WIPP site, and is considered to be a potential pathway for radionuclide release from the controlled area. Potable water is reported from shallow drilling in the Dewey Lake formation (although not necessarily in the immediate vicinity of the WIPP site).

The IRG considers that, from a dose perspective, greater attention could be given to considering whether any credible scenarios exist in which contaminants might reach these potable or nearly potable resources, under present day and alternative climate conditions[18].

3.1.2 Natural resources

The existence of potash resources at the WIPP site and in the immediate area has been the subject of extensive investigation. This is an unusual situation for a radioactive waste disposal site. Not only is it expected that (unless prevented) mining will occur within a few years, but also, because of the well-understood nature of the potash deposits, it can be estimated which areas of the ore horizons will be mined over the site.

The potential impacts of mining (at the repository horizon and on potential paths for brine and contaminant movement) are not fully discussed in the CCA Volume I, because the EPA has restricted the range of effects to be considered in performance assessment, see Section 2.2.4. The only effect considered, an increase in the hydraulic permeability of the Culebra over the mined areas, turns out to be beneficial: it increases the transport times and hence reduces the calculated release of radionuclides during the 10,000-year regulatory period.

---

[18] From a dose perspective, the containment requirement may be conservative where the releases occur in media which man is unlikely to exploit or come into contact with, i.e. saline water in the anhydrite beds or in the Culebra.

It would be preferable to see information on the observed effects of potash mining locally. Reasoned arguments could then be presented on the selection of the processes that are represented in the analysis.

The hydrocarbon resources of the Delaware Basin are well known. They consist of oil and associated gas reservoirs found in the Permian strata, and gas condensate in the Pennsylvanian strata. These strata exist beneath the WIPP site and immediately surrounding areas. The relevant information is presented in Appendix DEL, but is poorly discussed in the CCA Volume I, probably because the EPA specifies the assumptions to be adopted in demonstrating compliance, see Section 2.2.4.

A historical description on the rate of development of oil and gas wells, and discussion of alternative scenarios for future exploitation of oil and gas resources, based on actual practice and the extent of resources in the basin, could set the assumptions used in the analysis in perspective. Depending on the future needs of energy and the current trend towards shallow oil exploitation in the Delaware basin, there is a possibility that the drilling rate in the near future will be greater than the one in the last 100 years, although the rate would not be sustainable over the 10,000-year regulatory period.

3.1.3 The underground facility

The WIPP project has accumulated an impressive database on rock mechanics based on extensive and long-term laboratory and in-situ measurements. This is complemented by detailed and high quality modelling of rock-salt creep, for example, by the SANTOS model. The precise knowledge of the stratigraphy in the salt formation, and salt properties, has facilitated the development of quite detailed repository layouts and designs for various seal elements.

The high quality and extent of the data base, with very specific data relevant to rock mechanical processes and design, provides a high level of confidence in the analyses made on these components.

The DOE gives considerable attention to the design of the multiple-component shaft seals intended to prevent hydraulic connection and movement of brine or contaminants in the shafts after closure. In the long term, the lengths of crushed, compacted rock-salt can be expected to be restored to a low permeability, similar to the host formation, as a consequence of salt creep. The longer-term performance of elements above and below must be less certain since they represent chemical and physical anomalies within the formation. The performance of these elements, however, need only be assured over a period of a few hundreds of years during which the crushed rock salt sections achieve low permeability.

The IRG is content that shaft seals can be constructed to provide the required long-term performance.

Information on the detailed mechanical modelling of the shaft and its associated disturbed rock zone (DRZ) is summarised in Volume I of the CCA and presented in detail in Appendix SEAL. In the BRAGFLO performance calculations, however, a range of time-independent properties are assigned to the shaft and DRZ.

The IRG was not able to fully trace the parameters concerning shaft and DRZ properties given in Appendix PAR to the information in Appendix SEAL. Thus, it is unclear whether the simplified treatment of the shaft and DRZ in performance calculations results from a lack of confidence in estimating time-dependent properties of the shaft seals and DRZ, or a pragmatic finding that the performance of the disposal system is relatively insensitive to a range of shaft and DRZ properties.

Not much data is available on waste compaction, and, due to the variability of the waste, it is difficult to have confidence in the data provided.

The mechanical resistance of the waste is not considered in the modelling of the room closure, and it is not clear whether this approach is conservative, see Section 3.2.4.

A DRZ also forms around the disposal rooms as a consequence of unloading the rock in the vicinity of the excavation. Increased permeability is created by micro-fractures along grain boundaries and by bed separation along lateral seams. Following closure, salt creep will tend to restore low permeabilities within the salt beds, however, some fracturing in non-halitic rock, such as anhydrite, and bed separation on clay seams, may be irreversible.

An area where an improved confidence in the repository evolution might be useful is the understanding of the gas and brine permeability of the DRZ around the disposal rooms. At present, this zone is assumed to release brine to the disposal rooms and to connect the repository-waste void with the anhydrite marker beds above and below the repository horizon. A good understanding of variability of the zone properties and their evolution, especially "healing", might allow a less conservative treatment in assessment models.

3.1.4 The waste inventory

The WIPP facility is designed to receive radioactive and mixed waste, which results mainly from nuclear weapons production and associated activities in the US. By its origin and composition, this is not a waste type which occurs in many other countries. The waste components in the TRU waste are similar to what are internationally called low- and intermediate-level wastes with long-lived radionuclides.

The waste that is expected to be disposed of in WIPP is well documented in appendices of the CCA: the origin, form, characteristics and inventory of the different waste types are described, as well as the characterisation methodologies and controls. Two classes of waste are considered: remote-handled (RH)-TRU-waste and 599 different types of contact-handled (CH)-TRU-waste. Volumes and characteristics are forecast for each class and type.

Only a limited fraction of the wastes to be disposed of is conditioned and packaged already and the characteristics of wastes yet to arise are forecast. As waste processing may change with time, the eventual waste inventory may differ in content and characteristics from those now forecast. This source of uncertainty is not addressed in the CCA.

Repository-based emplacement limits have been imposed by the Land Withdrawal Act (LWA), which specifies a total volume capacity (of RH- and CH-TRU waste) of 6.2 million cubic feet (175,600m^3) and total activity capacity for RH-TRU waste of 5.1 million curies

(1.9x10^5 TBq). Radionuclide inventory limits have been established by the DOE on this basis.

The IRG noted that the inventory of Cs-135 considered in the CCA appears to be inconsistent with that of Cs-137 based on typical fission ratios for these two isotopes. In particular, the Cs-135 inventory appears to be underestimated by three to four orders of magnitude. The implications for the performance calculations were preliminarily checked by the DOE during the IRG visit to the WIPP and found to be insignificant within the EPA regulatory framework. The latter focuses the attention on long-lived alpha emitters, whereas a regulatory context based on dose to the individual would enhance the role of more mobile long-lived radionuclides such as Cs-135. In any event, this inconsistency reveals a weakness in the exchange of information between the waste producers and the performance assessors.

3.2 Identification of Relevant FEPs and Scenarios

3.2.1 General procedure and documentation

According to the CCA, the starting point for the identification of relevant features, events and processes (FEPs) is a compilation of several performance assessment FEP lists made in support of the Swedish SITE-94 study [Stenhouse et al. 1993]. The original purpose of this compilation was to provide a list against which to audit a list of FEPs that were specific to the case of a KBS-3 style repository in Swedish bedrock, where the list of site-specific FEPs was achieved through an independent consideration by yet another study group.

There must be some doubt as to whether a list that was originally intended for one quite specific purpose, related to high-level wastes in a hard rock site in northern Europe, is a sufficiently representative starting point for a catalogue of FEPs related to disposal of transuranic wastes in a bedded salt formation in south-eastern New Mexico.

In the CCA Volume I it is stated: "Finally, to ensure comprehensiveness, other FEPs specific to the WIPP were added based on review of key project documents and broad examination of the preliminary WIPP list by both project participants and stakeholders."

There is no clear indication in Volume I or in Appendix SCR of exactly how this review and examination was managed, or specifically what additions or modifications resulted. The IRG finds this surprising because conversations with WIPP project staff indicated a quite encyclopaedic knowledge of the site and relevant processes. The record shown in the CCA does not indicate that this resource was fully used, although in practice it may have been.

The qualitative and semi-quantitative arguments regarding FEPs that are collected in the Appendix SCR are a key component of the assessment.

This appendix is clear in recording what FEPs are and are not carried forward to further analysis, but does not give a sufficient level of evidence or support for many of the screening decisions. The methodology is satisfactory in principle, but the IRG has difficulties in *understanding the rationale for screening out of individual FEPs*[19]*. The IRG suggests that the Appendix SCR should be more critically reviewed with a view to bringing forward more detailed information to support the decisions made.*

Several FEPs were rejected on the basis of regulatory considerations[20].

It would improve the confidence of the reader if the DOE presented the logical or physical arguments for not considering these processes in the assessment, in addition to noting that they are not required in a compliance demonstration. Otherwise, there is an impression that processes that might deserve consideration from a safety perspective have been eliminated.

3.2.2 Climatic and geologic FEPs

The potential for climatic and geological changes within the 10,000-year regulatory period is well documented in the CCA.

The DOE has investigated an appropriate range of future climatic and geological processes, and the possible effects within the 10,000-year regulatory period have been considered. For perspective, it would be helpful to include some qualitative discussion of the possible impact of climatic and geologic FEPs over longer time periods.

3.2.3 Future human actions

The selection of FEPs related to future human actions to be considered in the CCA are closely specified by the EPA (see Section 2.2.4).

Examination of the CCA and conversations with project staff identified a number of events and processes that are not analysed and might deserve consideration from a radiological safety perspective. These are:

- water flooding due to nearby brine injection to aid oil recovery, and possibly other secondary and tertiary recovery methods;
- solution extraction of salt, e.g. for use in drilling muds or other purposes;
- solution mining of underground cavities for storage, e.g. of oil or gas, or for disposal of other wastes;
- disturbance of flow regime due to extraction boreholes just outside the controlled area[21].

---

19 An example of the further documentation on FEPs and screening procedures in project records was provided by the DOE.

20 The IRG presumes that the EPA decision to constrain and limit the analysis is based on an earlier evaluation of the relative importance of various processes. As far as the IRG is aware, however, this is not documented in the open literature.

21 A borehole outside the controlled area could affect flow and transport because it would modify the boundary conditions for the flow calculations. In the Salado formation, the dilution effect for the transport of radionuclides along the marker beds, which is observed in the dose calculations, might then be reduced by a more focused flow towards the borehole. This scenario should be included in the undisturbed performance, e.g. assumed to occur with some probability.

All of these, except the last, are ruled out by the EPA regulations.

From a safety perspective, the IRG considers that the documentation and evaluation of FEPs related to future human actions is incomplete. Even if the CCA is focused on regulatory compliance, a demonstration that those processes that must be considered in regulatory compliance are indeed an appropriate and sufficiently representative set, would make the DOE performance assessment more widely acceptable[22].

3.2.4 Waste and repository-related FEPs

The wastes to be disposed of in the WIPP facility are highly heterogeneous. This will lead to a heterogeneity (of initial conditions at least) in the emplaced waste within each waste room both in terms of physical properties, chemical properties and radioactivity. Moreover, as rooms and panels will be filled sequentially over time, and there will be variations in wastes arising, there may be significant variation in physical, chemical and radionuclide inventory between disposal rooms.

The effects of heterogeneity at the room scale are of most concern: in particular, whether the homogenous physical and chemical conditions assumed for the source term and repository modelling will be achieved in reality. This is important because the expected mode of release from the repository involves discrete interceptions of quite small volumes within the total repository volume. The specific conditions at that small volume scale, and immediate vicinity, may be quite different from the averaged mixed conditions of the whole repository. The IRG suggests that (1) additional qualitative thinking is done to identify possible effects of waste heterogeneity and emplacement, and this is supported by (2) quantitative detailed modelling to investigate the possible physical and chemical evolutions within small sections of the repository (of the order of a few square metres).

Flow and transport processes in the repository area depend on the pressure build-up due to the production of gas. The pressure build-up depends on the available void or pore volume in the repository. This volume is reduced by the creep convergence of the salt.

The creep calculations in the CCA account for the pressure build-up itself but not for the mechanical resistance of the waste or for volumetric change of the backfill material (see below). Taking these processes into account could reduce the convergence rate. It is unclear whether neglecting these processes is conservative or not.

The specification of a magnesium oxide (MgO) backfill with the purpose of controlling pH, and hence actinide solubilities, around the wastes is a very late development. Indeed, the most relevant entry of the Appendix SCR - SCR.2.1.5 "Backfill characteristics" - does not say what the backfill material is, referring to it as a "chemical conditioner". The subject is discussed in more detail elsewhere, e.g. Section 6.4.3.4 of Volume I and Appendix BACK. These discussions, however, focus on the desired chemical effects assuming an intimate and instantaneous mixing effect with incoming brine.

---

[22] While the EPA regulations allow the DOE not to evaluate the above scenarios, they do not forbid the DOE from presenting ancillary analyses of the scenarios.

The IRG considers that (1) confidence has not been developed that wastes within individual drums, or the brines entering these drums, will undergo the rapid chemical conditioning effect assumed (see comments on heterogeneity above), and (2) insufficient attention has been given to the volumetric expansion and other effects due to MgO reactions[23] *(see Section 3.3.2).*

3.3 Treatment of the Relevant Processes and Sub-system Models

3.3.1 Evolution of the geochemical environment

There is a large amount of mixed organic material contained within the TRU waste which is prone to bio-degradation and CO_2 production in contact with water. This makes the waste packages unstable under the disposal conditions. Therefore, the addition of a backfill material is necessary to stabilise both the pH and partial CO_2 pressure within the repository.

The DOE specifies a MgO backfill, and refers to this as an Assurance Requirement. However, the presumed effect is taken account of in the performance modelling and the IRG considers that a chemical conditioning backfill is required in order to make the performance of the system sufficiently predictable.

The waste panels in the WIPP repository will undergo a complex geochemical evolution that has to be properly addressed in the source term calculations. The processes to be considered in estimating the geochemical evolution include:

- corrosion of the steel waste containers by the contacting fluids;
- degradation of the organic content of the waste with the corresponding generation of both CH_4 and CO_2;
- hydration and subsequent carbonation of the MgO backfill material;
- dissolution of the actinide inventory.

In the CCA, instantaneous equilibrium is assumed in all the processes involved, except for the redox distribution of the actinide species. The result is that the PANEL code calculates radionuclide mobility out of the repository in a well-mixed reactor fashion.

The outcome in terms of actinide releases is non-conservative, as the assumption of full mixing has a beneficial effect on the repository pH and partial CO_2 pressure which is not fully backed up by the experimental evidence reported by the DOE.

The IRG suggests that (1) more detailed modelling is required of the assumed transition from heterogeneous to homogeneous physical and chemical conditions (see Section 3.2.3), and (2)

[23] Appendix SCR entry SCR.2.1.5 states, without further support, that backfill physical properties have been eliminated on the basis of low consequence.

the radionuclide release calculations should include the possibility of failure or insufficient reaction with the backfill and evolving CO_2[24].

3.3.2 Processes related to the magnesium oxide backfill

The magnesium oxide (MgO) backfill will react with the incoming brines and form magnesium hydroxide ($Mg(OH)_2$). If CO_2 is present, e.g. from waste degradation, magnesite ($MgCO_3$) will be formed after passing through intermediate, thermodynamically meta-stable phases such as dypingite, nesquehonite, and possibly others. This has implications for repository void volume, temperature and water budget as discussed below.

The chemical reaction of the MgO will result in a volumetric expansion of the backfill material. The reactions from MgO into magnesium hydroxide, and then into magnesite, increase the volume by factors of 2.2 and 2.4, respectively. Higher expansion factors can be reached when the intermediate phases between magnesium hydroxide and magnesite are considered.

This volumetric expansion is important and affects, for instance, the void volume that needs to be considered in the analyses of gas pressurisation effects, and may even reduce the pore volume locally to such an extent that uniform chemical mixing of the pore fluids cannot be assumed. Overall, the volumetric expansion of the MgO may entail both positive and negative implications, and a full examination needs to be carried out.

The hydration of MgO is an exothermic process. The heat generated will be deposited locally in each waste panel and it may not be readily dispersed as assumed in the CCA. This is because the waste panel material - mixed waste, backfill, and gas-filled void spaces - will have a relatively low thermal conductivity compared with halite, for example.

The thermal problem warrants a more complete analysis taking into account uncertainties in geometry and other parameters. The implications for the evolution of the underground facility will then need to be examined.

The hydration of MgO requires water, but its carbonation releases the water taken up in the hydration step. Thus water is not consumed in the hydration-carbonation process and will be available for further reaction with the waste and the backfill, and for radionuclide release.

This additional source of water and feedbacks to thermal and volumetric expansion processes are not addressed in the CCA, and warrant fuller consideration.

Overall, the IRG concludes that not all the physical implications of the chemical reactions that the MgO backfill may undergo have been explored in the CCA. This is an important omission. At the very least, the processes have the potential to modify the temporal evolution of the physical environment in the waste panels. The IRG recommends that the DOE give

---

[24] There are two issues here: insufficient chemical conditioning at the disposal room scale which would affect releases in the undisturbed case and E1E2 scenario; insufficient chemical conditioning at a smaller scale which may be relevant to the E1 and E2 scenarios.

urgent attention to a fuller examination of the physical implications of the hydration and carbonation of the MgO backfill material.

3.3.3 Calculation of actinide solubilities

The methodology used by the DOE to calculate the actinide solubilities in the repository assumes thermodynamic equilibrium for the main driving geochemical reactions, but excludes the possibility of redox equilibrium for the dissolved actinides.

This probably results in conservative estimates of actinide solubilities, although it is unsatisfactory from a chemical point of view.

The methodology for the derivation of the solubilities as reported in the CCA and Appendix SOTERM does not accord with the procedures used to derive similar parameters in performance assessments in other countries [e.g. SKB 1992; Nagra 1994]. Through discussions with the DOE and contractor staff responsible of this area, and by examining tertiary reports and scientific papers, however, the IRG confirmed that the procedures used in the calculation and derivation of the actinide solubilities were reasonable in terms of the quality of primary laboratory data used and the method of the calculations.

To accord with the methodologies used in other performance assessments, the DOE should include the key thermodynamic data used to derive the actinide solubilities, as well as the procedures used to independently check the validity of the solubility data in a comprehensive and accessible report, either as part of the Appendix SOTERM or as an additional document within the CCA document set.

3.3.4 Two-phase-flow and coupled mechanical and hydraulic modelling

Brine and gas movements in and around the repository and the Salado formation are affected by creep and the production and movement of gas. The coupled processes of brine and gas movement are accounted for by applying the BRAGFLO two-phase-flow model. The modelling also includes other basic features of the disposal system such as the generation of gas by different sources, the change of permeability of the marker beds due to the pressure in the repository, and the creep convergence as a function of the pressure.

The BRAGFLO model is state-of-the-art in two-phase, gas-brine modelling, and its application in performance assessment is in advance of practice in other countries. The model appears to represent all the important coupled hydrologic processes which could take place at repository level and within the marker beds.

The creeping of salt and the pressure build-up in the repository, i.e. the coupling between mechanical and hydraulic processes, is not represented mechanistically. The creeping of salt is modelled in the code SANTOS and the pressure built-up is handled in BRAGFLO. These codes run independently. A porosity surface, which gives the porosity as a function of time and pressure is generated by SANTOS, and the porosity values are picked up by BRAGFLO from this two-dimensional function at each time step.

It is not shown that this method is conservative under all circumstances.

To model brine intrusion into the repository from a Castile reservoir after a future drilling, the brine release to the repository model is estimated by a simple model in which the volume of the brine reservoir and its compressibility are sampled. The parameter range for the volume of the reservoir appears to be an underestimate, whereas the compressibility covers unrealistically high values.

This is a simple approach, but may be sufficient on the basis of currently available data (see, however, comments in Section 3.1.1). The combination of parameter values in the model leads to a very broad range of releases which exceeds the available amount of brine, and probably encompasses a sufficient degree of conservatism.

3.3.5 Modelling of the Culebra hydrology

The Culebra is a fractured and inhomogeneous aquifer system, varying in both horizontal and vertical directions. It is modelled as a horizontal, confined, porous-medium layer with the heterogeneity of the formation represented by statistically generated transmissivity fields. The modelling effort concerning the flow and transport in the Culebra has been considerable in the last few years, and has been the basis for an international intercomparison exercise.

The variability of the hydraulic properties of the Culebra has been treated by a state-of-the-art modelling approach. However, the IRG could not fully trace the incorporation of individual features, such as the instationarity of the flow regime and the density effects to the flow scheme. A more simplified and traceable approach might be preferable in the performance assessment calculations.

An issue of concern for the modelling of the Culebra flow (and especially for the definition of future flow direction on the basis of present head measurements) is the inconsistency between the measured geochemical and isotopic data, and the flow directions inferred from head and transmissivity measurements.

This issue is poorly reported in the CCA and deserves more attention. From the information received during the review, it seems that more recent 3D-modelling of the Culebra[25] *could help to correlate flow directions and observed geochemical and isotopic data.*

3.3.6 Modelling of radionuclide transport

The modelling of nuclide transport in the Salado formation is based on the time-dependent, advective flow field for the liquid phase from the two-phase-flow modelling. The transport in the Salado formation does not account for diffusion and dispersion terms.

Diffusion is likely to be significant in such a low flow environment, and dispersion may be significant in the anhydrite marker beds. Examination of time-dependent results indicate

[25] The recent study simulates the hydrogeology of the regional basin over the period from 14,000 years in the past to 10,000 years in the future. Infiltration from the overlying beds and the regional transient response to changes in the rate of recharge due to past climatic changes are represented.

that there is significant numerical dispersion, and this may be greater than the true physical effects of diffusion and dispersion. This is unsatisfactory from a modelling point of view and, taking into account the time cut-off of the assessment, the results are not necessarily conservative.

The modelling of nuclide transport in the Culebra formation is based on the steady-state flow fields from the groundwater flow modelling, and modelling of a conservative-tracer. Other processes such as sorption and radioactive decay are then factored in multiplicatively. The chemical retardation of actinide transport is conceptualised by sorption on to the dolomite component of the formation. No credit is given to the existence of clays in the formation, but there is a reliance on matrix diffusion effects as a retardation factor.

The conceptual model used to handle the chemical retardation of actinides through the Culebra appears to be conservative, and the contribution of matrix diffusion is backed up by extensive hydrogeological and tracer tests of the formation. This, however, is not well documented in the CCA. The confidence of the IRG in the experimental basis for the dual-porosity concept applied to the Culebra (and especially the importance of matrix diffusion) comes from prior knowledge of the WIPP programme.

The colloidal transport of radionuclides is considered in detail in the CCA. Different colloidal forms (i.e. humic, microbial, mineral fragment and intrinsic actinide colloids) are distinguished. In the Salado, sorption and filtration processes of dissolved and colloidal forms are neglected. In the Culebra, colloidally transported radionuclides are assumed to remain associated with their colloid carriers. The transport of microbial and mineral-fragment colloids is neglected due to filtration effects. Intrinsic actinide colloids are assumed to occur in insignificant quantities. The sorption of humic colloids is assumed to be the same as the sorption of dissolved radionuclides.

The experimental basis for the above model assumptions is sparse, at least as documented in the CCA. The treatment in the Salado is clearly conservative but the situation is less clear for the modelling of actinide transport in the Culebra.

3.4 System Modelling and Calculations

3.4.1 The system model framework

The WIPP performance assessment is based on a probabilistic analysis using an integrated system model. The major computer codes and the flow of information among them, as they are used to generate radionuclide releases are illustrated, e.g. in Figure 6.25 of Volume I of the CCA, and well documented in Appendix CODELINK.

The limited examination of CCA documents by the IRG, indicates good code configuration and management of data flows. The IRG has confidence that the procedures applied in these areas are consistent with best practice for performance assessment internationally. The IRG is also aware of the long involvement of the WIPP project in international comparison exercises which gives confidence in the performance of several of the component models.

The strategy for connecting submodels is different from that usually adopted in assessment of multi-barrier systems. Usually, an assessment model will consider a linear set of sub-models (e.g. source term, near field, geosphere, biosphere) which may be supported by more detailed models of specific processes (e.g. hydrogeology, geochemistry). In the CCA, a relatively detailed model of hydraulic performance (coupling mechanical and hydraulic pressure, repository gas generation, gas and brine movements) of the whole disposal system - BRAGFLO - is at the core of the analysis.

The codes are not run as a directly coupled system. Rather, for reasons of computing efficiency and convenience, families of simulations are performed with each code (in particular the BRAGFLO, BRAGFLO_DBR and CUTTINGS codes) and outputs held in intermediate files ready to be picked up for uncertainty analysis or input to further calculation (see Section 3.4.3).

Subjective uncertainty in the disposal system parameters (see Section 2.2.5) is represented by latin-hypercube sampling (LHS) of parameters within the BRAGFLO and NUTS models. Parameters which are expected to evolve significantly over time, such as fluid pressure, saturation and porosity, are calculated as a time-evolving function of time-independent parameters. Uncertainty in the models adopted is not addressed directly, although, in some cases, the parameter distributions represent alternative assumptions concerning the possible evolution of the repository.

The overall system-model framework is appropriate, and well suited to the physical and phenomenological characteristics of the disposal system. However, operational factors affect the way the codes are run and linked together (see Section 3.4.3).

3.4.2 Undisturbed performance calculations

Within the 10,000-year period considered, the only pathway by which releases are estimated to occur is through movement of contaminated brine through the marker beds. Movement up the sealed shafts is modelled but no releases occur within the period of regulatory interest. Contamination reaches the site boundary by migration in the marker beds in 9 of 300 calculations.

Although there is no plausible path by which contaminants in the marker beds should then reach the human environment, the EPA requires the DOE to calculate doses corresponding to this release. To effect a calculation, it is assumed that brine from the beds is diluted with fresh water by a factor of about 30 to bring the total dissolved solids of the solution down to about 10,000 mg l^{-1}. This water is then used as a source of human drinking water at a rate of 2 l d^{-1}. This scenario, which must be considered conservative, gives rise to dose estimates in the range zero (for most simulations) to 0.5 mrem y^{-1} (0.005 mSv y^{-1}) compared to a dose limit of 15 mrem y^{-1} specified by the EPA.

The analysis may be sufficient for the EPA requirement. The IRG observes, however, that only two or three of the 300 simulations would contribute to the arithmetic mean of dose, i.e. the result is unlikely to be converged, although so low as to be of no concern.

3.4.3 Disturbed performance calculations

To represent the disturbed case the detailed model - BRAGFLO - is run 300 times for each of six subjectively-selected deterministic scenarios (determined sequences of future drilling penetrating the repository). These results are used to generate a look-up table of estimated conditions of brine and gas pressure, and their evolution after repository penetration, for other times of intrusion. A larger number of calculations by BRAGFLO_DBR and CUTTINGS are required to generate look-up information on radionuclide releases considering radioactive decay. The CCDF-GF code is then used to generate random sequences of future drilling, including times of intrusion. The code automatically picks appropriate results from the previously-generated look-up tables.

This procedure, which is adopted for operational reasons, carries a possibility of introducing bias. It would be prudent to verify the procedure by running the detailed model set for a selected set of time sequences generated by CCDF_GF and to compare outputs (e.g. time history of release and total release) with the results from the interpolation procedure employed in the CCA calculations. The selected sequences should include at least some in which multiple drilling events occur at early times when radioactive decay is most rapid. Satisfactory agreement in respect of total release in a 10,000-year period will be much easier to achieve than satisfactory agreement over time. Therefore, the IRG estimates that the bias is unlikely to be significant for the cumulative estimates of release required by the EPA.

The concentration of radionuclides in solid waste and in brine, calculated by CUTTINGS and BRAGFLO_DBR respectively, is depleted only in respect of radioactive decay, i.e. the inventory of solid wastes is not depleted due to dissolution in brine and the total inventory of the repository is not depleted due to movement of contaminated brine away from the wastes, e.g. into the marker beds.

This is conservative, leading to some "double-counting" of activity in direct brine and cutting releases and, possibly, to an over-estimate of radionuclides in direct releases, especially for more mobile elements.

To investigate the range of model behaviours that can be generated by subjective uncertainty, 300 simulations are carried out for each subjectively selected deterministic scenario (see above).

There is a concern over whether this relatively small sample size is sufficient to adequately explore the range of behaviours of such a complex model. Time-dependent intermediate results[26] indicate the presence of outlying results, which reinforce this concern. The requirements set by the EPA in respect of statistical meaningfulness of the result are trivial. To meet the EPA containment requirement is a much less demanding condition statistically[27] than if the end-point of concern was risk or mean dose. The IRG observes that it is likely that

[26] "Preliminary Summary of Uncertainty and Sensitivity Analysis Results Obtained in Support of the 1996 CCA for the WIPP", memo by J. Helton, 12/23/96.

[27] For example, simulations with a probability of less than 1 in 1,000 are of no concern at all. This is in contrast to assessments of risk in which simulations with a much lower probability than this can contribute significantly to total risk or mean dose.

the behaviour of the models has not been fully explored but that the number of samples may be sufficient for the purpose of demonstrating compliance with EPA regulations.

Overall, the IRG concludes that the analysis of disturbed performance in the CCA is a competent technical analysis and may be sufficient to meet the EPA requirements. The CCDFs are an appropriate method of summary presentation. The case, however, could have been considerably strengthened by presentation of additional intermediate results, especially as a function of time. These would have given better quantitative understanding of the physical processes operating, and hence confidence in the results as expressed in the form of the CCDFs.

3.4.4 Supplementary radiological calculations

The IRG requested the DOE to provide information on the levels of contamination at the surface and radiation doses which might be received as a result of drilling of a borehole into the repository. This information is not required by the EPA and is not available in CCA. The DOE was able to provide this information, informally, for an intrusion at 1,000 years after closure, by extending calculations already made within the analysis of disturbed performance.

The drilling scenario considers the transfer of radionuclides from the repository to the surface environment in the form of drilling cuttings, spallings and brine releases. Radiation doses are estimated to the drill operator from external irradiation due to the handling of drill core samples and due to exposure to radionuclides which accumulate in a mud pit. The dose to the workers during the remediation of the mud pit due to the inhalation of wind-borne material is also evaluated, as are the concentrations of radionuclides that would remain as a potential radioactive anomaly after remediation.

These supplementary calculations have not been formally reviewed by the IRG. They are, however, of value to set the impacts of the drilling scenario in perspective. In particular, they allow the IRG to draw the conclusion that, at least for this scenario, it is likely that the WIPP facility could meet an individual risk-based standard typical of those used in other countries.

3.5 Documentation

The IRG appreciates the very substantial effort that is required to document a performance assessment and its basis at the level of detail that is presented in the CCA. The IRG also appreciates that the documentation was drafted and assembled in a remarkably short period of time, consistent with schedule requirements of the DOE . Cross-referencing, at least between the Volume I and Appendices, is generally good, and is much eased by the use of the electronic version on CD-ROM.

Overall, the IRG finds the CCA difficult to follow and is disappointed with the CCA as a technical description. The main criticisms are that:

- *the documents are repetitious;*
- *many statements concerning the need, or not, to represent processes in the analyses are not sufficiently supported, e.g. by site-specific and experimental evidence, reasoned arguments and reference to natural analogues;*
- *relevant or important information is not always brought forward into Volume I of the CCA, and reviewers had to go deeply into the appendices or referenced documents.*

As a result, it was laborious for the IRG to understand, from the CCA, what was done in the performance assessment: not all the issues of concern could be traced, even using the electronic version of the documentation.

The clarity and general usefulness of the CCA documents to wider audiences have suffered as a result of the guidance from the EPA on content, and possibly also as a result of the limited time available for internal scientific review by the DOE. The IRG suggests that, provided this would not interfere with its prime requirement to achieve approval of the CCA from the EPA, the DOE should consider preparing a more generally-based performance assessment overview document at a level suited to a general technical audience.

4. Conclusions

The results of the review are summarised in the following sections which present:

- observations on the specificity of the WIPP case;
- the evaluation of the CCA against the Terms of Reference specified for the review, in particular, whether the 1996 performance assessment is:
  - appropriate in the context of the EPA requirements,
  - technically sound,
  - in conformity with international practices, and
  - in conformity with international guidance and standards;
- the overall judgement arising from the experience of the review.

4.1 Observations on the Specificity of the WIPP Case

The WIPP project, and the CCA, are different in several respects from geological disposal projects, and assessment documentation, in other countries.

- The WIPP facility is sited in an area in which mineral resources are being actively and extensively exploited.
- The regulator has provided detailed guidance on the assessment approach, documentation and, for the assessment of future human actions, model assumptions.
- The CCA is tightly focused on compliance with the EPA regulations, and does not represent a full safety case as understood in most other countries.

These observations are statements of fact, not criticisms. Such differences, however, have had a strong influence on the performance assessment carried out by the DOE, and have been taken into account by the IRG in formulating its conclusions.

4.2 Evaluation with Respect to the Terms of Reference

4.2.1 Appropriateness

The CCA was specifically designed by the DOE to meet the requirements of the EPA regulations. The IRG has not, during its review, found any indication that the information presented is not appropriate in the context of the EPA requirement. This, however, is a matter for the EPA to judge.

4.2.2 Technical soundness

The analyses contained in the CCA are based on an extensive geological data set resulting from high quality acquisition programmes and compilation of regional data. This has been supplemented by a focused geotechnical and experimental programme that has provided a world-leading understanding of processes relevant to rock-salt behaviour. The uncertainty associated with characterisation of the wastes, processes related to waste and backfill evolution in the repository, and chemical speciation of radionuclides in the repository environment, are less well understood. In particular:

(1) the CCA does not sufficiently explore the possible physical implications of the chemical reactions that the magnesium oxide backfill may undergo. These implications may be both favourable and unfavourable to the performance of the facility;

(2) the CCA does not support the assumption, applied in the performance calculations, that the physically and chemically heterogeneous array of waste, packaging, backfill, reaction products, and void space, will quickly reach well-mixed homogeneous conditions within the disposal rooms. The basis for this assumption and implications of heterogeneities need to be analysed further.

The CCA indicates good code configuration and management of data flows. The IRG has confidence that the procedures applied in these areas are consistent with best practice for computer simulation internationally. The IRG is also aware of the long involvement of WIPP project in international comparison exercises, which gives added confidence in the performance of several of the detailed models.

Thus, the IRG has overall confidence in the majority of judgements and assumptions made in developing calculational models of the disposal system, and concludes that, in the main, the analyses presented in the CCA are based on appropriate studies and are technically sound.

4.2.3 Conformity with international practices

The methods used to assess the performance of the WIPP facility are generally in conformity with practices used in other countries. These include:

- the selection of features, events and processes (FEPs);
- development of scenarios and models representing the evolution of conditions in the repository, and the release of radionuclides;
- quantitative analysis of selected scenarios by means of a linked set of models and comparison of the results to regulatory limits.

The probabilistic analysis methods used by the DOE are comparable to those employed in a number of other countries, and the DOE contractors have contributed substantially to the development of probabilistic methods in the field of repository post-closure assessment.

Specific aspects of the assessment carried out by the DOE do not accord with assessment practices in other countries, and this can be partly traced to the influence of the EPA regulations and the strong focus of the CCA on compliance. For example:

- the probabilistic approach applied by the DOE deals only with parameter-based uncertainty. Conceptual model and scenario uncertainty, are not discussed in the CCA. These are considered to be important internationally;

- results in the CCA focus on the CCDFs of cumulative radionuclide release. Information on the behaviour of intermediate parameters and results of representative deterministic calculations, especially as a function of time, are lacking. Without this, it may not be possible to develop a good understanding of the behaviour of the disposal system;

- the EPA has ruled that the DOE only needs to consider a limited set of future human actions, and has specified the assumptions to make in assessing these actions. Thus, some scenarios that might affect safety have not been evaluated. The lack of a logically-argued explanation for the choice of scenarios analysed, or evaluation of these other scenarios, leads to the impression that the assessment is arbitrary.

4.2.4 Conformity with international guidance and standards

The CCA focuses on a demonstration of compliance with the EPA containment requirement. The latter is based on collective dose considerations, refers to the total activity in the repository, and cannot be related to the standards based on individual dose and risk adopted in most other countries. Moreover, the EPA regulations do not require the applicant to present descriptions or arguments concerning the performance of the disposal system beyond the 10,000-year regulatory period. Thus, for the general case, the CCA does not present calculated end-points that can be compared with international guidance and standards as implemented in other countries.

The CCA does present dose estimates for the undisturbed performance within the 10,000-year regulatory period based on a conservative hypothetical dose pathway. In this case, the results indicate that the WIPP can easily meet typical performance criteria based on dose to the individual. It is likely that, if undisturbed, the facility could meet individual dose criteria over much longer times, due to the long-term stability of the site and the absence of viable fresh water resources locally.

The IRG asked for information, not included in the CCA, on doses that might be received in the disturbed case, as result of drilling of a borehole into the repository. The results provided by the DOE indicated that, for this scenario, the WIPP facility would meet an individual risk-based standard typical of those used in other countries. The CCA does not demonstrate, however, that no other scenarios could contribute significantly to risk.

4.3 Overall Judgement

The WIPP project and the CCA are markedly different from geological disposal projects and assessment documentation in other countries. In particular, important decisions relating to what is a sufficient method and scope of assessment have already been taken, and the CCA is not required to present a complete performance assessment as understood internationally.

The CCA documentation is not transparent and is difficult to follow even from the point of view of experienced performance assessment practitioners. Technical issues are often difficult to trace and some of the choices made and modelling assumptions are not well supported. This, combined with the specificity of the EPA regulations, made it challenging to distinguish between decisions determined by the regulator and those made by the DOE.

Focusing on the decisions for which the DOE must take technical responsibility, the IRG finds that the performance assessment methodology implemented in the CCA is generally acceptable and conforms to practices in other countries. The IRG also has overall confidence in the majority of judgements and assumptions made in developing calculational models, and believes that the quality of assessment codes and data handling is generally good. Thus, in the main, the analyses contained in the CCA are technically sound.

On specific points, the IRG considers that the DOE should give further attention to:

(1) the implications - favourable and unfavourable - that the behaviour of the magnesium oxide backfill may have on the performance of the facility;

(2) the basis for the assumption that homogeneous conditions will be rapidly reached in the disposal rooms, and the potential consequences of heterogeneities in the source term.

The IRG is of the view that, in the case of undisturbed performance, the WIPP facility would meet radiological performance standards typical of those used in other countries. This judgement is based on the analysis presented in the CCA in respect of the 10,000-year regulatory period and, in respect of times beyond 10,000 years, on the geological stability of the site and the absence of viable fresh water resources. The case of disturbed performance is less clear: supplementary analyses by the DOE indicate that a risk target would be met in respect of an exploratory borehole drilling scenario. The CCA does not (and need not) make the case that this is the most important scenario to consider and, therefore, the IRG cannot reach a definite judgement.

Finally, from the experience of the review, the IRG observes that, by commissioning this international peer review the DOE has demonstrated a commendable openness and commitment to improving confidence in the performance assessment of the WIPP facility. The DOE and their contractors were very open in their discussions with the IRG, and were able to provide useful responses, often at short notice, on most issues raised. This was very useful and helpful to the review.

5. References

DOE 1996. Title 40 CFR Part 191 Compliance Certification Application of the Waste Isolation Pilot Plant. Volume I and appendices. US Department of Energy, Carlsbad Area Office, Carlsbad.

EPA 1996. Compliance Application Guidance for CFR Part 194. US Environmental Protection Agency, EPA 402-R-95-014, March 29, 1996.

IAEA 1994. Safety Indicators in Different Timeframes for the Safety Assessment of Underground Radioactive Waste Repositories. International Atomic Energy Agency TECDOC-767.

IAEA 1996. Issues in Radioactive Waste Disposal, International Atomic Energy Agency TECDOC-909

IPAG 1997. Lessons Learned from Phase-1 Activities (1995-1996). Final Report of the Working Group on Integrated Performance Assessments of Deep Repositories (IPAG). Document NEA/IPAG/DOC/(97)1, available on request from the OECD/NEA, Paris.

Kaplan, S. and Garrick, B.J. 1981. On the quantitative definition of risk. Risk Analysis 1(1), pp. 11-27.

Nagra 1994. Kristallin-1 Safety Assessment Report. Nagra Technical Report NTB 93-22, Wettingen, Switzerland.

NAS Committee on the WIPP 1996. The Waste Isolation Pilot Plant: A potential Solution for the Disposal of Transuranic Waste. National Academy of Sciences Committee on the Waste Isolation Pilot Plant Report, National Academy Press, Washington DC.

NEA 1992. Safety Assessments of Radioactive Waste Repositories: Systematic Approaches to Scenario Development. Report of the NEA Working Group. Published by OECD NEA, Paris.

NEA 1995. Safety Assessments of Radioactive Waste Repositories: Future Human Actions at Disposal Sites. Report of the NEA Working Group. Published by OECD NEA, Paris.

SKB 1992. SKB 91: Final disposal of spent nuclear fuel: Importance of the bedrock for safety. Swedish Nuclear Fuel and Waste Management Co. Report 92-20, Stockholm.

Stenhouse, M.J., Chapman, N.A. and Sumerling, T.J. 1993. SITE-94 Scenario Development FEP Audit List Preparation: Methodology and Presentation. SKI Technical Report 93-27, Swedish Nuclear Power Inspectorate, Stockholm.

SSI 1993. Conservation and Retrieval of Information. Final Report of the Nordic Nuclear Safety Research Project KAN-1.3, NKS Report 1993:596, Roskilde, Denmark (also published as SKB Report 96-18; December 1996).

Sumerling, T.J. et al. 1996. The probability of future human actions affecting a geological repository for nuclear waste: developing a model that incorporates information science and historical perspectives. In <u>Probabilistic Safety Assessment and Management</u>, Cacciabue, P.C. and Papazaglou, I.A. (eds.), Springer, pp. 2178-2184

Appendix 1: The Members of the Review Group

Ken BRAGG (AECB, Canada) - Group Chairman

Ken Bragg graduated from the University of Toronto in 1965 with a Bachelor of Applied Science in Engineering Physics. He has 25 years' experience with industry and several government departments (Mines branch, Environment, and the Atomic Energy Control Board) covering a wide variety of industrial and radioactive wastes, such as uranium and other mine tailings, low-level radioactive waste, spent nuclear fuel, municipal waste and various effluent discharges from industry.

He served as a member of the Secretariat of the OECD/NEA in Paris for three years. He joined the Atomic Energy Control Board (AECB) in 1979 with responsibilities for uranium mine tailings and spent-fuel disposal. His current position is Head of the Nuclear Fuel Wastes & Special Assessments Section.

He has been a member of the Radioactive Waste Management Committee (RWMC) of the OECD/NEA since 1983, and the Chairman of the IAEA Working Group on Principles and Criteria for Radioactive Waste Disposal and of the NEA Working Group on the Regulatory Aspects of Future Human Actions at Radioactive Waste Disposal Sites.

Arnold BONNE (IAEA) - Secretariat

Arnold Bonne graduated from the University of Leuven (Belgium) in geological sciences.. He completed a Ph.D. in Natural Sciences (Metallogeny) in 1973, at the same university, and for the following 5 years held a research position at the Belgian National Research Foundation. He joined the National Nuclear Research Establishment SCK/CEN at Mol in Belgium in 1978 and was involved in the Geological Disposal research programme. From 1989 to 1993 he headed the Research Unit on Disposal and Waste. He acquired a broad experience in site investigation, performance assessment and waste characterisation and became acquainted with the international approaches to them through his participation in numerous advisory groups and committees, e.g. he was member of the Steering Committee of the European Commission's PAGIS programme (Performance Assessment of Geological Isolation Systems).

In 1993, he joined the International Atomic Energy Agency (IAEA), Vienna, to lead the unit on disposal of radioactive waste and was appointed Acting Head of the Waste Management Section (now Waste Technology Section) in mid-1995. He is also programme manager of the Waste Management Technical Review Programme (WATRP) at the IAEA.

Jordi BRUNO (QuantiSci, Spain)

Jordi Bruno holds a Master's Degree (M.Sc.) in Analytical and Inorganic Chemistry from the Autonomous University of Barcelona, Spain (1978), and a Ph.D. in Inorganic Chemistry from the Royal Institute of Technology, Stockholm, Sweden (1986). From 1988 to 1990 he was Associate Professor at the same Institute, where he headed the Natural Waters Chemistry Group. He also holds a Master of Business Administration (MBA) from the School of Economics of Stockholm, Sweden (1990). Since 1990, he has been a consultant in the field of environmental issues, and is now Managing Director of QuantiSci SL in Barcelona, Spain. Since 1996, he has been Associate Professor to the Institute of Environmental Sciences of the Autonomous University of Barcelona, Spain.

His areas of professional expertise include spent-fuel dissolution, actinide thermodynamics, radionuclide geochemistry and mobilisation, geochemical modelling, and performance assessment. He performed research work for the SKB (Sweden), and ENRESA (Spain). He has been involved in several international programmes within the European Commission (e.g. MIRAGE) and the OECD/NEA (e.g. GEOVAL, Sorption Modelling Project).

Klaus KÜHN (Technical University of Clausthal, Germany)

Klaus Kühn graduated from the Clausthal School of Mines (now Technical University of Clausthal) with a Dipl. Ing. in Mining Engineering, in 1963. He then worked as an assistant at the Mineralogical-Petrographic Institute of the same University. In 1968, he obtained a Ph.D. (Dr. Ing.) from the Technical University of Clausthal for a thesis on the geochemistry of nickel and cobalt. In 1987, he was appointed Honorary Professor at the same University where he is presently teaching and carrying out research part-time.

His professional activities have concerned all aspects pertaining to the disposal of radioactive waste, notably by substantial involvement in the development of the GSF-Institut für Tieflagerung. In 1973, he was appointed Director of the Institute and Head of its Department of Repository Technology. After the Institute disbanded in 1995, he was appointed Senior Scientist to the Asse Research Mine, where the majority of the in-situ investigations for the German disposal program are performed. He has also been a member of the Reaktor-Sicherheitskommission (RSK) which advises the Ministry of the Environment, Nature Conservation and Reactor Safety (BMU) on all topics related to safety of nuclear installations including the nuclear fuel cycle.

For some ten years he was one of the German representatives to the IAEA's "Technical Review Committee on Underground Disposal of Radioactive Wastes (TRCUD)", and, in 1993, chaired the International Peer Review Team which reviewed the radioactive waste management program of Finland in the WATRP framework. He was the first Chairman of the OECD/NEA "Co-ordinating Group on Geological Disposal" in 1975, and served for about seven years.

Philippe LALIEUX (OECD/NEA) - Secretariat

Philippe Lalieux is a geologist and geophysicist with ten 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 Master's Degree (M.Sc.) in Geophysical Sciences from the same university in 1984. From 1986 to 1994 he was a staff member of the Belgian Agency for the Radioactive Waste and Enriched Fissile Material (ONDRAF/NIRAS). His responsibilities included the management and supervision of geoscientific characterisation of potential sites for deep and near-surface repositories, and natural analogue studies. He was also in charge of the co-ordination and defence of a Safety Assessment and Feasibility Interim Report (SAFIR).

He joined the OECD/NEA Secretariat in 1995. He is in charge, within the Radiation Protection and Radioactive Waste Management Division, of the programmes on site characterisation and evaluation. In particular he is responsible for the Technical Secretariat of the Co-ordinating Group on Site Evaluation and Design of Experiments for Radioactive Waste Disposal (SEDE). His current activities also entail involvement in the NEA performance assessment related activities, notably through the launching of the GEOTRAP project on radionuclide transport.

Gordon LINSLEY (IAEA) - Secretariat

Gordon Linsley graduated from the University of Sheffield, in the United Kingdom in 1964 with a B.Sc. in physics. He went on to complete a Ph.D. in solid state physics, awarded in 1969, from the same university. From 1967, he worked in the field of medical physics for the Western Regional Hospital Board, in Glasgow, Scotland before specialising in the area of radiation protection. He was a staff member of the United Kingdom's National Radiological Protection Board (NRPB), Harwell, Oxfordshire, from its inception in 1970 until 1984. During a period as a radiation protection advisor, he acquired a broad experience in relation to the uses of ionising radiations in industry, research and medicine. In 1976, the focus of his work changed to environmental impact assessment and subsequently, he led a section at NRPB, working on this subject.

In 1984, he joined the International Atomic Energy Agency (IAEA), Vienna, Austria, to lead a small group concerned with the environmental aspects of radioactive waste management, safety assessment and radiological criteria for application to waste management. In 1996, he was appointed Head of the newly-formed Waste Safety Section at the IAEA. This section is responsible for establishing international safety standards in the area of waste management.

Sören NORRBY (SKI, Sweden)

Sören Norrby is a chemist with more than twenty-five years' experience in the field of radioactive waste management and disposal. He obtained his M.Sc. in Chemistry at the University of Uppsala, Sweden, in 1970. He worked for five years at the University of Uppsala on research projects mainly in the field of chemical radionuclide separation techniques. He worked for eight years at the Swedish Radiation Protection Institute (SSI) and was engaged in radioactive waste management and disposal matters.

Since 1980 he has worked for the Swedish Nuclear Power Inspectorate (SKI), since 1987 as the Director of the Office of Nuclear Waste. He has been engaged in supervision, regulatory review and licensing of nuclear waste management and disposal facilities in the Swedish nuclear waste programme (e.g. an intermediate storage facility for spent-fuel and a repository for low- and intermediate-level waste). He is also engaged in the review of the Swedish R&D programme on final disposal of spent nuclear fuel. He has served on several governmental committees to review Swedish legislation on nuclear waste. He is active in many aspects of international co-operation in the field of radioactive waste management and disposal.

He is a member of the Radioactive Waste Safety Standards Advisory Committee (WASSAC) at the IAEA and of the Radioactive Waste Management Committee (RWMC) at the OECD/NEA. He is the Chairman of the ACPM for the Community Plan of Action in the Field of Radioactive Waste.

Claudio PESCATORE (OECD/NEA) - Secretariat

Claudio Pescatore obtained a Laurea, *cum laude*, in Applied Physics from the University of Bologna in 1975 and a Ph.D. in Nuclear Engineering from the University of Illinois, Urbana-Champaign (US) in 1982. He has 19 years' experience in research and development, technical assistance to government and industry, university lecturing, and management of international programmes in the field of nuclear waste covering low-level waste, high-level waste, and spent-fuel storage and disposal.

He 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; reliability and modelling studies of waste package materials during storage and disposal; analyses of gaseous and aqueous pathways for radionuclide migration; peer reviews of environmental impact assessments studies and site characterisation plans. In 1989 he was nominated Group leader for Radioactive Waste Performance Assessment. Through 1995, he also was adjoint Professor of Marine Environmental Sciences at the University of New York at Stony Brook.

He joined the NEA/OECD Secretariat in 1992 in the Division of Radioactive Waste Management. He is in charge of the Agency's performance assessment programmes, and provides the technical secretariat of the Performance Assessment Advisory Group, the Probabilistic System Assessment Group, the group on validation/confidence building in safety assessments, and the Integrated Performance Assessment Group. He also contributes in the field of site characterisation, and has been at the centre of several international initiatives such as the ASARR and GEOTRAP projects, and the GEOVAL'94 symposium. He was a Secretariat member of the international peer reviews of SKI's Project 90 and of the AECL Postclosure Assessment for the EIS on the Concept for Disposal of Canada's Nuclear Fuel Waste.

Richard STORCK (GRS, Germany)

Richard Storck was educated at the Technical University of Berlin as a nuclear engineer. He graduated from the same university with a thesis on probabilistic risk assessment of technical nuclear facilities (1980). He then worked as a scientific employee of the Technical University of Berlin for four years, on the first German project on the long-term safety of deep underground disposal systems for radioactive waste in salt formations (PSE).

He continued this work as a Group and Project Manager at the GSF research centre in Braunschweig. He was involved in the European performance assessments for high-level (PAGIS) and low-level waste (PACOMA), the long-term safety assessment for the application of the abandoned iron ore mine at the Konrad site for disposal of non-heat-producing radioactive waste, performance assessments for the planned repository at the Gorleben site for all types of waste including spent-fuel (SAM).

In 1995, he joined GRS (Gesellschaft fur Anlagen und Reaktorsicherheit) following the transfer of the repository research area of the GSF research centre to the GRS. Since that time he has been Head of the Long-Term Safety Analyses Department. One of his current main tasks is the long-term safety assessment of the Morsleben repository for low-level waste in the eastern part of the country.

Trevor SUMERLING (Safety Assessment Management Ltd., United Kingdom)

Trevor Sumerling obtained a 1st class honours degree in physics from Lancaster University in 1975. He spent 8 years at the UK National Radiological Protection Board where he gained experience in the fields of in vivo monitoring, internal dosimetry and environmental transfer of radionuclides, and became responsible for the in vivo measurement facilities and various environmental field studies at the NRPB. For the past 10 years he has worked in scientific and engineering consultancies on aspects of radioactive waste disposal assessment and assessment management. In this period, he has contributed significantly to nuclear waste disposal assessment projects in the UK, Switzerland, Sweden, Canada and Japan. He is now Director of Safety Assessment Management Limited, an independent consultancy specialising in radioactive waste disposal assessment.

His more recent experience has included:

- project co-ordination for an independent performance assessment of the Sellafield site and review of the proponent's safety documentation on behalf of the UK regulator, as well as development of assessment procedures and contributions to UK regulatory guidance documentation;
- scenario methodology development and application to both the Kristallin-I (HLW) project and Wellenberg (L/ILW) site, as well as technical work and editing contributing to the Kristallin-I safety assessment report, for the Swiss National Co-operative for Radioactive Waste Disposal;
- carrying out an international comparison of disposal concepts and assessments of nuclear fuel wastes for Atomic Energy of Canada Limited as input to the federal review process in Canada;
- participation in the NEA OECD "FEP Database" and "Integrated Performance Assessment" working groups.

Mr. Sumerling was retained as a consultant to assist the Secretariat in compiling and editing the report of the current review.

Hiroyuki UMEKI (PNC, Japan)

Hiroyuki Umeki is a nuclear-chemical engineer with more than 15 years' experience in the field of radioactive waste management. He obtained his Bachelor's and Master's degrees in Nuclear Engineering from the University of Tokyo in 1977 and 1979 respectively, following which, he worked for 6 years at the University of Tokyo on research and education pertaining to the nuclear fuel cycle, in particular, radioactive waste management.

After he obtained his Ph.D. in 1987, from the University of Tokyo with a thesis on radionuclide transport modelling and uncertainty analysis for the performance assessment of the disposal system, he joined the Power Reactor and Nuclear Fuel Development Corporation (PNC) which is a leading R&D organisation for the Japanese high-level waste disposal programme. His current positions are the Deputy General Manager and Senior Engineer of the Isolation System Research Programme in the Radioactive Waste Management Project. He is responsible for all performance assessment activities in the R&D programme for high-level waste disposal. This includes the H3 project completed in 1992, and the H12 project now on-going. He has been a member of the OECD/NEA Performance Assessment Advisory Group (PAAG) since 1988.

Appendix 2: Terms of Reference for the Review

Terms of Reference for the international review of the Waste Isolation Pilot Plant 1996 performance assessment were negotiated between the DOE, the NEA and the IAEA. Relevant parts of the Terms of Reference, agreed to in June 1997, are reproduced below.

Introduction

A joint international review of the post-closure part of the Compliance Certification Application (CCA) of the US Program for safe disposal of transuranic radioactive waste (TRUW) is to be organized by the Nuclear Energy Agency of the Organisation of Economic Co-operation and Development (NEA) and the International Atomic Energy Agency (IAEA). The review will be conducted by a group of independent experts appointed by the NEA and the IAEA (hereafter referred to as the Expert Group). A joint NEA/IAEA Secretariat will be established for the purpose, and will be managed by the NEA. This Expert Group will examine whether the post-closure performance assessment of the Waste Isolation Pilot Plant (WIPP) disposal system for TRUW is appropriate, technically sound, and in conformity with international standards and practices. The results of this international review will be submitted to the US Department of Energy (DOE) in a joint report.

The International Review Process

The international review will be organised jointly by the NEA and the IAEA as part of their international review services programs. The review is at the request of and sponsored by the DOE.

The Expert Group will draw on the experience of the world's leading experts in radioactive waste disposal and safety assessments and their views on the approaches taken by other countries towards the safe disposal of long-lived radioactive waste. As part of the review, the Expert Group may want to meet with scientific and technical groups and government agencies involved in the WIPP.

Objective of the International Review

The objective of the international review is to examine whether the post-closure performance assessment of the WIPP in the CCA is appropriate, technically sound, and in conformity with international standards and practices.

Scope of the International Review

The review should include an assessment of the state of the WIPP *(performance assessment)* technology in comparison to other nations' programs, and should include but not be limited to scenario development, conceptual model and computational model development, data/parameter acquisition and selection, computational model construction, and the results of the probabilistic analysis including tracking of uncertainty. The clarity and transparency of the documentation of the post-closure performance assessment results should also be reviewed. Finally, the Expert Group will review, from an international perspective, the technical soundness and appropriateness of the methodologies used and the arguments presented for the post-closure performance assessment on which the CCA was developed.

In carrying out the review, the Expert Group may consider comparing the post-closure part of the CCA with approaches being taken by other countries on the management and disposal of long lived radioactive waste.

Documentation for this review will primarily consist of the applicable portions of the CCA, the FEIS, the cited references, details of formal past licensing decisions concerning WIPP, and other information as may be requested. All relevant information used by the Expert Group should be listed in the final report resulting from this international review.

The issues which fall outside the scope of the post-closure part of the CCA and which have been dealt with separately or at an earlier stage of the decision-making process, such as repository siting and design, waste form and other pre-closure issues, should not be addressed as such. However, it is recognized that such issues may have a direct influence on post-closure performance and the Expert Group might wish to comment on how such an influence has been evaluated and taken into account from the point of view of post-closure performance assessment.

The scope of the review should exclude chemical toxicity aspects, socio-economic or political considerations, all aspects of the development of regulations, as well as any issues related to timing and institutional arrangements for the implementation of disposal.

It is anticipated that the international review will be carried out over a 6-month period. The material for the review (see Annex 1) will be made available to the joint NEA/IAEA Secretariat by October 1, 1996. The review will be completed and delivered to the CAO by March 30, 1997.

Deliverable

A report containing the Expert Group's findings will be delivered to the DOE Carlsbad Area Office (CAO). Prior to finalizing report, the Expert Group will present its findings to the CAO to ensure that all pertinent information and data were considered in the review.

Annex 1: US DOE reference documents

Primary Material to be reviewed:

- The CCA's main text, i.e. Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant, Volume I.

Other Information:

- FEIS Record of Decision.
- Appendices and references cited in the aforementioned documents, as required.
- Other information, as identified by the reviewers themselves.

Annex 2: International reference documents

1. IAEA, The Principles of Radioactive Waste Management, Safety Fundamentals, Safety Series No. 11 I-F (1995)
2. IAEA, International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (sponsored by FAO, IAEA, ILO, OECD/NEA, PAHO, WHO), Safety Series No. 115, (1996)
3. ICRP, Radiation Protection Principles for the Disposal of Solid Radioactive Waste, ICRP Publication 46, (1986)
4. OECD/NEA, Disposal of Radioactive Waste: Review of Safety Assessment Methods, (1991)
5. IAEA, Safety Principles and Technical Criteria for the Underground Disposal of High Level Radioactive Wastes, Safety Series No. 99 (1989)
6. IAEA, Safety Indicators in Different Timeframes for the Safety Assessment of Underground Radioactive Waste Repositories, TECDOC-767, (1994)
7. OECD/NEA, Safety Assessments of Radioactive Waste Repositories: Future Human Actions at Disposal Sites, (1995)
8. OECD/NEA, Safety Assessments of Radioactive Waste Repositories: Systematic Approaches to Scenario Development (1992)
9. OECD/NEA, Disposal of Radioactive Waste: Can Long-term Safety be Evaluated ? An International Collective Opinion, jointly sponsored by the NEA, IAEA and CEC (1991).
10. OECD/NEA, The Management of Long-Lived Radioactive Waste: The Environmental and Ethical Basis of Geological Disposal, A collective Opinion of the NEA Radioactive Waste Management Committee (1995).

Appendix 3: Selected Paragraphs From the EPA Regulations

This appendix reproduces selected parts of paragraphs and definitions from 40 CFR 191 and 40 CFR 194 which are referred to in Chapter 2 of the main report. It is emphasised that these have been selected as background to points on which the IRG wished to comment. They are not intended to summarise the EPA regulations.

A3.1 Selected paragraphs from 40 CFR 191

§<u>191.13 Containment requirements</u>.

(a) Disposal systems ... shall be designed to provide a reasonable expectation, based upon performance assessments, that the cumulative releases of radionuclides to the accessible environment* for 10,000 years after disposal from all significant processes and ... shall:

(1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 (Appendix A)*; and

(2) Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1 (Appendix A)*.

(b) Performance assessments need not provide complete assurance that the requirements of §191.13(a) will be met. ... Instead, what is required is a reasonable expectation, on the basis of the record before the implementing agency, that compliance ... will be achieved.

§<u>191.14 Assurance requirements</u>.

To provide the confidence needed for long-term compliance with the requirements of §191.13, ... :

(a) Active institutional controls* over disposal sites should be maintained for as long a period of time as is practicable ... however, performance assessments ... shall not consider any contributions from active institutional controls for more than 100 years after disposal.

(b) Disposal systems shall be monitored after disposal ...

(c) Disposal sites shall be designated by the most permanent markers, records, and other passive institutional controls* practicable ...

---

* Terms denoted by an asterisk have defined meanings, see Section A3.3.

(d) Disposal systems shall use different types of barriers to isolate the wastes ... engineered and natural barriers ...

(e) Places where there has been mining for resources, or where there is a reasonable expectation of exploration ... should be avoided in selecting disposal sites. Resources to be considered include minerals, petroleum or natural gas ... Such places shall not be ... unless the favorable characteristics of such places compensate for their greater likelihood of being disturbed in the future.

§191.15 Individual protection requirements.

(a) Disposal systems ... shall be designed to provide a reasonable expectation that, for 10,000 years after disposal, undisturbed performance* of the disposal system shall not cause the annual committed effective dose, ... to any member of the public ... to exceed 15 millirems (150 microsieverts).

A3.2 Selected paragraphs from 40 CFR 194

Containment Requirements

§194.25 Future State Assumptions

(a) Unless otherwise specified ... performance assessments and compliance assessments conducted pursuant the provisions of this part to demonstrate compliance with § 191.13, § 191.15 ... shall assume that characteristics of the future remain what they are at the time the compliance application is prepared, provided that such characteristics are not related to hydrogeologic, geologic or climatic conditions. ...

§194.32 Scope of performance assessments.

(a) Performance assessments shall consider natural processes and events, mining, deep drilling, and shallow drilling that may affect the disposal system during the regulatory time frame.

(b) Assessments of mining effects may be limited to changes in the hydraulic conductivity of the hydrogeologic units of the disposal system from excavation mining for natural resources. Mining shall be assumed to occur with a one in 100 probability in each century of the regulatory time frame. Performance assessments shall assume that mineral deposits of those resources, similar in quality and type to those resources currently extracted from the Delaware Basin, will be completely removed from the controlled area during the century in which such mining is randomly calculated to occur.

Complete removal of such mineral resources shall be assumed to occur only once during the regulatory time frame.

§194.33 Consideration of drilling events in performance assessments.

(a) Performance assessments shall examine deep drilling and shallow drilling that may potentially affect the disposal system during the regulatory time frame.

(b) The following assumptions and process shall be used... (1) Inadvertent and intermittent intrusion by drilling for resources (other ... the waste ... or engineered barriers ...) is the most severe human intrusion scenario. (2) ... drilling events shall be assumed to occur in the Delaware Basin at random intervals in time and space during the regulatory time frame. (3) The frequency of deep drilling shall be calculated in the following manner: (i) Identify deep drilling that has occurred for each resource in the Delaware Basin over the past 100 years ... (ii) The total rate of deep drilling shall be the sum of the rates of deep drilling for each resource. ...

(c) ... assumed that: (1) Future drilling practices and technology will remain consistent with practices in the Delaware Basin at the time a compliance application is prepared. ... The types and amounts of drilling fluids; borehole depths, diameters, and seals; and the fraction of such boreholes that are sealed by humans; ...

(d) ... performance assessments need not analyse the effects of techniques used for resource recovery subsequent to the drilling of the borehole.

§194.34 Results of performance assessments.

(a) The results of performance assessments shall be assembled into "complementary, cumulative distribution functions" (CCDFs) that represent the probability of exceeding various levels of cumulative release caused by all significant processes and events.

(b) Probability distributions for uncertain disposal system parameter values used in performance assessments shall be developed ...

(c) Computational techniques, which draw random samples from across the entire range of the probability distributions... shall be used in generating CCDFs ...

(d) The number of CCDFs generated shall be large enough such that, at cumulative releases of 1 and 10, the maximum CCDF generated exceeds the 99th percentile of the population of CCDFs with at least a 0.95 probability. ...

(e) Any compliance application shall display the full range of CCDFs generated.

(f) ... demonstrates that there is at least a 95 percent level of statistical confidence that the mean of the population of CCDFs meets the containment requirements of § 191.13 ...

Assurance Requirements

§194.41 Active institutional controls.

(a) ... include detailed descriptions of proposed active institutional controls ... Assumptions pertaining to active institutional controls and their effectiveness in terms of preventing or reducing radionuclide releases shall be supported by such descriptions.

(b) Performance assessments shall not consider any contributions from active institutional controls for more than 100 years after disposal.

§194.43 Passive institutional controls.

(a) ... include detailed descriptions of the measures that will be employed to preserve knowledge about the location, design, and contents of the disposal system. ... (1) Identification of the controlled area by markers ... (2) Placement of records in the archives and land record systems of local, State, and Federal governments, and international archives, ... (3) Other passive institutional controls practicable to indicate the dangers of the waste and its location.

(c) The Administrator may allow the Department to assume passive institutional control credit, in the form of reduced likelihood of human intrusion, if the Department demonstrates ... that such credit is justified ... Such credit ... cannot be used for more than several hundred years and may decrease over time. ...

§194.45 Consideration of the presence of resources.

Any compliance application shall include information that demonstrates that the favorable characteristics of the disposal system compensate for the presence of resources in the vicinity of the disposal system and the likelihood of the disposal system being disturbed as a result of the presence of those resources. If performance assessments predict that the disposal system meets the containment requirements of § 191.13 of this chapter, then the

Agency will assume that the requirements of this section and § 191.14(e) of this chapter have been fulfilled.

A3.3 Selected definitions from 40 CFR 191 and 40 CFR 194

§191.02 Definitions.

Transuranic radioactive waste, ... means waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes, with half-lives greater than twenty years, per gram of waste, except for: (1) High-level radioactive wastes; (2) wastes that the Department has determined, with the concurrence of the Administrator, do not need the degree of isolation required by this part; or (3) wastes that the Commission has approved for disposal on a case-by-case basis in accordance with 10 CFR Part 61.

§191.12 Definitions.

Accessible environment means: (1) The atmosphere; (2) land surfaces; (3) surface waters; (4) oceans; and (5) all of the lithosphere that is beyond the controlled area.

Active institutional control means: (1) Controlling access to a disposal site by any means other than passive institutional controls; (2) performing maintenance operatione or remedial actions at a site, (3) controlling or cleaning up releases from a site, or (4) monitoring parameters related to disposal system performance.

Controlled area means: (1) A surface location, to be identified by passive institutional controls, that encompasses no more than 100 square kilometers and extends horizontally no more than five kilometers in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system; and (2) the subsurface underlying such a surface location.

Disposal system means any combination of engineered and natural barriers that isolate spent nuclear fuel or radioactive waste after disposal.

Passive institutional control means: (1) Permanent markers placed at a disposal site, (2) public records and archives, (3) government ownership and regulations regarding land or resource use, and (4) other methods of preserving knowledge about the location, design, and contents of a disposal system.

Performance assessment means an analysis that: (1) Identifies the processes and events that might affect the disposal system; (2) examines the effects of these processes and events on the performance of the disposal system; and (3) estimates the cumulative releases of radionuclides, considering the associated uncertainties, caused by all significant processes and events. These estimates shall be incorporated into an overall probability distribution of cumulative release to the extent practicable.

Undisturbed performance means the predicted behaviour of a disposal system, including consideration of the uncertainties in predicted behaviour, if the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events.

A3.4 Appendix A to 40 CFR 191 - Table for Subpart B

TABLE 1--RELEASE LIMITS FOR CONTAINMENT REQUIREMENTS [Cumulative releases to the accessible environment for 10,000 years after disposal]

Radionuclide	Release limit per 1,000 MTHM or other unit of waste (see notes) (curies)
Americium-241 or -243	100
Carbon-14	100
Cesium-135 or -137	1,000
Iodine-129	100
Neptunium-237	100
Plutonium-238, -239, -240, or -242	100
Radium-226	100
Strontium-90	1,000
Technetium-99	10,000
Thorium-230 or -232	10
Tin-126	1,000
Uranium-233, -234, -235, -236, or -238	100
Any other alpha-emitting radionuclide with a half-life greater than 20 years	100
Any other radionuclide with a half-life greater than 20 years that does not emit alpha particles	1,000

Note 1: Units of Waste. The release limits in Table 1 apply to the amount of wastes in anyone of the following:

(e) An amount of transuranic (TRU) wastes containing one million curies of alpha-emitting transuranic radionuclides with half-lives greater than 20 years.

Note 2: To develop Release Limits for a particular disposal system, the quantities in Table 1 shall be adjusted for the amount of waste included in the disposal system. For example:

(b) If a particular disposal system contained three million curies of alpha-emitting transuranic wastes, the Release Limits for that system would be the quantities in Table 1 multiplied by three (three million curies divided by one million curies).