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SAND88-1452 • UC-721

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Draft Forecast of the Final Report for the Comparison to 40 CFR Part 191, Subpart B for the Waste Isolation Pilot Plant

Sharla G. Bertram-Howery, Melvin G. Marietta, D. R. (Rip) Anderson,
Kenneth F. Brinster, Leo S. Gomez, Robert V. Guzowski, Robert P. Rechard

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
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SAND88-1452

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**DRAFT FORECAST OF THE FINAL REPORT FOR THE COMPARISON
TO 40 CFR PART 191, SUBPART B,
FOR THE WASTE ISOLATION PILOT PLANT**

Sharla G. Bertram-Howery
Melvin G. Marietta
D. R. (Rip) Anderson, Kenneth F. Brinster*,
Leo S. Gomez, Robert V. Guzowski*,
and Robert P. Rechard

Sandia National Laboratories
Albuquerque, NM 87185

ABSTRACT

The United States Department of Energy (DOE) is planning to dispose of transuranic wastes, which have been generated by defense programs, at the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico. The WIPP Project will assess compliance with the requirements of the United States Environmental Protection Agency's Standard, *Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes* (40 CFR Part 191). Assessing compliance with the long-term performance criteria of Subpart B of the Standard is a cornerstone of successful implementation of a DOE TRU-waste disposal system.

This report forecasts the planned 1992 document, *Comparison to 40 CFR, Part 191, Subpart B, for the Waste Isolation Pilot Plant (WIPP)*. It has the same format, with the same table of contents. The text is, where available, a preview for 1992. Where not yet available, the text is either preliminary or incomplete. DOE, as the implementing agency for the WIPP under the Standard, is responsible for determining whether the WIPP complies with the four requirements of Subpart B. The 1992 document, which will describe the compliance evaluation process and compare the WIPP's performance with Subpart B of the Standard, will be the quantitative basis for DOE's determination. That report will evolve from this *Forecast*.

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ACKNOWLEDGEMENTS

The authors wish to acknowledge the research and development work of the scientists and engineers of the Waste Management Technology Department of Sandia National Laboratories who have conducted studies of the Waste Isolation Pilot Plant (WIPP) for over ten years. Their work is fundamental to the assessment of compliance with the EPA Standard, 40 CFR Part 191 Subpart B. Much of the work was conducted prior to the 1985 promulgation of the Standard. Our colleagues have successfully anticipated many of the data and modeling needs for performance assessment. The WIPP performance assessment activity at Sandia was initiated at the beginning of fiscal 1987 by the Department of Energy. As a result, we have found the work completed and ongoing by our colleagues to be invaluable. Because they planned and conducted much of their work in the absence of a Standard, some additional data and models have been defined as necessary to complete the performance assessment. The additional work has been incorporated into their activities and is described in *Preliminary Plan for Disposal-System Characterization and Long-Term Performance Evaluation of the Waste Isolation Pilot Plant* (Sandia National Laboratories SAND89-0178, April 1989, Bertram-Howery and Hunter, Editors). We are indebted to them for their contributions to our efforts to date, and recognize that the completion of the final performance assessment will depend in large part on their work.

We thank those whose review of earlier drafts provided insight and guidance for this version:

Performance Assessment Peer Review Panel

G. R. Heath, University of Washington
R. J. Budnitz, Future Resources Associates, Inc.
T. A. Cotton, J. K. Associates
P. A. Domenico, Texas A & M University
C. J. Mann, University of Illinois
T. H. Pigford, University of California at Berkeley

Sandia National Laboratories

J. E. Campbell, 6416
R. G. Klett, 6342

The schedule for preparation and production of this *Draft Forecast* was demanding. We could not have met it without the support of Tech. Reps., Inc. personnel Debra Medina and John Stikar for editing; Darcy Pulliam, Chris Northrop and the Illustration Department for illustration and coordination; Debbie Rivard, Ona Bailey, Theresa Allen and Dolores Miera for word processing, and Debbie Marchand, Debbie Salgado, and the Production Department, all directed by Bob Jones, of the Energy and Waste Management Department.

PREFACE

The United States Department of Energy (DOE) is planning to dispose of transuranic (TRU) wastes generated by defense programs at the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico. The WIPP Project will assess compliance with the requirements of the United States Environmental Protection Agency's (EPA) Standard, *Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes* (40 CFR Part 191; U.S. EPA, 1985). Assessing compliance with the long-term performance criteria of Subpart B of the Standard is a cornerstone of successful implementation of a DOE TRU-waste disposal system.

PURPOSE OF THE FORECAST

This report (to be referred to as the *Forecast*) forecasts the planned 1992 document, *Comparison to 40 CFR Part 191, Subpart B for the WIPP* (referred to as the *Comparison*). It has the same format and the same table of contents. Where results are available, the text is a preview of that for 1992. Where results are not yet available, the text is either preliminary or incomplete. DOE, as the implementing agency for the WIPP under the Standard, is responsible for determining whether the WIPP complies with the four requirements of Subpart B. The 1992 document, which will describe the compliance evaluation process and compare the WIPP's performance with Subpart B of the Standard, will be the quantitative basis for DOE's determination. That report will evolve from this *Forecast*.

The 1992 *Comparison* will be without precedent. Therefore, careful planning will be required to assure that the *Comparison* can be prepared and accepted on time and that it will be adequate to support the determination of compliance and to withstand external challenges. Coordination between the performance assessment team at Sandia National Laboratories; the DOE WIPP Project Office, Albuquerque Operations Office, and Headquarters; the WIPP Panel of the

National Research Council's Board on Radioactive Waste Management; the New Mexico Environmental Evaluation Group; and the EPA will be necessary if the format and scope are to be agreed upon prior to final preparation of the *Comparison*, which will start about October 1991. This *Forecast* is being used as the basis for those interactions.

The *Comparison* will be reviewed prior to publication by all of the above groups. Responding to comments and revising the report will be necessary before the report can be published. The review may conceivably necessitate additional analyses and incorporation of new data into the *Comparison*. The review and publication cycle is scheduled to be completed between September 1992 and July 1993; the schedule is too tight to allow rescoping and reformatting the *Comparison* at that late date. Therefore, this *Forecast* is published initially as a draft to afford all the review groups the opportunity to assist in establishing the format and scope of the *Comparison*.

NOMENCLATURE

AL - Albuquerque Operations Office
Am - americium
atm - atmosphere
Ba - barium
BEIR - biological effects of ionizing radiation
BIOTRAN - Biosphere Transport model
BLOT - Data plotting computer code
BRWM - Board on Radioactive Waste Management of the National Research Council
CAMCON - Compliance Assessment Methodology Controller
CAMDAT - Compliance Assessment Methodology Data Base
CAS - Compliance Assessment System
CCDF - complementary cumulative distribution function
CCDFPLT - computer code to calculate and display CCDF
Ce - cerium
Cf - californium
CFR - Code of Federal Regulations
CH - contact handled
Ci - curies
Cm - curium
Co - cobalt
Cs - cesium
Cu - copper
DOE - U. S. Department of Energy
DRZ - disturbed rock zone
EEG - Environmental Evaluation Group
Eh - oxidation potential
EIS - Environmental Impact Statement
EPA - Environmental Protection Agency
ERDA - Energy Research and Development Administration
Eu - europium
EXODUS - computer code to format files for finite-element programs
Fe - iron

FEIS - Final Environmental Impact Statement
FRP - fiberglass-reinforced plywood
FSAR - Final Safety Analysis Report
ft - foot
gal - gallon
GENESIS - computer code to format files for finite-element programs
GI - gastrointestinal
g - gram
HEPA - high efficiency particulate air (filter)
ICRP - International Commission on Radiological Protection
kg - kilogram
km - kilometer
l - liter
LHS - Latin hypercube sampling
MB139 - Marker Bed 139
mg/l - milligrams per liter
Mn - manganese
MPa - megapascal
mrem - millirem
NAS - National Academy of Sciences
nCi - nanocuries
NEA - Nuclear Energy Agency
NEFTRAN - computer model for groundwater flow and radionuclide transport
Ni - nickel
NM - New Mexico
Np - neptunium
NRC - Nuclear Regulatory Commission
Pa - Pascal
Pb - lead
pdf - probability distribution function
pH - the negative logarithm of the activity of hydrogen ion
Pr - praseodymium
Pu - plutonium
QA - quality assurance
Ra - radium
Rem - roentgen equivalent man

RH - remotely handled
Rn - radon
Ru - ruthenium
SAR - Safety Analysis Report
Sb - antimony
Si - silicon
Sm - samarium
SNL - Sandia National Laboratories
Sr - strontium
SWB - standard waste box
Te - tellurium
Th - thorium
TRU - transuranic
UND - undisturbed
U - uranium
WAC - waste acceptance criteria
WEC - Westinghouse Electric Corporation
WIPP - Waste Isolation Pilot Plant
WPO - WIPP Project Office
Y - yttrium
yr - year
§ - section of 40 CFR Part 191

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I. INTRODUCTION

PURPOSE AND ORGANIZATION OF THE COMPARISON

The Department of Energy (DOE) must comply with the United States Environmental Protection Agency's (EPA) *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes* (40 CFR Part 191; U.S. EPA, 1985), referred to herein as the Standard. Comparison of the long-term performance of the WIPP disposal system to the requirements of the Standard will contribute to the determination of whether the disposal system will provide safe disposal of radioactive wastes. The *Comparison*, when completed, will be the final report of the performance assessment of the WIPP disposal system.

The organization of the *Comparison*, which is forecast in this report, is based on the requirements of the Standard. Within the format of the requirements, it is organized according to the methodology developed by the performance assessment team to implement the guidance found in Appendix B to the Standard. This level of organization reflects the program elements described in the DOE management plan for the test phase (U.S. DOE, 1989a; also see Bertram-Howery and Hunter, 1989a).

Because this report is a preview of the final report, many sections are preliminary or incomplete. Brief descriptions of the Standard and the WIPP Project will be provided in this chapter. Chapter II will discuss application of Subpart B of the Standard to the WIPP disposal system. Chapter III will describe the compliance-assessment philosophy of the WIPP Project and will provide an overview of the methodology. Chapter IV will describe the methodology for assessing compliance with the Containment Requirements (§ 191.13) of the Standard. Chapter V will describe the methodology for assessing compliance with the Individual Protection Requirements (§ 191.15) of the Standard. Chapter VI will describe plans for implementation of the Assurance Requirements (§ 191.14) of the Standard. Chapter VII will present

the results of the assessment and Chapter VIII will compare the results to the requirements. Chapter IX will contain the recommendations of the WIPP Project relative to determination of compliance. Appendix A contains the full text of the Standard, as promulgated by the EPA in 1985. Appendix B will contain the reference data base for the compliance assessment.

There are no guidelines in the Standard for the preparation and review of compliance assessment reports. The *Comparison* will be reviewed extensively within the DOE and by the WIPP Panel of the National Research Council's Board on Radioactive Waste Management (BRWM); the State of New Mexico, including the Environmental Evaluation Group (EEG); and the EPA. Therefore, the planned organization of the final version of the document includes Appendix C, which will present the official review comments and responses to those comments, analogous to the comment-response section typically provided in decision-basis documents.

The *Comparison* focuses on Subpart B of 40 CFR Part 191. Compliance with other regulatory requirements and analyses for other purposes, such as safety assessments, are discussed in separate documents.

40 CFR PART 191, THE STANDARD (1985)

The Standard promulgated in 1985 by the EPA is divided into two subparts. Subpart A applies to a disposal facility prior to closure and limits annual radiation doses from waste management and storage operations to members of the public outside the site. Subpart B applies after closure and limits cumulative releases of radioactive materials to the accessible environment for 10,000 years. Subpart B also limits both radiation doses to members of the public in the accessible environment and radioactive contamination of certain sources of groundwater within or near the controlled area for 1,000 years after disposal. Appendix A of the Standard specifies how to determine release limits, and Appendix B of the Standard provides non-mandatory guidance for implementation of Subpart B. Application of the Standard to the WIPP is described in the *Compliance Strategy* (U.S. DOE, 1989b), which discusses the WIPP interpretation of various terms and definitions contained in the Standard.

1 The concept of "sites" is integral to limits established by Subparts A and B
2 for releases of waste from the repository, both during operation and after
3 closure. "Site" is used differently in the two Subparts; the meaning of
4 "site" at the WIPP for each Subpart is discussed and defined below in the
5 appropriate section. The definitions of "controlled area" and "accessible
6 environment," which are also important in assessing compliance with the
7 Standard, depend on the definition of "site." "Site" has also been used
8 generically for many years by the waste-management community (e.g., in the
9 phrases "site characterization" or "site specific"); few uses of the word
10 correspond to either of the EPA's usages (Bertram-Howery and Hunter, 1989b).

11 12 SUBPART A

13
14 Subpart A limits the radiation doses that may be received by members of the
15 public in the general environment as a result of management and storage of TRU
16 wastes at DOE disposal facilities not regulated by the NRC. Subpart A
17 requires that "the combined annual dose equivalent to any member of the public
18 in the general environment resulting from discharges of radioactive material
19 and direct radiation from such management and storage shall not exceed 25
20 millirems to the whole body or 75 millirems to any critical organ"
21 (§ 191.03(b)). The general environment is the "total terrestrial,
22 atmospheric, and aquatic environments outside sites within which any activity,
23 operation, or process associated with the management and storage
24 of...radioactive waste is conducted" (§ 191.02(o)).

25
26 "Site" for the purposes of Subpart A is the secured-area boundary shown in
27 Figure 1-1. This area will be under the effective control of the security
28 force at the WIPP, and only authorized persons will be allowed within the
29 boundary (U.S. DOE, 1989b). This means that unauthorized visitors to the site
30 vicinity can be assumed to be no closer than the secured-area boundary. In
31 addition, the DOE will gain control over the sixteen-section area within the
32 land-withdrawal boundary; this boundary is referred to in the agreement with
33 New Mexico and in the WIPP *Final Safety Analysis Report* (FSAR, U.S. DOE,
34 1989c) as the "WIPP site boundary." This control will prohibit habitation
35 within the boundary. Consequently, for the purposes of operational dose
36 assessment to nearby residents, the assumption can be made that no one lives
37 closer than the latter boundary (Bertram-Howery and Hunter, 1989b).

Figure 1-1. Map Showing Selected Features around the WIPP (U.S. DOE, 1989b).

1 Subpart A requires that the DOE control emissions along all pathways, so that
2 the dose limits are not exceeded. The actual mechanics of controlling
3 emissions are inherent in the design and operation of the WIPP. The design
4 and operation are described in the FSAR, as are projections of potential
5 releases to the general environment from normal operations. These projections
6 indicate that the WIPP, as designed, will comply with Subpart A. In the
7 Second Modification to the Consultation and Cooperation Agreement (U.S. DOE
8 and State of New Mexico, 1981), DOE agreed to begin compliance with Subpart A
9 with the first receipt of waste at WIPP. A pre-operational monitoring plan is
10 in place. Emissions monitoring-and-sampling systems and environmental
11 radiation monitoring programs will be implemented during operations (Bertram-
12 Howery and Hunter, 1989b).

13
14 A description of the Subpart A compliance approach is contained in the WIPP
15 *Compliance Strategy* (U.S. DOE, 1989b; cf. Bertram-Howery and Hunter, 1989b and
16 U.S. DOE, 1989c). Compliance with Subpart B is the topic of this report;
17 therefore, Subpart A will not be discussed further.

18 19 SUBPART B

20
21 In evaluating compliance with Subpart B, the WIPP Project intends to follow to
22 the extent possible the guidance found in Appendix B of the Standard (U.S.
23 DOE, 1989b). The application of Subpart B to the WIPP is discussed in detail
24 in Chapter II. The Containment Requirements (§ 191.13) and Individual
25 Protection Requirements (§ 191.15) necessitate predictions of releases for
26 10,000 years and of doses for 1,000 years. The Assurance Requirements
27 (§ 191.14) complement the Containment Requirements. The Groundwater
28 Protection Requirements (§ 191.16) protect "special sources of ground water"
29 from contamination at concentrations greater than certain limits and is the
30 only requirement in the Standard that limits radionuclide concentrations.

31
32 The term "disposal site" is used frequently in Subpart B and in Appendix B of
33 the Standard. For the purposes of the WIPP strategy for compliance with
34 Subpart B, the disposal site and the controlled area are the same. The "site"
35 for the purposes of Subpart A and the "disposal site" for the purposes of

1 Subpart B are not the same. The controlled area for Subpart B includes the
2 secured area and additional surrounding areas to be determined (U.S. DOE,
3 1989b). The Standard defines "disposal system" to mean any combination of
4 engineered and natural barriers that isolate the radioactive waste after
5 disposal. For the WIPP, the disposal system is the combination of the
6 repository/shaft system and the geologic and hydrologic systems of the
7 controlled area (Figure 1-2). The repository/shaft system, as defined,
8 includes the WIPP underground workings and all emplaced materials and the
9 altered zones within the Salado Formation and overlying units resulting from
10 construction of the underground workings. The controlled area defined by the
11 EPA is limited to the lithosphere and the surface within 5 km (3 mi) of the
12 outer boundary of the WIPP waste-emplacement panels. The boundary of this
13 maximum-allowable controlled area does not coincide with the proposed boundary
14 for the WIPP land withdrawal. The extent of the WIPP controlled area will be
15 defined during the performance assessment, but will not be less than the
16 withdrawn area (Bertram-Howery and Hunter, 1989a).

17
18 The EPA recognized that Subpart B must be implemented in the design phase
19 because active surveillance cannot be relied upon over the very long time
20 frames of interest. The EPA also recognized that the Standard "must
21 accommodate large uncertainties, including uncertainties in our current
22 knowledge about disposal system behavior and the inherent uncertainties
23 regarding the distant future" (U.S. EPA, 1985, p. 38070).

24
25 Both the Containment Requirements and the Individual Protection Requirements
26 require a "reasonable expectation" that their various quantitative tests can
27 be met. This test of judgment is meant by the EPA to "acknowledge the unique
28 considerations likely to be encountered upon implementation of these disposal
29 standards" (U.S. EPA, 1985, p. 38071). The Standard "clearly indicates that
30 comprehensive performance assessments, including estimates of the
31 probabilities of various potential releases whenever meaningful estimates are
32 practicable, are needed to determine compliance with the containment
33 requirements" (U.S. EPA, 1985, p. 38076). These requirements "emphasize that
34 unequivocal proof of compliance is neither expected nor required because of
35 the substantial uncertainties inherent in such long-term projections.

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Figure 1-2. Artist's Concept Showing the Two Components of the WIPP Disposal System: Controlled Area and Repository/Shaft System. The repository/shaft system scale is exaggerated. The proposed land-withdrawal boundary is shown at the same scale as the maximum extent of the controlled area (Bertram-Howery and Hunter, 1989a).

1 Instead, the appropriate test is a reasonable expectation of compliance based
2 upon practically obtainable information and analysis" (ibid.). The EPA states
3 that the Standard requires "very stringent isolation while allowing the [DOE]
4 adequate flexibility to handle specific uncertainties that may be encountered"
5 (ibid.).

6
7 The EPA's assumptions regarding performance assessments and uncertainties are
8 incorporated in Appendix B of the Standard, which the EPA intends the
9 implementing agencies to follow. The EPA intended these assumptions to
10 "discourage overly restrictive or inappropriate implementation" of the
11 requirements (U.S. EPA, 1985, p. 38077). The guidance in Appendix B to the
12 Standard indicates that "compliance should be based upon the projections that
13 the [DOE] believes are more realistic....Furthermore,...the quantitative
14 calculations needed may have to be supplemented by reasonable qualitative
15 judgments in order to appropriately determine compliance with the disposal
16 standards" (U.S. EPA, 1985, p. 38076). In particular, Appendix B states:

17
18 The [EPA] believes that the [DOE] must determine compliance with
19 §§ 191.13, 191.15, and 191.16 of Subpart B by evaluating long-term
20 predictions of disposal system performance. Determining compliance
21 with § 191.13 will also involve predicting the likelihood of events and
22 processes that may disturb the disposal system. In making these
23 various predictions, it will be appropriate for the [DOE] to make use
24 of rather complex computational models, analytical theories, and
25 prevalent expert judgment relevant to the numerical predictions.
26 Substantial uncertainties are likely to be encountered in making these
27 predictions. In fact, sole reliance on these numerical predictions to
28 determine compliance may not be appropriate; the [DOE] may choose to
29 supplement such predictions with qualitative judgments as well.

30
31 Portions of the disposal system should not be disregarded, even if
32 projected performance is uncertain, except for portions of the system
33 that make negligible contributions to the overall isolation provided by
34 the disposal system.

35
36 The Containment Requirements state, in § 191.13(b), that:

37
38 Performance assessments need not provide complete assurance that the
39 requirements of 191.13(a) will be met. Because of the long time period
40 involved and the nature of the events and processes of interest, there
41 will inevitably be substantial uncertainties in projecting disposal
42 system performance. Proof of the future performance of a disposal
43 system is not to be had in the ordinary sense of the word in situations
44 that deal with much shorter time frames. Instead, what is required is
45 a reasonable expectation, on the basis of the record before the [DOE],
46 that compliance with 191.13(a) will be achieved.

1 The EPA recognized that too many uncertainties exist in projecting the
2 behavior of natural and engineered components for 10,000 years and there are
3 too many opportunities for errors in calculations or judgments for the
4 numerical requirements to be sufficient for determining the acceptability of a
5 disposal system. Qualitative requirements were included in the Standard to
6 ensure that "cautious steps are taken to reduce the problems caused by these
7 uncertainties" (U.S. EPA, 1985, p. 38079). These qualitative Assurance
8 Requirements are an essential complement to the quantitative Containment
9 Requirements. Each qualitative requirement was chosen to compensate for some
10 aspect of the inherent uncertainty in projecting the future performance of a
11 disposal system. The Assurance Requirements begin by declaring that
12 compliance with their provisions will "provide the confidence needed for long-
13 term compliance with the requirements of 191.13."

14
15 The determination of compliance with Subpart B depends on the estimated
16 complementary cumulative distribution function (CCDF) and the estimated doses;
17 however, it also depends on the strength of the assurance strategies that will
18 be implemented and on the qualitative judgment of the DOE and its analysts.
19 The preceding discussion clearly demonstrates the EPA's recognition of the
20 difficulties involved in predicting the future and in quantifying the outcomes
21 of future events. It also shows that the EPA expects the DOE to understand
22 the uncertainties in the disposal system's behavior only to the extent
23 practical.

24
25 One type of uncertainty that cannot be completely resolved is the validity of
26 various models for predicting disposal system behavior 10,000 years into the
27 future. Although models will be validated to the extent possible, expert
28 judgment must be relied upon where validation is not possible. In the case of
29 competing conceptual models, if a single conceptual model cannot be
30 demonstrated to be the most consistent with available data, multiple
31 conceptual models will be developed and performance assessment calculations
32 will incorporate each model as appropriate.

33
34 The Standard (as promulgated in 1985) is reproduced in Appendix A of this
35 report.

1 STATUS OF THE STANDARD

2
3 Subpart B of the Standard was remanded to the EPA by the United States Court
4 of Appeals for the First Circuit in July 1987. The Court found that the EPA
5 had neither reconciled the Individual Protection Requirements with Part C of
6 the Safe Drinking Water Act nor explained the divergence between the two sets
7 of criteria; furthermore, the EPA had not explained the basis for the
8 1,000-year design criterion in the Individual Protection Requirements. The
9 Court also found that the Groundwater Protection Requirements were promulgated
10 without proper notice and comment. The Second Modification to the
11 Consultation and Cooperation Agreement (U.S. DOE and State of New Mexico,
12 1981) commits the WIPP Project to proceed with the evaluation of compliance
13 with the Standard as first promulgated until such time as a revised Standard
14 becomes available. Therefore, this report discusses the Standard as first
15 promulgated. Compliance plans for the WIPP will be revised as necessary in
16 response to any changes in the Standard resulting from the court's decision.

17
18 DESCRIPTION OF THE WIPP PROJECT

19
20 This section presents the WIPP Project mission and identifies the
21 participants in the Project, then briefly describes the repository/shaft
22 system, the site, and the waste.

23
24 MISSION

25
26 Congress authorized the WIPP in 1979 by Public Law 96-164 (Public Law 96-164,
27 1979) as a research and development facility. The WIPP is designed as a full-
28 scale pilot plant to demonstrate the safe management, storage, and disposal of
29 TRU defense waste. The WIPP performance assessment will help the DOE
30 determine whether the WIPP will isolate wastes from the accessible environment
31 sufficiently well to satisfy the disposal requirements in Subpart B of the
32 Standard. Predictions with respect to compliance with Subpart B of the
33 Standard will provide input to the decision on whether WIPP will become a
34 disposal facility. That decision is expected to occur upon completion of the
35 performance assessment. The DOE will apply Subpart A of the Standard to the
36 WIPP beginning with the first receipt of TRU waste (U.S. DOE, 1989b).

"Disposal," as defined in the Standard, will occur when the mined repository is sealed and decommissioned.

PARTICIPANTS

The DOE is the implementing agency, as defined in the Standard, for the WIPP Project. The WIPP Project is managed by the DOE Albuquerque Operations Office (DOE/AL) through the DOE WIPP Project Office (DOE/WPO) in Carlsbad, New Mexico. The WPO is assisted by two prime contractors: Westinghouse Electric Corporation (WEC) and Sandia National Laboratories (SNL). The operating contractor will be responsible for operations once the decision is made to permanently emplace waste at the WIPP and is also responsible for compliance with Subpart A and with the Assurance Requirements of Subpart B of the Standard. WEC is the operating contractor during the test phase. SNL provides scientific investigations of salt-bed disposal of TRU waste, site characterization, analysis, engineered-barrier designing, in situ testing, and evaluation of compliance with the long-term performance criteria in Subpart B of the Standard.

The DOE and the State of New Mexico have had an Agreement for Consultation and Cooperation since 1981 (U.S. DOE and State of New Mexico, 1981). This agreement ensures that the State, through the EEG, has an active part in assuring that public safety issues are fully addressed. In addition, external review of the WIPP Project is provided by the BRWM WIPP Panel. Informal review of the compliance evaluation will be provided by the EPA. The WIPP also receives close public scrutiny.

SITE: AREA OF PROPOSED LAND WITHDRAWAL

The characteristics of the WIPP site are described in detail in the WIPP *Final Safety Analysis Report* (FSAR) (U.S. DOE, 1989c). The WIPP (Figure 1-3) is located in southeastern New Mexico, about 42 km (26 mi) east of Carlsbad, in the Delaware Basin. The area has a low population density. The nearest population center is the city of Carlsbad (pop. 27,000). Two smaller communities, Loving (pop. 1,500) and Malaga (pop. 150), are located about 33 km (20 mi) to the southwest. Less than 30 permanent residents live within

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Figure 1-3. WIPP Location Map (after Bertram-Howery and Hunter, 1989b).

1 a 16-km (10-mi) radius. The nearest residents live in a ranch house about
2 5.6 km (3.5 mi) south of the WIPP surface facility (U.S. DOE, 1989c).

3
4 The surface of the proposed land withdrawal of the WIPP has been leased for
5 cattle grazing. At present, none of the ranches within ten miles use well
6 water for their livestock; the quality of the water is too poor for cattle.
7 Water for people and cattle is supplied by pipeline (U.S. DOE, 1989c).

8
9 Potash, oil, and gas are the only known important mineral resources; however,
10 resource extraction is not permitted within the proposed land withdrawal
11 boundaries. The volumes and locations of these resources are estimated in the
12 *Final Environmental Impact Statement* (FEIS) for the WIPP (U.S. DOE, 1980b).
13 The surrounding area is used primarily for grazing, potash mining, and oil and
14 gas exploration. There are about 56 oil and gas wells within a radius of
15 16 km (10 mi); the wells generally tap Pennsylvanian strata, about 4,200 m
16 (14,000 ft) deep. The nearest well is about 5 km (3 mi) to the south-
17 southwest of the surface facility. Three potash mines and two associated
18 chemical processing plants are between 8 and 16 km (5 and 10 mi) away. Potash
19 mining is anticipated within a radius of 3 to 8 km (2 to 5 mi) (U.S. DOE,
20 1989c). The potash zone is about 137 m (450 ft) thick and is encountered
21 about 457 m (1,500 ft) below the surface (Figure 1-4).

22 23 REPOSITORY/SHAFT SYSTEM

24
25 The WIPP repository is located in the Salado Formation, 655 m (2,150 ft) below
26 the land surface. The Salado is a 600-m- (2,000-ft-) thick sequence of
27 200-million-year-old salt with minor amounts of clay and anhydrite. The
28 nearest perennial stream is the Pecos River, 23 km (14 mi) away at its closest
29 point. Groundwater circulation in the Salado is extremely limited; water-
30 bearing units of the Rustler Formation overlying the Salado produce only small
31 amounts of water that is too salty for human consumption. The repository will
32 remain dry while it is ventilated, but slow seepage of interstitial brine does
33 occur. Brine under pressure occurs in localities below the Salado in the
34 Castile Formation (Waste Management Technology Department, 1987).

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Figure 1-4. WIPP Stratigraphy (after Waste Management Technology Dept., 1987).

1 If the DOE successfully demonstrates compliance with the Standard, the WIPP is
2 expected to become the nation's first and only large-scale, mined geologic
3 repository for TRU waste (Figure 1-5). Ultimately, eight panels of seven
4 rooms each will be mined. As each panel is filled with waste, the next panel
5 will be mined. Before the repository is closed permanently, each panel will
6 be sealed, waste will be placed in the drifts between the panels, and access
7 ways will be sealed off from the shafts. Because the WIPP is a research and
8 development facility, an extensive experimental area is also in use and under
9 construction north of the waste-disposal area (Bertram-Howery and Hunter,
10 1989b).

11
12 The WIPP underground facility is composed of four shafts connected to a single
13 underground disposal level. All shafts have four principle components: a
14 collar, a lined section penetrating the rock overburden; an unlined section
15 penetrating the salt; and a key at the rock/salt contact about 260 m (850 ft)
16 below the surface to provide a transition from the lined section to the
17 unlined section. The exhaust shaft is the exhaust air duct for the repository
18 and is 4 m (14 ft) in diameter from the bottom of the key to the repository
19 level. The construction and salt handling shaft provides the only means for
20 removing mined materials; it also serves as the secondary air supply and is
21 3 m (10 ft) in diameter below the key. The air intake shaft serves as the
22 primary air intake opening; it is 5 m (16 ft) in diameter below the key. The
23 waste shaft, designed to permit the transport of radioactive waste between the
24 surface waste-handling facilities and the underground disposal area, is 6 m
25 (19 ft) in diameter below the key; it also provides access for personnel,
26 materials, large equipment, and diesel fuel. The shafts will be sealed upon
27 decommissioning of the WIPP (U.S. DOE, 1989c).

28
29 Design of the WIPP provided for the access and disposal openings to remain
30 stable and provide minimum clearance for equipment during waste emplacement;
31 salt creep will eventually close these openings. The 100-acre disposal area
32 contains all of the underground facilities for waste handling, waste disposal,
33 operations, and maintenance. All of the underground horizontal openings are
34 rectangular in cross section. The disposal area drifts, in the southern part
35 of the repository, are 4 m (13 ft) high by 8 m (25 ft) wide; the disposal
36 rooms are 4 m (13 ft) high, 10 m (33 ft) wide, and 91 m (300 ft) long. Other

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Figure 1-5. Proposed WIPP Repository, Showing Both TRU-Waste Disposal Areas and Experimental Areas (after Waste Management Technology Dept., 1987).

drifts range from about 2 to 4 m (8 to 12 ft) high and 4 to 8 m (14 to 25 ft) wide. The width of the pillars between rooms is 30 m (100 ft). The drift entries to the disposal areas will be sealed to isolate the disposal panels. The conceptual design envisions a multiple-component seal approximately 30 m (100 ft) long (U.S. DOE, 1989c).

WASTE

The TRU waste for which WIPP is designed is defense-program waste generated by the United States government. TRU wastes are those radioactive wastes that, without regard to source or form, are contaminated with concentrations greater than 100 nCi/g of alpha-emitting, transuranic radionuclides with half-lives greater than 20 years. In accordance with DOE Order 5820.2A (U.S. DOE,

1980c), heads of DOE Field Organizations can determine that other alpha-contaminated wastes, peculiar to a specific waste-generator site, must be managed as TRU wastes. The WIPP Waste Acceptance Criteria (WAC) (Westinghouse, 1989) determine which TRU wastes will be accepted for emplacement at the WIPP. Under current plans, most TRU waste generated since 1970 will be disposed of at the WIPP; a small amount will be disposed of at other DOE facilities.

Most of the waste can be contact handled (CH) because the external dose rate (200 mrem/h or less) is so low that people can handle properly sealed drums and boxes without any special shielding. CH-TRU waste to be shipped to WIPP is contained in 55-gallon drums, metal boxes, and fiberglass-reinforced plywood (FRP) boxes (Table 1-1). Because the WIPP WAC requires a metal overpack for all combustible boxes as a fire prevention measure, FRP boxes and any other non-metal boxes will be overpacked and subsequently handled and disposed of in these overpacks. CH-TRU waste in drums and boxes will be stacked three high in the waste-storage rooms.

TABLE 1-1. APPROVED CH-TRU WASTE CONTAINERS FOR TRANSPORTATION AND EMPLACEMENT AT THE WIPP FACILITY (U.S. DOE, 1989c)

Container Description	Container Dimension (h x w x l)	Nominal Volume
DOT 17C 55- Gallon Drums	0.3 x 0.2 m dia (35 x 24 in)	0.2 m ³ (7.4 ft ³)
Steel Box	0.3 x 0.5 x 0.6 m (38 x 54 x 68 in)	2.3 m ³ (82 ft ³)
Steel Box	0.7 x 0.6 x 1.0 m (77 x 68 x 112 in)	9.5 m ³ (339 ft ³)
Steel Box (FRP Box Overpacked)	0.5 x 0.5 x 0.7 m (54 x 54 x 88 in)	4.1 m ³ (148 ft ³)
Seven-Pack of 55- Gallon Drums		1.5 m ³ (52* ft ³)
Standard Waste Box	0.3 x 0.6 x 0.5 m (38 x 71 x 55 in)	1.8 m ³ (64 ft ³)

*Envelope Volume - 2.2 m³ (78 ft³)

1 A small portion of the waste volume must be remotely handled (RH), that is,
2 the surface dose rate exceeds 200 mrem/h so that the waste canisters must be
3 packaged for handling and transportation in specially shielded casks. The
4 surface dose rate of RH-TRU canisters cannot exceed 1,000 mrem/h. RH waste in
5 canisters will be emplaced in holes drilled into the walls of the rooms. The
6 reference canister for the RH-TRU waste (U.S. DOE, 1989c) is a 26-in O.D.
7 right-circular cylinder made of 1/4-in carbon steel plate. Caps are welded at
8 both ends. The canister is 3 m (10 ft) in length, including the handling
9 pintle. Inside, the waste occupies about 850 ℓ (30 ft^3).

10

11 The WIPP's capacity is equivalent to about 863,000 drums containing about
12 9,000,000 Ci of CH-TRU waste and no more than 5,100,000 Ci of RH-TRU waste.
13 The total curies of RH-TRU waste is limited by the First Modification to the
14 Consultation and Cooperation Agreement (U.S. DOE and State of New Mexico,
15 1981). The complex analyses for the evaluation of compliance with Subpart B
16 of the Standard require knowledge of the waste inventory. Therefore, all
17 analyses will be based on current projections of the final inventory,
18 estimated at 385,000 drums and 19,500 boxes of CH-TRU waste (Lappin et al.,
19 1989) and 4,000 to 5,000 canisters of RH-TRU waste (U.S. DOE, 1989c).

20

21 Typically, the waste is composed of laboratory and production trash
22 contaminated with transuranic elements. This includes cloth, rubber,
23 polyethylene, paper, wood, metals, glass, filters, resins, graphite, oils,
24 solvents, alcohols, and sludges. The sludges may contain a solidifier (such
25 as cement), absorbent materials, inorganic compounds, complexing agents, and
26 organic compounds including oils, solvents, alcohols, emulsifiers,
27 surfactants, and detergents. For acceptance at the WIPP, the waste must be
28 stabilized or packaged so that it cannot propagate fires. Only small amounts
29 of free liquids are allowed in the packages. The density of CH-TRU waste is
30 assumed to be a maximum of 2.2 g/cm^3 (based on maximum inventory contained in
31 a 55-gallon drum) and is expected to average about 1.0 g/cm^3 (U.S. DOE,
32 1989c). The following CH-TRU waste forms have been identified as also
33 containing hazardous chemical constituents* (U.S. DOE, 1989c). Many of

34

35

36

37 *These hazardous materials are regulated separately by EPA and the State of New
38 Mexico

1 these constituents significantly affect the ability of radionuclides to
2 migrate out of the repository.

3
4 Cemented and Uncemented Aqueous Waste. This is a wastewater treatment
5 sludge that is precipitated at a pH of 10 to 12. It may be either an
6 uncemented, damp solid or cemented with portland cement. Alcohols and
7 halogenated organics in the sludge derive from the cleaning of
8 equipment and glassware and the degreasing of metals. Some aqueous
9 process waste may also contain metals, such as cadmium and lead.

10
11 Cemented and Uncemented Organic Waste. Organic waste containing oil
12 and halogenated organic solvents may be an uncemented, damp solid or
13 cemented with Envirostone cement and an emulsifier. Organic waste
14 consists of lathe coolants and degreasing solvents used in plutonium
15 fabrication.

16
17 Solidified Process and Laboratory Solid Waste. This consists of anion
18 and cation resins and incinerator ash that are neutralized and
19 immobilized with portland cement. Solvents in this waste are from
20 plutonium-recovery operations.

21
22 Combustible Waste. This includes paper and cloth (dry and damp),
23 various plastics such as polyethylene and polyvinyl chloride, wood, and
24 filters contaminated with trace quantities of halogenated organic
25 solvents. These materials are generated in plutonium-recovery and
26 plutonium-fabrication processes and analytical laboratories.

27
28 Metal Waste. Lead, tantalum, stainless steel, and aluminum constitute
29 the majority of these wastes, which include equipment, tools,
30 crucibles, and molds. Residual halogenated organic solvents may also
31 be found in this waste form.

32
33 Filter Waste. These wastes are Ful-Flo and high-efficiency particulate
34 air (HEPA) filters and processed filter media with portland cement
35 added to absorb any residual liquid and neutralize residual acids.
36 Exhaust stream filters may be contaminated with volatile organic
37 solvents used in plutonium fabrication and recovery processes.

Inorganic Solid Waste. Materials such as firebrick, Oil Dri, concrete, and soil are included in this waste form, which may be contaminated with residual halogenated organic solvents. This waste results from decontamination and decommissioning of plutonium recovery areas.

Leaded Rubber Waste. This includes leaded rubber gloves and aprons used throughout plutonium processing areas.

The estimated quantity of each waste form in CH-TRU waste from two DOE facilities is given in Table 1-2. Most of the organic solvents are present in

TABLE 1-2. ESTIMATED QUANTITIES OF TRU MIXED WASTE BY WASTE FORM FROM THE ROCKY FLATS PLANT AND THE IDAHO NATIONAL ENGINEERING LABORATORY (U.S. DOE, 1989c)

Description	Quantity (kg)
Cemented and uncemented sludges from aqueous wastewater treatment	6,121,100
Cemented and uncemented organic sludges	1,749,400
Solidified process and laboratory waste	95,300
Combustible waste	2,740,300
Metal waste	4,295,600
Filter waste	1,258,900
Inorganic solid waste	211,400
Leaded rubber	244,000
TOTAL	16,716,000

residual quantities from the cleaning of equipment, plastics, glassware, and filters. A major constituent of CH-TRU waste is lead that is present predominantly as shielding, glovebox parts, and lead-lined gloves and aprons (U.S. DOE, 1989c). Lead is used as shielding in most of the RH-TRU waste packages. Trace quantities of mercury, barium, chromium, and nickel have also been reported in some sludges (U.S. DOE, 1989c). The following two RH-TRU waste forms contain hazardous chemical constituents (U.S. DOE, 1989c):

1 Solid Waste. This waste contains mixtures of combustibles (e.g.,
2 paper, polyvinyl chloride, polypropylene, polyethylene, and neoprene)
3 and noncombustibles (e.g., laboratory equipment, tools, and small
4 electric motors) that were removed from a hot cell facility at Oak
5 Ridge National Laboratory. This waste will not contain free liquids or
6 particulates.

7
8 Sludges. Fuel sludges and process sludges will be solidified. This
9 waste will be a solid monolith packaged in lead-shielded canisters.

10
11 The inventory of radionuclides contained in the waste upon receipt at the WIPP
12 has been projected over the 25-year operational lifetime of the repository
13 (Tables 1-3 and 1-4). The radionuclide composition of CH-TRU waste varies
14 widely depending upon which DOE facility generated the waste. To simplify
15 radiological analyses, the mean activity of a 55-gallon drum for each
16 generator was weighted based on the estimated number of containers contributed
17 by each facility for disposal in the WIPP. The combined product of this
18 weighted activity with the individual radionuclide distributions in the waste
19 produced by each generator was used to represent the radionuclide content of
20 an average drum shipped to the WIPP (U.S. DOE, 1989c). The Oak Ridge National
21 Laboratory is projected to be the predominant source of RH-TRU waste. The
22 existing RH-TRU waste contains a wide range of radionuclides. The average
23 reference RH-TRU waste for the WIPP consists of a normalized actinide
24 inventory and an assumed distribution of mixed activation and fission
25 products. The concentration of all radionuclides in RH-TRU waste will not
26 exceed 23 Ci/l (U.S. DOE, 1989c).

27
28 The fissile material content in equivalent grams of plutonium-239 allowed by
29 the WAC is a maximum of 200 g for a 55-gallon drum and 5g/cm³ up to 350 g for
30 boxes. The average content is approximately 17 g for a drum and 90 g for the
31 most common box (U.S. DOE, 1989c).

32
33 Subpart B of the Standard sets release limits in curies for isotopes of
34 americium, carbon, cesium, iodine, neptunium, plutonium, radium, strontium,
35 technetium, thorium, tin, and uranium, as well as certain other radionuclides
36 (Appendix A of this report). Although the initial inventory contains little

or none of some of the listed nuclides, they may be produced as a result of radioactive decay and must be accounted for in the compliance evaluation. Moreover, any radionuclides not listed in Subpart B that could contribute to doses must be accounted for.

TABLE 1-3. REPRESENTATIVE RADIONUCLIDE CONTENT OF CH-TRU WASTE (U.S. DOE, 1989c)

<u>Radionuclide</u>	<u>Mass g/container</u>	<u>Activity Ci/container</u>
<u>Drum</u>		
Th-232	6.0×10^0	6.6×10^{-7}
U-233	1.7×10^0	1.7×10^{-2}
U-235	4.0×10^{-1}	8.8×10^{-7}
U-238	1.0×10^{-1}	3.5×10^{-6}
Np-237	3.1×10^{-2}	2.2×10^{-5}
Pu-238	6.2×10^{-1}	1.1×10^1
Pu-239	1.4×10^1	8.5×10^{-1}
Pu-240	8.5×10^{-1}	1.9×10^{-1}
Pu-241	6.6×10^{-2}	6.8×10^0
Pu-242	7.8×10^{-3}	3.1×10^{-5}
Am-241	4.9×10^{-1}	1.7×10^0
Cm-244	4.2×10^{-4}	3.4×10^{-2}
Cf-252	1.0×10^{-5}	5.4×10^{-3}
TOTAL		2.1×10^1
<u>Standard Waste Box (SWB)</u>		
Th-232	1.2×10^1	1.3×10^{-6}
U-233	6.7×10^0	6.5×10^{-2}
U-235	9.6×10^{-1}	2.1×10^{-6}
U-238	2.5×10^1	8.3×10^{-6}
Np-237	4.4×10^{-4}	3.1×10^{-7}
Pu-238	4.2×10^{-2}	7.2×10^{-1}
Pu-239	7.9×10^1	4.9×10^0
Pu-240	6.5×10^0	1.5×10^0
Pu-241	6.7×10^{-1}	6.9×10^1
Pu-242	7.5×10^{-2}	2.9×10^{-4}
Am-241	2.1×10^{-1}	7.3×10^{-1}
Cm-244	8.6×10^{-5}	7.0×10^{-3}
Cf-252	2.1×10^{-6}	1.1×10^{-3}
TOTAL		7.7×10^1

TABLE 1-4. REPRESENTATIVE RADIONUCLIDE CONTENT OF RH-TRU WASTE (U.S. DOE, 1989c)

<u>Radionuclide</u>	<u>Ci/canister</u>	<u>Ci/l</u>
Co-60	1.7×10^{-1}	2.0×10^{-4}
Sr-90	5.1×10^0	6.0×10^{-3}
Ru-106	3.5×10^{-2}	4.2×10^{-5}
Sb-125	1.1×10^{-3}	1.2×10^{-6}
Cs-137	4.3×10^0	5.0×10^{-3}
Ce-144	3.4×10^{-1}	4.0×10^{-4}
Eu-155	1.7×10^{-3}	2.0×10^{-6}
U-233	5.5×10^{-3}	6.5×10^{-6}
U-235	3.0×10^{-3}	3.6×10^{-6}
U-238	1.5×10^{-3}	1.7×10^{-6}
Pu-238	5.7×10^0	6.7×10^{-3}
Pu-239	6.8×10^0	8.0×10^{-3}
Pu-240	2.2×10^0	2.5×10^{-3}
Pu-241	1.2×10^1	1.4×10^{-2}
Pu-242	3.8×10^{-4}	4.5×10^{-7}
Am-241	2.1×10^{-1}	2.5×10^{-4}
Cm-244	1.6×10^{-1}	1.9×10^{-4}
Cf-252	2.8×10^{-1}	3.3×10^{-4}
TOTAL	3.7×10^1	4.3×10^{-2}

II. APPLICATION OF SUBPART B TO THE WIPP

Subpart B of the Standard applies at the WIPP to cumulative releases of radioactive materials into the accessible environment (§ 191.13) and to annual radiation doses received by members of the public in the accessible environment (§ 191.15) as a result of TRU waste disposal. It requires actions and procedures (§ 191.14) to increase confidence that the release limits will be met at the WIPP. It would also apply to radioactive contamination of certain sources of groundwater (§ 191.16) in the vicinity of the WIPP disposal system from such TRU wastes, if any of these sources of groundwater were found to be present (U.S. DOE, 1989b). Each of the four requirements of Subpart B and their evaluation by the WIPP Project is discussed below. The full text of the Standard is reproduced as Appendix A of this report.

Appendix B to the Standard is EPA's guidance to the implementing agency (in this case, the DOE). In the preamble to the Standard (U.S. EPA, 1985, p. 38069), the EPA stated that it intends the guidance to be followed:

...Appendix B...describes certain analytical approaches and assumptions through which the [EPA] intends the various long-term numerical standards of Subpart B to be applied. This guidance is particularly important because there are no precedents for the implementation of such long-term environmental standards, which will require consideration of extensive analytical projections of disposal system performance.

The EPA based Appendix B on some of the analytical assumptions it used to develop the technical basis for the numerical disposal standards. Thus, the EPA "believes it is important that the assumptions used by the [DOE] are compatible with those used by the EPA in developing this rule. Otherwise, implementation of the disposal standards may have effects quite different than those anticipated by EPA" (U.S. EPA, 1985, p. 38074). Chapter II documents the assumptions and interpretations of the Standard used in the compliance assessment.

2 CONTAINMENT REQUIREMENTS

3
4 The primary objective of Subpart B is to isolate the waste from the accessible
5 environment by limiting long-term releases. This objective is reflected in
6 § 191.13, the Containment Requirements. Evaluation of compliance is based on
7 a performance assessment, which has specific meaning within the Standard:
8

9
10 "Performance Assessment" means an analysis that: (1) identifies the
11 processes and events that might affect the disposal system; (2)
12 examines the effects of these processes and events on the performance
13 of the disposal system; and (3) estimates the cumulative releases of
14 radionuclides, considering the associated uncertainties, caused by all
15 significant processes and events. These estimates shall be
16 incorporated into an overall probability distribution of cumulative
17 release to the extent practicable (§ 191.12(q)).
18

19 The assessment as defined must provide reasonable expectations that all
20 releases resulting from significant processes and events that may affect the
21 disposal system for 10,000 years after disposal have: (1) a likelihood of less
22 than one chance in ten of exceeding quantities specified in Appendix A of the
23 rule; and (2) a likelihood of less than one chance in 1,000 of exceeding ten
24 times the specified quantities. The term "performance assessment" has come to
25 be used to refer to the prediction of all long-term performance, because the
26 performance assessment methodology, with minor modifications, can also be used
27 to assess compliance with the 1,000-year performance. Henceforth, this report
28 will refer to the assessment of compliance with both the Containment
29 Requirements and the Individual Protection Requirements as the "performance
30 assessment".
31

32 Appendix A to the Standard establishes release limits for all the regulated
33 radionuclides. Table 1 in that appendix gives the limit for cumulative
34 releases to the accessible environment for 10,000 years after disposal for
35 each radionuclide per unit of waste. Note 1(e) to Table 1 defines the unit of
36 waste as an amount of TRU waste containing one million curies of alpha-
37 emitting transuranic radionuclides with half-lives greater than 20 years.
38 Note 2(b) describes the development of release limits for a TRU waste disposal
39 system: the release limits are the quantities in Table 1 multiplied by the
40 units of waste. Note 6 describes the manner in which release limits are to be
41 used to determine compliance with § 191.13: for each radionuclide released,

1 the ratio of the cumulative release to the total release limit for that
2 radionuclide must be determined; ratios for all radionuclides released are
3 summed for comparison to the requirements of § 191.13. Thus, the quantity of
4 a radionuclide that may be safely released depends on the quantities of all
5 other nuclides projected to be released, but cannot exceed its own release
6 limit. The summed normalized release cannot exceed 1 for probabilities
7 greater than 0.1 and cannot exceed 10 for probabilities greater than 0.001.
8 Potential releases estimated to have probabilities less than 0.001 are not
9 regulated.

10
11 For example, Table 1 in Appendix A to the Standard lists the release limits
12 for plutonium-239 and americium-241 as 100 curies each per waste unit. For a
13 repository with a waste unit of one and a release that contained only those
14 two nuclides, the sum of the two must not be greater than 100 curies unless
15 the probability of the release is less than 0.1 and must not be greater than
16 1,000 curies unless the probability is less than 0.001. The smallest release
17 limit in the table is 10 curies per waste unit for thorium-230 or -232; the
18 largest release limit is 1,000 curies per waste unit for technetium-99. For
19 the WIPP, the maximum possible waste unit for the stated capacity is about 15;
20 however, all radioactivity in the waste cannot be included in the waste unit
21 because it is not all from "alpha-emitting transuranic radionuclides with
22 half-lives greater than 20 years." The waste unit for the WIPP will likely be
23 about six. Regardless of the waste unit, all regulated radionuclides must be
24 included in release calculations.

25
26 For the WIPP performance assessment, the disposal system consists of the
27 underground facility with its engineered barriers and the subsurface geology
28 and hydrology of the disposal site. The engineered barriers are backfill in
29 the rooms; seals in the drifts and panel entries; backfill and seals in the
30 shafts; and plugs in the boreholes (U.S. DOE, 1989b). Engineered
31 modifications to the repository could include making the waste form a barrier.

32
33 The most significant event that may affect the disposal system probably will
34 be human intrusion. Typical examples of human intrusion include but are not
35 limited to exploratory or exploitative drilling for any reason, mining, or
36 the construction of other facilities for reasons unrelated to the repository.

1 The EPA gives specific guidance in Appendix B of the Standard for
2 consideration of human intrusion. The EPA believes that only realistic
3 possibilities for human intrusion that may be mitigated by design, site
4 selection, and passive institutional controls need be considered. In
5 particular, as long as passive institutional controls "endure and are
6 understood" they can be assumed to deter systematic or persistent exploitation
7 of the disposal site, and furthermore, can reduce the likelihood of
8 inadvertent, intermittent human intrusion to a degree to be determined by the
9 DOE. However, passive institutional controls can never be assumed to
10 eliminate the chance of inadvertent, intermittent human intrusion. EPA
11 suggests that exploratory drilling for resources is the most severe intrusion
12 that must be considered (U.S. EPA, 1985).

13
14 Active institutional controls cannot be considered to prevent intrusion for
15 more than 100 years after closure. For the WIPP, the likelihood of
16 inadvertent intrusion is assumed, based on the EPA guidance, to be no greater
17 than 30 boreholes per km² (0.4 mi²) of repository area per 10,000 years (U.S.
18 DOE, 1989b). Effects of the site, design, and passive institutional controls
19 can be used in judging the likelihood and consequences of inadvertent drilling
20 intrusion. The EPA suggests in Appendix B of the Standard that intruders will
21 soon detect or be warned of the incompatibility of their activities with the
22 disposal site by their own exploratory procedures or by passive institutional
23 controls (U.S. EPA, 1985).

24
25 Four conclusions may be drawn for the WIPP performance assessment relative to
26 human intrusion:

27
28 No human intrusion of the repository will occur during the period of active
29 institutional controls. Credit for active institutional controls can be
30 taken only for 100 years after closure.

31
32 While passive institutional controls endure, no mineral exploitation will be
33 carried out deliberately inside the controlled area, but reasonable, site-
34 specific exploitation outside the controlled area may occur and should be
35 considered in the performance assessment.

1 Intrusion of the repository leads to its detection. No mechanism for
2 detection need be advanced. The EPA's use of the word "incompatibility"
3 allows the conclusion that the intruders will plug and abandon their
4 boreholes to avoid the effects of the repository.

5
6 The number of exploratory boreholes assumed to be drilled inside the
7 controlled area is to be based on site-specific information and need not
8 exceed 30 boreholes/km² (0.4 mi²) per 10,000 years. No more severe
9 scenarios for human intrusion inside the controlled area need be considered.
10 While passive institutional controls endure, the drilling rate may be
11 significantly reduced, although the likelihood cannot be eliminated.

12
13 The repository area is not defined in the Standard but is necessary for
14 evaluating the human intrusion scenarios. For the WIPP, the repository area
15 includes the entirety of the excavated workings at mine level and all unmined
16 or unexcavated salt of any size that lies between any two portions of the
17 excavated workings. Thus the repository area is defined as the smallest
18 convex polygon that will enclose the excavated workings (Figure 2-1) (U.S.
19 DOE, 1989b).

20
21 In the Second Modification to the Consultation and Cooperation Agreement, the
22 DOE agreed to prohibit subsurface mining, drilling, slant drilling under the
23 withdrawn area, or resource exploration unrelated to the WIPP Project on the
24 sixteen square miles to be withdrawn under DOE control. The EPA guidance
25 advises that active institutional controls (such as the above prohibition)
26 will be effective for no more than 100 years after the repository is
27 decommissioned. Inadvertent intrusion will be considered possible in the
28 analysis beginning at that time, based on the DOE plan for active
29 institutional controls (see Chapter VI below).

30
31 The definition of performance assessment requires the consideration of
32 numerous uncertainties in the projected performance of the disposal system.
33 The WIPP Project will use the interpretation of the EPA requirement for
34 uncertainty analysis developed in previous work at SNL for high-level waste
35 disposal (Cranwell et al., 1982; Pepping et al., 1983; Hunter et al., 1986;
36 Cranwell et al., 1987; Campbell and Cranwell, 1988; Rechard, 1989). The EPA

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Figure 2-1. Repository Area (after U.S. DOE, 1989b).

has explicitly recognized that performance assessments will contain uncertainties and that many of these uncertainties cannot be eliminated. The WIPP Project will reduce uncertainty to the extent practicable using a variety of techniques (Table 2-1).

TABLE 2-1. TECHNIQUES FOR ASSESSING AND REDUCING UNCERTAINTY IN THE WIPP PERFORMANCE ASSESSMENT (after Bertram-Howery and Hunter, 1989a)

<u>Type of Uncertainty</u>	<u>Technique for Assessing or Reducing Uncertainty</u>
Scenarios (Completeness, Logic, and Probabilities)	Expert Judgment and Peer Review; Quality Assurance
Conceptual Models	Expert Judgment and Peer Review; Sensitivity Analysis; Quality Assurance
Computer Models	Expert Judgment and Peer Review; Verification and Validation*; Sensitivity Analysis; Quality Assurance
Parameter Values and Variability	Expert Judgment and Peer Review; Data-Collection Programs; Sampling Techniques; Sensitivity Analysis; Uncertainty Analysis; Quality Assurance

*to the extent possible

The Standard requires that the results of the performance assessment be incorporated into an overall probability distribution of cumulative release to the extent practicable. In Appendix B, the EPA suggests that the results be assembled into a single complementary cumulative distribution function (CCDF) that indicates the probability of exceeding various levels of cumulative release (Figure 2-2). The EPA suggests that this single curve can incorporate all parameter and scenario uncertainty, and if this single distribution function meets the requirement of § 191.13, then a disposal system can be considered to be in compliance with the Containment Requirements (Bertram-Howery and Hunter, 1989b). Thus, EPA states that satisfying the numeric

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Figure 2-2. Hypothetical CCDF Illustrating Compliance with the Containment Requirements (after Rechard, 1989).

requirements is sufficient to demonstrate compliance with § 191.13 but does not say it is absolutely necessary.

The EPA acknowledged that implementation of the Containment Requirements might require modification of those standards in the future. This implementation

...will require collection of a great deal of data during site characterization, resolution of the inevitable uncertainties in such information, and adaptation of this information into probabilistic risk assessments. Although [EPA] is currently confident that this will be successfully accomplished, such projections over thousands of years to determine compliance with an environmental regulation are unprecedented. If--after substantial experience with these analyses is acquired--disposal systems that clearly provide good isolation cannot reasonably be shown to comply with the containment requirements, the [EPA] would consider whether modifications to Subpart B were appropriate... (U.S. EPA, 1985, p. 38074).

This statement implies that there can be a basis for concluding that a system provides good isolation that does not totally depend upon the calculated CCDF.

2 ASSURANCE REQUIREMENTS

3

5 The EPA has included Assurance Requirements (§ 191.14) in the Standard to
6 provide the confidence needed for long-term compliance with the Containment
7 Requirements for those facilities not regulated by the NRC. The Assurance
8 Requirements include six provisions: active institutional controls; post-
9 closure monitoring for performance deviations; passive institutional controls;
10 different types of barriers, encompassing both engineered and natural
11 barriers; avoidance of sites where a reasonable expectation of future resource
12 exploration exists, unless favorable disposal characteristics compensate; and
13 the possibility of removal of wastes for a reasonable period of time. Some of
14 the activities required to comply with the Assurance Requirements cannot be
15 fully defined until after the performance assessment is well underway, because
16 that assessment will identify parameters needed for certain of the
17 requirements (Bertram-Howery and Hunter, 1989b).

18

29 INDIVIDUAL PROTECTION REQUIREMENTS

21

22 The Individual Protection Requirements (§ 191.15) necessitate the prediction
24 of potential doses to man resulting from releases to the accessible
25 environment during the first 1,000 years after closure of the repository, in
26 the event that the PA predicts such releases. Although challenges to this
27 requirement contributed to the remand of Subpart B to the EPA, the WIPP
28 Project cannot assume that the requirement will change when the Standard is
29 repromulgated.

30

31 The methodology developed for assessing compliance with the Containment
32 Requirements can be used to predict releases in order to estimate doses as
33 specified by the Individual Protection Requirements. However, the EPA
34 suggests in Appendix B of the Standard that compliance with § 191.15 can be
35 determined based upon "best estimate" predictions rather than a CCDF. Thus,
36 when uncertainties are considered, only the mean or median of the appropriate
37 distributions, whichever is greater, need fall below the limits, according to
38 Appendix B.

39

1 The Individual Protection Requirements limit the annual dose equivalent from
2 the disposal system to any member of the public in the accessible environment
3 to 25 millirems to the whole body or 75 millirems to any critical organ.
4 These requirements apply to undisturbed performance of the disposal system,
5 considering all potential release and dose pathways for 1,000 years after
6 disposal. The Standard requires that modeled individuals be assumed to
7 consume 2 l (0.5 gal)/day of drinking water from a significant source of
8 groundwater, which is specifically defined in the Standard.

9
10 "Undisturbed performance" means predicted behavior of a disposal
11 system, including consideration of the uncertainties in predicted
12 behavior, if the disposal system is not disrupted by human intrusion or
13 the occurrence of unlikely natural events (§ 191.12(p)).

14
15 "Significant source of groundwater" as used in this Part, means: (1)
16 An aquifer that: (i) Is saturated with water having less than 10,000
17 milligrams per liter of total dissolved solids; (ii) is within 2,500
18 feet of the land surface; (iii) has a transmissivity greater than 200
19 gallons per day per foot, provided that any formation or part of a
20 formation included within the source of groundwater has a hydraulic
21 conductivity greater than 2 gallons per day per square foot; and (iv)
22 is capable of continuously yielding at least 10,000 gallons per day to
23 a pumped or flowing well for a period of at least a year; or (2) an
24 aquifer that provides the primary source of water for a community water
25 system as of [November 18, 1985].

26
27 Human intrusion means any human activities other than those directly related
28 to repository characterization, construction, operation, or monitoring. The
29 effects of intrusion are specifically excluded for the undisturbed performance
30 analysis (U.S. DOE, 1989b).

31
32 Unlikely natural events at the WIPP will be those events and processes that
33 have not occurred in the past at a sufficient rate to affect the Salado
34 Formation at the repository horizon within the controlled area in such a way
35 as to have caused the release of radionuclides, had they been present. Only
36 the presence of groundwater has affected the Salado in the vicinity of the
37 WIPP at the repository horizon for the past several million years. Therefore,
38 the WIPP Project will model only groundwater flow and the effects of the
39 repository as the undisturbed performance (U.S. DOE, 1989b).

40
41 No water-bearing unit at the WIPP meets the first definition of significant
42 source of groundwater everywhere, because the level of dissolved solids is

high and transmissivity is low in most places (Mercer, 1983); however, the WIPP Project will assume that any *portion* of an aquifer that meets the first definition is a significant source of groundwater. Communication between non-qualifying and qualifying portions will be evaluated. No community water system is being supplied by any aquifer near the WIPP, therefore no aquifer meets the second definition of significant source of groundwater (U.S. DOE, 1989b).

The Dewey Lake Red Beds are saturated only in some areas. Neither the Magenta Dolomite Member nor the Culebra Dolomite Member of the Rustler Formation (Figure 1-4) appears to be a significant source of groundwater. Aquifers below the Salado Formation are more than 760 m (2,500 ft) below the land surface at the WIPP. The nearest aquifer that meets the first definition of a significant source of groundwater over its entire extent is the alluvial and valley-fill aquifer along the Pecos River at Malaga Bend, 26 km (16 mi) away. Communication between this aquifer and any other aquifers in the vicinity of the WIPP will be evaluated (U.S. DOE, 1989b).

No releases from the repository/shaft system are expected to occur within 1,000 years (Lappin et al., 1989; Marietta et al., 1989); therefore, dose predictions for undisturbed performance may be unnecessary.

GROUNDWATER PROTECTION REQUIREMENTS

Special sources of groundwater are protected from contamination at levels greater than certain limits by the Groundwater Protection Requirements (§ 191.16).

SPECIAL SOURCES OF GROUNDWATER

Special sources of groundwater are defined as

...those Class I groundwaters identified in accordance with the [EPA's] Ground-Water Protection Strategy published in August 1984 that: (1) Are within the controlled area encompassing a disposal system or are less than five kilometers beyond the controlled area; (2) are supplying drinking water for thousands of persons as of the date the [DOE]

1 chooses a location within that area for detailed characterization as a
2 potential site for a disposal system...; and (3) are irreplaceable in
3 that no reasonable alternative source of drinking water is available to
4 that population (§ 191.12(o)).
5

6 REQUIREMENT DOES NOT APPLY TO THE WIPP
7

8
9 At the time the DOE chose the WIPP location (and indeed at present), no source
10 of water within 5 km (3 mi) of the maximum allowable extent of the controlled
11 area (Figure 2-3) was supplying drinking water for thousands (or even tens) of
12 persons. Therefore, no special sources of groundwater will be affected by the
13 WIPP project and the requirement to analyze radionuclide concentrations in
14 such groundwater does not apply.
15
16

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Figure 2-3. Illustration of Certain Definitions (after U.S. DOE, 1989b). The dashed line, drawn 5 km (3 mi) from the maximum allowable extent of the controlled area (§ 191.12(g)), shows the maximum area in which the occurrence of a special source of groundwater (§ 191.12(o)) is of regulatory interest. The performance assessment will help determine the extent of the WIPP controlled area.

III. COMPLIANCE ASSESSMENT PHILOSOPHY AND METHODOLOGY OVERVIEW

The long-term performance requirements of Subpart B of the Standard are the focus of this report. For the WIPP, two requirements must be met. The Containment Requirements (§ 191.13) limit cumulative releases of radioactive materials to the accessible environment for 10,000 years. The Individual Protection Requirements (§ 191.15) limit radiation doses to members of the public in the accessible environment for 1,000 years. First, the philosophy for assessing compliance of the WIPP with these requirements is discussed. Second, a methodology for performing this assessment is described.

PHILOSOPHY

THE CONTAINMENT REQUIREMENTS

The Standard (§ 191.13(a)) requires that performance assessments be used to determine whether cumulative releases to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system will meet specific release limits (U.S. EPA, 1985).

Whereas no specific requirements are indicated as to how compliance is to be demonstrated, Appendix B to Subpart B of the Standard describes how compliance can be determined by use of a complementary cumulative distribution function (CCDF).

A performance-assessment methodology consists of the following parts (Hunter et al., 1986; Cranwell et al., 1987; Cranwell et al., 1989): (1) procedures for scenario development, (2) models for use in determining releases to the accessible environment, and (3) a procedure for a compliance assessment with the regulatory standards. Descriptions of the procedure for compliance assessment based on the construction of a CCDF are available (Cranwell et al., 1982; Pepping et al., 1983; Hunter et al., 1986; Cranwell et al., 1987; Campbell and Cranwell, 1988; and Rechard, 1989).

1 Scenarios are sets of naturally occurring, human-induced, or waste-induced
2 conditions that represent realistic potential future states of the repository,
3 the geologic systems, and the groundwater flow systems that could affect the
4 migration and transport of radionuclides from the repository to the accessible
5 environment (Cranwell et al., 1989). Whereas the Standard does not mention
6 "scenarios" as such, the need for their development is implied in § 191.13.

7
8 Several different techniques have been proposed for the development of
9 scenarios. The basic steps are summarized (Cranwell et al., 1982) as: (1)
10 identifying a comprehensive list of events and processes that may affect the
11 long-term isolation of the radioactive waste, (2) classifying the events and
12 processes to aid in completion arguments, (3) screening the events and
13 processes based on well-defined criteria, (4) forming scenarios by combining
14 the remaining events and processes, and (5) screening the scenarios by well-
15 defined criteria. Appendix B of the Standard indicates that individual events
16 and processes, and by implication their combined form as scenarios, do not
17 have to be considered in performance assessment if their probability of
18 occurrence is less than one chance in 10,000 in 10,000 years, or their
19 omission is not expected to significantly change the probability distribution
20 of cumulative releases. Another screening criterion is the physical
21 reasonableness of the event or process for a specific disposal system and of
22 the combination of events and processes in scenarios.

23
24 Scenario development provides a means for analysis of uncertainty in future
25 states of the disposal system. Uncertainty in the events and processes that
26 make up a scenario is represented by assigning a probability of occurrence to
27 each event or process. The probability of occurrence of the scenario is
28 derived from the constituent events and processes. These constituent
29 probabilities are estimated where possible and determined by expert judgment
30 when data is insufficient to support probability estimates.

31
32 The goal of the scenario-development procedure is to develop a comprehensive
33 set of mutually exclusive scenarios that could result in the release of
34 radionuclides to the accessible environment. To initiate an analysis, the
35 physical processes being modeled are carefully defined, and multi-dimensional

1 conceptual and mathematical models are developed that adequately describe the
2 processes over the range of conditions to be modeled. For these models to be
3 credible, phenomena and parameters that are determined to be important to the
4 performance measure by sensitivity analyses must be included.

5
6 Individual scenarios that significantly affect the groundwater-flow regime are
7 usually analyzed separately to identify important parameters and examine the
8 scenario's affect on the conceptual model. These sensitivity analyses may use
9 complex, two- or three-dimensional models of groundwater flow and transport.
10 When the flow behavior and other parameters are better understood, simpler
11 models of flow and transport and other processes that mimic the predicted
12 behavior can be substituted for use in repetitive uncertainty analyses.

13
14 An important aspect of model development and application is model verification
15 and validation. Verification ensures that the model correctly performs the
16 operations specified in the numerical procedures. Verification does not
17 assess the physical correctness of the solution, therefore, a model is
18 verified when it numerically solves the specified problem correctly. Model
19 validation is the procedure that addresses physical correctness. Validation
20 usually involves a test of the model output against available data to ensure
21 that the model is a correct representation of natural processes or systems for
22 which it is intended. Such tests evaluate both the mathematical and related
23 conceptual models. Few models that describe environmental systems can ever be
24 fully validated on the space and time scales of interest. Rather, model
25 adequacy for the particular application is a subjective judgment of the
26 analyst based on partial validation exercises.

27
28 In principle, models used for performance assessment can be either
29 deterministic or stochastic. Deterministic models do not explicitly account
30 for uncertainties, whereas stochastic models may. The models currently being
31 considered for use in the WIPP performance assessment are all deterministic,
32 because stochastic models incorporating the many processes affecting
33 performance of the WIPP disposal system would be too complex to develop and
34 use effectively. Many stochastic processes are included through deterministic
35 assumptions. Monte Carlo sampling techniques are used to perform stochastic
36 analysis with systems of deterministic models.

1 The physical processes by which radioactive material can be released to the
2 accessible environment are complex. As a result, the models being used for
3 the WIPP performance assessment are generally complex, and the results of the
4 consequence estimates have large uncertainties associated with them. In
5 general, uncertainty in the consequence modeling has two components: model
6 uncertainty and data uncertainty (Cranwell and Helton, 1981). Model
7 uncertainty is partially addressed by verification and validation. There are
8 always unquantifiable uncertainties associated with judging model adequacy.
9 Because validation of environmental models on the time scales of interest is
10 impossible, model uncertainty must ultimately be assessed by subjective
11 judgments based on partial model validation. In WIPP performance assessment,
12 data uncertainties are handled by first selecting ranges and distributions for
13 each parameter and then using a statistical sampling procedure to select
14 parameter values for each deterministic calculation. Many sampled values are
15 used to generate a distribution of consequence values, and the range and
16 distribution of these values reflect data uncertainty.

18 THE INDIVIDUAL PROTECTION REQUIREMENTS

20 The Standard (§ 191.15) requires that whole-body and critical-organ doses be
21 calculated for radionuclide releases to the accessible environment from all
22 pathways assuming undisturbed conditions during the first 1,000 years after
23 disposal. One of the products of scenario development for the Containment
24 Requirements will be a scenario for undisturbed conditions. The techniques
25 for analyzing this scenario will be available through the performance
26 assessment required by the Containment Requirements. If releases to the
27 accessible environment are predicted to occur during the first 1,000 years
28 after closure, compliance with the Standard will be determined using pathway
29 and dosimetry models described below.

31 METHODOLOGY OVERVIEW

33 The WIPP compliance assessment methodology comprises the procedures and tools
34 necessary for implementing the compliance assessment philosophy. Migration of
35 radionuclides from the repository is estimated by applying a collection of
36 techniques and computer codes in the methodology. The methodology consists of

1 characterization of the disposal system and the region, techniques for
2 scenario development and probability estimates, computer codes for consequence
3 modeling, statistical techniques for uncertainty and sensitivity analyses, and
4 a procedure that assembles the above results into a CCDF.

5
6 The methodology (Figure 3-1) builds on previous work at SNL for high-level-
7 waste disposal in hypothetical repositories in bedded salt (Cranwell et al.,
8 1987) and basalt (Bonano et al., 1988). It also builds on work done at SNL
9 in collaboration with the International Nuclear Energy Agency of the
10 Organization for Economic and Cooperative Development (NEA, 1988) to analyze
11 empirical data for potential subseabed repositories.

12
13 The first step in the analysis is describing the disposal system.
14 Characteristics of the controlled area, the repository/shaft system, and the
15 waste are described. Based on the disposal system description, those events
16 and processes that are most likely to contribute to migration of radionuclides
17 from the repository/shaft system and transport to the accessible environment
18 are identified and screened. Once these events and processes have been
19 developed into scenarios and these scenarios have been screened based on
20 physical reasonableness and probability, a sequence of models is used to
21 estimate the consequence of each remaining scenario (Figure 3-2).

22
23 The physical processes simulated in consequence modeling for the Containment
24 Requirements include groundwater flow; repository resaturation from brine
25 inflow; gas generation from corrosion and microbiological activity; room
26 closure from salt creep; radionuclide transport in rooms, drifts, MB139, and
27 shafts; and radionuclide transport in the geosphere. For the Individual
28 Protection Requirements, radionuclide transport to and dispersion in the
29 biosphere (i.e., surface and near-surface) and human intake of radionuclides
30 must also be included.

31
32 Groundwater flow is simulated at regional and local scales for computational
33 efficiency. The Los Medanos regional and local models are coupled through
34 boundary conditions that are passed from regional to local models. For
35 calibration, each model can provide boundary conditions to the other. These

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Figure 3-1. Compliance Assessment Methodology Structure (after Rechard, 1989).

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Figure 3-2. A Sequence of Codes for Consequence Modeling (Rechard, 1989).

1 hydrologic models provide flow fields necessary for calculating radionuclide
2 transport to the accessible environment where the cumulated release of each
3 radionuclide can be obtained by integrating the discharge rate over 10,000
4 years.

5
6 For the Individual Protection Requirements, the biosphere transport code
7 simulates the movement of radionuclides through the surface and near-surface
8 environment and uptake by humans. This information is then used to estimate
9 the whole-body and critical-organ doses.

10
11 For the Containment Requirements, comparison with the Standard can be made by
12 a probability vs. consequence curve in the form of a CCDF. The CCDF of a
13 value χ of consequence X indicates the probability of X having values greater
14 than χ . Because consequence models currently being considered for use in WIPP
15 performance assessment are deterministic models, the uncertainty of input data
16 can be incorporated into the analysis through Monte Carlo sampling of these
17 data. The following is a brief description of an approach to generate a CCDF
18 using a Monte Carlo sampling technique.

19
20 Appropriate ranges and distributions for model parameters are chosen for each
21 significant scenario. This establishes a set of variables for characterizing
22 data uncertainties over all scenarios. The distributions are statistically
23 sampled to obtain sets of values (referred to as "input vectors"). For all
24 scenarios, m input vectors are generated. The same m input vectors are used
25 for m consequence calculations for each scenario, but not all parameters may
26 be used in a single scenario analysis. Cumulative release to the accessible
27 environment is the consequence calculated for each input vector, producing a
28 distribution of cumulative releases for each scenario. A single CCDF is then
29 generated by normalizing each consequence by the EPA limits for each
30 significant scenario, ranking these normalized releases from largest to
31 smallest, calculating the probability that a release is larger than some R_0
32 from this ranking, weighting this probability by the probability of the
33 associated scenario, summing over all significant scenarios, and plotting the
34 result against R_0 for each combination of R_0 and weighted sum of probabilities
35 to obtain a probability versus consequence curve (step function) that is the
36 CCDF (Cranwell et al., 1982; Pepping et al., 1983; Hunter et al., 1986;

1 Cranwell et al., 1987; Campbell and Cranwell, 1988; and Rechard, 1989). If
2 all portions of the CCDF (Figure 2-2) lie within the envelope of the EPA's
3 Containment Requirements, compliance is indicated.

4
5 The compliance assessment methodology uses a modular system of computer codes
6 controlled by a computerized executive package. This system is referred to as
7 the "Compliance Assessment Methodology CONTroller" (CAMCON). CAMCON contains
8 translators that automatically translate the output of one computer code into
9 the appropriate input format for the next code. In this way, the executive
10 controller can perform a computation for m input vectors through the entire
11 set of modules with little operator intervention.

12
13 CAMCON contains three data bases that are strictly controlled for quality-
14 assurance (QA) purposes. The primary data base comprises observational data
15 in a reduced form that are transformed, either objectively/subjectively using
16 interpolations or optimal-estimation routines or totally subjectively by
17 expert judgment, into a secondary data base that can be accessed by the
18 executive controller. Transformation of primary data to secondary data is
19 carefully quality controlled. During the calculation of cumulative release,
20 the executive controller creates a computational data base that is generated
21 anew for each input vector.

22
23 An important feature of CAMCON is that QA of calculations, data manipulation,
24 and file management is explicitly included and automatically controlled. This
25 QA process guarantees reproducibility for each computation and minimizes human
26 error. QA for the performance assessment is included in the SNL QA program
27 for the WIPP Project (SNL, 1988).

IV. CONTAINMENT REQUIREMENTS

The Containment Requirements (§ 191.13) are described in Chapter II (also Appendix A). An overview of a methodology for assessing compliance with this requirement is provided in Chapter III. This chapter applies the methodology to the WIPP. Because research and development work is continuing, required data and understanding for some parts of the system are incomplete (Bertram-Howery and Hunter, 1989a). Subsystems where work is nearly complete are well understood and are described in more detail in the following sections. These sections are indicated clearly below. Subsystems that are not well understood are described in less detail and include considerable judgment. Such judgment is based on the experience of the research staff, and must be confirmed with data-acquisition programs, design-demonstration tests, and (to the extent possible) model validation. These sections are also indicated clearly below.

SCENARIOS

Performance assessment for the Containment Requirements consists of a series of analyses that predict the performance of the disposal system for 10,000 years and compare the predicted performance with the Standard. Performance assessment includes scenario development and screening and probability assignment. A scenario is a combination of events and processes representing a possible future state of the disposal system. There are four criteria for using scenarios to construct a CCDF for evaluating whether a disposal system meets the Containment Requirements: (1) the set of scenarios selected for analysis must comprehensively describe all possible future states of the disposal system, (2) scenarios in the set must be mutually exclusive, (3) consequences of each scenario must be estimated, and (4) probability of occurrence of each scenario must be assigned. Analyses of consequences of initial scenarios may suggest areas of further research, which may in turn suggest new scenarios.

The combination of all the events and processes that might affect a disposal system would produce an extremely large number of scenarios, most of which

1 would have little or no effect on the performance of the disposal system.
2 Certain criteria established in the Standard allow for the elimination from
3 consideration of those events and processes (and by implication scenarios)
4 having low probability of occurrence and/or having little consequence. Both
5 of these criteria are described in Appendix B of the Standard (reproduced in
6 Appendix A to this report). In addition, the Standard restricts to 10,000
7 years the time period over which these events and processes must be
8 considered.

9
10 This section identifies events and processes considered for scenario
11 development for the WIPP performance assessment. Barring unexpected results
12 from research programs or consequence analysis, a subset of these events and
13 processes will be selected for the set of scenarios to be used for the final
14 comparison of WIPP's predicted performance to the Containment Requirements
15 (§ 191.13).

16 17 EVENTS AND PROCESSES RETAINED

18
19 Several reports have described events and processes that could result in
20 radionuclide releases from the WIPP disposal system (e.g., Claiborne and Gera,
21 1974; Bingham and Barr, 1979; U.S. DOE, 1980a; Environmental Evaluation Group,
22 1980; Hunter, 1989) and for releases from real and hypothetical bedded-salt
23 repositories other than WIPP (e.g., Cranwell et al., 1982; Cranwell et al.,
24 1989). New evidence and new regulatory developments combined to make some of
25 the events and processes of earlier workers unimportant (Hunter, 1989). Other
26 evidence necessitates the consideration of events and processes not previously
27 considered. Although these events and processes (Table 4-1) represent a
28 nearly final set, the set will be iteratively revised during consequence
29 analysis and data collection (Hunter, 1989).

30
31 Effects of human intrusion, repository construction, and waste emplacement
32 dominate events considered in this section. For the most part, natural events
33 and processes other than groundwater flow and climatic change probably will
34 not contribute to eventual development of a final scenario set. Most natural

TABLE 4-1. EVENTS AND PROCESSES RETAINED FOR SCENARIO DEVELOPMENT (after Hunter, 1989)

	Groundwater Flow
	Climate Change
	Drilling into Repository
	Effects of Pressurized Brine Occurrence
	Effects of Mining for Resources
	Seal Performance
	Leaching
	Nuclear Criticality
	Waste/Rock Interaction
	Waste Effects (e.g., gas generation, radiolysis)

events that occur in southeastern New Mexico take place so infrequently, affect such small areas, or change the system so slightly that they cannot contribute to scenarios that are of concern to the performance assessment. Thus, events and processes considered are groundwater flow, climatic change, human intrusion, seal performance, and near-field dissolution. Other phenomena considered include effects of pressurized brine injection, waste/rock interactions, and waste effects.

EVENTS AND PROCESSES SCREENING

Four screening criteria follow the guidelines in the Standard (e.g., Cranwell et al., 1989; Hunter et al., 1986): physical reasonableness, probability, potential consequences, and regulatory guidelines. A number of events and processes were screened from further consideration (Table 4-2) in the WIPP performance assessment on the basis of one or more of these criteria (Hunter, 1989). For the most part, events and processes that were dismissed have very low probabilities, although some also can be dismissed using one or more of the other criteria.

Four dissolutional processes were dismissed. Dissolution of the repository horizon by fresh water (except for solution mining) was dismissed because it

TABLE 4-2. EVENTS AND PROCESSES DISMISSED FROM FURTHER ANALYSIS (after Hunter, 1989)

Dissolution Other Than Leaching	Glaciation
Breccia-Pipe Formation	Igneous Intrusion
Migration of Brine Aquifer	Meteorite Impact
Migration of Brine Inclusions	Sabotage, Warfare
Induced Diapirism	Subsidence
Exhumation, Sedimentation	Thermal Effects from Waste
Faulting	Uplift of Surface
Diffusion	

is physically unreasonable. Migration of the Rustler-Salado residuum was dismissed on the basis of negligible consequence. Vertical dissolution would not expose a repository at WIPP for 2 to 3 million years and was dismissed because it is of no consequence on the regulatory time scale. Breccia pipes were dismissed on three premises. First, the occurrence of a breccia pipe at the WIPP is not physically reasonable. Second, granting for the sake of argument that one might occur, the probability of intersecting the repository is less than the cutoff in the Standard. Third, preliminary analysis of consequences (Spiegler, 1982) has shown them to be negligible, or even zero, during the 10,000-year regulatory period (Hunter, 1989).

Induced diapirism in the salt is physically unreasonable and should not be retained for consequence analysis. Similarly, diffusion of significant amounts of waste to the accessible environment is physically unreasonable. Releases resulting from migration of intracrystalline brine inclusions through salt in response to thermal gradients were dismissed on the basis of physical unreasonableness. Glacial loading of the disposal system was also considered to be physically unreasonable, although climatic changes accompanying continental or alpine glaciation were retained (Hunter, 1989).

Neither exhumation by erosional processes nor significant sedimentation are reasonable within 10,000 years. Thermal effects and surface uplift were also dismissed on the basis of negligible consequence. Faulting, igneous

1 intrusion, and meteorite impact have low probability. The analysis of release
2 of waste from the WIPP disposal system by sabotage or warfare is unnecessary
3 according to the Standard, and is improbable in any event (Hunter, 1989).

4
5 Three kinds of subsidence might occur at and near the WIPP: subsidence of the
6 overlying rock into the repository, subsidence as a result of conventional or
7 solution mining for potash, or regional subsidence as a result of oil and gas
8 extraction. Subsidence could in turn conceivably affect the disposal system
9 in three ways: by increasing the hydraulic conductivity of the country rock,
10 by creating fractures through the country rock, or by disturbing the surface
11 drainage. Increased hydraulic conductivity and transport through fractures
12 that result from subsidence were dismissed on the basis of negligible
13 consequence. Increased releases as a result of subsidence and disruption of
14 surface drainage was considered to be physically unreasonable (Hunter, 1989).
15 Increased vertical connection that results from subsidence and its effect on
16 recharge is retained, because it may be important in combination with extreme
17 climatic changes.

18 19 SCENARIO DEVELOPMENT, SCREENING PROCEDURE, AND PROBABILITY ASSIGNMENT

20
21 Those events and processes that survive screening are combined to form
22 scenarios. For the construction of a CCDF, the scenarios must be
23 comprehensive and mutually exclusive. In the past, events and processes were
24 combined by the use of event trees (Bingham and Barr, 1979; Hunter, 1983;
25 Hunter et al., 1982; Hunter et al., 1983). An event tree is an inductive
26 logic method for identifying possible outcomes of a given initiating event
27 (McCormick, 1981). Once the systems that can be utilized after a failure are
28 identified and enumerated, the failure and success states are identified
29 through bifurcations within the tree. If partial failures are considered, a
30 greater number of branches are needed. The result is an event tree that
31 provides accident sequences associated with an initiating event. Analyses of
32 this type commonly are used to assess potential accidents at nuclear power
33 plants (e.g., U.S. NRC, 1975).

34
35 The disadvantages of using event trees to develop scenarios for natural
36 systems are: (1) the imposed temporal relationship of events and processes to

1 one another, (2) the apparent arbitrariness of branching within the tree, (3)
2 the inability to assure completeness of the final scenario set, and (4) the
3 inability of the tree to handle feedback loops, whereby development along one
4 branch may change the systems to the point where the branching that resulted
5 in that scenario will be reversed. In addition, parameter values commonly are
6 used to identify separate branches of the tree, thereby implying that the
7 final scenarios are not mutually exclusive and creating confusion with both
8 the application and interpretation of uncertainty analyses.

9
10 Logic diagrams may be used to resolve the above concerns (Cranwell et al.,
11 1989). Hypothetical release and transport events and processes are combined
12 to form scenarios through the use of a logic diagram (Figure 4-1). Events and
13 processes are phenomena (such as human intrusion events, which occur at a
14 specific time, and surface erosion, which is a process occurring over a time
15 period) that affect radionuclide transport through the disposal system. No
16 temporal relationship between the events and processes is implied by their
17 sequence across the diagram. Parameter values are not used to define the
18 events and processes. At each junction within the diagram a yes/no decision
19 is made as to whether the next event or process is added to the scenario. The
20 logic diagram produces scenarios that are comprehensive, because all possible
21 combinations of events and processes are developed; the scenarios are mutually
22 exclusive, because each scenario is a unique set of events and processes; and
23 possible feedback loops may be incorporated in models of the combination of
24 events and processes. The time of occurrence for an event or process is a
25 variable that can be sampled during the uncertainty analysis. Such a diagram
26 is constructed after the events and processes have been screened (Table 4-1)
27 so that only those events and processes retained for scenario development are
28 used.

29
30 After the scenarios are developed, further screening can substantially reduce
31 their number. The criteria for screening are physical reasonableness,
32 probability of occurrence, and consequence. Whereas the events and processes
33 that make up the scenarios are physically reasonable for the disposal system
34 (because physically unreasonable events and processes were eliminated
35 earlier), certain combinations may not be. These so-called "physically

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Figure 4-1. Example of a Logic Diagram with Two Release (R) and Three Transport (T) Phenomena for the Construction of Scenarios (after Cranwell et al., 1989), Illustrating Scenario Probability Assignment.

1 unreasonable" combinations can also be interpreted as having low probability.
2 If possible, assigning probabilities and screening scenarios on this basis may
3 be the more credible approach. In either case, these combinations may be
4 eliminated from further consideration. As was the case with individual events
5 and processes, each scenario with a probability of occurrence of less than one
6 chance in 10,000 in 10,000 years can be eliminated from consideration. The
7 scenario probability is determined after the probability of an occurrence and
8 of a nonoccurrence of each event and process is estimated for the appropriate
9 "yes" and "no" legs at each junction in the logic diagram (Figure 4-2). Final
10 probability estimates for the events and processes retained in the WIPP
11 scenario development have not been made. Opinions of panels of experts are
12 likely to be used to estimate probabilities of occurrence. The scenario
13 probability is the product of the probabilities of all the "yes" and "no" legs
14 along the pathway to the complete scenario, assuming phenomena are
15 independent.

16

17 This mechanical procedure for assigning probabilities to the scenarios uses
18 previously estimated probabilities for individual events and processes.
19 Guidelines for elimination of low-probability scenarios described in
20 Appendix B of the Standard will be rigorously applied to scenario screening.

21

22 A final screening criterion is consequence, meaning integrated discharge to
23 the accessible environment for 10,000 years. Based on the guidance in
24 Appendix B, scenarios can be eliminated from consideration if their omission
25 would not significantly change the final CCDF. Because the degree to which
26 the CCDF will be affected by omitting such scenarios is difficult to estimate
27 prior to constructing the CCDF, only those scenarios that have no releases
28 will be omitted from consideration. If a scenario results in no discharge
29 within 10,000 years, it can be deleted from inclusion in the CCDF. An
30 additional step is to eliminate duplicate scenarios. Each event and process
31 in a scenario must contribute to the migration or transport of radionuclides.
32 Any event or process that does not contribute is extraneous, and as a result,
33 the scenario is effectively a duplicate of another scenario without the
34 extraneous events or processes.

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Figure 4-2. Potential Scenarios for the WIPP Disposal System.

1 One of the products of a logic diagram is a "base-case" scenario (Figure 4-2).
2 This scenario consists of the repository in the geologic and hydrologic
3 systems and all events and processes that are certain to occur in all
4 scenarios. The parameters that define these events and processes have ranges
5 of values that may be the result of parameter uncertainty caused by natural
6 variability, experimental design, or limited understanding of the processes
7 involved, and their interaction. All other scenarios are imposed on these
8 base-case conditions. By imposing a disruptive scenario upon the base-case
9 scenario, the parameter values of the base-case scenario are replaced by the
10 corresponding values in the disruptive scenario. Parameters unaffected by the
11 disruptive scenario retain their base-case values. The probability of
12 occurrence of this scenario must be less than 1, because this probability is
13 the product of the "no" legs along its path in the logic diagram.

14
15 For this scenario development methodology to be successfully applied to a
16 specific location, the retained radionuclide migration and transport phenomena
17 must be carefully selected according to the definitions required for the
18 construction of a logic diagram. Some of the events and processes retained
19 (Table 4-1) for WIPP must be redefined so that each branch point in the
20 diagram is clearly a yes/no decision for which probabilities of occurrence
21 (and non-occurrence) can be estimated. Phenomena such as groundwater flow,
22 seal performance, leaching, and probably climate change are necessary parts of
23 the analysis of each scenario, and are not branch points in the logic diagram.

24 25 APPLICATION OF SCENARIO DEVELOPMENT AND SCREENING TO THE WIPP

26
27 The following discussion on scenarios for the WIPP is only a preliminary,
28 incomplete analysis. This is because the screening of individual events and
29 processes and subsequent scenarios is based primarily on physical
30 reasonableness and arguments of physical reasonableness usually can be reduced
31 to low probability. Because probabilities of occurrence of the scenarios are
32 critical for screening and for constructing the CCDF, a formal process for
33 estimating probabilities, with complete documentation, is required. For this
34 reason, probabilities are not used to screen out events or processes, except
35 where the probabilities are not specific to the WIPP disposal system and are

1 well established in the literature. Consequence, either as effect on the
2 system or as integrated release, has not been used, because the modeling
3 capability for disposal system evaluation is still under development.

4
5 For preliminary analysis, a modified list of potentially disruptive events and
6 processes from Table 4-1 is used. Groundwater flow, seal performance,
7 leaching, waste/rock interaction, and waste effects are all part of the base
8 case scenario (Figure 4-2). Effects of these processes are included through
9 parameter variations in the uncertainty analysis of every scenario. Nuclear
10 criticality is presumed to be a low probability event that will be screened
11 separately. For preliminary analyses, climatic change is interpreted to mean
12 unlikely climatic change (TC), such as pluvial periods, and not to mean
13 natural climate variability, which would be part of the base case scenario.
14 Whether such events must be considered in scenario development for
15 constructing the final CCDF will be the subject of a separate scenario-
16 screening task. Included in this task would be "effects of mining for
17 resources" because subsidence (TS) could enhance recharge in combination with
18 an unlikely climatic event that results in increased recharge. Mining for
19 resources need not be considered within the controlled area. Exploratory
20 drilling must be considered. The remaining events to be included in
21 preliminary scenario definitions are drilling into the waste-filled room (E2)
22 and drilling through the room into a pressurized brine occurrence (E1). A
23 withdrawal well downgradient (Lappin et al., 1989) could possibly pump
24 radionuclide-bearing brine to the surface. Such withdrawal wells are included
25 in preliminary scenario construction.

26
27 Figure 4-2 is the logic diagram for constructing all of the possible
28 combinations of the five events and processes that survive the screening
29 process. The next step in the procedure is to screen the scenarios. Two
30 criteria can be used to quickly screen out some scenarios:

31
32 TC, TS, E3, TCE3, TCTS, and TCTSE3 - none contains a radionuclide-release
33 mechanism (i.e., E1 or E2).

34
35 TS without TC - TS provides areas for additional recharge to occur, but TC
36 is needed to provide significantly more precipitation.

1 One of the requirements of a scenario is that each event and process within
2 the scenario must contribute to the migration or transport of radionuclides.
3 Figure 4-3 indicates which scenarios are retained after this preliminary
4 screening. The base case (UND) represents the UNDisturbed scenario (Bertram-
5 Howery and Hunter, 1989a). The next six scenarios, from the HUMAN INtrusion
6 (HUMINT) group (Bertram-Howery and Hunter, 1989a), do not include TC. The
7 remaining human-intrusion scenarios in the Climate/Hydrology/Repository/Shaft
8 (CHRS) scenario group (Bertram-Howery and Hunter, 1989a) do include TC (and
9 TS). A methodology demonstration (Marietta et al., 1989) has provided
10 preliminary analyses of UND and HUMINT (i.e., seven scenarios). The CHRS
11 group will be screened using consequence as the criterion. If the preliminary
12 consequence analysis indicates that TC should be included in the base case
13 and, therefore, in all scenarios, the logic diagram (Figure 4-3) would be
14 decreased by the deletion of the first branch point.

15

16 The CHRS group includes human intrusion events, E1, E2, and E3, because
17 significant release does not occur without E1 or E2 (Lappin et al., 1989).
18 Preliminary analyses have not included the complete set of scenarios for the
19 WIPP performance assessment. The addition of other events or processes may
20 enlarge the set. Screening out some scenarios by low probability or
21 consequence may reduce the set. The process of identifying and screening
22 events and processes, constructing and screening scenarios, and assigning
23 probabilities to final scenarios is a continuing process that occurs along
24 with consequence modeling. Because the WIPP compliance assessment will be the
25 first time that the performance assessment methodology has been applied to a
26 real disposal system, the procedures for scenario development and probability
27 assignment have not been tested before. Scenario (event/process) screening
28 and probability assignment will always be based, in part, on incomplete data
29 and models because "unlikely" events will be poorly understood. Alternate
30 procedures for developing final scenarios and assigning probabilities to them
31 will always exist. Credibility of whatever procedures are used often will
32 depend on the subjective judgment of appropriate experts for each event or
33 process. Expert judgment will be relied upon in selecting the procedure for
34 WIPP scenario development, screening, and probability assignment.

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Figure 4-3. Preliminary Set of Scenarios for the WIPP Disposal System.

COMPLIANCE ASSESSMENT SYSTEM

The WIPP compliance assessment system contains the procedures and modeling tools necessary to perform consequence modeling and parameter uncertainty and sensitivity analyses. Radionuclide migration from the repository is estimated by applying a collection of techniques and computer codes in the methodology. This section describes conceptual models and computer codes that comprise the modules of the system used for consequence modeling and the statistical techniques used for uncertainty and sensitivity analyses. The components of the compliance assessment system are shown in Figure 3-2. These components are described in more detail in the following sections.

Characterization of the hydrology and geology above the Salado Formation is nearly complete. No plans exist to collect significantly more data on these formations except possibly for radionuclide retardations. The present understanding of the geology and hydrology in the Culebra Dolomite Member is thought to be adequate for supporting performance assessment. Therefore, discussions under Hydrogeology of the Northern Delaware Basin, Calibration of Groundwater Models, and Radionuclide Transport below, as well as their supporting documentation, are not expected to change significantly. Similarly, the computer software for controlling the repetitive calculations of uncertainty and sensitivity analyses is nearly complete, although some development and verification work is continuing. The discussions of CAMCON: Controller for Compliance Calculations and Parameter Uncertainty and Sensitivity Analyses, which describe this software, are not expected to change much either.

However, some of the discussion in the sections describing the repository and shaft subsystems is speculative, because data and understanding have not advanced far enough to confirm hypothesized behavior and to test component designs. Extensive work (Bertram-Howery and Hunter, 1989a) is continuing, so discussions of this work and their supporting documentation are expected to change significantly before the final *Comparison* is prepared.

A SUMMARY OF THE HYDROGEOLOGY OF THE NORTHERN DELAWARE BASIN

An understanding of the hydrogeology of the Study Area is fundamental to Performance Assessment. Evaluation of travel time, possible flow paths, and radionuclide retardation depends on the regional geology and hydrology. The stratigraphy and hydrostratigraphic units important to modeling regional groundwater flow in the northern Delaware Basin are summarized in this section (Brinster, 1989).

The Los Medaños Study Area is in the north-central part of the Delaware Basin, which is in the southern part of the Pecos Valley of the Great Plains physiographic province. This province is between the high plains of West Texas and the Guadalupe and Sacramento Mountains of southeastern New Mexico. The Study Area is 40 by 40 km (25 by 25 mi) and extends from the Pecos River in southern Eddy County eastward into Lea County and southward from just inside the Delaware Basin to about 20 km (12 mi) north of the New Mexico-Texas state line (Figure 4-4). The Study Area includes two prominent surface features, Nash Draw, and The Dunes (Los Medaños).

Nash Draw, in the western part of the Study Area, is a broad shallow topographic depression with no external surface drainage. Nash Draw extends almost 35 km (22 mi) from the Pecos River east of Malaga, New Mexico, almost due north to the Maroon Cliffs area. This feature is bounded on the east by Livingston Ridge and on the west by Quahada Ridge.

The Dunes is a region of gently rolling hills that slopes upward to the northeast from Livingston Ridge on the eastern boundary of Nash Draw to a low ridge called "The Divide". The elevation of the Study Area ranges from 900 m (2,900 ft) at Malaga Bend to 1,100 m (3,600 ft) near the Eddy-Lea County line. The WIPP is located in The Dunes.

Hydrogeology of the Bell Canyon Formation

The lowest hydrostratigraphic unit of interest to performance assessment in the Delaware Basin is the Bell Canyon Formation (Figure 4-5). The Bell

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Figure 4-4. Map of the Los Medaños Study Area Showing the Boundaries of the Los Medaños Model (Brinster, 1989), the Local Model (LaVenue, et al., 1988), the Proposed Land Withdrawal and the Observation Well Network (Haug et al., 1987).

System	Series	Group	Formation	Member
Recent	Recent		Surficial Deposits	
Quater- nary	Pleisto- cene		Mescalero Caliche	
			Gatuña	
Triassic		Dockum	Undivided	
Permian	Ochoan		Dewey Lake Red Beds	
			Rustler	Forty-niner
				Magenta Dolomite
				Tamarisk
				Culebra Dolomite
				unnamed
	Salado			
	Castile			
	Guadalupian	Delaware Mountain	Bell Canyon	
			Cherry Canyon	
			Brushy Canyon	

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Figure 4-5. Generalized Stratigraphic Column of the Delaware Mountain Group and Younger Sedimentary Rocks of and near the WIPP Disposal System (Beauheim, 1987).

1 Canyon Formation is the fore-reef equivalent of the Capitan Reef Limestone.
2 These units interfinger with the Capitan at the basin margins and are
3 contained completely within the reef margins (Hayes, 1964; Mercer, 1983;
4 Lambert, 1983). On a regional scale, the Bell Canyon Formation dips eastward
5 at about 1 degree. On a more local scale, the nose of a southerly plunging
6 asymmetrical syncline extends from Lea County into Texas. The formation
7 occurs at a depth of about 1,200 m (3,900 ft) in the vicinity of the WIPP.
8 The Bell Canyon Formation is also the oldest formation to crop out in the
9 Delaware Basin. These outcrops are in topographically low areas west and
10 south of the Study Area.

11

12 The upper part of the Bell Canyon Formation consists of sandstone and shale
13 members that are composed of sandstone, siltstone, shale, and, locally,
14 limestone. In ascending order, these informally named members are the Hays
15 sandstone, the Olds sandstone, the Ford shale, the Ramsey sandstone, and the
16 Lamar limestone. The siltstones and shales in the upper part of the Bell
17 Canyon Formation contain elongated sandstone stringers about 0.5 to 8 km (0.3
18 to 5 mi) wide, 1 to 35 m (3 to 115 ft) thick, extending basinward up to 70 km
19 (~44 mi) in a southwesterly direction (Figure 4-6). These isolated stringers
20 were deposited by density currents moving basinward (Williamson, 1978; Hiss,
21 1976).

22

23 Groundwater occurs in the upper portion of the unit that consists of poorly
24 cemented sandstone stringers. The vertical potential of the fresh-water-
25 equivalent heads of this unit is upwards. This has led to the speculation
26 that the Bell Canyon Formation waters have contributed to dissolution of the
27 Castile Formation causing collapse features that can be seen at the surface
28 (Anderson et al., 1978; Anderson, 1981), the implication being that
29 dissolution beneath the repository could breach it. If a source of fluid for
30 dissolution does originate in the Bell Canyon Formation, the mechanism
31 involved must consist of several parts: a source of unsaturated brine, a path
32 upward, a path downward for the dense fluid, and a path to carry away the
33 newly formed denser brine. The Anderson model does not contain these four
34 essential parts. The Castile Formation does not have an extensive fracture
35 network to provide pathways upward to the halites and back down to the Bell
36 Canyon Formation (Lambert, 1983; Mercer, 1983).

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Figure 4-6. Map Showing the Orientation of the Upper Bell Canyon Sandstone Stringers in the Vicinity of the WIPP (Lappin, 1988).

1 No flow route exists for the brines once the saturated fluid returns to the
2 Bell Canyon Formation. Examination of the freshwater potentiometric surface
3 map (Mercer, 1983) suggests that groundwater movement in the Bell Canyon is to
4 the northeast, but no apparent movement occurs either vertically or laterally.
5 The geology, groundwater chemistry, and head relationships of the Bell Canyon
6 Formation and the upper hydrostratigraphic units are evidence that the Bell
7 Canyon flow system is stagnant. Gas wells producing from the same horizon of
8 the Bell Canyon Formation have no apparent effect on each other (Lambert,
9 1983), thereby indicating that production is from separate units. Groundwater
10 chemistry of the Bell Canyon Formation indicates no connection between
11 sandstone stringers, no connection with the Capitan aquifer, and no recharge
12 from precipitation (Lambert, 1983). Examination and comparison of the
13 hydraulic heads of the Bell Canyon Formation and upper units (Lappin, 1988)
14 showed that it is erroneous to just consider the freshwater heads and to
15 conclude that the potential for flow is upward. The natural densities of the
16 fluid, which must be considered when determining vertical potentials, show
17 that the potential for flow is downward. Also, drilling in an open hole will
18 increase fluid density, effectively lowering the hydraulic head and inhibiting
19 upward flow.

20
21 The Bell Canyon Formation will not be included in performance assessment
22 modeling because of the poor hydraulic connection to the upper
23 hydrostratigraphic units; furthermore, any radionuclides reaching the Bell
24 Canyon Formation will not be transported laterally with significant velocity.

25 26 Hydrogeology of the Castile and Salado Formations

27
28 The Castile Formation conformably overlies the Bell Canyon Formation. The
29 contact is transitional within a 1-m (3-ft) zone (Cys, 1978). The Castile is
30 contained completely within the Delaware Basin in New Mexico and is bounded on
31 all sides by the contemporaneous Capitan Limestone (Figure 4-7). Near the end
32 of Bell Canyon Formation deposition, circulation within the Delaware Basin
33 became more constricted. This condition resulted in the formation of a
34 sequence of organically derived layers alternating with siltstone laminations.
35 The sequence changes rapidly in character upward from layered calcite to
36 calcite-layered anhydrite to anhydrite. This sequence forms the lower

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Figure 4-7. Map Showing the Outline of the Delaware Basin and the Generalized Locations of the Castile and Salado Formations (modified from Lappin, 1988).

1 Castile, which grades into the anhydrite-layered halite of the upper Castile.
2 The transition continues into thick halite of the Salado Formation (Anderson
3 et al., 1972). The Castile Formation consists of seven lithologic members
4 that include four anhydrite members intercalated with three halite members.
5 The formation is present throughout the Study Area but is eroded away
6 southwest of the Study Area (Figure 4-7). In Loving County, Texas, where the
7 Castile section is complete, the unit is 640 m (~2,100 ft) thick. North of
8 the WIPP, the Castile is about 360 m (~1,200 ft) thick and thickens
9 southward. At the WIPP, it is about 470 m (~1,500 ft) thick. At the southern
10 edge of the Study Area the Castile is about 500 m (~1,600 ft) thick.

11
12 As originally defined, the Castile Formation included a halite-rich upper
13 section and an anhydrite-rich lower section (Richardson, 1904 in Mercer,
14 1983). That formation was later divided into two formations, the lower,
15 called the Castile Formation and the upper salt section, called the Salado
16 Formation (Lang, 1938). The Salado Formation is of particular interest,
17 because it is the host rock for the WIPP. The Salado in the northern
18 Delaware Basin conformably overlies and interfingers with the Castile
19 (Bachman, 1981). Some earlier workers had concluded that the contact was an
20 angular unconformity (Adams, 1944).

21
22 Little hydrologic data exists for the Castile Formation. The only data are
23 from the locally pressurized brine encountered in fractured anhydrite during
24 exploratory drilling at ERDA-6 and WIPP-12 by the DOE and at 13 of about 100
25 petroleum exploratory wells in the vicinity. Hydrologic and geochemical data
26 indicate these pressurized brine occurrences are isolated hydraulically and
27 contain stagnant pockets of fluid (Lambert, 1978; Lappin, 1988). Water with
28 high amounts of dissolved solids also occurs in the fractured, weathered
29 portions of the Castile Formation at the western margins of the Delaware
30 Basin, far outside of the Los Medanos Study Area. In the Study Area, the
31 Castile Formation is intact, and no regional flow occurs.

32
33 Drill-stem tests (DST's) of the Castile Formation have shown permeability to
34 be less than the measurement capability of the testing apparatus (Mercer and
35 Orr, 1979; Mercer, 1983; Mercer, 1987). A conservative estimate (Mercer,
36 1983) of the permeability of the Castile Formation, based on the capability of

1 the testing instruments, would be about one nanodarcy (which yields a
2 hydraulic conductivity of 1.0×10^{-14} m/s ($\sim 1 \times 10^{-14}$ ft/s)). Permeability
3 for anhydrite is estimated to be less than 0.1 microdarcy (1.0×10^{-12} m/s (~ 1
4 $\times 10^{-12}$ ft/s) with porosity of 0.001 (Mercer, 1987).

5
6 The Salado Formation underlies the entire Los Medanos Study Area but is absent
7 a few km west of the Pecos River, which is west of the Study Area (Figure
8 4-7). Because of its extreme solubility, the Salado does not crop out at the
9 surface. Throughout the Study Area, the Salado Formation consists of about
10 600 m ($\sim 2,000$ ft) of thick, bedded salt rhythmically interbedded with
11 anhydrite, polyhalite, glauberite, and some thin mudstones (Jones, 1973, 1975;
12 Borns and Shaffer, 1985; Bachman, 1981; Mercer, 1983, 1987). The Salado
13 Formation was divided into three informal members on the basis of their
14 economic importance, even though the lithologies are similar (Jones, 1975).

15
16 The structural features recognized in the Salado Formation consist of a series
17 of small anticlines and shallow synclines with axes dipping southeastward. In
18 the northeastern part of the Study Area, the Salado surface dips steeply
19 northeastward. Unlike the Castile Formation, the Salado Formation overlaps
20 the reef structure and is present outside of the reef area, extending eastward
21 for many kilometers into West Texas and the Texas panhandle region.

22
23 As in the Castile Formation, groundwater occurrence in the Salado Formation is
24 restricted to areas in the Delaware Basin where extensive dissolution of the
25 halite has occurred and only a breccia remains. In the Study Area, where the
26 Salado Formation is intact, circulation of groundwater is almost zero because
27 although porous, the Salado Formation lacks open fractures (Mercer, 1983).
28 Permeability of the Salado Formation is very low but measurable (Mercer, 1983,
29 1986; Powers et al., 1978; Bredehoeft, 1988). The average permeability of
30 rock salt at lithostatic pressure is 0.05 microdarcies (Powers et al., 1978).
31 Drill stem tests in seven wells in the Salado Formation (Mercer, 1987) and in
32 the walls of the WIPP (Stormont et al., 1987) also indicate that permeability
33 is measurable in this formation. Drill stem tests in the extremely low-
34 permeability Salado Formation are similar to conventional DST's used in the
35 petroleum industry but for one significant difference, the addition of an

1 extra set of packers above and below the original packers forming a "guard-
2 zone" (Peterson et al., 1985). The guarded system allows for measurement of
3 gas that flows past the first set of packers. Other problems in testing low
4 permeability rocks are the result of the time it takes for proper setting of
5 the packers and the time it takes to examine flow beyond the disturbed zone.
6 Tables of the DST's (Mercer et al., 1987; Mercer, 1987) show a range of
7 permeabilities from 9 nanodarcies to 25 microdarcies throughout the Salado
8 Formation. A porosity of 0.001 was assumed in all of the tests.

9
10 Shut-in pressures of wells completed in the Salado Formation vary but, in some
11 wells, the hydraulic heads are higher than heads in aquifers in the overlying
12 Rustler. No measurable buildup of pressure has been observed at wells DOE-2
13 and AEC-7 although pressure was found at some potash wells and at Cabin Baby-
14 1, WIPP-12, and WIPP-13 (Mercer, 1987). Cabin Baby-1, WIPP-12, and WIPP-13
15 had formation pressures between lithostatic and hydrostatic; however, these
16 rapidly declined with little fluid production.

17
18 The WIPP repository provides access to in situ salt of the Salado Formation.
19 A permeability of 1 to 10 nanodarcies was determined from gas flow
20 measurements in the wall of the repository (Stormont et al., 1987). The
21 higher permeabilities (in the microdarcy range) are the result of disturbance
22 of the salt, whereas the lower measurements are probably more representative
23 of the undisturbed salt and anhydrites. A fluid porosity of 0.001 was
24 assumed.

25
26 The Salado Formation is not "dry", but is presupposed to be saturated medium
27 with low permeability; hence after the repository is decommissioned, brine
28 will flow in at a rate of 0.01 l/day/m of tunnel (Bredehoeft, 1988; see also
29 Lappin et al., 1989, section 3.2). This conclusion was drawn from numerical
30 predictions of Darcian flow in the salt based on the following observations.
31 Experimental heater holes and fifty-four vertical boreholes in the repository
32 produce fluids. Completed boreholes in the evaporites produce brine and salt
33 efflorescences occur throughout the facility. Permeability is measureable in
34 the Salado Formation.

1 In summary, the Castile and Salado Formations have low permeabilities and
2 effective (connected) porosities. Permeabilities vary from the nanodarcy
3 range to 25 microdarcies and porosity is on the order of 0.001 (Mercer, 1987;
4 Peterson et al., 1987). Formation pressures are seen to vary from hydrostatic
5 to somewhat less than lithostatic (8.3 to 10.3 MPA). The formation appears to
6 be saturated, but the low effective porosity (.001) allows little groundwater
7 movement.

8 9 Hydrogeology of the Rustler Formation

10
11 The Salado Formation is conformably overlain by the Rustler Formation, which
12 is the youngest unit of the Ochoan evaporite series (Figure 4-8). The Rustler
13 Formation is of particular interest because it contains water-bearing units
14 that may provide potential pathways for radionuclides to reach the accessible
15 environment.

16
17 The composition of the Rustler Formation is about 0.40 anhydrite, 0.30 halite,
18 0.20 siltstone and sandstone, and 0.10 anhydritic dolomite (Lambert, 1983).
19 The Rustler was divided into four formally named members and a lower unnamed
20 member on the basis of the lithologies of units that crop out along Nash Draw
21 west of the WIPP (Vine, 1963). The five units (Vine, 1963; Mercer, 1983) are,
22 in ascending order, the lower unnamed member (oldest), the Culebra Dolomite
23 Member, the Tamarisk Member, the Magenta Dolomite Member, and the Forty-niner
24 Member (youngest).

25
26 Groundwater in the Rustler originally was thought to be restricted to the
27 residuum between the Rustler and Salado Formations (termed the Rustler-Salado
28 Residuum) and the two dolomite members: the Culebra and Magenta (Vine, 1963;
29 Mercer, 1983). At present, evidence of flow occurs in a siltstone unit of the
30 unnamed lower member, and in claystones of the Tamarisk and Forty-niner
31 Members (Beauheim, 1987a; Holt et al., 1989). Claystone in the Tamarisk
32 Member is separated from dolomite in the Culebra and Magenta Members by
33 anhydrite layers. The claystone in the Forty-niner Member is likewise
34 isolated from the Magenta Dolomite and the overlying Dewey Lake Red Beds by
35 anhydrite. Data on the unnamed lower member, the Tamarisk Member, and the
36 Forty-niner Member, are from two wells: H-14 and H-16 (discussed below). The

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Figure 4-8. Geologic Cross-Section Across the WIPP Disposal System (Mercer, 1983).

1 first part of the review of the Rustler Formation geohydrology will
2 concentrate on aquitards and the second part will discuss the geohydrology of
3 the hydrostratigraphic units.

4 5 Hydrogeology of the Rustler Aquitards

6
7 The lower unnamed member has a mean thickness of 40 m (~131 ft) and is about
8 36 m (~118 ft) thick at the WIPP. The unit thickens slightly eastward across
9 the Study Area (Figure 4-8). The unit is composed mostly of fine-grained
10 silty sandstones and siltstones interbedded with anhydrite (converted to
11 gypsum at Nash Draw) in the western part of the Study Area with increasing
12 amounts of halite present in the eastern part of the Study Area. Halite in
13 the unnamed lower member is present over the WIPP (Figure 4-8) but north and
14 south of the WIPP at the so-called "Nash Draw Reentrants", halite is absent.

15
16 The only DST of the unnamed lower member to date was at H-16. Transmis-
17 sivities of $2.9 \times 10^{-10} \text{ m}^2/\text{s}$ ($2.7 \times 10^{-4} \text{ ft}^2/\text{d}$) and $2.4 \times 10^{-10} \text{ m}^2/\text{s}$ ($2.2 \times$
18 $10^{-4} \text{ ft}^2/\text{d}$) were calculated for the first and second buildup periods of the
19 DST (Beauheim 1987). Simulations of a single porosity medium using the first
20 transmissivity and a skin factor of -0.4 and assuming a porosity of 0.3, a
21 system compressibility of $1.0 \times 10^{-5} \text{ Pa}^{-1}$, and a viscosity of 1.0 cp showed an
22 excellent fit to the data curve for the first buildup, indicating a static
23 formation pressure of 1.47 MPa. A second simulation requiring a slightly
24 lower transmissivity indicating well damage yielded a pressure of 1.44 MPa.
25 From these results, pressure for the claystone unit tested was estimated at
26 1.58 MPa for an elevation of 793 m (2,600 ft) (Beauheim, 1987).

27
28 The Tamarisk Member ranges in thickness from 21 to 75 m (69 to 246 ft) in
29 southeastern New Mexico. It has a mean thickness of 21 m (69 ft) in the Study
30 Area and is about 36 m thick at the WIPP. The Tamarisk consists of mostly
31 anhydrite interbedded with thin layers of claystone and siltstone. The
32 Tamarisk Member outcrops along the southwestern part of Nash Draw. The
33 surface structure of the Tamarisk Member is similar to that of the lower
34 units.

1 Unsuccessful attempts were made in two wells, H-14 and H-16, to test a 2.4 m
2 (7.9 ft) sequence of the Tamarisk Member that consists of claystone/mudstone/
3 siltstone overlain and underlain by anhydrite. The permeability of the
4 Tamarisk Member was too low to yield transmissivity values in both wells, but
5 Beauheim (1987) estimates the transmissivity of the claystone sequence to be
6 about two orders of magnitude less than the values for the unnamed lower
7 member.

8
9 The uppermost member of the Rustler Formation, the Forty-niner Member,
10 consists of anhydrite interbedded with a layer of siltstone. The unit ranges
11 in thickness from 7 to 26 m (23 to 85 ft) and has a mean thickness of 21 m (69
12 ft). At the WIPP, the unit is about 20 m (66 ft) thick, has a uniform
13 thickness throughout the Study Area, and has a structure similar to that of
14 the lower units. Tests were conducted also on a claystone in the Forty-niner
15 Member in well H-14 and on a clay unit in well H-16 (Beauheim, 1987). The
16 tests on the claystone in well H-14 yielded a hydraulic conductivity of about
17 5×10^{-9} m/s ($\sim 2 \times 10^{-8}$ ft/s) and the tests on the clay in well H-16 yielded a
18 hydraulic conductivity of 5×10^{-10} m/s (2×10^{-9} ft/s).

19
20 To summarize the properties of the aquitard units: the unnamed lower member,
21 the Tamarisk Member, and the Forty-niner Member are considered to be isotropic
22 and homogeneous aquitards of very low permeability throughout the Study Area.
23 The presence of the halite is correlated to a decrease in permeability in the
24 dolomitic members in the eastern part of the Study Area and will be discussed
25 in the hydrology section. Halite is present in the Tamarisk and Forty-niner
26 members to the east but does not extend westward over the WIPP. The estimated
27 hydraulic conductivities of the three hydraulically tight units are, in
28 ascending stratigraphic order, 1×10^{-10} m/s ($\sim 1 \times 10^{-10}$ ft/s), 1×10^{-12} m/s
29 ($\sim 1 \times 10^{-12}$ ft/s), and 1×10^{-9} m/s ($\sim 1 \times 10^{-9}$ ft/s). The Tamarisk was too
30 tight to test, so the value of 10^{-12} m/s ($\sim 10^{-12}$ ft/s) is only an estimate.
31 For transport simulations, the porosity of the aquitards is considered to be
32 0.3.

Rustler-Salado Residuum Hydrostratigraphic Unit

In the vicinity of Nash Draw the Rustler-Salado residuum (from dissolution of the salt at the base of the lower unnamed member) overlies the halite of the Salado Formation. The residuum is known as the "brine aquifer." The unit is made up of a distinctive gray residue of gypsum, clay, and sandstone that grades eastward, intertonguing with the clayey halite of the lower unnamed member. This residuum ranges in thickness in the vicinity of Nash Draw from 3 m (10 ft) to about 20 m (66 ft) and averages about 8 m (26 ft) (Robinson and Lang, 1938; Mercer and Orr, 1977; Mercer, 1983). Lang (1938, in Robinson and Lang, 1938) noted that "...the structural conditions that caused the development of Nash Draw might also control the position of a body of salt water beneath it in the basal Rustler." Subsequent drilling and testing has confirmed this conjecture to some extent, but evidence from wells P-14 and H-7 indicates that the brine aquifer extends farther east than first reported (Mercer, 1983). It is estimated that the elongated aquifer thickens northward and has a range of thickness from 3 to 30 m (10 to 100 ft) and a mean thickness of about 8 m (26 ft) (Robinson and Lang, 1938). More recent information (Mercer, 1983) shows a range of 2.4 m (7.9 ft) in test hole P-14 to 33 m (108 ft) in test hole WIPP-29.

Hydraulic conductivity data for the brine aquifer in the Study Area are concentrated in and around the WIPP with the exception of a few data points near Malaga Bend. The hydraulic conductivity ranges from 10^{-6} to 10^{-12} m/s with a mean of log values of -9.4. The hydraulic conductivities at Nash Draw are higher by several orders of magnitude than the values east of the draw, ranging from 10^{-8} to 10^{-6} m/s. Eastward, the range is from 10^{-12} to 10^{-9} m/s (Figure 4-9). Near Malaga Bend, hydraulic conductivities were reported to be around 10^{-3} m/s (Hale et al., 1954; Havens and Wilkins, 1979). A contour plot of the negative-log hydraulic conductivities measured in the brine aquifer indicates that two distinct zones of hydraulic conductivity occur with the aquifer becoming tighter east of Nash Draw (Figure 4-9).

Effective porosity estimates for the brine aquifer range from 0.15 to 0.33 (Hale and Clebsch, 1958; Robinson and Lang, 1938; Geohydrology Associates, Inc., 1979; and Mercer, 1983). An average effective porosity of 0.2 has been assumed in previous work (Hale and Clebsch, 1958 and Mercer, 1983).

Figure 4-9. Negative Log Hydraulic Conductivities (m/s) of the Rustler-Salado Residuum of the Rustler Formation in the Los Medaños Area (Brinster, 1989).

1 A contour map of the potentiometric surface adjusted to freshwater density
2 illustrates the decrease in hydraulic conductivity east of Nash Draw (Figure
3 4-10). At the WIPP, where the hydraulic conductivity is low, the
4 potentiometric surface is steep and west of the WIPP where the hydraulic
5 conductivity is several orders of magnitude higher, the surface is flatter.
6 The hydraulic gradient in Nash Draw is 0.002. At the WIPP, the hydraulic
7 gradient is 0.007.

8
9 The waters from the Rustler-Salado residuum are brines consisting mostly of
10 sulfates and chlorides of calcium, magnesium, sodium, and potassium with
11 sodium and chloride the major constituents (Mercer, 1983). These waters have
12 the highest concentrations of dissolved solids in the WIPP area. The lowest
13 observed density water (1.048 g/cm^3) is at well H-7c and has a concentration
14 of dissolved solids of 79,800 mg/l. The highest observed density water (1.24
15 g/cm^3) has a concentration in excess of 450,000 mg/l and is at test hole H-4c
16 (Figure 4-11).

17
18 Recharge to and discharge from the brine aquifer to Laguna Grande de la Sal
19 (Figure 4-4) and the relationship of Surprise Spring to the lake was first
20 investigated by Robinson and Lang (1938) and later by Hale et al. (1954) and
21 Mercer (1983). The lake is not thought to be connected hydraulically to the
22 brine aquifer, because waters from wells in units under the lake have a lower
23 chloride content than the lake water and near the lake wells, which penetrate
24 lower units, flow (Robinson and Lang, 1938; Mercer, 1983). These observations
25 do not necessarily mean, however, that no connection to lower aquifers exist.
26 If the lake is a discharge area for the lower units, the low chloride content
27 and different water chemistry would be masked by the influx of surface runoff
28 or near-surface flow from gypsiferous members of the Rustler. The largest
29 spring in the area, Surprise Spring, probably gets its water from the Tamarisk
30 and discharges into the northern end of the lake (Mercer, 1983).

31
32 Conclusions that the underlying units are confined in lower Nash Draw assume
33 horizontal flow in the Culebra Dolomite Member and the brine aquifer.
34 Horizontal flow in confined aquifers means that flow lines are normal to

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Figure 4-10. Adjusted Potentiometric Surface of the Rustler-Salado Residuum in the Los Medaños Area (Brinster, 1989).

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Figure 4-11. Brine Densities of Water from the Rustler-Salado Residuum in the Los Medaños Area (Brinster, 1989).

1 vertical equipotential lines when viewed in cross section. In regions where
2 aquifers intersect the water table (such as southern Nash Draw), recharge and
3 discharge result in equipotential lines that are not necessarily vertical but
4 parallel to the recharge and discharge surfaces. Flowing wells in the region
5 near Malaga Bend do not necessarily mean that the water-bearing unit is
6 confined (Brinster, 1989).

7
8 The potentiometric-surface map of the freshwater-equivalent hydraulic heads
9 (Figure 4-10) indicates recharge east of the WIPP and discharge south-
10 southwest to the river. The gradient of the potentiometric surface of the
11 brine aquifer is southerly, thus indicating recharge from the north, near Bear
12 Grass Draw (T. 18 S., R. 30 E.) (Robinson and Lang, 1938; Lang, 1938).
13 Recharge occurs at Clayton Basin (Figure 4-4) and upper Nash Draw (Mercer,
14 1983). The higher potentiometric surface of the brine aquifer shown east of
15 the WIPP on the potentiometric-surface map indicates recharge may be occurring
16 in the eastern part of the Study Area. Insufficient data exists to indicate
17 if indeed recharge is occurring in this region. A possible source of recharge
18 may be from the upper dolomitic units: the Culebra Dolomite Member and the
19 Magenta Dolomite Member (Mercer, 1983). Some local recharge occurs in the
20 brine aquifer in the vicinity of Malaga Bend. An almost immediate water level
21 rise was reported in a brine-aquifer observation well after a heavy rainstorm
22 (Hale et al., 1954). A good hydraulic connection, possibly a sinkhole, from
23 the surface through the Rustler Formation to the brine aquifer, was inferred
24 to exist in the vicinity of Malaga Bend with local recharge occurring only
25 under exceptional conditions (Hale et al., 1954). The brine aquifer
26 discharges at the southern end of Nash Draw into the Pecos River at Malaga
27 Bend (Hale et al., 1954).

28 29 The Culebra Dolomite Hydrostratigraphic Unit

30
31 The Culebra Dolomite Member of the Rustler Formation is microcrystalline,
32 grayish dolomite or dolomitic limestone with solution cavities (Vine, 1963).
33 The Culebra Dolomite, where present, ranges in thickness from 4 to 11.6 m (13
34 to 38.3 ft) and has a mean thickness of about 7 m (~23 ft). In the Study Area
35 the Culebra has a uniform thickness of about 8 m (~26 ft). The Culebra

1 Dolomite has a shallow regional dip of less than .001 m/m to the southeast but
2 in the vicinity of the WIPP it dips fairly steeply to the northeast. Outcrops
3 of the Culebra Dolomite occur in the southern part of Nash Draw and along the
4 Pecos River.

5
6 Hydrologic Properties of the Culebra Dolomite Hydrostratigraphic Unit
7

8 More is known about the hydrologic properties of the Culebra Dolomite Member
9 than any other unit in the Study Area (Mercer and Orr, 1977; Mercer and Orr,
10 1979; Mercer, 1983; Mercer et al., 1987; Beauheim, 1987; LaVenue et al., 1988;
11 and Davies, 1989). A comprehensive data base has been computed (LaVenue et
12 al., 1988). Transmissivity data exists (Figure 4-12) for 20 locations around
13 the WIPP (Mercer, 1983). Eighteen new locations have been tested since 1983,
14 and new transmissivities have been estimated for seven previously tested
15 locations (DOE-2, H-11, and WIPP-13) (Beauheim, 1987; Beauheim, 1986;
16 Saulnier, 1987). Most of the data collected are from wells (30 of 38) within
17 six miles of the center of the WIPP and 25 of the wells are within the
18 proposed WIPP land withdrawal boundary.

19
20 A contour map of the negative-log hydraulic conductivities (Figure 4-13) shows
21 the variation in the hydraulic conductivities in the Study Area. The log
22 hydraulic conductivities were determined from the mean transmissivities at
23 each hydropad (well cluster) (LaVenue et al., 1988) and divided by the mean
24 Culebra Dolomite Member thickness at each hydropad. The log transmissivities
25 range from -8.7 to -2.7 m^2/s with a mean of -5.5 m^2/s in the vicinity of the
26 WIPP. The log hydraulic conductivities range from -9.7 to -3.7 m/s with a
27 mean of -6.4 m/s .

28
29 Variation in transmissivities is observed throughout the Study Area. This
30 variation resulted from fracturing of the Culebra Dolomite due to subsidence
31 associated with post-depositional dissolution of salt in the Rustler Formation
32 (Snyder, 1985), or from removal of overburden (Holt and Powers, 1988), or
33 possibly from a combination of both processes. It has been noted by several
34 workers (Jones, 1973; Mercer, 1983; Mercer and Orr, 1977) that the Rustler

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Figure 4-12. Rustler Formation Halite and Culebra Dolomite Transmissivity around the WIPP (Lappin et al., 1989).

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Figure 4-13. Negative-Log Hydraulic Conductivities of the Culebra Dolomite Member of the Rustler Formation in the Los Medaños Area (Brinster, 1989).

1 thickens eastward from Nash Draw as the amount of halite increases in the non-
2 dolomitic members. Drill cores collected from east and south of the WIPP
3 where the Rustler is thicker do not show evidence of dissolution such as that
4 seen west of the WIPP towards Nash Draw where the Rustler is thinner (Mercer,
5 1983; Snyder, 1985). The thickness variation is somewhat erratic in the
6 vicinity of the WIPP (Figure 4-12), although a "smooth" transition of the
7 solution front from west to east has been reported (Beauheim, 1987).

8

9 A comparison of the Snyder model and the Holt-Powers model (Beauheim, 1987)
10 shows that well H-18, east of the halite boundary, has a low transmissivity
11 (consistent with the Snyder model) but WIPP-30, which has no halite, also has
12 a low transmissivity. In addition, DOE-1 and H-11, east of H-18, have
13 relatively high transmissivities. The low transmissivity of the Culebra
14 Dolomite at WIPP-30 is supported by the Holt-Powers model, but this model
15 cannot explain the high transmissivities of DOE-1 and H-11.

16

17 A value of 0.20 for the single porosity conceptualization and for the matrix
18 porosity of the dual porosity conceptualization of the Culebra has been used
19 (Haug et al., 1987) as representative of porosities ranging from 0.07 to 0.30,
20 which were obtained from laboratory analyses of 2.54-cm (1-in) plugs taken
21 from core samples. Two dolomite blocks taken from depths of 154 m and 157 m
22 during the access shaft excavation for the Gnome Project revealed total
23 porosities of 0.144 and 0.137 and effective porosities of 0.078 and 0.111
24 (Cooper and Glanzman, 1971).

25

26 An adjusted potentiometric surface map of the Culebra Dolomite Member (Figure
27 4-14) (Mercer, 1983) will be used in the preliminary modeling effort. Flow
28 west of the WIPP is from north to south, and the flow lines are roughly
29 parallel to the Pecos River. Northeast and east of the WIPP, data are
30 insufficient to determine flow direction and inference of a potentiometric
31 surface is difficult. A few data points exist south of the WIPP and flow is
32 inferred to be toward the Pecos River. Flow in the Culebra Dolomite probably
33 follows Nash Draw because of the higher transmissivity of dolomite in this
34 area. The gradient in the upper Nash Draw area (0.003) is steeper where the
35 Culebra Dolomite has more overburden. In the lower Nash Draw area near Malaga
36 Bend, where the Culebra Dolomite is near the surface, the gradient is flatter

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Figure 4-14. Adjusted Potentiometric Surface of the Culebra Dolomite Member of the Rustler Formation in the Los Medaños Area (Brinster, 1989).

(0.001 m/m). The potentiometric surface map indicates recharge from the north, possibly at Bear Grass Draw where the Rustler Formation is near the surface and farther south at Clayton Basin (Figure 4-4) where karst activity has disrupted the Culebra Dolomite Member (Mercer, 1983). Geochemical data suggest an alternative hypothesis for direction of recharge. Uranium concentrations and $^{234}\text{U}/^{238}\text{U}$ activity ratios show that originally flow may have been from west to east (Lambert and Carter, 1987). Activity ratios increase from Nash Draw eastward, which would be typical of flow in that direction in a reducing environment. This is at variance with present day flow. Rustler Formation groundwater is draining from high potentiometric level, low-permeability areas near the WIPP, without appreciable recharge (Lambert and Carter, 1987). This means that the Rustler Formation is not at steady-state and that recharge occurred at Nash Draw 10,000 to 30,000 years ago under much wetter conditions (Lambert and Carter, 1987; Lambert and Harvey, 1987; Lambert, 1987).

Recharge from infiltration of precipitation through the overburden seems unlikely under present day conditions. Comparisons of recharge data from two modern basins similar to the Delaware Basin led to the conclusion that definitive values for recharge to the confined Rustler Formation probably cannot be determined (Lambert and Harvey, 1987).

Discharge from the Culebra Dolomite Member in the Study Area is to the west-southwest either into the Pecos River at Malaga Bend or into the Balmorrhea-Loving Trough or both (Figure 4-4). Salinity of the Pecos River increases at Malaga Bend, which has been described as a discharge area for the region (Hale et al., 1954; Hale and Clebsch, 1958; Havens and Wilkins, 1979; Mercer, 1983). The increase in salinity could be from brine aquifer's local discharge instead of regional conditions. Culebra Dolomite might be discharging toward the Balmorrhea-Loving Trough. At this time, rates of discharge from the region can only be estimated.

The quality of water from the Culebra Dolomite Member is marginal; this water is used locally for livestock watering. Total dissolved solids range from 3,200 to 420,000 mg/l at test holes H-8b and P-18, respectively. The density of Culebra Dolomite waters increases eastward from the WIPP (Figure 4-15).

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Figure 4-15. Brine Densities of Water from the Culebra Dolomite Member of the Rustler Formation in the Los Medaños Area (Brinster, 1989).

1 A series of analyses of groundwater flow in the vicinity of the WIPP examined
2 the effects of density-related, flow-driving forces and the effects of
3 boundary conditions (Davies, 1989). Two dimensional model simulation showed
4 that density-related effects were unimportant at the WIPP and west of the WIPP
5 but were important north, northeast, and south of the WIPP. Boundary effects
6 simulations showed that if the Culebra Dolomite Member is relatively
7 impermeable east and northeast of the WIPP, the western part, including the
8 WIPP, is not affected by conditions on the boundary. These analyses also
9 showed that if the Culebra Dolomite is assumed to be confined throughout the
10 region, a change in the Pecos River elevation will eventually affect the
11 Culebra Dolomite at the WIPP.

12

13 Hydrogeology of the Magenta Dolomite Hydrostratigraphic Unit

14

15 The Magenta Dolomite Member of the Rustler Formation is a fine grained,
16 greenish-gray dolomite with reddish-purple layers. This member ranges in
17 thickness from 4 to 8 m (~13 to ~26 ft) and has a mean thickness of 6 m (~19
18 ft). The Magenta is about 6 m (~19 ft) thick at the WIPP. The unit thickens
19 slightly in the central part of the Study Area and thins to the southeast.
20 The Magenta crops out along most of Nash Draw and has a structure similar to
21 the underlying units. Groundwater yield is low, and consequently there has
22 been little interest in the member. The amount of data available reflects
23 this limited interest. Fourteen wells have been tested and reported (Mercer,
24 1983; Beauheim, 1987).

25

26 Hydrologic Properties of the Magenta Dolomite Hydrostratigraphic Unit

27

28 The Magenta Dolomite Member is unsaturated at outcrops along Nash Draw.
29 Spring deposits along the eastern rim of the Draw are thought to have been
30 formed when precipitation drained from the surface into fractures of the
31 Rustler Formation, dissolved soluble layers, and emerged at the edge of the
32 Draw where the water evaporated (Bachman, 1981). At Nash Draw, the Magenta
33 Dolomite is almost in contact with the Culebra Dolomite, separated only by a
34 few meters of dissolution residue.

1 Only 14 values of transmissivity have been measured from the Magenta Dolomite
2 Member, ranging over five orders of magnitude from 4.0×10^{-9} to $4 \times 10^{-4} \text{ m}^2/\text{s}$
3 ($\sim 4.0 \times 10^{-8}$ to $\sim 4.0 \times 10^{-3} \text{ ft}^2/\text{s}$) with a mean log transmissivity of
4 $-7.0 \text{ m}^2/\text{s}$. The log hydraulic conductivity for the Magenta ranges from -9.3
5 to -4.3 m/s (-3.7 ft/s), with a mean log hydraulic conductivity of -7.8 m/s
6 (-8.7 ft/s). The largest transmissivity tested ($4.0 \times 10^{-4} \text{ m}^2/\text{s}$
7 [$\sim 4 \times 10^{-3} \text{ ft}^2/\text{s}$]) was at WIPP-25 (at the edge of Nash Draw west of the WIPP).
8 The lowest transmissivity tested ($6.0 \times 10^{-9} \text{ m}^2/\text{s}$ [$6 \times 10^{-8} \text{ ft}^2/\text{s}$]) was at
9 test hole H-8. Test holes H-7a and WIPP-28 were drilled in an unsaturated
10 part of the Magenta Dolomite Member. Examination of a core of WIPP-28 re-
11 vealed bedding plane partings and fractures filled with gypsum (Mercer, 1983).

12
13 A contour map of log hydraulic conductivities of the Magenta Dolomite Member
14 (Figure 4-16) shows a decrease in conductivity from west to east with slight
15 indentations of the contours north and south of the WIPP that correspond to
16 inlets observable at the surface. A preliminary statistical analysis of the
17 correlation of overburden thickness to hydraulic conductivity shows a poor
18 correlation ($r=-5.0$). The poor correlation may result from the way the
19 material surrounding the Magenta Dolomite Member has been dissolved and from
20 the subsequent deposition of gypsum in parting planes and fractures.

21
22 No porosity measurements have been made on the Magenta Dolomite Member, but a
23 porosity of 0.20 was assumed (Beauheim, 1987). This is slightly high for
24 intact dolomite but may be close to an average porosity for dolomite that has
25 undergone some karstification.

26
27 Contours of the potentiometric-surface map (Figure 4-17) representing
28 freshwater-equivalent heads indicate a southwestward flow in the northeastern
29 part of Nash Draw and a gradient of 0.003. Flow is almost westward across the
30 WIPP with a gradient of 0.004. The Magenta Dolomite is absent in the
31 southwestern part of the Draw and, because no springs issue along the rim of
32 the Draw, the groundwater is assumed to flow into lower units through
33 fractures.

34
35 The potentiometric map indicates recharge to the Magenta Dolomite Member
36 probably occurs to the north, possibly in Clayton Basin (Figure 4-4) or

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Figure 4-16. Negative Log Hydraulic Conductivities of the Magenta Dolomite Member of the Rustler Formation in the Los Medaños Area.

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Figure 4-17. Adjusted Potentiometric Surface of the Magenta Dolomite Member of the Rustler Formation in the Los Medaños Area.

1 farther north at Bear Grass Draw where the Rustler crops out (Mercer, 1983).
2 Apparent recharge to the east of the WIPP may be an artifact of variable water
3 quality corrections and density effects on the static-head estimate (Mercer,
4 1983). Discharge is probably into the lower units (Tamarisk Member and
5 Culebra Dolomite Member).

6
7 Water density varies from 1.004 g/cm³ (only slightly saline) at test hole H-9a
8 in the southern part of the Study Area to 1.171 g/cm³ at test hole H-10
9 southeast of the WIPP (Figure 4-18). The Magenta Dolomite water-quality
10 distribution is not as well defined as the Culebra Dolomite water-quality
11 distribution but is, nevertheless, distinguishable and reflects the degree of
12 dissolution of underlying halite (Mercer, 1983).

13 14 Hydrogeology of the Supra-Rustler Rocks

15
16 Several rock units younger than the Ochoan Rustler are present in the Study
17 Area. These are of little hydrologic importance because they are not aquifers
18 and, indeed, are dry throughout most of the Study Area (Lappin et al., 1989).
19 However, the units should be considered because saturation could occur in the
20 upper units as a result of climatic changes or from a breach of a pressurized
21 brine reservoir. The Permian Dewey Lake Beds and the overlying Mesozoic,
22 Cenozoic, and Holocene material are lumped as one hydrologic unit for regional
23 modeling purposes and more detailed discussion of these units can be found in
24 references cited.

25
26 Conformably overlying the Rustler Formation are the youngest Ochoan rocks, the
27 Dewey Lake Red Beds (Pierce Canyon red beds in Vine, 1963), consisting of
28 reddish-brown alternating fine-grained sandstones and siltstones cemented with
29 calcite and gypsum. Bedding may be structureless or cross-laminated, and
30 ripple marks and mud cracks may be present. In the Study Area, the Dewey Lake
31 Red Beds are absent in Nash Draw, are as much as 60 m (196 ft) thick where
32 present west of the WIPP, and may be over 200 m (656 ft) thick east of the
33 WIPP. The Dewey Lake Red Beds are unconformably overlain by Mesozoic rocks
34 that consist of the Triassic Dockum Group and Cretaceous sediments. These
35 rocks and sediments are mostly absent west of Nash Draw; the thickness ranges
36 to over 100 m (328 ft) in western Lea County. Overlying the Mesozoic are

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Figure 4-18. Brine Densities of Water from the Magenta Dolomite Member of the Rustler Formation in the Los Medaños Area.

1 Cenozoic materials consisting of the Pliocene Ogallala Limestone on the
2 extreme eastern part of the Study Area. Overlying these units unconformably
3 are the Quaternary Gatuña and the informally named Mescalero caliche.
4 Overlying these units are Holocene soils. Where present, the supra-Rustler
5 units collectively range in thickness from 4 to 536 m (13 to 1758 ft). An
6 isopach map of the region shows the rock units thickening to the east, forming
7 a uniform wedge of overburden across the Study Area (Figure 4-19).

8
9 Drilling in the Dewey Lake Red Beds has not identified any continuous
10 saturated zone. Some localized zones of relatively high permeability were
11 identified by loss of drilling fluids at DOE-2 and H-3d (Mercer, 1983;
12 Beauheim, 1987). Some thin, lenticular, saturated, perched, and semiperched
13 sands were identified in the upper Dewey Lake Red Beds at wells H-1, H-2, and
14 H-3 (Mercer and Orr, 1979; Mercer, 1983). The only wells producing water from
15 the Dewey Lake Red Beds in quantities sufficient to water livestock are the
16 James Ranch wells, Fairview well, and Pocket well.

17
18 Preliminary hydrologic properties of supra-Rustler rocks are difficult to
19 determine because of the lack of long-term pump tests and lab tests. The
20 hydraulic conductivity of these rocks, assuming saturation, is estimated to be
21 1×10^{-11} m/s ($\sim 1 \times 10^{-11}$ ft/s), similar to the hydraulic conductivity of the
22 Forty-niner Member. The porosity is assumed to be 0.20, which is
23 representative of fine-grained sandstone. Storativity (storage coefficient)
24 is assumed to be 10^{-4} . Water density is assumed to be similar to that of the
25 water in the Magenta Dolomite Member.

26
27 The supra-Rustler units are recharged locally by water percolating downward
28 through fractures to bedding planes and fine-grained lenticular sandstones;
29 the units discharge to lower zones (Mercer, 1983). Lateral movement of
30 groundwater is restricted by the lenticular nature of the sands.

31 32 Surface Water

33
34 The Pecos River drainage system, the principal surface-water feature in
35 southeastern New Mexico, is part of the Rio Grande drainage basin and flows
36 southeastward in New Mexico approximately parallel to the axis of the Delaware

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Figure 4-19. Isopach Map of the Supra-Rustler Rocks in the Los Medaños Area.

Basin in Eddy County, draining into the Rio Grande in western Texas. In the vicinity of the WIPP, the drainage system consists of small ephemeral creeks and draws in addition to the Pecos River with a drainage area of about 50,000 km². The Pecos River, which is about 20 km (12 mi) southwest of the WIPP, flows diagonally across the southwestern corner of the Los Medanos Study Area and has the lowest surface elevation of the Study Area.

Several broad shallow lakes in Nash Draw that cover an area of about 16 km² (~6 mi²) lie north of Malaga Bend and southwest of the WIPP. The largest lake, Laguna Grande de la Sal, has existed for many years. Since 1942, effluent from potash mining and oil-well development in the area has formed smaller, intermittent lakes in closed depressions north of Laguna Grande de la Sal (Hunter, 1985). The effluent has enlarged Laguna Grande de la Sal. The lakes also collect precipitation, surface drainage, and groundwater discharge from springs and seeps. The rate of discharge from the groundwater to the lakes in the area is estimated to be 0.67 m³/s (~24 ft³/s) (Hunter, 1985). Very little, if any, of the water from these lakes reaches the Pecos river (Robinson and Lang, 1938; Lambert, 1983).

The only spring of importance in the Study Area is Surprise Spring at the northern edge of Laguna de la Sal. In 1942, the spring discharged at a rate of less than 0.01 m³/s (1 ft³/day) and this rate has since declined (Lambert and Harvey, 1987; Hunter, 1985).

Summary

The important hydrostratigraphic units for regional groundwater flow in the vicinity of the WIPP are, in ascending order, the Rustler-Salado residuum and the Culebra and Magenta Dolomite Members of the Rustler Formation.

The Rustler-Salado residuum is the first hydrostratigraphic unit above the Salado Formation and consists of residue from dissolution of upper Salado and lower Rustler Formation halite. The log hydraulic conductivity ranges within an order of magnitude from -12.0 m/s in the vicinity of the WIPP to -6 m/s in Nash Draw. The mean effective porosity of the unit is about 0.20. The unit is under confined conditions over most of the area but under water table

1 conditions in the vicinity of Malaga Bend in the southwestern corner of the
2 Study Area. The residuum recharges north of the WIPP and discharges to the
3 southwest.

4
5 The Culebra Dolomite Member of the Rustler Formation is a microcrystalline
6 dolomite that is of relatively consistent thickness, around 8 m (26 ft), and
7 is present throughout the Study Area. The Culebra is under confined
8 conditions in the vicinity of the WIPP and under water table conditions near
9 Malaga Bend at the lower end of Nash Draw. The log hydraulic conductivity
10 ranges within an order of magnitude from -10 m/s in the eastern part of the
11 Study Area to -4 m/s in the western part of the Study Area in Nash Draw and
12 near Malaga Bend. The average porosity of the unit is about 0.20. The
13 Culebra recharges from the north and east and discharges to the southwest.

14
15 The Magenta Dolomite Member of the Rustler Formation is similar in composition
16 and thickness to the Culebra Dolomite Member but is not present in the western
17 part of the Study Area in Nash Draw. Log-hydraulic conductivity ranges within
18 an order of magnitude from about -9 m/s to -4 m/s. Effective porosity of the
19 Magenta is about 0.20. The Magenta recharges from the north and possibly east
20 and discharges through fractures into the Tamarisk and Culebra Dolomite
21 Members.

22
23 The units above the Rustler are considered as one hydrostratigraphic unit with
24 a composite hydraulic conductivity based on the values for all the overlying
25 units. The unit is unsaturated except for some locally perched sands that may
26 provide water for a few livestock wells. Recharge to the supra-Rustler units
27 is probably from precipitation. A 3-m (10-ft) thick unit of caliche that is
28 present throughout the area allows very little recharge to the Rustler
29 Formation.

30 31 CALIBRATION OF GROUNDWATER MODELS

32
33 Groundwater flow models must be calibrated using available data. Calibration
34 provides initial fluid fields and material property fields for long time-scale
35 simulations, and benchmarks for judging model performance.

1 There are two transients with documented time scales. A short time scale on
2 the order of decades (Lappin, 1988), reflects a perturbation because of potash
3 mining and local pumping such as for WIPP data acquisition. The longer time
4 scale reflects residual transiency from the last glacial age (Lappin, 1988;
5 Lambert, 1988). How this longer time scale affects 10,000-year predictions
6 for WIPP compliance assessment is still unknown. Transient model predictions
7 must confirm intuitive assessments of the effects on transport of these two
8 transients in the present groundwater flow over the time interval for each
9 significant scenario. Calibrated models provide initial fluid fields and
10 material property fields for these simulations. Preliminary modeling of the
11 Los Medanos groundwater flow system used the Sandia Waste-Isolation Flow and
12 Transport code (SWIFT II), a transient, three-dimensional finite-difference
13 code that solves the fully coupled equations for flow and transport in porous
14 media (Reeves et al., 1986).

15

16 Calibrating models is a tuning procedure that attempts to reproduce observed
17 information within some acceptable range of an appropriate measure. For the
18 WIPP site characterization, calibration focused first on reproducing
19 approximate steady-state head conditions and simulating the H-3 and WIPP-13
20 multipad-scale interference tests. Transient head distributions, including
21 hydraulic stresses resulting from construction of the Air-Intake Shaft and
22 from the H-11 multipad-tracer test were simulated to complete the calibration
23 efforts.

24

25 Successful calibration means that the observed groundwater flow was simulated
26 adequately over the time period of the hydropad tests using a numerical model.
27 Calibration over a time period using a dynamical model is more than just
28 interpolation of observed field data; the subjective combination of filling
29 interpolated and predicted fields to observed time series of data at isolated
30 points is a "dynamical interpolation". The time records are short (on the
31 order of years) compared to relevant groundwater time scales so the dynamical
32 interpolation is a snapshot in time compared to a prediction. Therefore,
33 calibration is not model validation for performance assessment. Calibration
34 provides initial fluid fields and a conceptual model for material property
35 fields. The former are not important for long-term prediction, but the latter
36 are very important because stationarity (in time) is inherently assumed for
37 uncertainty analyses.

1 REPOSITORY/SHAFT SYSTEM OVERVIEW

2
3 The repository/shaft module of the compliance assessment system includes flow
4 and transport within the underground workings at the repository horizon and
5 within various shafts and boreholes that connect the underground workings with
6 overlying formations. Figure 4-20 shows the repository design in a plan view.
7 The waste-disposal rooms occupy the southern end of the mined horizon. All
8 rooms, drifts, and shafts will be backfilled when the repository is closed.

9
10 A model of this complex repository/shaft system must be included as a module
11 in the compliance assessment methodology (i.e., in CAMCON) for performing
12 uncertainty and sensitivity analyses. This model includes the source term and
13 all important processes that bear upon transport of radionuclides from the
14 storage rooms. For the UND scenario, the modeling problem is to predict
15 transport of radionuclides from the rooms through the entire repository/shaft
16 system to overlying fluid-bearing zones, such as the Culebra Dolomite Member
17 of the Rustler. A source within the hydrology model for this member can be
18 specified and a coupled fluid-flow/transport simulation continued to the
19 boundary between the controlled area and the accessible environment. A
20 similar separation can be performed for the CHRS scenario group and the HUMINT
21 scenario group.

22
23 An intrusion borehole that penetrates a storage room serves as a possible flow
24 connection with overlying or underlying formations. Flow and transport
25 through this connection can be described, and sources characterized within
26 fluid-bearing zones that are appropriate for each human-intrusion scenario.
27 In this case, the repository/shaft module impacts the analysis only through
28 the waste-storage room of the system model. The degree of consolidation of
29 the room and its contents at the time of intrusion help define the source term
30 for the simulation.

31
32 CAMCON provides an efficient, readily available tool for modularizing
33 components within the repository/shaft system. The design of the repository
34 and shafts divides into components that are connected but can be treated
35 separately. Each component includes the various processes determined to be

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Figure 4-20. Plan View of Storage Horizon Showing Shaft, Drift and Panel Seal Locations (after Stormont, 1988).

important for the transport problem. These processes and important parameters are selected on the basis of sensitivity analyses performed on the repository/shaft systems model.

Construction of a repository/shaft systems model is complicated because of the wide range of model types used to analyze different processes that influence repository design. Many of these models are also important for consequence modeling, and would normally be used during compliance assessment. However, models used for design may be simple analytical models or complex finite-element models. A reasonable match of component models and data is required for systems studies. Construction of a compliance assessment module provides a mechanism for feedback to the designers through sensitivity analyses that are used to match modeling components and data. The repository/shaft systems model for compliance assessment is RESYSM (REpository-Shaft SYStem/Source-term Model).

The component of RESYSM that represents a single room incorporates many phenomena. Predicting the final state of the room is the main objective, but predicting impacts of human intrusion is also important. To predict the room's final state, many factors must be considered during model development, even though some of them may not be important or even appear in the final RESYSM (Table 4-3).

TABLE 4-3. FACTORS POTENTIALLY IMPORTANT FOR MODELING THE ROOM (Tyler et al., 1988; Lappin et al., 1989, Bertram-Howery and Hunter, 1989a).

Creep closure of the salt
Brine inflow from the Salado Formation
Structural response of the backfill mix
Structural response of the waste containers and contents
Inventory and waste categories
Room and brine chemistry
Gases generated by microbiological, radiolytic, and corrosive decomposition of waste materials
Brine and gas interactions with the backfill mix
Gas interactions with the Salado Formation
Brine and gas interaction with MB139
Radionuclide solubilities in the room environment
Effect of intruding drilling fluids
Effect of injected pressurized brines

For the HUMINT scenario group, the room is directly connected to overlying fluid-bearing zones by intrusion boreholes. Concentrations of radionuclides in the room as a function of time following these intrusions must be estimated to describe the rate of radionuclide migration (source) to overlying water bearing units. Preliminary calculations (Lappin et al., 1989; Marietta et al., 1989) use solubility-limited source terms that include the volume of an entire panel. Sensitivity analyses (Marietta et al., 1989, Appendix A; Rechard et al., 1989) are assessing this assumption to refine the volume of waste accessible to an intrusion borehole and to account for brine flow rate through the waste panel. Those estimates primarily use the room component of RESYSM. For other scenarios, transport through panel seals (Figure 4-20) and the MB139 seal (Figure 4-21) must be modeled (Table 4-4).

TABLE 4-4. FACTORS TO BE CONSIDERED IN THE PANEL-SEAL COMPONENT OF RESYSM (Tyler et al., 1988; Lappin et al., 1989, Bertram-Howery and Hunter, 1989a).

Consolidation of seal materials
Saturation effects on consolidation
Gas effects on seal consolidation and saturation
Pressure effects on seal materials after pressurized brine injection
Pressure driven flow and transport through seals, along seal/host rock interface, and through disturbed rock zone
Radionuclide retardation in brine-saturated seals and host rock in the saturated brine environment

The features of a single panel seal are considered during sensitivity studies and seal design. The eventual module for RESYSM must account for the system of panel seals and backfilled drifts. The room/panel seal connection will be integrated and scaled into a network that combines the effect of many rooms, drifts, and seals into one module for systems simulations. This network represents everything to the south of the northernmost panel seals (Figure 4-20).

MB139 is an important parallel path for radionuclide transport to the shafts. MB139 will be sealed under all panel seals. Portions of MB139 under the backfilled drifts also will be included in RESYSM (Figure 4-21).

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Figure 4-21. Conceptual Model Used in Simulating Undisturbed Performance (Lappin et al., 1989).

The system of drifts from the northernmost panel seals to the bottoms of the various shafts (Figure 4-20) and MB139 form the drift component of RESYSM. The features of this component that must be considered in developing a systems module are similar to features of the panel-seals module except that there is no over-excavation of the drift and stiff members are not present. Backfill material in this part of the drifts may be identical to panel-seal material (i.e., salt blocks), but crushed salt probably will be used in the drifts.

TABLE 4-5. FACTORS TO BE CONSIDERED IN THE DRIFT/MB139 COMPONENT OF RESYSM (Tyler et al., 1988; Lappin et al., 1989, Bertram-Howery and Hunter, 1989a).

Backfill consolidation
Reconsolidation of disturbed rock zone
Saturation effects on consolidation
Radionuclide retardation in host rock and backfill materials
Brine and gas interaction with host rock and backfill materials
Brine and gas interaction with MB139
Radionuclide retardation in MB139 and backfill materials

The shaft/seal component of RESYSM is another separate system of seals with stiff structural members that maintain seal-material integrity during consolidation. This component is represented by a single module. The seal material in the lower seal system was selected to reproduce the desirable natural-barrier features of the Salado Formation. The seal material and design in the upper seal system was selected to prevent fluid seepage from overlying fluid-bearing zones. Material for stiff members was selected to maintain system integrity until final consolidation, which will occur by lateral rather than vertical salt creep, is complete.

Two fluid-flow applications of the shaft/seal component are necessary for compliance assessment. First, upward transport through the seal system to overlying water bearing units must be considered for undisturbed performance analyses. Second, fluid seepage downward represents a possible mechanism for repository saturation and should be simulated as part of design sensitivity analyses. Modeling of both flow directions is required to analyze CHRS scenarios.

TABLE 4-6. FACTORS TO BE CONSIDERED FOR THE SHAFT/SEAL COMPONENT OF RESYSM (Tyler et al., 1988; Lappin et al., 1989, Bertram-Howery and Hunter, 1989a).

Consolidation of seal materials
Saturation of the shaft/seal system from host rock, overlying water-bearing units, or pressurized Castile Formation brine
Radionuclide retardation by host rock and seal materials
Flow and transport through seal materials, along the host rock/shaft interface, and through the disturbed rock zone

The bottom of the shaft is separated from the drift by a concrete seal that is included in the shaft/seal system. Stiff-member materials like this concrete layer at the bottom of the shaft are not designed to survive in the brine environment beyond a hundred years after repository closure. Therefore, the connection between the drift and shaft modules for RESYSM is only a transition from drift backfill to shaft-seal material. A sensitivity analysis to assess the importance of drift backfill materials within the overall system will guide materials selection. Similarly, the shaft seal system above the repository horizon can be modeled as a seal consisting only of consolidated salt because degradation time for the stiff member is short compared to the 10,000-year Containment Requirements.

The assembly of these RESYSM components into a systems model requires individual component and system sensitivity analyses to identify important parameters and processes. Detailed complex models such as finite-element structural-analysis codes are used where data are extensive (e.g., room closure). **Simplified analytical or even network flow models may be used where** data are sparse (e.g., transport through shaft seals). Even though highly detailed, finite-element and finite-difference fluid-flow codes are available, model selection must be commensurate with supporting data and module importance to the performance measure.

Many of the important phenomena must be considered in a coupled mode. Consolidation with back-pressure response of interstitial brines and simultaneous gas generation is one example. **The room module will be a set of** simplified empirical calculations using data derived from complex-model simulations, analytical solutions, and measurements. Empirical data fitting must be based on a systematic sensitivity analysis of the overall system.

1 ROOM MODEL

2
3 The disposal-room characterization program studies the interaction of TRU
4 waste and backfill mixtures in a waste room during and after consolidation by
5 creep deformation of the surrounding salt. Brine inflow and gas generated by
6 waste decomposition will influence room closure. The interaction of waste
7 and containers, backfill mixtures, brine, gases, and closure are studied
8 through laboratory tests, small- and large-scale field experiments for
9 different engineered modifications and sensitivity analyses to assess
10 performance and safety. A major aspect of room modeling will be coupling
11 individual components into a model that allows room conditions to be estimated
12 as a function of time. For WIPP performance assessment, it is important to
13 know not only the state of the room when an intrusion event occurs but also
14 the transient response following that event so that migration of radionuclides
15 away from the room can be predicted.

16
17 The room model will be developed from the studies of room processes that are
18 currently underway. Any discussion of the model and the radionuclide source
19 term would be highly speculative at this time. Therefore, this material will
20 be added in the future.

21
22 PANEL-SEAL MODELING

23
24
25 Panel seals isolate disposal rooms from the remainder of the repository
26 (Figure 4-20). A number of diverse activities must be integrated to complete
27 the conceptual-seal design (Figure 4-22). Analyses of brine inflow from the
28 host rock, consolidation of seal materials, creep closure of the host rock,
29 disturbed zone formation and closure, and stress must be applied to panel-seal
30 design and modeling. Structural analysis and fluid-flow codes developed for
31 room design can be used to analyze performance of seal components.

32
33 Various empirical, analytical, or numerical codes must be merged and may be
34 simplified for use as a module within RESYSM. Significant differences exist
35 in model setup. Seal geometry requires different meshes to represent seal
36 shape and material differences. Analysis of seal performance requires
37 simulating three possible flow paths: flow through seal materials, flow along

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Figure 4-22. Schematic Design of a WIPP Panel Seal (Lappin et al., 1989).

1 the interface between seal materials and the host rock, and flow through the
2 host rock including the disturbed rock zone. Panel-seal models must simulate
3 flow and transport along these three pathways. If a pathway is determined to
4 be unimportant during sensitivity studies, it will not be included in RESYSM.
5 Final modules for room/panel seals must account for the full assemblage of
6 rooms and seals (Figure 4-22), so a network modeling approach may be the most
7 reasonable choice. The network model will require that individual components
8 of the system be fully modeled.

9
10 Studies to develop process models for panel-seal design and RESYSM-module
11 development are a subset of the room-model studies with different geometry and
12 materials.

13 14 Seal-Material-Consolidation Modeling

15
16 These studies use the same models for constitutive and structural analyses
17 that are used in modeling backfill-mix consolidation and closure for the room.
18 Crushed and block salt without additives must be analysed to determine the
19 final degree of consolidation of the system. The sensitivity of consolidation
20 of crushed-salt seal components to brine inflow, creep closure, initial
21 density, and other parameters (Nowak and Stormont, 1987), has been determined.
22 Seals include layers, probably consisting of bentonite and concrete, that
23 resist creep closure. Layering must be included in structural analyses. Seal
24 designs include over-excavation of the drift, which develops stress
25 concentrations at corners and causes the host rock to fracture. These effects
26 must be modeled using variable mesh generation and fracture models.

27 28 Brine-Inflow Modeling

29
30 Consideration of brine inflow is important in assessing panel-seal performance
31 during consolidation, because brine may create a backpressure that retards
32 closure. Predicting the final degree to which panel seals consolidate
33 requires coupling saturation and creep-closure models. If bentonite is a seal
34 material, its structural response to swelling must also be included. Again,
35 the models (e.g., Nowak et al., 1988) applied to the room can be applied to
36 different materials and geometries of panel seals.

1 Disturbed Rock Zone Modeling

2
3 Modeling flow through the DRZ is particularly important for panel seals and
4 shaft seals. Flow and transport through fractures of the DRZ could possibly
5 circumvent seal materials. The fracture pattern around panel seals will
6 probably be complex and anisotropic due to overexcavation of the drift. This
7 possible pathway can be assessed by simulating pressure-driven flow through
8 the DRZ. A pressure gradient may exist across panel seals in the final
9 consolidation state. As discussed in the human-intrusion scenario, injection
10 of Castile Formation brines into the room could also result in such a pressure
11 gradient. Seal performance under such hypothetical conditions must be
12 assessed.

13
14 Tracer-gas studies (Stormont et al., 1987; Peterson et al., 1987b) have been
15 conducted to estimate fracture continuity and apertures in MB139. These
16 studies indicated connection between the excavations and MB139 through the
17 fractured salt. Further studies are underway to analyze the effects of the
18 DRZ (i.e., its fracture-induced porosity) on hydrologic properties.
19 Simulating fracture flow and transport through the host rock requires a flow
20 code with a fracture model. First, formation of the DRZ in response to the
21 excavations of the drifts, rooms, and seals must be described. A concept of
22 processes that form the DRZ and how it will respond during closure (e.g., to
23 what extent the fractures will heal) can be developed by integrating various
24 fracture data. A predictive capability for simulating fracturing and fracture
25 closure can be developed from this conceptual model. A fracture model can
26 serve as a constitutive model and be included as part of the computational
27 scheme within structural analysis codes. If the fracture pattern is fixed, it
28 can be included in flow codes. Otherwise, the fracture model must be coupled
29 with a deformation code so the changing fracture pattern can be predicted.
30 Then fluid flow and its backpressure effects can be included. The pore space
31 within the DRZ is now unsaturated (Borns and Stormont, 1988; 1989) due to
32 microfracturing and mine ventilation. Because of this increased pore volume,
33 the DRZ's ability to accept fluids, both brine and gas, is enhanced. Codes
34 for modeling such coupled processes do not exist; although, in principle, they
35 can be assembled. For developing a RESYSM module commensurate with the
36 relative importance of panel seals within the repository/shaft system, a

1 fairly simple network model relying on dual porosity approximations is a
2 reasonable first step.

3 4 Flow and Transport Modeling

5
6 The undisturbed-scenario analysis requires simulations of flow and transport
7 through the repository/shaft system to overlying water-bearing units (e.g.,
8 the Culebra Dolomite Member). Human-intrusion scenarios include transient,
9 pressure-driven flow away from the borehole into the Culebra Dolomite. This
10 transient flow could result from injection into the repository of pressurized
11 brine from the Castile Formation. The transient could be extended by flow
12 into the borehole from the host rock if fluid pressure in the rock is greater
13 than hydrostatic pressure. For other scenarios, the primary mechanism for
14 transport through the saturated repository and shafts is pressure-driven flow.
15 Room consolidation or gas generation could cause pressure within the disposal
16 room to exceed hydrostatic pressure. Transport through, along, and/or around
17 panel-seal materials must be modeled. Capability for handling all scenarios
18 requires solving equations (including retardation and fracture flow) for
19 radionuclide transport along the three flow pathways. Because network models
20 only solve one-dimensional equations along preassigned pathways for fixed-
21 fluid fields, more detailed, multi-dimensional modeling may be required to
22 justify the use of these simplified models in the uncertainty analyses.

23 24 Panel Seal and Room Assemblage

25
26 Once transport past a single panel seal from a single room can be adequately
27 estimated by room-performance and panel-seal modules, the effect of all
28 storage rooms and drifts behind the northernmost panel seals can be estimated
29 by assembling individual component networks into a multicomponent network.
30 Diffusive and perhaps advective fluxes of radionuclides across the northern
31 panel seals are required for interfacing with the next RESYSM module. A
32 multipath, network model could be used although the results would be limited
33 by all the disadvantages of using oversimplified numerics and physics. The
34 network code applied would require careful benchmarking against more complete,
35 verified, dynamical codes on test problems designed for WIPP repository
36 geometry.

1 DRIFT MODELING

2
3 A module within RESYSM will simulate flow and transport from the northernmost
4 panel seals to the concrete bases of the shafts (Figure 4-23). Flow and
5 transport through the underlying MB139 will be included. Drifts may contain
6 backfill consisting of salt or salt mixed with other materials. Final
7 selection of backfill for these drifts depends on their importance within the
8 overall CAMCON system. Development of a drift module for RESYSM is another
9 application of the creep closure, brine inflow, flow, and transport codes used
10 for the room/panel-seal modules. Geometry and materials may be a little
11 different. Output of the drift module is radionuclide flux into the bottom of
12 the shaft seal material. Because concrete is not designed to last beyond a
13 hundred years, the drift backfill (if any) will be directly connected to
14 shaft-seal material when final consolidation has been achieved.

15
16 SHAFT SEAL SYSTEM

17
18 Seal components are divided into two categories according to function and time
19 scale. Temporary seal components protect the integrity of the seal system
20 during consolidation. They will be constructed of concrete bulkheads and
21 bentonite-containing materials. They must protect the seal system from
22 intrusion of Rustler Formation brines from above and repository gas from
23 below. Long-term seal components are constructed from blocks of
24 reconsolidated, crushed salt and crushed salt-based grouts. Crushed salt will
25 consolidate in response to creep closure of the host rock. Grout is used to
26 seal interbeds. These seal components are the primary barrier to radionuclide
27 migration. Candidate seal materials are WIPP crushed salt, bentonite and
28 bentonite-salt mixtures, concrete, and crushed salt-based grout. Both
29 laboratory and modeling studies are being conducted to evaluate these
30 materials.

31
32 The four shafts (Figure 4-20) will have multi-component seals extending from
33 the drift upward to the surface. Each shaft-seal system (Figure 4-23) will
34 consist of an upper seal and a lower seal.

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Figure 4-23. Schematic Design of a WIPP Lower Shaft Seal System (Lappin et al., 1989).

1 The upper seal is designed to limit seepage of Rustler Formation brine into
2 the lower system so that interstitial brine will not interfere with
3 consolidation of the lower seal. Consolidation should occur at a rate similar
4 to that of the storage panels beginning from the drifts upward. Crushed salt
5 will be placed in the upper seal system, but consolidation will be slower so
6 these seals are not considered a primary barrier to radionuclide transport.
7 Therefore, the upper seal has only a temporary function, and is expected to
8 degrade to a hydraulic state similar to silty sand (Stormont and Arguello,
9 1988).

10
11 Lower seals contain crushed salt that will consolidate to nearly 0.95 intact-
12 salt density (Nowak and Stormont, 1987) as the host rock creeps laterally into
13 the shaft. The lower seal's integrity is maintained by concrete bulkheads
14 emplaced at the bottom of the shaft and at the bottom of the upper seal.
15 Additional bulkheads will be placed in the drifts adjacent to the shafts to
16 protect the lower seals from possible degradation by waste-generated gases.
17 Once these lower seals consolidate, they will form the barrier (in the absence
18 of intrusion) to brine migration and radionuclide transport upward from the
19 repository.

20 21 Seal-Material-Consolidation Modeling

22
23 These studies use the same set of constitutive and structural-analysis models
24 that are used for modeling backfill-mix consolidation and closure for the
25 room, panel seals, and drifts. Consolidation will be most rapid near the
26 bottom of the shaft so estimates of closure rates along the shaft are
27 important to ensure that temporary seal components provide sufficient
28 protection.

29 30 Brine-Inflow Modeling

31
32 Brine inflow is important for assessing shaft-seal performance during
33 consolidation, because brine may create a backpressure that retards closure.
34 Predicting the final degree of consolidation of shaft seals requires coupling
35 resaturation and creep-closure models. In addition, models must include brine
36 seepage from above. Bentonite is a seal material only for temporary

components so its structural response (i.e., swelling) is not important for long-term seal behavior. The same models applied to the panel seals can be used for process studies to evaluate different materials and designs.

Disturbed Rock Zone Modeling

Modeling flow through the DRZ is particularly important for shaft seals. Flow and transport through fractures of the DRZ could possibly circumvent seal materials. Simulating flow through the DRZ is necessary to assess this possible pathway. Rustler brines conceivably could leak through the DRZ and saturate the lower seal system. To ensure the integrity of the lower seal system, sensitivity studies of the upper seal system will be performed to evaluate performance. These studies include the DRZ. Simulating fractured flow and transport through the host rock requires a flow code with a fracture model. The codes used for similar studies of panel seals and panels (rooms) can be used for shaft seals when the codes are available.

Flow and Transport Modeling

The undisturbed-scenario analysis requires simulating flow and transport through the repository/shaft system to overlying water-bearing units (e.g., the Culebra Dolomite Member). For human-intrusion scenarios, the primary concern is transport through a plugged intrusion borehole and not through consolidated drifts and shafts, although these pathways should be considered in defining room conditions. Transport through, along, and around shaft-seal materials must be modeled for the undisturbed scenario to determine repository conditions, especially for transient brine and gas flow and closure effects. Capability for handling all scenarios requires solving equations including retardation and fractures for radionuclide transport along the three transport pathways. Because network models solve only one-dimensional equations along preassigned pathways for fixed fluid fields, more detailed, multi-dimensional modeling may be required to justify the use of these simplified network models in the uncertainty analyses.

1 Shaft-Seal System in RESYSM

2
3 The interface with the next CAMCON module is lateral fluxes of radionuclides
4 in brines into water-bearing units that overlie the Salado Formation. The
5 network code applied would require benchmarking against more complete and
6 verified dynamical codes on idealized test problems designed for WIPP facility
7 geometry. However, a network model can be formulated to include flow through
8 seal materials, along the seal/host-rock interface, and through the DRZ. In
9 the absence of data, however, calculations are not reliable. The importance
10 of these seals in the overall RESYSM system must be evaluated by sensitivity
11 analysis to determine if increased understanding of flow and transport is
12 required. Preliminary calculations indicate that the undisturbed-performance
13 scenario is not a significant contributor to the release of radionuclides,
14 whereas human intrusion scenarios may be significant (Lappin et al., 1989).
15 Shaft seals are not important in human-intrusion scenarios.

16
17 RADIONUCLIDE TRANSPORT

18
19 The Culebra Dolomite Member of the Rustler Formation is the first significant,
20 laterally continuous, water-bearing unit above the WIPP repository. It has
21 been identified in the site characterization as one of the most important
22 paths for radionuclides to be transported from the repository to the
23 accessible environment. Before transport of radionuclides in the Culebra
24 Dolomite can be modeled, the dominant physical/chemical processes during
25 transport must be identified and simulated.

26
27 The characteristics of the Culebra Dolomite Member are described in A Summary
28 of the Hydrogeology of the Northern Delaware Basin. The significance for
29 transport of fractures in the Culebra Dolomite Member has been examined with
30 two hydropad tracer tests, H-3 and H-4, near the WIPP (Kelley and Pickens,
31 1986).

32
33 The SWIFT II code was used to simulate tracer breakthrough times at H-3 and
34 H-4. The main objective of the analysis was to conceptualize the governing

1 physical processes for solute transport in the Culebra Dolomite Member. Given
2 the fractured nature of the Culebra Dolomite, three conceptual models are
3 possible: (1) a discrete-fracture model, (2) a porous-flow model, and (3) a
4 dual-porosity model. Comparisons of the single- and double-porosity
5 assumptions in SWIFT II with observed breakthrough curves indicate that the
6 double-porosity calibration is more consistent with the observations.

7
8 For the H-4 tracer test, in addition to single- and dual-porosity models, a
9 layered, porous-medium model was also included. From the SWIFT II
10 simulations, the observed tracer-breakthrough curves were concluded to be best
11 simulated by representing the Culebra Dolomite Member with a layered system
12 consisting of alternating high- and low-permeability zones. The best fit was
13 obtained for five or six high-permeability zones, although none of the fits
14 were satisfactory, especially at longer times. This result indicates that
15 sensitivity analyses are needed to assess how vertical resolution within
16 important water-bearing units affects the results of transport simulations.

17 Regional-Scale Contaminant Transport Calculations in the Culebra Dolomite Member

18
19
20 Detailed field testing and interpretation of conservative-tracer testing at
21 the H-3 hydropad indicate that fracturing and dual-porosity behavior can play
22 a major role in transport of contaminants in the Culebra Dolomite at the
23 hydropad scale (30 m) (98 ft). The ultimate goal of the WIPP performance
24 assessment, however, is to estimate the amount and rate of release of
25 radionuclides from the disposal system to the accessible environment. Thus,
26 it is necessary to determine whether the governing transport behavior at the
27 hydropad scale is still valid at the regional scale.

28
29 The regional-scale contaminant transport within the Culebra Dolomite Member
30 under undisturbed head-distribution conditions has been investigated (Reeves
31 et al., 1987). Three transport mechanisms compared were discrete-fracture,
32 dual porosity, and equivalent porous medium. From the SWIFT II simulations,
33 the "effective" transport behavior of the Culebra Dolomite Member between any
34 point directly above the site and the 5-km (3 mi) boundary was concluded to be
35 adequately represented by an equivalent porous medium having a porosity equal

1 to the sum of matrix and fracture porosities. Inclusion of the dual-porosity
2 formalism at this scale apparently would not change expected travel times by
3 more than 0.10.

4
5 Validity of the results is contingent on assumptions concerning base-case
6 transport parameters. In the event of intrusion into pressurized Castile
7 Formation brine, the volume and pressure of brine injected into the Culebra
8 Dolomite Member might be sufficient to increase the hydraulic gradient. Under
9 this condition, the velocity of groundwater in fractures might be greatly
10 enhanced, making the characteristic diffusion time into the matrix much longer
11 than the characteristic transport time in the fracture. In this case, the
12 equivalent-porous-medium approximation would not be valid.

13 14 Transport Models

15
16 Numerous groundwater flow and transport models are available. They range from
17 simple, one-dimensional analytical solutions to sophisticated, three-
18 dimensional numerical models. Most of these models are for flow and transport
19 in porous media. In the numerical models, spatial and temporal variation of
20 system properties such as hydraulic conductivity, porosity, and dispersivity
21 can be included as required for different scenario analyses.

22
23 "Network" models represent a different approach to discretizing flow and
24 transport for efficient computation but with less accuracy and realism.
25 Instead of solving the governing differential equation for solute transport,
26 solute concentrations in these codes are determined by calculating the motion
27 of a large number of discrete particles in a network of known flowpaths.

28
29 Both inorganic and organic chemical reactions may occur during the transport
30 process. Most of what is known about the chemical behavior of contaminants in
31 groundwater pertains to inorganic contaminants. Two approaches are used for
32 the prediction of the chemical behavior of inorganic contaminants in
33 groundwater. The first approach involves use of distribution coefficients in
34 describing the sorption behavior. The second approach makes use of
35 thermodynamically based chemical-equilibrium models. Field experiments have
36 shown that for trace-level inorganic contaminants controlled by adsorption,

1 such as cationic radionuclides, the retardation relation provided estimates of
2 relative velocity within a factor of about 5 or better (Cherry et al., 1984).

3
4 Dissolved organic contaminants in groundwater can be influenced not only by
5 adsorption, oxidation, and hydrolysis, but also by microbiological
6 degradation. Trace organics, especially those that are nonpolar and
7 relatively insoluble, tend to be sorbed by sediments and soils. Sorption of
8 many trace organic compounds has been shown to follow a linear isotherm.
9 Therefore, retardation factors may be used to describe their transport. The
10 more hydrophobic a compound is, the more retarded it is (Roberts et al., 1980;
11 Schwarzenbach and Westall, 1981; MacKay et al., 1985). Good evidence exists
12 that certain organic groundwater contaminants can be biologically transformed
13 by microorganisms attached to solid surfaces within the aquifer (McCarty et
14 al., 1984). However, because the understanding of biotransformation processes
15 is limited, organic contaminants should be assumed to persist indefinitely,
16 particularly in the absence of evidence to the contrary.

17
18 Simulating transport of contaminants in fractured media may depend largely on
19 assumptions that can be made about the density and size of fractures and the
20 extent of dead-end pore volume intersecting fractures. If the medium is
21 densely fractured, with small apertures and high connectivity, and with
22 relatively little mobile fluid, a porous flow model may suffice. If the
23 medium is coarsely fractured with tight matrix adjacent to the fractures, flow
24 and transport probably takes place only in fractures. For media that fall
25 between these two cases, a dual-porosity model may be necessary. In a dual-
26 porosity concept, the advective transport takes place in the fractures with
27 molecular diffusion into the matrix. Many transport models with different
28 capabilities are available, and some (SWIFT II, NEFTRAN, SUTRA, REMTRAN,
29 TAKRAT) are already included in CAMCON. Final compliance analysis may use
30 several of these transport codes because the choice of code may differ among
31 scenarios.

32 33 CAMCON: CONTROLLER FOR COMPLIANCE ASSESSMENT SYSTEM

34
35 The complex disposal system at the WIPP requires that computer codes in the
36 compliance assessment system be controlled by a computerized executive

1 program. CAMCON is the controller for the system (Rechard, 1989; Rechard et
2 al., 1989). An executive program to control consequence calculations must
3 meet several requirements. These requirements can be grouped into two
4 categories: built-in flexibility and built-in quality assurance (QA). An
5 executive program must link several distinct model components with little
6 analyst intervention, trace calculations so that they can be repeated, track
7 parameter uncertainty using Monte Carlo techniques, and identify calculations
8 to avoid misinterpretation. The controller should also provide easy
9 examination of intermediate and final results, interpolation between modeling
10 scales, and iteration between computer modules. Easy replacement of computer
11 modules within the executive program is also necessary for scenario screening,
12 model/model comparisons, sensitivity analysis, and fine-tuning of the system
13 for final compliance assessment. CAMCON modularizes tasks so computer codes
14 for a particular module are interchangeable.

15
16 Compliance evaluation quality depends on data quality. Data bases have been
17 grouped into three categories: primary, secondary, and computational.

18 19 Primary Data Base

20
21 The primary data base contains measured field and laboratory data gathered
22 during the disposal-system and regional characterization. The important
23 requirements of the primary data base are: (1) data quality must be good,
24 because the analysis can be no better than these data, (2) the data base must
25 contain all necessary data for the compliance assessment and repository design
26 and (3) data should have as little subjective interpretation as possible.
27 Data base structure must be flexible to accommodate different organizations
28 and unforeseen types of data. Practical experience suggests that a relational
29 data base is best (Rautman, 1988).

30 31 Secondary Data Base

32
33 The secondary data base contains interpreted data, usually interpolated onto a
34 regular grid, and is a collection of information that comprises the conceptual
35 model of the disposal system. Levels of interpretation can vary from
36 objective interpolation of data combined with subjective judgments (possibly

reproducible by others) to totally subjective extrapolations of data (not reproducible by others unless documented in reports). Data from literature or professional judgment are used to fill knowledge gaps to complete the conceptual model. The secondary data base must be accessible to both the analyst and the executive package controlling the system, and accommodate two distinct types of data: stratigraphy and parameter distributions.

Computational Data Base

The computational data base is named CAMDAT for Compliance Assessment Methodology DATa. CAMDAT uses a neutral-file format (Figure 4-24) so that a series of codes can be linked by a "zig-zag" connection rather than the usual serial connection. This format has the following advantages: (1) only one plotting program, which reads the computational data base, is needed to display any intermediate or final results from the many codes linked together; (2) codes are easily changed; (3) iterative calculations during calibration or convergence studies on multiple computational domains or grids are readily controlled; (4) a controller that automates compliance assessment is easier to design if information is stored in one file format. The file format chosen for CAMDAT was based on GENESIS (Taylor et al., 1987) and EXODUS and their associated data manipulation and plotting programs (Gilkey, 1986a and b, 1988b; Gilkey and Flanagan, 1987).

Code-Linkage and Data-Flow Controller

Code linkage and data flow through CAMDAT is controlled by CAMCON. Computer programs that make up the CAMCON system are major program modules, minor program modules, and translators. Major program modules refer to programs that represent major tasks of the consequence modeling. Minor program modules refer to programs such as interpolators, that are necessary to facilitate use of major program modules. Translator program modules refer to programs that translate data either into or out of the computational data base. Major program modules for consequence modeling are the mesh-generation, Monte Carlo sampling, regional-hydrology, local-hydrology, repository-shaft-source, transport-hydrology, biological-pathways, human-dose, and human-response modules. Minor program modules interpolate boundary conditions between

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Figure 4-24. Coupling Through a Computational Data Base using a "Neutral File" (Rechard, 1989).

models, track particles through simulated flow fields, generate various diagnostics and plot results. Translators communicate between codes and the secondary and computational data bases. The algorithm for controlling a simple analysis using CAMCON is complex (Figure 4-25), but the advantages of rapid problem set up and execution with built-in quality assurance makes a logical data flow and execution program necessary.

Parameter Uncertainty and Sensitivity Analyses

Computer models that will be used for the WIPP performance assessment are complex. Parameters for these models are not precise because (1) measurement techniques may be either incorrect or misapplied, (2) parameter values are based on statistical reductions of measured data, (3) variable parameters are replaced with lumped parameters, (4) random variations are replaced with deterministic parameters, (5) data are misinterpreted (Cranwell and Bonano, 1987); there are also natural variations in the system.

A parameter uncertainty analysis determines the amount of variability in the results of a model that can be attributed to uncertainty in the input data. A sensitivity analysis identifies the main contributors to the observed variation in the results. Some techniques used to quantify and/or reduce parameter uncertainty are: (1) differential-analysis techniques, (2) statistical methods, and (3) stochastic modeling (Cranwell and Bonano, 1987). In the differential-analysis technique, a first order Taylor series expansion is used as an approximation of the model, and partial derivatives must be calculated. For an uncertainty analysis, the series approximation used with Monte Carlo simulations produces distribution functions for the performance measure.

Statistical methods are based either on experimental design/response-surface procedures or sampling/Monte Carlo methods. In the experimental design/response-surface procedures, an experimental design is used to select values of parameters for calculations using computer models. A least-squares method is used to determine a fitted response surface to match the data. The fitted response surface can be used to assess both parameter uncertainty and parameter sensitivity. In the sampling/Monte Carlo methods, the input

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Figure 4-25. Algorithm for Logical Data Flow During Compliance Assessment (Rechard, 1989).

1 parameters are considered to be random variables with probability
2 distributions. Statistical-sampling techniques are used to select input
3 parameters for the model. Repeated runs of the model produce a distribution
4 of the results. Stochastic models incorporate information on the correlation
5 between parameters directly into the model. One set of equations is solved
6 for the mean behavior of the dependent variables, and another set is solved
7 for the variance about the mean.

8
9 A comparison study of several widely used uncertainty and sensitivity analysis
10 techniques was performed on three models having large uncertainties and
11 varying degrees of complexity. The technique using LHS and regression
12 analysis gave the best overall results (Iman and Helton, 1985). Therefore,
13 the WIPP performance assessment has adopted the LHS sampling approach. LHS is
14 a modified Monte Carlo technique for obtaining sets of parameters for computer
15 models (McKay, Conover, and Bechman, 1979). The technique has been used at
16 SNL for performance assessment of hypothetical disposal systems in bedded salt
17 (Cranwell et al., 1987) and basalt sites (Bonano et al., 1988). A brief
18 description of the LHS technique is presented below (Iman et al., 1980).

19
20 To obtain n different values from each of K variables $x_1 \dots x_K$, an LHS
21 sample is obtained by first dividing the range of each variable into n non-
22 overlapping intervals on the basis of equal probability (Figure 4-26). One
23 point value from each interval is selected at random with respect to the
24 probability density in the interval. The n values thus obtained for x_1 are
25 paired in a random fashion with n values of x_2 . These n pairs are combined in
26 a random manner with the n values of x_3 , and so on, until a set of n_K -tuples
27 is formed.

28
29 Due to the random pairing of input values in LHS, undesired correlations may
30 be induced among some of the variables. Such unwanted correlations can be
31 avoided by a technique that restricts the possible pairings (Iman and Conover,
32 1982b; Iman and Shortencarier, 1984). In addition, if a known correlation
33 exists between variables (an example would be hydraulic conductivity and
34 porosity), LHS allows the pairings to produce the desired correlation (Iman et
35 al., 1980). This feature ensures that unbiased estimates of the output are
36 obtained.

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Figure 4-26. Intervals Used with a Latin Hypercube Sample of Size $n = 5$ in Terms of the Density Function and Cumulative Distribution Function for a Normal Random Variable (Iman and Shortencarier, 1984).

1 The choice of sample size n for LHS depends mainly on the time required to
2 analyze all the samples and the number of input variables K . A rule of thumb
3 is $n \geq (4/3) K$ (Iman and Helton, 1985). It is also important to note that the
4 restricted pairing technique (Iman and Conover, 1982a) can be applied only if
5 $n > K$.

6

7 Sensitivity analyses identify important input parameters by quantitatively
8 estimating the amount of variation in the output that results from a
9 particular variation in the input parameter. Results of a sensitivity
10 analysis can aid in reducing uncertainty by directing research efforts towards
11 understanding the relationship between relevant parameters and reduction of
12 the ranges of the values of these parameters, if possible.

13

14 Two approaches to performing sensitivity analyses are (1) statistical sampling
15 of input parameters followed by stepwise regression analysis of the results as
16 a function of the input value, and (2) the differential or deterministic
17 approach where explicit relationships between input and output are described
18 in a computer code, and important parameters are identified by using a direct
19 method such as the adjoint method. For preliminary WIPP performance
20 assessment, statistical sampling using LHS, followed by stepwise regression
21 analysis (Draper and Smith, 1981) will be used for the parameter sensitivity
22 analysis. Other techniques will be used when necessary for specific studies.

23

24 In LHS, if all input variables are varied simultaneously, the sensitivity of
25 the output relative to an individual input variable may be difficult to
26 determine. Calculating the partial correlation coefficient is a technique
27 that can quantify such sensitivity. However, this technique will not provide
28 a reliable measure of sensitivity if extreme values of input variables are
29 present. The partial rank correlation coefficient technique (Iman and Helton,
30 1985) is used to avoid this problem. Here, variable data and results are
31 replaced by their corresponding ranks from 1 to n , and all the necessary
32 calculations in determining the partial correlation coefficients are done on
33 these ranks.

34

35 For the WIPP performance assessment, different sensitivity analysis techniques
36 will be compared to ensure that the best technique will be used.

37

V. INDIVIDUAL PROTECTION REQUIREMENTS

COMPLIANCE ASSESSMENT APPROACH

The Standard contains Individual Protection Requirements:

"Disposal systems for transuranic wastes shall be designed to provide a reasonable expectation that for 1000 years after disposal, undisturbed performance of the disposal system shall not cause the annual dose equivalent from the disposal system to any member of the public in the accessible environment to exceed 25 mrem to the whole body and 75 mrem to any critical organ." (§ 191.15)

Two previous studies (U.S. DOE, 1980a; Lappin et al., 1989) reported doses to humans resulting from hypothetical releases from WIPP for selected scenarios. Although these studies employed deterministic calculations and were not concerned with assessing compliance with § 191.15, they have an important bearing on the design of probability-based dose calculations. The approach in the *WIPP Final Environmental Impact Statement* (U.S. DOE, 1980a) for analyzing the effects of release of radioactivity from WIPP was to estimate the consequences of five different hypothetical scenarios that might move radionuclides to the biosphere. The analyses of these scenarios proceeded from radionuclide movement through the geosphere to transport through the biosphere after discharge into the Pecos River at Malaga Bend, and finally, predicted radiation doses received by people. The human dose estimates were based on the "Report of ICRP Committee II on Permissible Dose for Internal Radiation, International Commission on Radiological Protection, Publication 2" (ICRP, 1959), and is usually referred to as ICRP 2. The travel times for radionuclides arriving at Malaga Bend were on the order of a million years, but this study predates the Standard, which specifies a time scale of one thousand years for individual protection.

The second study (Lappin et al., 1989), performed as a basis for the WIPP *Draft Supplemental Environmental Impact Statement* (U.S. DOE, 1989e), analyzed the effects of release of radioactivity from WIPP by estimating the consequences of two different hypothetical cases. Human dose estimates were based on the new ICRP philosophy as described in ICRP Publications 26 (ICRP, 1977) and ICRP 30 (ICRP, 1979), respectively.

1 The Standard requires that an uncertainty analysis of undisturbed conditions
2 be performed to assess compliance with § 191.15. In this case, the
3 performance measure is dose to humans. However, the recent study (Lappin et
4 al., 1989) indicated that, in the absence of human intrusion, releases
5 resulting in doses via a route through the Culebra Dolomite Member to a
6 livestock well will not occur in the 1,000-year time scale of § 191.15.
7 Repeating that study to include uncertainty analyses is unlikely to provide
8 any parameter selection that results in doses in a 1,000-year time scale.
9 This hypothesis has been verified for saturated repository conditions without
10 gas generation (Marietta et al., 1989) and it is unlikely that gas generation
11 can affect radionuclide migration within 1,000 years.

12

13 Therefore, dose calculations are not expected to be a part of the WIPP
14 assessment of compliance with 40 CFR Part 191. However, Subpart B is in
15 remand. The outcome of the remand may require dose calculations over longer
16 times. This discussion presents the WIPP performance assessment approach for
17 calculating human doses if required. Dose analyses for purposes other than
18 comparison to § 191.15 also can be done using this methodology.

19

20 **UNDISTURBED PERFORMANCE**

21

22 **RELEASE AT A LIVESTOCK POND**

23

24 This scenario is the undisturbed disposal-system scenario used in analyses for
25 the Containment Requirements. Livestock wells are assumed to be located
26 downgradient from the repository. This scenario was selected for earlier
27 analyses (Lappin et al., 1989) because it was believed to be the only
28 realistic scenario that could result in transport of radionuclides to the
29 surface under undisturbed conditions.

30

31 Radioactive material is assumed to be carried by Salado brine fluids from the
32 storage panels into MB139. It seeps through and around grouted seals in the
33 marker bed, and migrates through the part of MB139 that underlies drift
34 excavations to the bottom of the sealed shafts. Radioactive material is then
35 assumed to continue to migrate up through the lower seal system due to the
36 pressure gradient between the repository and the Culebra Dolomite Member.

1 Material is then introduced into the Culebra Dolomite and entrained in the
2 groundwater flow. In order to provide a route to man, it is assumed that an
3 active livestock well penetrates the Culebra Dolomite downgradient from the
4 sealed shafts. Radioactive material migrates through the Culebra layer to the
5 livestock well where it is pumped to the surface and cattle drink the
6 contaminated water. This is the beginning of the biological pathway to humans
7 via a beef ingestion route (Lappin et al., 1989). Other possible pathways
8 exist and will be considered, but for undisturbed conditions, any possibility
9 requires a pumping well route to the surface. Because this route is not
10 completed in 1,000 years, no need exists to consider other possible pathways
11 for § 191.15 at this time, although the response to the remand may change this
12 position.

13
14 The procedure used to perform these analyses is to define a conceptual model
15 of the system based on present understanding (Lappin et al., 1989), and to use
16 numerical models to calculate groundwater flow, radionuclide transport to
17 humans, and human dosimetry and response.

18 19 CONCEPTUAL MODEL OF THE SYSTEM TO BE ANALYZED

20
21 In the initial system conceptual model, panels are filled with waste and
22 backfill and no free water is present. MB139 is fractured as a result of
23 excavation of the drifts and panels, and in response to later salt creep into
24 these excavations. These new fractures occur directly under all excavations,
25 but not under the intact salt pillars. Grout seals are in place in MB139
26 directly under panel seals. All access drifts and the experimental area are
27 backfilled and the shafts are sealed (Lappin et al., 1989).

28
29 Microbiological degradation of organic material in waste containers begins
30 when the containers are filled and continues in the repository. As salt creep
31 closes rooms and drifts, waste containers rupture and gas enters voids in the
32 rooms and drifts. Gas migrates into MB139 through the marker bed seals and
33 eventually fills the fracture volume. Gas pressure rises, slowing room
34 closure and brine inflow, and maintaining open fractures in MB139. As gas
35 generation slows, brine begins to resaturate the repository and MB139. The
36 balance of creep closure, gas generation and dispersion, and resaturation with

1 host rock brines is complex and highly dependent on room chemistry and waste
2 types. If the waste panels partially or fully saturate, transport can occur
3 by diffusion and advection in pressure-driven brine, provided a pressure
4 gradient exists (Lappin et al., 1989).
5
6 Available codes assume Darcy flow along each leg of the transport path and
7 transport calculations must assume saturated media along the flowpaths.
8 Multiphase codes are being evaluated, and the assumptions of saturation and
9 incompressible Darcy flow will be assessed through sensitivity analyses.
10 Radionuclides are assumed available for dissolution in the brine according to
11 their solubility limits. Parameter uncertainty will be reflected in the
12 analysis. Parameter distributions for uncertainty analysis describe the
13 room's moisture content (saturation). If sampled parameter values indicate
14 room saturation, transport can occur because Darcy flow applies and the
15 calculation proceeds for that Monte Carlo input vector. If sampled parameter
16 values indicate the room is not saturated, transport cannot occur and the
17 calculation is terminated with a zero consequence for that vector (Lappin et
18 al., 1989). The importance for performance assessment of modeling transport
19 in partially saturated waste within the repository and Salado will be assessed
20 through sensitivity analyses.
21
22 In the conceptual model of the repository system (Figure 4-22), the preferred
23 transport path is assumed to be from the waste panels into MB139, through the
24 grout seal, along fractures in MB139 to the base of the shafts, and through
25 the lower and upper shaft seals to the Culebra Dolomite Member. The lower
26 shaft seal is assumed to be well consolidated whereas the upper seal is less
27 consolidated. Flow is driven by a pressure gradient between waste panels and
28 the Culebra Dolomite Member. Transport continues through the Culebra Dolomite
29 to the livestock well (Lappin et al., 1989).
30
31 Flow through MB139 and up the shafts is more likely because each leg has a
32 higher permeability than the host rock. An alternate flow path from the waste
33 panels through the intact Salado and Rustler Formations to the Culebra
34 Dolomite Member also must be considered because of the large cross-sectional
35 area of the waste panels. Darcy flow must be assumed for the Salado Formation
36 if available codes are used (Lappin et al., 1989).

Another alternate path to be considered is the route through MB139 to ERDA-9 and up to the Culebra Dolomite Member. This path requires migration of brine and radionuclides through a fully consolidated part of the marker bed within the host rock. The shortest distance from an excavated drift is only about 100 m (300 ft), which may be important for transport on a 10,000-year time scale, but not a 1,000-year time scale.

COMPLIANCE ASSESSMENT SYSTEM

To evaluate compliance with the Individual Protection Requirements (§ 191.15), radionuclide concentrations as a function of space and time must be calculated. Undisturbed conditions are used for these calculations. Evaluating compliance with § 191.15 requires that the analyst replace the CCDF module with the biotransport and dosimetry modules (Figure 3-1). The performance measure becomes dose to humans instead of a CCDF. Extra modules must be included in CAMCON so that input-parameter uncertainty can be considered. The calculation results in a probability distribution function for human-exposure. Additional modules are: (1) biological-pathways, (2) human-dosimetry, and (3) dose-response modules.

EXPOSURE PATHWAYS IDENTIFICATION

An "exposure pathway" is a potential route through which humans may be exposed to radionuclides or radiation. General pathway categories are external exposure, inhalation, and ingestion. A specific pathway describes the route of exposure within these categories such as a contaminated-water-to-beef-to-man ingestion pathway. Release points to the biosphere must be considered when defining these biological pathways. WIPP scenarios (see Chapter IV) include direct release to the surface through cuttings and eroded particles or withdrawal wells. Only pathways that arise from withdrawal wells will be considered for compliance with § 191.15; therefore, withdrawal wells are included within the definition of undisturbed conditions. Withdrawal wells will be assumed to provide water for livestock in tanks or ponds, irrigation, and general domestic purposes for local ranches. Livestock ponds will dry after they are abandoned, and provide a starting point for airborne releases. Exposure pathways will include external pathways due to the rancher's exposure

1 to withdrawal well fluids, inhalation pathways due to airborne particulates
2 arising from a dry livestock pond, ingestion pathways arising from consumption
3 of food products grown in soil contaminated by airborne particulates from a
4 dry livestock pond, ingestion pathways arising from consumption of food
5 products grown with irrigation water from a contaminated withdrawal well, and
6 ingestion pathways arising from the consumption of meat and milk products
7 processed from livestock that was watered at ponds or holding tanks
8 contaminated through withdrawal wells.

10 COMPUTER MODELS AND DATA

12 Many pathways and dose models exist as well-developed, quality-assured, user-
13 friendly codes (Moore et al., 1979; Till et al., 1987; Napier et al, 1988) and
14 as developmental research codes (Gallegos et al., 1980; Gallegos and Wenzel,
15 1984; Wenzel and Gallegos, 1985). These codes can be applied to the WIPP data
16 base, but any set of dosimetry/effects codes is very dependent upon the
17 selection of input data.

19 Input data for dose calculations will be taken from several readily available
20 sources (transfer factors from Baes et al., 1984 and Till and Meyer, 1983;
21 ingestion rates from NCRP, 1984 and Till and Meyer, 1983; Committed Effective
22 Dose Equivalents (CEDE) from U.S. DOE, 1988b, which has replaced U.S. DOE,
23 1985). The CEDE factors will be taken from U.S. DOE, 1988b, because that
24 document is intended to be used as the primary reference by the DOE and its
25 contractors for calculating dose equivalents for the public resulting from the
26 ingestion or inhalation of radionuclides. Wide variability exists in
27 published parameter values within these references. Calculated 50-year CEDEs
28 can differ by a factor of 10 because of this variability between literature
29 sources (Lappin et al., 1989). No obvious reason is known for preferentially
30 selecting transfer factors or ingestion rates from one specific reference.
31 For example, ingestion rates for beef consumption range from 86 g/d (NCRP,
32 1984) to 206 g/d (Till and Meyer, 1983). The beef consumption rate of 86 g/d
33 assumes that other meats are eaten as well. If human dose calculations are
34 required, the uncertainty in these input parameters will have to be included.

VI. ASSURANCE REQUIREMENTS PLAN

As prescribed in the Second Modification to the Consultation and Cooperation Agreement, the WIPP Project has prepared a plan for implementing the Assurance Requirements (U.S. DOE, 1987). That plan is briefly summarized here. The plan is preliminary, because better methods and technologies could evolve over the operational time period. In accordance with the Project's interpretation of the EPA's intention, the Project will select assurance measures based on the uncertainties in the final performance assessment. This discussion will be updated as the operating contractor (see Chapter I) updates the implementation plans. The current plan includes definitions and clarifications of the Standard as it applies to the WIPP, the implementation objective for each requirement, an outline of the implementation steps for each requirement, and a schedule of activities leading to final compliance. The implementation objective for each requirement follows.

ACTIVE INSTITUTIONAL CONTROLS

Active institutional controls are expected to include post-operational monitoring, decontamination and decommissioning, land reclamation, evaluation of land use in the area, maintaining fences and buildings, and guarding the facility. The objectives of these activities are to restore the land surface to its original condition to avoid future preferential selection of the area for incompatible uses, to provide a facility and presence at the site during active cleanup, and to monitor the disposal system.

DISPOSAL SYSTEM MONITORING

Monitoring is required if the monitoring program will be useful for evaluating uncertainties associated with the long-term performance predictions and if the time period over which data can be collected is realistic for exercising active control over the site. The objective would be to detect substantial and detrimental deviation from the expected performance of the disposal system. Monitoring activities will be identified during the course of the performance assessment.

PASSIVE INSTITUTIONAL CONTROLS

The Project will implement passive institutional controls over the entire controlled area, including markers, records, and federal ownership. The DOE or some successor agency will retain ownership and administrative control over the land in accordance with Appendix B of the Standard. The federal agency responsible for the land will institute regulations that appropriately restrict land use and development. Markers will include on-site structures engineered and constructed to survive for at least 5,000 years as a means of preserving knowledge of the location of TRU radioactive wastes. The objectives are to restore the disposal site to nearly original condition, to preserve a record of the disposal site and its contents in perpetuity, and to warn those in the vicinity of the disposal site of the hazards associated with subsurface development activities.

MULTIPLE BARRIERS

The Standard requires that both natural and engineered barriers be used as part of the isolation system. At the WIPP, natural barriers include both the salt formation, with its favorable characteristics, and the geohydrologic setting. Engineered barriers include the repository, backfills, and plugs and seals that isolate volumes of wastes. The effectiveness of these barriers is being modeled for the performance assessment. The objective is to provide a disposal system that isolates the radioactive wastes to the levels required in the Standard.

NATURAL RESOURCES

The Standard requires that locations containing recoverable resources not be used unless it can be shown that the favorable characteristics of a location compensate for the greater likelihood of being disturbed in the future. The WIPP Project met this requirement when the site was selected, and the Project will issue a finding to that effect.

WASTE REMOVAL

The Standard requires that it be technologically feasible to locate and recover the waste for a reasonable period of time after disposal. In promulgating the Standard, the EPA stated that "any current concept for a mined geologic repository meets this requirement without any additional procedures or design features" (U.S. EPA, 1985, p. 38082). Thus, the WIPP satisfies this requirement.

VII. RESULTS

CONTAINMENT (PERFORMANCE ASSESSMENT)

SCENARIO RELEASE ANALYSES

This section will summarize the scenario-by-scenario consequences and probabilities that must be used to construct the CCDF.

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION (CCDF)

This section will describe the step-by-step construction of the CCDF and the actual curve superimposed on the regulatory curve (Figure 2-2). A discussion of important scenarios, important parameters, and important radionuclides will be included.

The final steps to assess regulatory compliance with § 191.13 are to calculate an EPA sum for each scenario, generate the CCDF, and compare with the release limits of the containment section.

INDIVIDUAL PROTECTION

RELEASES

This section will present radionuclide releases to the biosphere, along biological transport pathways, and external/internal human exposures.

Compliance with § 191.15 will be demonstrated by calculating doses to humans resulting from releases to the biosphere for the undisturbed-performance scenario only. For extremely conservative assumptions, no releases occur in 10,000 years (Lappin et al., 1989). The present regulatory time scale is 1,000 years for individual protection. No releases that will require dose calculations to show compliance are expected to occur within 1,000 years. To

1 demonstrate that dose calculations are not required, transport calculations
2 through 10,000 years will be reported, as will results of deterministic
3 transport calculations (Lappin et al., 1989). Uncertainty analysis of the
4 undisturbed scenario is required by § 191.15. Parameter uncertainty will be
5 included as described by § 191.13. If releases actually occur, the
6 appropriate performance measure should be dose, and uncertainty in dose values
7 should be reported as a probability distribution function. Because no
8 releases are expected, this performance measure is not meaningful, and others
9 should be reported. Only arrival times at major nodes within the system are
10 reported (e.g., the bottom of the lower shaft-seal system, the top of the
11 lower shaft-seal system, or the Culebra Dolomite Member of the Rustler
12 Formation) (Lappin et al., 1989). Extending these calculations to include
13 parameter uncertainty will provide a probability distribution function for
14 these arrival times. In addition, integrated flux of radionuclides across the
15 same nodes provides a measure of the state of transport at 10,000 years and
16 the uncertainty in that state. Both arrival times and integrated flux will be
17 reported at important nodes in the system.

18

19 DOSES

20

21 This section will report the predicted doses including critical pathways,
22 critical radionuclides, critical organs, and total body dose.

23

24 This section is included only to describe how doses would be reported if
25 releases occur. Such dose calculations may be required if the response to the
26 remand of Subpart B results in an extension of time scale and an inclusion of
27 human intrusion within the Individual Protection Requirements.

28

29 Compliance with § 191.15 requires that uncertainty be considered when
30 comparing to the regulation. The methodology is the same as used for
31 comparison with Containment Requirements, but the performance measure is dose
32 to humans instead of integrated discharge to the accessible environment.
33 Parameter uncertainty is included through Monte Carlo techniques using CAMCON.
34 The results are frequency distributions for dose to the whole body and
35 critical organs of maximally-exposed individuals. Following the same
36 frequentist approach described for generating the CCDF, plots of probability

1 versus dose will be produced to compare with the regulatory limits of 25 and
2 75 mrem to critical organs and whole body respectively. Because § 191.15 only
3 requires analysis of the undisturbed performance scenario, unlikely events and
4 scenario probabilities are not considered. Because final uncertainty analyses
5 will probably rely on beta distributions for sampled input parameters, the
6 calculated probability distributions for doses will be truncated at the
7 extreme or conservative end of the range, i.e., the integral of the
8 probability distribution function is arbitrarily close to but not equal to
9 one.

10
11 Dose measures that could be reported are maximum individual; peak annual;
12 whole body; and critical organ doses including critical pathways and
13 radionuclides, average individual dose in the critical population, 50-year-
14 dose commitment including critical pathways and radionuclides, integrated
15 average individual dose in the same critical population over 50- or 70-year
16 time periods including age and sex subgroups in the tracked cohort.

17 18 **ASSURANCE PLANS**

19
20 Changes to the plans that will be required to support predictions of
21 compliance with the Containment Requirements predictions will be described in
22 this section. Such changes could include establishing criteria and
23 specifications for passive markers to minimize the probability of inadvertent
24 intrusion through exploratory drilling. Another possible change is specifying
25 techniques for borehole plugging; such techniques might be incorporated into
26 the legal records along with the description and location of the disposal
27 system. The records might also contain a warning about the potential effects
28 of drilling through the repository and into pressurized brine in the Castile
29 Formation.

VIII. COMPARISON TO THE STANDARD

This chapter will compare the final compliance assessment to Subpart B of the Standard.

CONTAINMENT REQUIREMENTS

ASSURANCE REQUIREMENTS

INDIVIDUAL PROTECTION REQUIREMENTS

GROUNDWATER PROTECTION REQUIREMENTS

IX. RECOMMENDATIONS

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GLOSSARY

Actinide - Any element in the actinium series of elements of increasing atomic numbers beginning with actinium (89) and ending with Lawrencium (103).

Advection - The process of transport of an aqueous property by mass motion.

Alpha Particle - A positively charged particle emitted in the radioactive decay of certain nuclides. Made up of two protons and two neutrons bound together, it is identical to the nucleus of a helium atom. It is the least penetrating of the three common types of radiation -- alpha, beta, and gamma.

Anhydrite - A mineral consisting of anhydrous calcium sulfate (CaSO_4). It is gypsum without water, and is denser, harder, and less soluble.

Anisotropic - Variation in hydraulic conductivity with direction.

Anticline - A fold of rocks, generally convex upward, whose core contains stratigraphically older rocks.

Aperture - The open space along a fracture in rock.

Aquifer - A body of rock that is sufficiently permeable to conduct groundwater and to yield significant quantities of groundwater to wells and springs. The opposite of an aquiclude.

Aquitard - A confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer.

Backfill - Material placed around the waste containers, filling the open space in the room.

Backpressure - Pressure caused by a force operating in a direction opposite to that being considered, such as that of a pore fluid pressure on matrix.

Glossary

- 1 **Bell Canyon Formation** - A sequence of rock strata that form the topmost
2 formation of the Delaware Mountain Group.
3
- 4 **Benchmark** - To compare predictions made with one code with those obtained with
5 other codes or with analytical solutions. Benchmarking is a part of
6 verification.
7
- 8 **Bentonite** - A commercial term applied to clay materials containing
9 montmorillonite (smectite) as the essential mineral.
10
- 11 **Biodegradable** - Possessing the ability of being broken down by microorganisms.
12
- 13 **Biosphere** - The life zone of the earth, including the lower part of the
14 atmosphere, the hydrosphere, soil, and the lithosphere to a depth of about 2
15 km (1 mi).
16
- 17 **Biotransformation** - The transformation of chemical compounds within a living
18 system.
19
- 20 **Biotransport** - Transport of radionuclides over biological pathways, such as
21 through the food chain.
22
- 23 **Borehole** - (1) A manmade hole in the wall, floor, or ceiling of a subsurface
24 room used for verifying the geology, observation, or the emplacement of waste
25 canisters. The horizontal wall holes are used for remote-handled (RH-TRU)
26 waste. (2) A hole drilled from the surface for purposes of geologic or
27 hydrologic testing, or to explore for resources; sometimes referred to as a
28 drillhole.
29
- 30 **Breccia** - A rock consisting of very angular, coarse fragments held together by
31 a mineral cement or a fine-grained matrix (as sand or clay).
32
- 33 **Brine Aquifer** - The Rustler-Salado Residuum; a zone of residual material at
34 the interface of the Rustler and Salado Formations left after dissolution of
35 the original salt. It is highly permeable and contains much brine.

1 **Brine Inclusion** - A small opening in a rock mass (salt) containing brine;
2 also, the brine included in such an opening. Some gas is often present.

3
4 **Calibrate** - To fit and/or tune computational models to simulate observed data.

5
6 **Caliche** - A calcareous material commonly found in layers on or within the
7 surface of stony soils of arid or semi-arid regions. It occurs as gravels,
8 sands, silts, and clays cemented together by calcium carbonate (lime) or as
9 crusts at the surface of the soil.

10
11 **Canister** - A container, usually cylindrical, for remotely handled waste, spent
12 fuel, or high-level waste; affords physical containment but not radiation
13 shielding. Waste remains in its canister during and after burial.

14
15 **Capitan Reef** - A fossilized limestone reef of Permian age that surrounds most
16 of the Delaware Basin.

17
18 **Cask** - A radiation shielded shipping container.

19
20 **Castile Formation** - A formation of evaporite rocks (interbedded halite and
21 anhydrite) of Permian age that immediately underlies the Salado Formation (in
22 which the WIPP disposal level is being built).

23
24 **C&C Agreement (Consultation and Cooperation Agreement)** - An agreement that
25 affirms the intent of the Secretary of Energy to consult and cooperate with
26 the State of New Mexico with respect to State public health and safety
27 concerns. It is an appendix to a July 1981 agreement (the Stipulated
28 Agreement) made with the State and approved by the District court when that
29 court stayed the proceedings of a lawsuit against the DOE by the State. The
30 C&C agreement identifies a number of "key events" and "milestones" in the
31 construction and operation of the WIPP that must be reviewed by the State
32 before they are started. The C&C agreement has been updated and extended as
33 recently as March 1988.

34
35 **Cenozoic** - An era of geologic time from the beginning of the Tertiary period
36 (~65 million years ago) to the present.

Glossary

- 1 CH-TRU Waste - Contact-Handled TransUranic waste is packaged TRU waste whose
2 external surface dose rate does not exceed 200 mrem per hour.
3
- 4 CHRS - Climate/Hydrology/Repository/Shaft scenario.
5
- 6 Claystone - An indurated clay having the texture and composition of shale but
7 lacking the fine lamination and fissility.
8
- 9 Compressibility - The property of a substance capable of being reduced in
10 volume by application of pressure; quantitatively, the reciprocal of the bulk
11 modulus.
12
- 13 Conductivity - A shortened form of hydraulic conductivity.
14
- 15 Confirm - To use full-scale in situ experiments to corroborate portions of
16 parameter ranges or distributions established by laboratory or small-scale
17 tests.
18
- 19 Conformably - Said of strata or stratification characterized by an unbroken
20 sequence in which the layers are formed one above the other by regular,
21 uninterrupted deposition.
22
- 23 Connectivity - The description of the way individual nodes or points connect
24 together to form elements or legs.
25
- 26 Consolidation - Process by which backfill and waste mass loses pore space in
27 response to the increasing weight of overlying material.
28
- 29 Creep - A usually very slow deformation of solid rock resulting from constant
30 stress; refers to the geologic phenomenon experienced as the gradual flow of
31 salt under high compressive loading.
32
- 33 Creep Closure - Closure of underground openings, especially openings in salt,
34 by plastic flow of the surrounding rock under pressure.

1 Cretaceous - Latest period of the Mesozoic Era, between ~144 and ~65 million
2 years ago.

4 Criticality - The state of a mass of fissionable material when it is
5 sustaining a chain reaction.

7 Culebra Dolomite Member - The lower of two layers of dolomite within the
8 Rustler Formation that are locally water bearing.

10 Curie - A unit quantity of any radionuclide in which 3.7×10^{10}
11 disintegrations occur per second.

13 Cuttings - Rock chips cut by a bit in the process of drilling a borehole or
14 well.

16 Darcy - A standard unit of permeability (m^2).

18 Decommissioning - Actions taken upon abandonment of DOE facilities to reduce
19 potential health and safety impacts, including activities to stabilize,
20 reduce, or remove radioactive materials or to demolish the facilities.

22 Decontamination - The removal of radioactive contamination from facilities,
23 equipment, or soils by washing, heating, chemical, or electrochemical action,
24 mechanical cleaning, or other techniques.

26 Delaware Basin - The part of the Permian Basin in southeastern New Mexico and
27 adjacent parts of Texas where a sea deposited large thicknesses of evaporites
28 some 200 million years ago. It is partially surrounded by the Capitan Reef.

30 Delaware Mountain Group - A set of three formations of Permian age that
31 underlie the Castile Formation at the Los Medaños site.

33 Depositional - Pertaining to the process of deposition.

35 Deterministic - Pertaining to an exact mathematical relationship between the
36 dependent and independent variables in a system.

Glossary

- 1 Dewey Lake Red Beds - A formation that overlies the Rustler Formation and is
2 composed of reddish brown marine mudstones and siltstones interbedded with
3 finegrained sandstone.
4
- 5 Diapirism - The process of piercing or rupturing of domed or uplifted rocks by
6 mobile core material by the effect of geostatic load in sedimentary rocks.
7
- 8 Diffusive - Characterized by the transfer of chemical components from a region
9 of higher to one of lower concentration.
10
- 11 Disposal - Emplacement of waste in a manner that assures isolation from the
12 biosphere with no intent of retrieval and that requires deliberate action to
13 regain access to the waste.
14
- 15 Dockum Group - A geologic sedimentary sequence that overlies the Dewey Lake
16 Red Beds over part of the Los Medaños area.
17
- 18 DOE - The U.S. Department Of Energy, established in 1978 as a successor to
19 ERDA and the AEC.
20
- 21 Dolomitic - Dolomite-bearing or containing dolomite (usually 5 to 50 percent
22 of the mineral dolomite).
23
- 24 Dose - A general term indicating the amount of energy absorbed per unit mass
25 from incident radiation.
26
- 27 Dose Equivalent - The product of absorbed dose and modifying factors that take
28 into account the biological effect of the absorbed dose. While dose includes
29 only physical factors, dose equivalent includes both physical and biological
30 factors and provides a radiation-protection scale applicable to all types of
31 radiation. Units are rem for individual and person-rem for a population
32 group.
33
- 34 Dosimetry - The measurement of radiation doses.
35
- 36 Drift - A horizontal passageway in a mine.

1 Dynamical - A family of solutions to an ordinary differential equation.

2
3 EEG - The Environmental Evaluation Group, an agency of the State of New Mexico
4 that reviews the safety of the WIPP.

5
6 Emplacement - At WIPP, the placing of radioactive wastes within the waste
7 rooms.

8
9 EPA - Environmental Protection Agency of the U.S. Government.

10
11 Equipotential - Lines connecting points of same potential.

12
13 Evaporite - A sedimentary rock composed primarily of minerals produced by
14 precipitation from a solution that has become concentrated by the evaporation
15 of a solvent, especially salts deposited from a restricted or enclosed body of
16 seawater or from the water of a salt lake. In addition to halite (NaCl) these
17 salts include potassium, calcium, and magnesium chlorides and sulfates.

18
19 Fissile - Capable of being split along closely spaced planes.

20
21 Flowpath - The path traveled by a neutral particle released into a groundwater
22 flow field.

23
24 Frequentist - Based on the patterns of recurrence of events or processes
25 exhibited over a period of time.

26
27 Geochemical - Pertaining to the study of the distribution and amounts of the
28 chemical elements in minerals, ores, rocks, soils, water, and the atmosphere.

29
30 Geology - The study of the earth, the materials of which it is made, the
31 processes that act on these materials, the products formed, and the history of
32 the planet and its life forms since its origin.

33
34 Geosphere - The solid portion of the earth as compared to the atmosphere and
35 the hydrosphere.

Glossary

- 1 **Geohydrology** - Referring to the hydrologic or flow characteristics of
2 subsurface waters.
3
- 4 **Glaciation** - The formation, movement, and recession of glaciers or ice sheets.
5
- 6 **Glauberite** - A brittle, light-colored, monoclinic mineral: $\text{Na}_2\text{Ca}(\text{SO}_4)_2$. It
7 has a vitreous luster and saline taste and occurs in saline residues.
8
- 9 **Grout** - A cement slurry of high water content.
10
- 11 **Gypsiferous** - Containing the mineral gypsum.
12
- 13 **Halite** - A dominant mineral in evaporites; salt, NaCl .
14
- 15 **Halogenated** - Atoms from the halogen family of elements combined with other
16 atoms such as carbon.
17
- 18 **HEPA Filter** - A High Efficiency Particulate Air filter usually capable of
19 99.97% efficiency as measured by a standard photometric test using a $0.3\mu\text{m}$
20 droplets (aerodynamic equivalent diameter) of DOP.
21
- 22 **Holocene** - An epoch of the Quaternary period from the end of the Pleistocene
23 epoch (~8,000 years ago) to the present.
24
- 25 **Horizon (geol)** - An interface indicative of a particular position in a
26 stratigraphic sequence. An underground level; for instance, the waste-
27 emplacement horizon at the WIPP is the level about 650 m (2,150 ft) deep in
28 the Salado Formation where openings are mined for waste disposal.
29
- 30 **Hot Cell** - A heavily shielded compartment in which highly radioactive material
31 can be handled, generally by remote control.
32
- 33 **HUMINT** - HUMAN INTRusion scenario.
34
- 35 **Hydraulic** - Pertaining to a fluid in motion.

Hydraulic Gradient - A quantity defined in the study of groundwater hydraulics that describes the rate of change of total head per unit distance of flow in a given direction.

Hydrogeology - The science dealing with subsurface waters and with related geologic aspects of surface waters.

Hydrology - The science that deals with global water, its properties, circulation, and distribution.

Hydropad - A complex of hydro-wells closely spaced in order to perform tests on hydrostratigraphic units.

Hydrophobic - Lacking an affinity for, repelling, or failing to adsorb or absorb water.

Hydrostratigraphic - Pertaining to a body of rock having considerable lateral extent and composing a geologic framework for a reasonably distinct hydrologic system.

In situ - In the natural or original position; used to distinguish in-place experiments, rock properties, and so on, from those in the laboratory.

Interbedded - Pertaining to sedimentary beds lying between or alternating with other beds with different characteristics.

Interfinger - The disappearance of sedimentary bodies in laterally adjacent masses owing to splitting into many thin layers, each reaching an independent pinch out.

Interpolators - Computer codes used to estimate an intermediate value of one (dependent) variable which is a function of a second variable.

Intracrystalline - Pertaining to something within a mineral crystal.

Glossary

- 1 **Isopach** - A line drawn on a map through points of equal true thickness of a
2 designated stratigraphic unit or group of stratigraphic units.
3
- 4 **Isotherm** - A line on a map connecting points of equal temperature.
5
- 6 **Isotope** - A species of atom characterized by the number of protons and the
7 number of neutrons in its nucleus. In most instances an element can exist as
8 any of several isotopes, differing in the number of neutrons, but not the
9 number of protons, in their nuclei. Isotopes can be either stable isotopes or
10 radioactive isotopes (also called radioisotopes or radionuclides).
11
- 12 **Isotropic** - Hydraulic conductivities of a porous media independent of
13 direction of measurement.
14
- 15 **Iterative** - A computational procedure in which replication of a cycle of
16 operations produces results which approximate the desired result more and more
17 closely.
18
- 19 **Karst** - A topography formed over limestone, dolomite, or gypsum; characterized
20 by sinkholes, caves, and underground drainage.
21
- 22 **Karstification** - The formation of karst features by the solutional and
23 mechanical action of water.
24
- 25 **Lenticular** - Resembling in shape the cross-section of a lens, esp. of a
26 double-convex lens. The term may be applied to a body of rock or a
27 sedimentary structure.
28
- 29 **Lithologic** - Pertaining to the description of rocks.
30
- 31 **Lithosphere** - The solid portion of the earth as opposed to the atmosphere and
32 the hydrosphere. Same as geosphere.
33
- 34 **Lithostatic Pressure** - Subsurface pressure caused by the weight of overlying
35 rock or soil.

- 1 **Los Medaños** - Literally "the dunes." The area in which the WIPP is located.
2
- 3 **Mesozoic** - The era of geologic time from ~245 million years ago to ~65 million
4 years ago.
5
- 6 **Meta** - A prefix for benzene-ring compounds when two side chains are connected
7 to carbon atoms with an unsubstituted carbon atom between them.
8
- 9 **Microbiology** - A branch of biology dealing especially with microscopic forms
10 of life.
11
- 12 **Microcrystalline** - Crystals too small to see with the naked eye.
13
- 14 **Microdarcy** - A unit of permeability (1,000,000th of a Darcy).
15
- 16 **Microfracturing** - The formation of fractures that cannot be detected with the
17 unaided eye.
18
- 19 **Microwave** - A comparatively short electromagnetic wave between 100 centimeters
20 and 1 centimeter in wavelength.
21
- 22 **Modular** - Constructed with standardized units or dimensions for flexibility
23 and variety in use.
24
- 25 **Monte Carlo Sampling** - A random sampling technique using computer simulation
26 to obtain approximate solutions to mathematical or physical problems,
27 especially in terms of a range of values each of which has a calculated
28 probability of being the solution.
29
- 30 **Mrem** - Millirem.
31
- 32 **Multipad** - See hydropad.
33
- 34 **Multipath** - The propagation phenomenon that results in signals reaching a
35 radio receiving antenna by two or more paths, causing distortion in radio and
36 ghost images in television.

Glossary

- 1 Nash Draw - A shallow 5-mile-wide valley open to the southwest located to the
2 west of the WIPP site.
3
- 4 NRC - Nuclear Regulatory Commission of the U.S. Government.
5
- 6 Neoprene - A synthetic rubber made by the polymerization of chloroprene.
7
- 8 Noncombustibles - Materials that will not burn.
9
- 10 Nonpolar - Not having or requiring the presence of electrical poles.
11
- 12 Nuclide - A species of atom characterized by the construction of its nucleus.
13
- 14 Organics - Compounds containing carbon.
15
- 16 Overexcavation - Excavation of the disturbed rock zone prior to emplacement of
17 a seal.
18
- 19 Overpack (waste) - A container put around another container. In the WIPP,
20 overpacks would be used on damaged or otherwise contaminated drums, boxes, and
21 canisters that it would not be practical to decontaminate.
22
- 23 Particulate - Of or relating to minute separate particles.
24
- 25 Pecos River - Major surface hydrological feature in eastern New Mexico.
26
- 27 Pennsylvanian - Second to the last Paleozoic period (~320 million to ~280
28 million years ago).
29
- 30 Performance Assessment - An analysis that identifies the processes and events
31 that might affect the disposal system; examines the effects of these processes
32 and events on the performance of the disposal system; and estimates the
33 cumulative releases of radionuclides, considering the associated uncertainties
34 caused by all significant procedures and events.

1 Permeability - A measurement of the ability of a rock or soil to transmit
2 fluid under hydraulic gradient.

3
4 Pillar - Rock left in place after mining to provide underground vertical
5 support.

6
7 Pintle - A cylindrical flanged device on the end of an RH-TRU waste canister
8 used for grasping and lifting the canister.

9
10 Plutonium - A reactive metallic element, symbol Pu, atomic number 94, in the
11 transuranium series of elements; used as a nuclear fuel, to produce
12 radioactive nuclides for research, and as a fissile agent in nuclear weapons.

13
14 Pluvial - Of a geologic episode, change, deposit, process, or feature
15 resulting from the action or effects of rain.

16
17 Polyethylene - Various partially crystalline lightweight thermo-plastics made
18 from ethylene.

19
20 Polyhalite - An evaporite mineral: $K_2MgCa_2(SO_4)_4 \cdot 2H_2O$; a hard, poorly soluble
21 mineral.

22
23 Polypropylene - A plastic made from propylene.

24
25 Polyvinyl - A plastic made from vinyl chloride.

26
27 Potash - Specifically K_2CO_3 . Also loosely used for many potassium compounds,
28 especially as used in agriculture or industry.

29
30 Potential - A function or set of functions of position in space, from whose
31 first derivatives a vector can be formed, such as that of a static field
32 intensity.

33
34 Potentiometric Surface - An imaginary surface representing the total head of
35 groundwater and defined by the level to which water will rise in a well.

Glossary

1 Predictive - Estimates of future states of a system.

2

3 Probabilistic - Using the probability of a given set of events from a family
4 of outcomes.

5

6 Quality Assurance - All those planned and systematic actions necessary to
7 provide adequate confidence that a structure, system, or component will
8 perform satisfactorily in service.

9

10 Quaternary - The second period of the Cenozoic era, following the Tertiary,
11 starting 1.6 million years ago and continuing to the present; the
12 corresponding system of rocks.

13

14 Radioactivity - The emission of energetic particles and/or radiation during
15 radioactive decay.

16

17 Radioactive Waste - Solid, liquid, or gaseous material of negligible economic
18 value that contains radionuclides in excess of threshold quantities.

19

20 Radiological - Pertaining to nuclear radiation and radioactivity.

21

22 Radiolysis - The damage to a material caused by radiation.

23

24 Radionuclide - A radioactive nuclide.

25

26 Reentrants - A prominent, generally angular indentation in a land form.

27

28 Rem - Roentgen Equivalent Man.

29

30 RH-TRU Waste - Remote-Handled TransUranic waste. Packaged TRU waste whose
31 external surface dose rate exceeds 200 mrem per hour, but not greater than
32 1,000 rem per hour.

33

34 Rustler Formation - A sequence of upper Permian age elastic and evaporite
35 sedimentary rocks that contains two dolomite marker beds, and overlies the
36 Salado Formation.

1 **Salado Formation** - A sequence of ~200-million yr old salt with minor amounts
2 of clay and anhydrite. Location of the WIPP repository.

3
4 **Scenario** - A combination of events and processes that represents a possible
5 future state of the repository, geologic, and groundwater systems.

6
7 **Sealing** - Formation of barriers within man-made penetrations (shafts,
8 drillholes, tunnels, drifts).

9
10 **Sedimentation** - The action or process of forming or depositing sediment.

11
12 **Shaft** - A man-made hole, either vertical or steeply inclined, that connects
13 the surface with the underground workings of a mine.

14
15 **Sinkhole** - A hollow in a limestone region that communicates with a cavern or
16 passage.

17
18 **Sludge** - A muddy or slushy mass, deposit, or sediment.

19
20 **Solute** - The material dissolved in a solvent.

21
22 **Sorb** - To take up and hold by either adsorption or absorption.

23
24 **Source term** - The kinds and amounts of radionuclides that make up the source
25 of a potential release of radioactivity. For the performance assessment, the
26 source term is defined as the sum of the quantities of the important
27 radionuclides in the WIPP inventory that will be mobilized for possible
28 transport to the accessible environment, and the rates at which these
29 radionuclides will be mobilized.

30
31 **Standard** - 40 CFR Part 191

32
33 **Stationarity** - A stochastic process is said to be stationary if its set of
34 associated pdfs are invariant under arbitrary time translators.

Glossary

- 1 Stochastic Process - Involving a random variable or random vector synonymous
2 with random function or random process.
3
- 4 Storativity - The volume of water released by an aquifer per unit surface area
5 per unit drop in hydrologic head.
6
- 7 Stratigraphy - The science of rock strata; concerned with the original
8 succession and age relations of rock strata, their form, distribution,
9 lithologic composition, fossil content, and geophysical and geochemical
10 properties.
11
- 12 Surfactant - A surface active substance.
13
- 14 Syncline - A fold having stratigraphically younger rock material in its core;
15 it is usually concave upward.
16
- 17 Thermodynamic - Pertaining to the relation of heat to mechanical and other
18 forms of energy.
19
- 20 Topographic - Pertaining to the configuration of a land surface, including its
21 relief and the position of its natural and man-made features.
22
- 23 Transiency - Ability to affect something or produce results beyond itself.
24
- 25 Translator - A code that translates output from one code to input for another
26 code. Also referred to as pre- and post-processors.
27
- 28 Transmissivity - The rate at which water of the prevailing kinematic viscosity
29 is transmitted through a unit width of the aquifer under a unit hydraulic
30 gradient.
31
- 32 Triassic - The first period of the Mesozoic era, lying above the Permian and
33 below Jurassic, ~208 to ~245 million years ago.

1 TRU Waste - TRansUranic Waste. Without regard to source or form, waste that
2 is contaminated with alpha-emitting transuranium radionuclides with half-lives
3 greater than 20 years and concentrations greater than 100 nCi/g at the time of
4 assay. Heads of field organizations can determine that other alpha
5 contaminated wastes, peculiar to a specific site, must be managed as TRU
6 waste.

7
8 Unconformably - Not conformable, i.e., a break in deposition of sedimentary
9 material.

10
11 UND - UNDisturbed scenario.

12
13 Unsaturated - All the pores in rock or soil are not full of water.

14
15 Validate - To establish confidence that the model (and the associated computer
16 code) correctly simulates the appropriate physical and chemical phenomena.
17 Validation is accomplished through either laboratory or in situ experiments,
18 as appropriate.

19
20
21 Verification - The process of assuring that a computer code (computational
22 model) correctly performs the operation specified in a numerical model. Each
23 computational model must be verified and the verification documented.
24 Benchmarking is a verification method that compares the results produced by
25 one computational model against results produced by other computational models
26 that solve similar problems.

APPENDIX A:
TITLE 40, CODE OF FEDERAL REGULATIONS,
SUBCHAPTER F, PART 191

APPENDIX A

TITLE 40, CODE OF FEDERAL REGULATIONS SUBCHAPTER F—RADIATION PROTECTION PROGRAMS

PART 191—ENVIRONMENTAL RADIATION PROTECTION STANDARDS FOR MANAGEMENT AND DISPOSAL OF SPENT NUCLEAR FUEL, HIGH-LEVEL AND TRANSURANIC RADIOACTIVE WASTES

Subpart A—Environmental Standards for Management and Storage

Sec.

- 191.01 Applicability.
- 191.02 Definitions.
- 191.03 Standards.
- 191.04 Alternative standards.
- 191.05 Effective date.

Subpart B—Environmental Standards for Disposal

- 191.11 Applicability.
- 191.12 Definitions.
- 191.13 Containment requirements.
- 191.14 Assurance requirements.
- 191.15 Individual protection requirements.
- 191.16 Ground water protection requirements.
- 191.17 Alternative provisions for disposal.
- 191.18 Effective date.

Appendix A Table for Subpart B

Appendix B Guidance for Implementation of Subpart B

Authority: The Atomic Energy Act of 1954, as amended; Reorganization Plan No. 3 of 1970; and the Nuclear Waste Policy Act of 1982.

Subpart A—Environmental Standards for Management and Storage

§ 191.01 Applicability.

This Subpart applies to:

(a) Radiation doses received by members of the public as a result of the management (except for transportation) and storage of spent nuclear fuel or high-level or transuranic radioactive wastes at any facility regulated by the Nuclear Regulatory Commission or by Agreement States, to the extent that such management and storage operations are not subject to the provisions of Part 190 of title 40; and

(b) Radiation doses received by members of the public as a result of the management and storage of spent nuclear fuel or high-level or transuranic wastes at any disposal facility that is operated by the Department of Energy and that is not regulated by the Commission or by Agreement States.

§ 191.02 Definitions.

Unless otherwise indicated in this Subpart, all terms shall have the same meaning as in Subpart A of Part 190.

- (a) "Agency" means the Environmental Protection Agency.
- (b) "Administrator" means the Administrator of the Environmental Protection Agency.
- (c) "Commission" means the Nuclear Regulatory Commission.
- (d) "Department" means the Department of Energy.
- (e) "NWPA" means the Nuclear Waste Policy Act of 1982 (Pub. L. 97-425).
- (f) "Agreement State" means any State with which the Commission or the Atomic Energy Commission has entered into an effective agreement under subsection 274b of the Atomic Energy Act of 1954, as amended (68 Stat. 919).
- (g) "Spent nuclear fuel" means fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing.
- (h) "High-level radioactive waste," as used in this Part, means high-level radioactive waste as defined in the Nuclear Waste Policy Act of 1982 (Pub. L. 97-425).
- (i) "Transuranic radioactive waste," as used in this Part, 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.
- (j) "Radioactive waste," as used in this Part, means the high-level and transuranic radioactive waste covered by this Part.
- (k) "Storage" means retention of spent nuclear fuel or radioactive wastes with the intent and capability to readily retrieve such fuel or waste for subsequent use, processing, or disposal.
- (l) "Disposal" means permanent isolation of spent nuclear fuel or radioactive wastes from the accessible environment with no intent of recovery, whether or not such isolation permits the recovery of such fuel or waste. For example, disposal of waste in a mined geologic repository occurs when all of the shafts to the repository are backfilled and sealed.
- (m) "Management" means any activity, operation, or process (except for transportation) conducted to prepare spent nuclear fuel or radioactive waste for storage or disposal, or the activities associated with placing such fuel or waste in a disposal system.

(n) "Site" means an area contained within the boundary of a location under the effective control of persons possessing or using spent nuclear fuel or radioactive waste that are involved in any activity, operation, or process covered by this Subpart.

(o) "General environment" means the total terrestrial, atmospheric, and aquatic environments outside sites within which any activity, operation, or process associated with the management and storage of spent nuclear fuel or radioactive waste is conducted.

(p) "Member of the public" means any individual except during the time when that individual is a worker engaged in any activity, operation, or process that is covered by the Atomic Energy Act of 1954, as amended.

(q) "Critical organ" means the most exposed human organ or tissue exclusive of the integumentary system (skin) and the cornea.

§ 191.03 Standards.

(a) Management and storage of spent nuclear fuel or high-level or transuranic radioactive wastes at all facilities regulated by the Commission or by Agreement States shall be conducted in such a manner as to provide reasonable assurance that the combined annual dose equivalent to any member of the public in the general environment resulting from: (1) Discharges of radioactive material and direct radiation from such management and storage and (2) all operations covered by Part 190; shall not exceed 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other critical organ.

(b) Management and storage of spent nuclear fuel or high-level or transuranic radioactive wastes at all facilities for the disposal of such fuel or waste that are operated by the Department and that are not regulated by the Commission or Agreement States shall be conducted in such a manner as to provide reasonable assurance that the combined annual dose equivalent to any member of the public in the general environment resulting from discharges of radioactive material and direct radiation from such management and storage shall not exceed 25 millirems to the whole body and 75 millirems to any critical organ.

§ 191.04 Alternative standards.

(a) The Administrator may issue alternative standards from those standards established in 191.03(b) for waste management and storage activities at facilities that are not regulated by the Commission or Agreement States if, upon review of an application for such alternative standards:

(1) The Administrator determines that such alternative standards will prevent any member of the public from receiving a continuous exposure of more than 100 millirems per year dose equivalent and an infrequent exposure of more than 500 millirems dose equivalent in a year from all sources, excluding natural background and medical procedures; and

(2) The Administrator promptly makes a matter of public record the degree to which continued operation of the facility is expected to result in levels in excess of the standards specified in 191.03(b).

(b) An application for alternative standards shall be submitted as soon as possible after the Department determines that continued operation of a facility will exceed the levels specified in 191.03(b) and shall include all information necessary for the Administrator to make the determinations called for in 191.04(a).

(c) Requests for alternative standards shall be submitted to the Administrator, U.S. Environmental Protection Agency, 401 M Street, SW., Washington, DC 20460.

§ 191.05 Effective date.

The standards in this Subpart shall be effective on November 18, 1985.

Subpart B—Environmental Standards for Disposal

§ 191.11 Applicability.

(a) This Subpart applies to:

(1) Radioactive materials released into the accessible environment as a result of the disposal of spent nuclear fuel or high-level or transuranic radioactive wastes;

(2) Radiation doses received by members of the public as a result of such disposal; and

(3) Radioactive contamination of certain sources of ground water in the vicinity of disposal systems for such fuel or wastes.

(b) However, this Subpart does not apply to disposal directly into the oceans or ocean sediments. This Subpart also does not apply to wastes disposed of before the effective date of this rule.

§ 191.12 Definitions.

Unless otherwise indicated in this Subpart, all terms shall have the same meaning as in Subpart A of this Part.

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

(b) "Waste," as used in this Subpart, means any spent nuclear fuel or radioactive waste isolated in a disposal system.

(c) "Waste form" means the materials comprising the radioactive components of waste and any encapsulating or stabilizing matrix.

(d) "Barrier" means any material or structure that prevents or substantially delays movement of water or radionuclides toward the accessible environment. For example, a barrier may be a geologic structure,

a canister, a waste form with physical and chemical characteristics that significantly decrease the mobility of radionuclides, or a material placed over and around waste, provided that the material or structure substantially delays movement of water or radionuclides.

(e) "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.

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

(g) "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.

(h) "Ground water" means water below the land surface in a zone of saturation.

(i) "Aquifer" means an underground geological formation, group of formations, or part of a formation that is capable of yielding a significant amount of water to a well or spring.

(j) "Lithosphere" means the solid part of the Earth below the surface, including any ground water contained within it.

(k) "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.

(l) "Transmissivity" means the hydraulic conductivity integrated over the saturated thickness of an underground formation. The transmissivity of a series of formations is the sum of the individual transmissivities of each formation comprising the series.

(m) "Community water system" means a system for the provision to the public of piped water for human consumption, if such system has at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents.

(n) "Significant source of ground water," as used in this Part, means: (1) An aquifer that: (i) Is saturated with water having less than 10,000 milligrams per liter of total dissolved solids; (ii) is within 2,500 feet of the land surface; (iii) has a transmissivity greater than 200 gallons per day per foot, provided that any formation or part of a formation included within the source of ground water has a hydraulic conductivity greater than

2 gallons per day per square foot; and (iv) is capable of continuously yielding at least 10,000 gallons per day to a pumped or flowing well for a period of at least a year; or (2) an aquifer that provides the primary source of water for a community water system as of the effective date of this Subpart.

(o) "Special source of ground water," as used in this Part, means those Class I ground waters identified in accordance with the Agency's Ground-Water Protection Strategy published in August 1984 that: (1) Are within the controlled area encompassing a disposal system or are less than five kilometers beyond the controlled area; (2) are supplying drinking water for thousands of persons as of the date that the Department chooses a location within that area for detailed characterization as a potential site for a disposal system (e.g., in accordance with Section 112(b)(1)(B) of the NWPA); and (3) are irreplaceable in that no reasonable alternative source of drinking water is available to that population.

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

(q) "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.

(r) "Heavy metal" means all uranium, plutonium, or thorium placed into a nuclear reactor.

(s) "Implementing agency," as used in this Subpart, means the Commission for spent nuclear fuel or high-level or transuranic wastes to be disposed of in facilities licensed by the commission in accordance with the Energy Reorganization Act of 1974 and the Nuclear Waste Policy Act of 1982, and it means the Department for all other radioactive wastes covered by this Part.

§ 191.13 Containment requirements.

(a) Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation, based upon performance assessments, that cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system 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. Because of the long time period involved and the nature of the events and processes of interest, there will inevitably be substantial uncertainties in projecting disposal system performance. Proof of the future performance of a disposal system is not to be had in the ordinary sense of the word in situations that deal with much shorter time frames. Instead, what is required is a reasonable expectation, on the basis of the record before the implementing agency, that compliance with 191.13(a) will be achieved.

§ 191.14 Assurance requirements.

To provide the confidence needed for long-term compliance with the requirements of 191.13, disposal of spent nuclear fuel or high-level or transuranic wastes shall be conducted in accordance with the following provisions, except that these provisions do not apply to facilities regulated by the Commission (see 10 CFR Part 60 for comparable provisions applicable to facilities regulated by the Commission):

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

(b) Disposal systems shall be monitored after disposal to detect substantial and detrimental deviations from expected performance. This monitoring shall be done with techniques that do not jeopardize the isolation of the wastes and shall be conducted until there are no significant concerns to be addressed by further monitoring.

(c) Disposal sites shall be designated by the most permanent markers, records, and other passive institutional controls practicable to indicate the dangers of the wastes and their location.

(d) Disposal systems shall use different types of barriers to isolate the wastes from the accessible environment. Both engineered and natural barriers shall be included.

(e) Places where there has been mining for resources, or where there is a reasonable expectation of exploration for scarce or easily accessible resources, or where there is a significant concentration of any material that is not widely available from other sources, should be avoided in selecting disposal sites. Resources to be considered shall include minerals, petroleum or natural gas, valuable geologic formations, and ground waters that are either irreplaceable because there is no reasonable alternative source of drinking water available for substantial populations or that are vital to the preservation of unique and sensitive ecosystems. Such places shall not be used for disposal of the wastes covered by this Part unless the favorable characteristics of such places compensate for their greater likelihood of being disturbed in the future.

(f) Disposal systems shall be selected so that removal of most of the wastes is not precluded for a reasonable period of time after disposal.

§ 191.15 Individual protection requirements.

Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation that, for 1,000 years after disposal, undisturbed performance of the disposal system shall not cause the annual dose equivalent from the disposal system to any member of the public in the accessible environment to exceed 25 millirems to the whole body or 75 millirems to any critical organ. All potential pathways (associated with undisturbed performance) from the disposal system to people shall be considered, including the assumption that individuals consume 2 liters per day of drinking water from any significant source of ground water outside of the controlled area.

§ 191.16 Ground water protection requirements.

(a) Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation that, for 1,000 years after disposal, undisturbed performance of the disposal system shall not cause the radionuclide concentrations averaged over any year in water withdrawn from any portion of a special source of ground water to exceed:

- (1) 5 picocuries per liter of radium-226 and radium-228;
- (2) 15 picocuries per liter of alpha-emitting radionuclides (including radium-226 and radium-228 but excluding radon); or
- (3) The combined concentrations of radionuclides that emit either beta or gamma radiation that would produce an annual dose equivalent to the total body or any internal organ greater than 4 millirems per year if an individual consumed 2 liters per day of drinking water from such a source of ground water.

(b) If any of the average annual radionuclide concentrations existing in a special source of ground water before construction of the disposal system already exceed the limits in 191.16(a), the disposal system shall be designed to provide a reasonable expectation that, for 1,000 years after disposal, undisturbed performance of the disposal system shall not increase the existing average annual radionuclide concentrations in water withdrawn from that special source of ground water by more than the limits established in 191.16(a).

§ 191.17 Alternative provisions for disposal.

The Administrator may, by rule, substitute for any of the provisions of Subpart B alternative provisions chosen after:

(a) The alternative provisions have been proposed for public comment in the **Federal Register** together with information describing the costs, risks, and benefits of disposal in accordance with the alternative provisions and the reasons why compliance with the existing provisions of Subpart B appears inappropriate;

(b) A public comment period of at least 90 days has been completed, during which an opportunity for public hearings in affected areas of the country has been provided; and

(c) The public comments received have been fully considered in developing the final version of such alternative provisions.

§ 191.18 Effective date.

The standards in this Subpart shall be effective on November 18, 1985.

Appendix A—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

Application of Table 1

Note 1: *Units of Waste.* The Release Limits in Table 1 apply to the amount of wastes in any one of the following:

(a) An amount of spent nuclear fuel containing 1,000 metric tons of heavy metal (MTHM) exposed to a burnup between 25,000 megawatt-days per metric ton of heavy metal (MWd/MTHM) and 40,000 MWd/MTHM;

(b) The high-level radioactive wastes generated from reprocessing each 1,000 MTHM exposed to a burnup between 25,000 MWd/MTHM and 40,000 MWd/MTHM;

(c) Each 100,000,000 curies of gamma or beta-emitting radionuclides with half-lives greater than 20 years but less than 100 years (for use as discussed in Note 5 or with materials that are identified by the Commission as high-level radioactive waste in accordance with part B of the definition of high-level waste in the NWPA);

(d) Each 1,000,000 curies of other radionuclides (i.e., gamma or beta-emitters with half-lives greater than 100 years or any alpha-emitters with half-lives greater than 20 years) (for use as discussed in Note 5 or with materials that are identified by the Commission as high-level radioactive waste in accordance with part B of the definition of high-level waste in the NWPA); or

(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: Release Limits for Specific Disposal Systems. 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 compared to the various units of waste defined in Note 1. For example:

(a) If a particular disposal system contained the high-level wastes from 50,000 MTHM, the Release Limits for that system would be the quantities in Table 1 multiplied by 50 (50,000 MTHM divided by 1,000 MTHM).

(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).

(c) If a particular disposal system contained both the high-level wastes from 50,000 MTHM and 5 million curies of alpha-emitting transuranic wastes, the Release Limits for that system would be the quantities in Table 1 multiplied by 55:

$$\frac{50,000 \text{ MTHM}}{1,000 \text{ MTHM}} + \frac{5,000,000 \text{ curies TRU}}{1,000,000 \text{ curies TRU}} = 55$$

Note 3: Adjustments for Reactor Fuels with Different Burnup. For disposal systems containing reactor fuels (or the high-level wastes from reactor fuels) exposed to an average burnup of less than 25,000 MWd/MTHM or greater than 40,000 MWd/MTHM, the units of waste defined in (a) and (b) of Note 1 shall be adjusted. The unit shall be multiplied by the ratio of 30,000 MWd/MTHM divided by the fuel's actual average burnup, except that a value of 5,000 MWd/MTHM may be used when the average fuel burnup is below 5,000 MWd/MTHM and a value of 100,000 MWd/MTHM shall be used when the average fuel burnup is above 100,000 MWd/MTHM. This adjusted unit of waste shall then be used in determining the Release Limits for the disposal system.

For example, if a particular disposal system contained only high-level wastes with an average burnup of 3,000 MWd/MTHM, the unit of waste for that disposal system would be:

$$1,000 \text{ MTHM} \times \frac{(30,000)}{(5,000)} = 6,000 \text{ MTHM}$$

If that disposal system contained the high-level wastes from 60,000 MTHM (with an average burnup of 3,000 MWd/MTHM), then the Release Limits for that system would be the quantities in Table 1 multiplied by ten:

$$\frac{60,000 \text{ MTHM}}{6,000 \text{ MTHM}} = 10$$

which is the same as:

$$\frac{60,000 \text{ MTHM}}{1,000 \text{ MTHM}} \times \frac{(5,000 \text{ MWd/MTHM})}{(30,000 \text{ MWd/MTHM})} = 10$$

Note 4: Treatment of Fractionated High-Level Wastes. In some cases, a high-level waste stream from reprocessing spent nuclear fuel may have been (or will be) separated into two or more high-level waste components destined for different disposal systems. In such cases, the implementing agency may allocate the Release Limit multiplier (based upon the original MTHM and the average fuel burnup of the high-level waste stream) among the various disposal systems as it chooses, provided that the total Release Limit multiplier used for that waste stream at all of its disposal systems may not exceed the Release Limit multiplier that would be used if the entire waste stream were disposed of in one disposal system.

Note 5: Treatment of Wastes with Poorly Known Burnups or Original MTHM. In some cases, the records associated with particular high-level waste streams may not be adequate to accurately determine the original metric tons of heavy metal in the reactor fuel that created the waste, or to determine the average burnup that the fuel was exposed to. If the uncertainties are such that the original amount of heavy metal or the average fuel burnup for particular high-level waste streams cannot be quantified, the units of waste derived from (a) and (b) of Note 1 shall no longer be used. Instead, the units of waste defined in (c) and (d) of Note 1 shall be used for such high-level waste streams. If the uncertainties in such information allow a range of values to be associated with the original amount of heavy metal or the average fuel burnup, then the calculations described in previous Notes will be conducted using the values that result in the smallest Release Limits, except that the Release Limits need not be smaller than those that would be calculated using the units of waste defined in (c) and (d) of Note 1.

Note 6: Uses of Release Limits to Determine Compliance with 191.13. Once release limits for a particular disposal system have been determined in accordance with Notes 1 through 5, these release limits shall be used to determine compliance with the requirements of 191.13 as follows. In cases where a mixture of radionuclides is projected to be released to the accessible environment, the limiting values shall be determined as follows: For each radionuclide in the mixture, determine the ratio between the cumulative release quantity projected over 10,000 years and the limit for that

radionuclide as determined from Table 1 and Notes 1 through 5. The sum of such ratios for all the radionuclides in the mixture may not exceed one with regard to 191.13(a)(1) and may not exceed ten with regard to 191.13(a)(2).

For example, if radionuclides A, B, and C are projected to be released in amounts Q_a , Q_b , and Q_c , and if the applicable Release Limits are RL_a , RL_b , RL_c , then the cumulative releases over 10,000 years shall be limited so that the following relationship exists:

$$\frac{Q_a}{RL_a} + \frac{Q_b}{RL_b} + \frac{Q_c}{RL_c} < 1$$

Appendix B—Guidance for Implementation of Subpart B

[Note: The supplemental information in this appendix is not an integral part of 40 CFR Part 191. Therefore, the implementing agencies are not bound to follow this guidance. However, it is included because it describes the Agency's assumptions regarding the implementation of Subpart B. This appendix will appear in the Code of Federal Regulations.]

The Agency believes that the implementing agencies must determine compliance with §§ 191.13, 191.15, and 191.16 of Subpart B by evaluating long-term predictions of disposal system performance. Determining compliance with § 191.13 will also involve predicting the likelihood of events and processes that may disturb the disposal system. In making these various predictions, it will be appropriate for the implementing agencies to make use of rather complex computational models, analytical theories, and prevalent expert judgment relevant to the numerical predictions. Substantial uncertainties are likely to be encountered in making these predictions. In fact, sole reliance on these numerical predictions to determine compliance may not be appropriate; the implementing agencies may choose to supplement such predictions with qualitative judgments as well. Because the procedures for determining compliance with Subpart B have not been formulated and tested yet, this appendix to the rule indicates the Agency's assumptions regarding certain issues that may arise when implementing §§ 191.13, 191.15, and 191.16. Most of this guidance applies to any type of disposal system for the wastes covered by this rule. However, several sections apply only to disposal in mined geologic repositories and would be inappropriate for other types of disposal systems.

Consideration of Total Disposal System. When predicting disposal system performance, the Agency assumes that reasonable projections of the protection expected from all of the engineered and natural barriers of a disposal system will be considered. Portions of the disposal system should not be disregarded, even if projected performance is uncertain, except for portions of the system that make negligible contributions to the overall isolation provided by the disposal system.

Scope of Performance Assessments. Section 191.13 requires the implementing agencies to evaluate compliance through performance assessments as defined in § 191.12(q). The Agency assumes that such performance assessments need not consider categories of events or processes that are estimated to have less than one chance in 10,000 of occurring over 10,000 years. Furthermore, the

performance assessments need not evaluate in detail the releases from all events and processes estimated to have a greater likelihood of occurrence. Some of these events and processes may be omitted from the performance assessments if there is a reasonable expectation that the remaining probability distribution of cumulative releases would not be significantly changed by such omissions.

Compliance with Section 191.13. The Agency assumes that, whenever practicable, the implementing agency will assemble all of the results of the performance assessments to determine compliance with § 191.13 into a "complementary cumulative distribution function" that indicates the probability of exceeding various levels of cumulative release. When the uncertainties in parameters are considered in a performance assessment, the effects of the uncertainties considered can be incorporated into a single such distribution function for each disposal system considered. The Agency assumes that a disposal system can be considered to be in compliance with § 191.13 if this single distribution function meets the requirements of § 191.13(a).

Compliance with Sections 191.15 and 191.16. When the uncertainties in undisturbed performance of a disposal system are considered, the implementing agencies need not require that a very large percentage of the range of estimated radiation exposures or radionuclide concentrations fall below limits established in §§ 191.15 and 191.16, respectively. The Agency assumes that compliance can be determined based upon "best estimate" predictions (e.g., the mean or the median of the appropriate distribution, whichever is higher).

Institutional Controls. To comply with § 191.14(a), the implementing agency will assume that none of the active institutional controls prevent or reduce radionuclide releases for more than 100 years after disposal. However, the Federal Government is committed to retaining ownership of all disposal sites for spent nuclear fuel and high-level and transuranic radioactive wastes and will establish appropriate markers and records, consistent with § 191.14(c). The Agency assumes that, as long as such passive institutional controls endure and are understood, they: (1) can be effective in deterring systematic or persistent exploitation of these disposal sites; and (2) can reduce the likelihood of inadvertent, intermittent human intrusion to a degree to be determined by the implementing agency. However, the Agency believes that passive institutional controls can never be assumed to eliminate the chance of inadvertent and intermittent human intrusion into these disposal sites.

Consideration of Inadvertent Human Intrusion into Geologic Repositories. The most speculative potential disruptions of a mined geologic repository are those associated with inadvertent human intrusion. Some types of intrusion would have virtually no effect on a repository's containment of waste. On the other hand, it is possible to conceive of intrusions (involving widespread societal loss of knowledge regarding radioactive wastes) that could result in major disruptions that no reasonable repository selection or design precautions could alleviate. The Agency believes that the most productive consideration of inadvertent intrusion concerns those realistic possibilities that may be usefully mitigated by repository design, site selection, or use of passive controls (although passive institutional controls should not be assumed to completely rule out the possibility of intrusion). Therefore,

inadvertent and intermittent intrusion by exploratory drilling for resources (other than any provided by the disposal system itself) can be the most severe intrusion scenario assumed by the implementing agencies. Furthermore, the implementing agencies can assume that passive institutional controls or the intruders' own exploratory procedures are adequate for the intruders to soon detect, or be warned of, the incompatibility of the area with their activities.

Frequency and Severity of Inadvertent Human Intrusion into Geologic Repositories. The implementing agencies should consider the effects of each particular disposal system's site, design, and passive institutional controls in judging the likelihood and consequences of such inadvertent exploratory drilling. However, the Agency assumes that the likelihood of such inadvertent and intermittent drilling need not be taken to be greater than 30 boreholes per square kilometer of repository area per 10,000 years for geologic repositories in proximity to sedimentary rock formations, or more than 3 boreholes per square kilometer per 10,000 years for repositories in other geologic formations. Furthermore, the Agency assumes that the consequences of such inadvertent drilling need not be assumed to be more severe than: (1) Direct release to the land surface of all the ground water in the repository horizon that would promptly flow through the newly created borehole to the surface due to natural lithostatic pressure—or (if pumping would be required to raise water to the surface) release of 200 cubic meters of ground water pumped to the surface if that much water is readily available to be pumped; and (2) creation of ground water flow path with a permeability typical of a borehole filled by the soil or gravel that would normally settle into an open hole over time—not the permeability of a carefully sealed borehole.

APPENDIX B:
REFERENCE DATA BASE

**APPENDIX C:
RESPONSE TO REVIEW COMMENTS**

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