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Draft Title 40 CFR 191 Compliance Certification Application for the Waste Isolation Pilot Plant

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United States Department of Energy
Waste Isolation Pilot Plant

Carlsbad Area Office
Carlsbad, New Mexico

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PREFACE

The U.S. Department of Energy (DOE) is preparing an application to demonstrate compliance with the requirements outlined in Title 40, Part 191 of the Code of Federal Regulations (CFR) for the permanent disposal of transuranic wastes. As mandated by the Waste Isolation Pilot Plant (WIPP) Land Withdrawal Act of 1992, the U.S. Environmental Protection Agency (EPA) must evaluate this compliance application and provide a determination regarding compliance with the requirements within one year of receiving a complete application. Because the WIPP is a very complex program, the DOE has planned to submit the application as a draft in two parts. This strategy will allow for the DOE and the EPA to begin technical discussions on critical WIPP issues before the one-year compliance determination period begins. Today's submittal is the first of these two draft submittals. The DOE plans to submit the second part of the Draft 40 CFR Part 191 Compliance Certification Application (DCCA), providing more details relative to human intrusion scenarios, in the Summer of 1995.

On January 30, 1995, the EPA issued a proposed rule entitled *Criteria for the Certification and Determination of the Waste Isolation Pilot Plant's Compliance with Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes* (60 FR 5766). This rule, which will be codified in Title 40, Part 194 of the Code of Federal Regulations when it is final, sets forth the requirements that the DOE must follow in applying for certification from the EPA that the WIPP facility will comply with the environmental standards for the disposal of transuranic wastes. Because 40 CFR Part 194 was proposed quite recently, the Department was unable to follow all of the guidance in it in preparing this draft application. The DOE has attempted to identify every instance in this application where it differs from the requirements proposed in Part 194. These differences should not be interpreted as commentary on the proposed regulation. The DOE intends to submit any comments it has on the proposed 40 CFR Part 194 on or before May 1, 1995, the date when the public comment period closes.

This document is the first of such draft submittals to the EPA. Its focus is upon background repository information, the methodology used to conduct performance assessments, the scenarios that the DOE has determined to be the most likely to occur over the 10,000-year regulatory period, the characteristics of the radioactive wastes to be disposed of in the WIPP repository, the Quality Assurance program implemented by the DOE to support the compliance application, and the DOE's approaches to demonstrating compliance with the assurance requirements of the disposal regulation. The DOE proposes to begin technical discussions in these areas because they are at a level of maturity suitable for in-depth consultations with the EPA.

This draft does not provide detailed information on the following topics:

- Experimental work, engineered alternatives, and additional research needed to support a full-scale prediction (including human intrusion events) for the performance of WIPP
- Level of quality of performance assessment software and input data
- Detailed designs for long-term monitoring, permanent markers, and active institutional controls
- Performance-Based Waste Acceptance Criteria

Additionally, the EPA will note that today's submittal does not present the complete picture of long-term repository performance. Although the various models, data, and parameters used by the DOE to calculate the Complementary Cumulative Distribution Function (CCDF) contained within this draft application are thought to be reasonable for use in a performance assessment of the disposal system, full justification of this information is not available today. The CCDF presented here is not in final form because sufficient confidence in the models and computer codes has not been established, quality assurance activities have not been completed, and the number of realizations used in its development was restricted. Today's submittal focuses upon undisturbed repository performance only. The effects of human-initiated events have not been considered.

The DOE plans to submit the second part of the DCCA in the Summer 1995 timeframe. This second part will contain additional information relative to disturbed repository performance. The second part will most likely not detail all remaining aspects of a compliance application. As the DOE finalizes work beyond this second submittal, separate reports describing this work will be transmitted to the EPA for its information. The content of these reports will be incorporated into the final compliance certification application in December 1996.

The DOE welcomes comments on this document and hopes that observations regarding "missing" areas be given a lower priority at this time. Finally, the DOE recognizes that, by law, the EPA cannot approve any part of this draft document.

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AASHTO	American Association of State Highway and Transportation
AC	Alternating Current
ACA	Agency for Conservation Archaeology
ACGIH	American Conference of Governmental Industrial Hygienists
ACGLF	Adjustable Center-of-Gravity Lift Fixture
AEA	Atomic Energy Act
AEC	Atomic Energy Commission
AFFF	Aqueous Film Forming Foam
AIM	Agricultural and Industrial Minerals, Inc.
AISC	American Institute of Steel Construction
ALARA	As Low As Reasonably Achievable
AMS	Atmospheric Monitoring Station
ANL-E	Argonne National Laboratory–East
ANL-W	Argonne National Laboratory–West
ANSI	American National Standards Institute
AQCR	Air Quality Control Regulations
ARM	Area Radiation Monitoring
ASER	Annual Site Environmental Report
ASME	American Society of Mechanical Engineers
ASME NQA-1	American Society of Mechanical Engineers' *Nuclear Quality Program Requirements for Nuclear Facilities*
BEAR	Backfill Engineering Analysis Report
BIR	Baseline Inventory Report
BLM	U.S. Bureau of Land Management
BSEP	Brine Sampling and Evaluation Program
C&C	Consultation and Cooperation
C&SH	Construction and Salt Handling Shaft
CAA	Clean Air Act
CAAA	Clean Air Act Amendment
CAM	Continuous Air Monitor
CAMCON	Compliance Assessment Methodology Controller
CAO	Carlsbad Area Office
CB	Cabin Baby
CBP	Central Basin Platform
CCDF	Complementary Cumulative Distribution Function
CDF	Cumulative Distribution Function
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CH	Contact-Handled
CMR	Central Monitoring Room
COE	U.S. Army Corps of Engineers
CRS	Closure Review Study
CWA	Clean Water Act

D&D	Decontamination and Decommissioning
DBE	Design Basis Earthquake
DBT	Design Basis Tornado
DC	Direct Current
DMG	Delaware Mountain Group
DNAG	*The Decade of North American Geology* by A.R. Palmer
DOE	U.S. Department of Energy
DOI	U.S. Department of Interior
DOL	U.S. Department of Labor
DOP	Dioctylphthalate
DOT	U.S. Department of Transportation
DQO	Data Quality Objective
DRZ	Disturbed Rock Zone
DZ	Disturbed Zone
EATF	Engineered Alternatives Task Force
EEG	Environmental Evaluation Group
EFB	Exhaust Filter Building
EM	Electromagnetic
EM	Emergency Management
EMP	Environmental Monitoring Plan
EMR	Environmental Monitoring Report
EOC	Emergency Operations Center
EPA	U.S. Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
ERDA	U.S. Energy Research and Development Administration
ETEC	Energy Technology Engineering Center
FC	Flood Control
FEIS	Final Environmental Impact Statement
FEP	Feature, Event, and Process
FFCA	Federal Facilities Compliance Act
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FLPMA	Federal Land Policy and Management Act
FP	Future Panel
FR	Federal Register
FSAR	Final Safety Analysis Report
FWS	Fish and Wildlife Service
GEP	Good Engineering Practice
HAP	Hazardous Air Pollutant
HBL	Health-Based Level
HEAST	Health Effects Assessment Summary Tables
HEPA	High Efficiency Particulate Air
HERE	Horizontal Emplacement and Retrieval Equipment
HLW	High-Level Waste
HMTA	Hazardous Materials Transportation Act
HPIC	High Pressure Ionization Chamber

HSWA	Hazardous and Solid Waste Amendments
HTMR	High Temperature Metals Recovery
HVAC	Heating, Ventilation, and Air Conditioning
HWMR	Hazardous Waste Management Regulations
HWMU	Hazardous Waste Management Units
IAEA	International Atomic Energy Act
ICV	Inner Containment Vessel
IDB	Integrated Database
INEL	Idaho National Engineering Laboratory
IR	Irrigation
IRIS	Integrated Risk Information System
ISC	Industrial Source Complex
KAPL	Knolls Atomic Power Laboratory
LANL	Los Alamos National Laboratory
LBL	Lawrence Berkeley Laboratory
LDR	Land Disposal Restrictions
LLNL	Lawrence Livermore National Laboratory
LLW	Low-Level Waste
LTM	Long-Term Monitoring
LWA	Land Withdrawal Act
M&O	Management and Operations
MB	Marker Bed
MOC	Managing and Operating Contractor
MOUND	Mound Laboratory
MOU	Memorandum of Understanding
MP	Markers Panel
MP	Monitoring Program
MCS	Master Control Station
MDL	Minimum Detection Level
MSDS	Material Safety Data Sheet
MSHA	Mine Safety and Health Act
MWIR	Mixed Waste Inventory Report
NAAQS	National Ambient Air Quality Standards
NACEPT	National Advisory Council on Environmental Policy and Technology
NAS-NRC	National Academy of Sciences-National Research Council
NDA/NDE	Non-Destructive Assay/Non-Destructive Examination
NEPA	National Environmental Policy Act
NES	Nonradiological Environmental Surveillance
NESHAP	National Emission Standards for Hazardous Air Pollutant
NGS	National Geodetic Survey
NHPA	National Historic Preservation Act
NID	Nonradionuclide Inventory Database
NIOSH	National Institute of Occupational Safety and Health
NMAC	New Mexico Administrative Code
NMAQCB	New Mexico Air Quality Control Bureau

NMBMMR	New Mexico Bureau of Mines and Mineral Resources
NMD	No-Migration Determination
NMDG&F	New Mexico Department of Game and Fish
NMED	New Mexico Environment Department
NMHWA	New Mexico Hazardous Waste Act
NMVP	No-Migration Variance Petition
NPDES	National Pollutant Discharge Elimination System
NRC	U.S. Nuclear Regulatory Commission
NRHP	National Register of Historic Places
NTPO	National TRU Program Office
NTS	Nevada Test Site
NWPA	Nuclear Waste Policy Act
OCA	Outer Containment Assembly
OEDC	Organization for Economic Cooperation and Development
OP&R	Overpack and Repair
OPRR	Overpack and Repair Room
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
P&P	Planning and Permitting
PA	Performance Assessment
PAD	Paducah Gaseous Diffusion Plant
PAX	Private Automatic Exchange
PBWAC	Performance-Based Waste Acceptance Criteria
PCB	Polychlorinated Biphenyl
PDP	Performance Demonstration Program
PDPP	Performance Demonstration Program Plan
PMS	Permanent Marker System
PPE	Personal Protective Equipment
PTB	Project Technical Baseline
QA	Quality Assurance
QARD	QA Requirements Document
QA/QC	Quality Assurance/Quality Control
QAPD	Quality Assurance Program Description
QAPjP	Quality Assurance Project Plan
QAPP	Quality Assurance Program Plan
R	Recreation
RBP	Radiological Baseline Program
RCRA	Resource Conservation and Recovery Act
RCS	Radar Cross-Section
RCSMP	Regulatory Compliance Strategy and Management Plan
RfC	Reference Concentration
RfD	Reference Dose
RF	Radio Frequency
RFETS	Rocky Flats Environmental Technology Site
RFP	Rocky Flats Plant

RH	Remote-Handled
ROD	Record of Decision
RTR	Real-Time Radiography
SAR	Safety Analysis Report
SARA	Superfund Amendments and Reauthorization Act
SARP	Safety Analysis Report for the TRUPACT-II Shipping Package
SB	Support Building
SDD	System Design Description
SDS	Subsidence Data Study
SDWA	Safe Drinking Water Act
SEIS	Supplement Environmental Impact Statement
SEPM	Society of Economic Paleontologists and Mineralogists
SF	Slope Factor
SHPO	State Historic Preservation Officer
SHS	Salt Handling Shaft
SLO	State Land Office
SNL	Sandia National Laboratories
SOP	Standard Operating Procedure
SPDV	Site Preliminary Design Validation
SPIC	High Pressure Ionization Chamber
SPM	Systems Prioritization Methodology
SPM-1	Systems Prioritization Method-1
SQL	Sample Quantitation Limit
SRS	Savannah River Site
SSBI	Small-Scale Brine Inflow
SSZ	Site Source Zone
SWB	Standard Waste Box
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TRAMPAC	TRUPACT-II Authorized Methods for Payload Control
TRU	Transuranic
TRUCON	TRUPACT-II Content
TRUDOCK	TRUPACT Dock
TRUPACT	Transuranic Package Transporter
TSCA	Toxic Substances Control Act
TSP	Total Suspended Particulates
TV	Television
UBC	Uniform Building Code
UCRL	University of California Research Laboratories
U/G	Underground
UIC	Underground Injection Control
UNAMAP	Users Network for Applied Modeling of Air Pollution
UNM	University of New Mexico
UPS	Uninterruptible Power Supply
URF	Unit Risk Factor

USBM	U.S. Bureau of Mines
USC	United State Code
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UST	Underground Storage Tank
USTR	Underground Storage Tank Regulations
UTM	Universal Transverse Mercator
VOC	Volatile Organic Compound
WAC	Waste Acceptance Criteria
WACCC	Waste Acceptance Criteria Certification Committee
WHB	Waste Handling Building
WID	Waste Isolation Division
WIPP	Waste Isolation Pilot Plant
WMC	Waste Matrix Code
WQSP	Water Quality Sampling Program
WTWBIR	WIPP Transuranic Waste Baseline Inventory Report
WVDP	West Valley Demonstration Project

LIST OF ABBREVIATIONS

Ar	argon
ARM	Area Radiation Monitoring
atm	atmospheres
ave	average
bbl	barrels
Bq/gm	becquerels per gram
dBm^2/m^2	decibels per square meter per square meter
cm/s^2	centimeters per second per second
D/H	Ratio of deuterium to hydrogen
°F	degrees Fahrenheit
ft	feet
ft^3	cubic feet
g/s	grams per second
g	acceleration due to gravity
GHz	gigahertz
Gpa	gigapascals
Hz	hertz
K	Kelvin
k	permeability
K	potassium
K-Ar	potassium-argon
K/Na	ratio of potassium to sodium
kg	kilograms
kg/m^3	kilograms per cubic meter
kPa	kilopascals
L/m^3	liters per cubic meter
m	meter
MCS	Master Control Station
m/s	meters per second
m^2	square meters
m^3	cubic meters
m^3/kg	cubic meters per kilogram
m^3/Pa	cubic meters per Pascal
m^3/s	cubic meters per second
max/min	maximum/minimum
mg/Ca	ratio of magnesium to calcium
mg/m^3	milligrams per cubic meter
MHz	megahertz
min	minute
mm Hg	millimeters of mercury
mol	moles
MPa	megaPascals
mph	miles per hour

mrem	milliroentgen equivalent man
mrem/hr	milliroentgen equivalent man per hour
μCi/gm	microcuries per gram
$\mu g/m^3$	micrograms per cubic meter
μg/g	micrograms per gram
MT Hm	metric tons of heavy metal
MW	molecular weight
N/A	not applicable
nCi/g	nanocuries per gram
N/S	not specified
Pa	Pascals
ppmv	parts per million per volume
psf	pounds per square foot
Rb-Sr	rubidium-strontium
rem	roentgen equivalent man
rem/hr	roentgen equivalent man per hour
RF	radio frequency
ρ	density
s	seconds
std dev	standard deviation

EXECUTIVE SUMMARY

The Waste Isolation Pilot Plant (WIPP) is a research and development facility for the demonstration of the permanent isolation of transuranic radioactive wastes in a geologic formation. The facility was constructed in southeastern New Mexico in a manner intended to meet criteria established by the scientific and regulatory community for the safe, long-term disposal of transuranic wastes.

The WIPP Land Withdrawal Act of 1992 requires that the Secretary of Energy submit to the Administrator of the U.S. Environmental Protection Agency (EPA) an application for certification of compliance with EPA regulation Title 40 Code of Federal Regulations (CFR) Part 191, *Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes.* Once the Department of Energy (DOE) demonstrates compliance with the disposal regulations and the EPA certifies that compliance, the WIPP facility will be used for the permanent disposal of transuranic waste.

The regulations require that the DOE demonstrate that the WIPP will isolate the wastes placed in the repository for 10,000 years. The DOE is applying an analytical method called performance assessment to demonstrate that the WIPP disposal system will meet the environmental performance standards.

Three general types of information are needed to effectively implement the performance assessment. These are an understanding of what can happen to the disposal system, what are the chances of it happening, and what are the consequences, if it happens. This information is obtained through a number of sources including field studies, laboratory evaluations, experiments, and, for those features not easily characterized, the judgments of experts. The information used in the performance assessment is described in terms of *features* of the disposal system that can be used to describe its isolation capabilities, *events* that can affect the disposal system, and *processes* that are reasonably expected to act on the disposal system. The combinations of features, events, and processes have been applied to the evaluation of the performance of the WIPP; they are described in this document.

To understand the features, events, and processes that may potentially impact the behavior of the repository in the long term, a reviewer must first have an understanding of relevant information pertaining to the site of the repository, its design and operation, and the characteristics of the waste proposed to be emplaced in the repository. The objective of the early chapters of this document is to provide the reviewer with this "foundation" of information upon which an understanding of the expected performance of the repository may be built.

The first of the three general components of the disposal system described in this document is the site at which the WIPP is located. This information provides input to the discussion of features, events, and processes and the subsequent selection of parameters for the performance assessment. Information is provided on the WIPP site geology, hydrology, climatology, air quality, ecology, and cultural and natural resources. Aspects of the location, geology, and climate of the site that are important to the isolation of radioactive wastes are described.

The WIPP disposal horizon is within a rock salt deposit known as the Salado Formation, at a depth of 2,150 feet (650 meters) below the ground surface. The Salado Formation was selected for a variety of reasons, in part because it is regionally extensive, includes continuous beds of salt without complicated structure, is deep enough to reduce the potential for dissolution, and is near enough to the surface to make access reasonable. Due to the plastic nature of the rock, openings in the underground will close with time and encapsulate the waste. In addition, the salt formation may be relatively easily mined using conventional mining techniques.

The second general component of the disposal system described here is the WIPP facility. The design and function of those systems at the WIPP facility which are important to the assessment of compliance and in meeting the disposal standards are also presented. Descriptions of surface structures, shafts, underground waste disposal and support facilities, and engineered barriers such as seals are provided to the extent that they are relevant to long-term containment.

The WIPP facility consists of a 16-square-mile (41.4-square-kilometer) area. The underground waste disposal area of the WIPP facility will ultimately consist of eight panels, each of which contains seven rooms. A 25-year operating time period is estimated to mine and fill all eight panels, the four access drifts, and the crosscuts in the WIPP repository. At the end of the 25-year period, up to 10 years will be required for decontamination and decommissioning and closure activities.

The facility is designed to receive up to 6.2 million cubic feet (175,600 cubic meters) of contact-handled transuranic waste and 250,000 cubic feet (7,080 cubic meters) of remote-handled transuranic waste. Contact-handled transuranic waste has a surface dose rate of less than 200 millirem per hour; remote-handled transuranic waste has a surface dose rate of 200 millirem per hour or greater.

The third of the three general components of the disposal system, the waste to be emplaced, is also described. Assessments of the performance of the repository are based in part on assumed characteristics of the wastes including factors such as the levels of radioactivity present in the waste, the amount of moisture in the waste, and the quantities of other materials that might have some affect on the potential for the waste to migrate toward the accessible environment. These characteristics of the wastes are documented. Methods to be employed by the DOE to ensure that only those wastes that are consistent with these descriptions are actually emplaced in the repository are also described. Additional information is provided on the nature of transuranic waste, the sources of the waste, waste inventories, and plans for the further characterization of these wastes.

The DOE may only emplace those radioactive wastes in the WIPP that meet both the definition of transuranic waste, as defined in the WIPP Land Withdrawal Act, and which can be certified to the project's waste acceptance criteria. As defined in the Land Withdrawal Act, transuranic waste contains more than 100 nanocuries of alpha-emitting transuranic isotopes per gram of waste, and has a half-life greater than 20 years. In accordance with the Land

Withdrawal Act, no remote-handled transuranic waste received at WIPP may have a surface dose rate in excess of 1,000 rem per hour, and no more than 5 percent by volume of the remote-handled transuranic waste may have a surface dose rate in excess of 100 rem per hour.

Compliance evaluations and analyses must be of documented quality. DOE quality assurance (QA) policies pertaining to the establishment, maintenance, and implementation of an effective QA program that complies with applicable DOE Orders and EPA requirements are described. It is the DOE's goal to fulfill its mission while ensuring that risks and environmental impacts are identified and minimized, while safety, reliability, and performance are maximized.

The results of a preliminary performance assessment of the undisturbed performance of the repository are reported. This analysis will be updated and accompanied by an evaluation of disturbed performance in a revision to this draft document. For comparison with the containment requirements, the DOE has prepared a preliminary mean complementary cumulative distribution function (CCDF) displaying the probability of cumulative 10,000-year normalized radionuclide releases to the accessible environment. This CCDF is shown in Figure ES-1. It is a mean CCDF based on 60 realizations, and it is conditional on an assumption of undisturbed performance. The methodology, modeling system, and parameters used to calculate the CCDF are described.

Although the CCDF shown in Figure ES-1 is several orders of magnitude below the release limits stipulated in 40 CFR § 191.13(a), the DOE recognizes that it is insufficient for a demonstration of compliance with 40 CFR Part 191 and cannot be submitted for certification under the proposed 40 CFR Part 194. The CCDF is not in final form because a sufficient level of confidence remains to be established in the modeling system, data, and parameters. In addition, the quality of all of the work supporting the compliance evaluation has not yet been fully documented. Full justification of the models, data, and parameters will be provided in the final application. Analyses of disturbed performance, including consideration of human-initiated events and processes, will also be included in the final application.

In response to the uncertainties inherent in the prediction of the behavior of the disposal system for a period of 10,000 years, the EPA has established the assurance requirements of 40 CFR § 191.14. The assurance requirements are intended to ensure that the level of protection desired by the EPA is achieved. Six assurance requirements addressed in the rule are shown below:

- Active institutional controls
- Monitoring
- Passive institutional controls
- Barriers
- Resource disincentives
- Waste removal.

The DOE plans for the implementation of programs to comply with the assurance requirements provisions are described in this document.

The quantitative release limits set forth in the containment requirements provisions of 40 CFR § 191.13 are one of three long-term numerical performance requirements contained in 40 CFR Part 191. The WIPP facility also must comply with numerical performance standards contained in the individual protection requirements and the groundwater protection requirements.

Formal dose calculations to evaluate compliance with the individual protection standard have not been performed for the purposes of this Draft Compliance Certification Application. If the final compliance calculations indicate releases to the accessible environment under undisturbed conditions, formal dose calculations will be developed and presented. However, bounding doses for the releases indicated by the preliminary performance assessment are estimated.

The bounding analysis is based on the "stock pond–to–cow–to–man" pathway because it is the most important pathway in terms of delivering the maximum exposure to an individual. This pathway consists of a hypothetical well pumping water from the Culebra to a stock water tank. Cattle then drink the water and are subsequently consumed by humans. Under present-day conditions for undisturbed performance, this pathway dominates all others by orders of magnitude. A bounding dose of less than 10^{-8} millirem per year is estimated, based on an analysis of this pathway. This is much lower than the 40 CFR § 191.15 standard of 15 millirem per year.

To demonstrate compliance with the groundwater protection standard, the DOE must show that releases of radioactivity from the WIPP will not cause levels of radioactivity in any underground source of drinking water to exceed values specified in 40 CFR Part 141. The base-case analysis of the undisturbed performance of the WIPP shows that the total concentration of all radionuclides reaching the accessible environment is 10^{-3} picocuries per liter, well below the 5 and 15 picocuries per liter standards applicable to underground sources of drinking water.

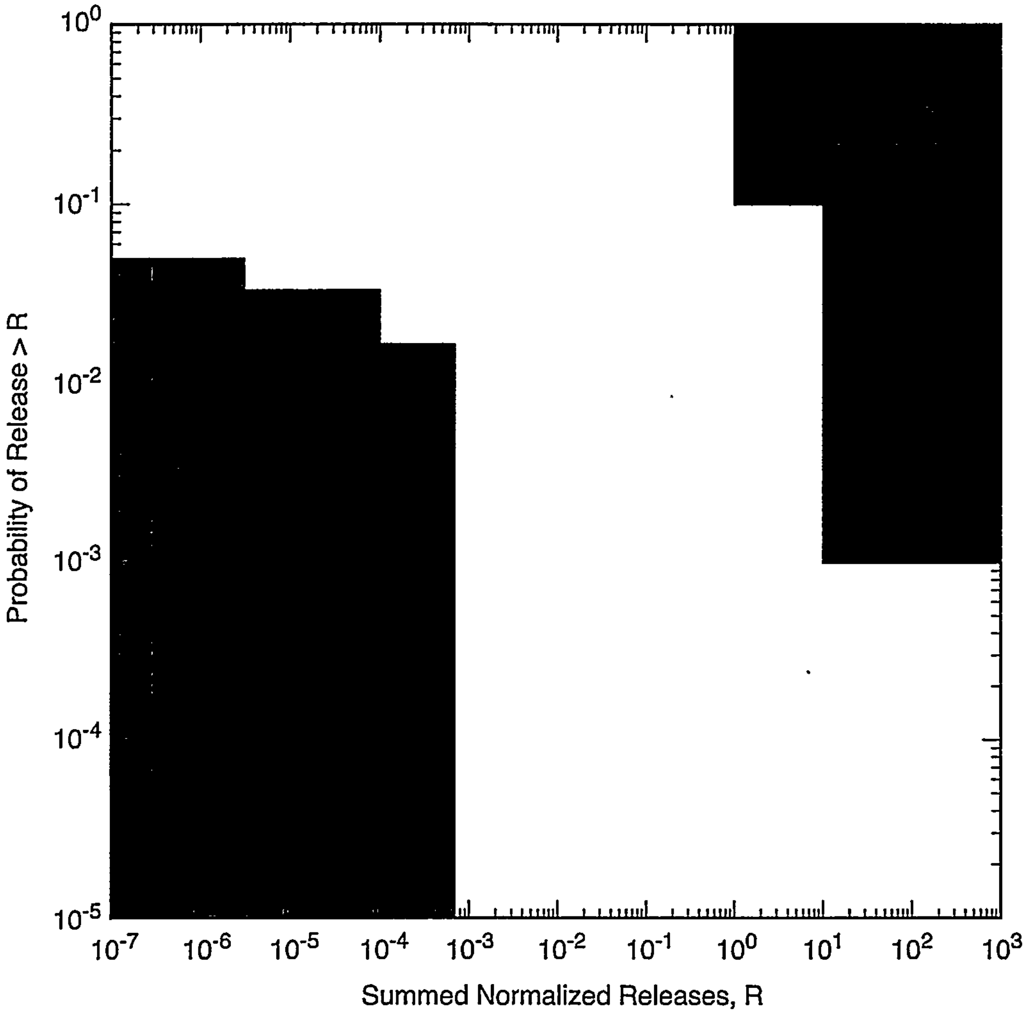

Figure ES-1. Mean CCDF Showing Probability of Cumulative 10,000-year, Normalized Radionuclide Releases from the WIPP. The CCDF is based on 60 realizations of undisturbed performance. This is a preliminary CCDF based on preliminary models and data, and does not address all requirements of 40 CFR Part 191 or proposed 40 CFR Part 194.

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1.0 INTRODUCTION

The U.S. Department of Energy (DOE) is responsible for the disposition of transuranic (TRU) waste generated by the production of nuclear weapons and other defense-related activities. TRU waste is defined as waste that contains more than 100 nanocuries of alpha-emitting transuranic isotopes, with half-lives greater than 20 years, per gram of waste. Some of these radioactive wastes are mixed with hazardous chemicals and are subject to the regulations that apply to the management of hazardous wastes. These wastes are called TRU mixed wastes.

Nuclear weapons production began in the 1940s. In 1970, the Atomic Energy Commission (AEC), the predecessor of the DOE, determined that TRU waste required more stringent management and more secure disposal facilities than low-level waste (LLW). Since 1970, DOE has temporarily stored its waste in a manner that will facilitate retrieval and placement in an appropriate disposal facility. Approximately 2.8 million cubic feet (74,500 cubic meters) of these wastes have been generated and are retrievably stored at government installations across the country. It is currently projected that an additional 2.0 million cubic feet (54,400 cubic meters) of these wastes will be generated, although this projection may increase as DOE decontamination and decommissioning and environmental restoration programs progress.

The Waste Isolation Pilot Plant (WIPP), located in southeastern New Mexico, was sited and constructed to meet the criteria established by the scientific and regulatory community for the safe, long-term disposal of TRU and TRU mixed wastes. This draft document initiates the process to certify WIPP's compliance with the radioactive waste disposal regulations set forth in Title 40 Code of Federal Regulations (CFR) Part 191, Subparts B and C. The DOE has followed guidance established in Appendix C of 40 CFR Part 191 in drafting this document.

Under the authority of the WIPP Land Withdrawal Act (LWA) of 1992, the U.S. Environmental Protection Agency (EPA) recently proposed criteria for certifying and determining WIPP's compliance with the 40 CFR Part 191 disposal standards. This document includes references to the requirements of the proposed rule, 40 CFR Part 194. In addition, the DOE will prepare a separate document to demonstrate compliance with the long-term hazardous waste disposal regulations, as required by the Resource Conservation and Recovery Act (RCRA).

1.1 (Draft) Certification Application Synopsis

This document contains the following information:

Chapter 2 describes the site and surrounding area as it existed prior to construction of the WIPP repository. Geological descriptions include both regional and local geology including structure, subsurface geology, geomorphology, geologic stability, soils, and topography.

Chapter 3 describes the facility systems relevant to long-term containment such as location, design, layout, and barriers.

Chapter 4 describes the wastes to be managed and disposed of at the facility.

Chapter 5 describes quality assurance programs and plans for each of the activities to be completed in support of the compliance certification.

Chapter 6 details the performance assessment process and explains how the process was applied to evaluate the performance of the WIPP.

Chapter 7 describes the DOE's implementation of each of the assurance requirements contained in 40 CFR Part 191.

Chapter 8 describes the DOE's compliance with the individual and groundwater protection requirements in 40 CFR Part 191.

1.2 Project Overview

The WIPP facility near Carlsbad, New Mexico, was constructed to determine the efficacy of an underground repository for disposal of TRU waste and TRU mixed waste. The LWA transferred jurisdiction of the land used for the WIPP project from the Secretary of the Department of the Interior to the Secretary of the DOE and imposed requirements on the use of the facility. The LWA requirements relevant to this application focus on the criteria for certification of compliance with the radioactive waste disposal regulations issued by the EPA. Once the DOE demonstrates compliance with the disposal regulations and the EPA certifies that compliance, the WIPP facility will be used for the permanent disposal of TRU waste.

The regulations require that the DOE demonstrate that the WIPP will isolate the wastes placed in it for 10,000 years. The DOE has developed a phased approach demonstrating the performance of the WIPP facility. The phased approach implemented by DOE provides the information needed to predict how the disposal system will perform during the 10,000-year period.

The DOE began the development of the WIPP facility by selecting a site. The DOE evaluated several alternatives and the present site was selected as the best on the basis of extensive geotechnical research supplemented by testing (see Section 1.3). Based upon the properties of the site, the DOE designed the repository and prepared safety analyses. Subsequent research has expanded the understanding of the geologic, hydrologic, geochemical, and mechanical properties of the host rock and surrounding strata of the site. This siting phase ended with the publication of a Final Environmental Impact Statement (FEIS) in 1980, which evaluated alternatives for the safe, long-term isolation of TRU waste. The Record of Decision (ROD) concluded that the phased development of the WIPP facility was the preferred alternative of those considered.

The site and preliminary design validation (SPDV) phase followed the siting phase. During this phase, the DOE constructed two shafts, excavated an underground testing area, and investigated various geologic, hydrologic, and other geotechnical features, further expanding the knowledge of the site's characteristics. In addition, the DOE evaluated methods for assessing the long-term performance of the WIPP facility. A series of geologic and hydrologic studies began in 1984 under an agreement between the DOE and the State of New Mexico. The majority of these studies have been completed and site characterization has ended. However, limited geologic and hydrologic studies of the WIPP site continue.

The construction phase followed the SPDV, during which the DOE built surface structures for receiving waste and completed underground excavations for waste emplacement. The DOE's decision was reached after all prerequisites for ending construction were met and documented. These documents used the data collected since 1980 to evaluate the potential short-term and long-term impacts of the WIPP facility.

Once the DOE demonstrates compliance with applicable federal and state laws and regulations, the WIPP facility will proceed through three additional phases: a disposal phase, a decommissioning phase, and a post-decommissioning phase. During the disposal phase, expected to last 25 years, the DOE will receive, handle, and emplace TRU and TRU mixed waste in the repository. Additional scientific studies may continue during the disposal phase. The disposal phase will end when the design capacity of the repository is reached.

The decommissioning phase will follow the disposal phase. The repository will be prepared for permanent closure during this phase. Surface facilities will be decontaminated and decommissioned, underground excavations will be closed, and shaft seals will be emplaced. The decommissioning phase is expected to last 10 years.

Active and passive institutional controls will be implemented during the disposal phase. Active institutional controls include activities such as control of access to the site. Such controls will be implemented consistent with applicable regulations and permit conditions. Only the first 100 years of such controls will be included in the assessment of the disposal system's performance. Passive institutional controls include notification devices such as permanent markers and archives. These controls will be designed to reduce the likelihood of human intrusion to the extent practicable.

1.3 Site Selection Process

In 1955, the National Academy of Sciences–National Research Council (NAS-NRC) recognized salt as a medium well suited for radioactive waste disposal. Salt has relatively high thermal conductivity (which serves to conduct heat away from waste rapidly) and has favorable plastic (creep) properties, which permit the absorption of significant pressure without fracturing. The existence of large salt deposits demonstrates isolation from circulating groundwaters for long periods of geologic time; the depositional nature and preservation of large salt deposits demonstrate the region has been stable for long periods of time.

The site selection process for the WIPP began in 1973 with a review of information on potential disposal media. This work focused on salt beds and salt domes. The tentative selection criteria used in the initial stage of the process emphasized radiation and mine safety, hydrologic isolation, and ease of construction. The criteria specified the following conditions: 1,000–2,500 feet (305–762 meters) depth to salt, 200 feet (61 meters) minimum of salt thickness, lateral extent of salt sufficient to protect against dissolution, favorable tectonics (low historical seismicity and no salt-flow structures nearby), minimal groundwater, low resource potential, minimum number of existing boreholes, low population density, and maximum use of federal lands. The U.S. Geological Survey (USGS) and the Oak Ridge National Laboratory (ORNL) selected eastern New Mexico as the area which best satisfied the tentative selection criteria from the bedded salt regions surveyed.

During the second stage of the selection process, two of the three locations were determined to be inadequate: the Clovis-Portales site, because shallow salt formations had a significant clay content and the purer salt formations were too deep; and the Mescalero Plains area, because of extensive oil field development. After shifting the potential site twice (in order to avoid borehole penetrations of the salt within 2 miles (3.2 kilometers) of the repository border), ORNL selected a site in the Delaware Basin for extensive characterization.

In the final stage of the process, eight areas in the Delaware Basin in Eddy and Lea counties were evaluated. The Los Medaños site was determined to be the best site. Eight additional selection criteria were considered at this stage in the process:

1. The site should be at least 6 miles (10 kilometers) from the Capitan Limestone, referred to as the "Capitan Reef," a major aquifer, to avoid any possible deformation hazard related to the nearness of the reef.

2. To minimize potential conflicts with exploration of mineral resources, the central 4 square miles (10 square kilometers) of the repository itself should not be in the known Potash District, and as little as possible of the surrounding buffer zone should be in the district.

3. No part of the central area should be less than 1 mile (1.6 kilometers) away from holes drilled through the Castile Formation into underlying rocks in order to avoid dissolution by water flowing upward through an inadequately plugged borehole.

4. Known oil and gas stratigraphic trends should be avoided.

5. The nearest dissolution front should be at least 1 mile (1.6 kilometers) from the site.

6. The bedding of geological strata should be nearly flat as can be determined by surface geophysical investigations to ensure mine safety and ease of construction and to avoid the need for numerous exploratory holes that could pose a subsequent risk to the integrity of the repository.

7. Salt of high purity should be available at depths between 1,000 and 3,000 feet (305 and 914 meters) to ensure mine safety and ease of construction. In addition, a salt thickness of 200 feet (61 meters) or more is preferred to confine thermal and mechanical effects to the salt.

8. The use of state and private land should be minimized, especially in the central area, to simplify land acquisition and to avoid any relocation of residents.

The FEIS provided the basis for making the final decision regarding siting the WIPP facility at the Los Medaños site. This decision weighed the numerous advantages of the location and its suitability against potentially adverse environmental impacts. The WIPP site (Figure 1-1) was selected as the best of the alternatives. The specific horizon in the bedded salt was selected because of its desirable stratigraphic features. The stratigraphy is continuous throughout a large geographic area and clay seams and interbeds of anhydrite or polyhalite are removed from the repository horizon. The facility has been constructed at a horizon such that operational and rock-support problems are minimized. Subsequent validation and construction activities have confirmed that the site's features are suitable for the long-term isolation of radioactive and hazardous wastes. The DOE has concluded that these favorable features offset any enhanced risk of human intrusion associated with resources in the vicinity.

1.4 Regulatory Framework

The EPA is responsible for developing environmental standards for the protection of the public and the environment from radioactivity. The authority for establishing and implementing the regulatory standards applicable to the operation, closure, and long-term performance of the WIPP facility are found in the Atomic Energy Act of 1954, Reorganization Plan Number 3 of 1970, and in the Nuclear Waste Policy Act (NWPA) of 1982. The regulations affecting the radioactive waste disposal operations that will occur at the WIPP are found in 40 CFR Part 191, *Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Waste.*

The EPA is also responsible for establishing criteria to certify if the WIPP complies with the 40 CFR Part 191 Subparts B and C radioactive waste disposal standards. Pursuant to the LWA, the EPA is currently developing these criteria, which will appear in 40 CFR Part 194, *Criteria for the Certification and Determination of the Waste Isolation Pilot Plant's Compliance with Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Wastes.* The EPA recently published the proposed 40 CFR Part 194 rule; the DOE will specifically address the certification criteria when the EPA promulgates the final rule. Once the EPA finalizes 40 CFR Part 194 and the DOE has completed any additional investigations that might be necessary, the DOE will revise this document and prepare a final application for certification.

Since the mid-1970s, the EPA has been developing guidance and standards for the management and disposal of radioactive waste. The EPA's final rule, 40 CFR Part 191, was first published on September 19, 1985. This standard was vacated and remanded to the EPA by a Federal Court of Appeals in 1987. The LWA reinstated the 1985 disposal standard except for the aspects of the standard that were specifically questioned by the court (i.e., § 191.15, Individual Protection Requirements, and § 191.16, Ground Water Protection Requirements). On December 20, 1993, the EPA promulgated, effective January 19, 1994, final disposal standards which corrected deficiencies associated with the individual and groundwater protection requirements.

40 CFR Part 191 establishes standards and measures of performance for the following aspects of a disposal system:

- Waste management and storage
- Protection of individuals from radiation exposures for a period of 10,000 years
- Protection of groundwater from radioactive contamination for 10,000 years
- Isolation of radionuclides sufficient to meet the containment requirements of the disposal system.

To demonstrate that a disposal system will comply with 40 CFR Part 191, DOE must demonstrate a reasonable expectation that each performance measure will be satisfied.

The assurance requirements, § 191.14, were promulgated in order to provide the confidence needed for long-term compliance with the containment requirements in § 191.13. They include: (1) active and passive institutional controls to preclude or mitigate the potential for human disturbance of the repository for an extended period of time, (2) natural and engineered barriers to ensure the integrity of the containment system, and (3) other measures taken to enhance confidence in the disposal system performance.

1.5 Program for Evaluating Long-Term Performance

For evaluating compliance with the long-term performance requirements of 40 CFR Part 191, the DOE will collect data and perform analyses. The DOE uses a technique developed especially for predicting the behavior of geologic repositories over the thousands of years required for waste isolation. This technique is performance assessment-a multi-disciplinary, iterative, analytical process that begins by using available information that characterizes the waste and the disposal system (the design of the repository, the repository seals, and the natural barriers provided by the host rock and the surrounding formations). The DOE uses performance assessment to identify the processes (i.e., phenomena that might develop over long periods of time) and events that might affect the system and then examines the effects of these processes and events on the performance of the system. The DOE subsequently uses performance assessment to estimate the releases of radionuclides, based on the probabilities of

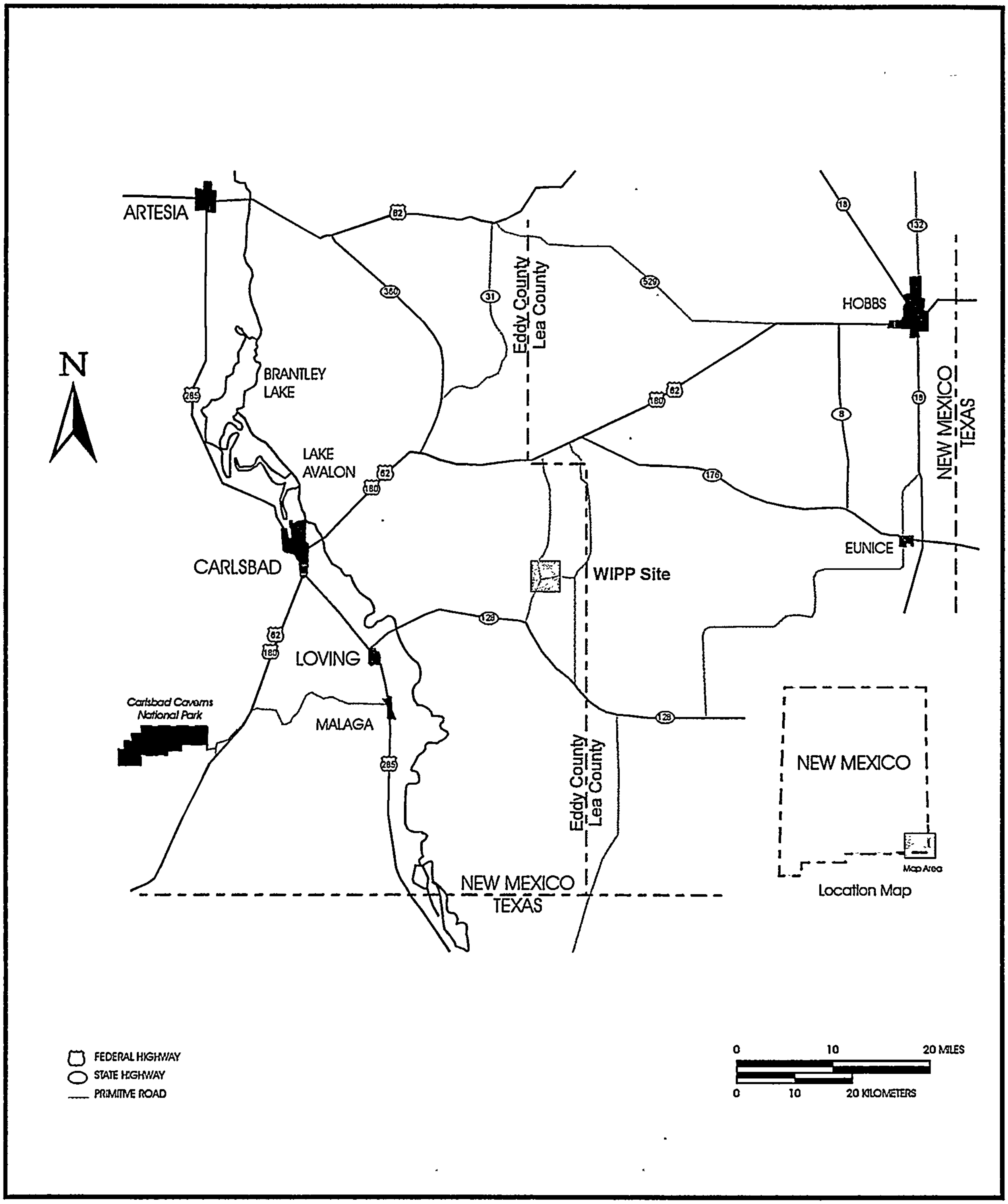

Figure 1-1. WIPP Location in Southeastern New Mexico

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these processes and events occurring and the consequences. Sensitivity analyses are used by the DOE to determine which characteristics of the disposal system exert the greatest effect on performance. The results of sensitivity analyses will be provided in the final application. The results of performance assessment are used by the DOE in the 40 CFR Part 191 compliance program to assess the disposal system's behavior and the possible environmental releases.

The structure of the DOE's program for assessing the ability of the WIPP to satisfy the requirements in 40 CFR Part 191 is illustrated in Figure 1-2. Performance assessment modeling and analyses will provide the quantitative evaluation of long-term radionuclide isolation and containment. Information necessary to simulate long-term performance must adequately represent the repository as well as the interactions of the waste with the disposal system. The DOE must also evaluate the probability of human intrusion and its impacts. The WIPP performance assessment method has been reviewed by the NAS, the Environmental Evaluation Group (EEG), and experts in and outside the United States.

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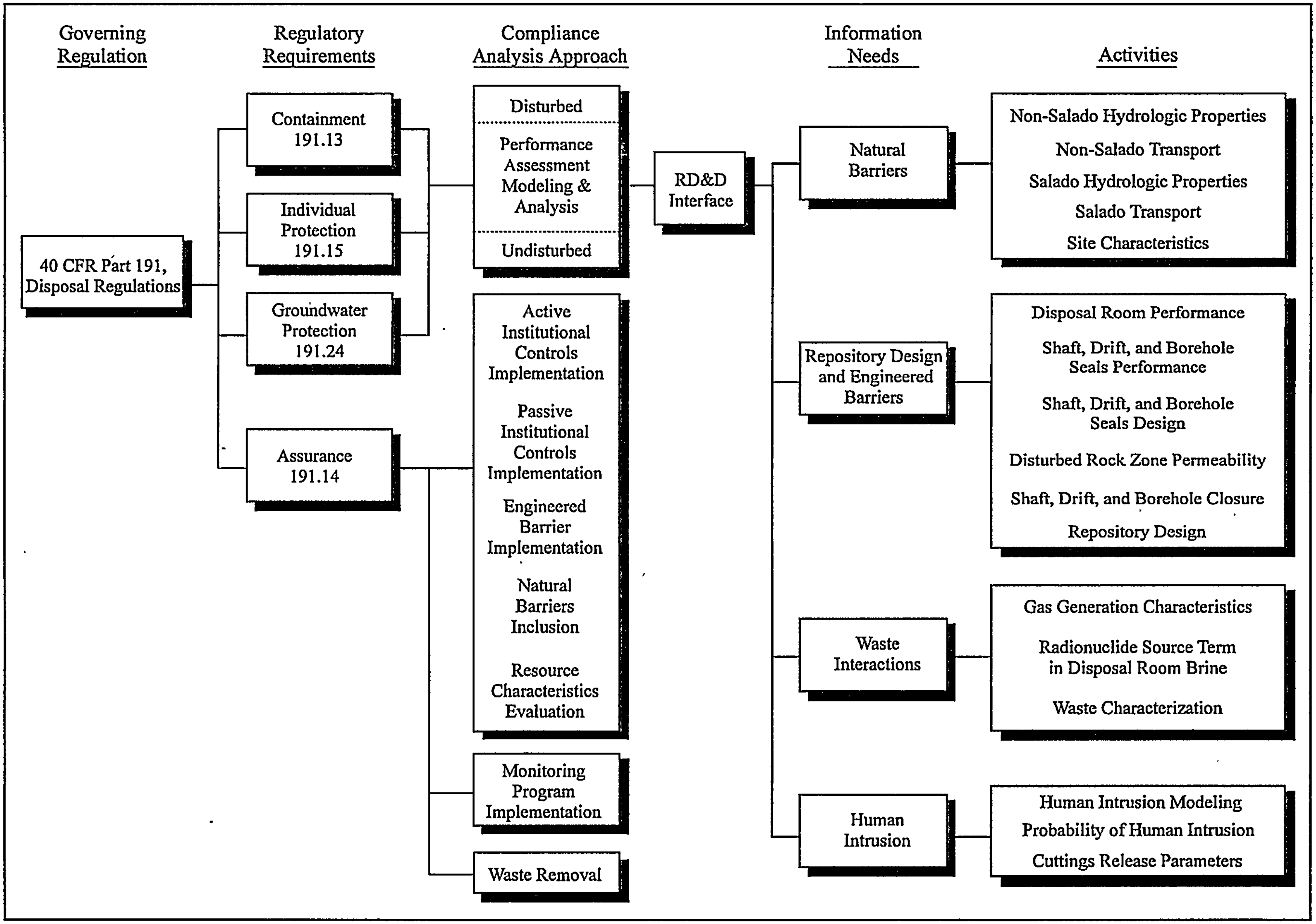

Figure 1-2. Long-Term 40 CFR Part 191 Compliance Program Structure

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2.0 SITE CHARACTERIZATION

The U.S. Department of Energy (DOE) uses the performance assessment methodology described in Section 6.1 to demonstrate that the Waste Isolation Pilot Plant (WIPP) disposal system will meet the environmental performance standards of Title 40 of the Code of Federal Regulations (CFR) Part 191 Subparts B and C. In order to effectively use performance assessment, three inputs are necessary: what can happen to the disposal system? what are the chances of it happening? and what are the consequences if it happens? The information shaping the substance of these inputs comes from a number of sources including field studies, laboratory evaluations, experiments, and, in the case of those feature not easily characterized, the judgment of experts. The information used in performance assessment is described in terms of *features* of the disposal system that can be used to describe its isolation capability; *events* that can affect the disposal system, and *processes* that are reasonably expected to act on the disposal system. The combinations of features, events, and processes (FEPs) that have been applied to the WIPP are discussed in detail in Section 6.2. This chapter provides the information supporting the Section 6.2 discussion of FEPs and the subsequent selection of parameters for the performance assessment.

The DOE's approach in selecting the WIPP site was, in essence, a screening process intended to emphasize selection of an area that possessed as many of the favorable FEPs as possible while excluding the unfavorable FEPs. The actual screening process used by the DOE is discussed in detail in numerous documents such as the Final Environmental Impact Statement (FEIS) which the DOE published in 1980 (DOE 1980 in the bibliography). The details of the DOE's site screening and selection are discussed explicitly in the scenario screening process in Section 6.2.

The DOE's site screening and selection and subsequent characterization led to the identification of specific FEPs that required in-depth evaluation in order to form the basis for evaluation in the performance assessment. The DOE dealt with these FEPs, for the most part, with studies identified in an agreement signed by the DOE and the State of New Mexico (see the reference to the Consultation and Cooperation [C&C] agreement in the bibliography). A list of these "issues" is presented in Table 2-1 within the context of the scenario development process in Section 6.2 where these issues are either retained for inclusion in the performance assessment or are rejected for reasons detailed in Section 6.2. Table 2-1 also includes some FEPs that are considered to be human-induced. These are included to the extent they require information about the natural system for their screening and associated scenario development. The DOE's basis for retention or elimination of FEPs in the scenario development process is based on the information presented in this chapter. This information consists of the results of field studies, laboratory studies, and expert judgment.

Specifically, in this chapter the DOE describes the WIPP site geology, hydrology, climatology, air quality, ecology, and cultural and natural resources. This chapter's purpose is to provide information on the disposal system's natural FEPs that are relevant to the assessment of the WIPP site as a potential repository for transuranic (TRU) waste and to establish: (1) the favorable characteristics of the site, (2) background environmental quality, and (3) parameters needed to conduct performance assessments.

Table 2-1. Issues Related to the Natural Environment that were Evaluated for the WIPP Performance Assessment Scenario Screening

FEP Topical Heading	WIPP Issue	Discussion
	Geological Effects	
Regional tectonics	Regional uplift	§ 2.1.5.1
	Regional subsidence	§ 2.1.5.1
Volcanic activity	Volcanism	§ 2.1.5.3
Magmatic activity	Regional dikes	§ 2.1.5.3
Fault movement	Movements on faults	§ 2.1.5.2
	Fault activation	§ 2.1.5.2
	Formation of new faults	§ 2.1.5.2
Seismic activity	Earthquakes	§ 2.6
	Natural seismicity	§ 2.6
	Externally induced seismicity	§ 2.6
Salt deformation	Deformation	§ 2.1.6.1
Deep dissolution	Breccia pipes	§ 2.1.6.2
	Castile and Salado	§ 2.1.6.2
	Collapse breccias	§ 2.1.6.2
Mineralogical changes	Fracture mineralization—Culebra	§ 2.1.3.5.2
	Dissolution of fracture fillings—Culebra	§ 2.1.3.5.2
	Natural rock properties—general	§ 2.1.3
	Salinity	§ 2.4.2.1, § 2.7
	Changes in sorptive surfaces—Culebra	§ 2.1.3.5.2
	Climate Effects	
Climate change	Climate change—historic and current	§ 2.5.1, § 2.5.2
Glaciation	Glacial and interglacial cycling	§ 2.5.1
	Geomorphological Effects	
Erosion and sedimentation	Wind erosion	§ 2.1.4.2
	Major incision	§ 2.1.4.2
	Changes in topography	§ 2.1.4.2
	Surface flow characteristics	§ 2.1.4.2
	Surface and Near-Surface Hydrological Effects	
Flooding	Flooding	§ 2.1.4.2, § 2.2.2
Shallow dissolution and soil development	Surface-water chemistry	§ 2.2.2
	Soil properties	§ 2.1.3.10
Infiltration and recharge	Variation in groundwater recharge	§ 2.2.3
	Precipitation, temperature and soil/water balance	§ 2.5.2
	Surface hydrological change	§ 2.2.2
	Near-surface runoff processes	§ 2.2.2
	Surface flow characteristics	§ 2.2.2
	River flow and lake level changes	§ 2.2.2
	Groundwater discharge to surface-water	§ 2.2.3
	Groundwater discharge to springs	§ 2.2.3
	Ecological Effects	
Vegetational changes	Land use changes	§ 2.3.2.2
	Terrestrial ecological development	§ 2.3.2.3
	Farfield Flow and Transport	
Groundwater flow	Rock properties	§ 2.2.1

FEP Topical Heading	WIPP Issue	Discussion
Groundwater flow (continued)	Dewatering and water level	§ 2.2.1.7
	Saturated groundwater flow—Rustler	§ 2.2.1.5
	Groundwater recharge	§ 2.2.3
	Groundwater conditions (saturated and unsaturated)	§ 2.2.1
	Changes in geometry of the flow system—Rustler	§ 2.2.1.5
	Changes in driving forces of the flow system—supra-Salado	§ 2.2.1.5, § 2.2.1.6
	Changes in groundwater flow direction—Culebra	§ 2.2.1.5.2
	Fracture—Culebra	§ 2.2.1.5.2
	Channelling—Culebra	§ 2.2.1.5.2
Groundwater geochemistry and radionuclide transport	Groundwater composition changes—Culebra	§ 2.2.1.5.2
	Drilling	
Deep drilling	Exploratory boreholes: intrusive	NMBMMR 1995
	Archeological investigations: intrusive	§ 2.3.2.3
	Geothermal energy investigations	Appendix DEL[a]
	Exploratory boreholes: non-intrusive	Appendix DEL[a]
	Drilling: enhanced oil and gas production (non-intrusive)	NMBMMR 1995
	Drilling: liquid waste disposal	Appendix DEL[a]
	Drilling: hydrocarbon storage (non-intrusive)	Appendix DEL[a]
	Drilling: archaeology (non-intrusive)	Appendix DEL[a]
Shallow drilling	Exploratory boreholes (potash, water)	NMBMMR 1995
	Post-Drilling Events and Processes	
Fluid extraction	Groundwater extraction	§ 2.2.1.6.1
	Ranching	§ 2.2.1.6.1
Fluid injection	Injection wells	Appendix DEL[a]
	Excavations	
Mining	Potash mining	§ 2.3.1.1
	Mining other than potash	§ 2.3.1
	Surface Activities	
Irrigation	Irrigation—Santa Rosa	§ 2.2.1.6.2
	Explosions	
Underground testing of nuclear devices	Underground weapons testing	§ 2.3.2.3

[a]Appendix DEL is in press.

The DOE is developing the WIPP as a deep geologic repository for disposal of TRU waste from government defense installations across the country. In order for the DOE to formulate a reasonable expectation of site conditions far into the future, the DOE has characterized the site in detail to provide basic data for a variety of geologic and hydrologic parameters. The DOE uses these parameters in computational models to predict the likelihood and possible consequences of various scenarios expected to apply to the WIPP site over a 10,000-year period as specified in the regulations. The DOE will also use the computational models to evaluate the efficacy of the natural and man-made barriers in meeting environmental performance standards (Chapter 6). Results of these predictive models will be used by the DOE to demonstrate that the DOE has a reasonable expectation that the waste will not reach the accessible environment in quantities exceeding the regulatory limits.

The DOE has prepared this chapter to be consistent with what it believes is necessary to demonstrate compliance with the long-term disposal standards of 40 CFR Part 191. The contents follow, for the most part, recommendations found in regulatory guidance documents as reflected in the DOE's *Format and Content Guide for Regulatory Submittals* (DOE 1994). Specific guidance is scheduled to be issued by the U.S. Environmental Protection Agency (EPA) as part of the criteria for certification of the DOE's compliance at WIPP. This guidance will be part of 40 CFR Part 194. When the final rule is issued, the DOE may have to adjust the contents of this chapter to include additional topics, to provide greater detail on topics already included, or to reformat the contents in accordance with EPA guidance. These adjustments will be made for the final compliance certification application.

The DOE located the WIPP site 26 miles (42 kilometers) east of Carlsbad, New Mexico, in Eddy County (Figure 2-1). The region surrounding the WIPP site has been under study for many years, and exploration of both potash and hydrocarbon deposits has provided extensive knowledge of the geology of the region. Two exploratory holes were drilled by the federal government in 1974 at a location northeast of the present site; that location was abandoned in 1975 as a possible repository site after U.S. Energy Research and Development Administration (ERDA)-6 was drilled and unacceptable structure and pressurized brine were encountered. The results of these investigations are reported in Powers et al. (1978, p. 2-6; included in this document as Appendix GCR). During late 1975 and early 1976, the ERDA identified the present site and an initial exploratory hole (ERDA-9) was drilled. By the time an initial phase of site characterization was completed in August 1978, 47 holes had been drilled or were in progress for various hydrologic and geologic purposes. Geophysical techniques were applied to augment data collected from boreholes. Since 1978, the DOE has drilled additional holes to support hydrologic programs, geologic programs, and facility design. Geophysical logs, cores, basic data reports, geochemical sampling and testing, and hydrological testing and analyses are reported by the DOE and its scientific advisor, Sandia National Laboratories (SNL), in numerous documents and maintained in reference libraries that are available to the public such as the Sandia WIPP Central File (in Albuquerque, New Mexico). Many of those documents form the basis for the DOE's assertions in this application. Where necessary, specific references from these documents are cited to reinforce the statements being made. Additional sources of information on the various topics in this section are listed in a bibliography at the end of the chapter.

Biological studies of the site began in 1975 to gather information for the Environmental Impact Statement. Meteorological studies began in 1976, and economic studies were initiated in 1977. Baseline environmental data were initially reported in 1977 and are now updated annually by the DOE.

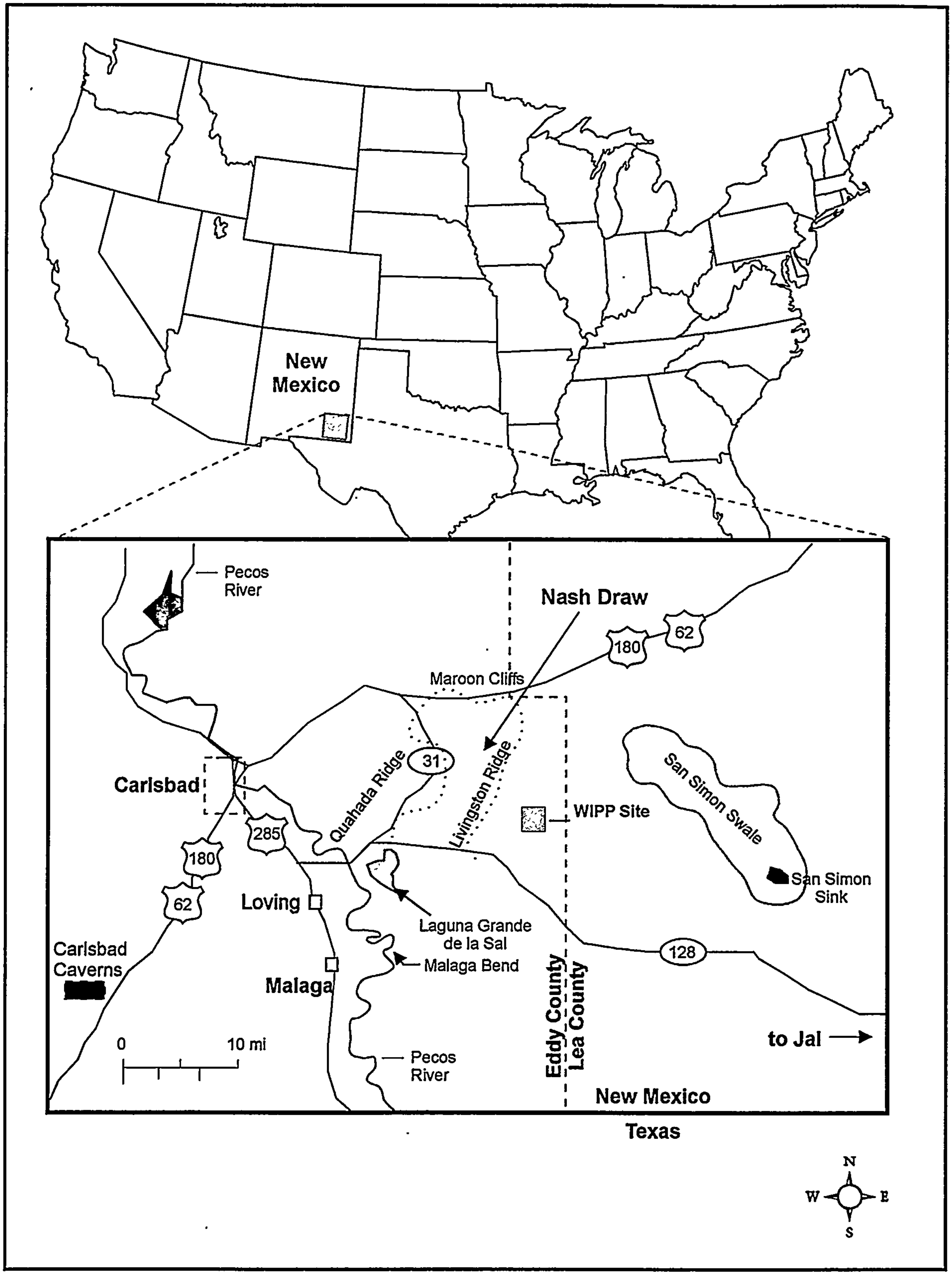

Figure 2-1. WIPP Site Location in Southeastern New Mexico

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The DOE selected the WIPP disposal horizon to be located within a rock salt deposit known as the Salado Formation (hereafter referred to as the Salado) at a depth of 2,150 feet (650 meters) below the ground surface. The Salado is regionally extensive; includes continuous beds of salt without complicated structure; is deep with little potential for dissolution; and is near enough to the surface to make access reasonable. Particular site selection criteria narrowed the choices when the present site was located during 1975–76 as discussed in Appendix GCR (p. 2-10*ff*).

One reason the DOE has for presenting a discussion of site characteristics and other features is to document how the DOE arrived at the various parameters used in the numerical codes to predict disposal system performance. This information is presented in the course of the discussions that are presented in the following chapters. A discussion of the actual values and distributions used for the performance assessment is reserved for Chapter 6. For those parameters that have been determined to be more important in terms of impact on overall system performance evaluation, the DOE is providing additional detail in appendices, such as Appendix PAR. In Appendix PAR, parameters are summarized in the form of parameter sheets. Where necessary, parameter sheets provide probability distribution functions and supporting data values. For this draft application, example parameter sheets are provided. Additional parameters will be included in the final application.

2.1 Geology

A thorough description of the WIPP facility's natural environmental setting is considered crucial by the DOE for a demonstration of compliance with the disposal standards. In this section, the DOE is addressing environmental factors and long-term environmental changes that are important for assessing the waste isolation potential of the disposal system. The detail provided by the DOE is believed to be sufficient to assess the degree of waste isolation achievable. The first of these environmental factors is the geology of the site and vicinity.

Geological data have been collected from the WIPP site and surrounding area for use in evaluating the site's suitability as a radioactive waste repository. These data have been collected principally by the DOE and its predecessor agencies, the United States Geological Survey (USGS), the New Mexico Bureau of Mines and Mineral Resources (NMBMMR), and private organizations engaged in natural resource exploration and extraction. The DOE has analyzed the data provided in the following discussion and believes it supports the DOE's position that the WIPP site is suitable for the long-term isolation of radioactive waste. Many issues have been discussed, investigated, and resolved in order for the DOE to reach the conclusion that the site is suitable. The DOE discusses these issues in the following with emphasis on the resolution of the issues. The majority of the data collected have been reported or summarized in two reports which the DOE has included as Appendix GCR and Appendix SUM.

2.1.1 Data Sources and Quality

The geology of southeastern New Mexico has been of great interest for more than a century. The Guadalupe Mountains have become a common visiting and research point for geologists because of the spectacular exposures of Permian-age reef rocks and related facies. (See Shumard [1858], Crandall [1929], Newell et al. [1953], and Dunham [1972] in the bibliography for a historical perspective.) Because of intense interest in both hydrocarbon and potash resources in the region, there exists a large volume of data as potential background for the WIPP site, though some data are proprietary. Finally, there is the geological information developed directly and indirectly by studies sponsored by WIPP; it ranges from raw data to interpretive reports.

Elements of the geology of southeastern New Mexico have been discussed or described in professional journals or technical documents from many different sources. These types of articles are an important source of information and, where there is no contrary evidence, the information in these articles is included through reference where subject material is relevant. Implicit rules of professional conduct of research and reporting are assumed to have been applied, and journal and editorial review has normally been applied. Certain elements of the geology presented in such sources have been deemed critical to the WIPP, and have been the subject of specific WIPP-sponsored studies.

The geological data which the DOE has developed explicitly for the WIPP project have been produced over a 20-year period by different organizations and contractors, during which time national standards for quality assurance (QA) and documentation have evolved. Early project data, especially, do not have all the same elements of QA that more recent data may have; for at least some studies there is a sufficient record to follow clearly the field programs, objectives, and results. Other data from project records will be incorporated here through specific reference or appendices. The DOE's activities to specifically address the quality of site characterization and other experimental data are described in Chapter 5.0.

Geological data have been developed by the DOE through a variety of WIPP-sponsored studies using drilling, mapping or other direct observation, geophysical techniques, and laboratory work. Most of the techniques and statistics of data acquisition will be incorporated by specific discussion. Boreholes are, however, a major source of geological data for the WIPP and surrounding area. From boreholes come raw data (e.g., depth measurements, amount of core, geophysical logs) that provide the basis for point data and interpreted data sets. These data are the base for computing other useful elements such as structure maps for selected stratigraphic horizons or isopachs (thickness) of selected stratigraphic intervals.

The borehole data set in Appendix BH is included as reference information. A map of some borehole locations in this data set used in this chapter is provided in Figure 2-2.

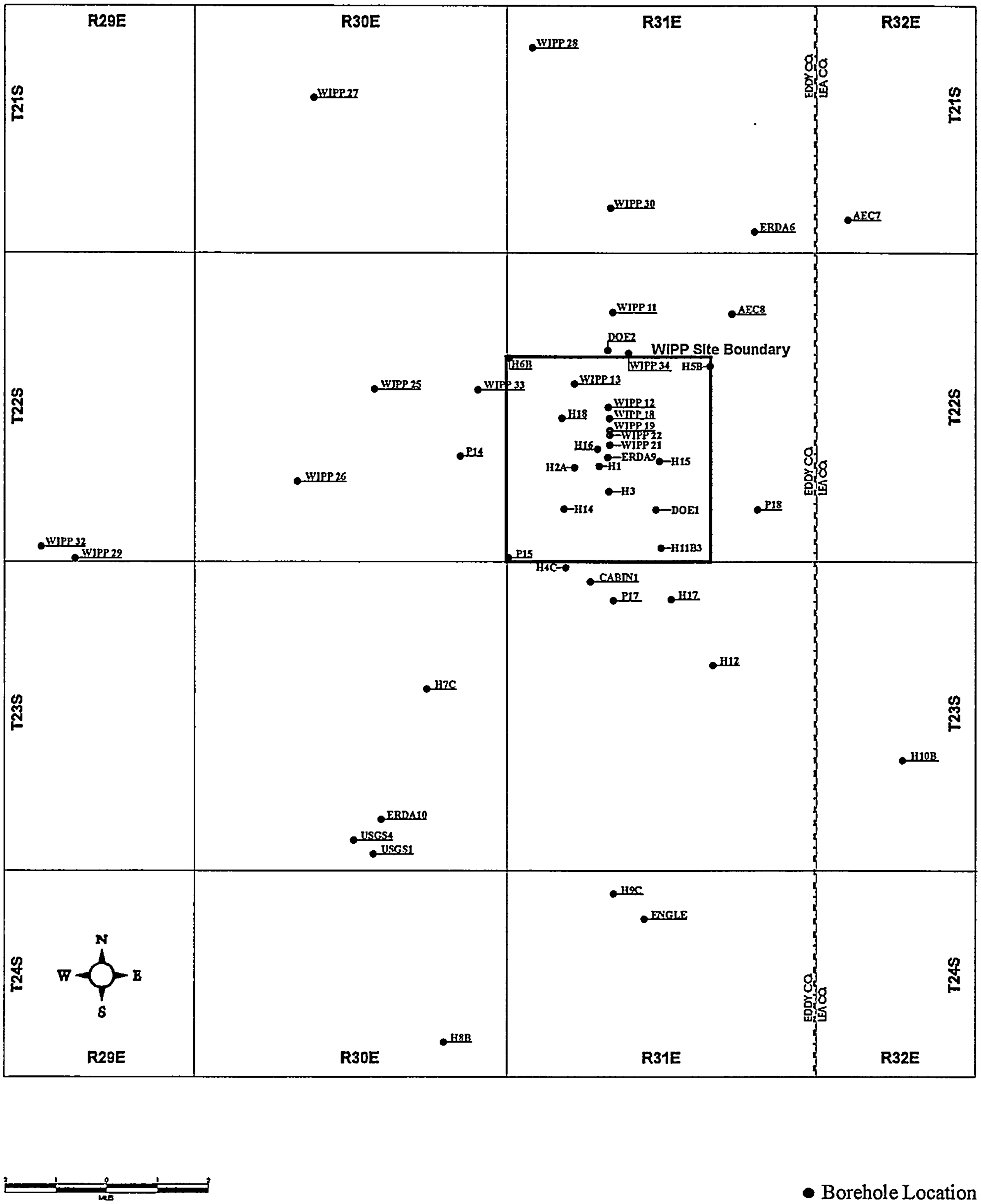

Figure 2-2. Borehole Location Map

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2.1.2 *Geologic History*

In this section the DOE summarizes the more important points of the geologic history within about 200 miles (320 kilometers) of the WIPP site, with emphasis on more recent or nearby events. Major elements of the geological history from the end of the Precambrian in the vicinity of the WIPP site were compiled in graphic form (Figure 2-3). The geologic time scale that the DOE uses for WIPP is based on the compilation by Palmer (1983, pp. 503–504) for *The Decade of North American Geology* (DNAG). There are several compiled sources of chronologic data related to different reference sections or methods (see, for example, Harland et al. [1982] and Salvador [1985] in the bibliography). Although most of these sources show generally similar ages for chronostratigraphic boundaries, there is no consensus on either reference boundaries or most-representative ages. The DNAG scale is accepted by the DOE as a standard that is useful and sufficient for WIPP purposes, as no known critical parameters require more accurate or precise dates.

The geologic history in this region can conveniently be subdivided into three general phases:

- A Precambrian period, represented by metamorphic and igneous rocks, ranging in age from about 1.5 to 1.0 billion years old
- A period principally of erosion from about 1.0 to 0.5 billion years, as there is not known to be any rock record from this time
- An interval from 0.5 billion years to the present represented by a more complex set of mainly sedimentary rocks and shorter periods of erosion and dissolution.

This latter phase is the main subject of the DOE's detailed discussion of this text.

Precambrian crystalline rocks have been penetrated in only a few deep boreholes in the vicinity of the WIPP, and therefore relatively little petrological information is available. Foster (1974, fig. 3) extrapolated the elevation of the Precambrian surface under the area of WIPP as being between 14,500 feet (4.42 kilometers) and 15,000 feet (4.57 kilometers) below sea level; the site surface at WIPP is about 3,400 feet (1,036 meters) above sea level. Keesey (1976, vol. I, exhibit no. 2) projected a depth to the top of Precambrian rocks of about 18,200 feet (5,545 meters) based on the geology of the nearby borehole in Section 15, T22S, R31E.

Precambrian rocks of a variety of types crop out in the following locations: the Sacramento Mountains northwest of WIPP; around the Sierra Diablo and Baylor Mountains near Van Horn, Texas; west of the Guadalupe Mountains at Pump Station Hills; and in the Franklin Mountains near El Paso, Texas. East of the WIPP, a relatively large number of boreholes on the Central Basin Platform have penetrated the top of the Precambrian (Foster 1974, fig. 3). As summarized by Foster (1974, p. 10), Precambrian rocks in the area considered similar to those in the vicinity of the site range in age from about 1.14 to 1.35 billion years.

For a period of about 500 million years (1.1 to 0.6 billion years ago), there is no certain rock record in the region around the WIPP. The most likely rock record for this period may be the Van Horn sandstone, but there is no conclusive evidence that it represents part of this time period. The region is generally interpreted to have been subject to erosion for much of the period, until the Bliss sandstone began to accumulate during the Cambrian.

2.1.3 Stratigraphy and Lithology in the Vicinity of the WIPP Site

In this section the DOE presents the stratigraphy and lithology of the Paleozoic and younger rocks underlying the WIPP site and vicinity (Figure 2-4), emphasizing the units nearer the surface. Details begin with the Permian (Guadalupian) Bell Canyon Formation (hereafter referred to as the Bell Canyon)—the upper unit of the Delaware Mountain Group—because this is the uppermost water-bearing formation below the evaporites. The principal stratigraphic data are the chronologic sequence, age, and extent of rock units, including some of the nearby relevant facies changes. Characteristics such as thickness and depth are summarized here from published sources for deeper rocks and are mainly based on data sets presented in Appendix BH for shallower rocks (above the Bell Canyon). The lithologies of upper formations and some formation members are described.

2.1.3.1 General Stratigraphy and Lithology below the Bell Canyon Formation

As stated previously, the Precambrian basement near the site is projected to be about 18,200 feet (5,545 meters) below the surface (Keesey 1976, vol. II, exhibit no. 2), consistent with information presented by Foster in 1974. Ages of similar rock suites in the region range from about 1.14 to 1.35 billion years.

The basal units overlying Precambrian rocks are clastic rocks commonly attributed either to the Bliss sandstone or the Ellenberger Group (Foster 1974, p. 10*ff*), considered most likely to be Ordovician in age in this area. The Ordovician system comprises the Ellenberger, Simpson, and Montoya groups in the northern Delaware Basin. Carbonates are predominant in these groups, with sandstones and shales common in the Simpson group. Foster (1974, p. 12) reported 975 feet (297 meters) of Ordovician north of the site area and extrapolated a thicker section of about 1,300 feet (396 meters) at the present site (p. 17). Keesey (1976, vol. II, exhibit no. 2) projected a thickness of 1,200 feet (366 meters) for the Ordovician system within the site boundaries.

Silurian-Devonian rocks in the Delaware Basin are not stratigraphically well defined, and there are various notions for extending nomenclature into the basin. Common drilling practice is not to differentiate, though the Upper Devonian Woodford shale at the top of the sequence is frequently distinguished from the underlying dolomite and limestone (Foster 1974, p. 18). Foster (p. 21) showed a reference thickness of 1,260 and 160 feet (384 and 49 meters) for the carbonates and the Woodford shale, respectively; he estimated thickness of these units at the present WIPP site of about 1,150 feet (351 meters) and 170 feet (52 meters), respectively. Keesey (1976, vol. II, exhibit no. 2) projected 1,250 feet (381 meters) of carbonate and showed 82 feet (25 meters) of the Woodford shale.

ERA	PERIOD	EPOCH	YEARS: DURATION	YEARS: BEFORE PRESENT	MAJOR GEOLOGIC EVENTS - SOUTHEAST NEW MEXICO REGION
CENOZOIC	Quaternary	Holocene	10,000		Eolian and erosion/solution activity. Development of present landscape.
		Pleistocene	1,590,000	1,600,000	
	Tertiary	Pliocene	3,700,000		Deposition of Gatuña fan sediments. Formation of caliche caprock. Regional uplift and east-southeastward tilting; Basin-Range uplift of Sacramento and Guadalupe-Delaware Mountains.
		Miocene	18,400,000		
		Oligocene	12,900,000		Erosion dominant. No Early to Mid-Tertiary rocks present.
		Eocene	21,200,000		Laramide "revolution" Uplift of Rocky Mountains. Mid tectonism and igneous activity to west and north.
		Paleocene	8,600,000	66,400,000	
MESOZOIC	Cretaceous		77,600,000	144,000,000	Submergence. Intermittent shallow seas. Thin limestone and clastics deposited.
	Jurassic		64,000,000	208,000,000	Emergent conditions. Erosion, formation of rolling terrain. Deposition of fluvial clastics.
	Triassic		37,000,000	245,000,000	Erosion. Broad flood plain develops.
PALEOZOIC	Permian		41,000,000	286,000,000	Deposition of evaporite sequence followed by continental redbeds. Sedimentation continuous in Delaware, Midland, Val Verde basins and shelf areas.
	Pennsylvanian		34,000,000	320,000,000	Massive deposition of clastics. Shelf, margin, basin pattern of deposition develops.
	Mississippian		40,000,000	360,000,000	Regional tectonic activity accelerates, folding up Central Basin platform. Matador arch, ancestral Rockies. Regional erosion. Deep, broad basins to east and west of platform develop.
	Devonian		48,000,000	408,000,000	Renewed submergence. Shallow sea retreats from New Mexico; erosion. Mild epeirogenic movements. Tobosa basin subsiding. Pedernal landmass and Texas Peninsula emergent until Middle Mississippian.
	Silurian		30,000,000	438,000,000	
	Ordovician		67,000,000	505,000,000	Marathon-Quachita geosyncline, to south, begins subsiding. Deepening of Tobosa basin area; shelf deposition of clastics, derived partly from ancestral Central Basin platform and carbonates.
	Cambrian		65,000,000	570,000,000	Clastic sedimentation - Bliss sandstone.
	PRECAMBRIAN				Erosion to a nearly level plain. Mountain building, igneous activity, metamorphism, erosional cycles.

Figure 2-3. Major Geologic Events - Southeast New Mexico Region

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SYSTEM	SERIES	GROUP	FORMATION	MEMBER
RECENT	RECENT		SURFICIAL DEPOSITS	
QUARTER-NARY	PLEISTO-CENE		MESCALERO CALICHE	
			GATUÑA	
TERTIARY	MID-PLIOCENE		OGALLALA	
TRIASSIC		DOCKUM	SANTA ROSA	
PERMIAN	OCHOAN		DEWEY LAKE	
			RUSTLER	Forty-niner
				Magenta Dolomite
				Tamarisk
				Culebra Dolomite
				unnamed
			SALADO	upper
				McNutt Potash
				lower
			CASTILE	
	GUADALUPIAN	DELAWARE MOUNTAIN	BELL CANYON	
			CHERRY CANYON	
			BRUSHY CANYON	

Figure 2-4. Site Geologic Column

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The Mississippian system in the northern Delaware Basin is commonly attributed to "Mississippian limestone" and the overlying Barnett shale (Foster 1974, p. 24), but the nomenclature is not consistently used. At the reference well used by Foster (p. 25), the limestone is 540 feet (165 meters) thick and the shale is 80 feet (24 meters); isopachs at the WIPP are 480 feet (146 meters) and less than 200 feet (61 meters). Keesey (1976, vol. II, exhibit no. 2) indicates 511 feet (156 meters) and 164 feet (50 meters), respectively, within the site boundaries.

The nomenclature of the Pennsylvanian system applied within the Delaware Basin is both varied and commonly inconsistent with accepted stratigraphic rules. Chronostratigraphic or time-stratigraphic names are applied to these lithologic units: the Morrow, Atoka, and Strawn, from base to top (Foster 1974, p. 31). Foster (p. 34) extrapolated thicknesses of about 2,200 feet (671 meters) for the Pennsylvanian at the WIPP site. Keesey (1976, vol. II, exhibit no. 2) reports 2,088 feet (636 meters) for these units. The Pennsylvanian rocks in this area are mixed clastics and carbonates, with carbonates more abundant in the upper half of the sequence.

The Permian is the thickest system in the northern Delaware Basin, and it is divided into four series from the base to top: Wolfcampian, Leonardian, Guadalupian, and Ochoan. According to Keesey (1976, vol. II, exhibit no. 2), the three lower series total 8,684 feet (2,647 meters) near the site. Foster (1974, p. 35*ff*) indicates a total thickness for the lower three series of 7,665 feet (2,336 meters) for a reference well north of WIPP. Foster's isopach maps of these series indicate about 8,500 feet (2,591 meters) for the WIPP site area. The Ochoan series at the top of the Permian is considered in more detail later because the formations host and surround the WIPP repository horizon. Its thickness at DOE-2, about 2 miles (3.2 kilometers) north of the site center, is 3,938 feet (1,200 meters) according to Mercer et al. (1987, pp. 23–24; this document is appended to the Compliance Certification Application as Appendix HYDRO).

The Wolfcampian series is also referred to as the Wolfcamp Formation (hereafter referred to as the Wolfcamp) in the Delaware Basin. In the site area, the lower part of the Wolfcamp is dominantly shale with carbonate and some sandstone according to Foster (1974, p. 38); carbonate increases to the north. Clastics increase to the east toward the margin of the Central Basin Platform. Keesey (1976, vol. II, exhibit no. 2), reports the Wolfcamp to be 1,493 feet (455 meters) thick at a well near the WIPP site.

The Leonardian Series is represented by the Bone Spring Limestone or Formation (hereafter referred to as the Bone Spring). According to Foster (1974, p. 39) the lower part of the formation is commonly interbedded carbonate, sandstone, and some shale, while the upper part is dominantly carbonate. Near the site, the Bone Spring is 3,247 feet (990 meters) thick according to Keesey (1976, vol. II, exhibit no. 2).

The Guadalupian series is represented in the general area of the site by a number of formations exhibiting complex facies relationships (Figure 2-5). The Guadalupian series is known in considerable detail west of the site from outcrops in the Guadalupe Mountains, where numerous outcrops and subsurface studies have been undertaken. (See, for example, P.B. King [1948], Newell et al. [1953], and Dunham [1972] in the bibliography). According to Garber et al. (1989, p. 36), similar facies relationships are expected from the site to the north (Figure 2-5).

Within the Delaware Basin, the Guadalupian series comprises three formations: Brushy Canyon, Cherry Canyon, and Bell Canyon, from base to top. These formations are dominated by submarine channel sandstones with interbedded limestone and some shale. A limestone (Lamar) generally tops the series, immediately underneath the Castile Formation (hereafter referred to as the Castile). Around the margin of the Delaware Basin, reefs developed during the same time the Cherry Canyon and Bell Canyon formations were being deposited. These massive reef limestones, the Goat Seep and Capitan limestones, are equivalent in time to these basin sandstone formations, but were developed much higher topographically around the basin margin. A complex set of limestone to sandstone and evaporite beds was deposited further away from the basin behind the reef limestones. The Capitan reef limestones are well known because the Carlsbad Caverns are partially developed in these rocks.

2.1.3.2 The Bell Canyon Formation

The Bell Canyon is known from outcrops on the west side of the Delaware Basin and from subsurface intercepts for oil and gas drilling. Several informal lithologic units are commonly named during such drilling. Mercer et al. (1987, p. 28) stated that DOE-2 penetrated the Lamar limestone, the Ramsey sand, the Ford shale, the Olds sand, and the Hays sand. This informal nomenclature is used for the Bell Canyon in some other WIPP reports.

The Clayton Williams Badger Federal borehole near the WIPP (Section 15, T22S, R31E) intercepted 961 feet (293 meters) of Bell Canyon, including the Lamar limestone, according to Keesey (1976, vol. II, exhibit no. 2). Reservoir sandstones of the Bell Canyon were deposited in channels that are straight to slightly sinuous. Density currents flowed from shelf regions, cutting channels and depositing the sands which are identified in Harms and Williamson (1988, pp. 299–317).

Within the basin, the Bell Canyon (Lamar limestone)–Castile contact is distinctive on geophysical logs because of the contrast in low natural gamma of the basal Castile anhydrite compared to the underlying limestone. Density or acoustic logs are also distinctive because of the massive and uniform lithology of the anhydrite compared to the underlying beds. In cores, the transition is sharp, as described by Mercer et al. (Appendix HYDRO, p. 312) for DOE-2.

2.1.3.3 The Castile Formation

The Castile is the lowermost lithostratigraphic unit of the Late Permian Ochoan series (Figure 2-6). It was originally named by Richardson for outcrops in Culberson County, Texas. The Castile crops out along a lengthy area along the western side of the Delaware Basin. The two distinctive lithologic sequences now known as the Castile and the Salado were separated into the upper and lower Castile by Cartwright. Lang clarified the nomenclature by restricting the

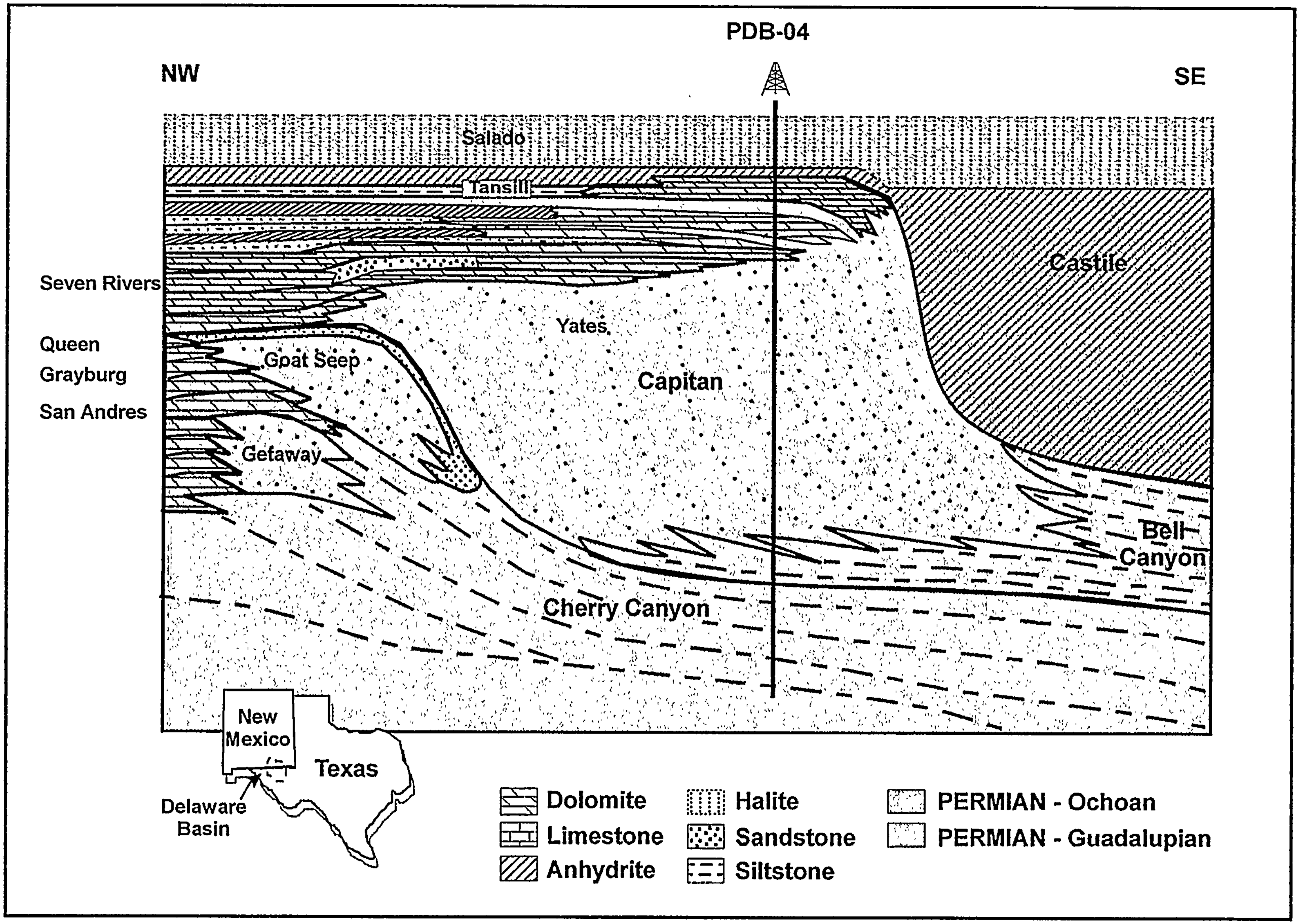

Figure 2-5. Cross-Section from Delaware Basin (southeast) through Marginal Reef Rocks to Back-Reef Facies

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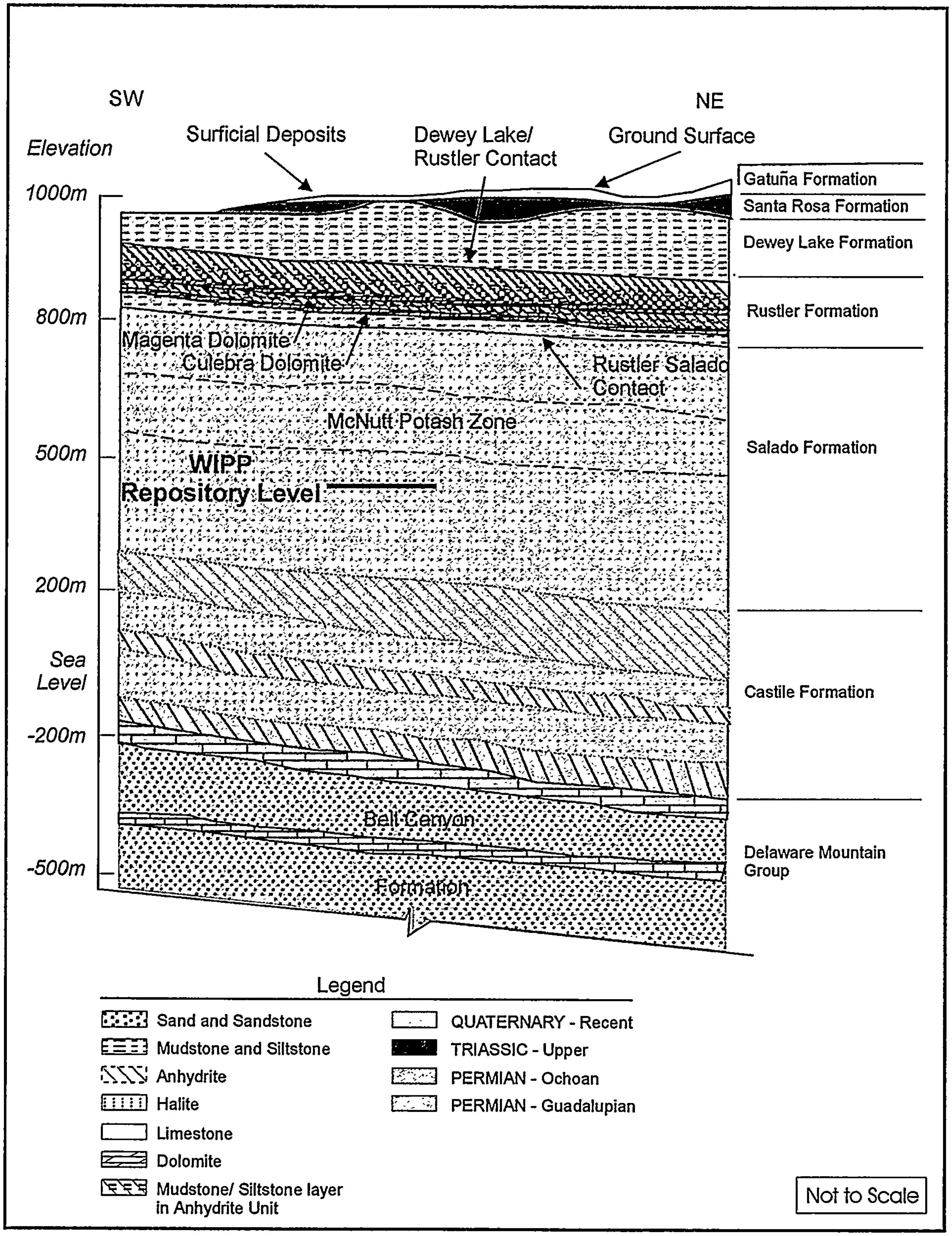

Figure 2-6. Generalized Stratigraphic Cross-Section above Bell Canyon Formation at WIPP Site

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Castile to the lower unit and naming the upper unit the Salado. By defining an anhydrite resting on the marginal Capitan limestone as part of the Salado, Lang effectively restricted the Castile to the Delaware Basin inside the reef rocks.

Through detailed studies of the Castile, Anderson et al. (1972, pp. 59–86) introduced an informal system of names that are widely used and included in many WIPP reports. They named the units from the base as anhydrite 1 (A1), halite 1 (H1), anhydrite 2 (A2), etc. The informal nomenclature varies through the basin from A3 up because of complexity of the depositional system. The Castile consists almost entirely of thick beds of two lithologies: (1) interlaminated carbonate and anhydrite and (2) high-purity halite. The interlaminated carbonate and anhydrite are well known as possible examples of annual layering or varves.

In the eastern part of the Delaware basin, the Castile is commonly 1,400–1,500 feet thick (427–457 meters) (derived from Borns and Shaffer 1985, figs. 9, 11, 16). At DOE-2, the Castile is 989 feet (301 meters) thick. The Castile is thinner in the western part of the Delaware Basin, and it lacks halite units. Anderson and Powers (1978, figs. 1, 3, 4, 5) correlated geophysical logs, interpreting thin zones equivalent to halite units as dissolution residues. Anderson further attributed the lack of halite in the basin to its removal by dissolution.

For borehole DOE-2, a primary objective was to ascertain whether a series of depressions in the Salado 2 miles (3.3 kilometers) north of the site was due to dissolution in the Castile as proposed by Davies in his doctoral thesis in 1984. Studies have suggested that these depressions were not due to dissolution but halokinesis in the Castile (see, for example, Borns [1987] and Chaturvedi [1987] in the bibliography). Robinson and Powers (1987, pp. 69–79) analyzed one such unit as partly due to synsedimentary, gravity-driven, clastic deposition and suggested that the extent of dissolution may be overestimated. No Castile dissolution is known to be present in the immediate vicinity of the WIPP site. The process of dissolution and the resulting features are further discussed later in this chapter.

In Culberson County, Texas, the Castile hosts major native sulfur deposits. The outcrops of Castile on the Gypsum Plain south of White's City, New Mexico, have been explored for native sulfur without success, and there is no reported indicator of native sulfur anywhere in the vicinity of WIPP.

Appendix GCR reports that in part of the area around the WIPP, the Castile has been significantly deformed, and there are pressurized brines associated with the deformed areas; borehole ERDA-6 encountered both. WIPP-12, 1 mile (1.6 kilometers) north of the site center, revealed lesser Castile structure, but it also encountered a zone of pressurized brine within the Castile. Castile deformation is described and discussed later in Section 2.1.5 on structural features, and pressurized brines are described in Section 2.2 which details the area's hydrology.

The Castile continues to be an object of research interest unrelated to the WIPP program as an example of evaporites supposedly deposited in "deep water." Anderson (1993, pp. 12–13) discusses alternatives and contradictory evidence. Although these discussions and a resolution might eventually affect some concepts of Castile deposition and dissolution, this issue is largely of academic interest and bears no impact on the suitability of the Los Medaños region for the WIPP site.

2.1.3.4 The Salado Formation

The Salado is dominated by halite, in contrast to the underlying Castile. The Salado extends well beyond the Delaware Basin, and Lowenstein (1988, pp. 592–608) has termed the Salado a "saline giant." While the Fletcher Anhydrite Member, which is deposited on the Capitan reef rocks, is defined by Lang (1939, pp. 1569–1572; 1942, pp. 63–79) as the base of the Salado, some investigators consider that the Fletcher Anhydrite Member may interfinger with anhydrites normally considered part of the Castile within the basin. The Castile-Salado contact is not uniform across the basin, and whether it is conformable is unresolved. Around the WIPP site, the Castile-Salado contact is commonly placed at the top of a thick anhydrite informally designated A3; the overlying halite is called the infra-Cowden salt and is included within the Salado. Bodine (1978, pp. 28–29) suggests that the clay mineralogy of the infra-Cowden in ERDA-9 cores changes at about 15 feet (4.6 meters) above the lowermost Salado and that the lowermost clays are more like Castile clays. The top of the thick anhydrite remains the local contact for differentiating the Salado from the Castile, and there is no known significance to WIPP from these differences.

The Salado in the northern Delaware Basin is broadly divided into three informal members used here. Figure 2-7 details the Salado's stratigraphy. The middle member is known locally as the McNutt potash zone or member, and it includes 11 defined potash zones, 10 of which are of economic significance in the Carlsbad Potash District. The lower and upper members remain unnamed. The WIPP repository level is located below the McNutt potash member in the lower member.

Within the Delaware Basin, a system is used for numbering the more significant sulfate beds within the Salado, designating these beds as marker beds (MB) from MB 100 (near the top of the formation) to MB 144 (near the base). The system is generally used within the Carlsbad Potash District as well as at and around the WIPP site. The facility horizon is located between MB 139 and MB 138.

In the central and eastern part of the Delaware Basin, the Salado is at its thickest ranging up to about 2,000 feet (about 600 meters) thick and consisting mainly of interbeds of sulfate minerals and halite, with halite dominating. The thinnest portions of the Salado consist of a brecciated residue of insoluble material a few tens-of-feet-thick and crop out in parts of the western Delaware Basin. The common sulfate minerals are anhydrite ($CaSO_4$), gypsum ($CaSO_4 \bullet 2H_2O$) near the surface, and polyhalite ($K_2SO_4 \bullet MgSO_4 \bullet 2CaSO_4 \bullet 2H_2O$). They form beds and are also found along halite grain boundaries.

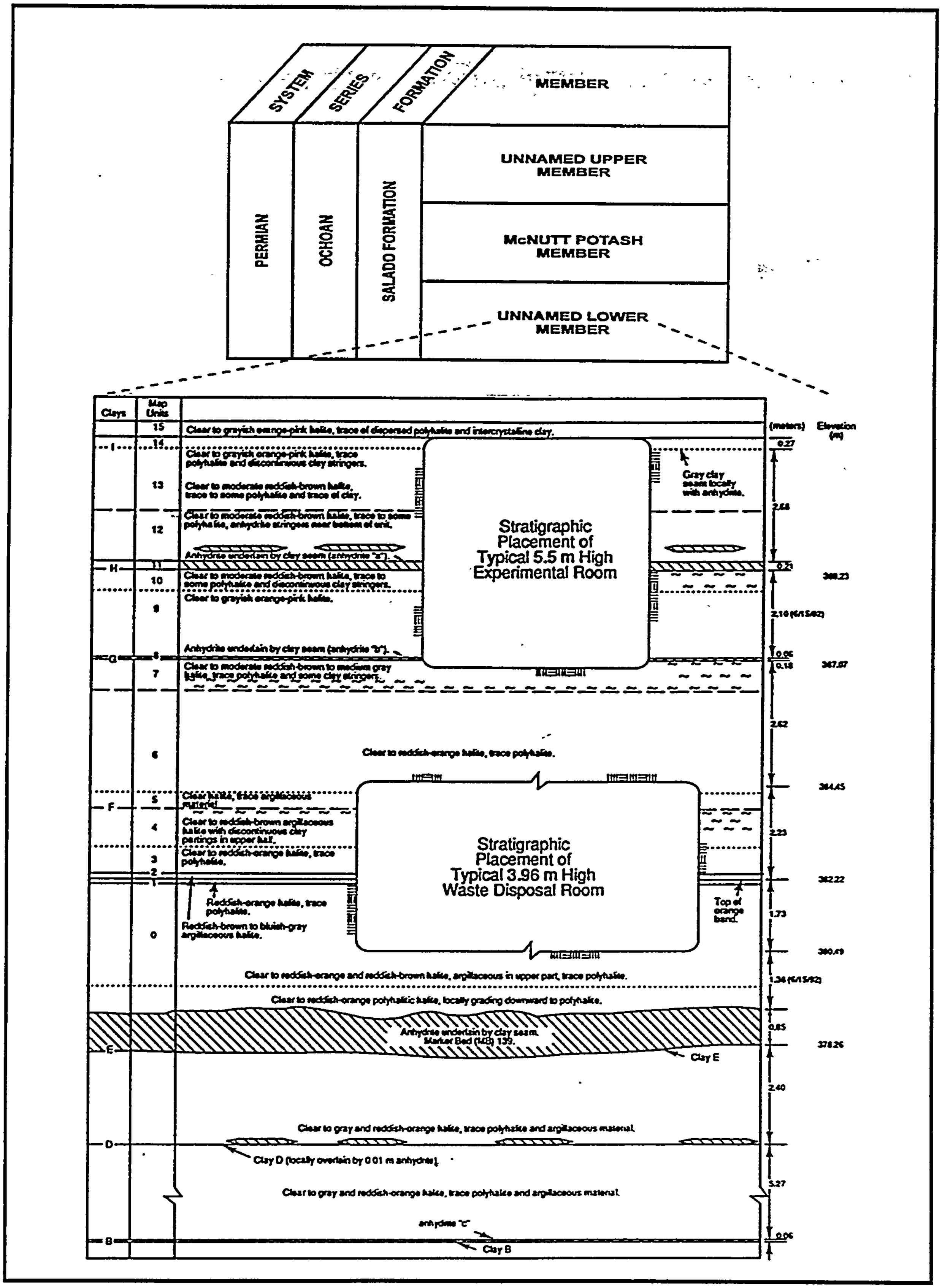

Figure 2-7. Salado Stratigraphy

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Early investigators of the Salado recognized a repetitious vertical succession or cycle of beds in the Salado: clay - anhydrite - polyhalite - halite and minor polyhalite - halite. Later investigators described the cyclical units as clay - magnesite - anhydrite, polyhalite or glauberite - halite - argillaceous halite capped by mudstone. Lowenstein (1988, pp. 592–608) defined a depositional cycle (Type I) consisting of (1) basal mixed siliciclastic and carbonate (magnesite) mudstone, (2) laminated to massive anhydrite or polyhalite, (3) halite, and (4) halite with mud. Lowenstein also recognized repetitious sequences of halite and halite with mud as incomplete Type I cycles and termed them Type II cycles. Lowenstein (1988, pp. 592–608) interpreted the Type I cycles as having formed in a shallowing upward, desiccating basin beginning with a perennial lake or lagoon of marine origin and evaporating to saline lagoon and saltpan environments. Type II cycles are differentiated because they do not exhibit features of prolonged subaqueous deposition and also have more siliciclastic influx than do Type I cycles.

From detailed mapping of the Salado in the Air Intake Shaft at WIPP, Powers and Holt (1990a, pp. 45–72) constructed a more detailed sedimentological analysis of Salado depositional cycles, similar in broad aspects to the Type I cycle of Lowenstein. The details available from the shaft demonstrated the important role of syndepositional water level to water table changes that created solution pits and pipes within the halitic beds while they were at the surface. Powers and Holt (1990a, app. F, p. 3-26) concluded that passive halite cements filled the pits and pipes, as well as less dramatic voids, as the water table rose (Powers and Holt 1990a, app. F, p. 3-26). Early diagenetic to synsedimentary cements filled the porosity early and rather completely, reducing the porosity to a very small volume according to Casas and Lowenstein. These void-filling halites are commonly clear and coarsely crystalline and might be mistaken for recrystallization textures. Although Holt and Powers did not find it in their 1988 study (which is included as Appendix FAC), other investigators have found much evidence for halite recrystallization (or halite diagenesis) in the Salado.

The effects of water-rock interactions resulting in evaporite dissolution in the Salado are observable near the surface in Nash Draw and other localities where gypsum karst is developed and where overlying units such as the Rustler Formation (hereafter referred to as the Rustler), Dewey Lake Redbeds (hereafter referred to as the Dewey Lake), and post-Permian rocks have subsided. Physical evidence of water-rock interation (e.g., post-depositional accumulation of insoluble residues, brecciation from differential collapse, mass removal) in the Salado is less apparent, especially where it is buried at depths greater than 990 feet (300 meters). However, given the susceptibility of evaporite minerals to dissolution by circulating groundwater, geochronological investigations provide a means of determining the approximation time of latest episode of regional recrystallization of the evaporite minerals, which can be inferred as the approximate time of the latest episode of freely circulating groundwater. Radiometric dates for minerals of the Salado are available from several sources (Register and Brookins 1980, pp. 29–31; Brookins 1980, pp. 29–31; Brookins et al. 1980, pp. 635–637; Brookins 1981, pp. 147–152; Brookins and Lambert 1987, pp. 147–152). The distribution of dates shows that rubidium-strontium (Rb-Sr) isochron determinations on evaporite minerals, largely sylvite (179–229 million years ago), are in good agreement with potassium-argon (K-Ar) determinations on pure polyhalites (195–216 million years ago).

The only recrystallization event found younger than Early Jurassic (200 million years ago) was known to be a contact phenomenon associated with emplacement of an Oligocene lamprophyre dike (21 million years ago for polyhalite versus 32–34 million years ago for the dike; see Calzia and Hiss 1978, pp. 39–45). Clay minerals have both Rb-Sr isochron and K-Ar ages significantly older (390±77 million years ago) than the evaporites.

It has been known that sylvite yields significantly younger K-Ar ages than Rb-Sr ages. This has been explained as loss of radiogenic argon. Radiogenic strontium, as a solid, and thus dating by the Rb-Sr isochron method is not considered as likely to give spurious results, especially if the isochron is well defined. The results of radiometric determinations argue for the absence of pervasive recrystallization of the evaporites in the Salado in the last 200 million years ago. This conclusion is supported by the number of replicate determinations, the wide distribution of dated minerals throughout the Delaware Basin, and the concordance of dates obtained by various radiometric methods.

Argillaceous halites and halitic mudstone at the top of many depositional cycles were interpreted by Powers and Holt (1990a, pp. 45–78) in terms of modern features such as those at Devil's Golf Course at Death Valley National Monument, California. The evaporative basin was desiccated, and varying amounts of insoluble residues collected on the surface through surficial dissolution, eolian sedimentation, and some clastic sedimentation from temporary flooding caused by runoff from surrounding areas. The surface developed local relief that could be mapped in some cycles, while the action of continuing desiccation and exposure increasingly concentrated insoluble residues. Flooding, most commonly from marine sources, reset the sedimentary cycle by depositing a sulfate bed.

Within Nash Draw, Robinson and Lang (1938, pp. 2-64–2-67) recognized a zone equivalent to the upper Salado but lacking halite. Test wells in southern Nash Draw produced brine from this interval, and it has become known as the brine aquifer. Robinson and Lang considered this zone a residuum from dissolution of Salado halite (see Section 2.1.6.2.1 later in this chapter). Jones et al. (1960, p. 25) remarked that the residuum should be considered part of the Salado, though geophysical log signatures may resemble the lower Rustler.

At the center of the site, Holt and Powers in their 1984 report recognized clasts of fossil fragments and mapped channeling in siltstones and mudstones above halite; they considered these beds to be a normal part of the transition from shallow evaporative lagoons and desiccated salt pans of the Salado to the saline lagoon of the lower Rustler. Though Salado salt may have been dissolved prior to deposition of Rustler clastics, this process is far removed from the concept of subsurface removal of salt from the Salado in more recent time to develop a residuum and associated "brine aquifer."

Based on Salado isopachs (see Section 2.1.6.2.2 later in this chapter), thickness begins to change significantly near Livingston Ridge, the eastern margin of Nash Draw. That should be the approximate eastward limit to the residuum and "brine aquifer," though the normal sedimentary sequence may yield limited fluids east of this margin.

The DOE believes the Salado is of primary importance to the containment of waste. As the principal natural barrier, many of the properties of the Salado have been characterized by the DOE and numerical codes were developed by the DOE to simulate the natural processes within the Salado that affect the disposal system performance. These properties fall into two categories: physical and hydrological. The physical properties of importance are summarized in Appendix RM and discussed in Chapter 6. The hydrological properties are included in Section 2.2.1. A discussion of the numerical code(s) used to simulate Salado performance is included in Chapter 6.

2.1.3.5 The Rustler Formation

The Rustler Formation (hereafter referred to as the Rustler) is the youngest evaporite-bearing formation in the Delaware Basin. It was originally named by Richardson for outcrops in the Rustler Hills of Culberson County, Texas. Adams (1944, p. 1614) first used the names "Culebra member" and "Magenta member" to describe the two carbonates in the formation, indicating that Lang favored the names, though Lang did not use these names in his most recent publication. Vine in his 1963 work described extensively the Rustler in Nash Draw and proposed the four formal names and one informal term for the stratigraphic subdivisions still used for the Rustler (from the base): unnamed lower member, Culebra Dolomite Member, Tamarisk Member, Magenta Dolomite Member, and Forty-niner Member (Figure 2-8). (The Culebra Dolomite Member, the Tamarisk Member, the Magenta Dolomite Member, and the Forty-niner Member are hereafter referred to as the Culebra, the Tamarisk, the Magenta, and the Forty-niner.) Though it has been noted by some investigators that the unnamed lower member might be named the Los Medaños Member, this nomenclature has not been formalized.

An additional system of informal subdivisions was contributed by Holt and Powers (Appendix FAC, fig. 3.2), based on more detailed lithologic units of the non-carbonate members (Figure 2-8). These subdivisions have partially been related to hydrostratigraphic units for the Rustler.

Two studies of the Rustler since Vine's 1963 work contribute important information about the stratigraphy, sedimentology, and regional relationships while examining more local details as well. Eager (1983, pp. 273–283) reported on relationships of the Rustler observed in the southern Delaware Basin as part of sulfur exploration in the area. Holt and Powers (Appendix FAC, Section 5.0) reported the details of sedimentologic and stratigraphic studies of WIPP shafts and cores as well as of geophysical logs from about 600 boreholes in southeastern New Mexico.

The Rustler is regionally extensive; a similar unit in the Texas panhandle is also called the Rustler. Within the area around WIPP, evaporite units of the Rustler are interbedded with significant siliciclastic beds and the carbonates. Both the Magenta and the Culebra extend regionally beyond areas of direct interest to the WIPP. In the general area of the WIPP, both the Tamarisk and the Forty-niner have similar lithologies: lower and upper sulfate beds and a middle unit that varies principally from mudstone to halite from west to east (Figure 2-8).

In a general sense, halite in the unnamed lower member broadly persists to the west of the WIPP site, and halite is found east of the center of the WIPP in the Tamarisk and the Forty-niner (Figure 2-9). (Additional detail on the lithologies of these members follow.) Two different explanations have been used to account for the halite distribution. A prominent model in many documents is that halite was originally deposited relatively uniformly in the non-carbonate members across southeastern New Mexico, including the WIPP site area. The modern distribution resulted from dissolution of Rustler halite to the west of the site. As shown in Appendix FAC (p. 6-20, 6-22), sedimentary features and textures within WIPP shafts and cores that led them to propose an alternative model of depositional facies for the mudstone-halite units; halite was dissolved syndepositionally from mud flat facies, especially to the west, and was redeposited in a halite pan to the east. Culebra transmissivity shows about six orders of magnitude variation across the area around the site, and the changes have commonly been attributed to deformation resulting from post-depositional dissolution of Rustler halite.

In the region around WIPP, the Rustler reaches a maximum thickness of more than 500 feet (152 meters) (Figure 2-10), while it is about 300–350 feet (91–107 meters) thick within most of the WIPP site. Much of the difference in Rustler thickness can be attributed to variations in the amount of halite contained in the formation from place to place. Variation in Tamarisk thickness accounts for a larger part of thickness changes than do variations in either the unnamed lower member or the Forty-niner.

Much project-specific information about the Rustler is contained in Appendix FAC. The WIPP shafts were a crucial element in Holt and Power's 1988 study, exposing features not previously reported. Cores were available from several WIPP boreholes, and their lithologies were matched to geophysical log signatures to extend the interpretation throughout a larger area in southeastern New Mexico.

2.1.3.5.1 Unnamed Lower Member

The unnamed lower member rests on the Salado with apparent conformity at the WIPP site. It consists of significant proportions of bedded and burrowed siliciclastic sedimentary rocks with cross-bedding and fossil remains. These beds record the transition from strongly evaporative environments of the Salado to saline lagoonal environments. The upper part of the unnamed lower member includes halitic and sulfitic beds within clastics. Holt and Powers (in Appendix FAC, p. 9-1*ff*) interpret these as facies changes within a saline playa environment. The implied model from earlier descriptions is that the non-halitic areas of the upper unnamed lower member are dissolution residues from post-depositional dissolution.

As shown in Appendix FAC (Fig. 4.7), the unnamed lower member ranges in thickness from about 96 to 126 feet (29 to 38 meters) within the site boundaries. The maximum thickness recorded during that study was 208 feet (63 meters) southeast of the WIPP site. Halite extends west of most of the site area in this unit (see Figure 2-9 for an illustration of the halite margins). Cross-sections based on geophysical log interpretations in Appendix FAC show the relationship between the thickness of the unit and the presence of halite.

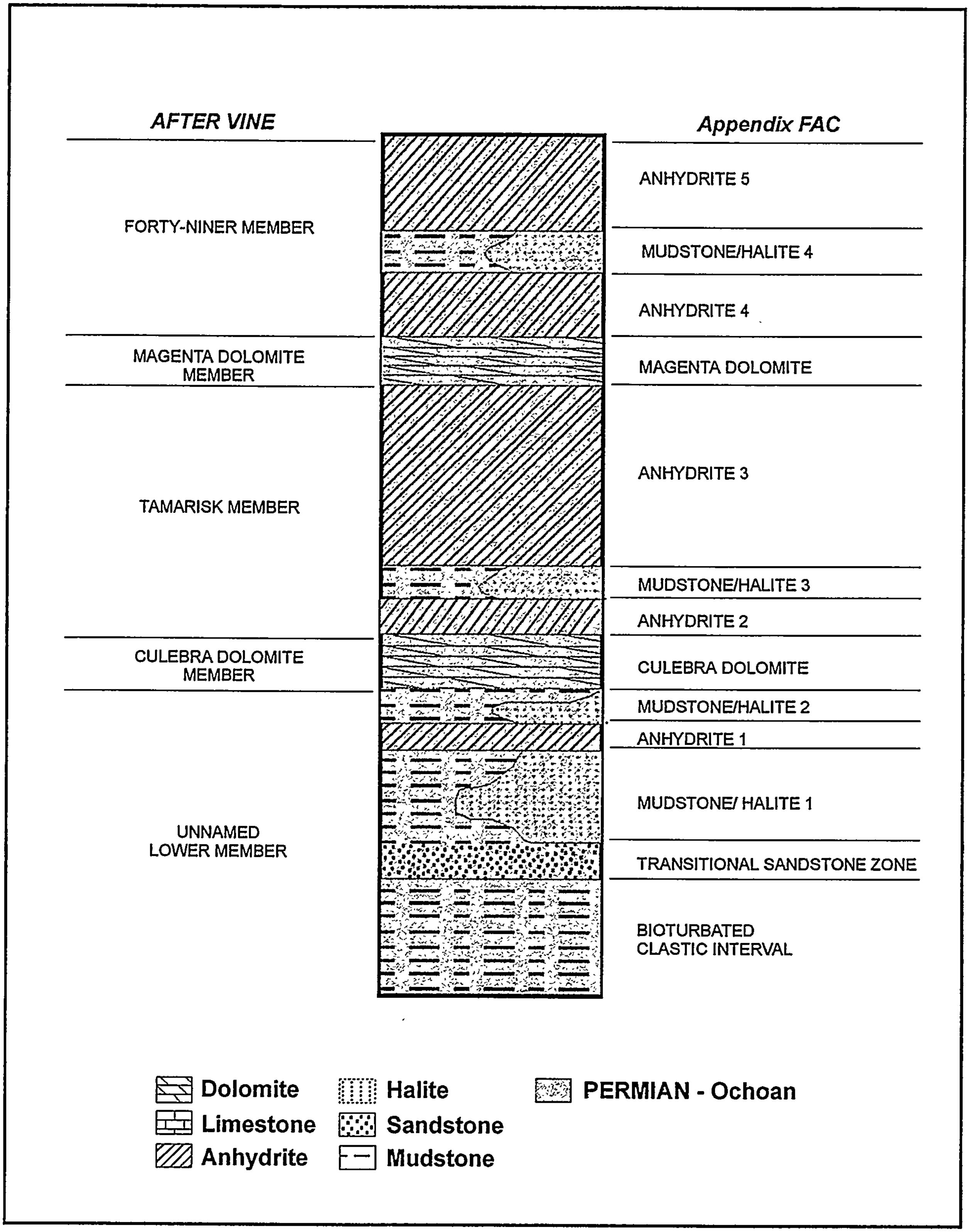

Figure 2-8. Rustler Stratigraphy

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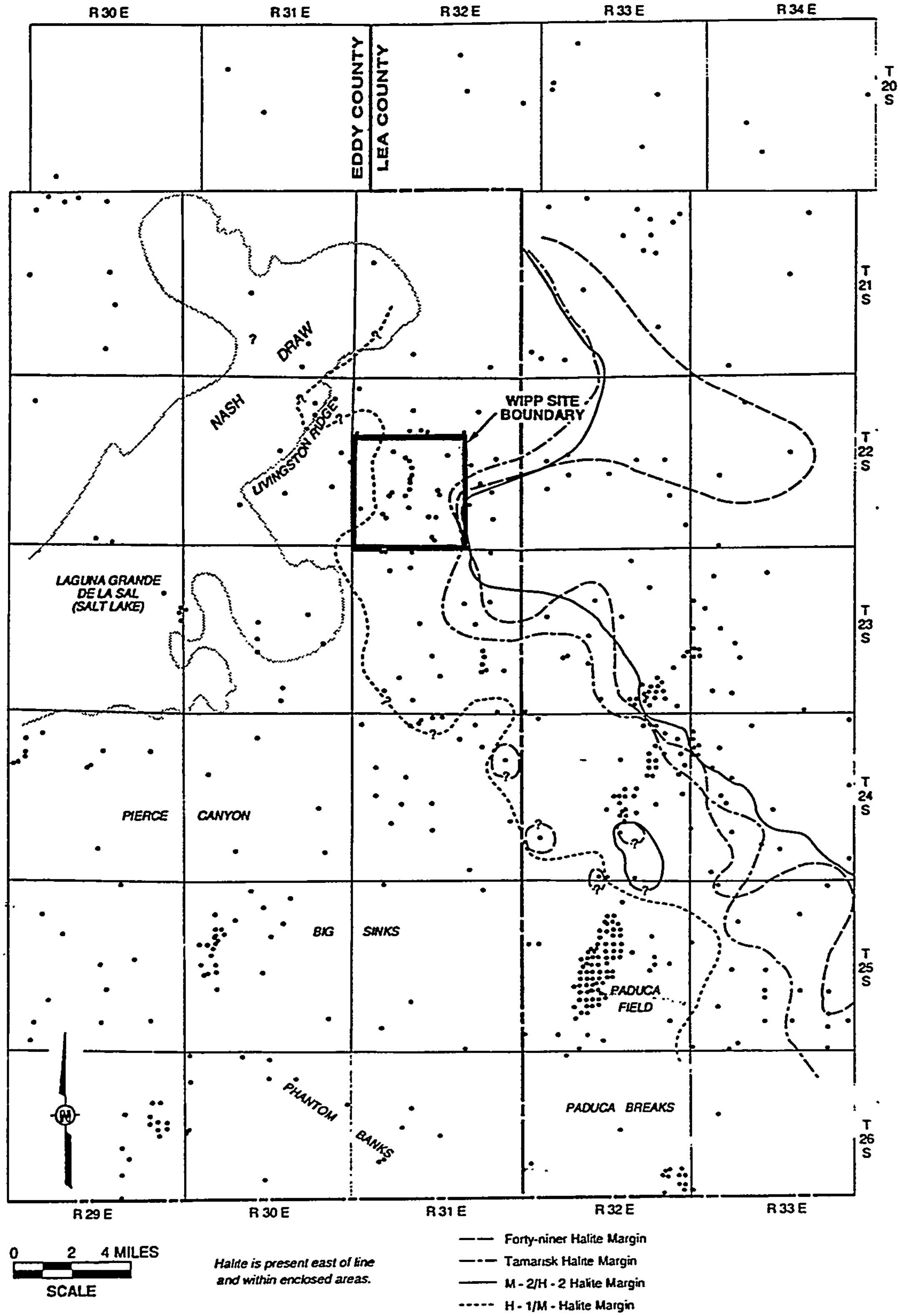

1 **Figure 2-9. Halite Margins in the Rustler**

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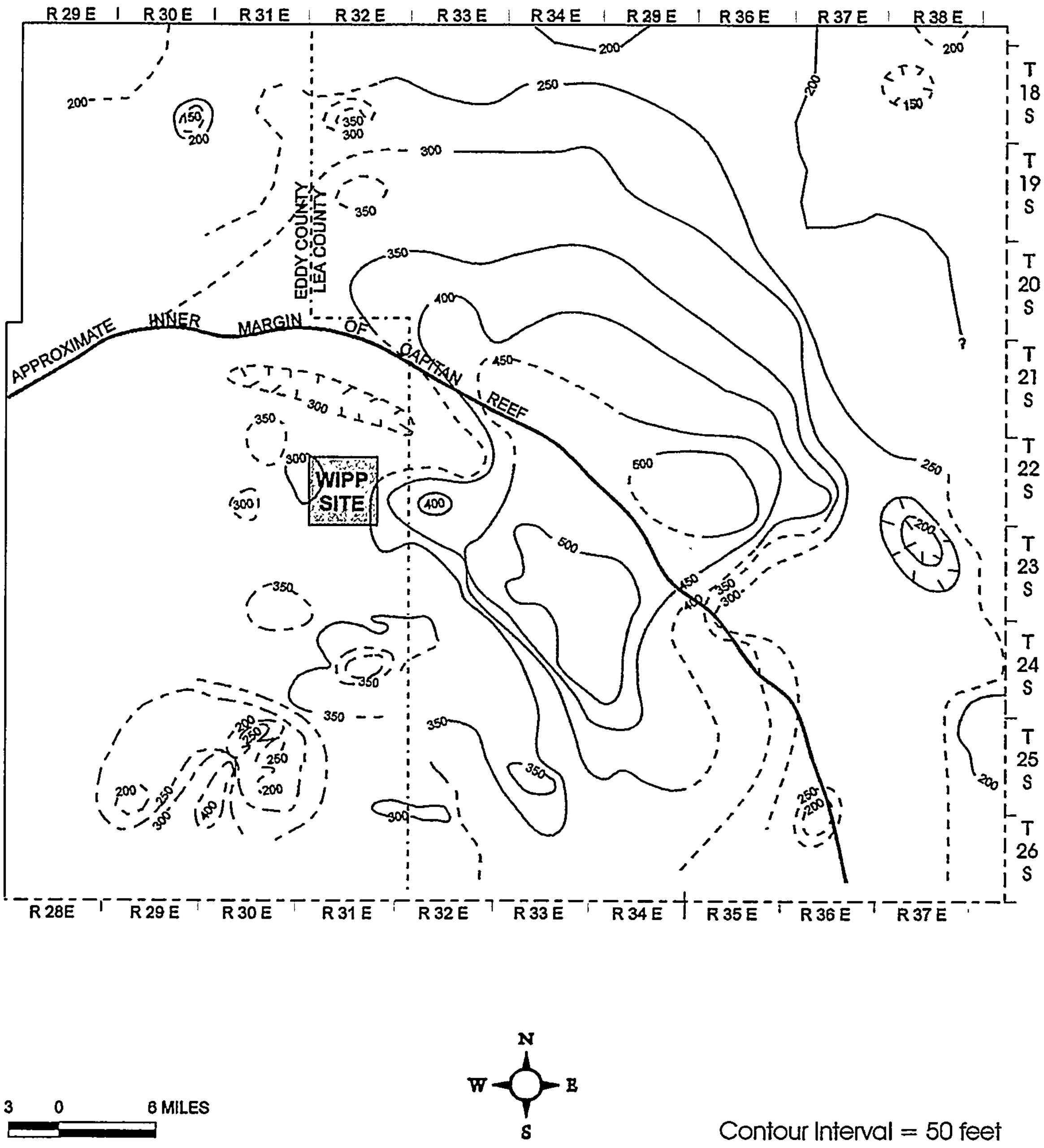

Figure 2-10. Isopach Map of the Entire Rustler

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2.1.3.5.2 The Culebra Dolomite Member

The Culebra rests with apparent conformity on the unnamed lower member, though the underlying unit ranges from claystone to its lateral halitic equivalent in the site area. West of the WIPP site, in Nash Draw, the Culebra is disrupted in response to dissolution of underlying halite. Holt and Powers (see Appendix FAC, pp. 6-12, 6-13, 8-14*ff*) attribute this principally to dissolution of Salado halite, while Snyder (1985, p. 6) indicates that salt was dissolved post-depositionally from the unnamed lower member. These alternative models provide the basis for differing explanations of how the existing Rustler hydrologic system developed and might continue to develop. The regulatory period of concern is short enough and boundaries close enough that these differences will not affect performance assessment.

The Culebra was described by Robinson and Lang as a dolomite 35 feet (11 meters) in thickness; Adams (1944, p. 78) noted that oölites are present in some outcrops as well. The Culebra is generally brown, finely crystalline, locally argillaceous and arenaceous dolomite with rare to abundant vugs with variable gypsum and anhydrite filling. Appendix FAC describes the Culebra features in detail, noting that most of the Culebra is microlaminated to thinly laminated while some zones display no depositional fabric. Holt and Powers (1984) described an upper interval of the Culebra consisting of waxy, golden-brown carbonate, dark organic claystone, and some coarser siltstone of probable algal origin. Because of the unique organic composition of this thin layer, Holt and Powers did not include it in the Culebra for thickness computations, and this will be factored into discussions of Culebra thickness. Based on core descriptions from the WIPP project, Holt and Powers (in Appendix FAC, p. 5-11) concluded that there is very little variation of depositional sedimentary features throughout the Culebra.

Vugs are an important part of Culebra porosity. They are commonly zoned parallel to bedding. In outcrop, vugs are commonly empty. In the subsurface, vugs may be filled with anhydrite or gypsum, or they may have some clay lining. Lowenstein (1988, pp. 20–21) noted similar features. In Appendix FAC, vugs are attributed partly to syndepositional growth as nodules and partly as later replacive textures. Lowenstein (1988, pp. 592–608) also described textures related to later replacement and alteration of sulfates. Vug or pore fillings vary across the WIPP site and contribute to the porosity structure of the Culebra. Natural fractures filled with gypsum are common east of the WIPP site center and in a smaller area west of the site center (Figure 2-11).

After dolomite, Sewards et al. (1991, p. IX-1) report that clay is the second most abundant mineral of the Culebra. Clay minerals include corrensite, illite, serpentine, and chlorite. Clay occurs in bulk rock and in fracture surfaces.

In the WIPP site area, the Culebra varies in thickness. Different data sources provide varying estimates (Table 2-2). Holt and Powers (Appendix FAC, p. 4-7) considered the organic-rich layer at the Culebra-Tamarisk contact separately from the Culebra in interpreting geophysical logs.

Comparing data sets, Holt and Powers, as shown in Appendix FAC, typically interpret the Culebra as being about 3 feet (about 1 meter) thinner than have other sources. In general, this reflects the difference between including or excluding the unit at the Culebra-Tamarisk contact. Each data set shows areal differences in thickness of the Culebra when it is examined township by township.

LaVenue et al. (1988, app. B) calculated a mean thickness of 25 feet (7.7 meters) for the Culebra based on thicknesses measured in 78 boreholes. Appendix HYDRO (Appendix HYDRO, table 1) reported a data set similar to LaVenue et al., but without statistics. The borehole database in Appendix BH makes it possible to defend choices of Culebra thicknesses for the area being modeled.

Table 2-2. Culebra Thickness Data Sets

Source	Data Set Location								
	T22S, R31E			T21-23S, R30-32E			Entire Set		
	n	ave	std dev	n	ave	std dev	n	ave	std dev
Richey (1989)	7	7.5 m	1.04 m	115	7.9 m	1.45 m	633	7.7 m	1.65 m
Holt and Powers Appendix FAC	35	6.4 m	0.59 m	122	7.0 m	1.26 m	508	6.5 m	1.89 m
LaVenue et al. (1988)							78	7.7 m	
WIPP Potash Drillholes									
Jones (1978)				21	7.5 m	0.70 m			
Holt and Powers Appendix FAC				21	6.3 m	0.50 m			

Key:
n = number of boreholes or data points
ave = average or mean
std dev = standard deviation

2.1.3.5.3 The Tamarisk Member

Vine (1963, p. B15) named the Tamarisk for outcrops near Tamarisk Flat in Nash Draw. Outcrops of the Tamarisk are distorted, and subsurface information was used to establish member characteristics. Vine reported two sulfate units separated by a siltstone, about 5 feet (1.5 meters) thick, interpreted by Jones et al. in 1960 as a dissolution residue.

The Tamarisk is generally conformable with the underlying Culebra. The transition is marked by an organic-rich unit interpreted as being present over most of southeastern New Mexico. The Tamarisk around the site area consists of lower and upper sulfate units separated by a unit that varies from mudstone (generally to the west) to mainly halite (to the east). Near the

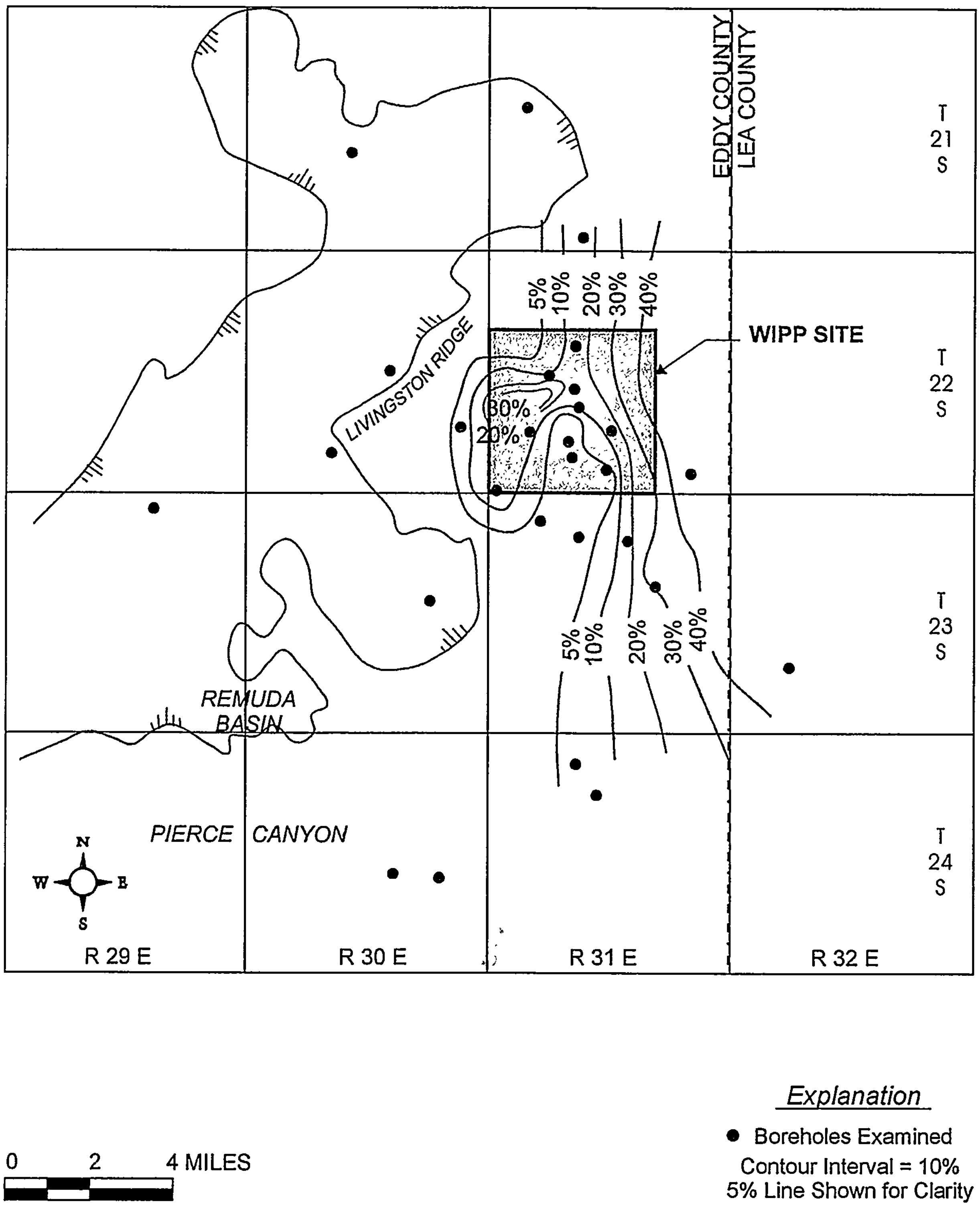

Figure 2-11. Percentage of Natural Fractures in the Culebra Filled with Gypsum

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center of the WIPP site, the lower anhydrite was partially eroded during deposition of the middle mudstone unit, as observed by in the WIPP Waste Handling and Exhaust shafts. The lower anhydrite was completely eroded at WIPP-19. Before shaft exposures were available, the lack of the lower Tamarisk anhydrite at WIPP-19 was interpreted as the result of solution and the mudstone was considered a cave filling.

Jones interprets halite to be present east of the center of the WIPP site based on geophysical logs and drill cuttings. Based mainly on cores and cuttings records from the WIPP potash drilling program, Snyder prepared a map in 1985 showing the halitic areas of each of the non-carbonate Rustler members. A very similar map was prepared independently by Powers based on geophysical log characteristics (see Figure 2-9).

Appendix FAC describes the mudstones and halitic facies in the middle of the Tamarisk, and interprets that the unit formed in a salt pan to mudflat system. Holt and Powers cited sedimentary features and the lateral relationships as evidence of syndepositional dissolution of halite in the marginal mudflat areas. In contrast, other investigators interpreted the lateral decrease in thickness and absence of halite to the west as evidence of post-depositional dissolution (see, for example, Jones et al. [1960], Jones [1978], and Snyder [1985] in the bibliography). The differing concepts for halite distribution in the Rustler, and particularly the Tamarisk, have been used in explaining the large changes in hydrologic properties of the Culebra as described in later sections.

The Tamarisk thickness varies greatly in southeastern New Mexico, principally as a function of the thickness of halite in the middle unit. Within T22S, R31E, Appendix FAC shows a range from 84 to 184 feet (26–56 meters) for the entire Tamarisk and a range from 6 to 110 feet (2–34 meters) for the interval of mudstone-halite between lower and upper anhydrites. Expanded geophysical logs with corresponding lithology illustrate some of the lateral relationships for this interval (Figure 2-12).

2.1.3.5.4 The Magenta Dolomite Member

Adams (1944, p. 1614) also attributes the name "Magenta member" to Lang, based on a feature north of Laguna Grande de la Sal named Magenta Point. According to Appendix FAC (p. 5-22*ff*), the Magenta is a gypsiferous dolomite with abundant primary sedimentary structures and well-developed algal features. It does not vary greatly in sedimentary features across the site area.

Around the WIPP site, Holt and Powers (Appendix FAC, p. 5-22) reported that the Magenta varies from 23 to 28 feet (7.0 to 8.5 meters); they did not contour the thickness because of limited changes.

2.1.3.5.5 The Forty-niner Member

Vine named the Forty-niner for outcrops at Forty-niner Ridge in eastern Nash Draw, but the outcrops of the Forty-niner are poorly exposed. In the subsurface around the WIPP, the Forty-niner consists of basal and upper sulfates separated by a mudstone. It is conformable with the underlying Magenta. As with other members of the Rustler, geophysical log characteristics can be correlated with core and shaft descriptions to extend geological inferences across a large area.

The Forty-niner ranges from 43 to 77 feet (13 to 23 meters) thick within T22S, R31E. East and southeast of the WIPP, the Forty-niner exceeds 80 feet (24 meters), and some of the geophysical logs from this area indicate halite is present in the beds between the sulfates.

Within the Waste Handling Shaft, the Forty-niner mudstone displayed sedimentary features and bedding relationships indicating sedimentary transport. The mudstone has been commonly interpreted as a residue from the dissolution of halitic beds because it is thinner where there is no halite. These beds are not known to have been described in detail prior to mapping in the Waste Handling Shaft at WIPP, and the features found there led Holt and Powers (Appendix FAC, p. i, ii) to re-examine the available evidence for, and interpretations of, dissolution of halite in Rustler units.

2.1.3.6 <u>Dewey Lake (Redbeds)</u>

The nomenclature for rocks included in the Dewey Lake (or alternatively Redbeds) was introduced during the 1960s to clarify relationships between these rocks assigned to the Upper Permian and the Cenozoic Gatuña Formation (hereafter referred to as the Gatuña).

There are three main sources of data about the Dewey Lake in the area around WIPP. Miller reported the petrology of the unit in 1955 and 1966. Schiel described outcrops in the Nash Draw areas and interpreted geophysical logs of the unit in southeastern New Mexico and west Texas to infer the depositional environments and stratigraphic relationships in 1984 and 1994. Powers and Holt (1990a) were able to describe the Dewey Lake in detail at the Air Intake Shaft for WIPP in 1990, confirming much of Schiel's information and adding data regarding the lower Dewey Lake.

The Dewey Lake overlies the Rustler conformably though local examples of the contact (e.g., the Air Intake Shaft described by Powers and Holt in 1990) show minor disruption by dissolution of some of the upper Rustler sulfate. The formation is predominantly reddish-brown fine sandstone to siltstone or silty claystone with greenish-gray reduction spots. Thin bedding, ripple cross-bedding, and larger channeling are common features in outcrops, and additional soft sediment deformation features and early fracturing are described from the lower part of the formation by Powers and Holt. Schiel (1988; 1994, p. [5-13]) attributed the Dewey Lake to deposition on "a large, arid fluvial plain subject to ephemeral flood events."

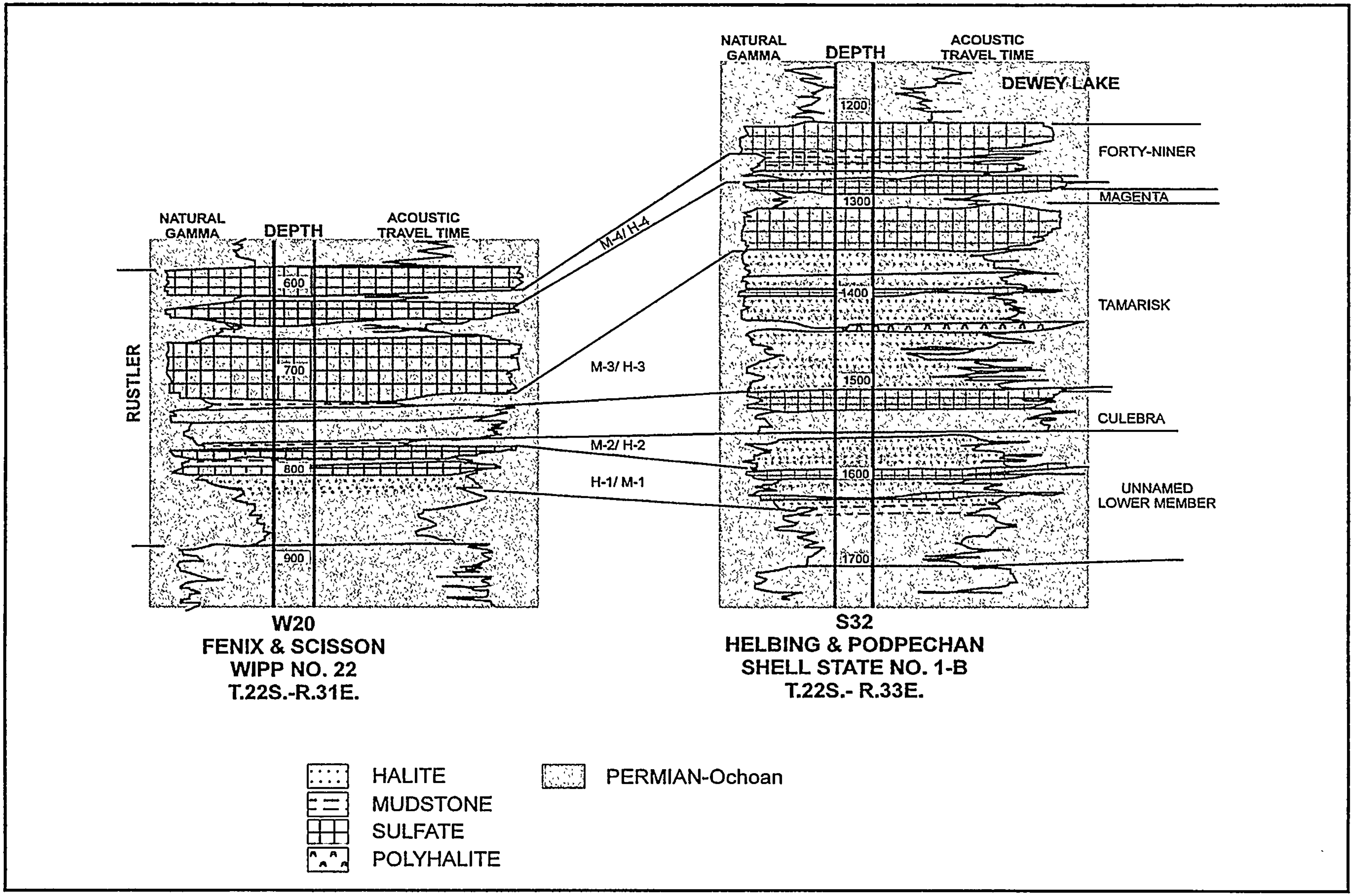

Figure 2-12. Log Character of the Rustler Showing Mudstone-Halite Lateral Relationships

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There is little direct faunal or radiometric evidence of the age of the Dewey Lake. It is assigned to the Ochoan series of late Permian age, and it is regionally correlated with units of similar lithology and stratigraphic position. Schiel in both 1988 and 1994 reviewed the limited radiometric data from lithologically similar rocks (Quartermaster Formation) and concluded that much of the unit could be early Triassic in age.

Near the center of the WIPP site, Powers and Holt (1990a, fig. 5) mapped 498 feet (152 meters) of the Dewey Lake (Figure 2-13). The formation is thicker to the east (Schiel 1994, p. 6) of the WIPP site, in part because western areas were eroded before the overlying Triassic rocks were deposited.

The Dewey Lake contains fractures, which are filled with minerals to varying degrees. Both cements and fracture fillings have been examined and have been used to infer groundwater infiltration. Powers and Holt (1990a, p. 3-8*ff*) described the Dewey Lake as cemented by carbonate above 164.5 feet (50 meters) in the Air Intake Shaft; some fractures in the lower part of this interval were also filled with carbonate, and the entire interval surface was commonly moist. Below this point, the cement is harder (probably anhydrite), the shaft is dry, and fractures are filled with gypsum. Powers and Holt (1990a, p. 3-11, fig. 16) suggested the cement change might be related to infiltration of meteoric water. They also determined that some of the gypsum-filled fractures are syndepositional. Dewey Lake fractures include horizontal to subvertical trends, some of which were mapped in detail (Holt and Powers 1986, figs. 6–8).

Lambert (1991, p. 5-65) analyzed the deuterium/hydrogen (D/H) ratios of gypsum in the Rustler and gypsum veins in the Dewey Lake. He suggests that none of the gypsum formed from evaporitic fluid such as Permian seawater, but that the D/H ratios all show influence of meteoric water. Nonetheless, Lambert (1991, p. 5-66) also infers that the gypsum D/H is not consistent with modern meteoric water; it may be consistent with earlier meteoric fluids. There is no obvious correlation with depth indicating infiltration. Strontium isotope ratios ($^{87}Sr/^{86}Sr$) indicate no intermixing or homogenization of fluids between the Rustler and the Dewey Lake, but there may be lateral movement of water within the Dewey Lake. Dewey Lake carbonate vein material shows a broader range of strontium ratios than does surface caliche, and the ratios barely overlap.

2.1.3.7 The Santa Rosa

There have been different approaches to the nomenclature of rocks of Triassic age in southeastern New Mexico. Bachman generally described the units in 1974 as "Triassic, undivided" or as the Dockum Group, without dividing it. Vine in 1963 used "Santa Rosa Sandstone," and Santa Rosa has become common usage. Lucas and Anderson in 1993 import other formation names that are unlikely to be useful for WIPP.

The Santa Rosa has been called disconformable over the Dewey Lake by Vine (1963, p. B25). These rocks have more variegated hues than the underlying uniformly colored Dewey Lake. Coarse-grained rocks, including conglomerates are common, and the formation includes a variety of cross-bedding and sedimentary features (Lucas and Anderson 1993, pp. 231–235).

Within the WIPP site boundary, the Santa Rosa is relatively thin to absent (Figure 2-14). At the Air Intake Shaft, Powers and Holt (1990a, fig. 5) attributed about 2 feet (0.6 meters) of rock to the Santa Rosa. The Santa Rosa is a maximum of 255 feet (78 meters) thick in potash holes drilled for WIPP east of the site boundary. The Santa Rosa is thicker to the east.

2.1.3.8 The Gatuña Formation

Lang in 1938 named the Gatuña for outcrops in the vicinity of Gatuña Canyon in the Clayton Basin. Rocks now attributed to the Gatuña in Pierce Canyon were once included in the "Pierce Canyon Formation" with rocks now assigned to the Dewey Lake. The formation has been mapped from the Santa Rosa, New Mexico, area south to the vicinity of Pecos, Texas. It is unconformable with underlying units.

Vine in 1963 and Bachman in 1974 provided some limited description of the Gatuña. The DOE's most comprehensive study of the Gatuña is based on WIPP investigations and landfill studies for Carlsbad and Eddy County. Much of the formation is colored light reddish-brown. It is broadly similar to the Dewey Lake and the Santa Rosa, though the older units have more intense hues. The formation is highly variable, ranging from coarse conglomerates to claystones with some highly gypsiferous sections. Sedimentary structures are abundant. Analysis of lithofacies indicates that the formation is dominantly fluvial in origin with areas of low-energy deposits and evaporitic minerals. It was deposited in part over areas actively subsiding in response to dissolution.

The thickness of the Gatuña is not very consistent regionally. Thicknesses range up to about 300 feet (91 meters) at Pierce Canyon, with thicker areas generally subparallel to the Pecos River. To the east, the Gatuña is thin or absent. Powers and Holt in 1990 reported about 9 feet (2.7 meters) of undisturbed Gatuña in the Air Intake Shaft at WIPP.

The Gatuña has been considered to be Pleistocene in age based on a volcanic glass in the upper Gatuña that has been identified as the Lava Creek B ash dated at 0.6 million years by Izett and Wilcox (1982). An additional volcanic ash from Gatuña in Texas yields consistent K-Ar and geochemical data, indicating it is about 13 million years (Powers and Holt 1993, p. 272). Thus the Gatuña ranges in age over a period of time that may be greater than the Ogallala Formation (hereafter referred to as the Ogallala) on the High Plains east of WIPP.

2.1.3.9 Mescalero Caliche

The Mescalero caliche (hereafter referred to as the Mescalero) is an informal stratigraphic unit apparently first differentiated by Bachman in 1974, though Bachman (1973, p. 17) described the "caliche on the Mescalero Plain." He differentiated the Mescalero from the older,

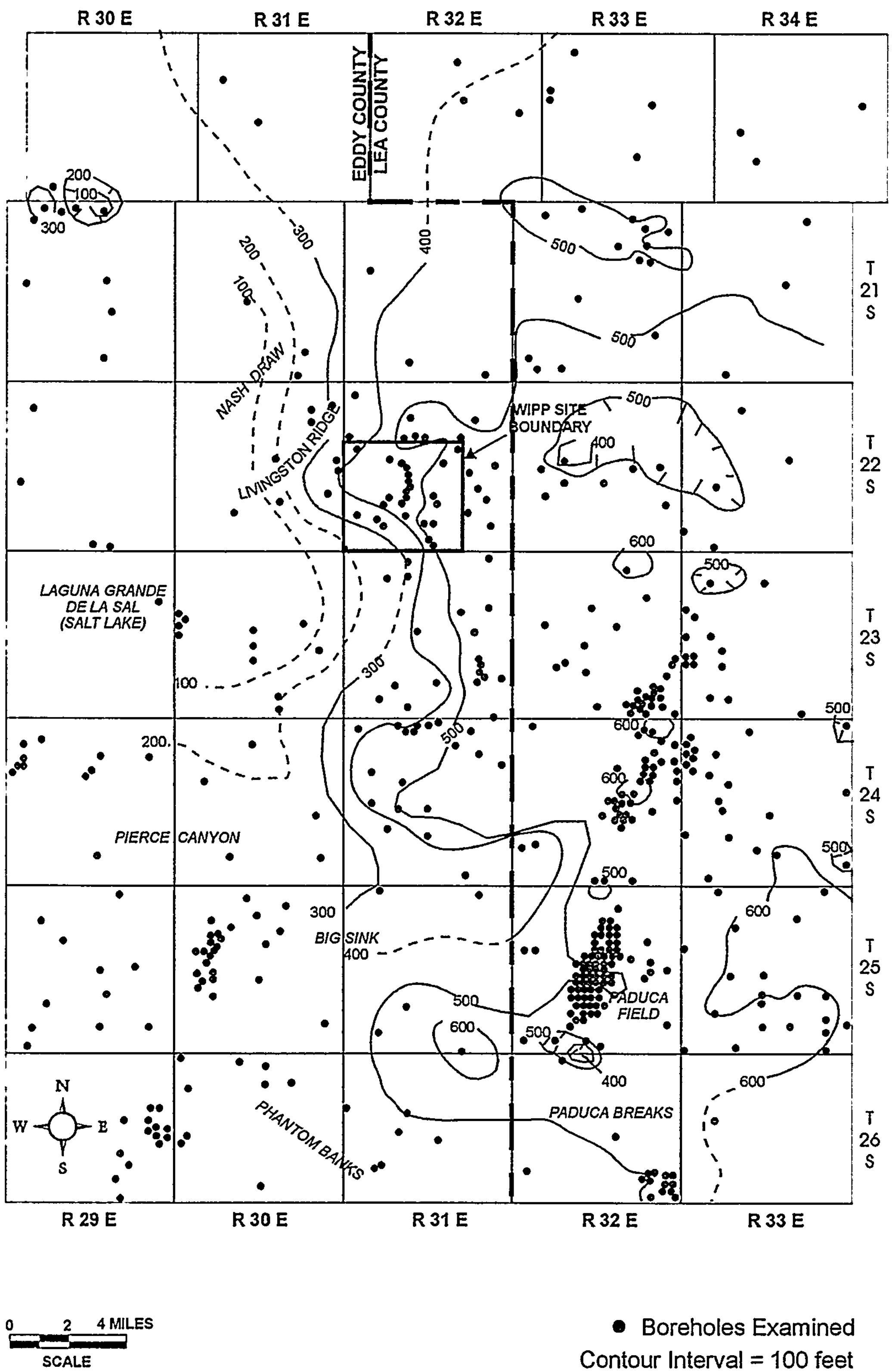

Figure 2-13. Isopach of the Dewey Lake

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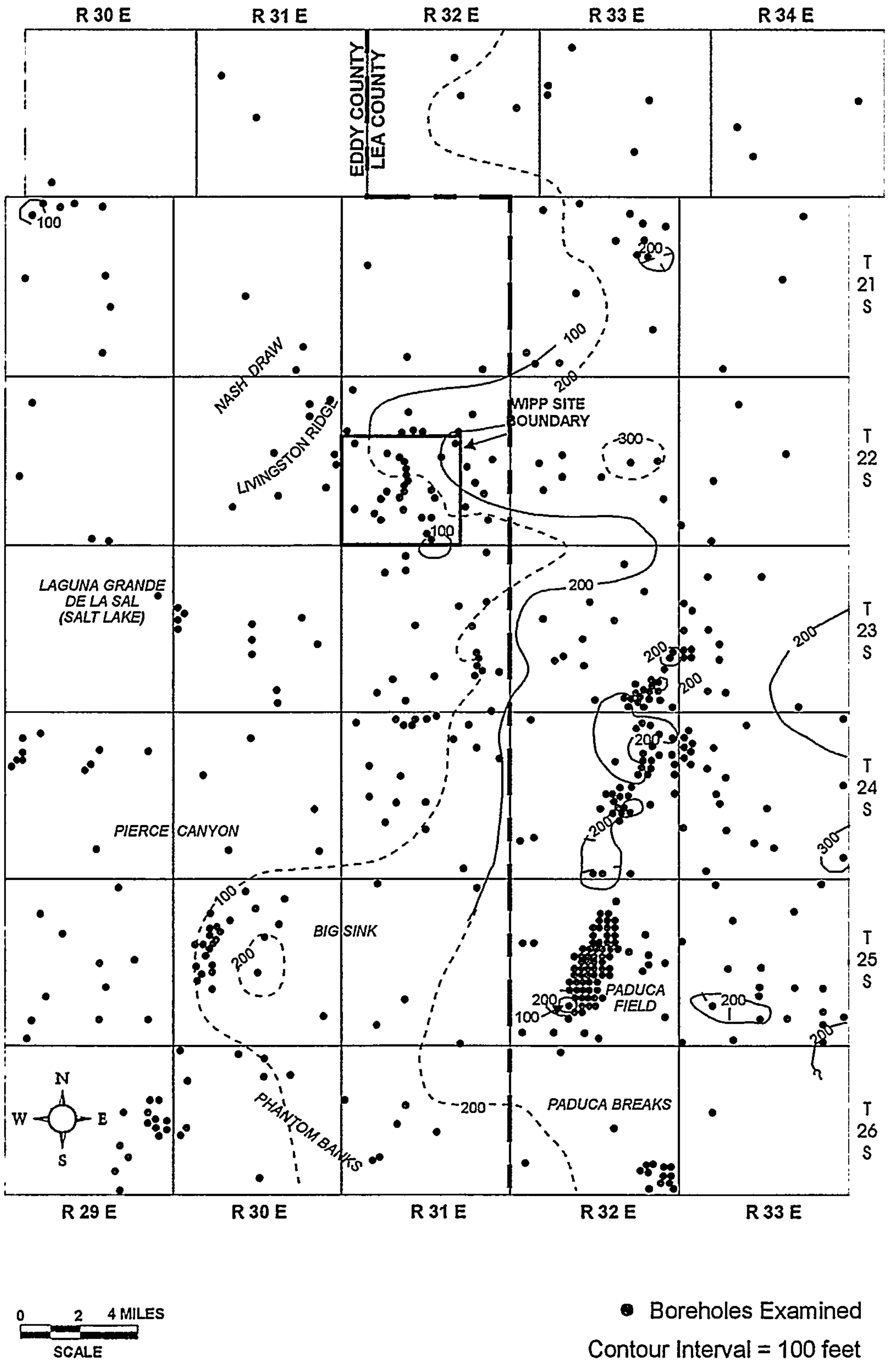

Figure 2-14. Isopach of the Santa Rosa

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widespread Ogallala caliche or caprock on the basis of textures, noting that breccia and pisolitic textures are much more common in the Ogallala caliche. The Mescalero has been noted over significant areas in the Pecos drainage, including the WIPP site area, and it has been formed over a variety of substrates.

Bachman described the Mescalero as a two-part unit: (1) an upper dense laminar caprock; and (2) a basal, earthy to firm, nodular calcareous deposit. Machette (1985, p. 5) classified the Mescalero as having Stage V morphologies of a calcic soil (the more mature Ogallala caprock reaches Stage VI).

Bachman (1976, p. 148) provided structure contours on the Mescalero caliche for a large area of southeastern New Mexico, including the WIPP site. From the contours and Bachman's discussion of the Mescalero as a soil, it is clear that the Mescalero is expected to be continuous over lÿÿÿarge areas. Explicit WIPP data are limited mainly to boreholes, though some borehole reports do not mention the Mescalero. The unit may be as much as 10 feet (3 meters) thick.

The Mescalero was inferred by Bachman on basic stratigraphic and climatic grounds as having accumulated during the early to middle Pleistocene. Bachman also reported finding a volcanic ash in the upper Gatuña along Livingston Ridge and underlying the Mescalero. His original report that this was the Pearlette "O" ash was superseded when Izett and Wilcox (1982) reported the ash as Lava Creek B, about 0.6 million years.

The Mescalero must therefore be younger. Samples of the Mescalero from the vicinity of the WIPP were studied using uranium-trend methods. Based on early written communication from Rosholt, Bachman (1985, p. 20) reports that the basal Mescalero began to form about 510,000 years ago and the upper part began to form about 410,000 years ago; these ages are commonly cited in WIPP literature. The samples are interpreted by Rosholt and McKinney in 1980 in the formal report as indicating ages of 570,000 ± 110,000 years for the lower part of the Mescalero and 420,000 ± 60,000 years for the upper part.

Based on morphology of caliche along part of the southern rim of Pierce Canyon some of the caliche within the Delaware Basin may be Ogallala caliche instead of Mescalero. This question has not been further addressed.

According to Bachman (1985, p. 19), the Mescalero soil is an indicator of stability or integrity of the WIPP site surface. Bachman (1985, p. 27) considered the Mescalero as an impediment to erosion; the discussion by Bachman indicates the Mescalero is an indicator of surface stability over the last 500,000 years.

2.1.3.10 Surficial Sediments

Soils of the region have developed mainly from Quaternary and Permian parent material. Parent material from the Quaternary system is represented by alluvial deposits of major streams, dune sand, and other surface deposits. These are mostly loamy and sandy sediments containing some coarse fragments. Parent material from the Permian system is represented by limestone, dolomite, and gypsum bedrock. Soils of the region have developed in a semiarid, continental climate with abundant sunshine, low relative humidity, erratic and low rainfall, and a wide variation in daily and seasonal temperatures. Subsoil colors normally are light brown to reddish brown but are often mixed with lime accumulations (caliche) that result from limited, erratic rainfall and insufficient leaching. A soil association is a landscape with a distinctive pattern of soil types (series). It normally consists of one or more major soils and at least one minor soil. There are three soil associations within 5 miles (8.3 kilometers) of the WIPP site: the Kermit-Berino, the Simona-Pajarito, and the Pyote-Maljamar-Kermit. Of these three associations, only the Kermit-Berino soil series have been mapped across the WIPP site by Chugg et al. (1952, sheet no. 113). These are sandy soils developed on eolian material. The Kermit-Berino soils include active dune areas. The Berino soil has a sandy A horizon; the B horizons include more argillaceous material and weak to moderate soil structures. A and B horizons are described as non-calcareous, and the underlying C horizon is commonly caliche. Bachman in 1980 interpreted the Berino soil as a paleosol that is a remnant B horizon of the underlying Mescalero.

Generally, the Berino series, which covers about 50 percent of the site, consists of deep, non-calcareous, yellow-red to red sandy soils that developed in wind-worked material of mixed origin. These soils are described as undulating to hummocky and gently sloping (ranging from 0 percent to 3 percent slopes). The soils are the most extensive of the deep, sandy soils in the Eddy County area. Berino soils are subject to continuing wind and water erosion. If the vegetative cover is seriously depleted, the water-erosion potential is slight, but the wind-erosion potential is very high. These soils are particularly sensitive to wind erosion in the months of March, April, and May, when rainfall is minimal and winds are highest.

The Kermit series consists of deep, light-colored, non-calcareous, excessively drained loose sands, typically yellowish-red fine sand. The surface is undulating to billowy (from 0 to 3 percent slopes) and consists mostly of stabilized sand dunes. Kermit soils are slightly to moderately eroded. Permeability is very high, and, if vegetative cover is removed, the water-erosion potential is slight but the wind-erosion potential is very high. Rosholt and McKinney applied uranium-trend methods to samples of the Berino soil from the WIPP site area. They interpreted the age of formation of the Berino soil as 330,000 ± 75,000 years.

2.1.4 Physiography and Geomorphology

In this section the DOE presents a discussion of the physiography and geomorphology of the WIPP site and surrounding area.

2.1.4.1 Regional Physiography and Geomorphology

The WIPP site is in the Pecos Valley section of the southern Great Plains physiographic province (Figure 2-15), a broad highland belt sloping gently eastward from the Rocky Mountains and the Basin and Range Province to the Central Lowlands Province. The Pecos Valley section itself is dominated by the Pecos River Valley, a long north-south trough that is

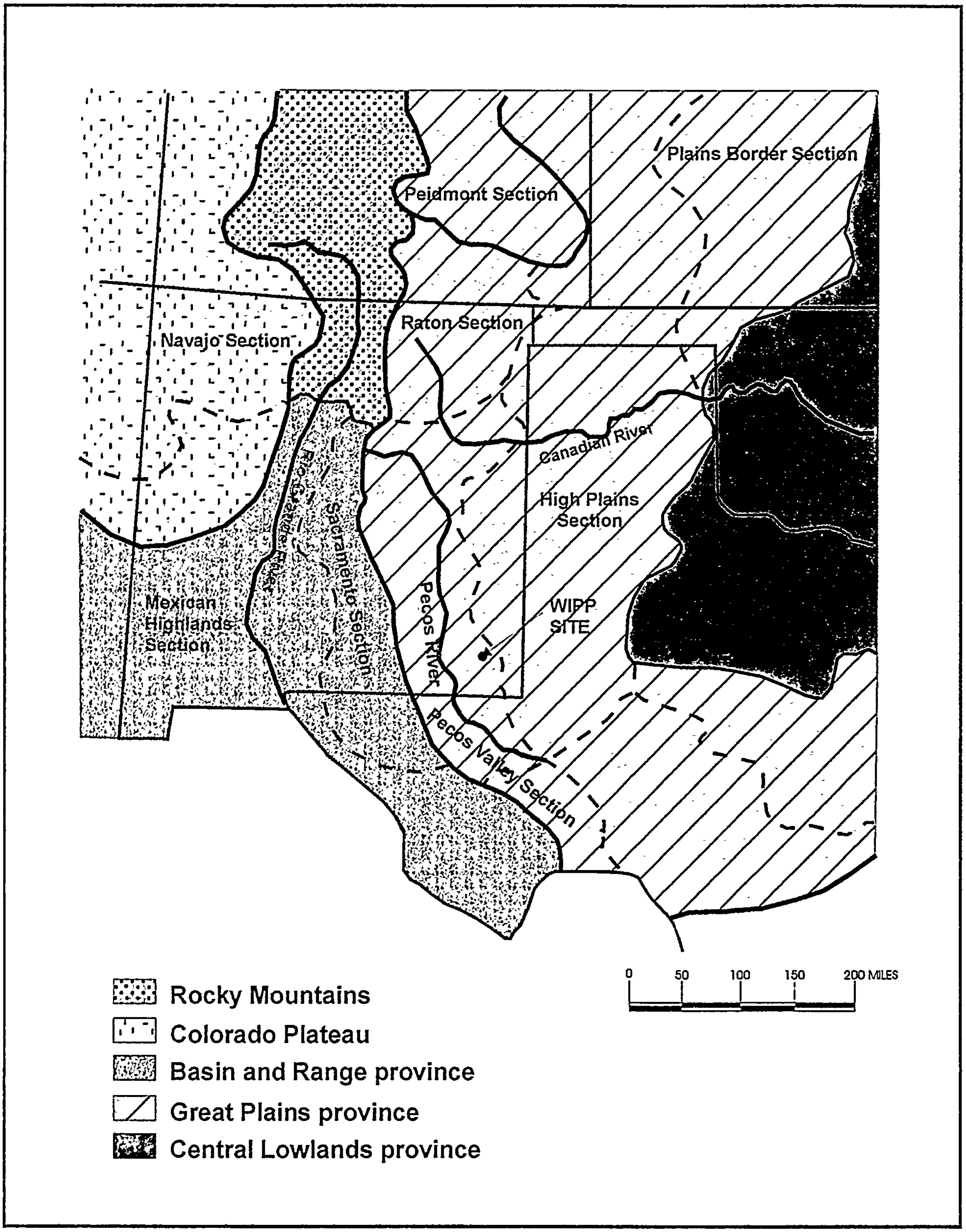

Figure 2-15. Physiographic Provinces and Sections

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from 5 to 30 miles (8.3 to 50 kilometers) wide and as much as 1,000 feet (305 meters) deep in the north. The Pecos River system has evolved from the south, cutting headward through the Ogallala sediments and becoming entrenched some time after the middle Pleistocene. It receives almost all the surface and subsurface drainage of the region; most of its tributaries are intermittent because of the semiarid climate. The surface locally has a karst terrain containing superficial sinkholes, dolines, and solution-subsidence troughs from both surface erosion and subsurface dissolution. The valley has an uneven rock- and alluvium-covered floor with widespread solution-subsidence features, the result of dissolution in the underlying upper Permian rocks. The terrain varies from plains and lowlands to rugged canyonlands, including such erosional features as scarps, cuestas, terraces, and mesas. The surface slopes gently eastward, reflecting the underlying rock strata. Elevations range from more than 6,000 feet (1,829 meters) in the northwest to about 2,000 feet (610 meters) in the south.

The Pecos Valley section is bordered on the east by the Llano Estacado, a virtually uneroded plain formed by river action. The Llano Estacado is part of the High Plains section of the Great Plains physiographic province and is a poorly drained eastward-sloping surface covered by gravels, wind-blown sand, and caliche that has developed since early to middle Pleistocene time. Few and minor topographic features are present in the High Plains section, formed when more than 500 feet (152 meters) of Tertiary silts, gravels, and sands were laid down in alluvial fans by streams draining the Rocky Mountains. In many areas, the nearly flat surface is cemented by a hard caliche layer.

To the west of the Pecos Valley section are the Sacramento Mountains and the Guadalupe Mountains, part of the Sacramento section of the Basin and Range Province. The Capitan escarpment along the southeastern side of the Guadalupe Mountains marks the boundary between the Basin and Range and the Great Plains provinces. The Sacramento section has large basinal areas and a series of intervening mountain ranges.

2.1.4.2 Site Physiography and Geomorphology

The land surface in the area of the WIPP site is a semiarid, wind-blown plain sloping gently to the west and southwest, and is hummocky with sand ridges and dunes. A hard caliche layer (Mescalero caliche) is typically present beneath the sand blanket and on the surface of the underlying Pleistocene Gatuña. Figure 2-16 is a topographic map of the area. Elevations at the site range from 3,570 feet (1,088 meters) in the east to 3,250 feet (990 meters) in the west. The average east-to-west slope is 50 feet per mile (9.4 meters per kilometer).

Livingston Ridge is the most prominent physiographic feature near the site. It is a west-facing escarpment that has about 75 feet (23 meters) of topographic relief and marks the eastern edge of Nash Draw, the drainage course nearest to the site. Nash Draw is a shallow 5-mile-wide (8-kilometer-wide) basin, 200–300 feet (61–91 meters) deep and open to the southwest. It was caused, at least in part, by subsurface dissolution and the accompanying subsidence of overlying sediments. Livingston Ridge is the approximate boundary between terrain that has undergone erosion and/or solution collapse and terrain that has been affected very little.

About 15 miles (24 kilometers) east of the site is the southeast-trending San Simon Swale, a depression due, at least in part, to subsurface dissolution. Between San Simon Swale and the site is a broad, low mesa named "the Divide." Lying about 6 miles (9.7 kilometers) east of the site and about 100 feet (30 meters) above the surrounding terrain, it is a boundary between southwest drainage toward Nash Draw and southeast drainage toward San Simon Swale. The Divide is capped by the Ogallala and the overlying caliche, upon which have formed small, elongated depressions similar to those in the adjacent High Plains section to the east.

Surface drainage is intermittent; the nearest perennial stream is the Pecos River, 12 miles (19 kilometers) southwest of the WIPP site boundary. The site's location near a natural divide protects it from flooding and serious erosion caused by heavy runoff. Should the climate become more humid, any perennial streams should follow the present basins, and Nash Draw and San Simon Swale would be the most eroded, leaving the area of the Divide relatively intact.

Dissolution-caused subsidence in Nash Draw and elsewhere in the Delaware Basin has caused a search for geomorphic indications of subsidence near the site. One feature that has attracted some attention is a very shallow sink about 2 miles (3 kilometers) north of the center of the site. It is very subdued, about 1,000 feet (305 meters) in diameter, and about 30 feet (9 meters) deep. Resistivity studies indicate a very shallow surficial fill within this sink and no disturbance of underlying beds, implying a surface, rather than subsurface, origin. Resistivity surveys in the site area showed an anomaly in Section 17 within the WIPP site boundary. It resembles the pattern over a known sink, a so-called breccia pipe, but drilling showed a normal subsurface structure without breccia, and the geophysical anomaly is assumed to be caused by low-resistivity rock in the Dewey Lake.

2.1.5 Tectonic Setting and Site Structural Features

The processes and features included in this section are those more traditionally considered part of tectonics, processes that develop the broad-scale features of the earth. Salt dissolution is a different process that can develop some features resembling those of tectonics.

Most broad-scale structural elements of the area around the WIPP developed during the late Paleozoic. There is little historical or geological evidence of significant tectonic activity in the vicinity. The entire region has tilted recently, and activity related to Basin and Range tectonics formed major structures southwest of the area. Seismic activity is specifically addressed in a separate section.

Broad subsidence began in the area as early as the Ordovician, developing a sag called the Tabosa Basin. By late Pennsylvanian to early Permian time, the Central Basin Platform developed (Figure 2-17), separating the Tabosa Basin into two parts: the Delaware Basin to the west and the Midland Basin to the east. The Permian Basin refers to the collective set of depositional basins in the area during the Permian period. Southwest of the Delaware Basin,

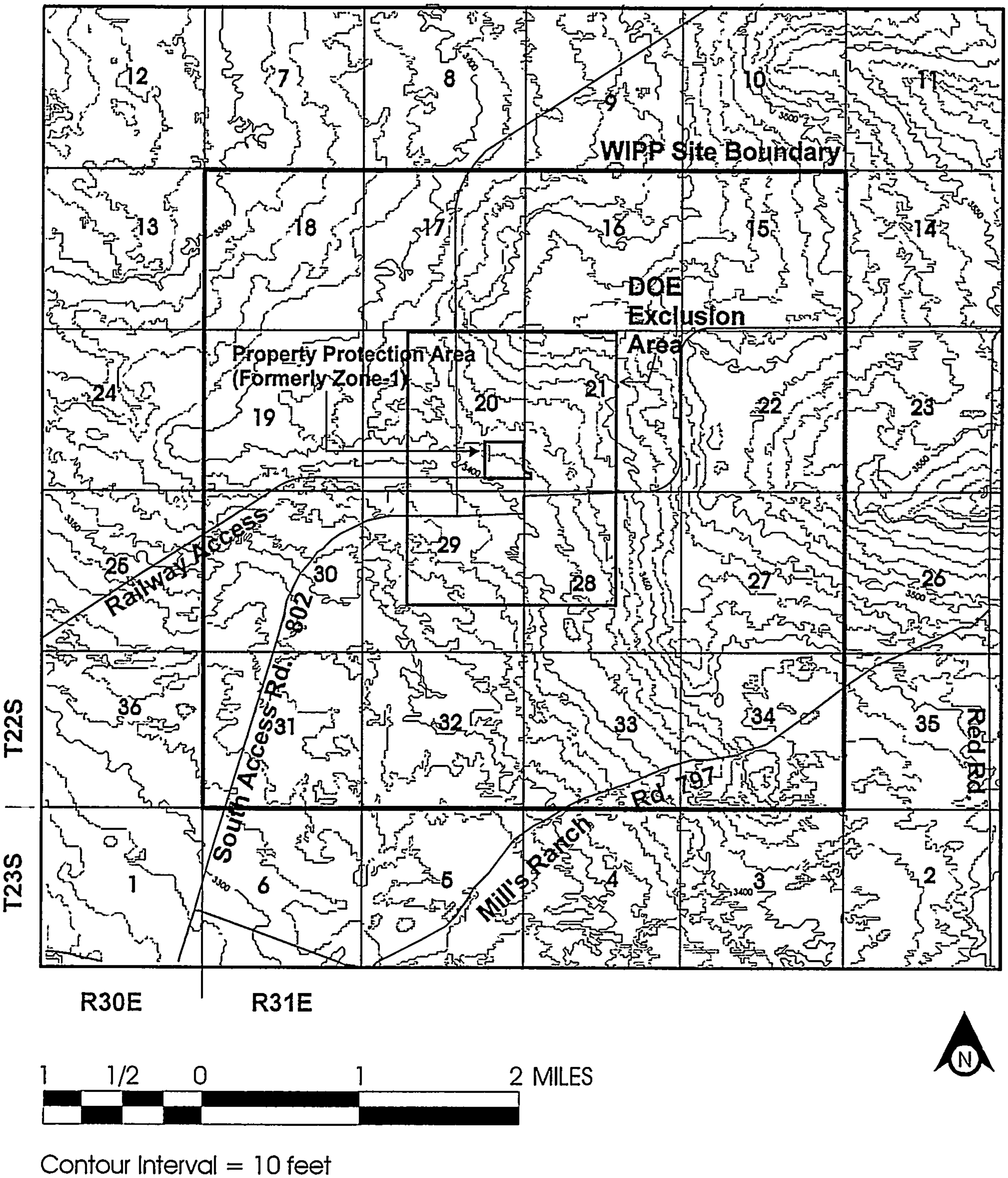

Figure 2-16. Site Topographic Map

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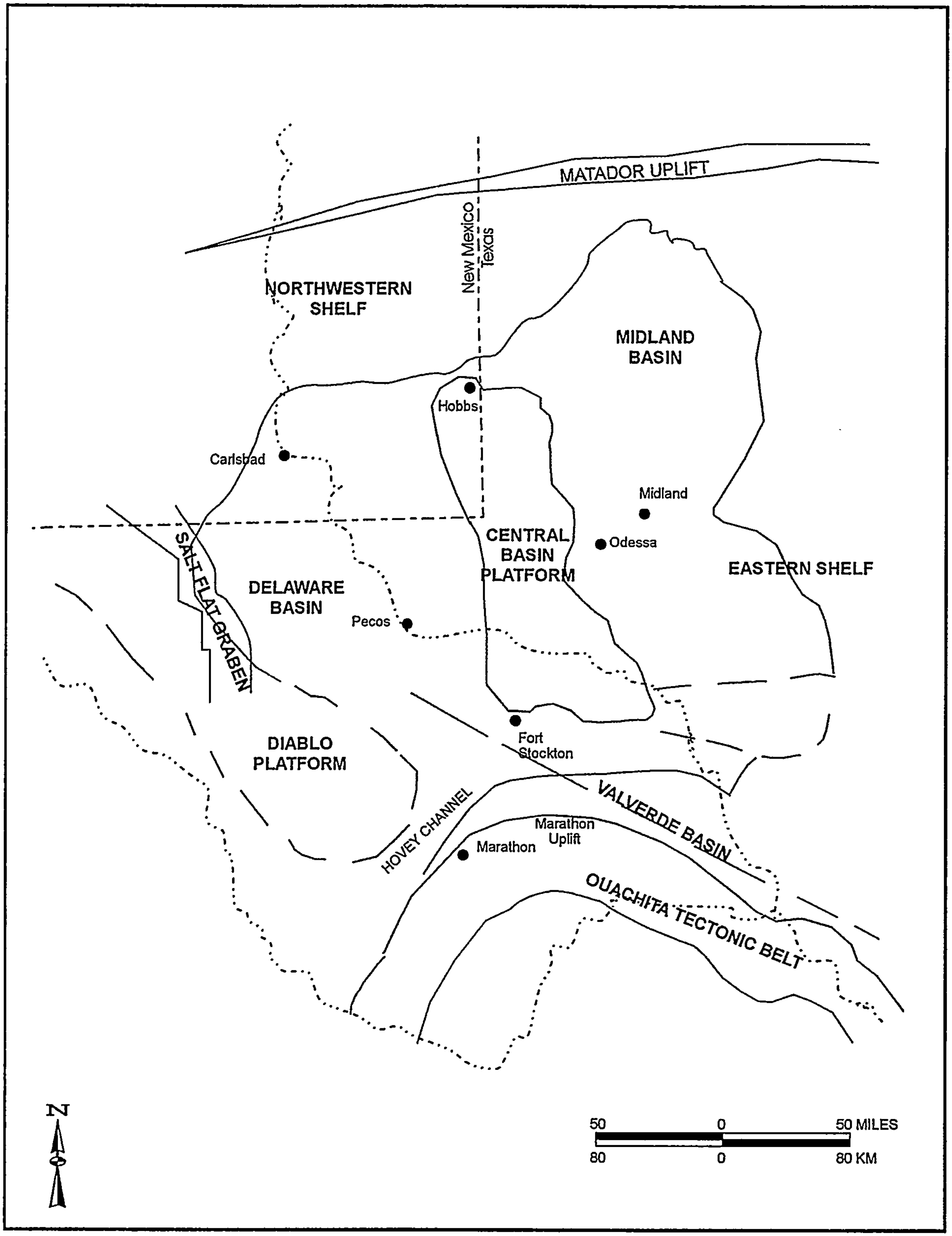

Figure 2-17. Structural Provinces of the Permian Basin Region

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the Diablo Platform began developing either late in the Pennsylvanian or early Permian. The Marathon Uplift and Ouachita tectonic belt limited the southern extent of the Delaware Basin. Most of these broader scale features surrounding the Delaware Basin formed during the late Paleozoic and have remained relatively constant in their relationships since.

2.1.5.1 Basin Tilting

According to Brokaw et al. (1972, p. 30) pre-Ochoan sedimentary rocks in the Delaware Basin show evidence of gentle downwarping during deposition, while Ochoan and younger rocks do not. A relatively uniform eastward tilt generally from about 75 to 100 feet per mile (14 to 19 meters per kilometer) has been superimposed on the sedimentary sequence. King (1948, p. 108) generally attributes the uplift of the Guadalupe and Delaware mountains along the west side of the Delaware Basin to later Cenozoic, though he also notes that some faults along the west margin of the Guadalupe Mountains have displaced Quaternary gravels.

King (1948, p. 144) also infers that the uplift is related to the Pliocene-age deposits of the Llano Estacado. Subsequent studies of the Ogallala of the Llano Estacado show that it ranges in age from Miocene (about 12 million years before present) to Pliocene. This is the most likely range for uplift of the Guadalupes and broad tilting to the east of the Delaware Basin sequence.

2.1.5.2 Faulting

Fault zones are well known along the Central Basin Platform, east of WIPP, from extensive drilling for oil and gas as reported by Hills (1984, pp. 250–267). Holt and Powers performed a more recent analysis in 1985 of geophysical logs to examine regional geology for the Rustler that showed these faults displaced at least Rustler rocks of late Permian age. The overlying Dewey Lake shows marked thinning along the same trend as the fault line or zone according to Schiel (1988, fig. 21), but the structure contours of the top of the Dewey Lake are not clearly offset. Schiel concluded that the fault was probably reactivated during the Dewey Lake's deposition, but movement ceased at least by the time the Santa Rosa was deposited. No surface displacement or fault has been reported along this trend, indicating movement has not been significant enough to rupture the overlying materials since Permian time.

Within the Delaware Basin, there are few examples of faults that may offset part of the evaporite section. At the northern end of the WIPP site, Snyder in Borns et al. (1983, p. 17*ff*) drew structure contours on the top of the basal anhydrite (A1) of the Castile for boreholes WIPP-11, WIPP-12, and WIPP-13. He interpreted northeast-southwest trending faults displacing this unit both north and south of WIPP-11. Snyder inferred that the Bell Canyon–Castile contact is also faulted and displaced along the same trend. Barrows in Borns et al. (1983, pp. 58–60) interpreted seismic reflection data to indicate, with varying confidence, faults within Castile rocks but not in underlying units.

The faults interpreted by Snyder around WIPP-11 depend on the correct identification of the basal Castile anhydrite (A1) in that borehole. The evaporite structure is complex, and some of the upper units of the Castile and the lower Salado differ from surrounding boreholes. The diagnostic Castile–Bell Canyon contact was not reached by this borehole, and the faults inferred for the Castile–Bell Canyon contact also depend on correct identification of A1 and projection of A1 thickness by Snyder. Inferred connections with the underlying Bell Canyon or deeper units could signify circulation of fluids to the evaporite section within the site boundaries. This is unlikely, given the Castile geology within boreholes WIPP-13 and DOE-2 near the trend of the inferred fault. Drilling for hydrocarbon exploration has been extensive around the north and west boundaries of the site since the mid-1980s.

Muehlberger et al. (1978, pp. 337–340) have mapped quaternary fault scarps along the Salt Basin graben west of both the Guadalupe and Delaware mountains. These are the nearest known Quaternary faults of tectonic origin to the WIPP. Kelley in 1971 inferred the Carlsbad and Barrera faults along the eastern escarpment of the Guadalupe Mountains based mainly on vegetative linaments. Hayes and Bachman re-examined the field evidence for these faults in 1979 and concluded that they were nonexistent.

On a national basis, Howard et al. (1971, sheets 1–2) assessed the location and potential for activity of young faults. For the region around the WIPP site, Howard et al. (1971, sheet 1) located faults along the western escarpment of the Delaware and Guadalupe mountains trend. These faults were judged to be late Quaternary (approximately the last 500,000 years) or older.

In summary, there are no known Quaternary or Holocene faults of tectonic origin offsetting rocks at the surface nearer to the site than the western escarpment of the Guadalupe Mountains. A significant part of the tilt of basin rocks is attributed to a mid-Miocene to Pliocene uplift along the Guadalupe-Sacramento mountains trend that is inferred on the basis of High Plains sediments of the Ogallala. Seismic activity is low and is commonly associated with secondary oil recovery along the Central Basin Platform.

2.1.5.3 Igneous Activity

Within the Delaware Basin, only one feature of igneous origin is known to have formed since the Precambrian. An igneous dike or series of echelon dikes occurs along a linear trace about 75 miles (120 kilometers) long from the Yeso Hills south of White's City to the northeast. At its closest, the dike trend passes about 8 miles (13 kilometers) northwest of the WIPP site center. Evidence for the extent of the dike range from outcroppings at Yeso Hills to subsurface intercepts in boreholes and mines to airborne magnetic responses.

An early radiometric determination by Urry (1936, pp. 35–40) for the dike yielded an age of 30 ± 1.5 million years. More recent work by Calzia and Hiss (1978, pp. 39–45) on dike samples are consistent with early work, indicating an age of 34.8 ± 0.8 million years. Work by Brookins et al. (1980, pp. 28–31) on dike samples in contact with polyhalite indicated an age of about 21.4 million years.

Volcanic ashes found in the Gatuña (Section 2.1.3.8) were airborne from distant sources such as Yellowstone and represent no volcanic activity at WIPP.

2.1.5.4 Loading and Unloading

The loading and unloading history of the site and surrounding areas may be considered a factor in the development of the hydrological system, including the Culebra, at the WIPP site. The depth to the base of the Culebra in the area (Figure 2-18) indicates the current state of loading for the unit. This depth is a function of regional dip, erosion, and dissolution/subsidence (Section 2.1.6.2.4).

Regional geology information has been used to construct a broader view of the loading and unloading history at the site for the Culebra. This information is currently being compiled and interpreted, and will be included in the final application.

2.1.6 Non-Tectonic Processes and Features

Halite in evaporite sequences is relatively plastic which can lead to the process of deformation; it is also highly soluble which can lead to the process of dissolution. Both processes (deformation and dissolution) can develop structural features similar to those developed by tectonic processes. The features developed by dissolution and deformation can be distinguished from similar-looking tectonic features where the underlying units do not reflect the same feature as do the evaporites. As an example, the evaporite deformation can commonly be shown not to affect the underlying Bell Canyon. The deformation also tends to die out in overlying units, and the Rustler or the Dewey Lake may show little, if any, of the effects of the deformed evaporites. Beds underlying areas of dissolved salt are not affected, but overlying units to the surface may be affected.

2.1.6.1 Evaporite Deformation

The most recent review of evaporite deformation in the northern Delaware Basin and original work to evaluate deformation is summarized here. More detail is in Appendix DEF.

2.1.6.1.1 Basic WIPP History of Deformation Investigations

The Castile has been known for many years to be deformed in parts of the Delaware Basin, especially along the northern margin. Jones et al. in 1973 clearly showed thicker isopachs of part of the Castile from the northwestern to northern part of the basin margin, just inside the Capitan Formation (hereafter referred to as the Capitan). A dissertation by Snider (1966, fig. 11, 14) and paper by Anderson et al. (1972, pp. 59–86) also presented maps showing some evidence of thicker sections of Castile next to the Capitan.

ERDA-6 was drilled during 1975 as part of the program to characterize an initial site for WIPP. The borehole penetrated increasingly deformed beds through the Salado into the Castile, and, at 2,711 feet (826 meters) depth, the borehole began to produce pressurized brine and gas. Anderson and Powers (1978, p. 2-83) and Jones (1981) interpreted beds to have been displaced structurally by several hundred feet. Some of the lower beds may have pierced overlying beds. The beds were considered to be too structurally deformed to mine reasonably along single horizons for a repository. Therefore, the site was abandoned in 1975, and the current site was located in 1976 (Appendix GCR). The deformed beds around ERDA-6 were considered part of a deformed zone within about 6 miles (10 kilometers) of the inner margin of the Capitan reef. As a consequence, the preliminary selection criteria prohibited locating a new site within 6 miles (10 kilometers) of the Capitan reef margin.

General criteria for the present site for the WIPP appeared to be met based on initial data from drilling (ERDA-9) and geophysical surveys. Beginning in 1977, the new site was more intensively characterized through geophysical surveys, including seismic reflection, and drilling. Extensive seismic reflection work revealed good reflector quality in the southern part of the site and poor quality or "disturbed" reflectors in a sector of the northern part of the site. The area of "disturbed" reflectors became known as the "disturbed zone" (DZ), "the area of anomalous seismic reflectors," or "zone of anomalous seismic reflection data." (The "disturbed zone" based on poor Castile seismic reflectors is completely different from the Disturbed Rock Zone [DRZ] which describes the deformation around mined underground openings at the WIPP.)

Powers et al. in Appendix GCR (fig. 4.4-6) generally shows the DZ beginning about 1 mile (1.6 kilometers) north of the WIPP site center. Borns et al. in 1983 included two areas south of the WIPP site as showing the same features of the DZ. Neill et al. also in 1983 summarized the limits to the DZ based on differing interpretations and included the area less than 1 mile (1.6 kilometers) north of the site center where the Castile begins to steepen in dip. WIPP-11 was drilled early during 1978 about 3 miles (5 kilometers) north of the site center over part of the DZ where proprietary petroleum company data had also indicated significant seismic anomalies. The borehole encountered highly deformed beds within the Castile and altered thicknesses of halite units, but no pressurized brine and gas were found.

Less than 1 mile (1.6 kilometers) north of the site center, seismic data indicated possible faulting of the upper Salado and the lower Rustler over the area of steepening Castile dips. Four boreholes (WIPP-18, -19, -21, -22) were drilled into the upper Salado and demonstrated neither faulting nor significant deformation of the Rustler-Salado contact. Lateral changes in the seismic velocity of the upper sections contributed to the interpretation of a possible fault and thus complicate interpretations of deeper structure.

WIPP-12 was located about 1 mile (1.6 kilometers) north of the center of the site and drilled during 1978 to the upper Castile to determine the significance of structure on possible repository horizons. The top of the Castile was encountered at an elevation about 160 feet (49 meters) above the same contact in ERDA-9 at the site center.

WIPP-12 was deepened during late 1981 to test for possible brine and gas in the deformed Castile. The probability that brine and gas would be found was considered low because ERDA-6 and other known brine reservoirs in the Castile occurred in areas with greater

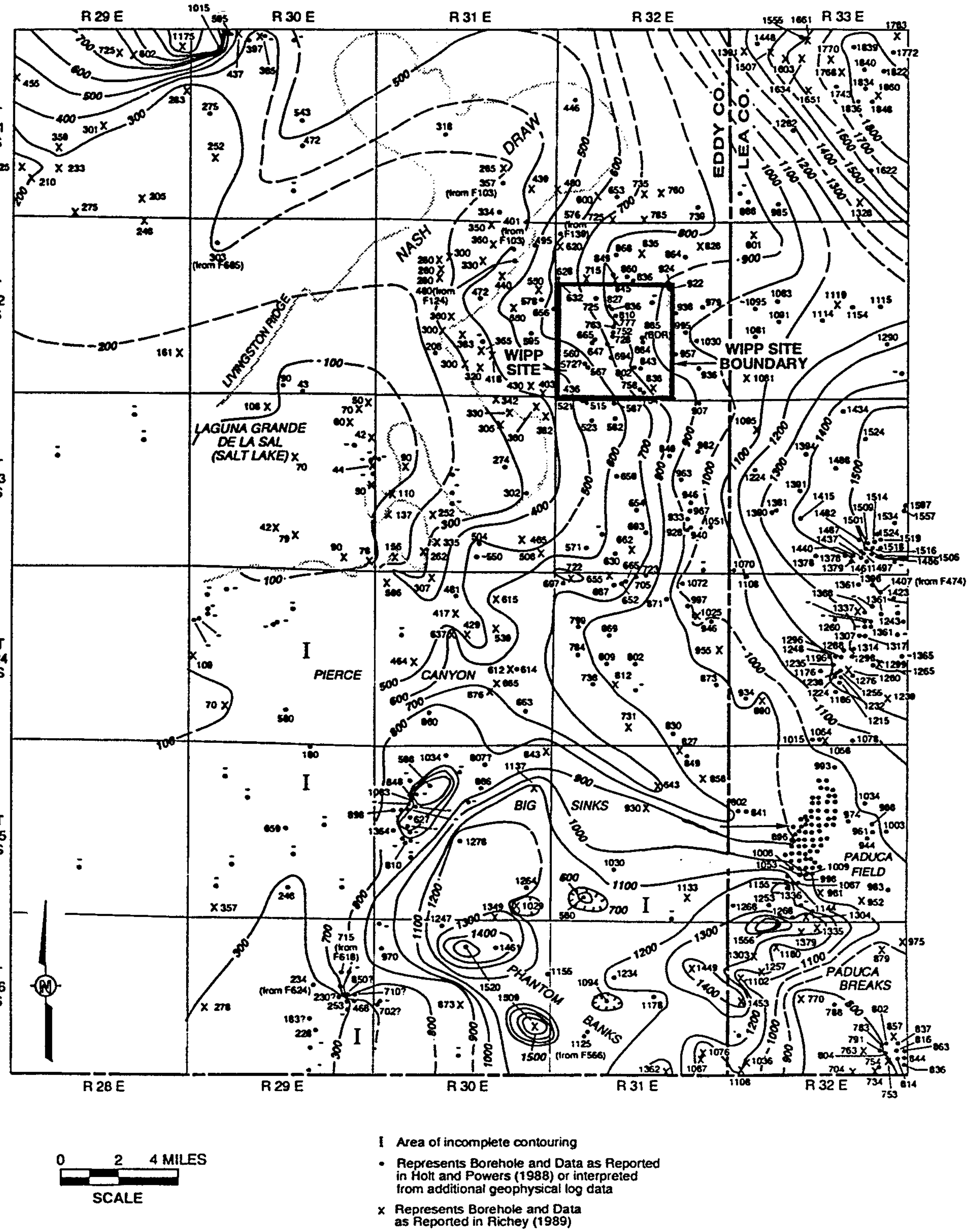

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Figure 2-18. Depth to Base of the Culebra

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deformation. During drilling, fractured anhydrite in the upper Castile (lower A3) began to yield pressurized brine and gas. The borehole was deepened to the basal anhydrite (A1) of the Castile. Reservoir testing was conducted to estimate reservoir size (see later section on Castile brines).

As a consequence of discovering pressurized brine and gas in WIPP-12, the Environmental Evaluation Group (EEG) recommended that the design of the facility be changed and that proposed waste storage areas in the north be moved or re-oriented to the south. After additional drilling of DOE-1, it was agreed by the DOE that the design change had advantages, and the disposal facilities were separated from the experimental area and placed south of the site center.

A microgravity survey of the site was designed to try to further delineate the structure within the DZ based on the large density differences between halite and anhydrite. The gravity survey was unsuccessful in yielding any improved resolution of the Castile structure.

DOE-2 was the last WIPP borehole to examine structure within the Castile. Salado structure from potash data suggested a low point about 2 miles (3.3 kilometers) north of the site center. It was proposed by Davies (1984, p. 175) that the Salado low might indicate deeper dissolution of Castile halite, somewhat similar to the dissolution causing breccia pipes (see Section 2.1.6.2 on evaporite dissolution). The borehole demonstrated considerable Castile deformation, but there was no indication that halite had been removed by dissolution.

2.1.6.1.2 Extent of the Disturbed Zone at the Site

Nearby surface drilling, shafts, and underground drilling during early excavations at WIPP showed that the repository horizon varies modestly from the regional structure over the central part of the site; north of the site center the beds dip to the south. Borns in 1987 suggested the south dip is probably related to the dip on the underlying Castile.

The upper surface of MB 139, under the repository horizon, exhibited significant relief in the exploratory Salt Handling Shaft. Jarolimek et al. (1983, p. 6-1*ff*) interpreted the relief as mainly due to syndepositional growth of gypsum at the water-sediment interface to form mounds and to subsequent partial crushing. Jarolimek et al. concluded that the MB relief was not due to deformation because the base of the MB showed no comparable relief. Based on concerns of the EEG, MB 139 was re-evaluated. Borns and Shaffer in 1985 found less relief on the upper surface of the MB in the areas they examined; they also concluded that depositional processes were responsible for the relief. In either case, the relief on MB 139 is not considered to have been caused by deformation.

A cross-section through the four boreholes from ERDA-9 to WIPP-11 and the cross-section to DOE-1 indicate the general nature of the Castile structure under the WIPP site. Only DOE-1 and DOE-2 penetrate the Castile–Bell Canyon contact.

2.1.6.1.3 Deformation Mechanisms

In analyzing Castile structure in the northern Delaware Basin, Borns et al. (1983) proposed five processes in 1983 as the principal hypotheses to explain the structure: gravity foundering, dissolution, gravity sliding, gypsum dehydration, and depositional processes. Gravity foundering appears to be the most comprehensive explanation and is in fact the best accepted hypothesis out of the five possibilities. It is based on the fact that anhydrite is much more dense (about 2.9 grams per cubic centimeter) than halite (about 2.15 grams per cubic centimeter), and anhydrite beds should have considerable potential for sinking into underlying halite. Modeling of similar systems suggests a rate of deformation of about 0.02 inches (0.05 centimeters) per year is possible and that, at that rate, the DZ could have developed over about 700,000 years. The principal difficulty with this hypothesis is that there should exist the same potential for foundering over much of the basin, yet the deformation is localized.

2.1.6.1.4 Timing of Deformation of the Disturbed Zone at the Site

Jones estimated in 1981 that deformation of the Castile and overlying rocks took place before the Ogallala Formation was deposited, as he believes the unit is undeformed. Anderson and Powers (1978, pp. 78–83) inferred that data from ERDA-6 indicate that the Castile was deformed after the basin was tilted. Though these lines of evidence could be consistent with mid-Miocene deformation, there are other interpretations of tilting consistent with older deformation (Madsen and Raup 1988, pp. 1–5, 9). There is no known evidence of surface deformation or other features to indicate recent deformation.

A regional first-order, Class I baseline for vertical control was established over much of the WIPP site during 1977 and was tied into existing lines of benchmarks in the area. The data along the line from Carlsbad toward El Paso showed vertical movement from Carlsbad consistent with regional geological uplift; relative subsidence over the Salt Flat Graben was consistent also with geological structure as interpreted by Reilinger et al. (1980, pp. 181–184). A resurvey of the WIPP area benchmarks in 1981 showed subsidence averaging about 0.72 inches (18 millimeters) total relative to benchmarks at Carlsbad over the 4-year period. Though these short-term results are consistent in direction of relative movement with the geological structure of the area (i.e., uplift on the west, tilting down to the east), the rates of movement are very high or improbable for this area for periods of geological time, given the geological history of the area.

The benchmarks can be monitored through resurveys during operation to determine any changes of significance and provide continuing evidence of the stability of the site area.

2.1.6.2 <u>Evaporite Dissolution</u>

Because evaporites are much more soluble than most other rocks, project investigators have considered it important to understand the dissolution processes and rates that take place within the site considered for long-term isolation. These dissolution processes and rates constitute the limiting factor in any evaluation of the site. Over the course of the WIPP project, extensive resources have been committed to identify and study a variety of features in southeastern New Mexico interpreted to have been caused by dissolution. The subsurface distribution of halite for various units has been mapped. Several different kinds of surface features have been attributed to dissolution of salt or karst formation. The processes proposed or identified include point-source (brecciation), "deep" dissolution, "shallow" dissolution, and karst. The categories are not well defined. Nonetheless, as discussed in the following sections, dissolution is not considered a threat to isolation of waste at the WIPP.

2.1.6.2.1 Brief History of Project Studies

Well before the WIPP project, several geologists recognized that dissolution is an important process in southeastern New Mexico and that it contributed to the subsurface distribution of halite and to the surficial features. A number of these are in the bibliography including Lee (1925, pp. 107–121), Maley and Huffington (1953, pp. 539–546), and Olive (1957, pp. 351–358). Robinson and Lang identified an area in 1938 under Nash Draw where brine occurred at about the stratigraphic position of the upper Salado–basal Rustler and considered that salt had been dissolved to produce a dissolution residue. Vine mapped Nash Draw and surrounding areas, reporting in 1963 on various dissolution features. Vine reported surficial domal structures later called "breccia pipes" and identified as deep-seated dissolution and collapse features.

As the USGS and Oak Ridge National Laboratory (ORNL) began to survey southeastern New Mexico as an area in which to locate a repository site in salt, Brokaw et al. in 1972 prepared a summary of the geology that included solution and subsidence as significant processes in creating the features of southeastern New Mexico. Brokaw et al. also recognized a solution residue at the top of salt in the Salado, and the unit commonly became known as the "brine aquifer" because it yielded brine in the Nash Draw area. Brokaw et al. also interpreted the east-west decrease in thickness of the Rustler to be a consequence of removal of halite and other soluble minerals from the formation by dissolution.

During the early 1970s, the basic ideas about shallow dissolution of salt (generally from higher stratigraphic units and within a few hundred feet of the surface) were set out in a series of reports by Bachman, Jones, and collaborators. Piper independently evaluated the geological survey data for ORNL. Claiborne and Gera concluded that salt was being dissolved too slowly from the near-surface units to affect a repository for several million years, at least.

By 1978, shallower drilling around the WIPP site to evaluate potash resources was interpreted by Jones (1978, p. 9), and he felt the Rustler included "dissolution debris, convergence of beds, and structural evidence for subsidence." Halite in the Rustler has been re-evaluated by the DOE, but there are only minor differences in inferred distributions among the various investigators. These investigators do have different explanations about how this distribution occurred (see previous section on Rustler stratigraphy): through extensive dissolution of the Rustler's halite after the Rustler was deposited, or through syndepositional dissolution of halite from saline mud flat environments during Rustler deposition.

Under contract to SNL, Anderson, in work reported in 1978, re-evaluated halite distribution in deeper units, especially the Castile and Salado formations. He identified local anomalies proposed as features developed after dissolution of halite by water circulating upward from the underlying Bell Canyon. In response to Anderson's developing concepts, ERDA-10 was drilled south of the WIPP area during the latter part of 1977. ERDA-10 is interpreted to have intercepted a stratigraphic sequence without evidence of solution residues in the upper Castile. Anderson mapped geophysical log signatures of the Castile and interpreted lateral thinning and change from halite to non-halite lithology as evidence of lateral dissolution of deeper units (part of "deep dissolution"). Anderson considered that deep dissolution might threaten the WIPP site.

A set of annular or ring fractures is evident in the surface around San Simon Sink, about 18 miles (30 kilometers) east of the WIPP site. Nicholson and Clebsch (1961, p. 14) suggested that San Simon Sink developed as a result of deep-seated collapse. WIPP-15 was drilled at about the center of the sink to a depth of about 811 feet (245 meters) to obtain samples for paleoclimatic data and stratigraphic data to interpret collapse. Anderson and Bachman both interpret San Simon Sink as dissolution and collapse features, and the annular fractures are not considered evidence of tectonic activity.

Following the work by Anderson, Bachman mapped surficial features in the Pecos Valley, especially at Nash Draw, and differentiated between those surface features in the basin which were formed by karst and deep collapse features over the Capitan reef. WIPP-32, WIPP-33, and two boreholes over the Capitan reef were eventually drilled. Their data, which demonstrated the concepts proposed by Bachman, are documented in Snyder and Gard (1982, p. 65).

A final program concerning dissolution and karst was initiated following a microgravity survey of a portion of the site during 1980. Based on localized low-gravity anomalies, Barrows et al. in 1983 interpreted several areas within the site as locations of karst. WIPP-14 was drilled during 1981 at a low-gravity anomaly. It revealed normal stratigraphy through the zones previously alleged to be affected by karst. As a followup, in 1985 Bachman also re-examined surface features around the WIPP and concluded there was no evidence for active karst within the WIPP site. The nearest karst feature is northwest of the site boundaries at WIPP-33 and is considered inactive.

2.1.6.2.2 Extent of Dissolution

Within members of the Rustler, the margins of halite have been mapped by different methods, which were summarized by Beauheim in 1987. There are few differences in interpretation, despite the different methods used (Figure 2-9). Lower members of the Rustler are halitic west of the site and higher members generally show halite only further east. Snyder interprets these margins as a consequence of post-depositional dissolution of halite. Holt and Powers in Appendix FAC (pp. 6-8, 6-9) interpret sedimentary structures within the Rustler mudstone as being equivalents to halite in order to indicate that most halite was removed during the depositional process and redeposited in a salt pan in the eastern part of the depositional basin.

Upper intervals of the Salado thin dramatically west and south of the WIPP site (Figures 2-19 and 2-20) compared to deeper Salado intervals (Figure 2-21). There are no cores for further consideration of possible depositional variations. As a consequence, this margin is interpreted as the edge of dissolution of the upper Salado.

2.1.6.2.3 Timing of Dissolution

The dissolution of Ochoan-Epoch evaporites through the near-surface processes of weathering and groundwater recharge has been studied extensively (Anderson 1981, pp. 133–145; Lambert 1983a; Lambert 1983b, pp. 291–298; Bachman 1984, pp. 1–22; see also Appendix FAC). The work of Lambert (1983a) was specifically mandated by the DOE's agreement with the State of New Mexico in order to evaluate, in detail, the conceptual models of evaporite dissolution proposed by Anderson (1981, pp. 133–145). There was no clear consensus of the volume of rock salt removed. Hence, estimates of the instantaneous rate of dissolution vary significantly. Dissolution may have taken place as early as the Ochoan, during or shortly after deposition. For the Delaware Basin as a whole, Anderson (1981, pp. 133–145) proposed that up to 40 percent of the rock salt in the Castile and Salado formations was dissolved during the past 600,000 years. Lambert (1983b, pp. 291–298) suggested that in many places the variations in salt-bed thicknesses inferred from borehole geophysical logs that were the basis for Anderson's calculation were depositional in origin, compensated by thickening of adjacent non-halite beds, and were not associated with the characteristic dissolution residues. Borns and Shaffer also suggested in 1985 a depositional origin for many apparent structural features attributed to dissolution.

Snyder (1985, pp. 85–229), together with earlier workers (e.g., Vine 1963, Lambert 1983b, pp. 291–298; Bachman 1984, pp. 1–22), attributes the variations in thickness in the Rustler, which crops out in Nash Draw, to post-depositional evaporite dissolution. Holt and Powers (in Appendix FAC, pp. 7-1–7-27) have challenged this view and attribute the east-to-west thinning of salt beds in the Rustler to depositional facies variability rather than post-depositional dissolution. Bachman (1974, pp. 74–194; 1976, pp. 135–144; 1980, pp. 80–1099) envisioned several episodes of dissolution since the Triassic, each dominated by greater degrees of evaporite exhumation and a wetter climate, interspersed with episodes of evaporite burial and/or a drier climate. Evidence for dissolution after deposition of the Salado and before deposition of the Rustler along the western part of the Basin was cited by Adams (1944, pp. 1596–1625). Others have argued that the evaporites in the Delaware Basin were above sea level and therefore subject to dissolution, during the Triassic, Jurassic, Tertiary, and Quaternary periods. Because of discontinuous deposition, not all of these times are separable in the geological record of southeastern New Mexico. Bachman contends that dissolution was episodic during the past 225 million years as a function of regional base level, climate, and overburden.

Some investigators have reasoned that wetter climate accelerated the dissolution. Various estimates of middle Pleistocene climatic conditions have indicated that climate was more moist during Gatuña time than during the Holocene. An example of evidence of mass loss from dissolution since Mescalero time (approximately 500,000 years ago) is found in displacements of the Mescalero caliche as large as 180 feet (55 meters) in collapse features in Nash Draw. However, given the variations in Pleistocene climate, it is unrealistic to apply a calculated average rate of dissolution, determined over 500,000 years ago, to shorter periods, much less extrapolate such a rate into the geological future.

There have been several attempts to estimate the rates of dissolution in the basin. Bachman provided initial estimates of dissolution rates in 1974 based on a reconstruction of Nash Draw relationships. Though these rates indicate no hazard to the WIPP related to Nash Draw dissolution, Bachman later reconsidered the Nash Draw relationships and concluded that pre-Cenozoic dissolution had also contributed to salt removal. Thus the initial estimated rates were too high. Anderson concluded in 1978 that the integrity of the WIPP to isolate radioactive waste would not be jeopardized by dissolution within about 1 million years. Anderson and Kirkland (1980, pp. 66–69) expanded on the concept of brine density flow proposed by Anderson in 1978 as a means of dissolving evaporites at a point by circulating water from the underlying Bell Canyon. Wood et al. (1982) examined the mechanism and concluded that, while it was physically feasible, it would not be effective enough in removing salt to threaten the ability of the WIPP to isolate TRU waste.

There is local evidence that Cenozoic dissolution occurred at the same time that part of the Gatuña was being deposited in the Pierce Canyon area. Nonetheless, there is no indicator that the rates of dissolution in the Delaware Basin are sufficient to affect the ability of the WIPP to isolate TRU waste.

2.1.6.2.4 Features Related to Dissolution

Bachman (1980, p. 97) separated breccia pipes, formed over the Capitan reef by dissolution and collapse of a cylindrical mass of rock, from evaporite karst features that appear similar to breccia pipes. There are surficial features, including sinks and caves, in large areas of the basin. Nash Draw is the result of combined dissolution and erosion. Within the site boundaries, there are no known surficial features due to dissolution or karst.

South of the WIPP site, there is a clear relationship between a subsurface structure on the Culebra (Figure 2-22) and dissolution. Salt has been removed from the underlying Salado to create a general anticline from near Laguna Grande de la Sal to the southeast. Beds generally dip to the east, and salt removed to the west created the other limb of the structure. Units below the evaporites do not apparently show the same structure.

2.2 Surface-Water and Groundwater Hydrology

The DOE believes the hydrological characteristics of the disposal system are important since contaminant transport via fluid flow has the potential of having the greatest impact on the disposal system. At the WIPP site, one of the DOE's selection criterion was to chose a location that would minimize these impacts. This was accomplished when the DOE selected (1) a disposal medium that is essentially devoid of groundwater; (2) a location where the effects of groundwater circulation are minimal and predictable; (3) an area where groundwater

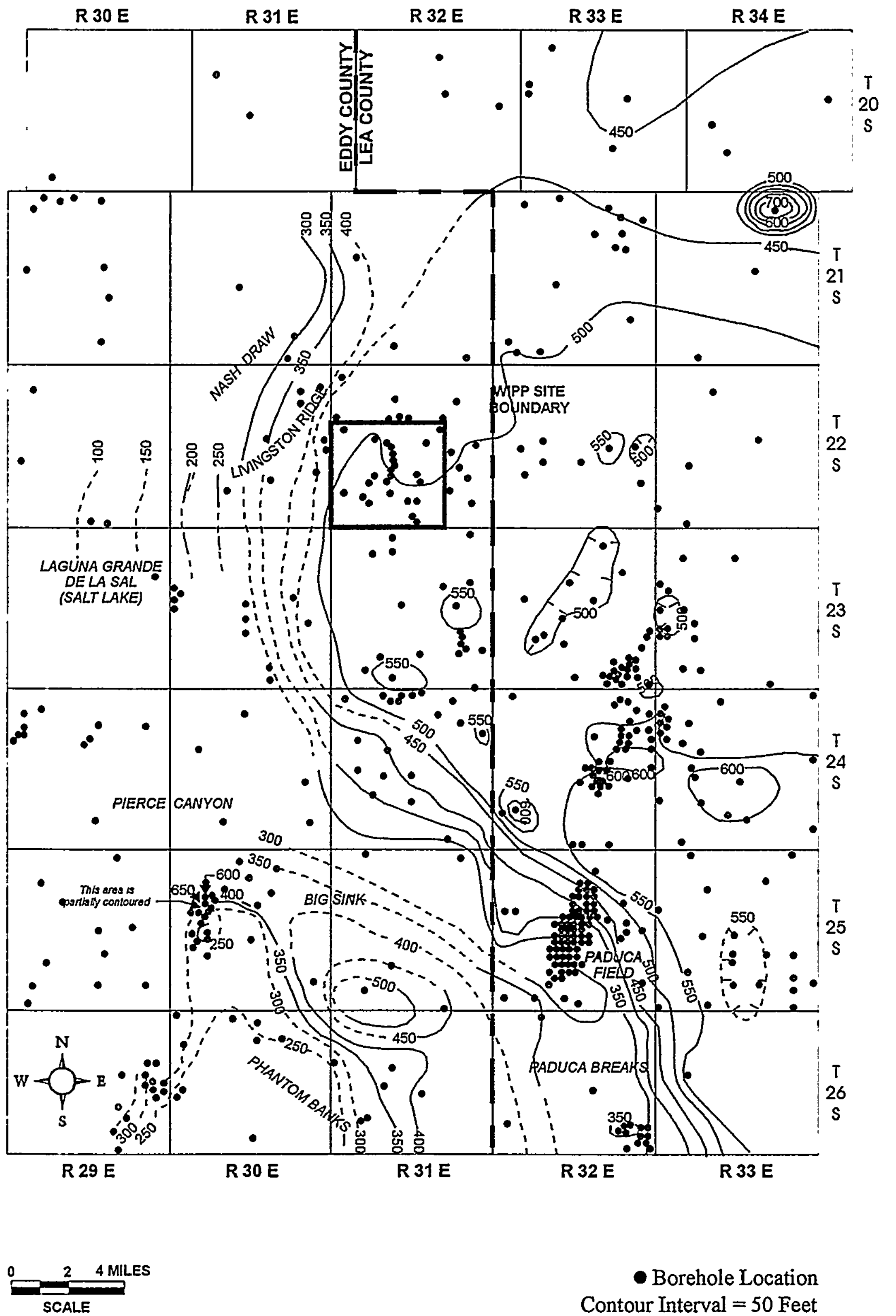

Figure 2-19. Isopach from the Top of the Vaca Triste to the Top of the Salado

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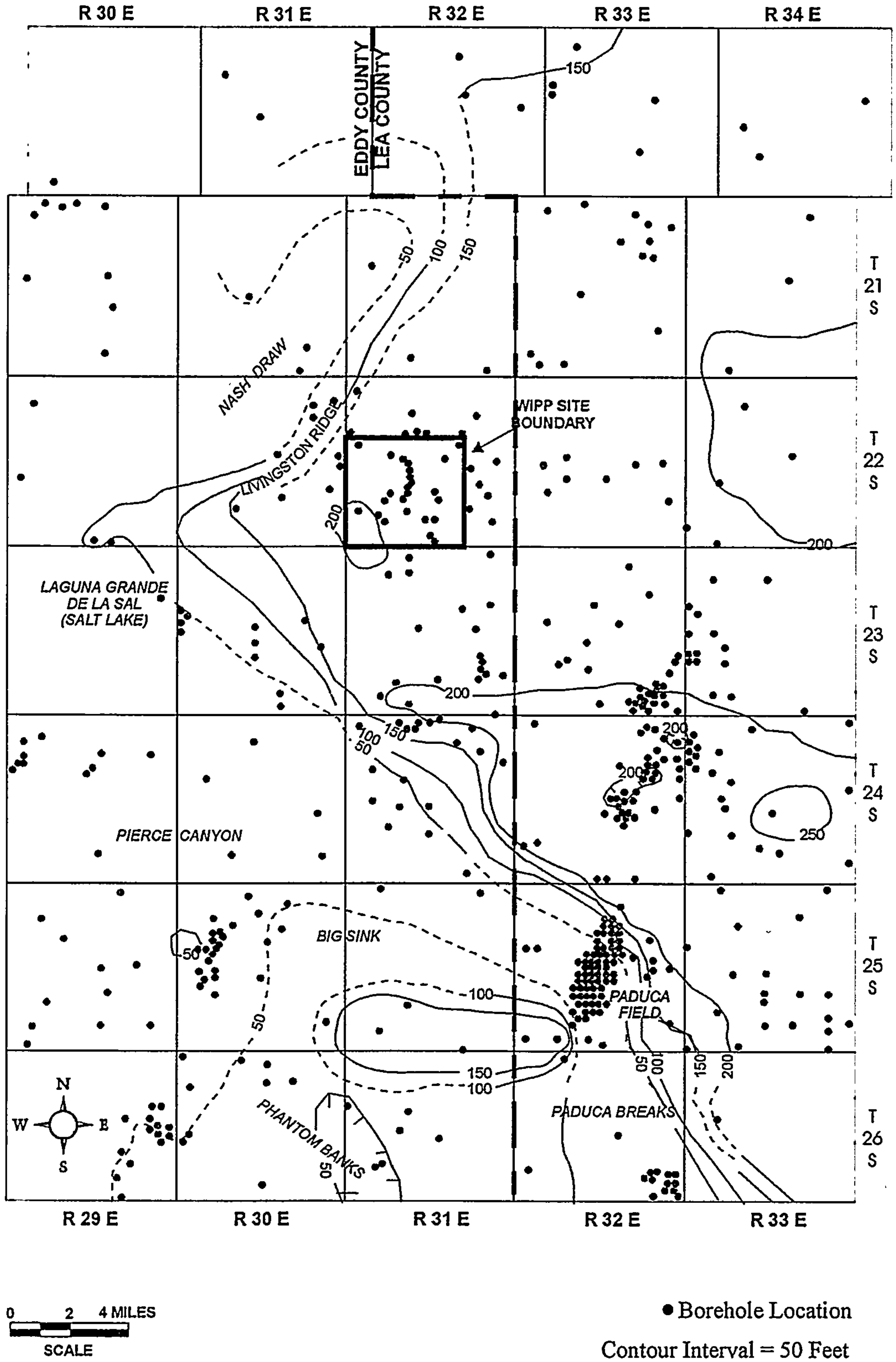

Figure 2-20. Isopach from the Base of MB 103 to the Top of the Salado

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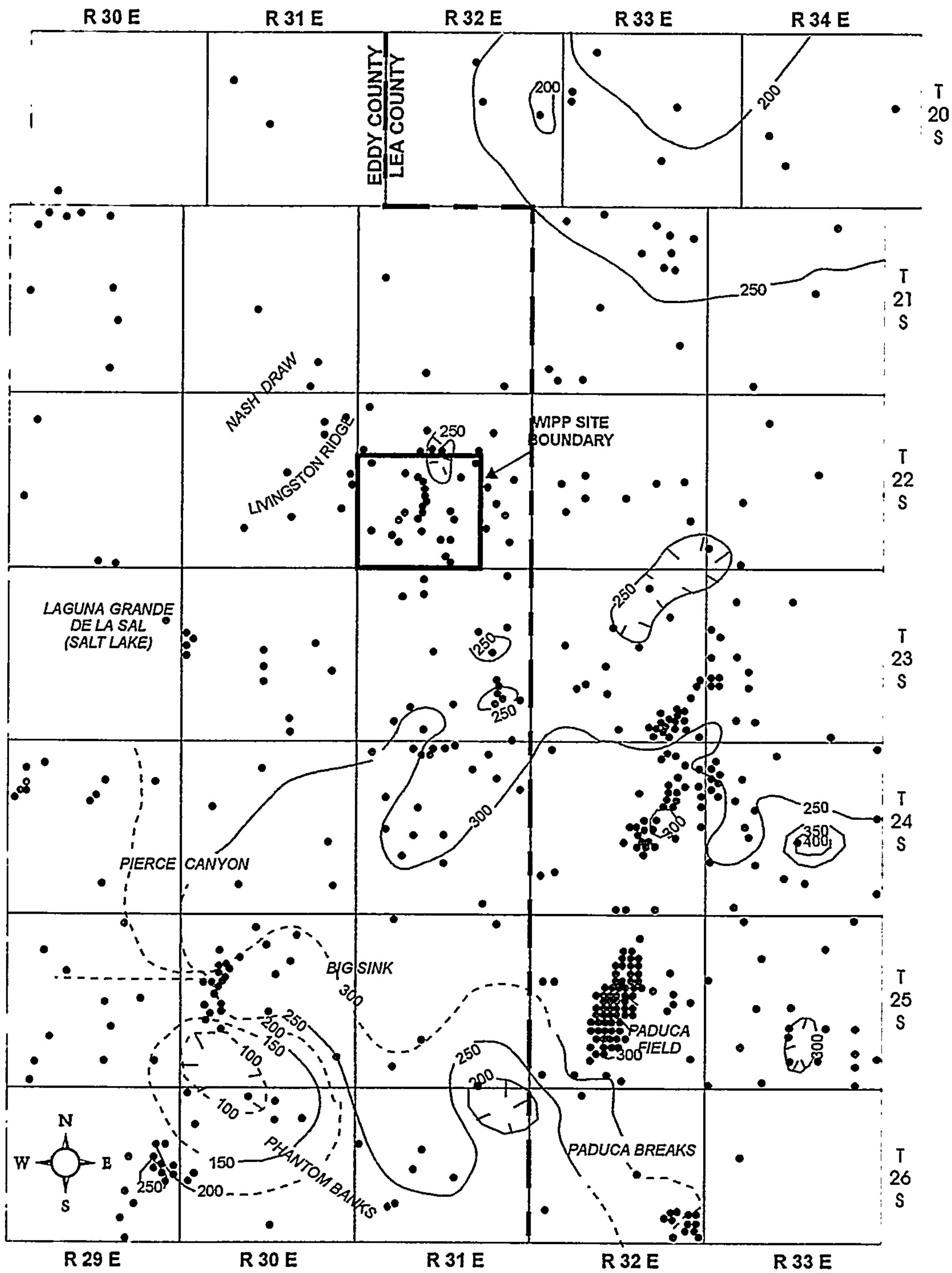

0 2 4 MILES
SCALE

● Borehole Location
Contour Interval = 50 Feet

Figure 2-21. Isopach from the Base of MB 123-124 to the Vaca Triste

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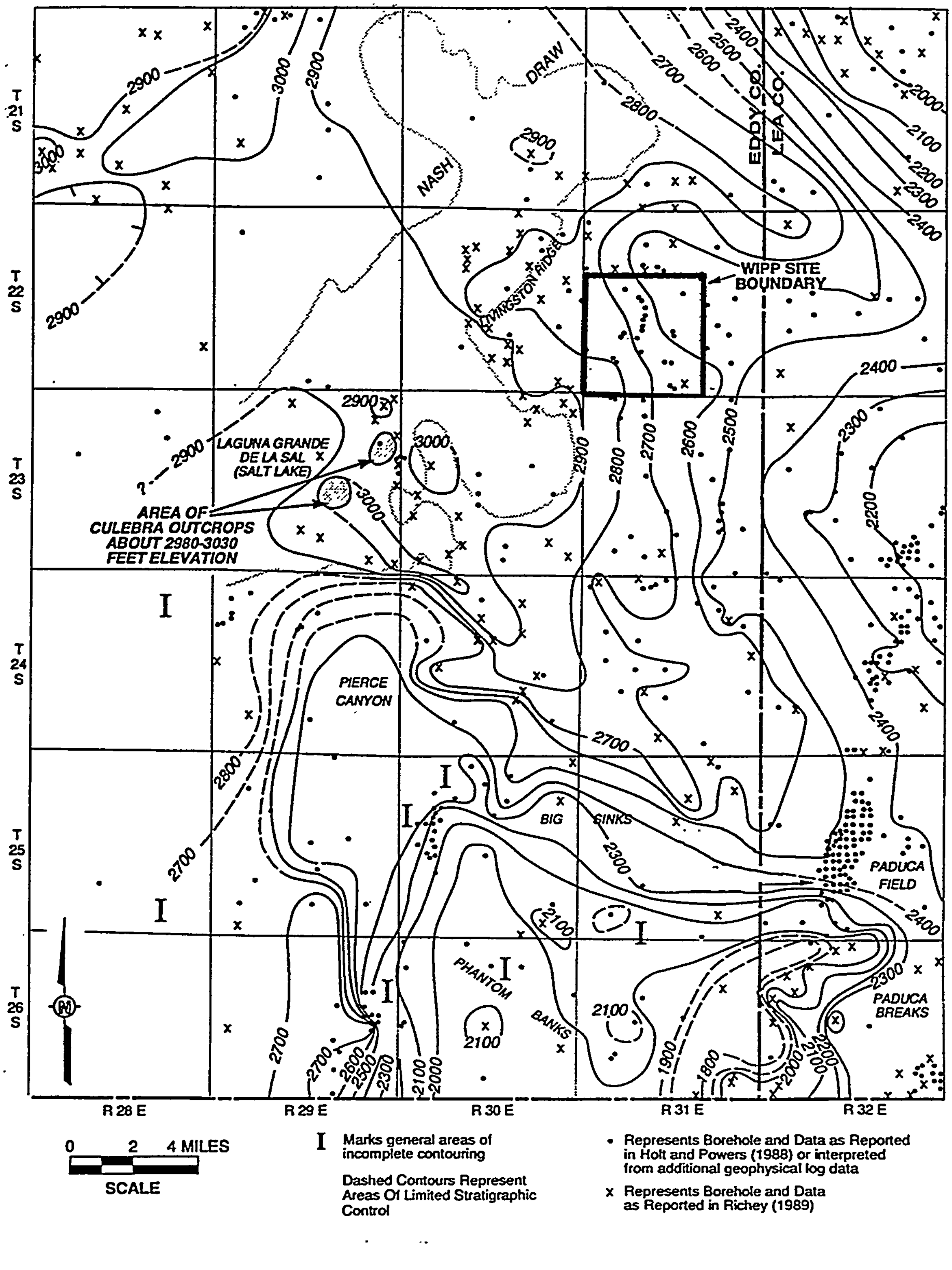

Figure 2-22. Structure Contour Map of Culebra Dolomite Base

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use is virtually non-existent; (4) an area where there are no surface-waters; (5) an area where future groundwater use is unlikely; and (6) a repository host rock that will not likely be affected by anticipated long-term climate changes possible within 10,000 years.

The following discussion summarizes the characteristics of the groundwater and surface-water at and around the WIPP site. This summary is based on data collection programs that were initiated at the inception of the WIPP program and which continue to some extent today. These programs have several purposes:

- To provide sufficient information to develop predictive models of the groundwater movement within the vicinity of the WIPP site
- To collect data to evaluate the predictive models and to adapt them to the specific conditions of the WIPP site
- To develop an understanding of the surface-water characteristics and the interaction between surface-waters and groundwater
- To develop predictive models of the interaction between surface-water and groundwater during reasonable expected climate changes.

In order to provide a comprehensive understanding of the impact of groundwater and surface-water on the disposal system, the following are the relevant factors which have been evaluated:

Groundwater

- General flow direction
- Flow type
- Horizontal and vertical flow velocities
- Hydraulic interconnectivity between rock units
- General groundwater use
- Chemistry (including, but not limited to, salinity, mineralization, age, Eh, and pH).

Surface-Water

- Regional precipitation and evapotranspiration rates
- Location and size of surface-water bodies
- Water volume, flow rate, and direction
- Drainage network
- Hydraulic connection with groundwater
- Soil hydraulic properties (infiltration)
- General water chemistry and use.

The specifics of groundwater modeling are found in Chapter 6. The hydrological system is divided into three segments for the purposes of modeling and discussion. These are (1) the Salado, which for the most part concerns the undisturbed performance of the disposal system;

(2) the non-Salado rock units, which essentially are impacted by the disturbed (human intrusion) performance of the disposal system; and (3) the surface-waters, which are impacted by the natural variability of the climate.

The WIPP site lies within the Pecos River drainage area (Figure 2-23). The climate is semiarid, with a mean annual precipitation of about 12 inches (0.3 meters), a mean annual runoff of from 0.1 to 0.2 inches (2.5 to 5 millimeters), and a mean annual pan evaporation of more than 100 inches (2.5 meters). Brackish water with total dissolved solids (TDS) concentrations of more than 3,000 parts per million is common in the shallow wells near the WIPP site. Surface-waters (Section 2.2.2) typically have high TDS concentrations, particularly of chloride, sulfate, sodium, magnesium, and calcium.

At the WIPP site, the DOE obtains hydrologic data from conventional and special-purpose test configurations in multiple surface boreholes. (Figure 2-2 is a map of borehole locations.) Geophysical logging of the boreholes has provided hydrologic information on the rock strata intercepted. Pressure measurements, fluid samples, and ranges of rock permeability have been obtained for selected formations through the use of standard and modified drill-stem tests.

Slug injection or withdrawal tests have provided additional data to aid in the estimation of transmissivity and storage. Also, the hydraulic head of groundwaters within many water-bearing zones in the region has been mapped from measured depths to water in the boreholes.

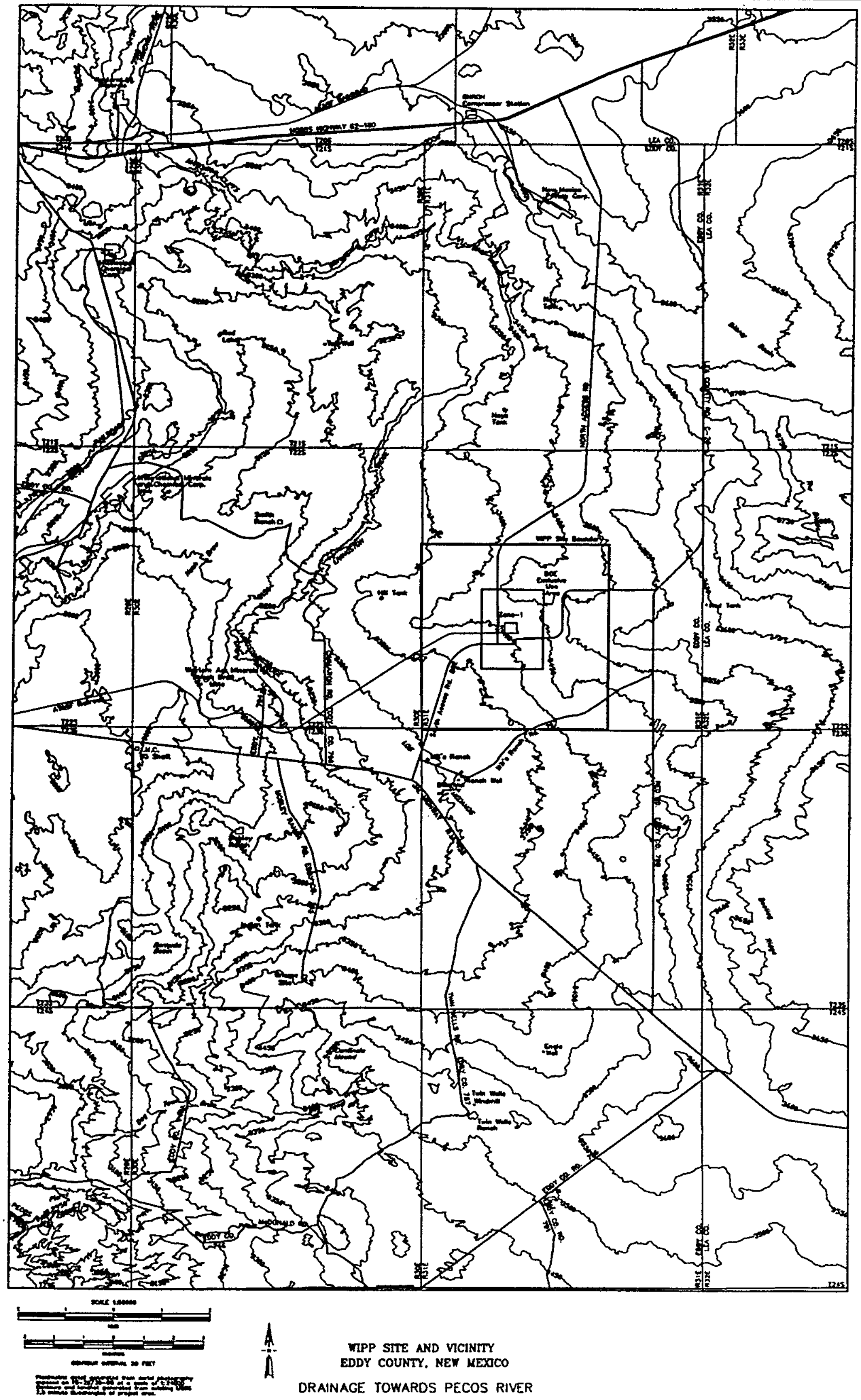
2.2.1 Groundwater Hydrology

Rock units that are important to WIPP hydrology are the Bell Canyon, the Castile, the Salado, the Rustler, the Dewey Lake, and the Santa Rosa (Figures 2-24 and 2-25).

The Bell Canyon is of interest to the DOE because it is the first regionally continuous water-bearing unit beneath the WIPP. The Castile provides a hydrologic barrier underlying the Salado, though it may contain pressurized brine.

The Culebra is the first laterally continuous unit located above the WIPP underground facility to display hydraulic conductivity sufficient to warrant concern about lateral contaminant transport. Barring a direct breach to the surface, the Culebra provides the most direct pathway between the WIPP underground and the accessible environment. The hydrology and fluid geochemistry of the Culebra are very complex and, as a result, have received a great deal of study in WIPP site characterization (see, for example, LaVenue et al. [1988], Haug et al. [1987], and Siegel et al. [1991] in the bibliography).

At the site, the Dewey Lake is 60 feet (18 meters) below the surface and about 490 feet (149 meters) thick. These units appear to be mostly unsaturated hydrologically in the vicinity of the WIPP shafts and over the waste emplacement panels.



1 **Figure 2-23. Drainage Pattern in the Vicinity of the WIPP Facility**

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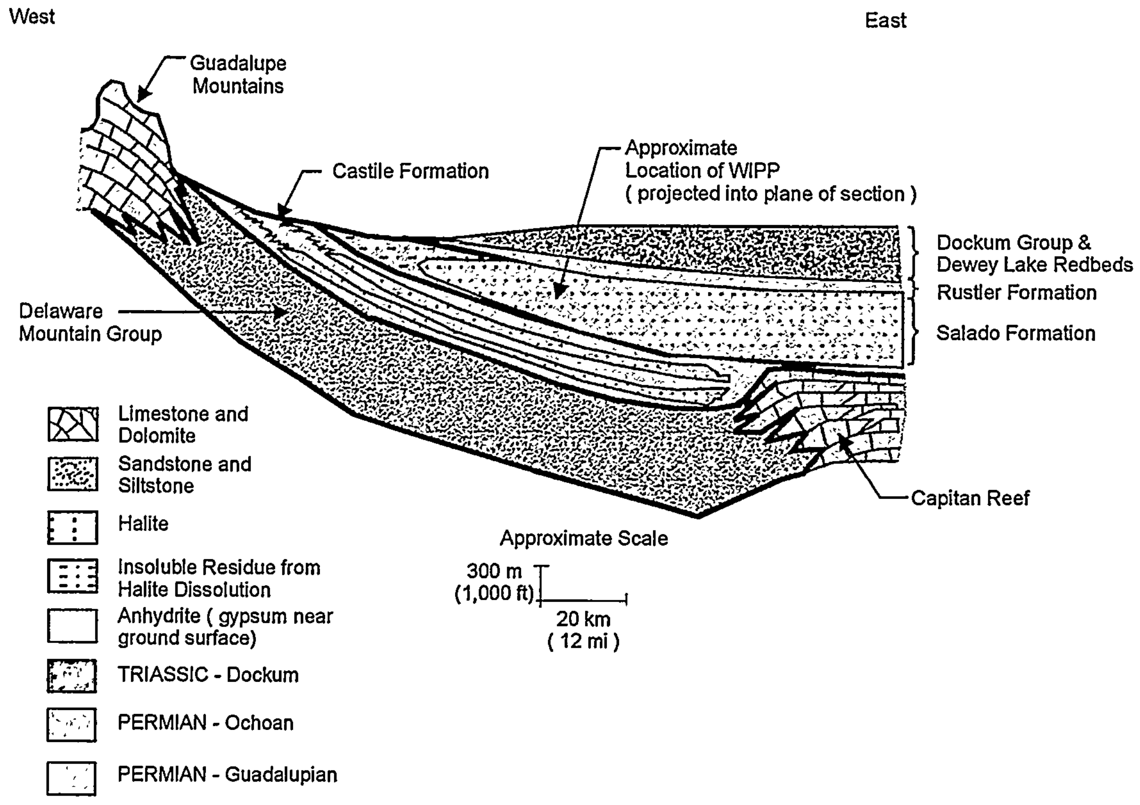

Figure 2-24. Schematic West-East Cross-Section through the North Delaware Basin

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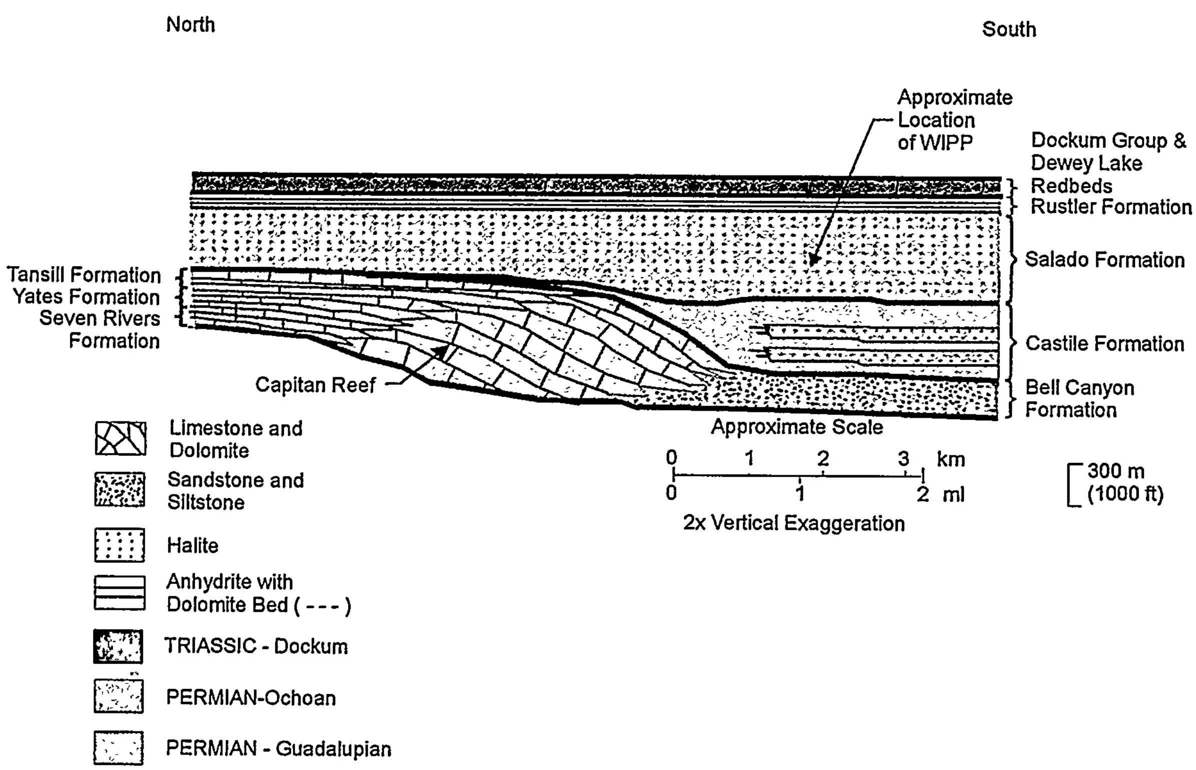

Figure 2-25. Schematic North-South Cross-Section through the North Delaware Basin

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At the WIPP site, the DOE recognizes the Culebra and the Magenta of the Rustler as the most significant water-bearing units. The DOE's sampling and analysis of non-Salado groundwater has focused on these two rock units, and the hydrologic background presented here is more detailed than for other non-Salado rock units. The hydrologic properties of the interface between the Rustler and the Salado will also be discussed. Table 2-3 provides an overview of the hydrologic characteristics of the rock units of interest at the WIPP site and the Rustler-Salado contact zone (Section 2.2.1.4 also describes the hydrology of the Rustler-Salado contact zone).

Table 2-3. Hydrologic Characteristics of Rock Units at the WIPP Site

	Thickness (m)		Hydraulic Conductivity (m/s)		Porosity	
Member Name	**max**	**min**	**max**	**min**	**max**	**min**
Forty-niner	20	—	5.0×10^{-9}	5.0×10^{-10}	—	—
Magenta	8	4	5.0×10^{-5}	5.0×10^{-10}	—	—
Tamarisk	84	8	—	—	—	—
Culebra	11.6	4	1×10^{-4}	2×10^{-10}	0.30	0.03
Unnamed	36	—	1×10^{-11}	6×10^{-15}	—	—
Rustler-Salado Contact Zone	33	2.4	1×10^{-6}	1×10^{-12}	0.33	0.15

2.2.1.1 <u>Hydrology of the Capitan Limestone</u>

The Capitan, cropping out in the southern end of the Guadalupe Mountains, is a massive limestone unit that grades basinward into recemented, partly dolomitized reef breccia and shelfward into bedded carbonates and evaporites. Its hydraulic conductivity ranges from 1 to 25 feet (0.3 to 7.6 meters) per day in southern Lea County and is 5 feet (1.5 meters) per day east of the Pecos River at Carlsbad. Hiss reported in 1976 average transmissivities around the northern and eastern margins of the Delaware Basin are 10,000 square feet (929 square meters) per day in thick sections and 500 square feet (46.5 square meters) per day in incised submarine canyons. In the aquifer, water table conditions are found southwest of the Pecos River at Carlsbad; however, artesian conditions exist to the north and east. A deeply incised submarine canyon near the Eddy-Lea county line has been identified. This canyon is filled with sediments of lower permeability than the Capitan and according to Hiss restricts fluid flow. The hydraulic gradient to the southeast of this restriction has been affected by large oil field withdrawals. The Capitan limestone is recharged by percolation through the northern shelf aquifers, by flow from underlying basin aquifers to the south and west, and by direct infiltration at its outcrop in the Guadalupe Mountains.

2.2.1.2 Hydrology of the Delaware Mountain Group

Formations of the Delaware Mountain Group underlie the Capitan reef and form the floor of the Delaware Basin evaporite sequence. Three separate formations, each about 1,000 feet (305 meters) thick, are assumed to form a single aquifer system, with an average hydraulic conductivity of 0.02 foot (0.065 meters) per day and a calculated transmissivity of about 50 square feet (4.6 square meters) per day. Figure 2-26 presents a potentiometric map representing a composite surface for the Delaware Mountain Group and the Capitan aquifer. The data were adjusted for saline density and expressed as freshwater equivalents. The brines in the Delaware Mountain Group flow northeasterly under a hydraulic gradient of from 25 to 40 feet per mile (4.7 to 7.6 meters per kilometer) and discharge into the Capitan aquifer. Velocities range from 0.2 to 0.3 feet (0.06 to 0.09 meters) per year, and groundwater yields from wells in the Delaware Mountain Group are from 0.6 to 1.5 gallons (2.3 to 5.8 liters) per minute.

2.2.1.3 Hydrology of the Salado and Castile Formations

As described in Sections 2.1.3.3 and 2.1.3.4, the Castile and the Salado consist mainly of halite and anhydrite. A considerable amount of information about the hydraulic properties of these rocks has been collected through field and laboratory experiments. Appendix HYDRO compiles and summarizes this information.

2.2.1.3.1 Salado Hydrology

Hydraulic testing in the Salado halite-rich sections provided quantitative estimates of the hydraulic properties controlling brine flow through the Salado. The tests are interpreted by Beauheim et al. in 1991 and 1993 using models based on potentiometric flow. The tests influence rock as far as 10 meters distant from the test zone and are not thought to significantly alter the pre-test conditions of the rock. The stratigraphic intervals tested include both pure and impure halite. Because tests close to the repository are within the DRZ, it is reasonable to use the results of the tests farthest from the repository as most representative of undisturbed conditions.

Twenty-two hydraulic tests have been performed in impure halite, and two in pure halite. Interpreted permeabilities using a Darcy-flow model range from 1×10^{-23} to 4×10^{-18} m^2 for impure halite intervals. Interpreted formation pore pressures range from 0.3 to 9.7 megapascals for impure halite. Tests in pure halite show no observable response, indicating either extremely low permeability ($<10^{-23}$ square meters), or no flow whatsoever, even though appreciable pressures are applied to the test interval. Appendix PAR contains a summary of the results of field permeability tests to date.

Fourteen hydraulic tests have been performed in anhydrite. Interpreted permeabilities using a Darcy-flow model range from 2×10^{-20} to 7×10^{-18} square meters for anhydrite intervals. Interpreted formation pore pressures range from atmospheric to 12.5 megapascals for anhydrite intervals. Lower values are caused by depressurization near the excavation.

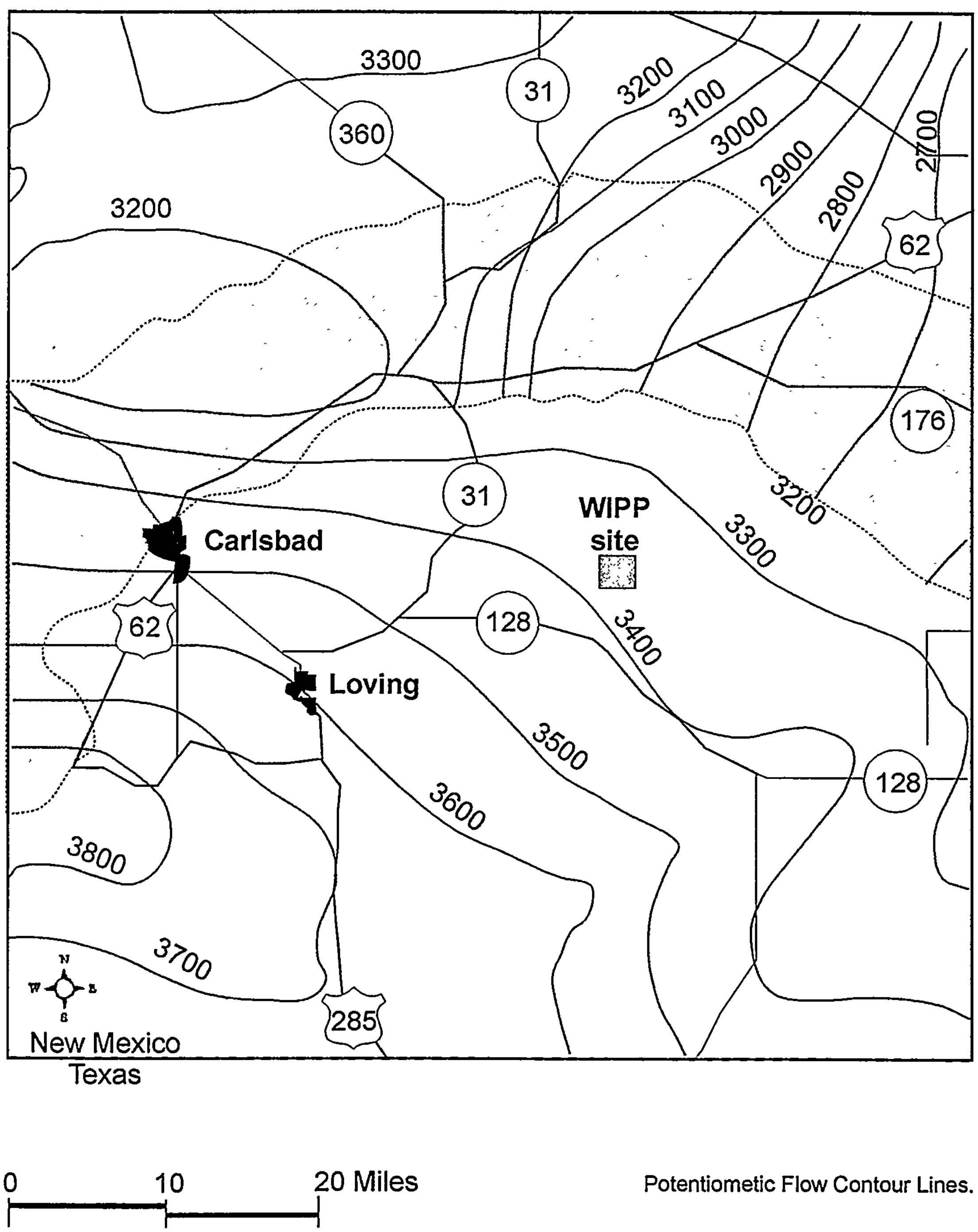

Figure 2-26. Potentiometric Surface Map (composite) of the Delaware Mountain Group and Capitan Aquifer

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The properties of anhydrite interbeds have also been investigated in the laboratory. Tests were performed on three groups of core samples from MB 139 as part of the Salado Two-Phase Flow Laboratory Program. The laboratory experiments provided porosity, intrinsic permeability, and capillary pressure data. Preliminary analysis of capillary pressure test results indicate a threshold pressure of less than 1 megapascal. The laboratory-measured effective porosity and intrinsic permeability data are shown in Appendix PAR.

Fluid pressures that are much higher than hydrostatic is a hydrologic characteristic of the Castile and the Salado that the DOE believes plays a potentially important role in the repository behavior. It is difficult to accurately measure natural pressures in these formations because the boreholes or repository excavations required to access the rocks decrease the stress in the region measured. Stress released instantaneously decreases fluid pressure in the pores of the rock, so measured pressures must be considered as a lower bound of the natural pressures. Stress effects related to test location, and the difficulty of making long-duration tests in lower permeability rocks, results in higher pore pressures being observed to date in anhydrites. The highest observed pore pressure in halite-rich units, near Room Q, is on the order of 9 megapascals, whereas the highest pore pressures observed in anhydrite are 12.5 megapascals. It is expected that the farfield pore pressures in halite-rich and anhydrite beds in the Salado at the repository level are similar. The reasons for this expectation are discussed in Chapter 6. For comparison, the hydrostatic pressure at the depth of the repository is about 7 megapascals and the lithostatic pressure calculated from density measurements in ERDA-9 is about 15 megapascals.

Fluid pressures in sedimentary basins that are much higher or much lower than hydrostatic are referred to as "abnormal pressures" in the literature of the petroleum industry, where they have received considerable attention. The explanations of how these pressures can be maintained over very long periods of time, perhaps millions of years, generally fall into two categories. The first is based on the concept that the maintenance of abnormal pressures indicates the rock volumes containing the high pressures must be "hydraulically isolated" from normally pressured sediments. The second maintains that all rocks have finite permeability and that abnormal pressures must be viewed as a transient phenomenon. In the absence of a generating method, according to the second category, these pressures would decay away over geologic time even in rocks with extremely low permeability.

Except for the pure halites, it has been demonstrated that the rocks of the Castile and the Salado have a small but finite permeability. The high pressures are almost certainly maintained because of the large compressibility and plastic nature of the halite, and to a lesser extent, the anhydrite. The lithostatic pressure at a particular horizon must be supported by a combination of the stress felt by the rock matrix and the pore fluid. In highly deformable rocks, the portion of the stress that must be borne by the fluid exceeds hydrostatic pressure but cannot exceed lithostatic pressure.

Brine content within the Salado is estimated at 1–2 percent by weight although the thin clay seams have been observed by the Brine Sampling and Evaluation Program (BSEP) reported in 1991 by Deal et al. to contain up to 25 percent brine by weight. This brine may move toward areas of low pressure, such as a borehole or mined section of the Salado.

Observation of the response of pore fluids in the Salado to changes in pressure boundary conditions at walls in the repository, in boreholes without packers, in packer-sealed boreholes, or in laboratory experiments is complicated by low permeability and low porosity. Flow has been observed to move to walls in the repository, to boreholes without packers, and to packer-sealed boreholes. In certain cases, evidence for flow is no longer observed where it once was; in others, flow has begun where it once was not observed. In many cases, observations and experiments must last for months or years to obtain useful results. In part because of design requirements such as duration (experimental period is short relative to the time required for the geological materials to fully respond), few quantitative data have been obtained for certain lithologic units within the Salado. There is much direct, qualitative experience regarding the behavior of flow crossing the walls of the repository.

2.2.1.3.2 Castile Hydrology

The hydrology of the Castile differs from that of the Salado in that fracturing in the upper anhydrite has generated regions with much greater permeability than the surrounding intact anhydrite. These regions are located in the area of structural deformation as discussed in Section 2.1.6.1.1. The higher permeability regions of the Castile contain brine at pressures greater than hydrostatic and have been referred to as "brine reservoirs." The fluid pressure measured in the WIPP-12 borehole (12.7 megapascals) is greater than the nominal hydrostatic pressure for a column of equivalent brine at that depth (11.1 megapascals). Therefore, under open-hole conditions, brine could flow upward through an intrusion borehole.

Hydraulic tests performed in the ERDA-6 and WIPP-12 boreholes suggest that the highly permeable portions of the Castile are limited in extent. The vast majority of brine is thought to be stored in low-permeability microfractures; about 5 percent of the overall brine volume is stored in large open fractures. The volumes of the ERDA-6 and WIPP-12 brine reservoirs were estimated by Popielak et al. in 1983 to be 3.5×10^6 cubic feet (100,000 cubic meters) and 9.5×10^6 cubic feet (2,700,000 cubic meters), respectively.

The origin of brine in the Castile has been investigated geochemically. Popielak et al. concluded that the ratios of major and minor element concentrations in the brines indicate that these fluids originated from ancient seawater and that there is no evidence for fluid contribution from present meteoric waters. The gas and brine chemistries of Castile waters from the ERDA-6 and WIPP-12 reservoirs are distinctly different from each other and from local groundwaters. The brines are saturated, or nearly so, with respect to halite and, consequently, have little or no halite dissolution potential.

2.2.1.4 Hydrology of the Rustler-Salado Contact Zone

In the vicinity of the Nash Draw, the contact between the Rustler and the Salado is an unstructured residuum of gypsum, clay, and sandstone created by the dissolution of halite. The residuum is absent under the WIPP site. It is clear that dissolution in Nash Draw occurred after deposition of the Rustler.

Brine in the Rustler-Salado contact residuum, immediately above the top of the salt in the vicinity of Nash Draw, was first described by Robinson and Lang in 1938 and referred to as the "brine aquifer." They suggested that the structural conditions that caused the development of Nash Draw might control the occurrence of the brine; thus, the brine aquifer boundary may coincide with the topographic surface expression of Nash Draw. Their studies show the brine to be concentrated along a strip from 2 to 8 miles (3.3 to 13 kilometers) wide and about 26 miles (43 kilometers) long. Data from the test holes Robinson and Lang drilled indicate that the residuum (containing the brine) ranges in thickness from 10 to 60 feet (3 to 18 meters) and averages about 24 feet (7 meters). In 1954, hydraulic properties were determined by Hale et al. primarily for the area between Malaga Bend on the Pecos River and Laguna Grande de la Sal. They calculated a value of transmissivity of 8,000 square feet per day (8.6×10^{-3} square meters per second) and estimated the potentiometric gradient to be 1.4 feet per mile (0.27 meters per kilometer). In this area, the "Rustler-Salado residuum" apparently is part of a continuous hydrologic system as evidenced by the coincident fluctuation of water levels in the test holes (as far away as Laguna Grande de la Sal) with pumping rates in irrigation wells along the Pecos River.

In the northern half of Nash Draw, the approximate outline of the brine aquifer (Rustler-Salado contact residuum) as described by Robinson and Lang in 1938 has been supported by drilling associated with the WIPP hydrogeologic studies. These studies also indicate that the main differences in areal extent occur along the eastern side where the boundary is very irregular and, in places (test holes P-14 and H-07), extend farther east than previously indicated by Robinson and Lang.

Other differences from the earlier studies include the variability in thickness of residuum present in test holes WIPP-25 through WIPP-29. These holes indicate thicknesses ranging from 11 feet (3.3 meters) in WIPP-25 to 108 feet (33 meters) in WIPP-29 in Nash Draw, compared to 8 feet (2.4 meters) in test hole P-14 east of Nash Draw. The specific geohydrologic mechanism that has caused dissolution to be greater in one area than in another is not apparent, although a general increase in chloride concentration in water from the north to the south may indicate the effects of movement down the natural hydraulic gradient in Nash Draw.

The average hydraulic gradient within the residuum in Nash Draw is about 10 feet per mile (1.9 meters per kilometer); in contrast, at the WIPP site the average gradient is 39 feet per mile (7.4 meters per kilometer). This difference reflects the changes in transmissivity, which are as much as five orders of magnitude greater in Nash Draw. The transmissivity determined from aquifer tests in test holes completed in the Rustler-Salado contact residuum of Nash

Draw ranges from $2x10^{-4}$ square feet per day ($2.1x10^{-10}$ square meters per second) at WIPP-27 to 8 square feet per day ($8.6x10^{-6}$ square meters per second) at WIPP-29. This is in contrast to the WIPP site proper, where transmissivities range from $3x10^{-5}$ square feet ($3.2x10^{-11}$ square meters per second) per day at test holes P-18 and H-05c to $5x10^{-2}$ square feet per day ($5.4x10^{-8}$ square meters per second) at test hole P-14. Locations and estimated hydraulic heads of these wells are illustrated in Figure 2-27.

Hale et al. believed the Rustler-Salado contact residuum discharges to the alluvium near Malaga Bend on the Pecos River. Because the confining beds in this area probably are fractured due to dissolution and collapse of the evaporites, the brine (under artesian head) moves up through these fractures into the overlying alluvium and then discharges into the Pecos River.

Evidence for very slow groundwater movement is found in the water quality, especially in the magnesium concentrations. Large magnesium concentrations appear to be indicative of an environment in which groundwater flow is extremely slow and there has been extensive interaction between the water and its host rock. Large concentrations of magnesium, ranging from 21,000 milligrams per liter in water from test hole H-06 to 82,000 milligrams per liter in water from test hole H-05, were present in most of the test wells in the eastern part of the WIPP site. Aquifer tests at these test holes were characterized by very low transmissivities. To the west, approaching the more developed part of the flow system of the Rustler-Salado contact residuum in Nash Draw, the magnesium concentrations decreased by one to two orders of magnitude. Magnesium concentrations of 1,200 milligrams per liter in water from test hole P-14 and 350 milligrams per liter in water from test hole P-15 may indicate the eastern boundary of the more developed Rustler-Salado flow system. Magnesium concentrations are as small as 430 milligrams per liter in water from test hole H-08; other values range from 910 milligrams per liter in water from test hole H-07 to 3,200 milligrams per liter in water from test hole WIPP-25.

According to Appendix HYDRO, water in the Rustler-Salado contact residuum contains the largest concentrations of dissolved solids in the WIPP area, ranging from 79,800 milligrams per liter in test hole H-07 to 480,000 milligrams per liter in test hole H-01. These waters are classified as brines. The dissolved mineral constituents in the brine largely consist of sulfates and chlorides of calcium, magnesium, sodium, and potassium; the major constituents are sodium and chloride. Concentrations of the other major ions vary according to the spatial location of the sample and probably are directly related to the interaction of the brine and the host rocks and reflect residence time within the rocks. Residence time of the brine depends upon the transmissivity of the rock. For example, the presence of large concentrations of potassium and magnesium in water is correlated with minimal permeability and a relatively undeveloped flow system.

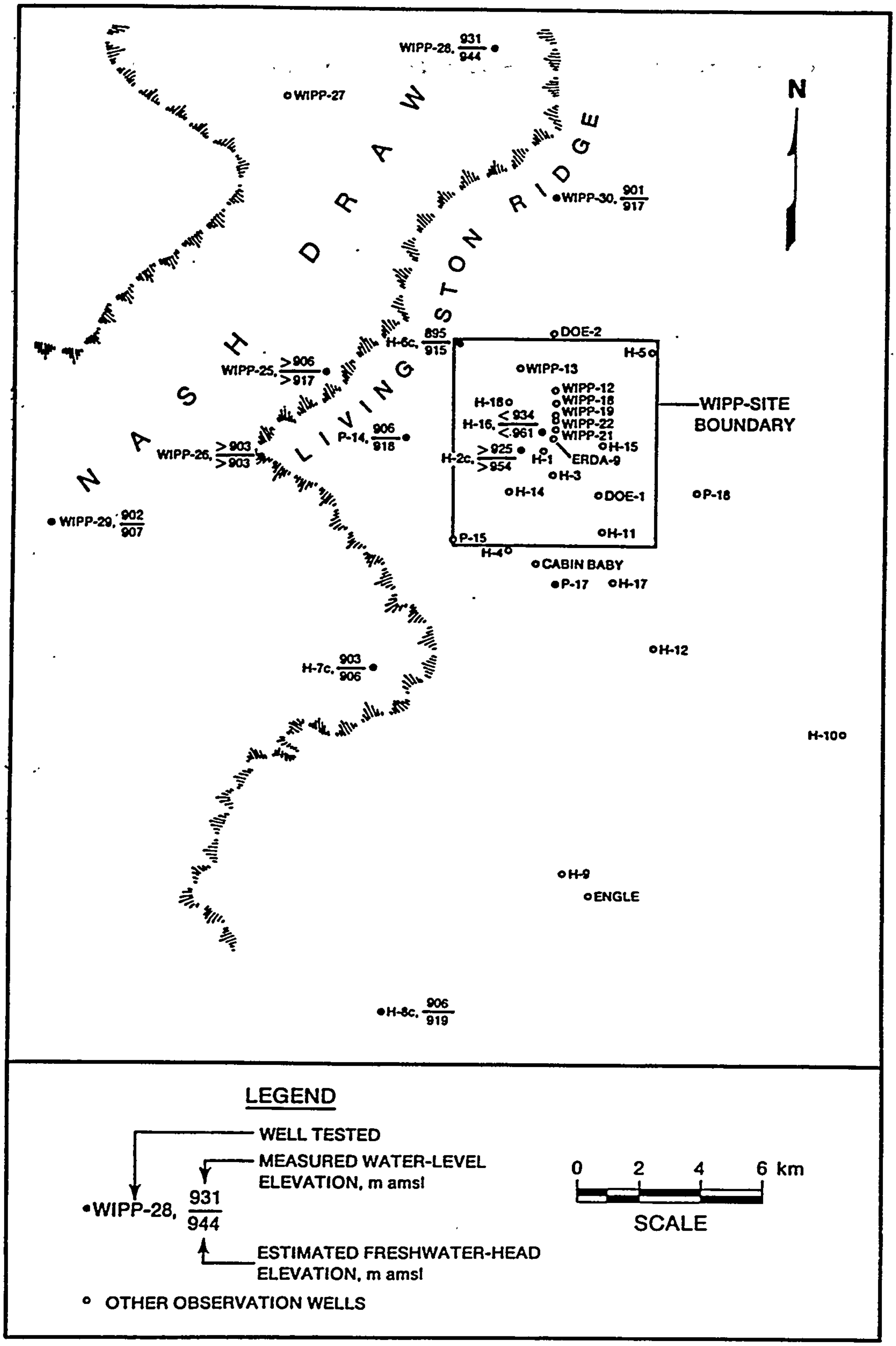

Figure 2-27. Measured Water Levels and Estimated Freshwater Heads of the Unnamed Lower Member and Rustler-Salado Contact Zone

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2.2.1.5 Hydrology of the Rustler Formation

The Rustler is of particular importance for WIPP because it contains the most transmissive units above the repository. The Rustler is divided into four formally named members and an unnamed lower member. These five units are, in ascending order, the unnamed lower member (the oldest), the Culebra, the Tamarisk, the Magenta, and the Forty-niner (the youngest).

2.2.1.5.1 Unnamed Lower Member of the Rustler Formation

The basal interval of the unnamed lower member is composed of siltstone, mudstone, and claystone and can be considered the water-producing zones of the lowermost Rustler. Transmissivities of $2.7x10^{-4}$ square feet per day ($2.9x10^{-10}$ square meters per second) and $2.2x10^{-4}$ square feet per day ($2.4x10^{-10}$ square meters per second) were calculated by Beauheim (1987, p. 50) from tests at well H-16 that included this interval. These transmissivity values correspond to hydraulic conductivities of $4.2x10^{-6}$ feet per day ($1.5x10^{-11}$ meters per second) and $3.4x10^{-6}$ feet per day ($1.2x10^{-11}$ meters per second). Hydraulic conductivity in the lower portion of the unnamed lower member is believed by the DOE to increase to the west in and near Nash Draw, where dissolution in the underlying Rustler-Salado contact zone has caused subsidence and fracturing of the sandstone and siltstone.

The remainder of the unnamed lower member contains mudstones, anhydrite, and variable amounts of halite. The hydraulic conductivity of these lithologies is extremely low: tests of mudstones and claystones in the Waste Handling Shaft gave hydraulic conductivity values ranging from $2x10^{-9}$ feet per day ($6x10^{-15}$ meters per second) to $3x10^{-8}$ feet per day ($1x10^{-13}$ meters per second) according to Saulnier and Avis (1988, p. 6-11).

2.2.1.5.2 The Culebra Member of the Rustler Formation

The Culebra is modeled in the performance assessment as the most likely pathway for the release of radionuclides to the accessible environment because of its relatively high transmissivity near the WIPP site, and hydrologic research activity has concentrated on the unit for over a decade.

According to Appendix HYDRO, the transmissivity of the Culebra varies over six orders of magnitude from east to west in the vicinity of the WIPP (Figure 2-28). It ranges from $1x10^{-3}$ square feet per day ($1x10^{-9}$ square meters per second) at well P-18 east of the WIPP site to $1x10^{3}$ square feet per day ($1x10^{-3}$ square meters per second) at well H-7 in Nash Draw (see Figure 2-2 for the locations of these wells).

Measured matrix porosities of the Culebra range from 0.03 to 0.30. Fracture porosity values have not been measured directly, but interpreted values from tracer tests at the H-3, H-6, and H-11 hydropads range from $5x10^{-4}$ to $3x10^{-3}$. Data are insufficient to map the spatial variability of the porosity.

Variations in transmissivity in the Culebra are believed by many experts to be controlled by the relative abundance of open fractures rather than by primary (i.e., depositional) features of the unit. Lateral variations in depositional environments were small within the mapped region, and primary features of the Culebra show little map-scale spatial variability according to Appendix FAC. Direct measurements of the density of open fractures are not available from core samples because of incomplete recovery and fracturing during drilling, but comparisons with the relatively unfractured exposures in the WIPP shafts suggest that the density of open fractures in the Culebra decreases to the east. Qualitative correlations have been noted between transmissivity and several geologic features possibly related to open-fracture density, including (1) the distribution of overburden above the Culebra; (2) the distribution of halite in other members of the Rustler; (3) the dissolution of halite in the upper portion of the Salado; and (4) the distribution of gypsum fillings in fractures in the Culebra.

The distribution of groundwater hydrogeochemical facies is not consistent with the southward flow direction calculated by LaVenue et al. in 1990 from potentiometric data, if one assumes that the ionic strength of a groundwater increases along a flow path. One possible model for the relationship between the facies distribution and the flow paths has been proposed by Chapman in 1986 and 1988, who coupled an extensive compilation of stable and radiogenic isotope ratios of Rustler groundwaters with isotopic data from regional groundwaters and surficial waters. Chapman cited evidence for short times of Culebra groundwaters and postulated that recharge from the surface could account for the less concentrated groundwaters south of the WIPP site. That explanation, however, is not supported by interpretations of isotopic and solute data presented by Lambert, Siegel, and others.

Specifically, radiogenic isotopic signatures suggest that the age of the groundwater in the Culebra is on the order of tens of thousands of years (see, for example, Lambert 1987; Lambert and Carter 1987; Lambert and Harvey 1987 in the bibliography). A conceptual model was put forth by Siegel et al. in 1991. Those authors contend that there has been a change in the location and amount of recharge since the last glacial maximum and that the present distribution of solutes and isotopes in the Culebra is a relict of a flow regime of a wetter climate. The current distribution of hydrogeochemical facies, therefore, represents a rock-water system that is still slowly reaching a new chemical and physical equilibrium. However, a conceptual or calculational model of how paleoflow could have been to the east has not been presented.

Currently, the issue of the relationship between water chemistry and groundwater flow in the Culebra remains unresolved. It is possible that lack of resolution reflects the way the problem has been posed and the relatively simple conceptual models that have been used to represent the hydrology of the system. Previous discussions, for example, have focused on flow directions but not flow rates. Computer models of flow in the Culebra suggest that flow rates are orders of magnitude slower in the region of the halite facies than in the region of the anhydrite facies. It is possible that the geochemical signature of flow from the halite facies to the anhydrite facies is not observed because only minute amounts of water flow along this path. In addition, some of the previous studies have not considered, or have not ruled out, transport of solutes from units above and below the Culebra. For example, the region of the

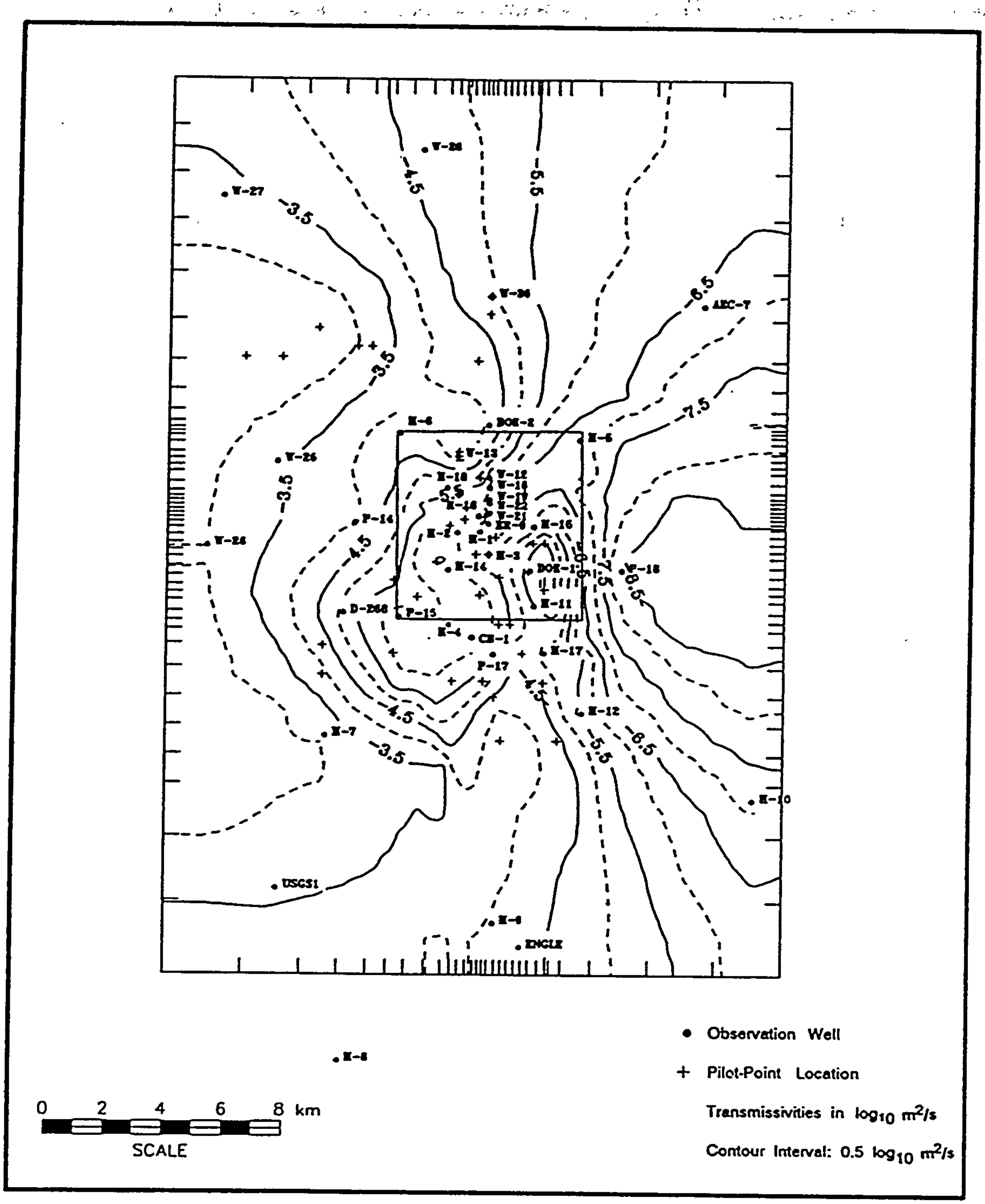

Figure 2-28. The Transient Calibrated Log_{10} Transmissivities

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halite facies correlates well with the extent of halite in strata above and below the Culebra. The possibility that the halite facies results from vertical advective or diffusive transport into a region of extremely slow flow in the Culebra has not been investigated. Preliminary results of calculations using the groundwater basin approach suggest that addressing these issues as a three-dimensional transport system will facilitate resolution.

2.2.1.5.3 The Tamarisk Member of the Rustler Formation

Attempts were made in two wells, H-14 and H-16, to test a 7.9-foot (2.4-meter) sequence of the Tamarisk that consists of claystone, mudstone, and siltstone overlain and underlain by anhydrite. Permeability was too low to measure in either well within the time allowed for testing; consequently Beauheim in 1987 estimated the transmissivity of the claystone sequence to be one or more orders of magnitude less than that of the tested interval in the unnamed lower member. Transmissivity in the Tamarisk was estimated to be less than approximately $2.5x10^{-5}$ square feet per day ($2.7x10^{-11}$ square meters per second), corresponding to a hydraulic conductivity of less than approximately $1.3x10^{-6}$ square feet per day ($1.4x10^{-12}$ meters per second).

2.2.1.5.4 The Magenta Member of the Rustler Formation

The Magenta of the Rustler is a fine-grained dolomite that ranges in thickness from 13 to 26 feet (4 to 8 meters) and is about 19 feet (6 meters) thick at the WIPP. The Magenta is saturated except near outcrops along Nash Draw, and hydraulic data are available from 15 wells. According to Appendix HYDRO, transmissivity ranges over five orders of magnitude from $1x10^{-3}$ to $4x10^{2}$ square feet per day ($1x10^{-9}$ to $4x10^{-4}$ square meters per second).

The hydraulic transmissivities of the Magenta, based on sparse data, show a decrease in conductivity from west to east, with slight indentations of the contours north and south of the WIPP that correspond to the topographic expression of Nash Draw. In most locations, the hydraulic conductivity of the Magenta is one to two orders of magnitude less than that of the Culebra.

No porosity measurements have been made on the Magenta. Beauheim (1987, pp. 111, 115) assumed a porosity representative of dolomite of 0.20 for the interpretations of well tests. The hydrologic gradient across the site varies from 16 to 20 feet per mile (3 to 4 meters per kilometer) on the eastern side, steepening to about 32 feet per mile (6 meters per kilometer) along the western side near Nash Draw (Figure 2-29).

2.2.1.5.5 The Forty-niner Member of the Rustler Formation

The uppermost member of the Rustler, the Forty-niner, is about 20 meters (66 feet) thick throughout the WIPP area and consists of low-permeability anhydrite and siltstone. Tests by Beauheim in 1987 in H-14 and H-16 yielded transmissivities of about $3x10^{-2}$ to $7x10^{-2}$ square feet per day ($3x10^{-8}$ to $8x10^{-6}$ square meters per second) and $5x10^{-3}$ to $6x10^{-3}$ square feet per day ($3x10^{-9}$ to $6x10^{-9}$ square meters per second), respectively.

2.2.1.6 Hydrology of the Supra-Rustler Rocks (the Dewey Lake and the Santa Rosa)

The supra-Rustler rocks consist of (in ascending order) the Dewey Lake and the Santa Rosa are comprised of a confining siltstone bed, water-bearing sandstone, and a confining mudstone bed (respectively). The Dewey Lake may retard downward percolation of surface waters while the Santa Rosa provides water for irrigation and livestock.

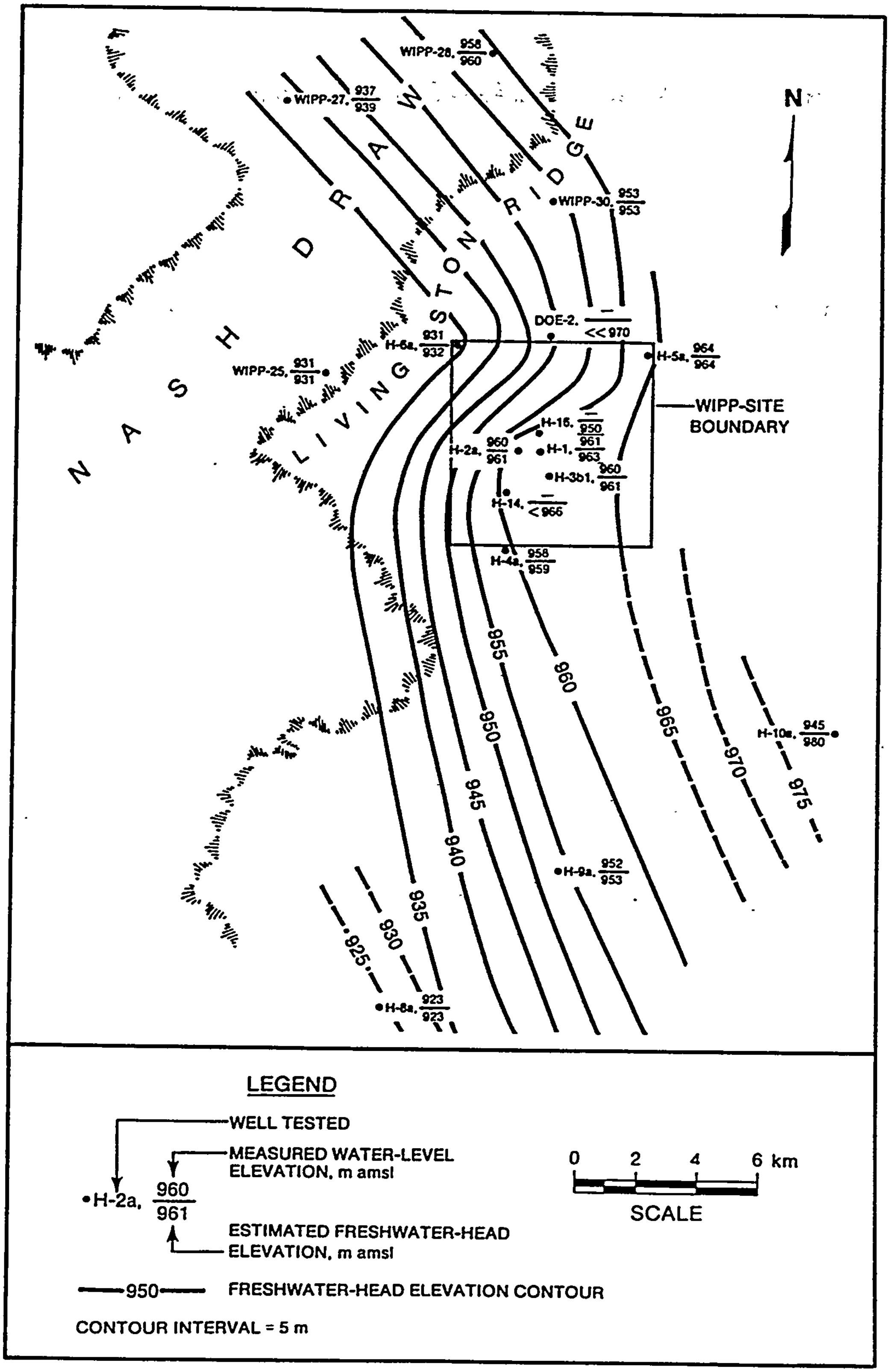
2.2.1.6.1 The Dewey Lake (Redbeds)

Hydrologic properties of the Dewey Lake are characterized based on only a few measurements compared to the more extensive data set available for members of the Rustler. As a result, the position of the water table is not well known. The average hydraulic conductivity of the Dewey Lake, assuming saturation, is estimated to be 3×10^{-3} feet per day (10^{-8} meters per second), corresponding to the hydraulic conductivity of fine-grained sandstone and siltstone. Hydraulic properties are somewhat variable as relatively high water production from a fractured zone within the WIPP site boundary was recently observed at Water Quality Sampling Program (WQSP)-6A. However, in the vicinity of the WIPP shafts, the Dewey Lake has not produced water. Several wells operated by the J.C. Mills Ranch south of the WIPP produce sufficient quantities of water from the Dewey Lake to supply livestock.

2.2.1.6.2 The Santa Rosa

The Santa Rosa is about 140–300 feet (43–91 meters) thick and is present over the eastern half of the WIPP site. It dips gently westward, except in local areas of collapse, and crops out northeast of Nash Draw. As a water-bearing unit, the Santa Rosa near the WIPP site has a saturated thickness of only from 1 to 2 feet (0.3 to 0.61 meters) and occurs in limited extent. It has a porosity of about 13 percent and a specific capacity of 0.14–0.20 gallons per minute per foot (0.029–0.041 liters per second per meter) of drawdown. Lows in the potentiometric surface near the Eddy-Lea county line and the San Simon Swale suggest recharge into underlying rocks, possibly through collapse zones, and a possibility of a groundwater divide (at a surface ridge) between the site and San Simon Swale. In general, groundwater flows south and is of better quality than that found in the Rustler.

It is not known at this time what quantities of water, if any, from the Santa Rosa recharge the shallow aquifers along the Pecos River. The groundwater gradient in adjacent Texas along the Pecos River is influenced by a large-scale withdrawal of groundwater, resulting in a net loss of groundwater storage. The declines in water levels have created sizable cones of depression along the river and gradients toward the river. The Santa Rosa aquifer in southwest Texas adjacent to the New Mexico border is not downgradient from the WIPP site. Several reasons for believing that Santa Rosa waters at the WIPP site flow into the Pecos River rather than to the south into Texas are the configuration of the potentiometric head map, the influence of extensive pumping, and a topographic groundwater divide east of the WIPP site. Groundwaters pumped from the Santa Rosa and alluvium deposits are used extensively for irrigation and livestock.



1 **Figure 2-29. Water Levels and Estimated Freshwater Heads**
2 **in the Magenta**

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2.2.1.7 Groundwater Elevation Measurements in 1991

Groundwater levels have been measured continuously in some units in the vicinity of the WIPP site for several decades. These levels can be used to determine the longer term trends in water-level changes, either natural or in response to human activities in the region. The groundwater-level data indicate that there is a gradual trend of rising water-level elevations within the Culebra. Of the surveillance locations, 39 of the 46 showed some increase in water-level elevations within the Culebra. Two anomalous occurrences were noted in the data. The first was a net loss of 8.64 feet (2.62 meters) of groundwater-level elevation at the Cabin Baby (CB)-1 well site from January through December 1991, and the second was a gain of 24.77 feet (7.51 meters) of groundwater-level elevation at well P-18 (Figure 2-2). The two wells are located within 5 miles (8.3 kilometers) of each other. The suspected cause of the loss of water-level elevation at Cabin Baby is the failure of a bridge plug located between the Culebra and the portion of the hole open to the Salado and the Castile. The anomalous water-level elevation increase at P-18 is gradually decreasing from year to year. In 1988, the water level in well P-18 increased approximately 45 feet (14 meters), whereas the increase was approximately 33 and 25 feet (10 and 7.6 meters), respectively, in 1990 and 1991. The smaller increase from year to year indicates that P-18 is trending toward an equilibrium state; however, the magnitude of elevation gains indicates that years may pass before equilibrium is achieved.

Freshwater head distribution in the Culebra indicates that the generalized directional flow of groundwater is north to south. However, caution should be used when making assumptions based on groundwater-level data alone. Recent studies in the Culebra have shown that fluid density variations in the Culebra can affect flow direction. One should also be aware that the fractured media of the Culebra, coupled with variable fluid densities, can cause localized flow patterns to have little or no relationship to general flow patterns.

Measurements at 11 surveillance locations in the Magenta also indicated an upward trend in water-level elevations. No anomalous losses or gains were noted within the Magenta. Seven of eleven Magenta surveillance locations show a gain in the elevation of groundwater levels from January to December 1991. Four wells showed lower groundwater-level elevations in December than in January 1991. All of the four surveillance locations that indicated a loss of head elevation from January to December were wells that are pumped routinely as part of the WQSP. These locations are H-03b1, H-04c, H-05c, and H-06c. Recovery from these pumping events may have influenced the water-level data collected at these locations.

When groundwater elevations taken in 1991 are compared to potentiometric elevation maps produced by Appendix HYDRO, groundwater elevations appear to be below 1983 levels. Mercer's study was performed prior to the onset of the large-scale hydrologic activities that took place in the vicinity of the WIPP site to support site characterization and other hydrologically oriented activities during the mid to late 1980s. Since the end of the 1980s, only modest amounts of groundwater have been removed from these formations. The possibility exists that the increasing groundwater elevations observed in 1991 represent a natural trend for the recovery of the formations to groundwater elevations near those of the 1983 potentiometric elevations.

2.2.2 Surface-Water Hydrology

The WIPP site is in the Pecos River basin, which contains about 50 percent of the drainage area of the Rio Grande Water Resources Region. The Pecos River headwaters are northeast of Santa Fe, and the river flows to the south through eastern New Mexico and western Texas to the Rio Grande. The Pecos River has an overall length of about 500 miles (805 kilometers), a maximum basin width of about 130 miles (209 kilometers), and a total drainage area of about 44,535 square miles (115,301 square kilometers) (about 20,500 square miles [53,075 square kilometers] contained within the basin have no external surface drainage and their surface waters do not contribute to Pecos River flows). Figure 2-23 shows the Pecos River drainage area.

The Pecos River is generally perennial, except in the reach below Anton Chico and between Fort Sumner and Roswell, where the low flows percolate into the stream bed. The main stem of the Pecos River and its major tributaries have low flows, and the streams are frequently dry. About 75 percent of the total annual precipitation and 60 percent of the annual flow result from intense local thunderstorms between April and September. The principal tributaries of the Pecos River, in downstream order, are the Gallinas River, Salt Creek, Rio Hondo, Rio Felix, Eagle Creek, Rio Peñasco, Black River, and Delaware River.

There are no perennial streams at the WIPP site. At its nearest point, the Pecos River is about 12 miles (19 kilometers) southwest of the WIPP site boundary. The drainage area of the Pecos River at this location is 19,000 square miles (47,500 square kilometers). A few small creeks and draws are the only westward flowing tributaries of the Pecos River within 20 miles (32 kilometers) north or south of the site. A low-flow investigation has been initiated by the USGS within the Hill Tank Draw drainage area, the most prominent drainage feature near the WIPP site. The drainage area is about 4 square miles (10.3 square kilometers), with an average channel slope of from 1 to 100, and the drainage is westward into Nash Draw. Two years of observations showed only four flow events. The USGS estimates that the flow rate for these events was under 2 cubic feet per second (0.057 cubic meters per second). The Black River (drainage area: 400 square miles [1,035 square kilometers]) joins the Pecos from the west about 16 miles (25 kilometers) southwest of the site. The Delaware River (drainage area: 700 square miles [1,812 square kilometers]) and a number of small creeks and draws also join the Pecos River along this reach. The flow in the Pecos River below Fort Sumner is regulated by storage in Sumner Lake, Brantley Reservoir, Lake Avalon, and several other smaller irrigation dams.

Four major reservoirs are located in the Pecos River basin: the Sumner Lake, Brantley Reservoir, Lake Avalon, and the Red Bluff Reservoir, the last located just over the border in Texas (Figure 2-30). The storage capacities of these reservoirs and other Pecos River reservoirs adjacent to the Pecos River basin are shown in Table 2-4.

Table 2-4. Capacities of Reservoirs in the Pecos River Drainage

Reservoir	River	Total Storage Capacity[a] (acre-feet)	Use[b]
Los Esteros	Pecos	282,000	FC
Sumner	Pecos	122,100	IR, R
Brantley	Pecos	42,000	IR, R, FC
Avalon	Pecos	5,000	IR
Red Bluff	Pecos	310,000	IR, P
Two Rivers	Rio Hondo	167,900	FC

[a]Capacity below the lowest uncontrolled outlet or spillway.
[b]*Key:*
FC = flood control R = recreation
IR = irrigation P = hydroelectric

With regards to surface drainage onto and off of the WIPP site, there are no major lakes or ponds within 10 miles (16 kilometers) of the center of the site. Laguna Gatuña, Laguna Tonto, Laguna Plata, and Laguna Toston are playas more than 10 miles (16 kilometers) north of the site and are at elevations of 3,450 feet (1.05 kilometers) or higher. Thus, surface runoff from the site (elevation 3,310 feet [1.01 kilometers] above sea level) would not flow toward any of them. To the north, west and northwest, Red Lake, Lindsey Lake, Laguna Grande de la Sal, and a few unnamed stock tanks are more than 10 miles (16 kilometers) from the site, at elevations of from 3,000 to 3,300 feet (914 to 1,006 meters).

The mean annual precipitation in the region is about 12 inches (0.3 meters), and the mean annual runoff is 0.1–0.2 inches (2.5–5 millimeters). The maximum recorded 24-hour precipitation at Carlsbad was 5.12 inches (130 millimeters) in August 1916. The predicted maximum 6-hour, 100-year precipitation event for the site is 3.6 inches (91 millimeters) and is most likely to occur during the summer. The maximum recorded daily snowfall at Carlsbad was 10 inches (254 millimeters) in December 1923.

The maximum recorded flood on the Pecos River occurred near the town of Malaga, New Mexico, on August 23, 1966, with a discharge of 120,000 cubic feet (3,396 cubic meters) per second and a stage elevation of about 2,938 feet (895 meters) above mean sea level. The minimum surface elevation of the WIPP site is over 500 feet (152 meters) above the river bed and over 400 feet (122 meters) above the elevation of this maximum historical flood elevation (DOE 1980, § 7.4.1).

More than 90 percent of the mean annual precipitation at the site is lost by evapotranspiration. On a mean monthly basis, evapotranspiration at the site greatly exceeds the available rainfall; however, intense local thunderstorms may produce runoff and percolation.

Water quality in the Pecos River basin is affected by mineral pollution from natural sources and from irrigation return flows (see Section 2.4.2.2 for surface-water quality). At Santa Rosa, New Mexico, the average suspended-sediment discharge of the river is about 1,650 tons per day. Large amounts of chlorides from Salt Creek and Bitter Creek enter the river near Roswell. River inflow in the Hagerman area contributes increased amounts of calcium, magnesium, and sulfate; and waters entering the river near Lake Arthur are high in chloride. Below Brantley Reservoir, springs flowing into the river are usually submerged and difficult to sample; springs that could be sampled had TDS concentrations of from 3,350 to 4,000 milligrams per liter. Concentrated brine entering at Malaga Bend adds an estimated 70 tons per day of chloride to the Pecos River.

2.2.3 Groundwater Discharge and Recharge

The only documented points of naturally occurring groundwater discharge in the vicinity of the WIPP are the saline lakes in Nash Draw and the Pecos River, primarily near Malaga Bend. Although this is local flow associated with Nash Draw and unrelated to groundwater flow at the WIPP site, it is presented here for completeness. Discharge into one of the lakes from Surprise Spring was measured by Hunter in 1985 at a rate of less than 0.35 cubic feet (0.01 cubic meters) per second in 1942. Hunter also estimated total groundwater discharge into the lakes is 24 cubic feet (0.67 cubic meters) per second. According to Appendix HYDRO, discharge from the spring comes from fractured and more transmissive portions of the Tamarisk of the Rustler, and the lakes are hydraulically isolated from the Culebra and lower units.

Groundwater discharge into the Pecos River is greater than discharge into the saline lakes. Groundwater discharge into the Pecos River between Avalon Dam north of Carlsbad and a point south of Malaga Bend was no more than approximately 32.5 cubic feet (0.92 cubic meters) per second. Most of this gain in stream flow occurs near Malaga Bend (see Figure 2-1) and is the result of groundwater discharge from the residuum at the Rustler-Salado contact zone.

The only documented point of groundwater recharge is also near Malaga Bend, where an almost immediate water-level rise has been reported by Hale et al. in 1954 in a Rustler-Salado well following a heavy rainstorm. This location is hydraulically downgradient from the repository, and recharge here has little relevance to flow near the WIPP. Examination of the potentiometric surface map for the Rustler-Salado contact zone (Figure 2-27) indicates that some inflow may occur north of the WIPP, where freshwater equivalent heads are highest. Additional inflow to the contact zone may occur as leakage from overlying units, particularly where the units are close to the surface and under water table conditions.

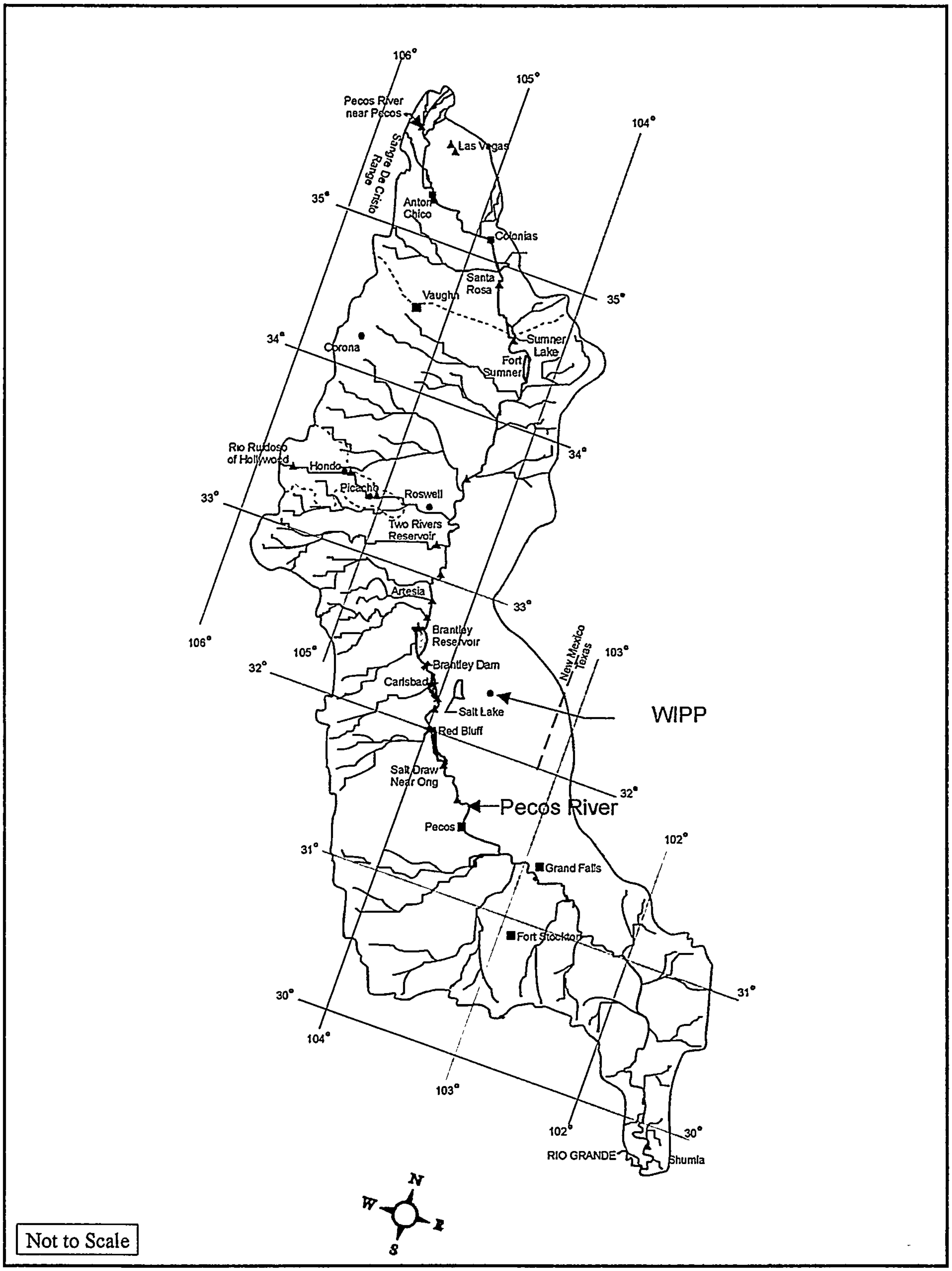

Figure 2-30. Location of Reservoirs and Gauging Stations in the Pecos River Basin

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No direct evidence exists for the location of either recharge to or discharge from the Culebra. The freshwater-head surface map (Figure 2-31) implies inflow from the north and outflow to the south. Recharge from the surface probably occurs 9–19 miles (15–30 kilometers) northwest of the WIPP in and north of Clayton Basin (Figure 2-27) where the Rustler crops out. An undetermined amount of inflow may also occur as leakage from overlying units throughout the region.

The freshwater head contour map (Figure 2-31) indicates that flow in the Culebra is toward the south. Some of this southerly flow may enter the Rustler-Salado contact zone under water table conditions near Malaga Bend and ultimately discharge into the Pecos River. Additional flow may discharge directly into the Pecos River or into alluvium in the Balmorhea–Loving Trough to the south.

Recharge to the Magenta may also occur north of the WIPP in Bear Grass Draw and Clayton Basin. The potentiometric surface map indicates that discharge is toward the west in the vicinity of the WIPP, probably into the Tamarisk and the Culebra near Nash Draw. Some discharge from the Magenta may ultimately reach the saline lakes in Nash Draw. According to Brinster in 1991, additional discharge probably reaches the Pecos River at Malaga Bend or the alluvium in the Balmorhea–Loving Trough.

Isotopic data from groundwater samples suggest that groundwater travel time from the surface to the Dewey Lake and the Rustler is long and rates of flow are extremely slow. Based on observations by Lambert and Harvey reported in 1987, low tritium levels in all WIPP-area samples indicate minimal contributions from the atmosphere since 1950. Lambert in 1987 indicated four modeled radiocarbon ages from Rustler and Dewey Lake groundwater are between 12,000 and 16,000 years. The uranium isotope activity ratios observed require a conservative minimum residence time in the Culebra of several thousands of years and more probably reflect minimum ages of from 10,000 to 30,000 years.

Potentiometric data from four wells support the conclusion that little infiltration from the surface reaches the transmissive units of the Rustler. Hydraulic head data are available for a claystone in the Forty-niner from wells DOE-2, H-3, H-4, H-5, and H-6. Beauheim in 1987 compared these heads to heads in the surrounding Magenta wells and showed that flow between the units at all four wells may be upward. This observation offers no insight into the possibility of infiltration reaching the Forty-niner, but it rules out the possibility of infiltration reaching the Magenta or any deeper units at these locations.

2.3 Resources

This section refers to the significance of specific natural resources that lie beneath the WIPP site. Resources are minerals or hydrocarbons that are potentially of economic value. Reserves are the portion of resources that are economic at today's market prices and with existing technology.

For hydrocarbons, proven reserves can be expected to be recovered from new wells on undrilled acreage or from existing wells where a relatively major expenditure is required to establish production. Probable reserves refer to reserves of hydrocarbons suspected of existing in certain locations based on favorable engineering and/or geologic data. Possible reserves are based on conditions where limited engineering and/or geologic data support recoverable potential.

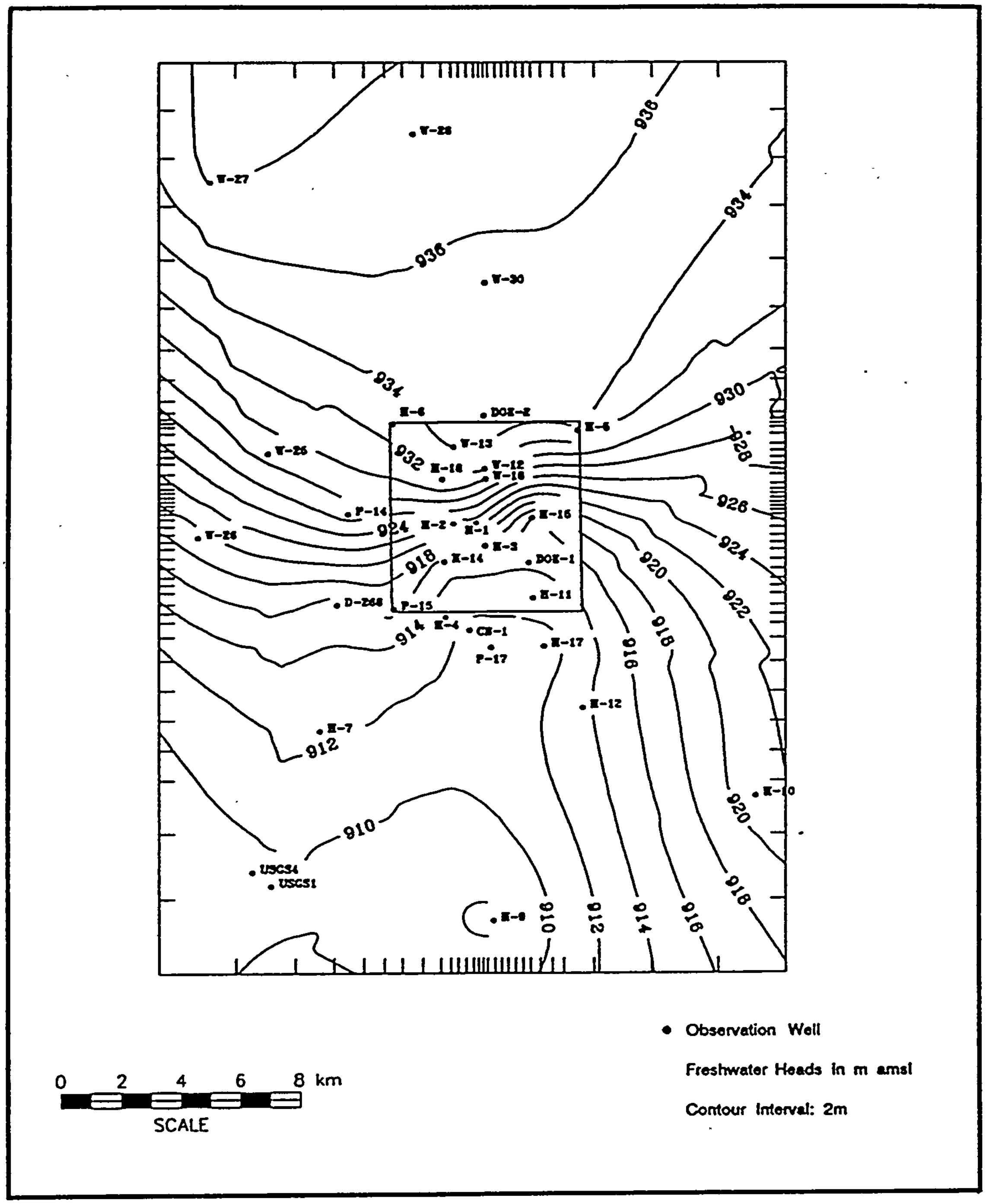
The topic of resources is used to broadly define both economic (mineral and non-mineral) and cultural resources associated with the WIPP site. These resources are important since they (1) provide evidence of past uses of the area, and (2) indicate potential future use of the area with the possibility that such use could lead to disruption of the closed repository. Because of the depth of the disposal horizon, it is believed that only the mineral resources are of significance in predicting the long-term performance of the disposal system. However, the non-mineral and cultural resources are presented for completeness.

Mineral resource discussions are focused principally on hydrocarbons and potassium salts, both of which have long histories of development in the region and both of which could be disruptive to the disposal system. The information regarding the mineral resources concentrates on the following factors:

- Number, location, depth, and present state of development including penetrations through the disposal horizon
- Type of resource
- Accessibility, quality, and demand
- Mineral ownership in the area.

The specific impacts of resource development are discussed in Chapter 6 where scenarios related to mineral development are included for evaluation of disposal system performance. A discussion of how these resources were considered during site selection is included in Chapter 7 as a demonstration of compliance to the resource considerations mandated by 40 CFR § 191.14. A database of Delaware Basin boreholes has been assembled to estimate future impacts of resource development. This database is Appendix DEL (in press) and is associated with the determination of future drilling rates.

The discussion of cultural and economic resources is focused on describing past and present land uses unrelated to the development of minerals. The archaeological record supports the observation that changes on land use are principally associated with climate and the availability of forage for wild and domestic animals. In no case does it appear that past or present land use has had an impact on the subsurface beyond the development of shallow groundwater wells to water livestock.



1 **Figure 2-31. Culebra Freshwater-Head Contour Surface**

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2.3.1 Extractable Resources

The geologic studies of the WIPP site have included the investigation of potential natural resources to evaluate the impact of denying access to these resources and other consequences of their occurrence. This study was completed in support of the FEIS to ensure knowledge of natural resources once the impacts of denying access was included in the decision-making process for WIPP. Of the natural resources expected to occur beneath the site, five are of practical concern: the two potassium salts sylvite and langbeinite, which occur in strata above the repository salt horizon; and the three hydrocarbons, crude oil, natural gas, and distillate liquids associated with natural gas, all three of which occur elsewhere in strata below the repository horizon and may occur below the repository. Other mineral resources beneath the site are caliche, salt, gypsum, and lithium; enormous deposits of these minerals near the site and elsewhere in the country are more than adequate (and more economically attractive) to meet future requirements for these materials. In 1995 the NMBMMR performed a reevaluation of the mineral resources at and within 1 mile (1.6 kilometers) around the WIPP site.

2.3.1.1 Potash Resources at the WIPP Site

Throughout the Carlsbad Potash District, commercial quantities of potassium salts are restricted to the middle portion of the Salado, locally called the McNutt potash zone or member. A total of 11 horizons, or orebeds, have been recognized in the McNutt potash member. Horizon Number 1 is at the base, and Number 11 is at the top. The 11th ore zone is not mined.

The USGS uses three established standard grades—low, lease, and high—to quantify the potash resources at the site. The USGS assumes that the "lease" and "high" grades comprise reserves because some lease-grade ore is mined in the Carlsbad Potash District. Most of the potash that is mined, however, is better typified by the high grade. Even the high-grade resources may not be reserves, however, if their properties make processing uneconomic.

The NMBMMR 1995 study contains a comprehensive summary of all previous evaluations.

Griswold (in NMBMMR 1995, ch. VII) used 40 existing boreholes drilled on and around the WIPP site to perform a re-evaluation of potash resources. He selected holes that were drilled using brine so that the dissolution of potassium salts was inhibited. The results of the chemical analyses of the ore-bearing intervals were adjusted to calculate the percentage equivalent as individual natural mineral species. Only the K_2O percentages as either sylvite or langbeinite were used to compute ore reserves. The conclusion reached by Griswold is that only the 4th and 10th ore zones contain economic potash reserves. The quantities are summarized in Table 2-5.

Table 2-5. Current Estimates of Potash Resources at the WIPP Site

		Recoverable Ore (10^6 tons)	
Mining Unit	**Product**	**Within the WIPP site**	**Outside the WIPP site**
4th Ore Zone	Langbeinite	40.5 @ 6.99%	126.0 @ 7.30%
10th Ore Zone	Sylvite	52.3 @ 13.99%	105.0 @ 14.96%

Source: NMBMMR 1995, ch. VII.

2.3.1.2 Hydrocarbon Resources at the WIPP Site

In 1974 the NMBMMR conducted a hydrocarbon resource study in southeastern New Mexico under contract to the ORNL. The study included an area of 1,512 square miles (3,914 square kilometers). At the time of that study, the proposed repository site was about 5 miles (8 kilometers) northeast of the current site. The NMBMMR evaluation included a more detailed study of a four-township area centered on the old site; the present site is in the southwest quadrant of that area. The NMBMMR hydrocarbon resources study is presented in more detail in the FEIS (DOE 1980, § 9.2.3.5). The reader is referred to the FEIS or the original study (Foster 1974) for additional information.

The resource evaluation was based both on the known reserves of crude oil and natural gas in the region and on the probability of discovering new reservoirs in areas where past unsuccessful drilling was either too widely spread or too shallow to have allowed discovery. All potentially productive zones were considered in the evaluation; therefore, the findings may be used for determining the total hydrocarbon resources at the site. A fundamental assumption in this study was that the WIPP area has the same potential for containing hydrocarbons as the much larger region in which the study was conducted and for which exploration data are available. Whether such resources actually exist can be satisfactorily established only by drilling at spacings close enough to give a high probability of discovery.

The NMBMMR 1995 mineral resource re-evaluation contains a comprehensive summary of all previous evaluations.

Broadhead et al. (NMBMMR 1995, ch. XI) provided a reassessment of hydrocarbon resources within the WIPP site boundary and within the first mile adjacent to the boundary. Calculations were made for resources that are extensions of known, currently productive oil and gas resources that are thought to extend beneath the study area with reasonable certainty (called probable resources in the report). Qualitative estimates are also made concerning the likelihood that oil and gas may be present in undiscovered pools and fields in the area (referred to as possible resources). Possible resources were not quantified in the study. The results of the study are shown in Tables 2-6 and 2-7.

Table 2-6. In-Place Oil within Study Area

Formation	Within WIPP site (10^6 bbl)	Outside WIPP site (10^6bbl)	Total (10^6 bbl)
Delaware	10.33	20.8	31.13
Bone Spring	0.44	0.8	1.25
Strawn	0.4	0.4	0.8
Atoka	1.1	0.1	0.2
Total	**12.3**	**22.9**	**35.3**

Source: NMBMMR 1995, ch. XI.

Table 2-7. In-Place Gas within Study Area

Formation	Gas Reserves (MCF)	
	Within WIPP Site Boundary	Adjacent to WIPP Site Boundary
Delaware	18,176	32,873
Bone Springs	956	1,749
Strawn	9,600	9,875
Atoka	123,336	94,410
Morrow	32,000	28,780

Source: NMBMMR 1995, ch. XI.

2.3.2 Cultural and Economic Resources

The demographics, land use, and history and archaeology of the WIPP site and its irons are characterized in the sections that follow.

2.3.2.1 Demographics

The WIPP facility is located 26 miles (42 kilometers) east of Carlsbad in Eddy County in southeastern New Mexico and includes an area of 10,240 acres. The facility is located in a sparsely populated area with fewer than 30 permanent residents living within a 10-mile (16-kilometer) radius of the facility. The area surrounding the facility is used primarily for grazing, potash mining, and hydrocarbon production. No resource development that would affect WIPP facility operations or the long-term integrity of the facility is allowed within the 10,240 acres that have been set aside for the WIPP project.

The community nearest to the WIPP site is the town of Loving, New Mexico, 18 miles (29 kilometers) west-southwest of the site center. The population of Loving decreased from 1,355 in 1980 to 1,243 in 1990. The nearest population center is the city of Carlsbad, New Mexico, 26 miles (42 kilometers) west of the site. The population of Carlsbad has decreased from 25,496 in 1980 to 24,896 in 1990. Hobbs, New Mexico, 36 miles (58 kilometers) to the east of the site had a 1980 population of 29,153 and a 1990 population of 29,115. Eunice, New Mexico, 40 miles (64 kilometers) east of the site, had a 1980 population of 2,970 and a 1990 population of 2,731. Jal, New Mexico, 45 miles (72 kilometers) southeast of the site, had a population of 2,575 in 1980 and of 2,153 in 1990.

The WIPP site is located in Eddy County near the border to Lea County, New Mexico. The Eddy County population increased from 47,855 in 1980 to 48,605 in 1990. The Lea County population decreased from 55,993 in 1980 to 55,765 in 1990.

2.3.2.2 Land Use

At present, land within 10 miles (16 kilometers) of the site is used for potash mining operations, active oil and gas wells, and grazing. This pattern is expected to change little in the future.

The Waste Isolation Pilot Plant Land Withdrawal Act (LWA) withdrew certain public lands from the jurisdiction of the BLM. The bill provided for the transfer of the WIPP site lands from the Department of the Interior (DOI) to the DOE and effectively withdraws the lands, subject to existing rights, from entry, sale, or disposition; appropriation under mining laws; and operation of the mineral and geothermal leasing laws. The LWA directed the Secretary of Energy to produce a management plan to provide for grazing, hunting and trapping, wildlife habitat, mining, and the disposal of salt and tailings.

There are no producing hydrocarbon wells within the volumetric boundary defined by the land withdrawal (T22S, R31E, S15-22, 27-34). One active well, referred to as James Ranch 13, was drilled in 1982 to tap gas resources beneath Section 31. This well was initiated in Section 6, outside the WIPP site boundary. The well enters Section 31 below a depth of 6,000 feet (1.82 kilometers) beneath ground level.

Grazing leases have been issued for all land sections immediately surrounding the WIPP facility. Grazing within the WIPP site lands operates within the authorization of the Taylor Grazing Act of 1934, the Federal Land Policy and Management Act (FLPMA), the Public Rangelands Improvement Act of 1978, and the Bankhead-Jones Farm Tenant Act of 1973. The responsibilities of the DOE include supervision of ancillary activities associated with grazing (e.g., wildlife access to livestock water development); tracking of water developments inside WIPP lands to ensure that they are configured according to the regulatory requirements; and ongoing coordination with respective allottees. Administration of grazing rights is in cooperation with the BLM according to the Memorandum of Understanding (MOU) and the coinciding Statement of Work through guidance established in the East Roswell Grazing Environmental Impact Statement. The WIPP site is composed of two grazing allotments administered by the BLM: the Livingston Ridge (No. 77027) and the Antelope Ridge (No. 77032).

2.3.2.3. History and Archaeology

The WIPP site boundary consists of a 16-square mile (10,240-acre) area located in southeastern New Mexico. From about 10,000 B.C. to the late 1800s, this region was inhabited by nomadic aboriginal hunters and gatherers who subsisted on various wild plants and animals. From about A.D. 600 onward, as trade networks were established with Puebloan peoples to the west, domesticated plant foods and materials were acquired in exchange for dried meat, hides, and other products from the Pecos Valley and Plains. In the mid-1500s, the Spanish Conquistadors encountered Jumano and Apachean peoples in the region practicing hunting and gathering and engaging in trade with Puebloans. After the Jumanos abandoned the southern Plains region, the Comanches became the major population of the area. Neighboring populations, with whom the Comanches maintained relationships ranging from mutual trade to open warfare, included the Lipan, or Southern Plains Apache; several Puebloan groups; Spaniards; and the Mescalero Apaches.

The best documented indigenous culture in the WIPP region is that of the Mescalaro Apaches, who lived west of the Pecos. The lifestyle of the Mescalaro Apaches represents a transition between the full sedentism of the Pueblos and the nomadic hunting and gathering of the Jumanos and Sumas. In 1763 the San Saba expedition encountered and camped with a group of Mescalaros in Los Medaños. Expedition records indicate the presence of both Lipan and Mescalero Apaches in the region.

A peace accord reached between the Comanches and the Spaniards in 1768 resulted in two historically important economic developments: (1) organized buffalo hunting by Hispanic and Puebloan "ciboleros"; and (2) renewal and expansion of the earlier extensive trade networks by Comancheros. These events placed eastern New Mexico in a position to receive a wide array of both physical and ideological input from the Plains culture area to the east and north and from Spanish-dominated regions to the west and south. Comanchero trade began to mesh with the Southwest American trade influence in the early nineteenth century. However, by the late 1860s the importance of Comanchero trade was cut short by Texan influence.

The first cattle trail in the area was established along the Pecos River in 1866 by Charles Goodnight and Oliver Loving. By 1868, Texan John Chism dominated much of the area by controlling key springs along the river. Overgrazing, drought, and dropping beef prices led to the demise of open range cattle ranching by the late 1880s.

Following the demise of open-range livestock production, ranching developed using fenced grazing areas and production of hay crops for winter use. Herd grazing patterns were influenced by the availability of water supplies as well as by the storage of summer grasses as hay for winter use.

The town now called Carlsbad was founded as "Eddy" in 1889 as a health spa. In addition to ranching, the twentieth century brought the development of the potash, oil, and gas industries that have increased the population eightfold in the last 50 years.

Although technological change has altered some of the aspects, ranching remains an important economic activity in the WIPP region. This relationship between people and the land is still an important issue in the area. Ranch-related sites which date to the 1940s and 50s are common in parts of the WIPP area. These will be considered historical properties within the next several years, and thus will be treated as such under current law.

The Natural Historic Preservation Act (NHPA; 16 USC Part 470 et seq.) was enacted to protect the nation's cultural resources in conjunction with the states, local governments, Indian tribes, and private organizations and individuals. The policy of the federal government includes (1) providing leadership in preserving the prehistoric and historic resources of the nation; (2) administering federally owned, administered, or controlled prehistoric resources for the benefit of present and future generations; (3) contributing to the preservation of non-federally owned prehistoric and historic resources; and (4) assisting state and local governments and the national trust for historic preservation in expanding and accelerating their historic preservation programs and activities. The act also established the National Register of Historic Places ("National Register"). At the state level, the State Historic Preservation Officer (SHPO) coordinates the state's participation in implementing the NHPA. The NHPA has been amended by two acts: the Archaeological and Historic Preservation Act (16 USC Part 469 et seq.), and the Archaeological Resource Protection Act (16 USC Part 470aa et seq.).

In order to protect and preserve cultural resources found within the WIPP site boundary, the WIPP submitted a mitigation plan to the New Mexico SHPO describing the steps to be taken to either avoid or excavate archaeological sites. A "site" was defined as a place used and occupied by prehistoric people. In May 1980, the SHPO made a determination of "no adverse effect from WIPP facility activities" on cultural resources. The National Advisory Council on Historic Preservation concurred that the WIPP Mitigation Plan is appropriate to protect cultural resources.

Known historical sites (more than 50 years old) in southeastern New Mexico consist primarily of early twentieth century homesteads that failed, or isolated features from late nineteenth century and early twentieth century cattle or sheep ranching and military activities. To date, no Spanish or Mexican conquest or settlement sites have been identified. Historic components are rare but are occasionally noted in the WIPP area. These include features and debris related to ranching.

Since 1976, cultural resource investigations have recorded 98 archaeological sites and numerous isolated artifacts within the 16-square mile (41.5-square kilometer) area enclosed by the WIPP site boundary. In the central 4-square mile (10.4-square kilometer) area, 33 sites were determined to be eligible for inclusion on the National Register as an archaeological district. Investigations since 1980 have recorded an additional 14 individual sites outside the central 4-square mile (10.4-square kilometer) area that are considered eligible for inclusion on the National Register. The major cultural resource investigations to date are broken out in the following. Additional information can be found in the bibliography.

1977 The first survey of the area was conducted in 1977 by Nielson of the Agency for Conservation Archaeology (ACA) for SNL. This survey resulted in the location of 33 sites and 64 isolated artifacts.

1979 MacLennan and Schermer of ACA performed the next survey in 1979. It was conducted for access roads and a railroad right-of-way for Bechtel, Inc. The survey encountered two sites and 12 isolated artifacts.

1980 Schermer performed another survey in 1980 to relocate the sites originally recorded by Nielson. This survey redescribed 28 of the original 33 sites.

1981 Hicks directed the excavation of 9 sites in the WIPP core area in 1981.

1982 Bradley in Lord and Reynolds in 1985 recorded one site and four isolated artifacts in an archaeological survey for a proposed water pipeline.

1985 Lord and Reynolds examined three sites in 1985 within the WIPP core area. These sites consisted of two plant-collecting and processing sites and one base camp used between 1000 B.C. and A.D.1400. The artifacts recovered from the excavations have been placed in the Laboratory of Anthropology at the Museum of New Mexico in Santa Fe.

1987 Mariah Associates, Inc. identified 40 sites and 75 isolates in 1987 in an inventory of 2,460 acres in 15 quarter-section units surrounding the WIPP site. In this investigation, 19 of the sites were located within the WIPP site's boundary. Sites encountered in this investigation tended to lack evident or intact features. Of the 40 new sites defined, 14 were considered eligible for inclusion in the National Register, 24 were identified as having insufficient data to determine eligibility, and 2 were determined to be ineligible for inclusion. The eligible and potentially eligible sites have been mapped and are being avoided by the DOE in its current activities at the WIPP site. Figure 2-32 maps out the 40 archaeological sites identified by the Mariah study.

1988–1992 Several archaeological clearance reports have been prepared for seismic testing lines on public lands in Eddy County, New Mexico, during this period.

The Delaware Basin has been used in the past for an isolated nuclear test. This test, Project Gnome, took place in 1961 at a location approximately 8 miles (13 kilometers) southwest of the WIPP. The primary objective of Project Gnome was to study the effects of an underground nuclear explosion in salt. The Gnome experiment involved the detonation of a 3.1-kiloton nuclear device at a depth of 1,200 feet (361 meters) in the bedded salt of the

Salado. The explosion created a cavity of approximately 1,000,000 cubic feet (27,000 cubic meters), and caused surface displacements over an area of about a 1,200-foot (360-meter) radius. Fracturing and faulting caused measurable changes in rock permeability and porosity at distances up to approximately 330 feet (100 meters) from the cavity. No earth tremors were reported at distances over 25 miles (40 kilometers) from the explosion. Project Gnome was decommissioned in 1979.

2.4 Background Environmental Conditions

Background environmental parameters have been assessed at the WIPP site to provide a baseline of existing conditions prior to emplacement of wastes. This assessment includes monitoring existing ecological features and sampling to create a numerical baseline of chemical and radiochemical parameters. This numerical baseline is included as Appendix RBP. Data collected as part of the operational monitoring programs, discussed in Chapter 5 of this document, will be compared to the background data. The environmental information is being continually updated and is reported yearly in the *Annual Site Environmental Report for WIPP*. The most recent of these is included as Appendix SER.

Background environmental conditions are provided in this application as part of the complete description of the WIPP and its vicinity. Background environmental conditions form the baseline for determining if releases to the environment have occurred during the operational period or during any post-operational monitoring period. Emphasis is placed on ecological conditions, water quality, and air quality as they currently exist, and on environmental pathways that could lead to exposure of human receptors to radionuclides associated with the waste being managed at the WIPP. This includes the following:

Ecological Conditions

- Vegetation
- Mammals
- Reptiles and amphibians
- Birds
- Arthropods
- Aquatic ecology
- Endangered species

Quality of Environmental Media

- Surface-water
- Groundwater
- Air

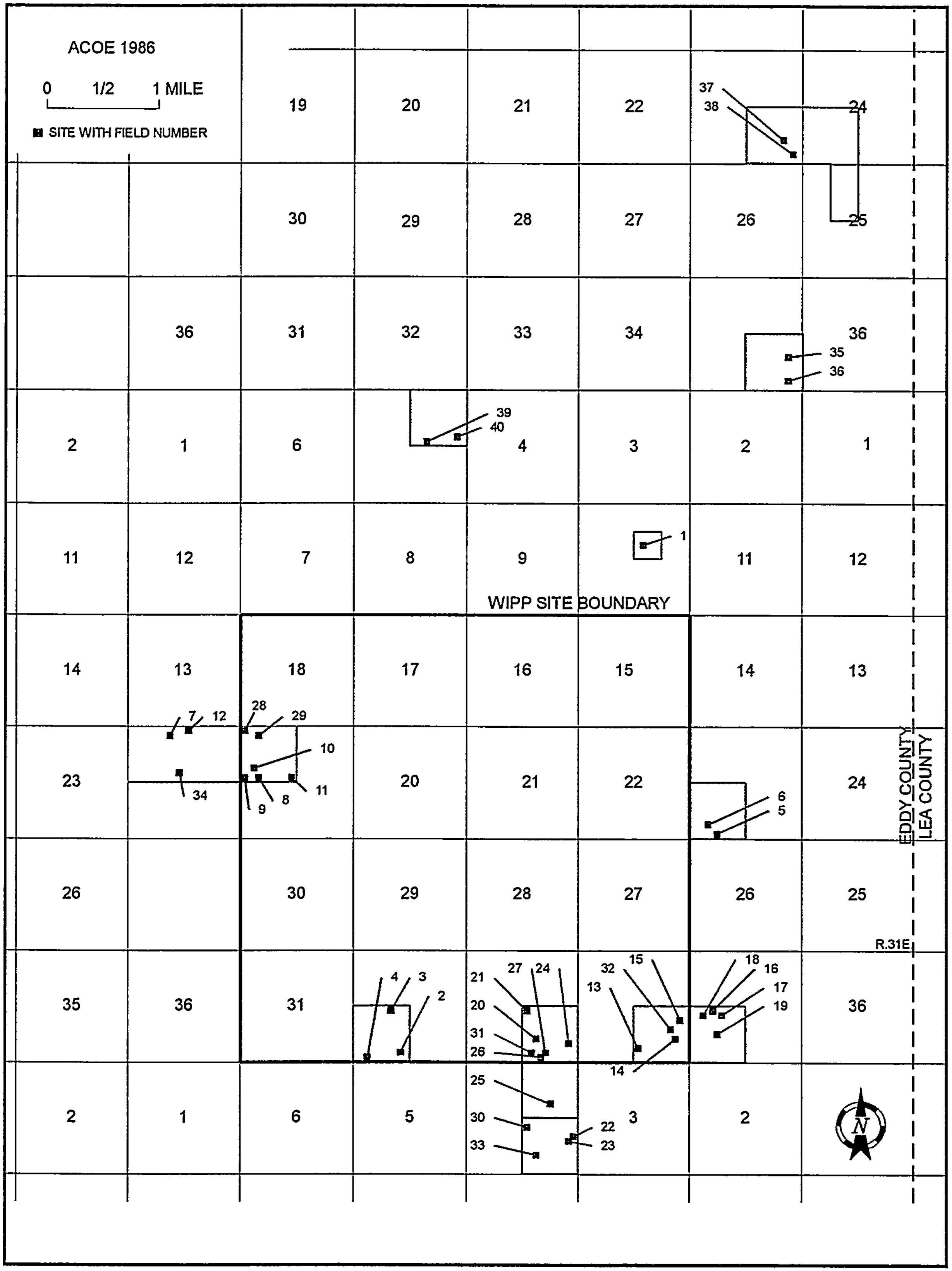

Figure 2-32. Mariah Study Archaeological Sites

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Pathways

- Atmospheric radiation
- Ambient radiation
- Terrestrial radiation
- Hydrologic radiation
- Biotic radiation.

2.4.1 Terrestrial and Aquatic Ecology

The vegetation, mammals, reptiles and amphibians, birds, arthropods, aquatic ecology, and endangered species of the WIPP site and its environs are characterized in the sections that follow.

2.4.1.1 Vegetation

The WIPP site is in an area characterized by stabilized sand dunes. The vegetation is dominated by shinnery oak, mesquite, sand sage, dune yucca, smallhead snakeweed, three-awn, and numerous species of forbs and perennial grasses. The dominant shrubs are deep-rooted species with extensive root systems. The shrubs not only stabilize the dune sand but serve as food, shelter, and nesting sites for many species of wildlife inhabiting the area.

The vegetation in the vicinity of the WIPP site is not a climax vegetation, at least in part because of past grazing management. The composition of the plant life at the site is heterogeneous because of variations in terrain and in the type and the depth of soil. Shrubs are conspicuous members of all plant communities. The site lies within a region of transition between the northern extension of the Chihuahuan Desert (desert grassland) and the southern Great Plains (Short Grass Prairie); it shares the floral characteristics of both.

Grazing, primarily by domestic livestock, and fire control are largely responsible for the shrub-dominated seral communities of much of southeastern New Mexico. A gradual retrogression from the tall- and mid-grass-dominated vegetation of 100 years ago has occurred throughout the region. The cessation of grazing would presumably not alter the domination by shrubs, but it would result in an increase in grasses. Experimental exclosures have been established to study site-specific patterns of succession in the absence of grazing, but long-term results are not yet available.

The semiarid climate makes water a limiting factor in the entire region. The amount and timing of rainfall greatly influence plant productivity and, therefore, the food supply available for wildlife and livestock. The seeds of desert plants are often opportunistic: they may lie dormant through long periods of drought to germinate in the occasional year of favorable rainfall. Significant fluctuations in the abundance and distribution of plants and wildlife are typical of this region. Several examples of such fluctuations have been documented in the area within 5 miles (8.3 kilometers) of the center of the WIPP site, which has been intensively studied.

Two introduced species of significance in the region are the Russian thistle, or tumbleweed, a common invader in disturbed areas, and the salt cedar, which has proliferated along drainageways.

Several distinct biological zones occur on or near the site: the mesa, the central dunes complex, the creosote-bush flats, the Livingston Ridge escarpment, and the Tobosa Flats in Nash Draw west of the ridge. A low, broad mesa named the Divide lies on the eastern edge of the study area and supports a typical desert-grassland vegetation. The dominant shrub and subshrub are mesquite and snakeweed, respectively. The most abundant grasses are black grama, bush muhly, ring muhly, and fluffgrass. Cacti, especially varieties of prickly pear, are present.

Where the ground slopes down from the Divide to the central dune plains, the soil becomes deep and sandy. Shrubs like shinnery oak, mesquite, sand sagebrush, snakeweed, and dune yucca are dominant. In some places, all of these species are present; in others, one or more are either missing or very low in density. These differences appear to be due to localized variations in the type and depth of soil. Thus, a number of closely related but distinct plant associations form a "patchwork" complex, or mosaic, across the stabilized dunes in the central area. Hummocky, partially stabilized sand dunes occur, and large, active dunes are also present. The former consist of "islands" of vegetation, primarily mesquite, separated by expanses of bare sand. The mesquite-anchored soil is less susceptible to erosion, mainly by wind, than is the bare sand. The result is a series of valley-like depressions, or blowouts, between vegetated hummocks. Active dunes running east to west are found 10 miles (16 kilometers) south and east of the site.

To the west and southwest, the soil changes again, becoming more dense and shallow (less than 10 inches [254 millimeters] to caliche) than in the dune area. The composition of the plant life is radically altered, and creosote bushes become dominant. Toward Livingston Ridge to the west and northwest, creosote bushes gradually give way to an acacia-dominated association at the top of the escarpment. The western face of the ridge drops sharply to a valley floor (flats) that is densely populated with tobosa grass, which is rare elsewhere in the study area.

2.4.1.2 Mammals

The most conspicuous mammals at the site are the black-tailed jack rabbit and the desert cottontail. Common small mammals found at the WIPP site include the Ord's kangaroo rat, the plains pocket mouse, and the northern grasshopper mouse. Big-game species, such as the mule deer and the pronghorn antelope, and carnivores, such as the coyote, are present in small numbers.

2.4.1.3 Reptiles and Amphibians

Commonly observed reptiles in the study area are the side-blotched lizard, the western box turtle, the western whiptail lizard, and several species of snakes, including the bullsnake, the prairie rattlesnake, the western diamondback rattlesnake, the coachwhip, the western hognose, and the glossy snake. Of these, only the side-blotched lizard is found in all habitats. The others are mainly restricted to one or two associations within the central dunes area, although the western whiptail lizard and the western diamondback rattlesnake are found in areas dominated by creosote bush as well. The yellow mud turtle is found only in the limited number of aquatic habitats in the study area (i.e., dirt stock ponds and metal stock tanks), but it is common in these locales.

Amphibians are similarly restricted by the availability of aquatic habitat. Aquatic habitats near the WIPP site include stock-watering ponds and tanks. These may be frequented by yellow mud turtles, tiger salamanders, and occasional frogs and toads. Fish are sometimes stocked in the ponds and tanks.

2.4.1.4 Birds

Numerous birds inhabit the area either as transients or year-long residents. Loggerhead shrikes, pyrrhuloxias, and black-throated sparrows are examples of common residents. Migrating or breeding waterfowl species do not frequently occur in the area. Some raptors (e.g., Harris hawks) are residents. The density of large avian predators' nests has been documented as among the highest recorded in the scientific literature.

2.4.1.5 Arthropods

About 1,000 species of insects have been collected in the study area. Of special interest are subterranean termites. Vast colonies of these organisms are located across the study area; they are detritivores and play an important part in the recycling of nutrients in the study area.

2.4.1.6 Aquatic Ecology

Aquatic habitats within a 5-mile (8-kilometer) radius of the WIPP site are limited. Stock-watering ponds and tanks constitute the only permanent surface waters. Ephemeral surface-water puddles form after heavy thunderstorms. At greater distances, seasonally wet, shallow lakes (playas) and permanent salt lakes are found.

Laguna Grande de la Sal is a large, permanent salt lake at the south end of Nash Draw. Natural brine springs, effluent brine from nearby potash refineries, and surface and subsurface runoff discharge into the lake. One of the natural brine springs at the northern margin of the lake has been found to support a small population of the Pecos River pupfish. This species is among the species recognized as threatened by the State of New Mexico. The spring, now called Pupfish Spring, is about 11 miles (18 kilometers) west-southwest of the WIPP site.

Several marine organisms are present in the lower Pecos River and in the Red Bluff Reservoir. They include small, shelled protozoans (Foraminifera), a Gulf Coast shrimp, an estuarine oligochaete and a dragonfly, and several species of marine algae. These species have presumably been introduced. Salt-tolerant species of insects, oligochaetes, and nematodes and unusual algal assemblages characterize this stretch of the river. The combination of high salinity, elevated concentrations of heavy metals, and salt-tolerant and marine fauna makes the lower Pecos River a unique system (DOE 1980, § 7.1.2.).

2.4.1.7 Endangered Species

The DOE consulted with the U.S. Fish and Wildlife Service (FWS) in 1979 to determine the presence of threatened and endangered species at the WIPP site (included in Appendix I of the FEIS). At that time the FWS listed the Lee pincushion cactus, the black-footed ferret, the American peregrine falcon, the bald eagle, and the Pecos gambusia as threatened or endangered and as occurring or having the potential to occur on lands within or outlying the WIPP site. The FWS advised the DOE that the list of species provided in 1979 is still valid except that the black-footed ferret should now be deleted. The DOE believes that the actions described in the 1990 *Supplement Environmental Impact Statement* (SEIS) will have no impact on any threatened or endangered species because these activities do not involve any ground disturbance that was not already evaluated in the FEIS. In addition, there is no critical habitat for terrestrial species identified as endangered by either the FWS or the New Mexico Department of Game and Fish (NMDG&F) at the site area.

Also in 1989, the DOE consulted with the NMDG&F regarding the endangered species listed by the state in the vicinity of the WIPP site. The NMDG&F currently lists (based on NMDG&F Regulation 657, dated January 9, 1988) seven birds and one reptile that are in one of two endangerment categories and that occur or are likely to occur at the site. The NMDG&F agreed in 1989 that the proposed WIPP activities would probably not have appreciable impacts on endangered species listed by the state in the area. *A Handbook of Rare and Endemic Plants of New Mexico* published by the University of New Mexico lists the plants in New Mexico classified as threatened, endangered, or sensitive, and includes 20 species, representing 14 families, that are found in Eddy County and could occur at or near the WIPP site.

2.4.2 Water Quality

In this section, the DOE presents a discussion of the quality of groundwater and surface-water in the WIPP area.

2.4.2.1 Groundwater Quality

Based on the major solute compositions described in Siegel et al. (1991), four hydrochemical facies are delineated for the Culebra.

Zone A. A sodium chloride brine (approximately 3.0 molar) with a magnesium/calcium (Mg/Ca) mole ration between 1.2 and 2.0. This water is found in the eastern third of the WIPP site. The zone is roughly coincident with the region of low transmissivity described by LaVenue et al. in 1988. On the western side of the zone, halite in the Rustler has been found only in the unnamed lower member. In the eastern portion of the zone, halite has been observed throughout the Rustler.

Zone B. A dilute anhydrite-rich water (ionic strength < 0.1 molar) occurs in the southern part of the site. The Mg/Ca mole ratios are uniformly low (0.0–0.5). This zone is coincident with a high-transmissivity region and halite is not found in the Rustler in this zone.

Zone C. Waters of variable composition with low to moderate ionic strength (0.3–1.6 molar) occur in the western part of the WIPP site and along the eastern side of Nash Draw. Mg/Ca mole ratios range from 0.5 to 1.2. This zone is coincident with a region of variable transmissivity. In the eastern part of this zone, halite is present in the lower member of the Rustler. Halite is not observed in the formation on the western side of the zone. The most halite-rich water is found in the eastern edge of the zone, close to core locations where halite is observed in the Tamarisk member.

Zone D. A fourth zone can be defined based on inferred contamination related to potash refining operations in the area. Waters from these wells have anomalously high solute concentrations (3–6 molar) and potassium/sodium (K/Na) weight ratios (0.22) compared to waters from other zones (K/Na = 0.01–0.09). In the extreme southwestern part of this zone, the composition of the Culebra well water has changed over the course of a 7-year monitoring period. The Mg/Ca mole ratio at WIPP-29 is anomalously high, ranging from 10 to 30 during the monitoring period.

This zonation is consistent with that described by Ramey in 1985, who defined three zones. The fourth zone (D) was added by Siegel et al. in 1991 to account for the local potash contamination.

Together, the variations in solutes and the distribution of halite in the Rustler exhibit a mutual interdependence. Concentrations of solutes are lowest where Rustler halite is less abundant, consistent with the hypothesis that solutes in Rustler groundwaters are derived locally by dissolution of minerals (e.g., halite, gypsum, and dolomite) in adjacent strata.

The TDS in the Magenta groundwater ranges in concentration from 5,460 to 270,000 milligrams per liter. This water is considered saline to briny. The transmissivity in areas of lower TDS concentrations is very low, thus greatly decreasing its usability, and the Magenta is not considered as a water supply. In general, the chemistry of Magenta water is variable. Groundwater types range from a predominantly sodium chloride type to a calcium-magnesium-sodium-sulfate type chemistry. The water chemistry may indicate a general overall increase in TDS concentrations to the south and southwest, away from the WIPP site, and a potential change to a predominantly sodium chloride water in that area.

In the WIPP area, the water quality of the Magenta is better than that of the Culebra. However, water from the Magenta is not used anywhere in the vicinity of the WIPP.

2.4.2.2 Surface-Water Quality

The Pecos River is the nearest permanent water source to the WIPP site. It ultimately receives any surface runoff drainage from the site via Laguna Grande de la Sal. Natural brine springs, representing outfalls of the brine aquifers in the Rustler, feed the Pecos River at Malaga Bend, 12 miles (19 kilometers) southwest of the site. This natural saline inflow adds approximately 70 tons of chloride per day to the Pecos River. Return flow from irrigated areas above Malaga Bend further contributes to the salinity. The concentrations of potassium, mercury, nickel, silver, selenium, zinc, lead, manganese, cadmium, and barium also show significant elevations at Malaga Bend but tend to decrease downstream. The metals presumably are rapidly adsorbed onto the river sediments. Natural levels of certain heavy metals in the Pecos River below Malaga Bend exceed the water quality standards of the World Health Organization, the EPA, and the State of New Mexico. For example, the maximum level for lead is 50 parts per billion, and levels of up to 400 parts per billion have been measured during WIPP-related studies.

As it flows into Texas south of Carlsbad, the Pecos River is a major source of dissolved salt in the west Texas portion of the Rio Grande Basin. Natural discharge of highly saline groundwater into the Pecos River in New Mexico keeps TDS levels in the water in and above the Red Bluff Reservoir very high. The TDS levels in this interval exceed 7,500 milligrams per liter 50 percent of the time and, during low flows, can exceed 15,000 milligrams per liter. Additional inflow from saline water-bearing aquifers below the Red Bluff Reservoir, irrigation return flows, and runoff from oil fields continues to degrade water quality between the reservoir and northern Pecos County in Texas. Annual discharge-weighted average TDS concentrations exceed 15,000 milligrams per liter. Water use is varied in the southwest Texas portion of the Pecos River drainage basin. For the most part, water use is restricted to irrigation, mineral production and refining, and livestock. In many instances, surface-water supplies are supplemented by groundwaters that are being depleted and are increasing in salinity.

2.4.3 Air Quality

Measurement of selected air pollutants at the WIPP site began in 1976 and were reported by DOE in the FEIS. Since the preparation of that document, a more extensive air quality monitoring program has been established. Seven classes of atmospheric gases regulated by the EPA have been monitored at the WIPP site between August 27, 1986 and October 30, 1994. These gases are carbon monoxide (CO), hydrogen sulfide (H_2S), ozone (O_3), nitrogen oxides (NO, NO_2, NO_x), and sulfur dioxide (SO_2). The total suspended particulates (TSPs) are monitored in conjunction with the air-monitoring programs of the WIPP. The results of the monitoring program are detailed in the annual reports for the WIPP Environmental Monitoring Program.

2.4.4 Environmental Radioactivity

The background radiation conditions in the vicinity of the WIPP site are influenced by natural sources of radiation, fallout from nuclear tests, and one local research project (Project Gnome). Prior to the WIPP project, long-term radiological monitoring programs were established in southeastern New Mexico to determine the widespread impacts of nuclear tests at the Nevada Test Site and to evaluate the effects of Project Gnome. Project Gnome resulted in the underground detonation of a nuclear device on December 10, 1961, at a site 7.5 miles (12.5 kilometers) southwest of the WIPP site.

The WIPP Radiological Baseline Program (RBP), which included the Radiological Environmental Surveillance Program, was initiated in July 1985 to describe background levels of radiation and radionuclides in the WIPP environment prior to the underground emplacement of radioactive waste. The RBP consisted of five subprograms: (1) atmospheric baseline; (2) ambient radiation (measuring gamma radiation); (3) terrestrial baseline (sampling soils); (4) hydrologic baseline (sampling surface-water and bottom sediments and groundwater); and (5) biotic baseline (analyzing radiological parameters in key organisms along potential radionuclide migration pathways). The RBP has been succeeded by the Environmental Monitoring Report (EMR), which is described in Chapter 5. The final report on the RBP is included as Appendix RBP.

2.4.4.1 Atmospheric Radiation Baseline

Historically, most gross alpha activity in airborne particulates has shown little variation and is within the range of from 1 to 3×10^{-15} microcuries per milliliter, which is equivalent to 3.7 to 11×10^{-11} becquerels per milliliter. Mean gross beta activity in airborne particulates fluctuates but is typically within the range of from 1 to 4×10^{-14} microcuries per milliliter (3.7 to 15×10^{-10} becquerels per milliliter). A peak of 3.5×10^{-13} microcuries per milliliter (1.2×10^{-8} becquerels per milliliter) in mean gross beta activity occurred in May 1986 and has been attributed to atmospheric fallout from the Chernobyl incident in the former Soviet Union. The average level of gamma radiation in the environment is approximately 7.5 microroentgens per hour, or approximately 66 millirem per year.

For 1993, the mean gross alpha concentrations show limited fluctuation throughout the year and range from 3.40×10^{-15} to 1.41×10^{-14} microcuries per milliliter (1.26×10^{-10} to 5.22×10^{-10} becquerels per milliliter). These fluctuations appeared to be consistent among all sampling locations. The mean gross beta concentrations fluctuate throughout the year within the range of 3.32×10^{-14} to 2.63×10^{-14} microcuries per milliliter (1.23×10^{-9} to 9.74×10^{-10} becquerels per milliliter). Individual gross alpha and beta concentrations reported for each location are documented in Appendix SER.

2.4.4.2 Ambient Radiation Baseline

Using the average rate of 7.5 microroentgens per hour, the estimated annual dose is approximately 66 millirem. The fluctuations noted are primarily due to calibration of the system and meteorological events such as the high-intensity thunderstorms that frequent this area in late summer. A seasonal rise in ambient radiation has been observed in the first and fourth quarters each year. It is speculated that this fluctuation may be due to variations in the emission and dispersion of radon-222 from the soil around the WIPP site. These variations can be caused by meteorological conditions, such as inversions, which would slow the dispersion of the radon and its progeny.

2.4.4.3 Terrestrial Baseline

Data were collected as part of the RBP at the WIPP in December 1985 and July 1987. Soil samples were collected and analyzed from a total of 37 locations within a 50-mile (80-kilometer) radius of the WIPP (see Table 2-8). The soil samples were analyzed for 19 radionuclides: ^{40}K, ^{60}Co, ^{90}Sr, ^{137}Cs, two isotopes of radium, three isotopes of thorium, four isotopes of uranium, ^{237}Np, four isotopes of plutonium (^{239}Pu and ^{240}Pu were measured together), ^{241}Am, and ^{244}Cm. Four isotopes (^{40}K, ^{234}U, ^{235}U, and ^{238}U) exhibited significant differences among the three geographic groups, with samples from the outer sites having significantly higher levels of radioactivity than those from the 5-mile (8-kilometer) ring sites (i.e., 16 sampling sites in a ring around the WIPP with a 5-mile [8-kilometer] radius). For ^{234}U, ^{235}U, and ^{238}U, the 5-mile (8-kilometer) ring sites also showed higher levels than the WIPP sites. The isotopes ^{137}Cs, ^{226}Ra, ^{228}Th, and ^{230}Th exhibited differences between the outer sites and the other two groups, which were indistinguishable. Again, the outer sites had significantly higher levels of radioactivity than the other two groups. Measured mean values for ^{40}K, ^{137}Cs, ^{226}Ra, the three thorium isotopes, and the three uranium isotopes were above detection limits as shown in Table 2-8. The mean values for ^{60}Co, ^{90}Sr, ^{228}Ra, ^{233}U, ^{237}Np, the plutonium isotopes, ^{241}Am, and ^{244}Cm fell below detection limits.

2.4.4.4 Hydrologic Radioactivity

The hydrologic radioactivity monitoring program is designed to establish characteristic radioactivity levels in surface-water bodies, bottom sediments, and groundwater.

2.4.4.4.1 Surface-Water and Sediment Background Radiation Levels

Samples of both surface-water and groundwater were collected for the RBP. These samples were analyzed for 19 radionuclides (^{3}H, ^{40}K, ^{60}Co, ^{90}Sr, ^{137}Cs, two isotopes of radium, three isotopes of thorium, four isotopes of uranium, ^{237}Np, and four isotopes of plutonium [^{239}Pu and ^{240}Pu were measured together]). The resulting data from the sampling of surface-water and groundwater were analyzed independently.

2.4.4.4.1.1 Surface-Water

Samples of surface-water were collected from 12 locations over the course of the RBP. Sampling locations were divided into three groups for an initial analysis of geographic variability. Stock tanks represented the largest group, with five locations; they are located closest to WIPP. Stock tanks in this area are typically man-made earthen catchment basins with no surface outflow. The Pecos River represents the next major surface-water group. Four sampling locations were used along the Pecos River, from a northern (up-river) point near the town of Artesia to a southern (down-river) point near the town of Malaga, New Mexico. The third group, called Laguna Grande de la Sal, represents water from a series of playa lakes at the lower end of Nash Draw.

The sample mean radioactivity levels for most radionuclides were below their respective detection limits. Peak levels of ^{40}K from Laguna Grande de la Sal were $2.7x10^{-5}$ microcuries per gram (1.0 becquerels per gram), whereas the mean level at all other sampling locations was less than $2.7x10^{-7}$ microcuries per gram (0.01 becquerels per gram). All four isotopes of uranium exhibited significant differences among the three geographic groups. For all four isotopes, radionuclide levels in the tanks were at least one order of magnitude lower than levels found in the Pecos River and Laguna Grande de la Sal. Similar to ^{40}K, levels of uranium were highest in Laguna Grande de la Sal. Only ^{60}Co, ^{137}Cs, ^{228}Ra, ^{234}U, and ^{238}U were found to be above detection limits. (See Appendix RBP for details.)

Table 2-8. Ranges of Mean Values Measured for Radioactive Isotopes at Sites at WIPP, 5 Miles from WIPP, and beyond 5 Miles from WIPP

	Range of Mean Values[a]	
Isotope	µCi/g	Bq/g
^{40}K	$4.9 to 9.3x10^{-6}$	$1.8 to 3.4x10^{-1}$
^{60}Co	—	0
^{90}Sr	—	0
^{137}Cs	$1.3 to 2.2x10^{-7}$	$4.7 to 8.1x10^{-3}$
^{226}Ra	$2.6 to 5.4x10^{-7}$	$9.6 to 20x10^{-3}$
^{228}Ra	—	*b
^{228}Th	$2.1 to 4.9x10^{-7}$	$7.8 to 18x10^{-3}$
^{230}Th	$2.5 to 52x10^{-7}$	$9.1 to 19x10^{-3}$
^{232}Th	$3.0x10^{-7}$	$1.1x10^{-2}$
^{233}U	—	*b
^{234}U	$1.5 to 3.3x10^{-7}$	$5.4 to 12x10^{-3}$
^{235}U	$4.4 to 17x10^{-9}$	$1.6 to 6.3x10^{-4}$
^{238}U	$1.6 to 3.0x10^{-7}$	$5.7 to 11x10^{-3}$
^{237}Np	—	*b
^{238}Pu	—	*b
$^{239/240}Pu$	—	*b
^{241}Pu	—	*b
^{241}Am	—	*b
^{244}Cm	—	*b

[a]The ranges of mean values are expressed in terms of microcuries per gram of soil (µCi/gm) and becquerels per gram of soil (Bq/g).
[b]Below minimum detection limit of $3.7x10^{-3}$ Bq/g.
Source: Appendix RBP.

2.4.4.4.1.2 Sediments

Sediments were collected for the WIPP RBP from six locations: Hill Tank, Indian Tank, Noye Tank, Laguna Grande de la Sal, and two sites along the Pecos River. These samples were analyzed for 18 radionuclides (tritium, ^{3}H, was not analyzed in the sediments.).

In all five cases where differences were found among location groups, the stock tanks had higher concentrations of radionuclides, possibly indicating an accumulation effect from the closed nature of the tanks. Laguna Grande de la Sal sediments contained significantly higher concentrations of ^{234}U than did the stock tanks and the Pecos River, which were indistinguishable.

2.4.4.4.2 Groundwater Radiological Characterization

Groundwater samples were collected from 37 wells: 23 completed in the Culebra, 4 completed in the Magenta, and 10 privately owned. The samples were analyzed for the same 19 radionuclides as the surface-water samples. Elevated levels of ^{40}K were found in the Magenta and private wells and in the Culebra (2.0 to 5.4×10^{-7} microcuries per gram, or 7.3 to 20×10^{-3} becquerels per gram, respectively) groundwater. The increased levels of ^{40}K can be attributed to the generally high levels of dissolved solids in groundwater in these formations. Only ^{60}Co, ^{137}Cs, radium, ^{234}U, and ^{238}U were found above detection limits and ^{226}Ra which was found to have a distinct geographic pattern in the Culebra. Means from individual wells, as shown in Table 2-9, show that levels of this radionuclide increase in concentration from west to east.

Groundwater samples were collected in accordance with the written procedures. The primary objective of the WQSP is to obtain representative and repeatable groundwater-quality data from selected wells under rigorous field and laboratory procedures and protocols. At each well site, the well is pumped and the groundwater serially analyzed for specific field parameters. Once the field parameters have stabilized, denoting a chemical steady-state with respect to these parameters, a final groundwater sample is collected to be analyzed for radionuclides.

2.4.4.5 <u>Biotic Baseline</u>

This subprogram characterizes background radioactivity levels in key organisms along possible food-chain pathways to man. Vegetation, rabbits, quail, beef, and fish are sampled, and palatable tissues are analyzed for concentrations of transuranics and common naturally occurring radionuclides. Because of the small sample sizes in this program, no attempt has been made to interpret these data. The results are presented in total in Appendix RBP.

Table 2-9. Mean Values Measured for Radionuclides in Water Wells around the WIPP Site

Isotope	Mean Value (10^{-4} Bq/g)
^{3}H	Below <MDL (56)
^{40}K	73 to 200
^{60}Co	12
^{90}Sr	<MDL (7.4)
^{137}Cs	7.2
^{226}Ra	6.9 to 52
^{228}Ra	9.6
^{228}Th	<MDL (3.7)
^{230}Th	<MDL (0.37)
^{232}Th	<MDL (0.37)
^{233}U	<MDL (0.37)
^{234}U	2.6
^{235}U	<MDL (N/S)
^{238}U	0.72
^{237}Np	<MDL (0.37)
^{238}Pu	<MDL (0.11)
$^{239/240}Pu$	<MDL (0.74)
^{241}Pu	<MDL (37)

Key: <MDL = Less than the minimum detection level (MDL is shown in parentheses)
N/S = MDL not specified
Source: Appendix RBP

2.5 Climate and Meteorological Conditions

The long time periods involved in the isolation of radioactive waste are significant with respect to potential changes in climate. Climate changes are documented through studies of floral, faunal, and geological data and lead to fuller understanding of cyclic effects that may impact the performance of the disposal system. The modeling of future climate changes is presented in Chapter 6. The purpose of this section is to build the basis for the modeling in Chapter 6.

2.5.1 Historic Climatic Conditions

Data that can be used to interpret paleoclimates in the American Southwest come from a variety of sources and indicate alternating arid and sub-arid to sub-humid climates throughout the Pleistocene. The information included in this section was taken from a paper written by Swift in 1992.

Prior to 18,000 years ago, radiometric dates are relatively scarce, and the record is incomplete. From 18,000 years ago to the present, however, the climatic record is relatively well constrained by floral, faunal, and lacustrine data. These data span the transition from the last full-glacial maximum to the present interglacial period; given the global consistency of glacial fluctuations described below, they can be taken to be broadly representative of extremes for the entire Pleistocene.

Early and middle Pleistocene paleoclimatic data for the southwestern United States are incomplete and permit neither continuous reconstructions of paleoclimates nor direct correlations between climate and glaciation prior to the last glacial maximum, which occurred 22,000–18,000 years ago. Stratigraphic and soil data from several locations, however, indicate that cyclical alternation of wetter and drier climates in the Southwest had begun by the early Pleistocene. Fluvial gravels in the Gatuña exposed in the Pecos River Valley of eastern New Mexico indicate wetter conditions 1.4 million years ago and again 600,000 years ago. The Mescalero caliche, exposed locally over much of southeastern New Mexico, suggests drier conditions 510,000 years ago, and loosely dated spring deposits in Nash Draw west of the WIPP imply wetter conditions occurring again later in the Pleistocene. The Blackwater Draw of the southern High Plains of eastern New Mexico and western Texas, correlating in time to both the Gatuña Formation and the Mescalero caliche, contains alternating soil and eolian sand horizons that show at least six climatic cycles beginning more than 1.4 million years ago and continuing to the present.

Data used to construct the more detailed climatic record for the latest Pleistocene and Holocene come from six independent lines of evidence dated using carbon-14 techniques: plant communities preserved in packrat middens throughout the Southwest, including sites in Eddy and Otero counties, New Mexico; pollen assemblages from lacustrine deposits in western New Mexico and other locations in the Southwest; gastropod assemblages from western Texas; ostracod assemblages from western New Mexico; paleolake levels throughout the Southwest; and faunal remains from caves in southern New Mexico.

Prior to the last glacial maximum 22,000 to 18,000 years ago, evidence from mid-Wisconsinan faunal assemblages in caves in southern New Mexico, including the presence of species such as the desert tortoise that are now restricted to warmer climates, suggests hot summers and mild, dry winters. Lacustrine evidence confirms the interpretation of a relatively dry climate prior to and during the glacial advance. Permanent water did not appear in what was later to become a major lake in the Estancia Valley in central New Mexico until some time before 24,000 years ago, and water depths in lakes at higher elevations in the San Agustin Plains in western New Mexico did not reach a maximum until between 22,000 and 19,000 years ago. Ample floral and lacustrine evidence documents cooler, wetter conditions in the Southwest during the glacial peak. These changes were not caused by the immediate proximity of glacial ice. None of the Pleistocene continental glaciations advanced farther southwest than northeastern Kansas, and the most recent, late-Wisconsinan ice sheet reached its limit in South Dakota, approximately 745 miles (roughly 1,200 kilometers) from WIPP. Discontinuous alpine glaciers formed at the highest elevations throughout the Rocky Mountains, but these isolated ice masses were symptoms, rather than causes, of cooler and wetter conditions and had little influence on regional climate at lower elevations. The closest such glacier to WIPP was on the northeast face of Sierra Blanca Peak in the Sacramento Mountains, approximately 135 miles (220 kilometers) to the northwest.

Global climate models indicate that the dominant glacial effect in the Southwest was the disruption and southward displacement of the westerly jet stream by the physical mass of the ice sheet to the north. At the glacial peak, major Pacific storm systems followed the jet stream across New Mexico and the southern Rocky Mountains, and winters were wetter and longer than either at the present or during the previous interglacial period.

Gastropod assemblages at Lubbock Lake in western Texas suggest mean annual temperatures 5°C below present values. Both floral and faunal evidence indicate that annual precipitation throughout the region was 1.6 to 2.0 times greater than today's values. Floral evidence also suggests that winters may have continued to be relatively mild, perhaps because the glacial mass blocked the southward movement of arctic air. Summers at the glacial maximum were cooler and drier than at present, without a strongly developed monsoon.

The jet stream shifted northward following the gradual retreat of the ice sheet after 18,000 years ago, and the climate responded accordingly. By the Pleistocene/ Holocene boundary approximately 11,000 years ago, conditions were significantly warmer and drier than previously, although still dominated by winter storms and still wetter than today. Major decreases in total precipitation and the shift toward the modern monsoonal climate did not occur until the ice sheet had retreated into northeastern Canada in the early Holocene.

By middle Holocene time, the climate was similar to that of the present, with hot, monsoon-dominated summers and cold, dry winters. The pattern has persisted to the present, but not without significant local variations. Soil studies show that the southern High Plains were drier from 6,500 to 4,500 years ago than before or since. Gastropod data from Lubbock Lake indicate the driest conditions from 7,000 to 5,000 years ago (precipitation, 0.89 times present values; mean annual temperature, 2.5°C higher than present values), with a cooler and wetter period 1,000 years ago (precipitation, 1.45 times present values; mean annual temperature, 2.5°C lower than present). Plant assemblages from southwestern Arizona suggest steadily decreasing precipitation from the middle Holocene to the present, except for a brief wet period approximately 990 years ago. Stratigraphic work at Lake Cochise shows two mid-Holocene lake stands, one near or before 5,400 years ago and one between or before 3,000 to 4,000 years ago; however, both were relatively short-lived, and neither reached the maximum depths of the late Pleistocene high stand that existed before 14,000 years ago.

Inferred historical precipitation indicates that during the Holocene, wet periods were relatively drier and shorter in duration than those of the late Pleistocene. Historical records over the last several hundred years indicate numerous lower intensity climatic fluctuations, some too short in duration to affect floral and faunal circulation. Sunspot cycles and the related change in the amount of energy emitted by the sun have been linked to historical climatic changes elsewhere in the world, but the validity of the correlation is uncertain. Correlations have also been proposed between volcanic activity and climatic change. In general, however, causes for past short-term changes are unknown.

The climatic record presented here should be interpreted with caution because its resolution and accuracy are limited by the nature of the data used to construct it. Floral and faunal assemblages change gradually and show only a limited response to climatic fluctuations that occur at frequencies that are higher than the typical life span of the organisms in question. For long-lived species such as trees, resolution may be limited to hundreds or even thousands of years. Sedimentation in lakes and playas has the potential to record higher frequency fluctuations, including single-storm events, but only under a limited range of circumstances. Once water levels reach a spill point, for example, lakes show only a limited response to further increases in precipitation.

With these observations in mind, three significant conclusions can be drawn from the climatic record of the American Southwest. First, maximum precipitation in the past coincided with the maximum advance of the North American ice sheet. Minimum precipitation occurred after the ice sheet had retreated to its present limits. Second, past maximum long-term average precipitation levels were roughly twice the present levels. Minimum levels may have been 90 percent of the present levels. Third, short-term fluctuations in precipitation have occurred during the present relatively dry, interglacial period, but they have not exceeded the upper limits of the glacial maximum.

Too little is known about the relatively short-term behavior of global circulation patterns to accurately predict precipitation levels over the next 10,000 years. The long-term stability of patterns of glaciation and deglaciation, however, do permit the conclusion that future climatic extremes are unlikely to exceed those of the late Pleistocene. Furthermore, the periodicity of glacial events suggests that a return to full-glacial conditions is highly unlikely within the next 10,000 years. Additional discussion about the future climate is given in Chapter 6.0.

2.5.2 Current Climatic Conditions

The climate of the region is semiarid, with generally mild temperatures, low precipitation and humidity, and a high evaporation rate. Winds are mostly from the southeast and moderate. In late winter and spring, there are strong west winds and dust storms. Figure 2-33 depicts the annual wind rose for 1993 for the WIPP site. During the winter, the weather is often dominated by a high-pressure system situated in the central portion of the western United States and a low-pressure system located in north-central Mexico. During the summer, the region is affected by a low-pressure system normally situated over Arizona.

Temperatures are moderate throughout the year, although seasonal changes are distinct. The mean annual temperature in southeastern New Mexico is 63°F. In the winter (December through February), night-time lows average near 23°F, and average maxima are in the 50s. The lowest recorded temperature at the nearest Class-A weather station in Roswell was -29°F in February 1905. In the summer (June through August), the day-time temperature exceeds 90°F approximately 75 percent of the time. The National Weather Service recently

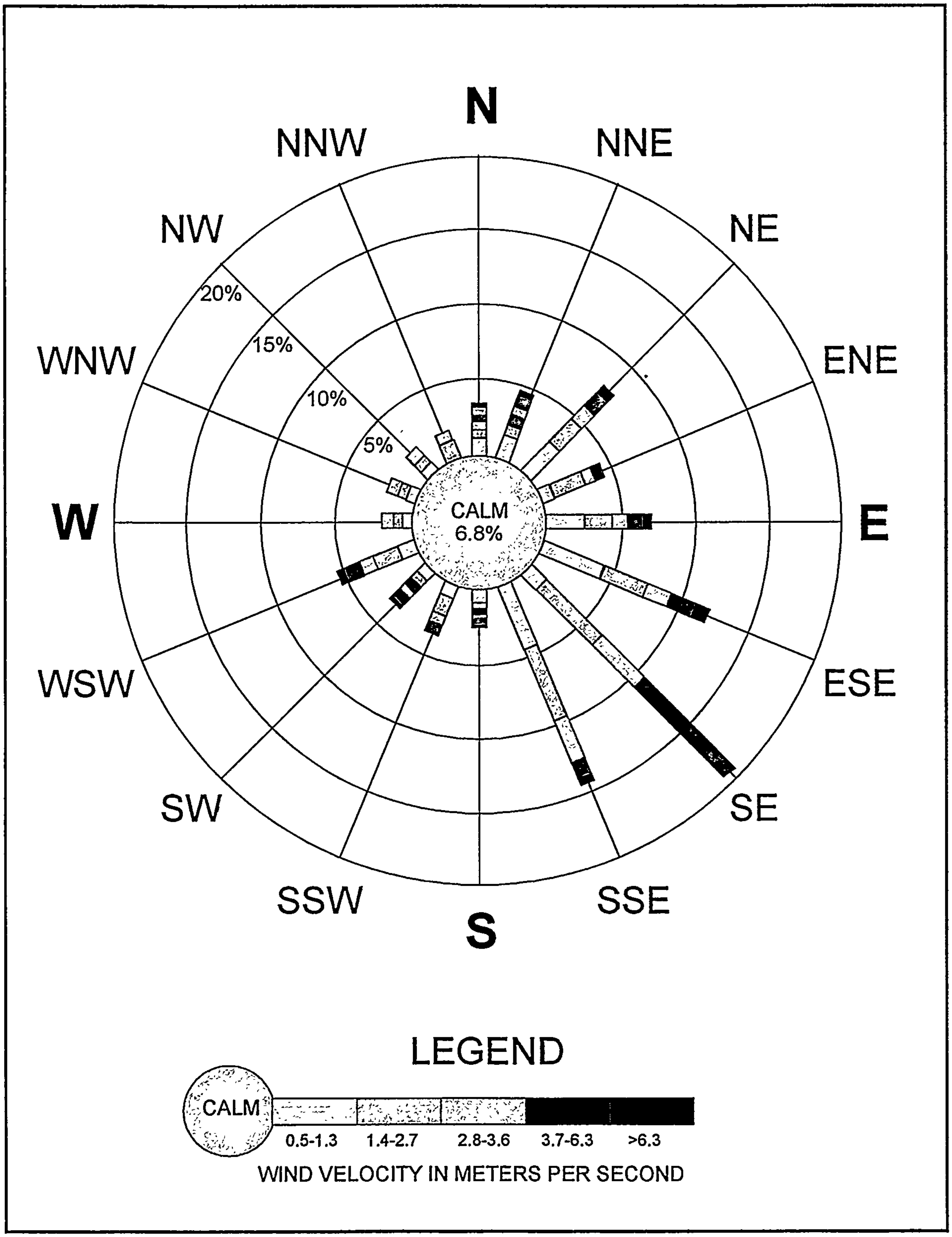

Figure 2-33. 1993 Annual Windrose

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documented a measurement of 122°F at the WIPP site as the record high temperature for New Mexico. This measurement occurred on June 27, 1994. Table 2-10 shows the average monthly maximum and minimum temperatures, and Figure 2-34 shows the mean monthly temperatures during 1993 at the WIPP site.

Precipitation is light and unevenly distributed throughout the year, averaging 12 inches (300 millimeters). Figure 2-35 shows the amount of monthly precipitation recorded at the WIPP site during 1993. Winter is the season of least precipitation, averaging less than 0.6 inches (15 millimeters) of rainfall per month. Snow averages about 5 inches (127 millimeters) per year at the site and seldom remains on the ground for more than a day at a time because of the typically above-freezing temperatures in the afternoon. Approximately half the annual precipitation comes from frequent thunderstorms in June through September. Rains are usually brief but occasionally intense when moisture from the Gulf of Mexico spreads over the region.

Table 2-10. Average Monthly Maximum and Minimum Temperatures at the WIPP Site from September 1992 through December 1993

	Maximum		Minimum	
Month	(°C)	(°F)	(°C)	(°F)
September 1992	31.7	89.06	14.9	58.82
October 1992	26.1	78.98	10.3	50.54
November 1992	16.8	62.24	1.1	33.98
December 1992	14	57.2	-1.8	28.76
January 1993	15	59	1	33.8
February 1993	18	64.4	1	33.8
March 1993	23	73.4	4	39.2
April 1993	28	82.4	8	46.4
May 1993	32	89.6	13	55.4
June 1993	36	96.8	19	66.2
July 1993	38	100.4	22	71.6
August 1993	29	84.2	21	69.8
September 1993	34	93.2	16	60.8
October 1993	28	82.4	9	48.2
November 1993	20	68	1	33.8
December 1993	18	64.4	-1	30.2

Source: WIPP Annual Site Environmental Report for Calendar Year 1992.

2.6 Seismology

The purpose of the seismic studies is to build a basis from which to predict ground motions that the WIPP repository may be subjected to in the near and distant future. The concern about seismic effects in the near future, during the operational period, pertains mainly to the design requirements for surface and underground structures for providing containment during seismic events. The concern about effects occurring over the long term, after the repository has been decommissioned and sealed, pertains more to relative motions (faulting) within the repository and possible effects of faulting on the integrity of the salt beds and/or shaft seals.

In this discussion, the magnitudes are reported in terms of the Richter scale, and all intensities are based on the modified Mercalli intensity scale. Most of the magnitudes were determined by the New Mexico Institute of Mining and Technology or described in Appendix GCR.

Seismic data are presented in two time frames, before and after the time when seismographic data for the region became available. The earthquake record in southern New Mexico dates back only to 1923, and seismic instruments have been in place in the state since 1961. Various records have been examined to determine the seismic history of the area within 180 miles (288 kilometers) of the site. With the exception of a weak shock in 1926 at Hope, New Mexico, and shocks in 1936 and 1949 felt at Carlsbad, all known shocks before 1961 occurred to the west and southwest of the site more than 100 miles (160 kilometers) away.

The strongest earthquake on record within 180 miles (288 kilometers) of the site was the Valentine, Texas, earthquake of August 16, 1931. It has been estimated to have been of magnitude 6.4 on the Richter scale (Modified Mercalli Intensity of VIII). The Valentine earthquake was 130 miles (208 kilometers) south-southwest of the site. Its Modified Mercalli Intensity at the site is estimated to have been V; this is believed to be the highest intensity felt at the site in this century.

In 1887, a major earthquake occurred in northeast Sonora, Mexico. Although about 335 miles (536 kilometers) west-southwest of the site, it is indicative of the size of earthquakes possible in the eastern portion of the Basin and Range Province, west of the province containing the site. Its magnitude was estimated to have been 7.8 (VIII to IX in Modified Mercalli Intensity). It was felt over an area of 0.5 million square miles (1.3 million square kilometers) (as far as Santa Fe to the north and Mexico City to the south); fault displacements near the epicenter were as large as 26 feet (18 meters).

Since 1961, instrumental coverage has become comprehensive enough to locate most of the moderately strong earthquakes (local magnitude >3.5) in the region. Instrumentally determined shocks that occurred within 180 miles (288 kilometers) of the site between 1961 and 1979 are shown in Figure 2-36. The distribution of these earthquakes may be biased by the fact that seismic stations were more numerous and were in operation for longer periods north and west of the site.

Except for the activity southeast of the site, the distribution of epicenters since 1961 differs little from that of shocks before that time. There are two clusters, one associated with the Rio Grande Rift on the Texas-Chihuahua border and another associated with the Central Basin Platform in Texas near the southeastern corner of New Mexico. The latter activity was not

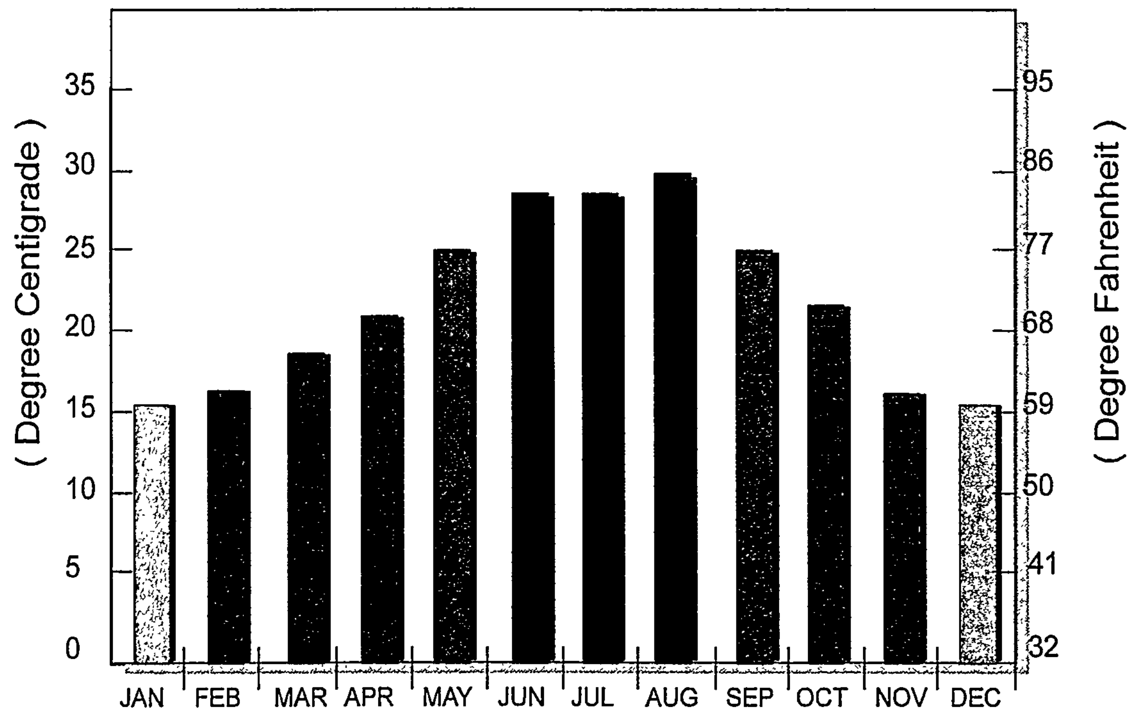

Figure 2-34. 1993 Mean Monthly Temperatures at the WIPP Site

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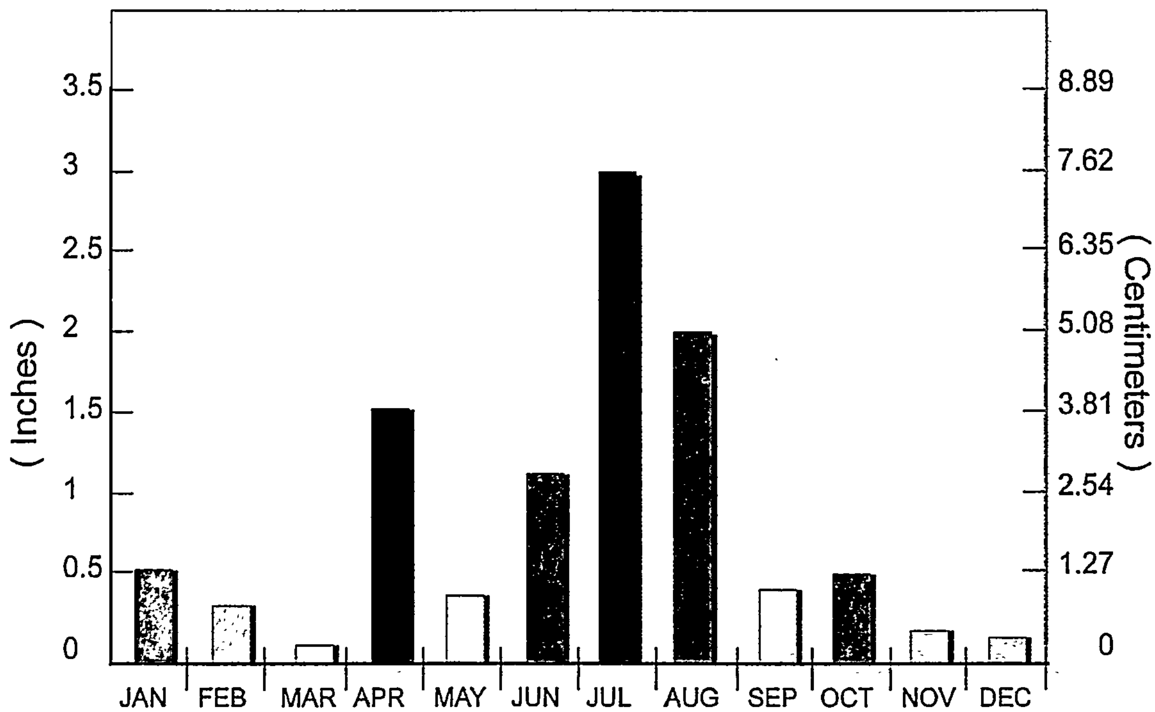

Figure 2-35. 1993 Precipitation at the WIPP Site

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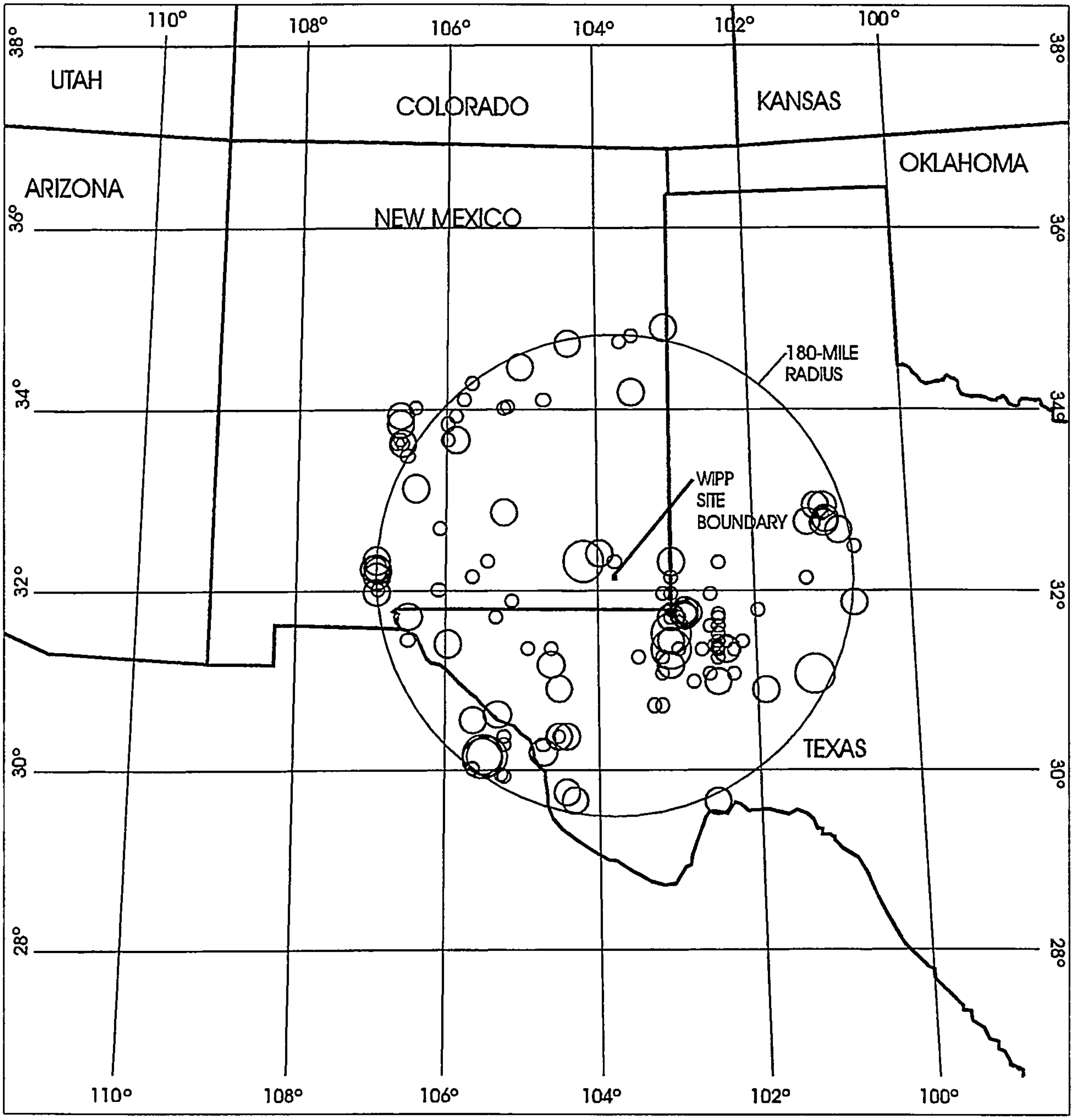

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50 0 50 100

NOTES:
LOCATIONS OF EARTHQUAKES WITHIN 180 MI. OF THE WIPP SITE. EPICENTERS WERE DETERMINED INSTRUMENTALLY AND COVER THE PERIOD FROM 1962 THROUGH 1993. FOR DRAFTING CLARITY NO EARTHQUAKE WITH A MAGNITUDE LESS THAN 2.0 IS SHOWN. IN AREAS WHERE CROWDING OCCURS SOME EPICENTERS ARE SLIGHTLY OFFSET FOR DRAFTING CONVENIENCE.

MAGNITUDE
- >3.5
- 2.5-3.5
- <2.5

Figure 2-36. Regional Earthquake Epicenters Occurring after 1961

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reported before 1964. It is not clear from the record whether earthquakes were occurring in the Central Basin Platform before 1964, although local historical societies and newspapers tend to confirm their absence before that time.

A station operating for 10 months at Fort Stockton, Texas, indicated many small shocks from the Central Basin Platform. Activity was observed at the time the station opened on June 21, 1964. This activity may be related to the injection of water underground for oil recovery. In the Ward–Estes North oilfield, operated by the Gulf Oil Corporation, the cumulative total of water injected up to 1970 was over 1 billion barrels. Accounting for 42 percent of the water injected in Ward and Winkler counties, Texas, the quantity is three times the total injected in all the oil fields of southeastern New Mexico during the same period. Water injection has not been used in the region of the WIPP site to stimulate gas production. The nearest oil fields in the Delaware Basin, where secondary recovery might be attempted, are adjacent to the WIPP site boundary in the Delaware Formations.

The most recent earthquake to be felt at the WIPP site occurred in January 1992 and is referred to as the Rattlesnake Canyon Earthquake. It occurred 60 miles (100 kilometers) east-southeast of the WIPP site. The earthquake was assigned a magnitude of 5.0. This event had no effect on any of the structures at the WIPP as documented by post-event inspections by the WIPP staff and the New Mexico Environment Department. This event was within the parameters used to develop the seismic risk assessment of the WIPP facility for the purposes of construction and operation.

The Rattlesnake Canyon event likely was tectonic in origin based on a 12 ± 2 kilometers depth. This suggest some uncertainty regarding the origin of earthquakes associated with the Central Basin Platform.

2.7 Rock Geochemistry

An understanding of the mineralogy and geochemistry of the host repository rock is considered critical to predicting the long-term waste isolation capability of the repository. Chemical composition of the different minerals and any impurities are important to understand and predict waste rock compatibility of the Salado. The interactions of the rock, brines, and waste are discussed in Chapter 6 to the extent that these interactions impact the long-term integrity of the disposal system. This section emphasizes the following topics:

- Mineral content and composition
- Fluid inclusions
- Fracture fillings.

The Salado is dominated by various evaporite salts; the dominant mineral is halite ($NaCl$) of varying purity and accessory minerals. The major accessory minerals are anhydrite ($CaSO_4$), clays, polyhalite ($K_2MgCa_2(SO_4)_4 \cdot 2H_2O$), and gypsum ($CaSO_4 \cdot 2H_2O$). In the vicinity of the repository, authigenic quartz (SiO_2) and magnesite ($MgCO_3$) are also present as accessory minerals. The MBs in the salt are described as anhydrite with seams of clay. The clays within the Salado are enriched in magnesium and depleted in aluminum. The magnesium enrichment probably reflects the intimate contact of the clays with brines derived from evaporating sea water, which are relatively high in magnesium.

A partial list of minerals found in the Delaware Basin evaporites, together with their chemical formulas, is given in Table 2-11. The table also indicates the relative abundances of the minerals in the evaporite rocks of the Castile, Salado, and Rustler. Minerals found either only at depth, removed from influence of weathering, or only near the surface, as weathering products, are also identified.

Table 2-11. Chemical Formulas, Distributions, and Relative Abundances of Minerals in Delaware Basin Evaporites

Mineral	Formula	Occurrence/Abundance
Amesite	$(Mg_4Al_2)(Si_2Al_2)O_{10}(OH)_8$	S, R
Anhydrite	$CaSO_4$	CCC, SSS, RRR (rarely near surface)
Calcite	$CaCO_3$	S, RR
Carnallite	$KMgCl_3 \bullet 6H_2O$	SS[b]
Chlorite	$(Mg,Al,Fe)_{12}(Si,Al)_8O_{20}(OH)_{16}$	S[a], R[a]
Corrensite	mixed-layer chlorite and smectite	S[a], R[a]
Dolomite	$CaMg(CO_3)_2$	RR
Feldspar	$(K,Na,Ca)(Si,Al)_4O_8$	C[a], S[a], R[a]
Glauberite	$Na_2Ca(SO_4)_2$	C, S (never near surface)
Gypsum	$CaSO_4 \bullet 2H_2O$	CCC (only near surface), S, RRR
Halite	NaCl	CCC, SSS, RRR (rarely near surface), S, RRR
Illite	$K_{1-1.5}Al_4[Si_{7-6.5}Al_{1-1.5}O_{20}](OH)_4$	S[a], R[a]
Kainite	$KMgClSO_4 \bullet 3H_2O$	SS[b]
Kieserite	$MgSO_4 \bullet H_2O$	SS[b]
Langbeinite	$K_2Mg_2(SO_4)_3$	S[c]
Magnesite	$MgCO_3$	C, S, R
Polyhalite	$K_2Ca_2Mg(SO_4)_4 \bullet 2H_2O$	SS, R (never near surface)
Pyrite	FeS_2	C, S, R
Quartz	SiO_2	C[a], S[a], R[a]
Serpentine	$Mg_3Si_2O_5(OH)_4$	S[a], R[a]
Smectite	$(Ca_{1/2},Na)_{0.7}(Al,Mg,Fe)_4(Si,Al)_8O_{20}(OH)_4 \bullet nH_2O$	S[a], R[a]
Sylvite	KCl	SS[c]

Key:
C = Castile Formation; S = Salado Formation; R = Rustler Formation
3 letters = abundant; 2 letters = common; 1 letter = rare or accessory

Notes:
[a]potash-ore mineral (never near surface)
[b]potash-zone non-ore mineral (never near surface)
[c]in claystone interbeds

Although the most common Delaware Basin evaporite mineral is halite, the presence of less soluble interbeds (dominantly anhydrite, polyhalite, and claystone) and more soluble admixtures (e.g., sylvite, glauberite, kainite) has resulted in chemical and physical properties significantly different from those of pure halite. In particular, the McNutt potash member, between MBs 116 and 126, is locally explored and mined for potassium bearing minerals of economic interest. Under differential stress, brittle interbeds (anhydrite, polyhalite, magnesite, dolomite) may fracture while, under the same stress regime, pure halite would undergo plastic deformation. Fracturing of relatively brittle beds, for example, has locally enhanced the permeability, allowing otherwise non-porous rock to carry groundwater (e.g., fractured dolomite beds in the Rustler). Some soluble minerals incorporated in the rock salt (e.g., polyhalite, sylvite, leonite, langbeinite) can be radiometrically dated, and their dates indicate the time of the formation. The survival of such minerals is significant, in that such dating is impossible in pure halite or anhydrite.

Liquids were collected from fluid inclusions and from seeps and boreholes within the WIPP drifts. Analysis of these samples indicated that there is compositional variability of the fluids showing the effects of various phase transformations on brine composition. The fluid inclusions belong to a different chemical population than do the fluids emanating from the walls. It was concluded that much of the brine is completely immobilized within the salt and that the free liquid emanating from the walls is present as a fluid film along intergranular boundaries mainly in clays and in fractures in anhydrites. Additional information can be found in Appendix GCR.

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3.0 FACILITY DESCRIPTION

Chapter 3 provides technical information about those systems at the Waste Isolation Pilot Plant (WIPP) facility that are important in meeting the disposal standards at Title 40 Code of Federal Regulations (CFR) Part 191. Descriptions relevant to long-term containment are provided for surface structures, shafts, underground waste disposal and support facilities, and engineered barriers (such as seals).

The WIPP facility is a transuranic (TRU) radioactive waste management facility owned and operated by the U.S. Department of Energy (DOE). The Westinghouse Electric Corporation Waste Isolation Division (WID) is the managing and operating (M&O) contractor. The WIPP facility consists of the 16-square-mile (41.4-square-kilometer) area placed under the jurisdiction of the DOE by the Waste Isolation Pilot Plant Land Withdrawal Act (LWA) (U.S. Congress 1992). The facility has been divided into four functional areas: (1) the property protection area which is surrounded by a chain-link security fence that encloses 35 acres (0.14 square kilometers) and provides security and protection for all major surface structures; (2) Zone II, which represents the maximum extent of allowed underground development; (3) the exclusion zone, which encompasses approximately 1,450 acres (5.9 square kilometers) and defines the area within which no prohibited articles (e.g., firearms) are allowed; and (4) the WIPP site boundary, which is defined on the surface by a 16-section (41.4-square-kilometer) federal land area under the jurisdiction of the DOE.

The DOE may only emplace those radioactive wastes in the WIPP that meet *both* the definition of TRU, as defined in the WIPP LWA, *and* which can be certified to the project's waste acceptance criteria (WAC) (details are in Chapter 4.0). As defined in the LWA, TRU waste means waste containing more than 100 nanocuries of alpha-emitting TRU isotopes per gram of waste with half-lives greater than 20 years. Generally, these wastes fall into two categories: contact-handled (CH) TRU waste, which has a surface dose rate of less than 200 millirem per hour, and remote-handled (RH) TRU waste, which has a surface dose rate of 200 millirem per hour or greater. In accordance with the LWA, no RH TRU waste received at WIPP may have a surface dose rate in excess of 1,000 rem per hour, and no more than 5 percent by volume of the RH TRU may have a surface dose rate in excess of 100 rem per hour (U.S. Congress 1992).

The waste disposal area of the WIPP facility consists of eight panels, each of which contains seven rooms (Figure 3-1). At present, a 25-year operating time period is estimated to mine and fill all eight panels, the four access drifts, and the crosscuts in the WIPP repository. At the end of the 25-year period, it is currently estimated that up to 10 years will be required for decontamination and decommissioning and closure activities (see Appendix D&D).

The WIPP facility is designed to receive up to 6.2 million cubic feet (175,600 cubic meters) of CH TRU waste and 250,000 cubic feet (7,080 cubic meters) of RH TRU waste. However, the actual amount of waste to be received at WIPP is governed by the LWA, which sets the total volume for CH and RH TRU waste combined at a maximum of 6.2 million cubic feet (175,600 cubic meters). The LWA restricted RH TRU waste to a maximum activity of 23 curies per liter and not to exceed a total of 5.1 million curies (U.S. Congress 1992).

Table 3-1 delineates pertinent site features of the WIPP facility.

Table 3-1. WIPP Site Features

Facility name	Waste Isolation Pilot Plant
EPA ID No.	NM 4890139088
Location	26 miles east of Carlsbad, New Mexico
County	Eddy
Section	15-22 and 27-34
Township	22S
Range	31E
Site area	10,240 acres (41.4 square kilometers)
Facility area	35 acres (0.14 square kilometers)
Depth	2,150 feet (655 meters)
Expected operational life of facility	25 years
Expected closure time (including decontamination and decommissioning)	10 years
Maximum amount of CH TRU waste designed to receive over life of facility	6.2 million cubic feet (175,600 cubic meters)
Maximum amount of RH TRU waste designed to receive over life of facility	250,000 cubic feet (7,080 cubic meters)

3.1 General Facility Design

The DOE has designed the WIPP facility to accomplish three primary goals:

1. To receive, handle, and dispose of TRU waste and TRU mixed waste (in this document, the term "TRU waste" is used to describe both TRU and TRU mixed waste unless otherwise noted)
2. To protect the health and safety of workers, the public, and the environment
3. To comply with applicable radiation protection standards, environmental regulations, and requirements of federal, state, and local agencies (as discussed in Appendix BECR).

The surface facilities at the WIPP accommodate the personnel, equipment, and support services required for the receipt, preparation, and transfer of TRU waste from the surface to the underground. The surface structures are located within a perimeter security fence. Access

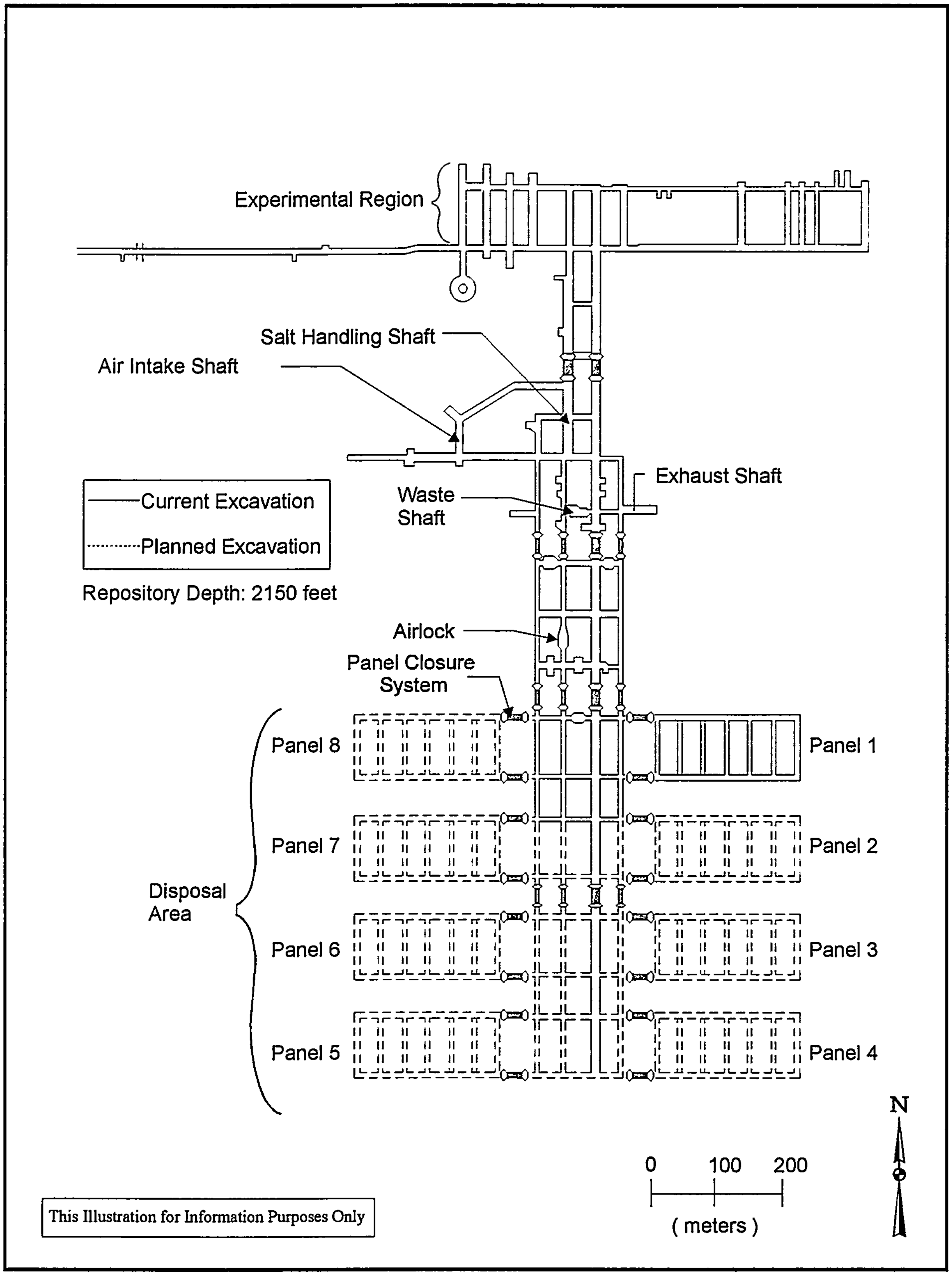

Figure 3-1. Plan View of WIPP Underground Facility and Panel Closure Systems

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is controlled by security officers 24 hours a day. Four vertical shafts connect the surface facilities to the underground. The underground facilities include the waste disposal area, the shaft pillar area, and associated support facilities. Figure 3-2 provides a spatial view of the WIPP facility.

3.1.1 DOE Facility Acquisition Process

Federal facility acquisition policies were applied to the design and construction of the WIPP facility, in accordance with DOE Order 4700.1, *Project Management System.* In addition, WIPP structures were designed to meet DOE design and quality assurance (QA) requirements specified in DOE Order 6430.1, *General Design Criteria.* Each WIPP facility item was evaluated against the Design Classification System Criteria (see DOE 1990, § 3.0, table 3.1.8). Application of these criteria identified no Design Class I items at the WIPP facility. The WIPP Waste Handling Building (WHB) was designed to meet the requirements applicable to Design Class II structures, systems, and components for non-reactor nuclear facilities. The underground area is classified as a Design Class IIIB non-reactor nuclear facility. The design class designations are defined for categorizing structures, systems, and components in accordance with the importance of their function relative to health and safety of the public and on-site personnel during plant operations.

3.1.2 Configuration Control

The DOE mandates that the configuration control of the WIPP facility is accomplished through written procedures and policies as set forth in DOE Order 4700.1, *Project Management Program.* For example, the WIPP System Design Descriptions (SDDs) provide a framework for the configuration control. Any changes to the facility, and subsequently configuration documentation (SDDs, as-built drawings, specifications, etc.), must be reviewed and approved by cognizant personnel. These documented reviews are performed to determine if the change will affect the ability of the facility to comply with applicable environmental, safety, and health requirements. The DOE must approve proposed changes that could affect the Final Safety Analysis Report (FSAR), and may elect to conduct an independent review of analyses supporting the change. QA requirements applicable to WIPP facility design and configuration control activities are founded on the basic and supplemental requirements of the American Society of Mechanical Engineers' *Quality Assurance Program Requirements for Nuclear Facilities* (ASME NQA-1). The DOE implements these requirements through the Carlsbad Area Office's (CAO) *Quality Assurance Program Description*, which is provided in Appendix QAPD. Design QA elements include: (1) documentation, review, and approval of design inputs, (2) control of design analyses, design verification, and design changes, and (3) institution of design interface controls and records management practices.

3.1.3 Surface Structures

WIPP surface structures accommodate the personnel, equipment, and support services required for the receipt, preparation, and transfer of waste from the surface to the underground areas. The surface facilities are located in an area of approximately 35 acres (141,645 square meters) within the perimeter fence. The principal surface structure is the WHB; other surface structures include the following:

Hoist Houses	Office Trailers
Support Building	Exhaust Filter Building
Guard and Security Building	Warehouse and Shops
Water Pump House	Engineering Building
TRUPACT Maintenance Building	Core Storage Building
Training Building	Safety and Emergency Services Building

In addition to these structures, the DOE has employed a system of berms and ditches to divert storm-water runoff away from the surface facilities. The WIPP facility drainage system is designed so that storm runoff due to the probable maximum precipitation event will not flood the WIPP facility.

3.2 Repository Configuration

The WIPP underground facilities are located on the repository horizon 2,150 feet (655 meters) beneath the surface (Figure 3-1). These facilities include the waste disposal area, the mining area, an experimental area, the shaft pillar area, interconnecting drifts, and associated support facilities. The underground support facilities service and maintain all underground equipment for mining and disposal operations, monitor for radioactive contamination, and allow limited decontamination of personnel and equipment.

There will be eight waste panels with each waste panel consisting of seven rooms. Each room will have nominal dimensions of 300 feet (91 meters) long, 33 feet (10.1 meters) wide, and 13 feet (4.0 meters) high. Pillars between rooms are 100 feet (30 meters) thick. The eight waste panels will be separated from each other and the main entries by nominally 200-foot (61-meter) pillars. Rockbolts, or related types of ground support, are used as necessary. In the panels, this will typically consist of localized bolting on an as-needed basis. The storage rooms and panels will be excavated in stages coordinated with scheduled arrival of waste. The rooms, as well as the drifts and crosscuts in the waste disposal area, are designed for waste disposal.

The underground is connected to the surface by four vertical shafts: the Waste Shaft, the Salt Handling Shaft (SHS), the Exhaust Shaft, and the Air Intake Shaft. The Waste Shaft, SHS, and Air Intake Shaft have permanently installed hoists capable of moving personnel, equipment, and materials between the surface and the repository. All shafts will eventually be sealed using the seal design as described in Section 3.3.2.

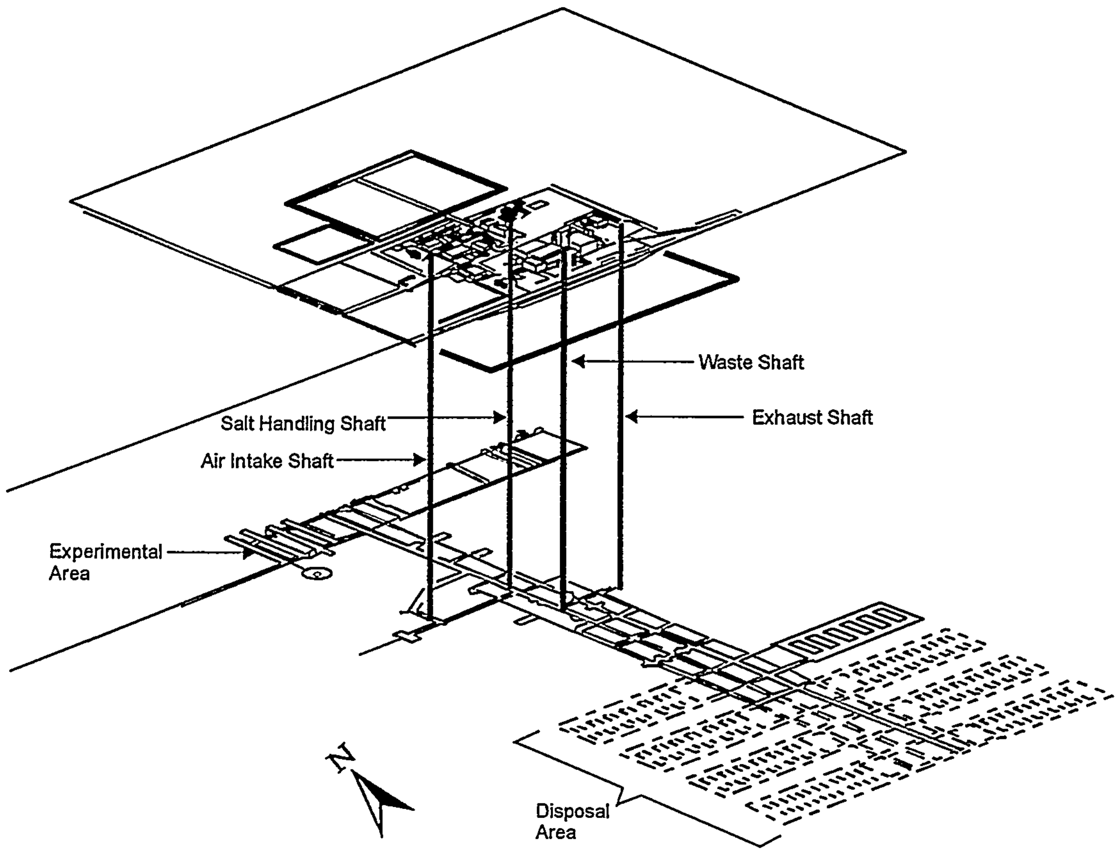

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Figure 3-2. Spatial View of the WIPP Facility

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3.3 Engineered Barriers

The DOE's design of the WIPP disposal system includes engineered barriers to significantly delay the migration of waste and waste constituents to the accessible environment. The DOE will rely on seals in shafts to prevent migration through the excavated openings of the repository. If DOE assessments of compliance with regulatory requirements indicate that additional barriers are needed to reduce potential transport of radionuclides or hazardous constituents, modifications can be made to the form of the waste, or to the design of the waste emplacement areas that will enhance long-term performance of the WIPP disposal system.

The DOE recognizes that the currently proposed 40 CFR Part 194 requires a study of engineered barrier alternatives and their benefits and costs. As such, the DOE is currently conducting an Engineered Alternatives Cost and Benefit Study which will evaluate the advantages and costs of various engineered alternatives. The results of this study will be provided to the EPA when complete.

3.3.1 Seals and Plugs

Sealing and plugging of boreholes and closure of underground mined openings are considered an issue under the engineered barriers concept for limiting the entry of water into the site and potential escape of contaminants beyond regulated levels at the site, as required by 40 CFR Part 191. The following sections address these issues.

3.3.1.1 Disturbed Rock Zone

A key to understanding the discussions about the WIPP facility sealing systems is a knowledge of the disturbed rock zone (DRZ) and its implications for the sealing of a drift or shaft. A DRZ exists around the mine openings where the Salado Formation (hereafter referred to as the Salado) properties have been altered from the undisturbed values. This DRZ generally forms within the first few meters of the repository. Within the DRZ, intrinsic permeability and porosity are increased due to fracturing caused by the excavation of rock to form the repository. Excavation-related stress redistribution may cause variations in the nearfield fluid pressure distribution. Within the DRZ, the dilation, drying, and dissolution of dissolved gas that occurs naturally in Salado brines may cause varying degrees of brine flow. Increased permeability, decreased pore-fluid pressure, and partially saturated conditions within the DRZ all contribute to enhancing potential gas flow pathways between the waste disposal rooms and nearby interbed units. According to Lappin et al. (1989), the DRZ is expected to undergo time-dependent changes in properties, with disturbed halite eventually healing to a final state nearly equivalent to undisturbed halite.

The DOE has characterized the DRZ by three approaches: visual observation, geophysical methods, and in situ hydrologic testing. Visual observations in boreholes and underground excavations indicate that fractures are common in the host rock immediately surrounding the underground WIPP facility. Fracturing occurs at many scales. Geophysical studies conducted by the DOE have utilized seismic refraction, seismic tomography, surface wave analysis, electromagnetic (EM) methods, and direct current (DC) methods. In conjunction with the in situ hydrologic tests, these studies define a DRZ extending to a depth of 3–16 feet (1–5 meters) throughout the underground facility. The DC and EM methods indicate that fracture saturation and fracture density vary laterally along the excavations. These in situ studies also demonstrate that microfracturing and desaturation of the pore space have occurred within the DRZ. The dilation that results from the microfracturing in the DRZ is one component of the observed closure. The processes involved in the development of the DRZ are complex, although basically related to stress relief and rapid strain rates. The redistribution of stress around the excavation, along with the development of the DRZ, drives coupled processes such as changes in permeability and porosity in response to fracture growth. In fact, input for a conceptual model of the repository zone requires the quantitative distributions for the porosity, permeability, and initial saturation of the DRZ. At the present time, the fluid flow characteristics of the DRZ have not been described by an experimentally derived conceptual model. While work is in progress on more complex models, work thus far on the DRZ has been limited to constitutive modeling of the structural deformation processes.

In summary, the fundamental understanding of the creep process, together with a capable predictive technology, is well developed. This predictive technology is important because continuum creep ultimately determines the time required for closure of the rooms and the eventual encapsulation of the waste, as well as being the force that causes recompaction. Predictive capability facilitates understanding the long-term response of rooms and sealing systems, especially where the DRZ has the potential to form a high-permeability path.

3.3.2 Shaft Seals

The system for sealing the shafts is designed to prevent water from entering the repository and to prevent gases or liquids from migrating out of the repository. The design has evolved as the DOE has gained experience with sealing openings in WIPP salt. The DOE has been able to add details to the basic design strategy that was developed for the WIPP a decade ago. With its reference seal design, the DOE provides a basis for calculations and analyses so that common input parameters are used for performance calculations. In this section the DOE describes the most current version of the reference seal system. The DOE describes the individual components of the seal system for a representative WIPP shaft and the performance functions assigned to each of the components are identified. The sealing system for a representative WIPP shaft is shown in Figure 3-3.

3.3.2.1 <u>Near-Surface Subsystems</u>

The near-surface subsystems include the components in the Rustler Formation (hereafter referred to as the Rustler) to separate water-bearing units as shown in Figure 3-4A. Because significant inflows were not seen in the Dewey Lake Redbeds during shaft construction, the near-surface subsystem is not currently required to retard groundwater movement. Its principal function is to prevent subsidence at and around the shafts. There are no limits placed on the effective life of this subsystem. The near-surface subsystem materials include concrete and the existing shaft liner, which is to be filled with earth. The existing shaft collar

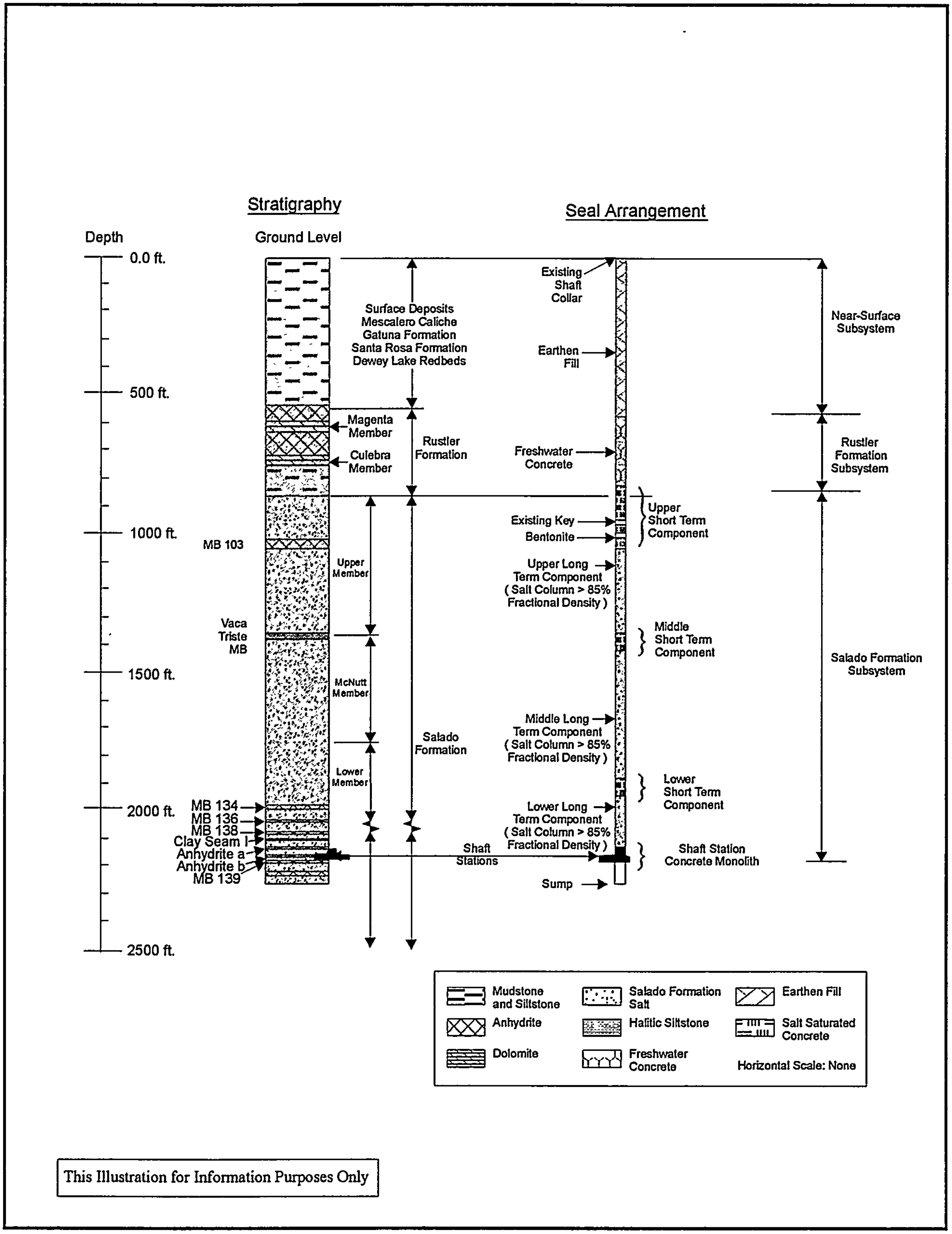

Figure 3-3. Typical Shaft Seal System

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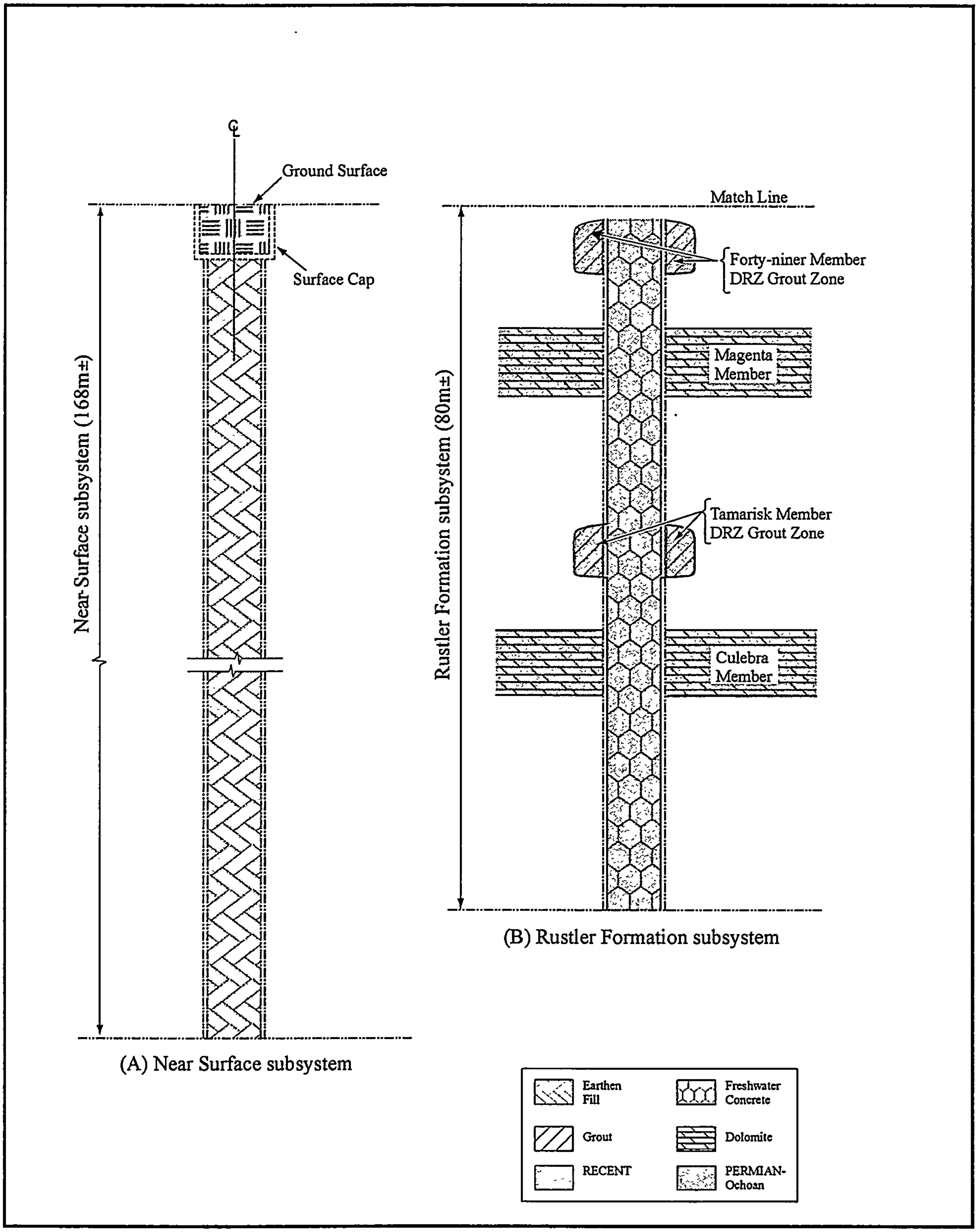

Figure 3-4. Near-Surface and Rustler Formation Subsystem Seal Components

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and shaft liner will likely be retained to minimize the disturbance to the near-surface area. The concrete plug (a monolith that fills the cross-section of the shaft collar) will deter entry into the shaft, and the earthen fill material will be compacted during placement to minimize the potential for subsidence.

The principal function of the Rustler seal subsystem (Figure 3-4B) is to assure compliance with the state of New Mexico's groundwater protection requirements. Within the site boundary, the total dissolved solids concentration in the Magenta range from approximately 4,000 to 25,000 milligrams per liter; the Culebra groundwaters range from approximately 10,000 to greater than 200,000 milligrams per liter; and the Rustler-Salado contact zone groundwaters are approximately 300,000 to 400,000 milligrams per liter. The State of New Mexico regulations require protection of groundwaters that have existing concentrations below 10,000 milligrams per liter total dissolved solids. The DOE satisfies the groundwater protection requirement by casting concrete of lower permeability than the surrounding rock through the entire length (262 feet [80 meters]) shown in Figure 3-4B and by grouting.

3.3.2.2 Salado Formation Subsystems

The Salado subsystems, shown in Figures 3-5A and 3-5B, extend from a point just above the top of the Salado to the terminus of each shaft. The air intake shaft and the exhaust shaft terminate at the floors of the drifts intersecting these shafts; the salt-handling shaft and the waste shaft terminate in sumps that extend 112 and 125 feet (34 and 38 meters), respectively, below the floors.

The repository is required to meet the standards set forth in 40 CFR Part 191 for undisturbed performance. In the performance assessment calculations, the DOE considers two containment flow paths in the evaluation of the WIPP's undisturbed performance. In the first path, brine or gas may migrate through drifts or the DRZ to the shafts and then upward to the compliance boundary. Transport to the boundary may occur laterally in the Culebra or may go directly to the surface. In the second path, migration may occur laterally toward the subsurface boundary within the anhydrite interbeds of the Salado. The principal function of the Salado subsystem is to provide a barrier to the transport of contaminants from the repository vertically to the compliance boundary.

Upper Short-Term Seal. The upper short-term components (shown in Figure 3-5A) are designed to limit the flow of groundwater into the upper salt column. It is believed that within 100 years, the crushed salt in the middle salt column will consolidate to nearly the same permeability exhibited by the host rock salt. If the middle salt column becomes saturated, reconsolidation of the crushed salt will be inhibited. For design considerations to date, the design life of the upper short-term components is nominally 100 years.

The upper short-term seal comprises eight elements:

- Existing key
- Upper salt-saturated concrete element

- Rustler-Salado grout zone
- New upper seal ring—either bentonite or chemical
- Middle salt-saturated concrete element
- New chemical seal ring
- Bentonite layer
- Lower salt-saturated concrete element.

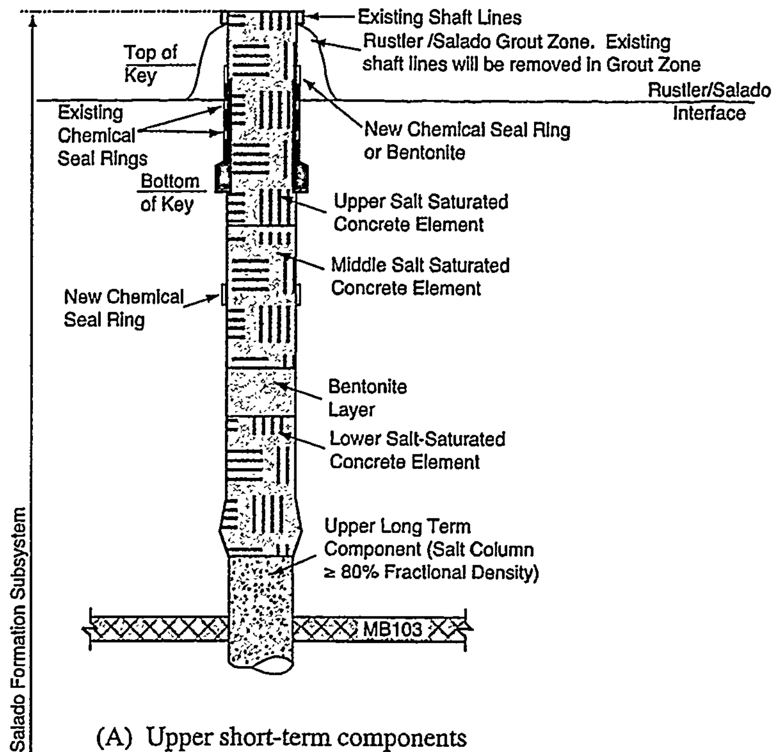
A formal report of the seal design, which includes deliberations leading to the proposed design, is forthcoming from the DOE. The DOE will summarize specifics about each component and other considerations in that report. In addition, a report summarizing materials selection and performance expectations will be prepared by the DOE in support of the proposed seal design. As can be witnessed in seal subsystems, the proposed design includes redundancy in number and use of different component materials. The DOE considers the design to be defensible in today's environment.

Upper Salt Column. The upper salt column shown in Figures 3-3, 3-4A, and 3-4B does not have any compliance-related requirements. It is referred to as a long-term component because of expected compatibility of emplaced salt with existing salt. The DOE expects creep closure of the shaft to consolidate the emplaced salt (with an initial density being 80 percent of intact WIPP host rock salt) into a material with a permeability approaching that of intact WIPP salt.

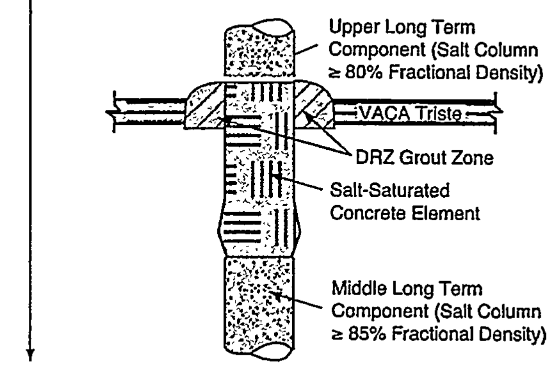
Middle Short-Term Component. The middle short-term component (shown in Figure 3-5B) is designed to limit flow of groundwater. Within 100 years, salt emplaced in the middle salt column is expected to consolidate to nearly the same permeability exhibited by the intact host rock salt. If the middle salt column were to become saturated, reconsolidation of the emplaced salt would be inhibited. Current design life of the middle short-term component is, therefore, nominally 100 years.

Two components comprise the middle short-term seal: grout in the DRZ at the Vaca Triste Sandstone and a salt-saturated concrete monolith. Because the concrete component is located approximately 126 feet (412 meters) below the surface, the DOE predicts that creep closure of the Salado will create a seal between this component and the shaft wall rapidly after installation. Creep closure is also expected to heal the DRZ in the halite surrounding the rigid concrete component.

Middle Salt Column. The middle salt column (Figures 3-3, 3-5B, and 3-5C) is the sole long-term barrier in the seal system. The DOE expects it to be fully effective 100 years after emplacement. Creep closure of the shaft is expected to consolidate the high-density salt seal material (with an initial density being greater than 85 percent of intact WIPP host rock salt) into a material whose permeability is essentially equivalent to that of intact WIPP host rock salt. The current design proposes to compact crushed salt dynamically for this seal component. Other salt placement possibilities to achieve high initial density are considered as alternatives, such as stacking quarried salt blocks in the shaft. The engineered column of salt would fill the shaft cross-section for approximately 590 feet (180 meters). In the performance



(A) Upper short-term components



(B) Middle short-term components

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Figure 3-5. Salado Formation Upper and Middle Short-Term Seal Components

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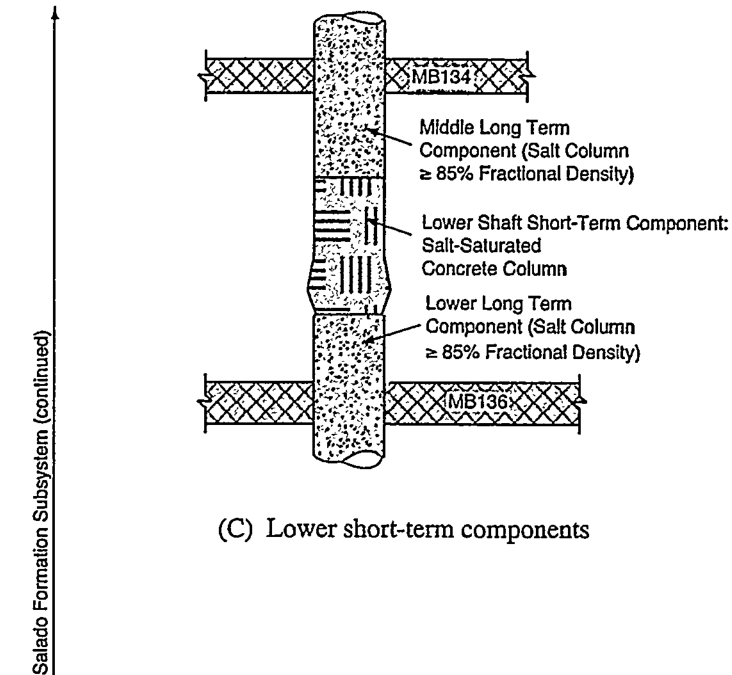
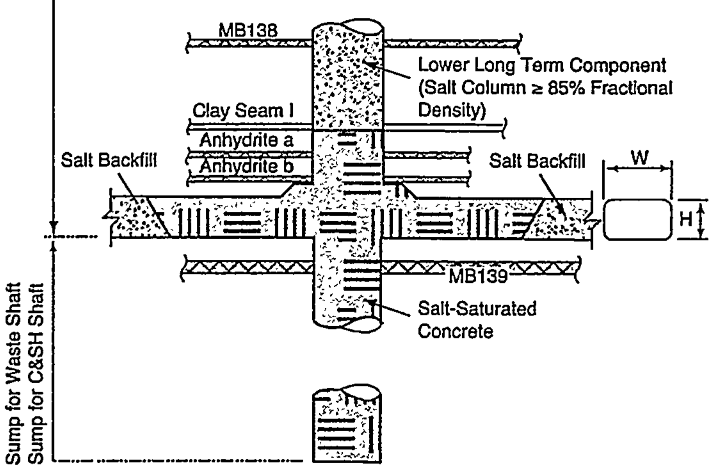


(C) Lower short-term components



(D) Shaft station concrete monolith

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Figure 3-5. Salado Formation Subsystem (continued)

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assessment, the height that the DOE assumes for this barrier ranges from 98 to 328 feet (30 to 100 meters), with a median value of 213 feet (65 meters). Effectiveness of the salt seal is anticipated to initiate at the lowest section and move upward with time; i.e., the effective length increases with time.

Lower Short-Term Component. The lower short-term component (shown in Figure 3-5C) is a salt-saturated concrete column. When the middle salt column is fully functional, there will no longer be a need for the lower short-term component or any other short-term components in the Salado. Therefore, the design life of the lower short-term component is nominally 100 years. Because the concrete monolith is located approximately 1,981 feet (604 meters) below the surface, creep closure of the Salado is expected to achieve a seal between this component and the shaft wall soon after its installation. The DOE also anticipates that creep closure will heal the DRZ in the halite surrounding this rigid component sufficiently to seal this zone.

Lower Salt Column. The DOE predicts that creep closure of the shaft will consolidate the high density (85 percent) salt seal material into a material with permeability that approaches that of intact WIPP host rock salt. The lower salt column adds length to the middle salt column. However, because of uncertainty regarding the marker beds and clay seams in the vicinity of the shaft station, efficient sealing functions are not currently modeled in the performance assessment for either the lower shaft salt component or the shaft station concrete monolith.

Shaft Station Concrete Monolith. The principal purpose of the shaft station concrete monolith (shown in Figure 3-5D) is to stabilize the lower portion of the shaft walls and the roof in the vicinity of the shaft station.

3.3.3 Borehole Plugs

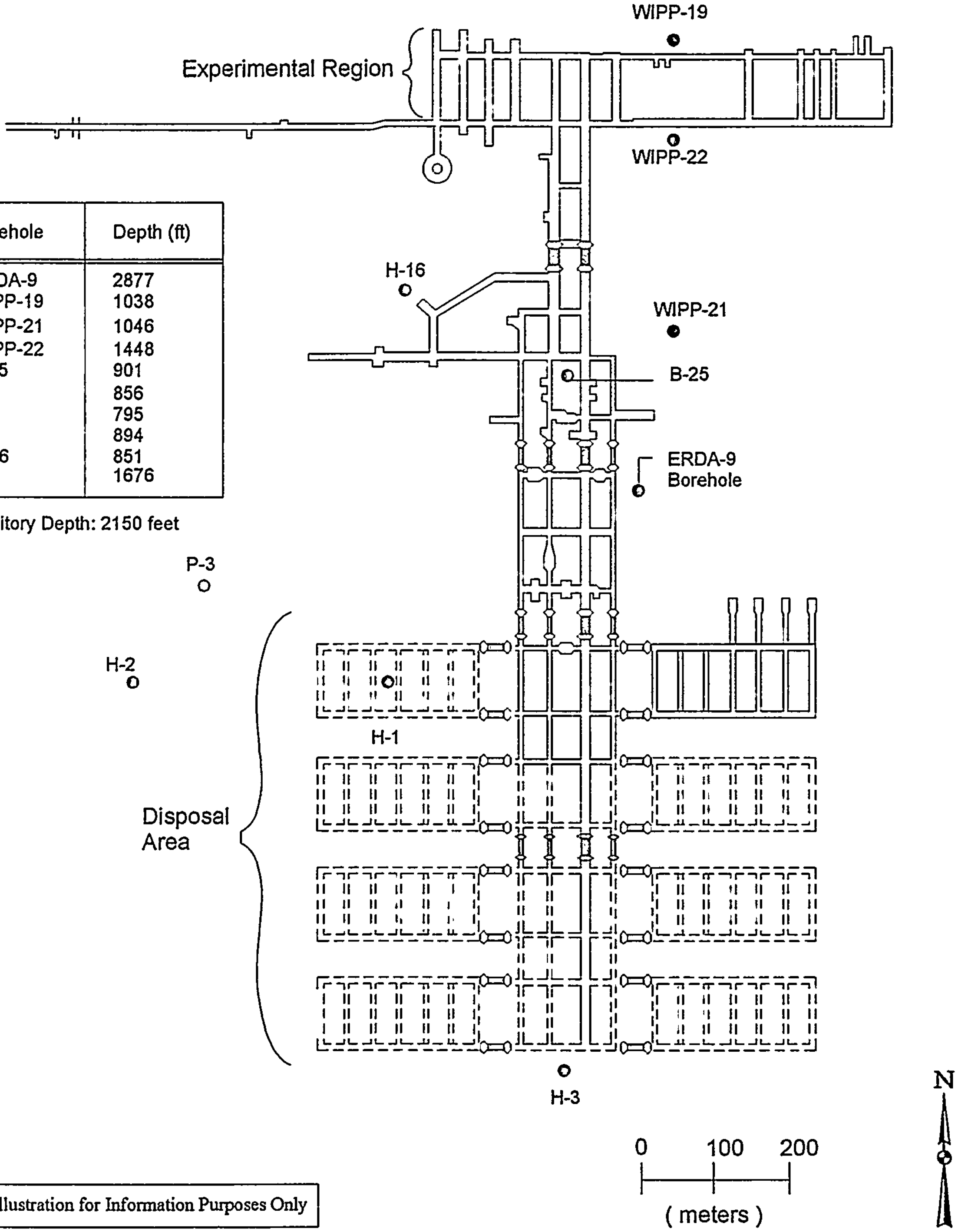
Figure 3-6 identifies where ten existing boreholes overlie the proximate area of the repository footprint. Of these identified boreholes in Figure 3-6, all but ERDA-9 are terminated hundreds of feet above the repository horizon. Only ERDA-9 is drilled to the repository horizon, near the WIPP underground.

To mitigate the potential for migration beyond the repository horizon, the DOE has specified that borehole seals be designed to limit the volume of water that could be introduced to the repository from the overlying water-bearing zones and to limit the volume of contaminated brine released from the repository to the surface or water-bearing zones.

Borehole plugging activities have been underway since the 1970s, from the early days of the development of the WIPP facility. Early in the exploratory phase of the project, a number of boreholes were sunk in Lea and Eddy counties. After the WIPP site was situated in its current location, an evaluation of all vertical penetrations was made by Christensen and Peterson (1981).

As an initial criterion, any borehole that connects a fluid-producing zone with the repository horizon becomes a plugging candidate.

Grout plugging procedures are routinely performed in standard oil-field operations; however, quantitative measurements of plug performance are rarely obtained. The Bell Canyon Test reported by Christensen and Peterson (1981) was a field test demonstration of the use of cementitious plugging materials and modification of existing industrial emplacement techniques to suit repository plugging requirements. Cement emplacement technology was found to be "generally adequate to satisfy repository plugging requirements." Christensen and Peterson (1981) also report "that grouts can be effective in sealing boreholes, if proper care is exercised in matching physical properties of the local rock with grout mixtures. Further, the reduction in fluid flow provided by even limited length plugs is far in excess of that required by bounding safety assessments for the WIPP." The governing regulations for plugging and/or abandonment of boreholes are summarized in Table 3-2.



Borehole	Depth (ft)
ERDA-9	2877
WIPP-19	1038
WIPP-21	1046
WIPP-22	1448
B-25	901
H-1	856
H-2	795
H-3	894
H-16	851
P-3	1676

Repository Depth: 2150 feet

This Illustration for Information Purposes Only

Figure 3-6. Approximate Locations of Boreholes in Relation to the WIPP Underground

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Table 3-2. Governing Regulations for Borehole Abandonment

Federal or State Land	Type of Well or Borehole	Governing Regulation	Summary of Requirements
Both	Groundwater Surveillance	State and federal regulation in effect at time of abandonment	Monitor wells no longer in use shall be plugged in such a manner as to preclude migration of surface runoff or groundwater along the length of the well. Where possible, this shall be accomplished by removing the well casing and pumping expanding cement from the bottom to the top of the well. If the casing cannot be removed, the casing shall be ripped or perforated along its entire length if possible, and grouted. Filling with bentonite pellets from the bottom to the top is an acceptable alternative to pressure grouting.
Federal	Oil and Gas Wells	40 CFR Part 3160, §§ 3162.3-4	The operator shall promptly plug and abandon, in accordance with a plan first approved in writing or prescribed by the authorized officer.
Federal	Potash	40 CFR Part 3590, § 3593.1	(b) Surface boreholes for development or holes for prospecting shall be abandoned to the satisfaction of the authorizing officer by cementing and/or casing or by other methods approved in advance by the authorized officer. The holes shall also be abandoned in a manner to protect the surface and not endanger any present or future underground operation, any deposit of oil, gas, or other mineral substances, or any aquifer.
State	Oil and Gas Well Outside the Oil-Potash Area	State of New Mexico, Oil Conservation Division, Rule 202 (eff. 3-1-91)	B. Plugging (1) Prior to abandonment, the well shall be plugged in a manner to permanently confine all oil, gas, and water in the separate strata where they were originally found. This can be accomplished by using mud-laden fluid, cement, and plugs singly or in combination as approved by the Division on the notice of intention to plug. (2) The exact location of plugged and abandoned wells shall be marked by the operator with a steel marker not less than four inches (4") in diameter, set in cement, and extending at least four feet (4') above mean ground level. The metal of the marker shall be permanently engraved, welded, or stamped with the operator name, lease name, and well number and location, including unit letter, section, township, and range.
State	Oil and Gas Wells Inside the Oil-Potash Area	State of New Mexico, Oil Conservation Division, Order No. R-111-P (eff. 4-21-88)	F. Plugging and Abandonment of Wells (1) All existing and future wells that are drilled within the potash area, shall be plugged in accordance with the general rules established by the Division. A solid cement plug shall be provided through the salt section and any water-bearing horizon to prevent liquids or gases from entering the hole above or below the salt selection. It shall have suitable proportions—but no greater than three (3) percent of calcium chloride by weight—of cement considered to be the desired mixture when possible.

3.4 Summary

This chapter has provided the pertinent structures of the WIPP facility which have an impact on the long-term performance of the WIPP. The DOE has configured both the facility and the underground layout, and designed engineered barriers in such a way that will minimize the potential for releases of contaminants to the accessible environment.

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4.0 WASTE DESCRIPTION

Compliance evaluations assess the behavior and interactions of natural systems present at the Waste Isolation Pilot Plant (WIPP) site, relevant "man-made" structures and facilities, and the waste emplaced in the repository. Previous chapters have described the site and the repository, the first two of the three general components of the repository system. This chapter describes the waste to be emplaced in the repository. This information is important because it supports the development of conceptual models of the anticipated behavior of the repository.

Assessments of the performance of the repository are based on assumed characteristics of the wastes to be emplaced in the WIPP. Assumed characteristics include factors such as the levels of radioactivity present in the waste, the amount of moisture in the waste, and the quantities of other materials that might have some effect on the potential for the waste to migrate toward the accessible environment. This chapter documents the characteristics of the wastes that are planned to be emplaced in the repository and provides one of the bases for the compliance assessments. It also describes methods to be employed by the U.S. Department of Energy (DOE) to ensure that only those wastes that are consistent with these descriptions are actually emplaced in the repository. Additional information is provided on the nature of transuranic (TRU) waste, the sources of the waste, waste inventories, and plans for the further characterization of these wastes.

The DOE has prepared this chapter to support the evaluation of compliance with the provisions of Title 40 of the Code of Federal Regulations (CFR) Part 191, as they apply to the WIPP. The DOE understands that proposed rule 40 CFR Part 194 may affect this chapter, when the proposed rule is finalized. In particular, § 194.24 of the proposed rule provides that the DOE shall conduct a study of the effects of waste characteristics on the containment of waste in the disposal system. Although the DOE believes that it has established an understanding of this topic, the available information is not currently in the format anticipated by the U.S. Environmental Protection Agency (EPA).

TRU waste is contaminated with alpha-emitting radionuclides having atomic numbers greater than 92, half-lives greater than 20 years, and concentrations of TRU isotopes greater than 100 nanocuries per gram of waste, at the time of assay. There are two categories of TRU waste: contact-handled (CH) and remote-handled (RH). CH TRU wastes are packaged TRU wastes with an external surface dose rate of 200 millirem per hour or less, while RH TRU wastes are packaged TRU wastes with an external surface dose rate exceeding 200 millirem per hour and less than 1,000 rem per hour.

TRU waste management activities (generation, retrievable storage, etc.) are performed at ten major and several minor DOE sites. The major sites are as follows:

1. Richland (Hanford) Site, Washington
2. Idaho National Engineering Laboratory (INEL), Idaho
3. Los Alamos National Laboratory (LANL), New Mexico
4. Oak Ridge National Laboratory (ORNL), Tennessee

5. Rocky Flats Environmental Technology Site (RFETS), Colorado
6. Savannah River Site (SRS), South Carolina
7. Argonne National Laboratory–East (ANL-E), Illinois
8. Lawrence Livermore National Laboratory (LLNL), California
9. Mound Laboratory (Mound), Ohio
10. Nevada Test Site (NTS), Nevada.

4.1 Current and To-Be-Generated Waste Inventory

TRU waste inventories are derived from the *Waste Isolation Pilot Plant Transuranic Waste Baseline Inventory Report* (BIR), which is included as Appendix BIR. The BIR has been developed from the best available information and process knowledge provided by the DOE TRU waste generator and storage sites.

The BIR categorizes waste as either retrievably stored or projected (future generation) waste. The volume (stored plus projected) reported in the BIR for each site that either generates or stores TRU waste represents the anticipated waste inventory. The current anticipated CH TRU inventory (total waste volume of CH TRU waste) for all generator and storage sites is less than the design capacity for TRU waste to be emplaced at the WIPP. Therefore, for purposes of performance assessment, anticipated CH inventory volumes are scaled to meet the full capacity of the WIPP. Since the RH TRU anticipated inventory reported by the generator and storage sites exceeds the WIPP RH inventory limits, the RH TRU waste was not scaled in the BIR. In the future, the DOE will monitor the RH TRU waste generation at the sites and determine which waste streams will be eligible for disposal in the WIPP.

It is important to understand that the BIR is not a waste characterization document. It is a database of waste information collected from the waste storage and generation sites for the purpose of preparing this application. As waste characterization programs are instituted at the generator and storage sites, the DOE will update the BIR. The waste characterization program planned by the DOE for waste shipped under any certification issued as the result of this application is described in Section 4.4.

4.1.1 CH TRU Waste

The greatest percentage of TRU waste emits principally alpha radiation, with some beta and gamma radiation. Alpha particles are dangerous if inhaled or ingested, but they are non-penetrating and thus do not represent an external radiation hazard. Beta emissions, like alpha, have limited penetration, and the waste container provides adequate personnel protection. Gamma radiation, however, is more penetrating. It can pass through several inches of lead and must be heavily shielded for safe management and storage. CH TRU waste contains predominately alpha-emitting radioisotopes and is managed in closed containers that provide protection from inhalation or ingestion.

The volume limit of TRU waste to be emplaced at the WIPP is 6.2 million cubic feet (175,600 cubic meters), as specified in the WIPP Land Withdrawal Act (LWA). The BIR provides estimated volumes of CH TRU waste to be supplied by the DOE waste generator and storage sites. In the past, ten sites have been listed as sources of TRU waste for disposal at WIPP. Activities associated with the Federal Facility Compliance Act (FFCA) have resulted in the identification of several sites which generate TRU wastes in small quantities. These sites are mentioned here for completeness and because their wastes are included in the totals in the BIR.

The anticipated volume of the CH TRU waste inventory is the sum of the approximately 2.8 million cubic feet (73,300 cubic meters) of currently stored waste, with an additional 1.9 million cubic feet (50,700 cubic meters) of waste that the DOE will generate in the future. Estimates of the volume of waste yet to be generated are expected to change in the future as a result of environmental restoration and remediation activities. The CH TRU waste volumes that are retrievably stored and projected to be generated at each site are provided in Table 4-1.

4.1.2 RH TRU Waste

A small percentage of TRU waste is designated as RH because it contains radioactive isotopes that emit high energy gamma radiation and some neutron radiation, as well as alpha radiation. The LWA prohibits the DOE from placing RH TRU waste in the WIPP that has a surface dose rate in excess of 1,000 rem per hour. The LWA limits the volume such that no more than 5 percent of the emplaced RH TRU waste may exhibit a dose rate in excess of 100 rem per hour. The volume of RH TRU waste that may be emplaced in the WIPP is limited by agreement with the State of New Mexico to 250,000 cubic feet (7,080 cubic meters). In addition, the waste is limited to a 5,100,000-curie total under the LWA. The RH TRU waste volumes that are retrievably stored and projected to be generated at each site are provided in Table 4-1.

4.1.3 TRU Mixed Waste

Hazardous wastes, as defined in 40 CFR Part 261 Subparts C and D, often occur as co-contaminants with TRU waste from defense-related operations, resulting in "TRU mixed waste." A significant percentage of the waste to be emplaced in the WIPP is TRU mixed waste, subject to regulation under the Resource Conservation and Recovery Act (RCRA).

Table 4-1. Estimated Quantities of Retrievably Stored and Newly Generated TRU Waste at DOE Sites

Site	Waste Composition, Volume (m3)					
	Contact-Handled			Remote-Handled		
	Retrievably Stored Waste	Newly Generated Waste	Total CH	Retrievably Stored Waste	Newly Generated Waste	Total RH
ANL-E	29.1	1.7	30.8	1.7	45.9	47.6
ANL-W	0.0	5.8	5.8	8.7	28.0	36.7
Ames Laboratory	0.0	0.1	0.1	0.0	0.0	0.0
Battelle Columbus Laboratory	0.0	0.0	0.0	0.0	71.0	71.0
Bettis Atomic Power Laboratory	0.0	120.0	120.0	0.0	1.6	1.6
Energy Technology Engineering Center	1.9	5.2	7.1	0.0	0.0	0.0
INEL	35,000.0	1.0	35,001.0	31.0	17.0	48.0
Knolls Atomic Power Laboratory	2.4	0.0	2.4	11.0	25.0	36.0
LANL	11,000.0	7,700.0	18,700.0	91.0	83.0	174.0
Lawrence Berkeley	0.9	4.4	5.3	0.0	0.0	0.0
Lawrence Livermore	210.0	690.0	900.0	0.0	0.0	0.0
Mound Plant	260.0	0.0	260.0	0.0	0.0	0.0
University of Missouri	0.1	1.6	1.7	0.0	0.0	0.0
NTS	620.0	0.0	620.0	0.0	0.0	0.0
Oak Ridge	780.0	260.0	1040.0	990.0	360.00	1350.0
Paducah Gaseous Diffusion Plant	3.5	0.0	3.5	0.0	0.0	0.0
Pantex Plant	0.6	0.0	0.6	0.0	0.0	0.0
RFETS	1100.0	5900.0	7000.0	0.0	0.0	0.0
Richland (Handford)	9300.0	21,000.0	30,300.0	33.0	3000.0	3033.0
Sandia National Laboratories-NM	8.0	7.0	15.0	0.0	7.0	7.0
Savannah River	15,000.0	15,000.0	30,000.0	0.0	64.0	64.0
TOTAL	73,316.5	50,696.8	124,013.3	1166.4	3702.5	4868.9

4.2 Waste Information Important to the Development of Conceptual Models

As described previously, some information regarding the character of the waste to be emplaced in the WIPP is needed to support the development of conceptual models of the behavior of the repository. In particular, information on waste characteristics is needed for three purposes: (1) to determine the inventory basis for normalizing radionuclide releases as required for comparison with 40 CFR § 191.13(a) (see Section 6.0); (2) to evaluate the potential for gas to be generated in the repository (see Section 6.3); and (3) to estimate the fraction of the actinides in the waste that might become available to migrate away from the waste-emplacement rooms (see Section 6.3). The following information is needed for these purposes:

Waste Inventory

- Quantities (in curies) of radionuclides to be emplaced in the repository

Gas-Generation Potential

- Quantities of metals in the waste including steel, steel alloys, aluminum, and aluminum alloys
- Quantities of combustible materials such as cellulosics, plastics, and rubber
- Quantities of various chemicals including water, cementitious material (calcium oxide and hydroxide), nitrate, sulphate, phosphate, and phosphorous

Actinide Inventory and Mobilities

- Quantities of the following actinides emplaced in the WIPP: ^{241}Am, ^{252}Cf, ^{244}Cm, ^{248}Cm, ^{137}Cs, ^{237}Np, ^{231}Pa, ^{210}Pb, ^{147}Pm, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu,^{242}Pu,^{244}Pu, ^{226}Ra,^{228}Ra, ^{90}Sr, ^{147}Sm, ^{229}Th,^{230}Th, ^{232}Th, ^{233}U,^{234}U,^{235}U,^{236}U, and ^{238}U
- Quantities of chelating agents or other organic ligands
- Quantities of soil or other humic material.

4.3 Waste Envelope

Only those wastes that meet established acceptance criteria will be emplaced in the repository. These criteria result from restrictions on waste acceptability from numerous sources which have been implemented by the DOE. In addition, restrictions may result from directions from regulatory authorities. The associated concepts of the "performance-based waste envelope" and "boundary conditions and process tolerance limits" are described in this section. The process for controlling the types of wastes to be sent to the WIPP is also described.

The WIPP facility will have boundary conditions and process tolerance limits imposed by the DOE (e.g., no explosives or compressed gases within containers, labeling on containers, etc.) and any boundary conditions established by the EPA and the New Mexico Environment Department (NMED). The DOE's boundary conditions and process tolerance limits are summarized in Table 4-2. Boundary conditions imposed by the EPA and the NMED, including safety-related conditions, are unknown at this time.

Table 4-2. Boundary Conditions and Process Tolerance Limits Established by the DOE

Determination	Parameter	Boundary Condition
Ignitability, Reactivity, and Corrosivity	Liquids or aqueous waste	Residual liquid only with all internal containers well drained (<1% free liquids)
	Oxidizers	No oxidizers
	Explosives	No explosives
	Compressed gases	No compressed gases
	Pyrophoric materials	No nonradionuclide pyrophoric materials
Compatibility	Waste form	Only those waste forms described in Section 4.4.2
Waste Category	Waste form	Only those waste forms described in Section 4.4.2

"Boundary conditions" are defined as the maximum acceptable values for waste properties. (This term is used in Chapter 6 in a different context and has a different meaning; Chapter 6's use of the term is in the context of modeling applications and refers to conditions at the boundaries of the system being modeled.) "Process tolerance limits" are defined as those characteristics that a waste management process can tolerate while maintaining permit compliance. Waste that exceeds boundary conditions or that could lead to process tolerance limits being exceeded will not be certified for shipment to the WIPP facility.

4.3.1 Waste Acceptance Criteria

The existing waste acceptance criteria are based on transportation and operational safety requirements. The formal document that describes the acceptance criteria for the inventory of DOE TRU wastes to be shipped to WIPP is the *Waste Acceptance Criteria for the Waste Isolation Pilot Plant.* (WAC) These criteria establish limits for the physical, radiological, and chemical characteristics of the waste, in addition to specifications for the waste packaging. Specific TRU wastes will not be approved for shipment to the WIPP until the wastes have been certified as meeting the WAC. The primary objectives of the WAC are: (1) to ensure that all TRU wastes are packaged so that handling and subsequent disposal can be performed safely, and (2) to maintain the repository's ability to isolate the waste.

Criteria that are anticipated to apply to wastes to be emplaced in the WIPP facility (pending final disposal system performance evaluation and permit conditions) will be published and implemented at DOE generator and storage facilities through a future revision of the WAC.

The WAC will guide future waste generation and packaging practices. Wastes currently stored or generated that do not meet the final WAC may require processing until certification can be attained. Any such processing would be the responsibility of the site proposing to ship the waste to the WIPP.

The WAC certification programs are overseen by the DOE through periodic audits. The DOE will ensure that TRU waste received at the WIPP facility meet these criteria through implementation of administrative and operational procedures at the generator sites. Implementation of the WAC certification programs at the generator sites results in controlled and consistent chemical and physical waste properties and final packaging.

4.3.2 Bounding Criteria Based on Disposal System Performance

The current WAC are based on transportation requirements and safe handling and storage criteria. If required, long-term performance-based WAC will be applied to the WIPP inventory baseline when the overall assessment of the disposal system's performance is complete.

The criteria that define the acceptable inventory, as determined through the performance assessment, are referred to as the performance-based waste acceptance criteria (PBWAC). The PBWAC identify the bounding characteristics of wastes acceptable for the WIPP based on repository performance. This "envelope" of wastes is based on consideration of only the physical and chemical form of the waste and its potential interaction with the repository. Information used to formulate and identify this envelope includes waste characterization activities and modeling.

As performance assessment activities provide insight relative to the importance of specific waste parameters, some parameters may be found to have significant impact on the performance of the overall disposal system. Waste parameters shown to have little or no impact on repository performance will be candidates for reduced characterization. The performance assessment results, combined with directions from state and federal regulators, will provide guidance for future waste generation practices, allowing the DOE to optimize future sampling and analysis programs.

The PBWAC will contain the criteria for waste acceptance based on possible effects of wastes on the performance of the repository. There are several other compliance programs that may also impose criteria applicable to waste acceptance at the WIPP. These include criteria required by permit conditions, requirements stemming from the EPA's no-migration determination, transportation and waste certification, and operational safety. The DOE will impose these criteria on all sites that send waste to WIPP through the WAC.

4.4 Waste Characterization

Waste characterization refers to the documentation of the contents of a container or containers of waste by sampling and analysis and/or the examination of TRU waste generation documentation and associated records. The TRU waste characterization program has evolved over the past several years as a result of compliance programs and associated waste information requirements.

4.4.1 Plans and Program Summary

Waste characterization and certification programs are described in this section.

4.4.1.1 Waste Characterization Program

The waste characterization program consists of testing, sampling, analytical activities, and non-intrusive examination methods used to characterize retrievably stored and newly generated TRU waste at DOE facilities planning to send TRU waste to the WIPP. Objectives of the waste characterization program are to confirm the radionuclide, to verify the physical and chemical waste form inventories on which the performance assessment is based, and to assure that no wastes are placed in the WIPP which are inconsistent with the disposal system's performance limitations.

Radioassays will be conducted on waste prior to shipment to the WIPP to confirm the radionuclide inventory. To ensure compliance, the DOE will determine and report the species and curie quantity of radionuclides that can be measured or derived. The DOE must account for more than 1 percent of the total activity in the container, prior to shipment to WIPP.

The parameters to be assessed for physical waste form will be determined based on their significance to the disposal system's long-term performance. The assessment of physical waste form parameters that do not affect compliance will be minimized in future waste characterization programs, and the characterization requirements will be revised, as necessary. If specific waste parameters are found to be important to compliance, characterization techniques will be developed to assure proper management. For example, possible load management alternatives may be considered to ensure the proper mix of waste forms on both panel and room scales. Because a large percentage of the waste is not yet generated, the DOE will be in a position to control the types and quantities of waste forms generated in the future.

4.4.1.1.1 Waste Streams

The identification of waste streams is an important component of the waste characterization process. A waste stream is generated (1) by a process or processes that have well-defined material inputs, processes, and material outputs; (2) by a change in equipment; or (3) in a building that results in a batch of waste containers. Waste streams may be combined for management and characterization if the generation practices, waste profiles, and data quality are similar and if the wastes are compatible.

The method for categorizing wastes into specific streams is based on the premise that the key information necessary for identifying the critical stream parameters is available. These parameters are based on the physical, radiological, and chemical properties of the waste.

The consistent application of categorization methods is important to ensure that each generator provides data consistent with those of other facilities. Many TRU waste streams may not be readily characterized by a single TRU waste code; therefore, multiple codes may be used to better describe streams containing more than one contaminant. Multiple profiles may also be required when changes in process knowledge, quality assurance programs, or generation process have occurred over time.

The type and quality of support information for the characterization of each waste stream is documented as part of the waste profiling process. The completeness of documentation will determine the uncertainty assigned to process knowledge and the level of sampling and analysis required for each waste stream.

The documentation of physical controls and barriers is also considered in the evaluation of process knowledge for each waste stream. Physical controls and barriers are devices that direct waste streams to specific locations and protect the waste stream from constituents that are not part of the waste generating process.

4.4.1.1.2 Waste Profiles

Waste profiles have been, and will continue to be, developed for each waste stream based on process knowledge, sampling and analysis results, and references to supporting documentation. The waste stream profiles are evaluated to determine the adequacy of the characterization and the level of uncertainty in the profile. This evaluation is used to develop and verify the waste generator's characterization program for certification of the waste stream. The waste streams are documented through profiles consisting of tables listing constituents and associated volumes and weight percentages with uncertainty ranges. Information provided on the profiles includes radioisotopes, such as ^{239}Pu, and physical and chemical matrix descriptors, such as polyethylene. Application of this profiling and categorization process ensures consistency of the data from different DOE facilities.

4.4.2 Physical Waste Characteristics

As required by the FFCA, the DOE has prepared the Mixed Waste Inventory Report (MWIR) (DOE 1994a), which provides information relative to the volumes of currently stored wastes and a 5-year forecast of future TRU mixed wastes. TRU wastes are classified in the MWIR according to their physical, chemical, and radiological characteristics. This classification is based on RCRA waste treatability groups. For consistency in reporting, the DOE plans to classify all TRU wastes according to this system. Physical forms of the wastes to be emplaced in the WIPP are described in the following subsections.

4.4.2.1 CH TRU Waste Forms

TRU waste is packaged at the generator sites in a primary confinement barrier (i.e., a Department of Transportation Type 7A steel drum or a standard waste box) to isolate contaminants from humans and the environment during transportation and handling. This packaging system may include rigid plastic inner liners, several layers of plastic bagging, and absorbents in the void spaces.

Pursuant to the WAC, free liquids and pressurized containers are prohibited in shipment of waste to the WIPP facility. Damp combustibles are neutralized, drained, or dried prior to packaging with absorbents (e.g., vermiculite) to prevent the accumulation of condensate. Discarded equipment is disassembled to remove any liquids from fluid reservoirs or lines. Glass waste is dried or drained to remove all free liquids. Pressurized containers are punctured or must have an opening that makes it obvious that the container is no longer pressurized.

Categories of wastes to be shipped to the WIPP are described below:

Combustibles. Combustible wastes are generated during a variety of processes. These wastes consist of paper, plastics, cloth rags and clothing, and wood resulting from almost all plutonium operations. Cloth and paper wipes are used to clean parts and gloveboxes during most operations. Depending on the operations, damp combustibles are usually used and then wrung out, drained, or dried. A small quantity of non-combustible waste, such as concrete, scrap metal, and equipment, may also be present in this waste category.

Non-Combustibles. Non-combustibles consist primarily of glass and metal. Much of this waste is laboratory equipment and glassware from research and development activities.

Combustibles and Non-Combustibles. Combustible and non-combustible waste is commonly generated in hot cells and gloveboxes. This waste category contains various mixtures of combustible waste, such as paper, and non-combustible waste, such as metal. The process-specific nature of the operations that generate many of the combustibles and non-combustibles makes the detailed segregation of various waste materials unnecessary. Small processes that use specific radionuclides do not require extensive segregation of waste materials for plutonium accountability or recovery.

Graphite. Graphite waste is produced from molds that are broken, cleaned, or scraped in gloveboxes to remove excess plutonium. Graphite is a uniform, well-defined material. Plutonium casting operations include the use of solvents from the cleaning of graphite molds, and thus residual spent solvents may be present on the surfaces of graphite pieces. In addition, residual metals may be present from impurities in plutonium metal.

Filters. This includes the following types of filters:

- High-Efficiency Particulate Air (HEPA) filters
- Ful-Flo® filters
- Filter media
- Processed filter media
- Prefilters.

Prefilters and HEPA filters are used on all ventilation intake and exhaust systems associated with plutonium operations. Filter frames can be either wood, aluminum, or stainless steel; the filter media may be Fiberglass®, Nomex®, or similar material. Fiberglass® is a trade name for a variety of products made of or with glass fibers or glass flakes. Nomex® is a trade name for an aramide fiber commonly derived from p-phenylenediamine and terephthaloyl chloride. Ful-Flo® filters consist of fibrous polypropylene (a synthetic, crystalline, thermoplastic polymer) filter media.

Filter media are generated from splitting absolute dry box and HEPA filters apart from their frames in the plutonium process areas. Loose particulate materials that are dislodged from the filters are stabilized and packaged separately from the media. Filter media are packaged in 1-gallon plastic bottles or bags. Processed filter media consist of Ful-Flo®, filter media, and whole filters removed from acid and non-acid environments. Filter media may be mixed with portland cement to neutralize residual nitric acid that may be present.

Filters are designed to remove and retain specific sizes of particulate materials from air or liquids. Although the filters associated with plutonium operations are not designed to retain organic vapors, they may contain these residues depending on the operations conducted in a glovebox or building. Airborne metals, resulting from grinding or machining operations, also may be trapped in glovebox filters.

Benelex® and Plexiglas®. Benelex® consists of approximately 99.5 percent wood, with residual amounts of the phenolic resin. Plexiglas® is a poly methyl methacrylate polymer used for glovebox windows and is generated as waste during the change-out of the glovebox windows. This waste category is composed of well-defined materials that are used as neutron shielding material and in glovebox construction. Organic residues may be present as a result of glovebox cleaning prior to disassembly.

Solidified Liquid. Solidified liquid is composed of aqueous waste that is not compatible with the primary aqueous wastewater treatment process because of the presence of complexing chemicals. This liquid waste is excluded from the production liquid waste because of the potential presence of complexing chemicals that would interfere with the recovery of actinides. Complexing chemicals include organic acids, alcohols, or other chelating agents. Batches of this waste may be as little as 1 liter or as much as several hundred liters and may be solidified with portland and magnesium cement. Other nonflammable aqueous waste is solidified with vermiculite.

Inorganic Process Solids and Soil. This waste category consists of solids that cannot be reprocessed or process residues from evaporator and other types of storage tanks, grit, firebrick fines, ash, salts, metal oxides, and filter sludge. This waste is typically solidified in portland or gypsum-based cements. Contaminated soil, asphalt, and sand are generated from the cleanup of spills, as well as decontamination and decommissioning activities at DOE generator sites, and may also be present in this waste.

4.4.2.2 RH TRU Waste Forms

RH TRU waste contains mixtures of combustibles (e.g., paper polyvinyl chloride, polypropylene, polyethylene, and neoprene) and non-combustibles (e.g., laboratory equipment, tools, filters, solidified liquids, solid materials, and small electric motors). Some RH TRU wastes are heterogeneous solids consisting of metallographic samples of fuel elements, fines, and combustibles packaged in metal cans and plastic bags or buckets. Free liquid or particulate wastes are not associated with processes that generate RH TRU waste.

4.4.2.3 Free Liquid Content

The WAC (DOE 1991b) precludes the acceptance of liquid waste and any waste containing free liquids. All internal containers are to be well drained. Residual liquids in well-drained containers are restricted to less than 1 percent of the volume of the internal container. The presence of free liquids is determined through characterization by real-time radiography (RTR). Drums have been excluded from the WIPP program due to non-conformance with the WAC criteria of no free liquids.

4.4.3 Radiological Waste Characteristics

The CH and RH radionuclide inventories are provided in Table 4-3. This inventory is used in the performance assessment to calculate a waste unit factor (f_m) consistent with the instructions in Table 1 of Appendix A of 40 CFR Part 191. The f_m is related to the quantity of radionuclides that may be released to the accessible environment.

The values presented in Table 4-3 are also used as input to the performance calculations. The values provided in Table 4-3 are based on the most current information available in January 1995, the time at which the calculations described in Chapter 6 were initiated. Since January 1995, the BIR has been updated. As a result, the values presented in the BIR, which is included as Appendix BIR, are not entirely consistent with those provided in Table 4-3. Because of this inconsistency, the performance calculations presented in Chapter 6 are not based on the most current inventory information. The calculations will be revised to be based on the most current inventory data as the WIPP compliance program progresses.

Table 4-3. Radionuclide Inventory

Radionuclide	CH Curies	RH Curies
^{227}Ac	1.17	3.35×10^{-3}
^{240}Am	1.61×10^{-2}	0.00
^{241}Am	2.40×10^{5}	2.21×10^{2}
^{243}Am	3.57×10^{1}	3.90×10^{-3}
^{137}Ba*	1.59×10^{4}	3.77×10^{5}
^{214}Bi	4.80×10^{-2}	0.00
^{249}Bk	5.88×10^{2}	6.70×10^{-4}
^{14}C	5.42×10^{-4}	7.91×10^{1}
^{109}Cd	6.68×10^{3}	0.00
^{144}Ce	1.42×10^{4}	3.58×10^{5}
^{249}Cf	5.33×10^{-2}	4.52×10^{-2}
^{250}Cf	5.40×10^{-1}	6.09×10^{-1}
^{251}Cf	4.03×10^{-3}	0.00
^{252}Cf	2.96×10^{3}	2.01×10^{2}
^{242}Cm	6.73×10^{1}	0.00
^{243}Cm	1.59	1.22×10^{3}
^{244}Cm	1.38×10^{4}	7.73×10^{3}
^{245}Cm	4.25×10^{1}	7.73×10^{3}
^{246}Cm	1.08×10^{-1}	0.00
^{248}Cm	2.46×10^{-2}	0.00
^{58}Co	2.04×10^{3}	2.58×10^{5}
^{60}Co	3.02×10^{2}	1.61×10^{4}
^{51}Cr	1.84×10^{2}	2.30×10^{4}
^{134}Cs	3.69×10^{2}	1.48×10^{4}
^{137}Cs	2.07×10^{4}	5.53×10^{5}
^{253}Es	1.02×10^{-1}	0.00
^{254}Es	1.99×10^{-2}	0.00
^{254}Es*	1.40×10^{1}	0.00
^{150}Eu	4.50×10^{-5}	0.00
^{152}Eu	8.96×10^{1}	3.76×10^{4}
^{154}Eu	8.86×10^{1}	2.29×10^{4}
^{155}Eu	5.84×10^{1}	6.71×10^{3}
^{55}Fe	6.11×10^{-4}	1.99×10^{1}
^{59}Fe	2.32×10^{1}	2.31×10^{3}
^{3}H	2.07	4.66×10^{1}
^{85}Kr	4.00×10^{-1}	4.83×10^{1}
^{54}Mn	1.40×10^{3}	1.78×10^{5}
^{95}Nb	2.75×10^{3}	6.52×10^{4}
^{59}Ni	8.45×10^{-3}	0.00

Table 4-3. Radionuclide Inventory (Continued)

Radionuclide	CH Curies	RH Curies
^{63}Ni	1.16	1.90x10^{1}
^{237}Np	6.67x10^{-1}	9.18x10^{-3}
^{239}Np	1.82x10^{-2}	0.00
^{231}Pa	3.30x10^{-3}	0.00
^{233}Pa	1.97x10^{-3}	0.00
^{210}Pb	2.10x10^{-2}	0.00
^{214}Pb	4.80x10^{-2}	0.00
^{147}Pm	5.25x10^{2}	1.81x10^{3}
^{209}Po	2.56x10^{-6}	0.00
^{210}Po	2.52x10^{-3}	0.00
^{214}Po	4.80x10^{-2}	0.00
^{218}Po	4.80x10^{-2}	0.00
^{144}Pr	1.42x10^{4}	3.37x10^{5}
^{236}Pu	5.76x10^{-2}	0.00
^{238}Pu	4.24x10^{6}	2.22x10^{3}
^{239}Pu	3.92x10^{5}	4.44x10^{3}
^{240}Pu	6.93x10^{4}	1.05x10^{3}
^{241}Pu	1.93x10^{6}	6.06x10^{4}
^{242}Pu	4.91x10^{4}	1.09x10^{1}
^{244}Pu	1.00x10^{-6}	0.00
^{245}Pu	0.00	3.35x10^{-3}
^{226}Ra	5.57	1.42x10^{1}
^{228}Ra	2.75x10^{-1}	0.00
^{106}Rh	6.20x10^{3}	1.47x10^{5}
^{222}Rn	4.80x10^{-2}	0.00
^{106}Ru	6.20x10^{3}	1.50x10^{5}
^{125}Sb	2.84x10^{3}	6.72x10^{4}
^{126}Sb	1.56x10^{-1}	0.00
^{151}Sm	1.07x10^{2}	2.52x10^{3}
^{90}Sr	9.85x10^{3}	5.48x10^{5}
^{182}Ta	0.00	3.79
^{99}Tc	4.22x10^{1}	4.59x10^{2}
^{125}Te*	7.09x10^{2}	1.67x10^{4}
^{228}Th	1.12	1.34x10^{-1}
^{230}Th	2.08x10^{2}	0.00
^{232}Th	6.11x10^{-1}	1.51x10^{-2}
^{234}Th	9.50x10^{-5}	0.00
^{232}U	3.02x10^{1}	6.70
^{233}U	1.31x10^{3}	4.80x10^{2}

Table 4-3. Radionuclide Inventory (Continued)

Radionuclide	CH Curies	RH Curies
^{234}U	1.75×10^{1}	0.00
^{235}U	1.15	5.66
^{236}U	2.98×10^{-1}	0.00
^{238}U	2.01×10^{-1}	7.28
^{90}Y	7.55×10^{3}	1.79×10^{5}
^{65}Zn	7.00	8.83×10^{2}
^{95}Zr	1.30×10^{3}	3.25×10^{4}
Total	7.05×10^{6}	3.47×10^{6}

*Metastable.

4.4.4 Analytical Methods

Characterization of TRU wastes includes application of methods to generate the information necessary for each data user. These data are necessary to meet the particular objectives of each compliance program. This section defines the sampling and analysis procedures used to characterize TRU waste at generator sites and the site-specific plans that identify and describe the administrative controls and procedures required to characterize, segregate and process, and package TRU waste in accordance with the WAC.

Use of the methods outlined in this section will provide the data necessary for WIPP compliance programs. If waste forms are not analyzed by these methods, alternative methods may be proposed, provided it can be demonstrated that data quality objectives defined in the *Quality Assurance Program Plan* (QAPP) are attained.

4.4.4.1 Radioassay

Radioassay consists of non-intrusive and intrusive measurement techniques used to determine the radionuclide content of the waste containers. Actual measurements may be mass or activity determinations convertible to specific activities of the individual isotopes by conventional radiochemical and radioactivity counting methods, as well as determinations by methods such as mass spectrometry.

Radioassay provides data on individual isotopes that can be used in applications such as determining the repository radionuclide inventory and the source term for performance assessment. Data generated by radioassay are also used to calculate other parameters to evaluate against specific criteria (e.g., ^{239}Pu equivalent activity, decay heat of waste containers, and fissile gram equivalent).

4.4.4.2 Non-Destructive Examination

RTR is a radiographic examination technique used at many generator sites. It is a non-destructive, non-intrusive examination method that enables a qualitative evaluation of the contents of a waste container. The technique uses X-rays and a video system to inspect the contents of a waste container and allows the operator to view events in progress. Radiographic examination is used to examine and verify the physical form of the waste for certain waste forms, to identify individual waste objects and parts, and to verify the absence of certain noncompliant items, as applicable. For example, radiographic examination can be used to verify that a drum identified as containing solidified waste actually contains solidified waste. Applications also include ensuring that waste containers comply with applicable limits on free liquids by obtaining an estimate of residual liquids in a waste container. The use of radiographic examination in the TRU waste management process and its limitations are documented in the Stored Waste Examination Pilot Plant Sampling Program at the INEL.

4.4.4.3 Visual Examination

Visual examination consists of examining and sorting the contents of the containers for removal of prohibited items before packaging and for the characterization of variables affecting performance assessment. For example, visual examination can be used to verify packaging.

Visual characterization will be implemented in all current waste generation process lines or repackaging programs. The draft *TRU Waste Characterization Quality Assurance Program Plan* addresses the use of visual examination to verify non-destructive examination data. Data obtained from visual examination are used to determine the percentage of miscertified waste containers. The QAPP specifies that the 90 percent upper confidence level (UCL_{90}) of the miscertification percentage will be less than 14 percent; however, if 14 percent of the waste containers are shown to be miscertified in any given year, it will be necessary to visually examine a significant percentage, if not all, of the waste containers. Therefore, any noncompliant waste containers will be repackaged to meet the requirements. Experience at the INEL has indicated a miscertification rate of only 2 percent. This miscertification includes all WAC and Transuranic Package Transporter (TRUPACT)-II Authorized Methods for Payload Control (TRAMPAC) criteria, not just the presence of free liquids.

4.4.4.4 Supporting Documentation Requirements for Generators

Implementation of the TRU Waste Characterization Program at DOE sites requires that all waste characterization activities be conducted in accordance with approved documentation that describes the management, operations, and quality assurance for the program. These documents ensure conformance with all applicable regulatory, programmatic, and operational requirements. The sites may also need to develop other documents (e.g., TRU waste management plans, safety analysis reports, and operational safety requirements) that address site-specific programmatic and operational requirements; these documents are not discussed here. The documentation requirements critical to the implementation of the TRU Waste Characterization Program at each site are discussed below.

Site Characterization Plans. The generator sites must prepare plans which specify how the requirements of the WAC will be met. These plans must include the administrative, procedural, and process controls used to determine waste acceptability.

Quality Assurance Requirements. All generator sites will ensure that implementation of their site-specific waste characterization program meets the quality assurance requirements of DOE Order 5700.6C. The QAPP describes the specific data quality objectives for the TRU Waste Characterization Program and incorporates the applicable elements of other governing documents, including EPA's *Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans.* The QAPP and the associated document, DOE's *WIPP Waste Characterization Program Sampling and Analysis Guidance Manual*, currently establish analytical methods for meeting regulatory requirements. Additional discussion on quality assurance is presented in Chapter 5 of this document.

Quality Assurance Project Plans (QAPjPs). Prior to initiating waste characterization activities, the sites must prepare site-specific Quality Assurance Project Plans (QAPjPs). These site-specific documents, to be developed in accordance with the applicable requirements in DOE Order 5700.6C and the QAPP (which is based on *EPA Requirements for Quality Assurance Project Plans for Environmental Data Operations,* QA/R-5), define quality management and program elements that provide for planning, implementation, and assessment of the TRU Waste Characterization Program and data collection activities.

Standard Operating Procedures (SOPs). The QAPP requires that each DOE site develop, implement, and control written standard operating procedures (SOPs) that provide detailed descriptions of routine, standardized, or critical waste characterization activities. The SOPs serve as the basis for quality assessments of waste characterization activities because they provide detailed descriptions of required activities.

Performance Demonstration Program. All facilities characterizing waste for disposal at the WIPP shall successfully participate in the applicable portions of the Performance Demonstration Program (PDP) for the TRU Waste Characterization Program as described in DOE's *Performance Demonstration Program Plan* (PDPP). The PDP supports the determination of a facility's ability to meet the quality assurance objectives identified in the QAPP. Facility performance is demonstrated by the successful analysis of blind audit samples. Blind audit samples (hereafter referred to as PDP samples) are used to assess facility performance regarding compliance with the QAPP quality assurance objectives. Acceptable performance will be demonstrated by all participating facilities prior to the initial analysis of TRU waste samples and on a continuing basis. The PDP samples must be analyzed using the same methods the facility anticipates using for the analysis of TRU waste samples. These methods will be developed and approved within the specifications of the QAPP.

4.4.5 Process Knowledge Documentation

Process knowledge is the initial step in the waste characterization program. Process knowledge refers to the knowledge of the processes and materials that generated the waste, along with accompanying records and documentation and the associated administrative, procurement, and quality assurance controls. The application of process knowledge as a waste characterization method is of particular importance in this program (1) to balance the requirements for providing definitive chemical and physical characterization of a waste stream with the need to reduce radiation exposure to personnel and the generation of additional waste; and (2) to address those circumstances where sampling and analysis may not be necessary.

Because of complex waste matrices and the potential for radiation exposure to personnel, these wastes have not been routinely sampled and analyzed. Wastes destined for the WIPP facility have been characterized by the DOE through knowledge of the wastes and/or the processes generating them. The requirements of strict product quality and concerns for safety in handling the radioactivity result in highly structured production and research activities. The nature of these activities requires that precise product information be maintained.

Process knowledge is a valuable source of information for characterizing waste streams and planning sampling and analysis programs, if it is documented and comes from reliable sources. This documentation, which could be in the form of a process flow diagram, data logs, documented procedures and other administrative controls, etc., will exhibit some attributes which provide evidence of quality. The following list provides some attributes of documentation that would be used to judge quality and evaluate uncertainty of process knowledge:

- Produced at the time the process was operating and waste was generated and packaged
- Signed and dated by responsible personnel
- Co-signed by an oversight organization (i.e., Quality Assurance)
- Documents are traceable to specific packages
- Documents are traceable to a group of packages
- Quality assurance programs were observed
- Proper training for personnel is documented.

Waste currently being generated will be characterized primarily through process knowledge. Sampling and analysis will be required for verification purposes for a portion of all waste streams. Specific guidance for process knowledge collection for current waste generation will be provided by DOE during the Waste Characterization Program implementation process. At a minimum, generators are required to document the process and waste constituent data governed by an approved quality assurance program and a documented management system.

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5.0 QUALITY ASSURANCE

5.1 Purpose

The U.S. Department of Energy (DOE) quality assurance (QA) policy is to establish, maintain, and implement an effective QA program that complies with applicable DOE Orders and requirements and U.S. Environmental Protection Agency (EPA) requirements. It is the DOE's goal to fulfill its mission while ensuring that not only are risks and environmental impacts identified and minimized, but also that safety, reliability, and performance are maximized.

QA programs define the management systems to be employed to meet the requirements and guidance described by the Carlsbad Area Office's (CAO's) Quality Assurance Program Description (QAPD), which is included in this document as Appendix QAPD. The purpose of specifying requirements and associated guidance for QA programs is to ensure that all participants develop and implement effective management systems to ensure that items, processes, and services meet or exceed applicable CAO QA requirements.

The proposed Title 40 Code of Federal Regulations (CFR) § 194.22, § 194.26, and § 194.27 specify requirements regarding QA, expert judgment, and peer review. These requirements are not addressed in this document.

5.2 QA Program Management

Effective implementation of the CAO QA program depends on the efforts of all levels of the CAO organization (including the CAO Manager, senior management, line management, and the personnel performing work). The CAO organization is structured such that the individual performing the work is responsible for achieving and maintaining quality; line management is responsible for verifying the quality; and independent assessors are responsible for assessing the quality of the work. The CAO QA Manager is responsible for defining, integrating, and ensuring effective implementation of QA activities throughout the CAO.

5.2.1 Organization

The hierarchy of QA program requirements and the organizational interfaces between the major project participants are illustrated in Figure 5-1. Major responsibilities of project participants are as follows:

- The DOE is the controlling organization for Waste Isolation Pilot Plant (WIPP) QA program development, implementation, and assessment

- The DOE reviews and approves the QA program documents of the Scientific Advisor (Sandia National Laboratories [SNL]), the Management and Operating (M&O) contractor (Westinghouse Waste Isolation Division [WID]), and the transuranic (TRU) waste generator sites

- TRU waste generator sites are responsible for TRU and TRU mixed waste characterization and for the waste certification programs

- The WID is responsible for WIPP site operation and maintenance and for monitoring the site environment

- SNL develops, confirms, and validates models used to simulate long-term repository performance; SNL also conducts research, experiments, and tests to collect the data needed for input to the models.

5.2.2 QA Program Requirements

QA program requirement sources include several federal requirements (10 CFR Part 830, 40 CFR Part 261, 40 CFR Part 264, 40 CFR § 268.6, and 10 CFR Part 71), DOE Orders (primarily DOE 5700.6C), and consensus standards (American Society of Mechanical Engineers Quality Assurance Requirements for Nuclear Facilities [ASME NQA-1], NQA-2 Part 2.7, and NQA-3). These requirements are directed through the DOE Environmental Management (EM) QA Requirements and Description to the DOE CAO. The CAO QAPD (refer to Appendix QAPD) reflects the QA requirements, lists other sources of program guidance, and describes the project interfaces and responsibilities.

Participant QA program descriptions include discussions of how the QA requirements will be satisfied taking into consideration the probability and consequences of risk associated with the work. These discussions include the rationale and methodology used for the compliance determination as well as discussions addressing applicability of the requirements to the work being performed.

The rigor of QA controls is commensurate with, but not limited to, the following criteria:

- Function or end-use of the item
- Importance and end-use of the data generated
- Probability of failure
- Complexity or uniqueness of design, fabrication, or implementation
- Reproducibility of the result
- History of the item or service quality
- Necessity for special controls or processes
- Ability to demonstrate functional compliance.

5.2.3 Qualification and Training Requirements

Personnel performing work are qualified and capable of performing their assigned tasks. Project participants have established formal methods for the evaluation, selection, indoctrination, training, and qualification of personnel performing work.

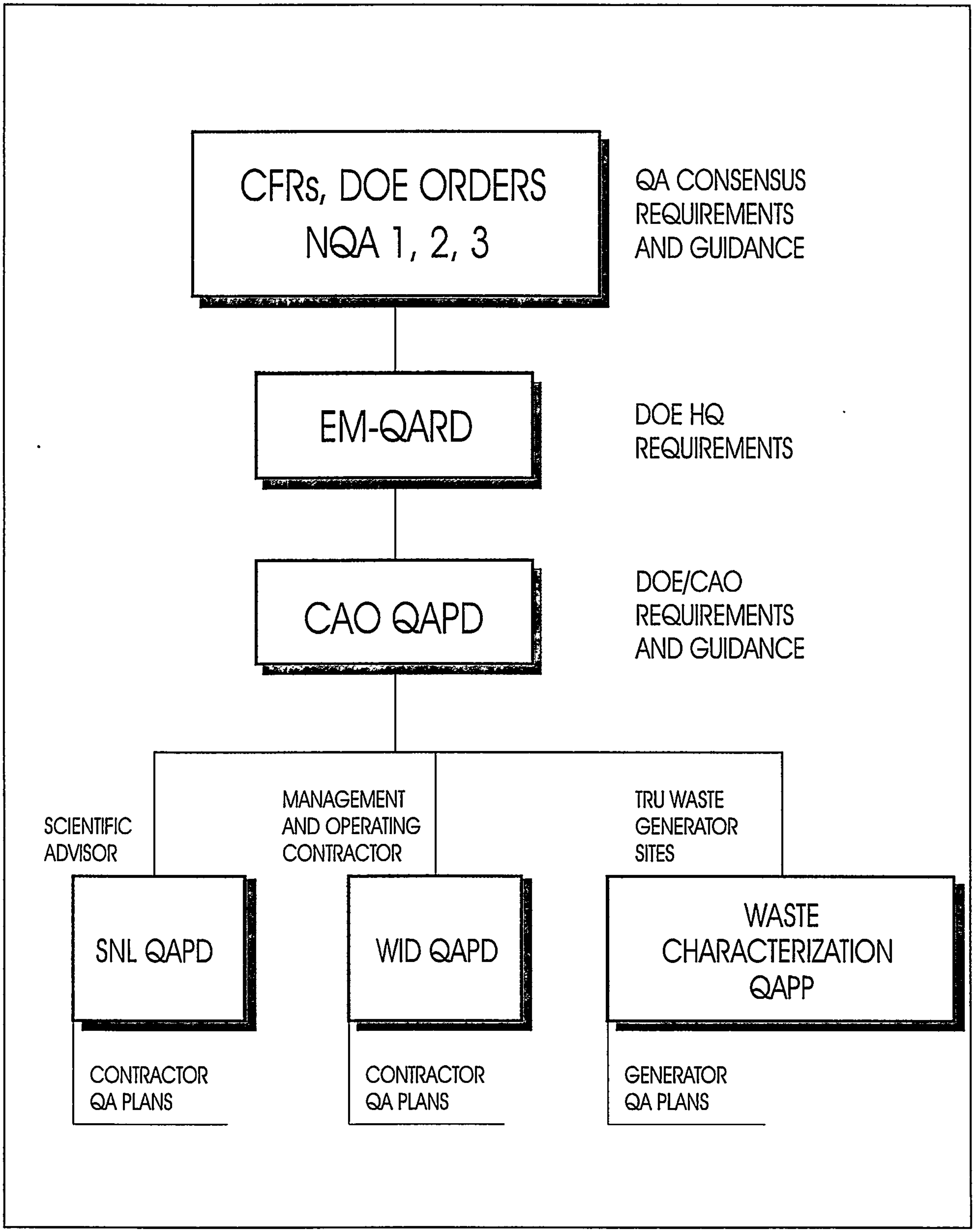

Figure 5-1. Hierarchy of DOE QA Programs

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5.2.4 Quality Improvement, Nonconformances, and Corrective Action

A culture which promotes continuous improvement is fundamental and integral to the WIPP mission; therefore, each organization's management seeks continuous improvement in the performance and efficiency of work processes and activities.

All personnel are responsible for identifying nonconforming items, activities, and processes and are encouraged by management to suggest improvements. Management at all levels strives to foster a "no-fault" attitude to encourage the identification of nonconforming items and processes. Nonconformances are documented, evaluated, and dispositioned. Corrective actions must address the following: root cause; actions to resolve the problem and to preclude recurrence; assessment of the extent of the problem; and scheduled completion dates.

5.2.5 Documents and Records

Documents and records generated under the CAO QA program are specified, prepared, reviewed, approved, controlled, and maintained in accordance with the CAO QAPD (refer to Appendix QAPD). The CAO QAPD provides a single reference for all project participants in meeting records management requirements as specified in DOE Orders and regulations.

5.3 QA Program Implementation

This section discusses aspects of implementing the QA Program.

5.3.1 Work Processes

Work is performed in accordance with established, approved, and documented technical standards and administrative controls. Work is also performed under controlled conditions using approved instructions, procedures, drawings, or other appropriate means. Items are identified and controlled to ensure their proper use. Items are maintained to prevent their damage, loss, or deterioration. Equipment used for process monitoring or data collection is calibrated and maintained. Handling, storage, cleaning, shipping, and other means of preserving, transporting, and packaging of items is conducted in accordance with established work and inspection procedures, shipping instructions, or other specified documents.

5.3.2 Design

Items and processes are designed using sound engineering and scientific principles and appropriate standards. Design work, including changes, incorporates appropriate requirements such as general design criteria and design bases. Design interfaces are identified and controlled. The adequacy of design products are verified by individuals or groups independent from those who performed the work. Verification is completed prior to approval and implementation of the design.

5.3.2.1 Design of Data Quality Objectives

For future work, the concept of designing data quality objectives for environmental data will apply. Project goals will be documented, decisions and inputs identified, the study bounded, and a decision rule developed. Limits on decision errors will determine the degree of confidence necessary for the data to be considered valid.

For past work, where data have already been collected, the end-use of the data determines the amount of uncertainty permissible. Existing data undergo a formal qualification process before being used in compliance submittals. Refer to Section 5.6.1 for further discussion on qualification of existing data.

5.3.3 Procurement Control

Controls are established to ensure that procured items and services meet applicable technical and QA requirements and that they perform as specified. Prospective suppliers are evaluated and selected on the basis of documented criteria. Procurement controls ensure that approved suppliers continue to provide acceptable items and services.

5.3.4 Inspection and Test Control

Essential parts of work planning processes include the identification of the following:

- Items and processes to be inspected or tested
- Parameters or characteristics to be evaluated
- Techniques to be used
- Acceptance criteria
- Hold points, and
- Organizations responsible for performing the tests and inspections.

Inspection and testing of specified items and processes are conducted using established criteria. The acceptance of an item is documented and approved by qualified and authorized personnel. Equipment used for inspections and tests is calibrated and maintained.

5.3.5 Waste Characterization Program

QA requirements and program guidance for waste characterization is contained in the DOE TRU Waste Characterization QA Program Plan (QAPP). The Waste Characterization QAPP establishes a single program applying to all DOE TRU waste generator sites that anticipate shipping radioactive and mixed wastes to the WIPP. The comprehensive scope of the Waste Characterization QAPP, encompassing all generator sites, is necessary for achieving a level of consistency in TRU and TRU mixed waste certification. The Waste Characterization QAPP addresses QA requirements from the following sources:

- 10 CFR Part 71, *Packaging and Transportation of Radioactive Materials*
- 40 CFR Part 268, *Land Disposal Restrictions*
- 40 CFR Part 264, *Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities*
- 40 CFR Part 191, *Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level, and Transuranic Radioactive Wastes.*

The original scope of the Waste Characterization QAPP was developed for the WIPP test phase (the test phase was canceled October 21, 1993 prior to implementation). The document is currently being updated to be consistent with the preoperational work scope. The Waste Characterization QAPP uses established quality objectives for determining whether or not waste destined for the WIPP meets acceptance criteria. Flow-down of applicable QA requirements from the Waste Characterization QAPP to each generator site is accomplished through the development of site-specific QA project plans.

The QA project plans for each TRU waste generator site establish organizational roles and responsibilities, describe the waste certification process, and reference approved procedures to be used.

In addition to non-destructive test methods and waste sampling and analysis, TRU and TRU mixed waste characterization uses process knowledge. QA controls for process knowledge include design documentation (e.g., drawings, specifications), construction and acceptance test records, operating reports, and process stream analyses.

5.3.6 WIPP Site Monitoring Programs

The environmental monitoring program at WIPP was initially established to acquire preoperational baseline environmental data in accordance with DOE Orders. The current program includes radiological and nonradiological monitoring carried out in accordance with the *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance*, DOE/EH-0173T. The guide is based on implementation of DOE Order 5400.1, *General Environmental Protection Program* and DOE Order 5400.5, *Radiation Protection of the Public and the Environment.*

The radiological portion of the site environmental monitoring program includes liquid and airborne effluents, ambient airborne particulates, biotic samples, soils and sediments, surface and drinking water, and groundwater. Nonradiological monitoring includes local meteorology, ambient volatile organic compounds (VOCs), airborne gases, ecological plots, aerial photography, and salt-impact studies.

QA requirements for WIPP environmental data operations are specified in the WID QAPD (Westinghouse 1995, attachment II, p. 2). Specified tolerances for data uncertainty, in terms of data accuracy, precision, and completeness are contained in project-specific plans for air, groundwater, stormwater, VOC, and site effluent monitoring. A series of approved procedures, instructions, and drawings are used to implement the technical and QA requirements. Data are assessed routinely and reported in the annual site environmental report. QA plans and procedures have also been issued for hazardous materials management and Resource Conservation and Recovery Act (RCRA) compliance.

5.4 QA Program Assessment

Oversight authority for QA programs rests with the DOE. Also, each project participant is responsible for conducting assessments and identifying and tracking areas for improvement. The accepted mechanisms for these assessments are management assessment and independent assessment. For specific activities (such as laboratory quality control), performance and system audits may be specified in QA plans or in subcontract work specifications.

Managers at all levels periodically assess the performance of their organization. The purpose for management assessment is to identify improvements and to determine how well the integrated QA program is working.

Several levels of independent assessments occur within the QA program:

- DOE performs independent assessment of major project participant processes and products
- All program participants internally assess their programs using personnel independent of the work
- Subcontractors undergo source inspections, surveys, and audits performed by other project participants.

5.5 Sample Control

Samples are controlled and identified in a manner consistent with their intended use. Sample controls define responsibilities such as interfaces between organizations for documenting and tracking sample possession from sample collection and identification through handling, preservation, shipment, transfer, analysis, storage, and final disposition.

5.6 Control of Scientific Investigations

Scientific investigations are defined, controlled, verified, and documented. Process variables affecting scientific investigations are measured and controlled. Planning determines the criteria to be used for subsequent evaluation of collected data. Scientific investigations are performed and documented in accordance with approved plans. Data are reviewed and validated prior to reporting the results.

5.6.1 *Qualification of Existing Data*

Qualification of existing data with indeterminate quality is necessary in cases where evidence does not exist that shows the data to be used were collected under the formal control of a QA program. Data that were not collected in accordance with the requirements of the CAO QAPD (refer to Appendix QAPD) shall be qualified for their intended use. A procedure developed for data qualification considers both QA programmatic and technical criteria.

The process for qualifying existing data to be used in performance assessment modeling was jointly established by CAO and SNL, with observation by the EPA. The process is based on the Nuclear Regulatory Commission's (NRC's) guidance documents, NUREGs 1298 and 1297.

The data qualification process begins with identification and prioritization of data sets needed for compliance calculations or for settlement of compliance issues. A data package is assembled by a team and is evaluated for completeness. An independent review team reviews the package for adequacy in meeting equivalent QA program requirements (evaluating the QA controls in place at the time of data collection). If necessary, alternative methods for qualifying the data are selected (i.e., corroborating data, confirmatory testing, or peer review). Data that cannot be qualified are abandoned.

5.6.2 *Background - Evolving QA Program Requirements*

The current DOE CAO QAPD (refer to Appendix QAPD) blends QA requirements and guidance from multiple sources. However, the DOE WIPP project work has been performed under formal QA programs since 1977 and throughout several project phases.

1977–1980 *Site Characterization Phase*. The earliest WIPP QA programs were based on the nuclear power plant QA requirements of the NRC's Title 10 CFR Part 50, app. B. Late in this phase, the ASME NQA-1 became the preferred QA standard.

1980–1983 *Site Preliminary Design Validation Phase*. NQA-1 requirements, as called for by the DOE Order 5700.6A, were the basis for WIPP QA programs.

1983–1989 *Construction Phase*. NQA-1 continued to be recognized through DOE Orders as the preferred standard for QA through DOE 5700.6B.

1989–1993 *Test Phase*[1]. The maturing WIPP QA programs, based on NQA-1, began to be supplanted by a performance-based QA standard, DOE Order 5700.6C.

[1]Tests were canceled October 21, 1993 prior to implementation.

1994–present *Preoperational Phase.* For environmental data quality, the current requirements are taken from DOE Order 5700.6C and selected EPA guidance documents. The process for qualifying existing data utilizes guidance from NUREGs 1297 and 1298. Title 10 CFR § 830.120 QA requirements apply to DOE nuclear facility contractors, including WIPP and the TRU waste generator sites.

5.7 Computer Software QA

The extent to which computer software controls are implemented is commensurate with the application, and their implementation is meant to ensure that the quality of the software meets its intended use. The implementation of specific requirements is prescribed in written plans and procedures.

Software determined to be important to regulatory compliance is subject to lifecycle considerations or other approved software QA methodologies as specified in the CAO QAPD (refer to Appendix QAPD). Controlled software is appropriately documented, tested, reviewed, and approved. All phases of the software lifecycle or all associated QA activities are documented.

Software QA control includes inventorying those applications that are designated to meet the CAO software requirements. Software essential to the operation of key equipment or systems or to the accomplishment of project objectives is included. Controlled software is catalogued and maintained under configuration management controls.

Lifecycle considerations are applied to software identified to be important to regulatory compliance. Lifecycle elements include specification and documentation of requirements, design, verification, installation, testing, validation, maintenance, configuration control, and retirement.

Since models and codes to be used for performance assessment were developed by the Scientific Advisor, the SNL WIPP QAPD forms the basis for their management and control. A series of implementing procedures is used to control (1) the development and use of computer software, (2) the selection of values for parameters used in the performance assessment process, (3) the analytical activities, (4) the preparation, review, approval, and issuance of reports, and (5) the use of expert judgment panels for developing as necessary those parameter values where experimental data are either unreasonable or impossible to obtain.

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Title 40 CFR Part 264, *Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities.*

Title 40 CFR Part 268, *Land Disposal Restrictions.*

6.0 CONTAINMENT REQUIREMENTS

The U.S. Environmental Protection Agency (EPA), in Title 40 Code of Federal Regulations (CFR) Part 191, specifies the generally applicable environmental standards for the disposal of transuranic (TRU) and high-level radioactive wastes.

In this chapter the U.S. Department of Energy (DOE) addresses compliance with the Containment Requirements at 40 CFR § 191.13. Furthermore, this chapter considers only undisturbed performance of the disposal system.

"Undisturbed performance" is defined at 40 CFR § 191.12 as "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." However, the Containment Requirements specify consideration of "all significant events and processes," and the proposed text of 40 CFR § 194.32 explicitly requires consideration of human-initiated processes and events for compliance with the Containment Requirements. Therefore, the DOE's preliminary performance assessment results presented in Section 6.3 that indicate compliance with 40 CFR § 191.13(a) must be considered incomplete. Additional analyses of undisturbed performance are in progress, and although results are not available for inclusion here, the essential background material concerning treatment of future human actions is discussed by the DOE.

The complete text of the 40 CFR § 191.13 Containment Requirements follows:

> (a) Disposal systems for spent nuclear fuel or high-level or TRU radioactive wastes shall be designed to provide a reasonable expectation, based on performance assessments, that the 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 met.

The term "accessible environment" is defined as: "(1) The atmosphere; (2) land surfaces; (3) surface waters; (4) oceans; and (5) all of the lithosphere that is beyond the controlled area" (40 CFR § 191.12). Further, "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" (40 CFR § 191.12). The requirements in 40 CFR § 191.13(a) refer to table 1 in appendix A. This table is reproduced here as Table 6-1.

Table 6-1. Release Limits for the Containment Requirements (EPA 1985, appendix A, table 1)

Radionuclide	Release limit L_i per 1000 MTHM[a] or other unit of waste (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

[a]Metric tons of heavy metal exposed to a burnup between 25,000 megawatt-days per metric ton of heavy metal (Wd/MTHM) and 40,000 Mwd/MTHM.

For a release to the accessible environment that involves a mix of radionuclides, the limits in Table 6-1 are used to define a normalized release for comparison with the release limits. Specifically, the normalized EPA release *nR* for TRU waste is defined by

$$nR = \sum_i (Q_i/L_i)(1x10^6 Ci/C) \quad (1)$$

where

Q_i = cumulative release in curies (Ci) of radionuclide into the accessible environment during the 10,000-year period following closure of the repository
L_i = the release limit in curies for radionuclide i given in Table 6-1
C = amount of TRU waste in curies emplaced in the repository.

The text of proposed 40 CFR Part 194 states that the total amount of TRU waste in curies (C in this equation) shall be "the expected curie activity 100 years after disposal of the waste...." Analyses performed by the DOE for this draft application do not follow this approach. Instead, the normalized release is calculated with respect to the inventory at the time of emplacement. If the approach in 40 CFR Part 194 is codified in the final rule, the DOE will perform analyses accordingly.

As indicated in Note 1(e) to the appendix A table (Table 6-1 in this document) the "other unit of waste" for TRU waste shall be "an amount of transuranic [TRU] wastes containing one million curies of alpha-emitting transuranic radionuclides with half-lives greater than 20 years."

The remainder of this chapter is organized as follows.

In Section 6.1 the DOE presents the overall system performance assessment methodology developed by the Waste Isolation Pilot Plant (WIPP) project to evaluate compliance with the Containment Requirements. The methodology has been developed by the DOE to undertake full system assessments, including the capability to address uncertainties associated with the occurrence of future human actions. Although the full methodology is described, aspects of it have not been exercised in preparing this draft application because analyses are restricted to undisturbed performance.

In Section 6.2 the DOE presents the scenario development methodology, including development of a comprehensive list of features, events, and processes (FEPs) that the DOE believes might affect disposal system performance, the screening methodology applied to that list, and the results to date of the screening process. FEPs relevant to both disturbed and undisturbed performance are discussed and screened. However, as noted above, analyses of disturbed performance are not included in this document.

In Section 6.3 the DOE presents the conceptual and computational models and parameter values used to estimate performance of the undisturbed disposal system for those FEPs that remain following the screening process. Section 6.3 also contains the results of the preliminary performance assessment calculations performed for this draft application.

6.1 Performance Assessment Methodology

The DOE's methodology for performance assessment uses relevant information about the disposal system and the waste to simulate performance over the regulatory time periods. This process is schematically represented by the flow diagram in Figure 6-1, which shows how information describing the disposal system is used by the DOE to develop scenarios, scenario probabilities, and the consequence models used to estimate performance. In this section the DOE discusses the methodology in a theoretical framework.

6.1.1 Conceptualization of Risk

The DOE uses a conceptualization for risk similar to that developed for risk assessments of nuclear power plants. This description provides a structure on which both the representation and calculation of risk can be based.

Kaplan and Garrick (1981) have presented this representation of risk as a set of ordered triples. The DOE uses their representation and defines risk to be a set R of the form

$$R = \{S_i, pS_i, \mathbf{cS}_i), {}_i = 1, ..., nS\} \tag{2}$$

where

S_i = a set of similar occurrences
pS_i = probability that an occurrence in set S_i will take place
$\mathbf{cS}_i$ = a vector of consequences associated with S_i
nS = number of sets selected for consideration

and the sets S_i have no occurrences in common (i.e., the S_i are disjoint sets). This representation formally decomposes risk into what can happen (the S_i), how likely things are to happen (the pS_i), and the consequences of what can happen (the $\mathbf{cS}_i$). The S_i are scenarios in the WIPP performance assessment, the pS_i are scenario probabilities, and the vector $\mathbf{cS}_i$ contains performance measures associated with scenario S_i.

As the DOE discusses in the following sections, risk results in R can be summarized with complementary cumulative distribution functions (CCDFs). These functions provide a display of the information contained in the probabilities pS_i and the consequences $\mathbf{cS}_i$. The consequence result cS in the vector $\mathbf{cS}$ is ordered so that $cS_i \leq cS_i$+1 for $i = 1, ..., nS$-1 and the CCDF for this consequence result is the function F defined by

$F(x)$ = probability that cS exceeds a specific consequence value x

$$= \sum_{j=i}^{nS} pS_j \tag{3}$$

where i is the smallest integer such that $\mathbf{cS}_i > x$.

As illustrated in Figure 6-2, F is a step function that represents the probabilities that consequence values on the abscissa will be exceeded. To avoid a broken appearance, CCDFs are usually plotted with vertical lines added at the discontinuities.

The steps in the CCDFs shown in Figure 6-2 result from the discretization of all possible occurrences into the sets $S_1,...,S_{nS}$. Unless the underlying processes are inherently disjoint, the use of more sets, S_i, will tend to reduce the size of these steps and, in the limit, will lead to a smooth curve.

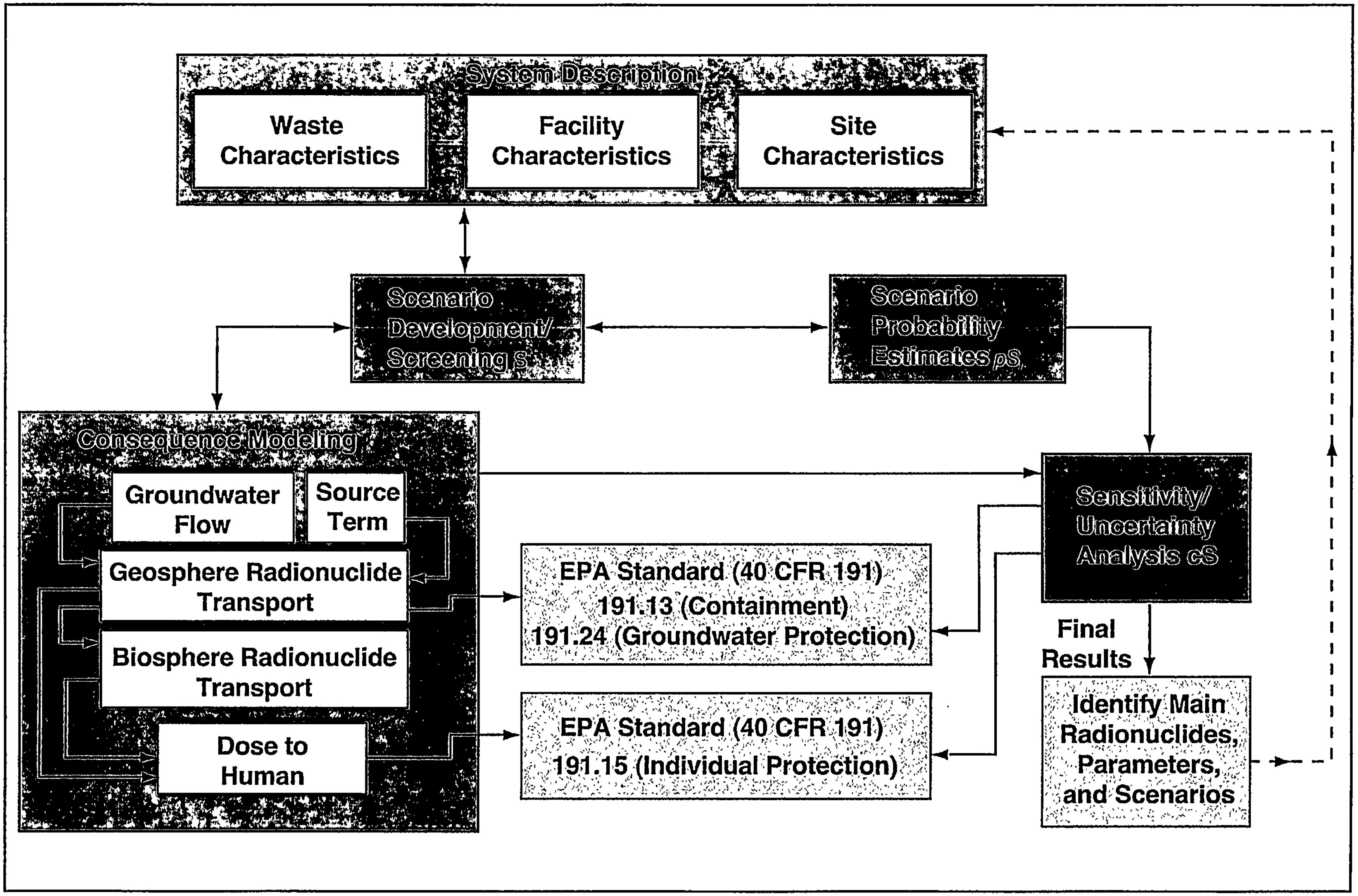

Figure 6-1. Methodology for Performance Assessment of TRU Repositories

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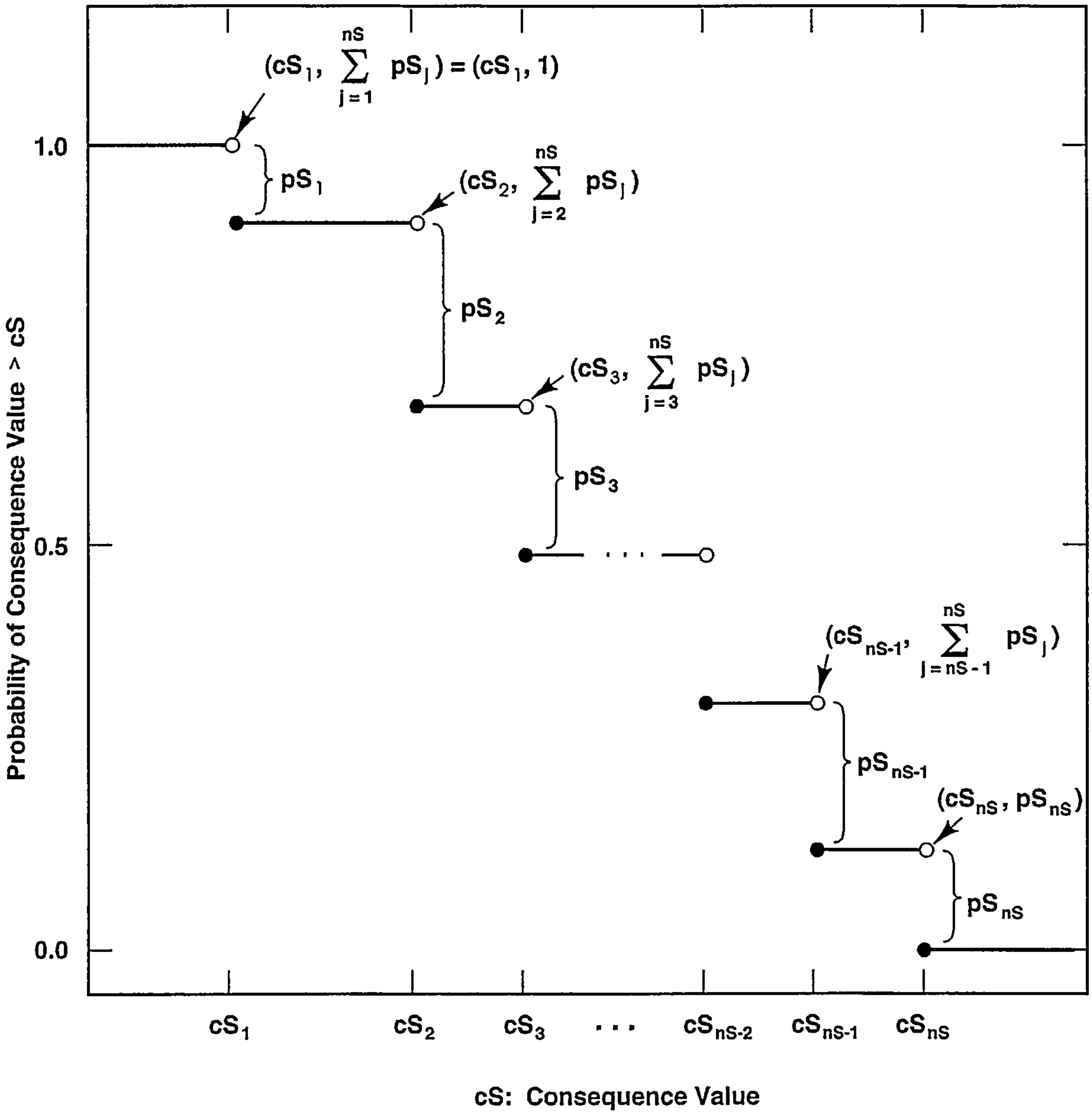

Figure 6-2. Estimated CCDF for Consequence Result cS. The open and solid circles at the discontinuities indicate the points included on (solid circles) and excluded from (open circles) the CCDF.

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6.1.1.1 Calculation of Risk

The calculation of risk and its associated uncertainty begins with the determination of the sets S_i, which are the scenarios to be analyzed. Once these sets are determined, their probabilities pS_i and associated consequences $\mathbf{cS}_i$ must be determined. In practice, development of the S_i is an iterative process that must take into account the procedures required to determine the probabilities pS_i and the consequences $\mathbf{cS}_i$. For the WIPP performance assessment, the overall process is organized so that pS_i and $\mathbf{cS}_i$ are calculated by various computational models, with the configuration of these models depending on the individual S_i.

Use of these models requires values for many imprecisely known variables that can be represented by a vector

$$\mathbf{x} = [x_1, x_2, \ldots, x_{nV}] \tag{4}$$

where each x_j is an imprecisely known input required in the analysis and nV is the total number of such inputs. If the analysis has been developed so that each x_j is a quantity for which the overall analysis requires a single value, the representation for risk in Equation 2 can be restated as a function of $\mathbf{x}$:

$$\mathrm{R}(\mathbf{x}) = \{[S_i(\mathbf{x}), pS_i(\mathbf{x}), \mathbf{cS}_i(\mathbf{x})], i=1, \ldots, nS(\mathbf{x})\} \tag{5}$$

As $\mathbf{x}$ changes, so will $\mathrm{R}(\mathbf{x})$ and all summary measures that can be derived from $\mathrm{R}(\mathbf{x})$. Thus, rather than a single CCDF for each consequence contained in the vector $\mathbf{cS}$ shown in Equation 2, a distribution of CCDFs results from the possible values that $\mathbf{x}$ can represent (Figure 6-3).

Distributions can be assigned to the individual variables x_j in $\mathbf{x}$ to characterize uncertainty in our knowledge of the modeling system. Factors that affect uncertainty in risk results can be subdivided into those that affect imprecisely known variables, those related to the selection of conceptual and computational models, and those related to scenario selection. Each of these three sources of uncertainty has the potential to affect all three of the elements of the triple introduced in Equation 2. Uncertainty about imprecisely known variables may result from incomplete data or measurement uncertainty. Uncertainty in the actual choice of models used in the assessment primarily affects pS_i and $\mathbf{cS}_i$, but because of the complexity of the analysis, also has the potential to affect the definition of the S_i. Factors related to scenario selection can be further subdivided into completeness, aggregation, and stochastic variation. Completeness refers to the extent that a performance assessment includes all possible occurrences for the system under consideration. In terms of the risk representation in Equation 2, completeness deals with whether or not all possible occurrences are included in the union of the sets S_i. Aggregation refers to the division of the possible occurrences into the sets S_i. Resolution is lost if the S_i are defined too coarsely (e.g., if nS is too small) or in some other inappropriate manner. Computational efficiency is affected if nS is too large. Stochastic variation is represented by the probabilities pS_i, which are functions of the many factors that affect the occurrence of the individual sets S_i.

Individual variables x_j may relate to each of these different types of uncertainty. For example, individual variables might relate to completeness uncertainty (e.g., the value for a cut-off used to drop low-probability occurrences from the analysis), aggregation uncertainty (e.g., a bound on the value for nS), model uncertainty (e.g., a 0–1 variable that indicates which of two alternative models should be used), variable uncertainty (e.g., a solubility limit or a retardation for a specific element), or stochastic uncertainty (e.g., a variable that helps define the probabilities for the individual S_i).

6.1.1.2 Characterization of Uncertainty in Risk

Characterization of the uncertainty in the results of a performance assessment requires characterization of the uncertainty in **x**, the vector of imprecisely known variables. This uncertainty can be described with a sequence of probability distributions

$$D_1, D_2, \ldots, D_{nV} \qquad (6)$$

where D_j is the distribution developed for the variable x_j, j = 1, 2, ..., nV, contained in **x**. The definition of these distributions may also be accompanied by the specification of correlations and various restrictions that further define the possible relations among the x_j. These distributions and other restrictions probabilistically characterize where the appropriate input to use in the performance assessment would most likely fall, given that the analysis is structured so that only one value can be used for each variable under consideration.

Once the distributions in Equation 6 have been developed, Monte Carlo techniques (Helton et al. 1992) can be used to determine the uncertainty in $\mathrm{R}(\mathbf{x})$ from the uncertainty in **x**. First, a sample

$$\mathbf{x}_k = [x_{k1}, x_{k2}, \ldots, x_k, nV], \; k = 1, \ldots, nK \qquad (7)$$

is generated according to the specified distributions and restrictions, where nK is the size of the sample. Performance assessment calculations are then performed for each sample element $\mathbf{x}_k$, which yields a sequence of risk results of the form

$$\mathrm{R}(\mathbf{x}_k) = \{[\mathrm{S}_i(\mathbf{x}_k), pS_i(\mathbf{x}_k), \mathbf{cS}_i(\mathbf{x}_k)\}, i = 1, \ldots, nS(\mathbf{x}_k)\} \qquad (8)$$

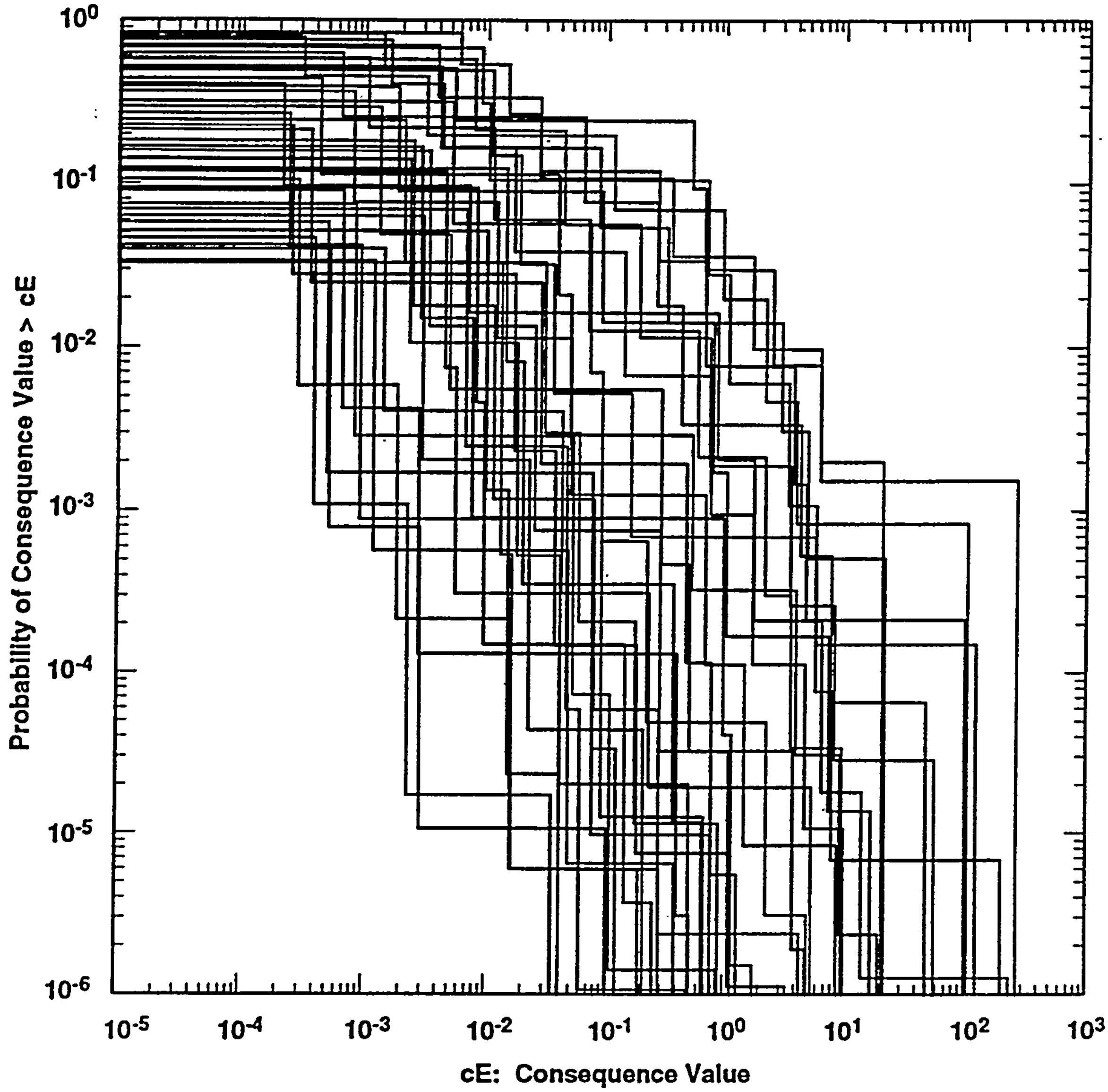

Figure 6-3. Example Summary Curves Derived from an Estimated Distribution of CCDFs.

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for $k = 1, ..., nK$. Each set $R(\mathbf{x}_k)$ is the result of one complete set of calculations performed with a set of inputs (i.e., $(\mathbf{x}_k)$ that the review process producing the distributions in Equation 6 concluded was possible. Further, associated with each risk result $R(\mathbf{x}_k)$ in Equation 8 is a probability or weight[1] that can be used in making probabilistic statements about the distribution of $R(\mathbf{x})$.

A single CCDF can be produced for each set $R(\mathbf{x}_k)$ of results shown in Equation 8, yielding a family of CCDFs of the form shown in Figure 6-3. The distribution of CCDFs in Figure 6-3 can be summarized with mean and percentile curves constructed in the following manner and illustrated in Figure 6-4. At each point on the abscissa in Figure 6-3, a vertical line is drawn through the nK exceedance probabilities from which the mean and various percentiles (e.g., 10%, 50%, 90%) can be determined. The curves in Figure 6-4 result from connecting the mean and percentile values obtained for individual consequence values. The percentile curves provide a probabilistic representation with respect to where the estimated exceedance probability associated with a given consequence value is located. For example, the probability is 0.8 that the exceedance probability for a particular normalized release is located between the 10 and 90 percentile curves, with this probability deriving from the distributions in Equation 6.

Consideration of a family of CCDFs allows a distinction between the uncertainty that controls the shape of a single CCDF and the uncertainty that results in a distribution of CCDFs. The stepwise shape of a single CCDF reflects the fact that a number of different occurrences have a real possibility of taking place. This type of uncertainty is referred to as stochastic variation. A family of CCDFs arises from the fact that fixed, but unknown, quantities are needed in the estimation of a CCDF. The distributions that characterize what the values for these fixed quantities might be lead to a distribution of CCDFs, with each single CCDF reflecting a specific sample element $(\mathbf{x}_k)$.

Both Kaplan and Garrick (1981) and the International Atomic Energy Agency (IAEA)(1989) distinguish between these two types of uncertainty. Specifically, Kaplan and Garrick distinguish between probabilities derived from frequencies and probabilities that characterize degrees of belief. Probabilities derived from frequencies correspond to the probabilities pS_i in Equation 2, while probabilities that characterize degrees of belief (i.e., subjective probabilities) correspond to the distributions indicated in Equation 6. The IAEA report distinguishes between what it calls Type-A uncertainty and Type-B uncertainty. The IAEA report defines Type-A uncertainty to be stochastic variation; as such, this uncertainty corresponds to the frequency-based probability of Kaplan and Garrick and the pS_i of Equation 2. Type-B uncertainty is defined to be uncertainty that is due to lack of knowledge

[1] In random or Latin hypercube sampling, this weight is the reciprocal of the same size (i.e., $1/nK$) and can be used in estimating means, cumulative distribution functions, and other statistical properties. This weight is often referred to as the probability for each observation (i.e., sample x_k). However, this usage is not technically correct. If continuous distributions are involved, the actual probability of each observation is zero.

about fixed quantities; thus, this uncertainty corresponds to the subjective probability of the Kaplan and Garrick and the distributions indicated in Equation 6. This distinction has also been made by other authors (for example, see Vesely and Rasmuson [1984], Paté-Cornell [1986], and Parry [1988] in the bibliography).

For a given conceptual model in the WIPP performance assessment, subjective uncertainty enters the analysis due to lack of knowledge about quantities such as solubility limits, retardation factors, and flow fields. In previous WIPP performance assessments, stochastic uncertainty entered the analysis through the assumption that future exploratory drilling will be random in time and space (i.e., follows a Poisson process). However, the rate constant in the definition of this Poisson process was assumed to be imprecisely known. Thus, subjective uncertainty can exist in a quantity used to characterize stochastic uncertainty. Because the analysis performed for this draft application considers undisturbed performance, only subjective uncertainty (Type-B) is addressed here.

6.1.1.3 Risk and the EPA Limits

The EPA expressly identifies the need to consider the impact of uncertainties in calculations performed to show compliance with the Containment Requirements. Specifically, appendix C of 40 CFR Part 191 states 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).

The representation for risk in Equation 2 provides a conceptual basis for the calculation of the CCDF for normalized releases specified in 40 CFR Part 191 Subpart B. Further, this representation provides a structure that can be used for both the incorporation of uncertainties and the representation of the effects of uncertainties.

A CCDF in the family of CCDFs that results from Equation 8 could be the appropriate choice for comparison against the EPA release limits, *if* $\mathbf{x}_k$ contained the correct variable values for use in determining the pS_i and $\mathbf{cS}_i$ *and if* the assumed conceptual models correctly characterize the disposal system. Increasing the sample size nK will, in general, produce a better approximation of the true distribution of CCDFs, but will not alter the fact that the distribution of CCDFs is conditional on the assumptions of the analysis.

If nK is large, displays of the complete family of CCDFs can be difficult to interpret. As discussed in the previous section, mean and percentile curves can be used to summarize the information contained in the family. Appendix C of 40 CFR Part 191 suggests that "the effects of the uncertainties considered can be incorporated into a single [CCDF]," but 40 CFR Part 191 does not contain specific guidance on which curve should be compared to the

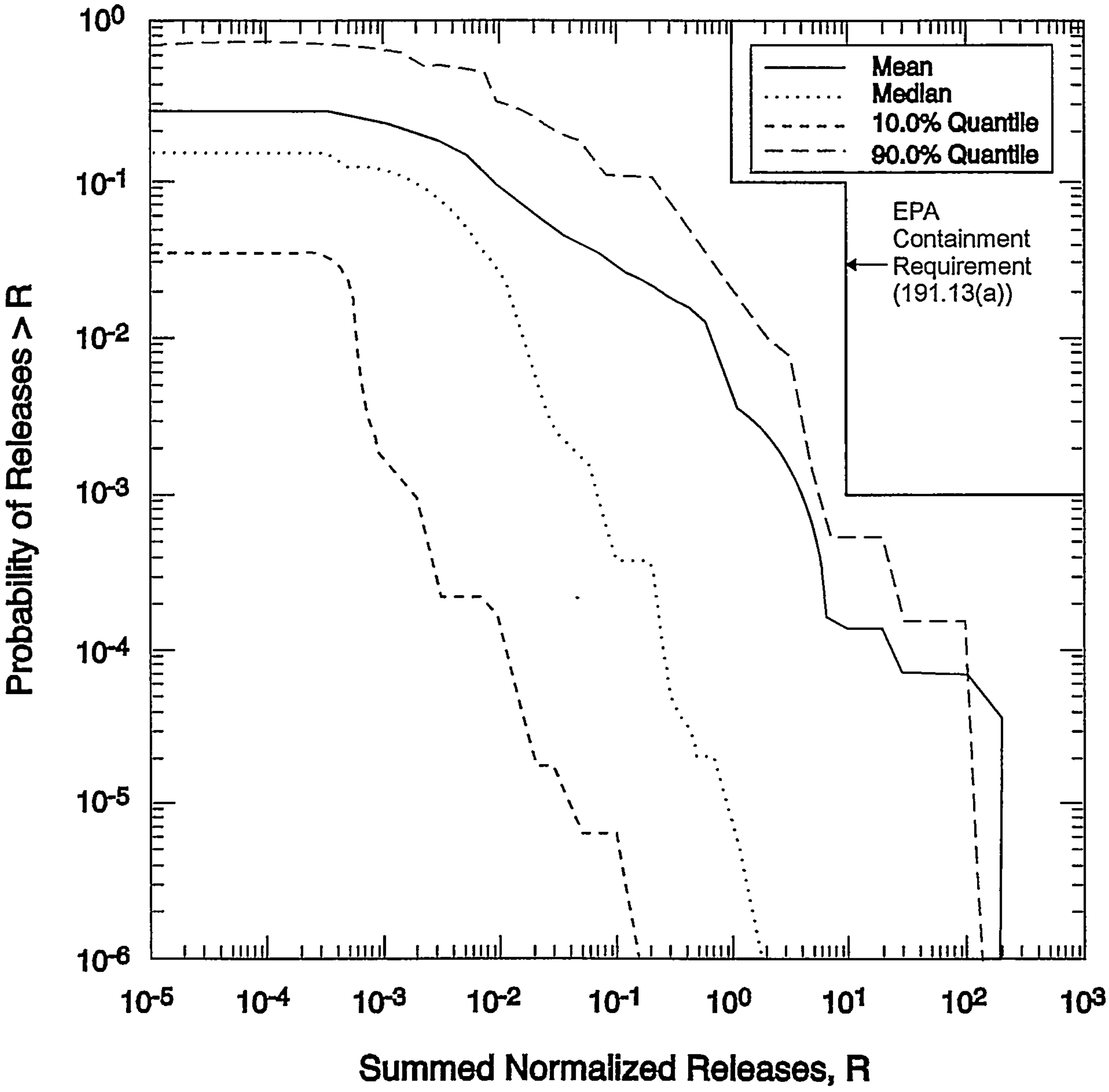

Figure 6-4. Example Summary Curves Derived from an Estimated Distribution of CCDFs. The curves in this figure were obtained by calculating the mean and the indicated percentiles for each consequence value on the abscissa in Figure 6-3. The 90th-percentile curve crosses the mean curve due to the highly skewed distributions for exceedance probability. This skewness also results in the mean curve being above the median curve.

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Containment Requirements. The mean curve is shown in Section 6.3 for preliminary comparison with the Containment Requirements. This approach is consistent with proposed 40 CFR Part 194. The complete distribution of curves, which is also requested in the proposed text of 40 CFR Part 194, is not shown.

Replicated Monte Carlo analyses can be used to characterize the uncertainty in a mean CCDF, as required in the proposed text of 40 CFR Part 194. Estimates of the uncertainty in the mean CCDF are not presented in the draft application.

6.1.2 Selection of Scenarios

The regulation 40 CFR Part 191 does not include the term "scenario" in its definition of performance assessment, referring instead only to events and processes that might affect the disposal system during the next 10,000 years. The various combinations of significant events and processes that could affect the behavior of the disposal system must be considered in a complete analysis. Combinations of events and processes are referred to as scenarios, S_i. The development of scenarios for this performance assessment is discussed in Section 6.2.

6.1.3 Determination of Scenario Probabilities

The second element of the ordered triples shown in Equation 2 is the scenario probability pS_i.

Because only undisturbed performance is addressed in this draft application, scenario probabilities do not enter into the analysis. For the purpose of constructing the CCDF shown in Section 6.3, the probability of undisturbed performance has been conditionally assigned a value of 1.0.

However, in past preliminary performance assessments, the probabilities pS_i have been based on the assumption that drilling into the repository follows a Poisson process (i.e., random in time and space) with a rate constant λ. This assumption is consistent with the requirements of proposed 40 CFR Part 194. Derivations of formulas for determining pS_i dependent on this assumption are general and include both the stationary (i.e., constant λ) and non-stationary (i.e., time-dependent λ) cases. Proposed 40 CFR Part 194 contains specifications for the determination of the appropriate value for the rate constant.

6.1.4 Calculation of Scenario Consequences

The third element of the ordered triples shown in Equation 2 is the scenario consequence, $\mathbf{cS}_i$. Estimation of $\mathbf{cS}_i$ requires a linked system of computational models.

The models used in the WIPP performance assessment, as in other complex analyses, exist at four different levels. First, conceptual models provide a framework in which information about the disposal system can be organized and linked to processes that can be simulated with quantitative models. An adequate conceptual model is essential for both the development of the scenarios S_i appearing in Equation 2. Alternative conceptual models that are equally consistent with the available information can exist. Consequences for each scenario must be estimated separately for each alternative conceptual model included in the analysis.

Second, mathematical models are developed to represent the processes at the site. The conceptual models provide the context within which these mathematical models must operate and define the processes they must characterize. The mathematical models are predictive in the sense that, given known properties of the system and possible perturbations to the system, they predict the response of the system. The following are among the processes represented by these mathematical models: fluid flow, mechanical deformation, radionuclide transport in groundwater, removal of waste through intruding boreholes, and human exposure to radionuclides released to the surface environment.

Third, numerical models are developed to approximate the mathematical models. Most mathematical models do not have closed-form solutions, and numerical procedures must be developed to provide approximations to the solutions of the mathematical models. In essence, these approximations provide "numerical models" that calculate results that approach the solutions of the original mathematical models. For example, Runge-Kutta procedures are often used to solve ordinary differential equations, and finite difference and finite element methods are used to solve partial differential equations. In practice, it is unusual for a mathematical model to have a solution that can be determined without the use of an intermediate numerical model.

Fourth, the complexity of the system requires the use of computer codes to implement the numerical models. The implementation of the numerical model in the computer code with specific initial and boundary conditions and parameter values is generally referred to as the computational model.

6.1.5 Monte Carlo Analysis Techniques

The DOE's performance assessment methodology uses Monte Carlo techniques for uncertainty and sensitivity analyses. Uncertainty analyses evaluate uncertainty in performance estimates that results from both the existence of alternative conceptual models and from the uncertainty about imprecisely known input variables. Sensitivity analyses determine the contribution of individual input variables to the uncertainty in model predictions. As used here, both these types of analyses provide information about the effects of subjective, or Type-B, uncertainty. The effects of stochastic, or Type-A, uncertainty are incorporated into the performance assessment through the scenario probabilities pS_i appearing in Equation 2.

Monte Carlo analyses involve five steps: (1) selection of the variables to be examined and the ranges and distributions for their possible values; (2) generation of the samples to be analyzed; (3) propagation of the samples through the analysis; (4) uncertainty analysis; and (5) sensitivity analysis. These steps are described briefly in the following sections.

6.1.5.1 Selection of Variables and Their Ranges and Distributions

Monte Carlo analyses use a probabilistic procedure for the selection of model input. Therefore, the first step in a Monte Carlo analysis is the selection of uncertain variables and of ranges and distributions that characterize the uncertainty in their possible values. These variables are typically input parameters to computer models, and the impact of the assigned ranges and distributions can be great: analysis results are controlled in large part by the choice of input. Results of uncertainty and sensitivity analyses, in particular, strongly reflect the characterization of uncertainty in the input data.

Information about the ranges and distributions of possible values is drawn from a variety of sources, including field data, laboratory data, literature, and in instances where significant uncertainty exists and site-specific information is unavailable or insufficient at the time of the analyses, subjective expert judgment. In general, data from these sources cannot be examined statistically and incorporated directly in performance assessment, because data are rarely gathered with the specific model application in mind. Spatial and temporal scales over which the data are valid often do not match those of the models' applications, and in many cases, real site-specific data are simply not available and/or are not reasonably obtainable. Data may be sparse or unavailable because measurements are unfeasible (e.g., drilling sufficient boreholes to determine the regional heterogeneity of transmissivity in overlying aquifers), because direct measurements would in themselves create risk (e.g., drilling of boreholes through the repository to determine the extent of an underlying brine reservoir), because measurements are impossible (e.g., future drilling parameters), or for other reasons.

A review process leads from the available data to the construction of the cumulative distribution functions (CDFs) used in the performance assessment. In part, because of the nature of the available data and the type of analysis, this review process is unavoidably subjective, and involves some judgment of the investigators and performance assessment analysts.

The ultimate outcome of the review process is a distribution function $F(x)$ of the form shown in Figure 6-5 for each independent variable of interest. For a particular variable x_j, the function F is defined such that

$$\text{prob}(x < x_j \leq x+\Delta x) = F(x+\Delta x) - F(x). \qquad (9)$$

That is, $F(x+\Delta x) - F(x)$ is equal to the probability that the appropriate value to use for x_j in the particular analysis under consideration falls between x and $(x+\Delta x)$.

6.1.5.2 Generation of the Sample

Various techniques are available for generating samples from the assigned distribution functions for the variables, including random sampling, stratified sampling, and Latin hypercube sampling. The DOE's performance assessment for WIPP uses stratified sampling and Latin hypercube sampling.

Stratified sampling is a modification of random sampling in which a systematic coverage of the full range of possible values is forced by subdividing the sample space into strata with assigned probabilities. Stratified sampling provides for the inclusion of low-probability (but possibly high-consequence) scenarios, and is used to incorporate stochastic (Type-A) uncertainty into the WIPP performance assessment.

Latin hypercube sampling, in which the full range of each variable is subdivided into intervals of equal probability and samples are drawn from each interval, is used to incorporate subjective (Type-B) uncertainty into the WIPP performance assessment. The restricted pairing techniques of Iman and Conover (1982) is used to prevent spurious correlations within the sample.

6.1.5.3 Propagation of the Sample through the Analysis

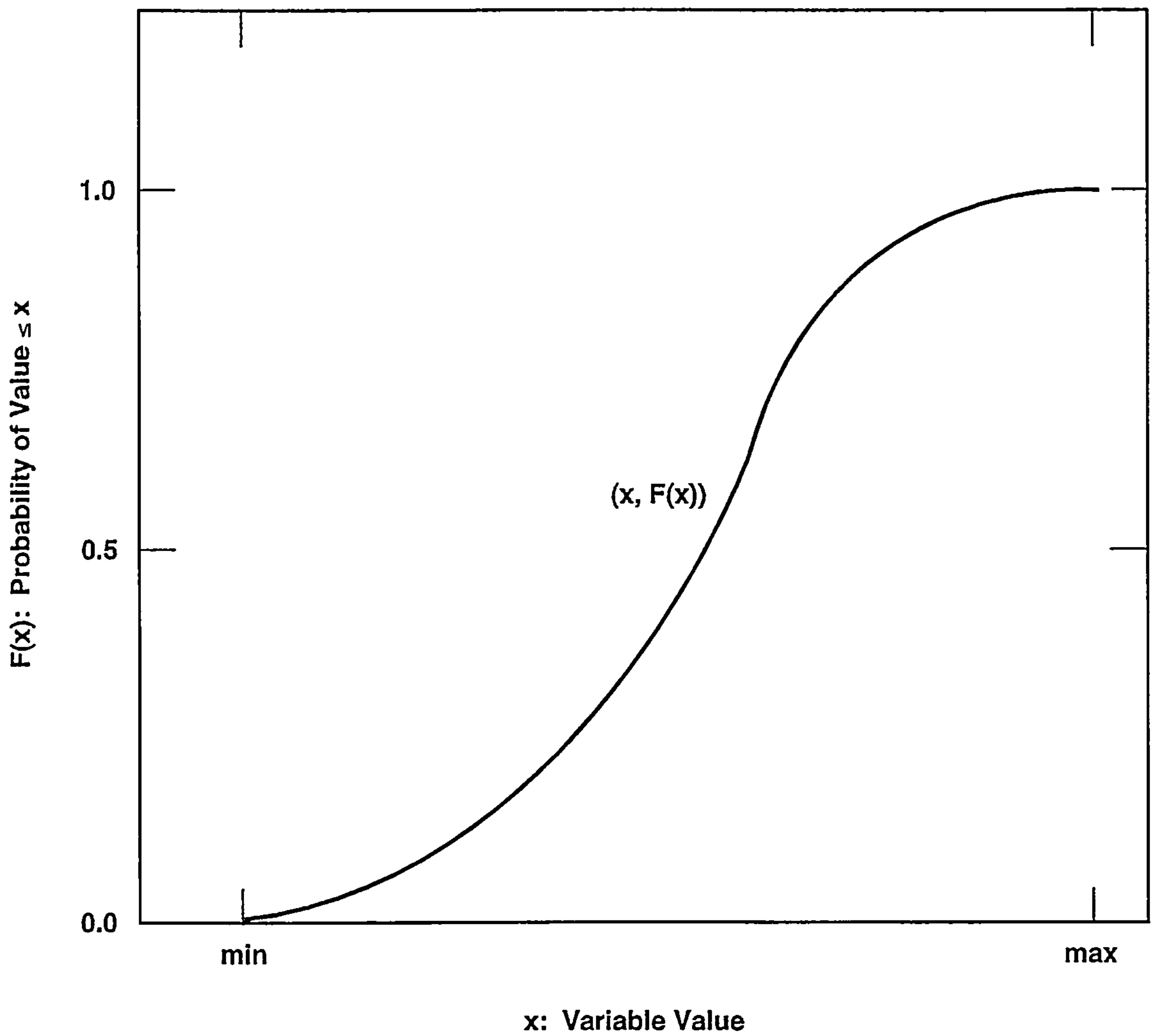
The next step is the propagation of the sample through the analysis. Each element of the sample is supplied to the model as input, and the corresponding model predictions are saved for use in later uncertainty and sensitivity studies. The Compliance Assessment Methodology Controller (CAMCON) has been developed to facilitate the complex calculations and storage of the input and output files from each program. This methodology incorporates databases, sampling procedures, model evaluations, data storage, uncertainty and sensitivity analysis procedures, and plotting capabilities into a unified structure.

6.1.5.4 Uncertainty Analysis

Once a sample has been generated and propagated through a model, uncertainty in the model predictions can be interpreted directly from the CCDF. Stochastic (Type-A) uncertainty is represented by the steps in an individual CCDF. Subjective (Type-B) uncertainty can be represented either with a family of CCDFs or with a summary diagram showing mean and quantile curves, as shown in Figures 6-3 and 6-4.

6.1.5.5 Sensitivity Analysis

The final step in a Monte Carlo study is sensitivity analysis, which provides information about the sensitivity of the modeling system to uncertainty in specific input parameters. Sensitivity analyses can identify those parameters for which reductions in uncertainty (i.e., narrowing of the range of values from which the sample used in the Monte Carlo analysis is drawn) have the greatest potential to increase confidence in the estimate of the disposal system's performance. However, because results of these analyses are inherently conditional on the models, data distributions, and techniques used to generate them, the analyses cannot provide insight about the correctness of the conceptual models and data distributions used. Qualitative judgment about the modeling system must be used in conjunction with sensitivity analyses to set priorities for performance assessment data acquisition and model development.



From Helton et al. 1991

Figure 6-5. Distribution Function for an Imprecisely Known Analysis Variable. For each value x on the abscissa, the corresponding value $F(x)$ on the ordinate is the probability that the appropriate value to use in the analysis is less than or equal to x.

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The DOE will perform a sensitivity analysis consistent with this approach to support preparation of a final application, as needed. The proposed 40 CFR Part 194 contains several requirements where sensitivity analyses will be useful.

6.2 Scenario Development and Selection

This section discusses the FEPs the DOE believes might affect the disposal system's performance, the screening methodology applied to that list, and the results to date of the screening process.

6.2.1 Identification and Screening of Features, Events, and Processes

The DOE uses four basic steps in the scenario development procedure as follows:

1. Identify and classify all the features, events, and processes (FEPs) potentially relevant to the performance of the disposal system

2. Eliminate FEPs according to well-defined screening criteria

3. Identify or form scenarios relevant to the performance of the disposal system

4. Specify scenarios for consequence analysis.

This procedure is similar to that proposed by Cranwell et al. (1990) and used in the 1991 and 1992 WIPP performance assessments. The list of FEPs has, however, been extended beyond Cranwell's potentially disruptive events to try to include all FEPs of potential relevance. It is important to be as comprehensive as possible during the initial stage of identifying FEPs, even if some of these FEPs may be eliminated in later stages of the screening process. This assures that interactions between FEPs are not overlooked and that a well-documented response to possible "what if" questions is available, as well as demonstrating comprehensiveness in a compliance application.

Catalogs of FEPs are being developed in many national radioactive waste disposal programs (see, for example, Guzowski and Newman [1993], Prij et al. [1993], Stenhouse et al. [1993] in the bibliography) as well as internationally (see, for example, OECD and NEA [1992], [1995] in the bibliography), with the aim of assembling relevant decisions and assumptions concerning the phenomena to be modeled. The catalogs can be used as an aid to organize and track assumptions during the assessment process, and between cycles of an iterative set of assessments to be conducted over several years.

In constructing a list of FEPs for the WIPP, the DOE drew on work done for other nuclear repository programs. As a starting point, a comprehensive list of potentially relevant FEPs was developed from a compilation of FEPs developed for the Swedish nuclear waste program. This Swedish list was based on a series of FEP lists developed for other disposal programs. A number of FEPs had been eliminated from the Swedish compilation because they were irrelevant to the particular disposal concept; these FEPs were reinstated, other FEPs specific to the WIPP were added, and several FEPs on the Swedish list were subdivided to facilitate screening. Some duplicate FEPs were eliminated for clarity of presentation, although many other duplicate FEPs were retained if a particular FEP could affect more than one part of the disposal system, or could interact with FEPs in more than one subcategory. The titles of all FEPs on the Swedish list were retained, although some were vague or poorly stated for the situation at the WIPP.

6.2.1.1 Criteria for Elimination of FEPs

The DOE's process of screening out of FEPs from the main system assessment modeling used explicit criteria to assure that the FEPs screened out are not relevant to the WIPP compliance determination. FEP screening criteria proposed by Cranwell et al. (1990) include physical reasonableness, probability of occurrence, and consequence of the occurrence. Additional screening criteria may be provided in regulatory guidance documents, or may be appropriate for a specific assessment scope or purpose. Four basic criteria are discussed below.

Regulation, or, more broadly, scope and purpose of the assessment. Specific screening criteria are supplied within several federal regulations. In particular, 40 CFR Part 191 provides a 10,000-year cut-off for quantitative assessment, and the DOE expects that specific guidance on the consideration of future human actions in the assessment will be provided in 40 CFR Part 194. The scope and purpose of an assessment may allow particular FEPs to be eliminated from consideration.

Potential consequences associated with the occurrence of the FEPs. The DOE uses this criterion in two ways. First, FEPs with similar consequences are grouped together for modeling purposes, provided their probabilities are combined appropriately. Grouping FEPs on consequence grounds has not been done formally within the WIPP project. Second, FEPs are eliminated on the basis of insignificant consequence. Consequence can refer to effects on the repository or site (in the early stages of screening FEPs) or to radiological consequence (when screening scenarios). This screening criterion must be used with caution: potentially important interactions with other FEPs need to be considered when eliminating FEPs on this basis.

Physical reasonableness of the FEPs being considered. The DOE uses this criterion to eliminate FEPs that are irrelevant to the disposal concept and site under consideration. For example, any FEP pertinent only to vitrified high-level waste (HLW) can be screened out for WIPP performance assessments, because the DOE does not intend to dispose of HLW at the WIPP.

Probability of occurrence of a FEP leading to significant release of radionuclides. Low-probability events can be excluded. In 40 CFR § 194.32(b), the EPA indicates that events and processes having a likelihood of occurrence of less than 10^{-4} over 10,000 years (equivalent to an annual probability of less than 10^{-8}) can be excluded. The physical reasonableness criterion can also be considered a subset of the probability criterion, in which the probability is assumed to be zero.

Criteria similar to those used for FEPs can be used for screening scenarios. However, care must be taken when screening individual scenarios on the basis of low probability. This is because a large number of scenarios, each with a very small likelihood of occurrence, could, when considered in combination, have a cumulative likelihood of occurrence sufficient to affect the estimation of repository performance. The DOE avoids this potential problem by placing a bound of 10^{-8} per year on the cumulative probability of all scenarios eliminated on the basis of low probability.

6.2.1.2 Screening of FEPs—Detailed Consideration and Classification

Because the WIPP FEP list was adapted from the Swedish list, the DOE could screen out many FEPs without further detailed consideration. For example, a FEP may be clearly irrelevant to the WIPP disposal system or potentially irrelevant to a post-closure performance assessment. A range of arguments was developed for further screening and classification of FEPs.

Undisturbed Performance FEPs

UP FEPs considered in the system modeling for undisturbed performance include those affecting both the nearfield and the farfield environments. The nearfield environment is defined here as the waste, containers, repository structures, shaft seal and panel closure systems, and the host rock formation. The farfield is the region beyond the engineered barriers and beyond the region of disturbed rock around the excavation. The UP FEPs exclude the effects of potentially disruptive future human actions. This allows the evaluation of releases for a determination of compliance with the individual dose criterion in 40 CFR § 191.15 and the groundwater protection requirements in 40 CFR § 191.24. The UP FEPs form part of the modeling system for evaluating compliance with 40 CFR § 191.13.

Disturbed-Case FEPs

DP FEPs pertaining to human intrusion, including the potential disruptive effects of drilling events that reach the level of the waste in the disposal system, are classified as DP. Consideration of these FEPs, which have an uncertain probability of occurrence, together with those classified as UP, is required to evaluate compliance with 40 CFR § 191.13. Disturbed-case calculations are not included in this draft application but will be in the final.

FEPs Requiring Additional Documentation

RB — FEPs retained for further consideration prior to documenting a screening decision are classified as RB. The DOE currently has calculational or experimental work underway within the project to increase understanding of the potential importance of some of these FEPs, but all are considered to be of low consequence. The basis for exclusion of these FEPs from the performance assessment modeling is not documented, and they are not included in the current system modeling. Documentation will be included in the final application.

FEPs Related to Design Changes

Two groups of FEPs have been identified that are related to modifications in the design of the disposal system. These FEPs are irrelevant to the performance assessment of the current disposal system design and can be screened out.

RD — FEPs classified as RD are preclosure events that represent significant deviations from the WIPP design specifications. Quality control procedures will ensure that the repository is constructed, operated, and decommissioned as described in the compliance documentation and within appropriate design tolerances.

RE — The classification RE is used for design modifications that may be made in the future. Engineering alternatives for the waste form, seal design, or the use and composition of backfill are examples of such design changes that would require a new or modified performance assessment.

Potentially Relevant FEPs Screened Out Based on Regulation, Consequence, or Probability

A structured approach to screening has established those FEPs that could be defensibly excluded. The criteria used are described earlier in this section. Each FEP was assessed against each criterion in the order presented below. Although many FEPs were excluded on the basis of more than one criterion, the first applicable screening criterion was used for classification.

SO-R — FEPs that can be screened out on the basis of regulatory guidance concerning the treatment of human actions are classified as SO-R. Defensible screening arguments for these FEPs have been developed and are discussed in the following sections.

SO-C — FEPs that may occur, but that can be screened out on the basis of insignificant consequence for all scenarios are classified as SO-C. Defensible screening arguments for these FEPs have been developed.

SO-P FEPs that are extremely unlikely to occur and can be screened out on the basis of low probability are classified as SO-P. Defensible screening arguments for these FEPs have been developed. In most cases, it is not possible to estimate a probability; in the absence of quantitative estimates, a strong qualitative argument is provided.

Screened Out on the Basis of Relevancy

NR Where evaluation of disposal system performance clearly does not rely on consideration of a particular FEP, the FEP was screened out, often without further discussion. The classification NR (not relevant) indicates that the FEP is not relevant to the WIPP site and the disposal concept outlined in the compliance application. FEPs with this classification may relate to HLW, long-lived waste containers, alternative host rock geologies, and biosphere evolution. In addition to FEPs that are not relevant to the design concept, there were a small number of FEPs on the Swedish list that were related directly to modeling decisions or whose title was incomprehensible. These FEPs were eliminated from consideration without further discussion.

6.2.2 Farfield Features, Events, and Processes

This subsection briefly discusses farfield FEPs concerned with radionuclide chemistry, radionuclide transport processes, gas effects and transport, and microbiological and biological activity. Table 6-2 shows the farfield FEPs and their screening classifications. The processes relevant to transport of radionuclides as dissolved species are classified as UP or RB, and modeling capability for these processes has been developed within the WIPP project. The DOE's detailed screening arguments are presented in Appendix SCR for FEPs that could change the present characteristics of the system and that might require changes in the boundary conditions or the parameter values for transport process modeling.

The biosphere FEPs discussed are limited to those relevant to the amount of infiltration and recharge that could occur to the Rustler Formation (hereafter referred to as the Rustler) and overlying formations, such as erosion, surface run-off, and land use changes. FEPs relating specifically and only to transport of contaminants within the biosphere are not discussed here. The biosphere may be important for evaluating compliance with the EPA's individual dose criterion in 40 CFR § 191.15. Compliance with this criterion is discussed in Chapter 8.

The DOE has screened out several natural FEPs on the basis of a low probability of occurrence at the WIPP site. In general, these are events for which the DOE has determined that there is no geological evidence within the Delaware Basin for at least 0.5 million years. For the purposes of this analysis, the probabilities of these events are assumed to be zero. Quantitative, non-zero probabilities for such events, based on numbers of occurrences, cannot be ascribed without considering regions much larger than the Delaware Basin, thus neglecting established geological understanding of the processes and events that occur within particular geographical provinces. There are also examples, notably deep dissolution, where the particular geological setting of the WIPP disposal system (in contrast to other parts of the Delaware Basin) is used to establish a low-probability screening argument. The overall geological setting of the Delaware Basin also is the basis for classifying a number of events and processes as low consequence; the history and setting of the region are such that the DOE believes the processes are likely to continue throughout the next 10,000 years at rates similar to those deduced for the past 0.5 million years. Processes that have had little effect on the characteristics of the region in the past are expected to be of low consequence in the future.

Table 6-2. Farfield FEPs and Their Screening Classifications

FEPs	Screening Classification	FEPs	Screening Classification
Meteorite impact	SO-P	Major incision	SO-P
Regional uplift and subsidence	SO-P	Changes in topography	SO-C
Metamorphic activity (e.g., orogenic, isostatic)	SO-P	Lake infilling	SO-C
Volcanism	SO-P	Surface flow characteristics: sediment transport	SO-C
Magmatic activity	SO-C	Surface flow characteristics: meander migration or other	SO-C
Movements at faults	SO-P	Surface flow characteristics: lake formation and sedimentation	SO-C
Fault activation	SO-P	Surface-water bodies: water flow	SO-C
Formation of new faults	SO-P	Surface-water bodies: suspended sediments	SO-C
Faulting and fracturing: change of properties (natural)	SO-P	Surface-water bodies: bottom sediments	SO-C
Formation of interconnected fracture systems	UP	Surface-water bodies: effects on vegetation	SO-C
Earthquakes, fluvial response	SO-C	Surface-water bodies: effects of fluvial system development	SO-C
Natural seismicity	SO-C	Surface-water mixing	SO-C
Externally induced seismicity	SO-C	Freshwater sediment transport and deposition	SO-C
Differential elastic response	SO-C	Rivercourse meander	SO-C
Non-elastic response	RB	Flooding	SO-C
Salt deformation and diapirism	SO-P	Soil and surface-water chemistry (pH, Eh)	SO-C
Formation of dissolution cavities	SO-P	Fluid interactions: dissolution, precipitation	SO-C
Digenesis	SO-C	Weathering, mineralization	SO-C
Fracture mineralization	SO-C	Altered soil or surface-water chemistry (pH, Eh)	SO-C
Dissolution of fracture fillings, precipitation	SO-C	Weathering	SO-C
Natural rock property changes (porosity, permeability, fractures, pore blocking)	RB	Alkali flats	SO-C
Salinity: implications of evaporite deposits and minerals	RB	Capillary rise in soil	SO-C
Changes in sorptive surfaces	RB	Soil properties (type, depth, pore-water pH, moisture, sorption)	SO-C
Changes in the earth's magnetic field	NR	Soil leaching	SO-C
Climate change	UP	Ionic exchange in soil	SO-C
Anthropogenic climate change drought (greenhouse effect)	RB	Pedogenesis	SO-C
Greenhouse-induced effects (e.g., sea level change, precipitation, temperature)	RB	Variation in groundwater recharge	UP
Greenhouse-induced storm surges	RB	Precipitation, temperature and soil water balance	SO-C
Ozone layer (failure)	SO-C	Surface hydrological change	SO-C
Acid rain	SO-C	Near-surface runoff processes: overland flow, interflow, return flow, macropore flow	SO-C
Glaciation	SO-P	Near-surface runoff processes: variable source area response	SO-C
Erosion: glacial	SO-P	Surface flow characteristics: stream and river flow	SO-C
Extreme erosion and denudation: glacial-induced (e.g., coastal and stream erosion)	SO-P	River flow and lake level changes	SO-C
Glacial and interglacial cycling effects (including sea level changes)	SO-P	Groundwater discharge (to surface-water)	SO-P
Permafrost	SO-P	Groundwater discharge (springs)	SO-P
Accumulation of gases under permafrost	SO-P		
Snow melt	SO-P		
Erosion: wind	SO-C		

Table 6-2. Farfield FEPs and Their Screening Classifications (Continued)

FEPs	Screening Classification	FEPs	Screening Classification
Stream erosion	SO-C	Land use changes	SO-C
Mass wasting	SO-C	Terrestrial ecological development: natural and agricultural systems	SO-C
Solifluction	SO-C	Terrestrial ecological development: effects of succession	SO-C
Sedimentation	SO-C	Sorption (linear)	UP
Land slide	SO-C	Sorption (non-linear, irreversible)	RB
Rock properties (porosity, permeability, discharge zones, fractures)	UP	Speciation	RB
Dewatering	RB	Solubility effects (pH and Eh, ionic strength, complexing agents, colloids)	RB
Salinity effects on flow	RB	Sorption effects (pH and Eh, ionic strength, complexing agents colloids)	UP
Saturated groundwater flow	UP	Dilution (mass, isotopic, species)	UP
Groundwater recharge	UP	Groundwater flow advection and dispersion (saturated conditions)	UP
Saline groundwater intrusion	RB	Diffusion (bulk, matrix, surface)	UP
Fresh groundwater intrusion	NR	Unsaturated transport	SO-C
Groundwater conditions (saturated and unsaturated)	UP	Gas-induced groundwater transport	SO-C
Changes in geometry of the flow system	SO-P	Gas transport into and through the farfield (gas phase and in solution)	SO-C
Changes in driving forces of the flow system	UP	Multiphase flow and gas-driven flow	UP
Groundwater flow: fracture	UP	Effects of natural gases	SO-C
Groundwater flow: effects of solution channels (preferential pathways)	RB	Transport of active gases	SO-C
Groundwater composition changes (pH, Eh, chemical composition)	RB	Gas-mediated transport	SO-C
Farfield hydrochemistry (acids, oxidants, nitrates)	RB	Microbial activity	UP
Effects at saline-freshwater interface	RB	Biogeochemical changes	RB
Chemical gradients (electrochemical effects and osmosis)	RB	Transport of radionuclides bound to microbes	UP
Non-radioactive solute plume in geosphere (effect on redox, effect on pH, sorption)	RB	Geothermal gradient effects	SO-C
Colloids: formation and effects (including inorganic and organic colloid transport)	UP	Variations in groundwater temperature	SO-C
Complexation by organics (including humic and fulvic acids)	RB	Thermal effects: fluid pressure, density, viscosity changes	SO-C
Precipitation, dissolution, recrystallization, reconcentration	RB	Thermal effects: fluid migration	SO-C
		Thermal differential elastic response	SO-C
		Thermal non-elastic response	SO-C
		Soret effect	SO-C

6.2.3 Waste- and Repository-Induced FEPs

The waste- and repository-induced FEPs specifically relate to the waste material, waste containers, shaft, and drift seals, the Salado rock surrounding the repository, and the investigation boreholes. The combination of these subsystems is also referred to as the "nearfield." These FEPs are discussed in more detail in the relevant subsections of Section 6.3.

The seals in drifts, shafts, and boreholes form the engineered barrier system designed to prevent groundwater from entering the repository and the migration of contaminants through the repository and through shafts and boreholes. The seal system assumed in this document is described in Chapter 3. At present, the WIPP repository's engineered barrier system does not assume that the waste form and waste containers play a role in retarding transport of contaminants in undisturbed conditions after closure of the repository. The Salado Formation (hereafter referred to as the Salado) forms a natural barrier to contaminant migration from the repository. The natural system, in combination with the current set of engineered barriers, is expected to assure that the disposal system meets all applicable environmental standards. However, if required to meet the standards, the DOE could make modifications to the waste acceptance criteria, waste form, containers, seals, or design of the waste emplacement area.

The completed excavation of the repository and the consequent changes in the stress field in the rock surrounding the excavated opening will result in the creation of a disturbed rock zone (DRZ) of fractures around the repository. As a result, the DRZ will exhibit different mechanical and hydrological properties to the intact rock beyond the DRZ.

Following closure of the repository, other processes will influence rock characteristics, alter fluid flow paths, and change the fluid flow distribution in the vicinity of the repository. Among the most significant of these processes are the following:

- Salt creep tends to heal fractures and reduce the permeability of the crushed salt in long-term seals to near that of the host rock salt

- Gas generation within the waste-filled room and drifts may result in pressures sufficient to both maintain or develop fractures and to change the fluid flow direction around the repository

- Non-consolidation or degradation of seals in shafts, drifts, panels, and investigation boreholes may result in pathways for flow to or from waste-filled rooms.

Table 6-3 shows the waste- and repository-induced FEPs and their classifications. The DOE's detailed screening discussions for FEPs that could change the present characteristics of the system and that might require changes in the boundary conditions or the parameter values for transport process modeling are contained in Appendix SCR.

Table 6-3. Waste- and Repository-Induced FEPs and Their Screening Classifications

FEPs	Screening Classification	FEPs	Screening Classification
Rock properties: Salado Formation	UP	Excavation-induced stress and fracturing in host rock	UP
Disposal geometry	UP	Disturbed zone (hydromechanical) effects	RB
Inventory: disposal system	UP	Repository-induced seismicity	SO-C
Backfill characteristics	RE	Creeping of rock mass	UP
Seal characteristics	UP	Roof falls (effects on nearfield)	UP
External stress: waste, seals	UP	Gas effects: pressurization (waste, host rock	UP
Long-term physical stability: seals	UP	Gas effects (pressurization): (seals)	UP
Sealing of cracks: concrete (grouting)	UP	Gas effects (disruption): seals, host rock	RB
Heterogeneity of waste forms	UP	Thermally induced stress and fracturing in host rock	RB
Radionuclide decay and ingrowth	UP		
Inventory: container	UP		
Container failure (early)	UP		

Table 6-3. Waste- and Repository-Induced FEPs and Their Screening Classifications (Continued)

FEPs	Screening Classification
Corrosion: container	UP
Mechanical container damage (failure)	UP
Design modifications: geometry	RE
Design modifications: backfill (e.g., buffer additives, bentonite)	RE
Design modifications: seals	RE
Design modifications: DRZ (e.g., grouting)	RE
Design modifications: waste (e.g., buffer additives, grouting)	RE
Design modifications: canister	RE
Hydrogen by metal corrosion: container steel	UP
Hydrogen by metal corrosion: waste	UP
Microbial degradation of cellulose and other organic wastes	UP
Methane and carbon dioxide production: aerobic degradation	UP
Methane and carbon dioxide production: anaerobic degradation	UP
Radiolysis	RB
He production	RB
Gas generation from concrete: short-term seals	RB
Gas from microbial degradation: effects of temperature	RB
Gas from microbial degradation: effects of lithostatic pressure	RB
Gas from microbial degradation: effects of biofilms	RB
Radioactive decay: heat generation	RB
Nuclear criticality (preclosure)	SO-R
Nuclear criticality: heat generation	RB
Rock property changes	UP
Formation of cracks	UP
Non-elastic response	UP
Convection: seals, host rock	RB
Repository thermally induced groundwater transport	RB
Source terms	UP
Release of radionuclides from the failed container	UP
Leaching: waste	UP
Speciation: waste	UP
Dissolution: waste	UP
Solubility: waste	UP
Redox front: seals, host rock	UP
Solubility effects (pH and Eh, ionic strength, complexing agents, colloids), seals, host rock	UP
Electrical effects of metal corrosion	RB
Sorption effects (pH and Eh, ionic strength, complexing agents, colloids), seals, host rock	NR
Speciation: seals, host rock	NR
Sorption: seals, host rock	NR
Diffusion: seals, host rock	NR
Unsaturated transport: seals, host rock	NR
Transport of radionuclides bound to microbes: seals, host rock	NR
Colloid transport	UP
Capillary rise	UP
Thermo-hydromechanical effects	RB
Gas effects (explosions): seals, host rock	SO-C
Nuclear criticality (explosions): (waste, container, seals, host rock)	SO-P
Shaft seal failure and degradation	RB
Preferential pathways in seals	RB
Mechanical effects: local fractures and cracks (preferential pathways)	RB
Seals: resaturation and desaturation	UP
Cracking: concrete	RB
Uneven swelling of bentonite	RB
Differing thermal expansion (seal-host rock)	RB
Thermal effects on the seal material (concrete hydration)	RB
Hydrogen: effects of microbial growth on concrete	RB
Degradation of bentonite by chemical reactions	RB
Coagulation of bentonite	RB
Radiation effects on bentonite	RB
Erosion of seal	RB
Alkali-aggregate reaction	RB
Investigation borehole seal failure and degradation	RB
Groundwater flow due to gas production: host rock	UP
Groundwater flow due to gas production: seals	UP
Repository-induced changes in groundwater flow direction	UP
Groundwater and gas flow: host rock	UP
Groundwater and gas flow: seals	UP
Chemical kinetics	RB
Chemical changes due to metal corrosion: waste, container	RB
Chemical changes due to gas production	RB
Speciation of corrosion products	RB
Soret effect	RB
Thermally induced chemical changes (water chemistry)	RB
Rinse	UP
Precipitation	RB
Reconcentration	RB
Dissolution: seals, host rock	RB
Advection and dispersion: radionuclides (seals, host rock)	UP
Recrystallization	RB
Electrochemical gradients	RB
Galvanic coupling	RB
Waste incompatibility	SO-R
Advection and dispersion: hazardous constituents (seals, host rock)	RB
Gas transport in the nearfield as gas phase and in solution: seals, host rock	NR
Unsaturated transport: seals, host rock	NR
Subsidence: farfield	RB
Active methane, carbon dioxide, radon, tritiated hydrogen, and other gases	RB

6.2.4 Human-Initiated Events and Processes

In this chapter the DOE addresses compliance with the Containment Requirements in 40 CFR § 191.13, which specify consideration of "all significant events and processes," including human-initiated events and processes. The preliminary performance assessment described in this chapter, however, considers only undisturbed performance and does not incorporate human-initiated events and processes. The DOE discusses the events and processes that would need to be included in an analysis of disturbed performance.

Both 40 CFR Part 191 and the proposed 40 CFR Part 194 indicate that the consideration of human-initiated events and processes should focus on drilling. The occurrence of drilling within the controlled area is predicated on the assumption that passive institutional control of the site fails at some time in the future, and that knowledge of the location of the repository is lost.

Drilling activities associated with resource exploration could inadvertently remove waste and provide direct connections for fluid flow from the repository to the surface or to any intersected hydraulically conductive zones. Boreholes with target depths below the repository horizon could intersect both the repository and, potentially, a pressurized brine pocket beneath the Salado, modifying fluid flow and radionuclide transport out of the repository horizon.

Likelihood of drilling. Resource exploration and exploitation are the most common reasons for drilling in the Delaware Basin, and are the most likely incentives for drilling in the future. Natural resources have been evaluated at the WIPP location for their occurrence in economic quantities. Powers et al. (1978a, b) investigated the potential for exploitation of caliche, gypsum, salt, uranium, sulfur, lithium, potash, and hydrocarbons. The extraction of caliche, gypsum, and salt were not considered to be economically viable at the WIPP because of the existence of more easily accessible deposits elsewhere in the region and their widespread occurrence. Uranium was not found to be present in economic quantities, and no sulfur deposits were identified in the northern Delaware Basin. There is no evidence that brine of an appropriate composition and quantity exists near the WIPP for lithium to be a potential resource. However, potash, oil, and gas reserves are currently exploited in the vicinity of the controlled area, and represent potential targets for exploratory drilling.

Other activities that potentially involve drilling include enhanced oil and gas production, oil and gas storage, fluid disposal, and archaeological investigations. Secondary and tertiary hydrocarbon production techniques can involve the drilling of additional wells for the injection of fluid to enhance recovery. As indicated by the New Mexico Bureau of Mines and Mineral Resources (NMBMMR) in their 1995 report, secondary production (waterflooding) is employed in the Delaware Basin, and may be employed in the near future in the vicinity of the WIPP site.

Oil and gas production byproducts are disposed of underground in the WIPP region. Also, strata elsewhere within the Delaware Basin are used for hydrocarbon storage (see, for example, Burton et al. [1993] in the bibliography). Currently, existing boreholes are used to inject fluid for disposal or storage. Assuming the continuation of current practice, however, the rate of drilling associated with these activities is likely to be insignificant by comparison with drilling for resource exploration. Underground storage or disposal of fluids is excluded on the grounds of low probability of occurrence in the immediate vicinity of the WIPP.

Archaeological investigations in the WIPP area have involved only minor surface disturbances and have not involved drilling. However, markers emplaced at the WIPP site to deter intrusion into the repository might provide an incentive for archaeological investigation, should knowledge of the markers' purpose be lost. Repository intrusions resulting from such investigations are excluded from performance assessments on regulatory grounds.

Potential consequences of drilling. The severity of the impact of drilling on system performance depends on the depth and location of the borehole. If the target drilling depth is below the repository horizon, and the borehole intersects a waste panel, particulate waste would be transported to the ground surface. This includes material intersected by the drill bit ("cuttings") and eroded from the borehole wall by circulating drilling fluid ("cavings"), and material that enters the borehole as the repository depressurizes ("spallings"). Future boreholes may provide direct connections for fluid flow between the repository horizon and the ground surface. Boreholes with degraded casing and plugs may also provide connection to other hydraulically conductive zones. Fluid flow in the borehole might be influenced by the intersection of pressurized fluid in the Castile Formation (hereafter referred to as the Castile) or a deeper formation.

6.3 Performance Assessment Modeling and Results

This section discusses the conceptual and computational models and parameter values used to estimate performance of the undisturbed disposal system for those FEPs that remain following the screening process.

6.3.1 Purpose and Scope

Although the various models, data, and parameters used by the DOE to calculate the CCDF are thought to be reasonable for use in a performance assessment of the disposal system, full justification of some aspects of the various models, data, and parameters used is not available at this time. Justification is dependent on the outcomes of certain experiments that are planned to be complete in time to support submittal of the final application. The CCDF presented here is not in final form because sufficient confidence in the conceptual models, process models, numerical codes, data, and model parameters used has not been established, quality assurance has not been completed, and the number of realizations executed was restricted. Furthermore, the CCDF presented here addresses undisturbed performance only. It is a conditional CCDF that does not include a probabilistic analysis of potentially disruptive future events including human-initiated events and processes, as required in 40 CFR Part 191 and the proposed 40 CFR Part 194, although that type of analysis will be included in the final application.

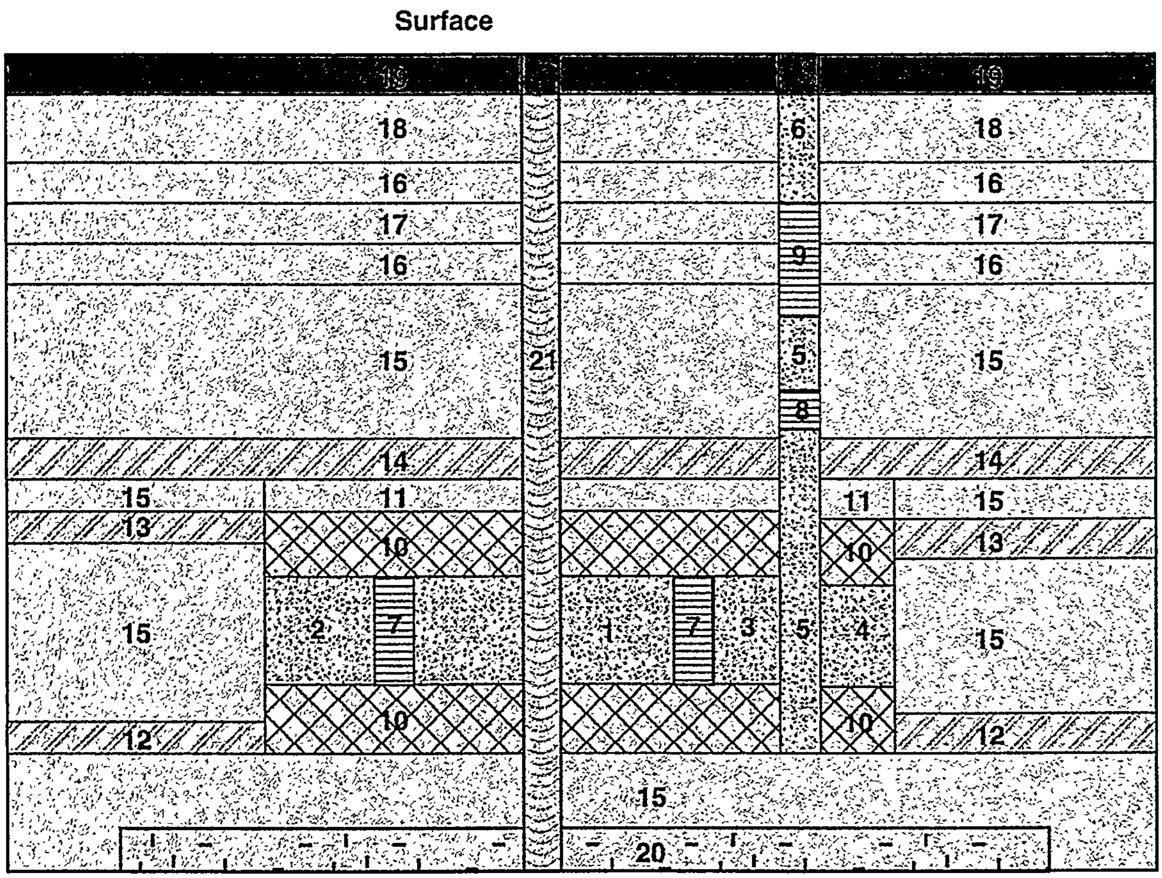
A single conceptual model for the disposal system was used to calculate the CCDF presented at the end of this section. This single model, however, can be conveniently described in terms of various submodels with each describing a part of the overall system. This section is organized to provide, for each submodel defined, an integrated, summary description of the conceptual model, process model, numerical model, experimental data, and model parameters used. The geometry used in the performance assessment model, BRAGFLO, will be described first, as this will provide a convenient framework for further discussion and for relating the various submodels to each other and to the whole.

For clarity, the following terms are defined. As discussed in Section 6.1, a *conceptual model* is the aggregate of processes, properties, and geometries considered for a particular part of a performance assessment, based on insight into system behavior obtained by experiment or experience. A *process model* is a verbal or mathematical description of how the conceptual model will be incorporated in to a performance assessment, and a *numerical model* is the actual algorithm (computer code, usually) used to numerically evaluate the process model. *Data* are descriptors of the physical system being considered, normally obtained by experiment or observation. *Parameters* are values necessary in process or numerical models. The distinction between data and parameters can be subtle, due to formulations of some process and numerical models that use parameters that are directly analogous to data that can be obtained by experiments. Parameters are distinct from data, however, for three reasons. First, data may be evaluated, statistically or otherwise, to generate parameters for a model so that uncertainty in data is accounted for. Second, some parameters have no relation to the physical system whatsoever, such as the parameters in a numerical model specified to determine when an iterative solution scheme has converged. Third, many model parameters are applied at a scale different from that which can be directly observed or measured.

6.3.2 Model Geometry

The fundamental geometry of the performance assessment model used for calculating the CCDF is shown in Figure 6-6. This geometry is a process model which represents the natural system, for the purposes of most fluid flow calculations, as a two-dimensional, vertical approximation of the three-dimensional physical system. Effects of flow in the third (out-of-plane) dimension are approximated with a two-dimensional element configuration that simulates radially convergent or divergent flow, centered on the repository, in intact rocks laterally away from the repository. A separate model of horizontal, confined flow is used to evaluate flow in the Culebra Dolomite Member (hereafter referred to as the Culebra) (Region 17) and is linked to the cross-section in Figure 6-6 via the shaft (Region 5 and Region 6).

In Figure 6-6, various regions are indicated which are distinguished from each other by the conceptual models, process and numerical models, or model parameters applied. The repository is represented by an equivalent panel (1), remaining panels (2), non-waste excavated areas (3 and 4), and panel closures (7). The repository is connected to the surface by a shaft (5 and 6), which contains seals of various types (8 and 9). The Salado is composed of halite-rich rocks (15), anhydrite-rich interbeds (12, 13, and 14), and areas where rock has



1 1 Equivalent Panel
2 Remaining Panels
3 Operations Region
4 Experimental Region
5 Lower Shaft
6 Upper Shaft
7 Panel Closures
8 Lower Shaft Seal
9 Upper Shaft Seal
10, 11 } Disturbed Rock Zone
12 MB 139
13 Anhydrite Layers A & B
14 MB 138
15 Intact Halite
16 Rustler (other than Culebra)
17 Culebra
18 Dewey Lake
19 Santa Rosa
20 Castile Brine Pocket
21 Borehole

Figure 6-6. Schematic BRAGFLO Model Geometry, Vertical Section

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been damaged due to excavation effects (10 and 11). The Rustler is represented by the Culebra (17) and other rocks (16). Region 16 is further subdivided in the calculations into the Magenta Dolomite Member (hereafter referred to as the Magenta) above the Culebra and the unnamed lower member below the Culebra. The Rustler is overlain by the Dewey Lake Redbeds (18) and the supra-Dewey Lake formations (19) (hereafter referred to as the Dewey Lake and the supra-Dewey Lake respectively). For the undisturbed case described here, the borehole (21) and the Castile Formation (hereafter referred to as the Castile) (20) regions are inactive. The conceptual models, data, process models, numerical models, and model parameters applied to these regions will be described in later sections.

6.3.3 The Repository

The repository is represented by regions 1, 2, 3, 4, and 7 in Figure 6-6. A number of submodels have been defined within these areas and will be described in this section. The submodels which have been defined for the repository are Disposal Rooms and Creep Closure (6.3.3.1), Repository Fluid Flow (6.3.3.2), Gas Generation (6.3.3.3), Actinide Source Term (6.3.3.4), and Colloid Source Term (6.3.3.5).

6.3.3.1 Disposal Rooms and Creep Closure

As discussed in Chapter 3, the waste disposal region, in which TRU waste will be permanently emplaced, consists of eight formal panels with seven disposal rooms each, and the access drifts that will be filled with waste and sealed as disposal operations retreat from adjacent panels that have been filled and sealed. North of the disposal region, the operations region and experimental regions will be left as is after waste emplacements ceases and the repository is closed and isolated by shaft seals. For computational purposes, the presence of 6804 drums within each disposal room is assumed. Waste properties in the process and numerical models are averaged values.

Disposal room closure begins immediately after excavation because loading of the salt is non-uniform around the repository due to the excavation. If the rooms were empty, closure would proceed to the point where most of the void volume created by the excavation would be eliminated as the surrounding formation seeks to return to its undisturbed, uniform stress state. This will occur in the operations region and experimental region. In the absence of substantial gas or brine the waste will continue to consolidate until load balance is achieved between waste and surrounding rock. The amount of consolidation and its duration is governed by the properties of the waste, the surrounding rock, and the dimensions and location of the room. Compaction of the waste is assumed to depend only on the applied load at a given time.

Liquid or gas in the repository can affect the closure process. Because the waste will not contain significant quantities of liquid upon emplacement, with respect to closure, liquid which might affect closure will be formation fluids entering the repository from the Salado or the shafts, depending on properties. In the presence of significant quantities of fluid (liquid or gas) closure and consolidation is slowed when fluid compression increases fluid pressure in the repository to the point where pressure is exerted on the surrounding rock. Load transfer occurs according to the effective stress principle:

$$\sigma_T = \sigma_e + p \tag{10}$$

where σ_T is the weight of the overlying rock and brine, p is the pressure of the fluids in the pores, and σ_e is the stress that is applied to the waste skeleton. In this process, the waste is considered a skeleton structure immersed in pore fluids. As the pore pressure increases, the weight of the overburden is transferred to the pore fluids. If the fluid pressure increases to lithostatic pressure, the portion of the load carried by the skeleton, σ_e, vanishes. Further consolidation ceases at this point, and will not begin again unless some of the pore fluids are released. Brine inflow into the repository is also reduced as pressure increases, and brine can be expelled from the repository if it is mobile and its pressure exceeds brine pressure in the immediately surrounding formation. For the undisturbed case, gas release away from the waste can occur by flow into lower pressure areas, which may include (depending on material properties) disturbed areas surrounding the repository, the interbeds, or the shafts. Gas flow into intact, halite-rich rock is not expected due to its high expected threshold pressure.

In summary, during closure: (1) the volume of the excavation decreases as the formation deforms over time to consolidate and encapsulate the waste, (2) brine may move towards the repository because initially fluid pressure adjacent to it is lower than the equilibrium fluid pressure that existed in the salt prior to excavation, and (3) chemical reactions within the waste generate gas, which may exert pressure which resists closure.

The volumetric plasticity model is the process model for room closure and waste consolidation. The experimental data used for the volumetric plasticity model and their interpretation are summarized in Butcher et al. (1991) and Luker et al. (1991). The volumetric plasticity model was numerically implemented in SANTOS, which has the same constitutive relations as the code SANCHO used in previous performance assessments, but has been vectorized for better performance, to calculate the closure of disposal rooms for performance assessment.

As a boundary condition, SANTOS requires estimates of the quantity of gas present in a disposal room. These estimates were obtained using the average stoichiometry model of gas generation (Section 6.3.3.3) with, in essence, different assumptions about brine availability in the disposal room. With the volumetric plasticity model and gas quantity boundary condition, SANTOS calculates the closure state of the disposal room through time.

In performance assessment, the SANTOS calculated condition of the disposal rooms versus time is linked to the fluid flow code BRAGFLO via a 'porosity surface' (a look-up table) with axes of time after sealing, disposal room pressure, and disposal room porosity. At the beginning of a time step, BRAGFLO evaluates the pressure of the waste-disposal region (which is sensitive to brine and gas flow and the previous compaction state of the room), and consults the porosity surface to find the void volume of the waste-disposal regions appropriate for the time and pressure. The porosity surface method of incorporating the dynamic effect of disposal room closure in performance assessment has been compared to more complex techniques that are computationally impractical for use in a performance assessment, and was found to be reasonable. Documentation will be provided with the final application.

The operations region and experimental region are to be left unfilled after closure; as these regions will not contain significant quantities of materials which may generate gas, they are expected to rapidly close. These regions, along with panel closures, are represented in performance assessment with constant porosity 7.5 percent and permeability of 10^{-12} m^2.

6.3.3.2 Repository Fluid Flow

Fluid flow modeling within the repository is concerned with (1) fluid distribution in the waste within the repository, and (2), depending on material properties, fluid flow to and from the Salado and shafts. These are important in assessing gas generation rates (Section 6.3.3.3) and the mobility of radionuclides in the disposal system.

Repository and disposal room flow is conceptually complex due to the varied properties of rooms resulting from creep closure, waste consolidation, reactions which dissolve radionuclides, and other reactions which generate gas. Some aspects of the changing properties of the waste have been evaluated experimentally.

The permeability of waste at a given time can influence repository system performance by controlling how rapidly gas or brine can flow through the waste. Tests reported by Luker et al. (1991) on simulated waste have shown material permeabilities on the order of from 10^{-12} to 10^{-16} m^2 in waste compacted under a lithostatic load.

Capillary rise (wicking) is the ability of a material to carry a fluid above the level it would normally seek in response to gravity. Since the average stoichiometry model for gas generation (Section 6.3.3.3) defines different rates depending upon whether the waste is in direct contact with liquid brine or gas containing water vapor, the physical extent of these regions could be important. Capillary rise is described by two-phase properties, which have not been measured for simulated waste. In part due to capillary rise, and also due to heterogeneity present in waste containers (depressions which may collect brine), the waste is expected to have high contact area with brine and high residual saturation, in general. For performance assessment, the DOE assumed brine in the disposal regions is not mobile (i.e., not able to move within or out of the waste-disposal region) unless its saturation is at least 50 percent. This value was chosen based on consideration of the heterogeneity of the waste. Brine can flow into the waste disposal region at saturations well below 50 percent.

For performance assessment, the intrinsic permeability of the waste is assumed constant at 5.58×10^{-12} m^2 (Table 6-4) which is conservative because high permeability promotes fluid flow under low-hydraulic gradients.

Table 6-4. Parameters for Fluid Flow in the Repository

Parameter	Maximum	Minimum	Median or Constant[a]
Permeability, k (m^2)	—	—	5.584×10^{-12}
Porosity, initial (%)	—	—	88.1%
Compressibility (1/Pa)	—	—	—[b]
Two-Phase Flow: Brooks/Corey	—	—	2/3
P_t (Pa)	$0.56 \times 10^{0.5} \times k^{-0.346}$	$0.56 \times 10^{-0.5} \times k^{-0.346}$	$0.56 \times k^{-0.346}$
S_{br}	0.8	0.5	0.65
S_{gr}	0.2	0	0.1
λ	10.0	0.2	5.1
van Genuchten-Parker	—	—	1/3
S_{br}	0.8	0.5	0.65
S_{gr}	0.2	0	0.1
m	0.91	0.17	0.84

[a]Parameters with no maximum and minimum values are treated as constants in the performance assessment.
[b]This parameter is dependent on the porosity surface.

Because two-phase relationships have not been measured for WIPP materials, including waste, performance assessment captures a range of possible two-phase conditions by sampling on the Brooks and Corey and the van Genuchten-Parker two-phase equations, and by sampling on parameters within the equations. These and other parameters in the disposal room and repository flow model are shown in Table 6-4.

6.3.3.3 Gas Generation

The processes that will produce gas in WIPP disposal rooms are corrosion, microbial activity, and radiolysis. Gas-consuming processes include reaction with cementitious materials and dissolution in brine.

Oxic corrosion (oxidation of metals by molecular O_2) will consume O_2 and H_2O in WIPP disposal rooms. Oxic corrosion of steel waste containers, Fe-based alloys in the waste, and other metals in the waste such as Al and Al-based alloys is, along with aerobic microbial activity, a major process that will consume O_2 in the repository. Radiolytically induced uptake by plastics and, perhaps, rubbers, and oxidation of dissolved, reduced species such as Fe^{2+} produced by dissolution of Fe(II)-bearing corrosion products will also consume O_2. These processes are expected to produce anoxic conditions rapidly after panels are sealed.

Anoxic corrosion, the oxidation of metals by reaction with H_2O or H_2S, will consume H_2O, CO_2, and H_2S, and produce H_2. Anoxic corrosion of steels and other Fe-based alloys by intergranular Salado brines with a neutral or nearly neutral pH may produce H_2 at a rate of 0.10 mole per square meter of reacting steel per year. The quantity of H_2 produced will depend on (1) the quantity of steels and other Fe-based alloys in the repository, (2) the quantity of aqueous H_2O present, and (3) which corrosion product forms. If sufficient steels, other Fe-based alloys, and H_2O are available, CO_2 and H_2S are absent, and $(Fe,Mg)(OH)_2 \cdot H_2O$ is the corrosion product, then anoxic corrosion of steels and other Fe-based alloys and concomitant H_2 production will continue until the H_2 fugacity increases to its equilibrium value of about 60 atmospheres. The equilibrium H_2 fugacity for Fe_3O_4, the other possible anoxic corrosion product in the absence of CO_2 and H_2S, is about 400 atmospheres. Therefore, if Fe_3O_4 forms, anoxic corrosion and H_2 production will continue even if the H_2 fugacity increases to its highest possible value of roughly 150 atmospheres (lithostatic pressure at the depth of the repository).

If sufficient CO_2 or H_2S is present, anoxic corrosion of steels and other Fe-based alloys may stop prior to the formation of significant quantities of H_2 and consumption of significant quantities of H_2O, because anoxic corrosion can be impeded by adherent corrosion products $FeCO_3$, FeS, or, perhaps, FeS_2.

Under humid conditions (water vapor is present, but not liquid water), anoxic corrosion of steels and other Fe-based alloys has not been observed on simulated WIPP waste.

Microbial activity in WIPP disposal rooms will consume O_2 and, perhaps, CO_2, and produce CO_2, N_2O, N_2, H_2S, H_2, and CH_4. Microbial consumption of cellulosics and, perhaps, plastic and rubber may produce significant quantities of gas if (1) the requisite microorganisms are present when the repository is filled and sealed, (2) these microorganisms persist for a significant fraction of the 10,000-year period of performance of the repository, (3) sufficient H_2O) is present, (4) sufficient electron acceptors (oxidants) are available, and (5) enough nutrients, especially N and P, are available.

Aerobic microbial activity will consume O_2 and produce CO_2 and H_2O in WIPP disposal rooms. Aerobic microbial metabolism and oxic corrosion of metal are the two major processes contributing to the formation of anoxic conditions in the repository.

The most important anaerobic microbial processes will be (1) denitrification, which consumes NO_3^- as the electron acceptor and produces CO_2, N_2O, and N_2; (2) SO_4^{2-} reduction, which consumes SO_4^{2-} as the electron acceptor and produces CO_2 and H_2S; (3) methanogenesis, which consumes organic acids and produces CH_4 and CO_2 or consumes CO_2 and H_2 and makes CH_4. The rates at which these processes will produce or, perhaps, consume gas will depend on whether or not conditions are humid or inundated, on the concentrations of electron acceptors such as NO_3^-, SO_4^{2-}, organic acids or CO_2, and the concentrations of nutrients such as N and P, and on the dissolved Pu concentration.

Radiolysis herein refers to "α radiolysis" (the chemical dissociation of molecules by alpha particles emitted during the radioactive decay of TRU waste) because other types of radiation will be insignificant. Radiolysis of H_2O in the waste and brine in WIPP disposal rooms will consume H_2O and produce H_2. Some oxidizing species, as well as O_2, may also result. Based on calculations using the results of laboratory studies of brine radiolysis, estimates of the quantities of brine that could be present in the repository after filling and sealing, and estimates of the solubilities of Pu, Am, Np, Th, and U in WIPP brines, radiolysis of H_2O will not affect the overall gas or H_2O content of the repository significantly. Radiolysis of cellulosics, plastic, and rubber in the waste and, in the case of plastic, the container liners can produce a variety of gases. However, such radiolytic gas production proceeds at lower rates than radiolysis of H_2O in the waste and brine, and is insignificant.

An average stoichiometry process model is used to implement gas generation in performance assessment calculations. The average stoichiometry model accounts only for CO_2 and H_2 formations. Several assumptions are necessary to predict gas generation in WIPP disposal rooms. These include (1) which corrosion product will form during anoxic corrosion of steels and other Fe-based alloys in the absence of CO_2 and H_2S; (2) the hydration number x of $(Fe,Mg)(OH)_2{\bullet}H_2O$, one of the two more likely corrosion products under CO_2 free and H_2S free conditions; (3) whether microorganisms capable of carrying out potentially significant respiratory pathways will be present when the repository is filled and sealed; (4) whether these microbes will survive for a significant fraction of the 10,000-year period of performance of the repository; (5) whether these microbes will consume significant quantities of plastic and rubber; (6) whether sufficient electron acceptors (oxidants) will be present and available; (7) whether enough nutrients, especially N and P, will be present and available; and (8) the stoichiometry of the overall reaction for each significant respiratory pathway, especially the number of moles of electron acceptors, nutrients, gases, and H_2O consumed or produced per mole of substrate consumed. The average stoichiometry model used for this performance assessment limits gas generation only by the quantity and distribution of brine within the disposal regions resulting from initial brine saturation and brine inflow. The disposal region generates gas at sampled rates for brine-inundated conditions commensurate with brine saturation; the rest of the disposal region generates gas at humid rates. A portion of the plastic and rubber in the waste is assumed to degrade by microbial action as part of the cellulosic content of the waste. Parameters used in the model for gas generation are listed in Table 6-5.

Table 6-5 Parameter Values Used in the Average Stoichiometry Gas Generation Model

Parameter	Maximum	Minimum	Median
Rate of gas generation by corrosion in brine-inundated conditions (mol/m^2 steel)	6.4×10^{-7}	0	—[a]
Rate of gas generation by corrosion in humid conditions (multiplicative factor of inundated rate)	5×10^{-4}	0	—[a]
Rate of gas generation by biodegradation in inundated conditions (mol/kg cellulosics sec)	1.6×10^{-8}	0	3.2×10^{-9}
Rate of gas generation by biodegradation in humid conditions (multiplicative factor of inundated rate)	0.2	0	0.1
Volume fraction of plastics and rubber that degrade as cellulosics	1	0	0.5
Corrosion stoichiometry (moles H_2/moles Fe)	4/3	1	7/6
Biodegradation stoichiometry (moles H_2/moles cellulosics)	1.67	0	0.84
Radiolysis	0	0	0

[a] A constructed distribution between the maximum and minimum values was used.

6.3.3.4 Actinide Source Term

The concentrations in the brine phase of five actinides have been determined to be important in the performance assessment of the WIPP: Americium (Am), Thorium (Th), Neptunium (Np), Uranium (U), and Plutonium (Pu). These actinides are soluble in four oxidation states: III through VI. These actinides do not occur in a gas phase under conditions expected in the WIPP.

The mobilization of actinides in waste in the disposal rooms is determined by the numerical codes NUTS and PANEL. NUTS is used to transport radionuclides using BRAGFLO flow fields in the disposal system. These codes require actinide oxidation states and solubilities as parameter input; these are presented in Table 6-6.

Table 6-6. Parameters for Actinide Source Term

Parameter	Maximum	Minimum	Constant[a]
Log solubility, molar, oxidation state III	0	-10	—[b]
Log solubility, molar, oxidation state IV	0	-10	—[b]
Log solubility, molar, oxidation state V	0	-10	—[b]
Log solubility, molar, oxidation state VI			0
Am oxidation state			All III
Th oxidation state			All IV
U oxidation state			0–20% VI Rest equal probability IV, VI
Np oxidation state			Equal probability IV, V
Pu oxidation state			0–20% VI Rest equal probability III. IV, V

[a]Parameters with no maximum and minimum values are treated as constants in the performance assessment.
[b]A constructed distribution between the maximum and minimum values was used.

6.3.3.5 Colloid Source Term

The only reasonable source of colloids in the disposal system is the disposal room environment. Because of the presence of soils and cellulosic substrate for microbial action in WIPP waste (see, for example, DOE 1994, table 4-1, Waste Matrix Code Group 4200), humic materials and microbes will be present in disposal room brines. Actinide intrinsic colloids may also form in the disposal rooms due to relatively high actinide concentrations. Processes affecting the transport of colloids are addressed in Section 6.3.6. Parameters for the colloid source terms are shown in Table 6-7.

Table 6-7. Parameters for Colloid Source Term

Parameter	Maximum	Minimum	Constant[a]
Source-term concentration of actinides carried by humic materials (per actinide), moles/liter			$2x10^{-8}$
Source-term concentration of actinides carried by microbes (per actinide), moles/liter			$1x10^{-8}$

[a]Parameters with no maximum and minimum value are treated as constants in the performance assessment.

6.3.4 Shafts and Shaft Seals

The four shafts connecting the repository to the surface are represented in performance assessment with a single shaft, represented by regions 5, 6, 8, and 9 on Figure 6-6. This single shaft has a cross-section and volume equivalent to the four real shafts it represents. Upon closure of the repository following waste emplacement, the shafts will be sealed as discussed in Section 3.3.2. The seals are responsible for short-term restriction of brine flow down the shaft, and long-term restriction of possible gas and brine flow up the shaft if repository pressure becomes high. The backfill components of the shaft system have no role in the performance of the repository.

The seal system has been simplified for performance assessment into (1) a short-term seal and (2) a long-term seal. The short-term seal model consists of all of the short-term components, both those at the Salado-Rustler contact designed to keep brine out of the shafts and those nearer the base of the shaft designed to keep gas out of the shafts. The long-term seal represents primarily the middle salt column and its expected behavior from 100 to 10,000 years. Shaft parameter values are shown in Table 6-8.

Table 6-8. Shaft Parameter Values

Parameter	Maximum	Minimum	Median or Constant[a]
Permeability, lower shaft seals (m^2) 0–100 years	—	—	10^{-12}
Permeability, lower shaft seals (m^2) 100–10,000 years	10^{-14}	10^{-19}	—[b]
Permeability, upper shaft seals (m^2) 0–100 years	10^{-14}	10^{-19}	—[b]
Permeability, upper shaft seals (m^2) 0–100 years 100–10,000 years	—	—	10^{-12}
Rest of shaft	—	—	10^{-12}
Shaft seals porosity (%)	—	—	5
Rest of shaft porosity (%)	—	—	7.5 to upper seal, 25 above upper seal
Seals and rest of shaft two-phase flow: Brooks/Corey	—	—	1.0
P_t	— —	— —	$0.56 x k^{-0.346}$ (seals) 0 (rest of shaft)
S_{br}	—	—	0.2
S_{gr}	—	—	0.2
λ	—	—	0.7
Lower seal length (m)	—	—	60
Upper seal length (m)	—	—	49
Rest of shaft pore compressibility (1/Pa)	—	—	$1.3 x 10^{-8}$ $4 x 10^{-9}$ above upper seal
Shaft seal pore compressibility (1/Pa)	—	—	$2 x 10^{-8}$

[a]Parameters without a maximum and minimum value are treated as constants in the performance assessment.
[b]A constructed distribution for between the maximum and minimum values.

6.3.5 *The Salado Formation*

The Salado is the principal natural barrier to fluid flow between the waste disposal panels and the accessible environment. This section will describe features of the natural and modeled Salado system important in performance assessment.

For performance assessment, the Salado is conceptualized as a porous medium composed of several rock types arranged in layers, except near the repository where damaged zones crosscut otherwise continuous layers. Two rock types, impure halite and anhydrite interbed, are used to represent the intact Salado. Near the repository a DRZ has increased permeability and porosity, and it serves to allow unimpeded flow between anhydrite interbeds and the repository. Specific information about the major rock types represented in performance assessment is presented in following sections.

6.3.5.1 Salado Halite

A single porous media with spatially constant properties (Region 15 in Figure 6-6) is used in performance assessment to represent the various intact, halite-rich layers present in the Salado and anhydrite interbeds contained within those layers that are not explicitly represented. A comparison has been made between the simplified stratigraphy used in performance assessment and a more detailed stratigraphy amenable in a more complex model; this comparison confirmed that the performance assessment stratigraphic representation is reasonable. This comparison will be available for the final application. The two-phase properties of the halite have not been measured. A wide range of possible two-phase properties is incorporated by sampling between two sets of multiphase equations, and by sampling on parameters within the different equations. Due to small pore size, the halite-rich units are expected to have threshold pressure high enough that waste-generated gas will not penetrate, and halite threshold pressure has accordingly been set arbitrarily high to prevent gas penetration. This assumption enhances gas migration in anhydrite interbeds. Table 6-9 shows parameters used in performance assessment for Salado halite.

Table 6-9. Salado Halite Parameter Values

Parameter	Maximum	Minimum	Median or Constant[a]
Permeability (m^2)[b]	10^{-20}	10^{-24}	—[c]
Porosity (%)	3	0.1	1.5
Specific Storage (1/m)	10^{-5}	10^{-7}	10^{-6}
Two-phase flow: Brooks/Corey	—	—	2/3
P_t			50MPa
S_{br}	0.6	0	0.3
S_{gr}	0.4	0	0.2
λ	10.0	0.2	5.1
van Genuchten-Parker	—	—	1/3
S_{br}	0.6	0	0.3
S_{gr}	0.4	0	0.2
m	0.91	0.17	0.836

[a]Parameters with no maximum and minimum values are treated as constants in the performance assessment.
[b]Parameter values based on data in Appendix PAR.
[c]A log uniform distribution between the maximum and minimum values was used.

6.3.5.2 Salado Interbeds

Performance assessment uses three distinct anhydrite interbeds in the BRAGFLO model, representing Marker Bed 138, anhydrites "a" and "b," and Marker Bed 139. The three interbeds have the same model parameter set assigned to them, and the parameters are spatially constant: the only difference between the interbeds is their position and thickness. Model parameters describing the interbeds are shows in Table 6-10.

Table 6-10. Anhydrite Interbed Parameter Values

Parameter	Maximum	Minimum	Median or Constant[d]
Permeability (m^2)[a]	10^{-15}	10^{-21}	—[b]
Porosity (%)	8	0.1	—[b]
Specific storage (1/m)	10^{-5}	10^{-7}	10^{-6}
Two-phase flow: [c] Brooks/Corey	—	—	2/3
P_t (Pa)	$5.6xk^{-0.346}$	$5.6x10^{-4}xk^{-0.346}$	—[b]
S_{br}	0.6	0	—[b]
S_{gr}	0.4	0	—[b]
λ	10.0	0.2	5.1
van Genuchten-Parker	—	—	1/3
S_{br}	0.6	0	—[b]
S_{gr}	0.4	0	—[b]
m	0.91	0.17	0.836

[a]Parameter values are based on data in Appendix PAR.
[b]A constructed distribution between the maximum and minimum values was used.
[c]Relative permeability model chosen was identical to that sampled for halite.
[d]Parameters with no maximum and minimum values are treated as constants in the performance assessment.

6.3.5.3 Interbed Fracture

Repository pressures are not expected to be greater than lithostatic because such pressures would result in negative effective stress in rock near the repository and cause dilation or fracturing. This will allow gas flow out of the repository, which reduces pressure. Field tests and laboratory tests in anhydrite interbeds support the use of a pressure-dependent permeability and porosity, and indicate that such alteration may take place below lithostatic pressure.

The model used in performance assessment to represent interbed fracture assigns a fracture initiation pressure such that when this pressure is reached, local fracturing takes place. Below the fracture initiation pressure, an interbed has a constant permeability and compressibility, and the porosity is determined using the standard integral equation. Above the fracture initiation pressure, the local compressibility of the interbed is assumed to increase linearly with pressure, which dramatically affects how rapidly porosity increases with increasing pore pressure. Additionally, permeability increases by the magnitude of porosity increase raised to a power. The compressibility, porosity, and permeability continue to increase until the full fracture pressure is reached, above which these values cease to change. Table 6-11 shows fracture parameters.

Table 6-11. Interbed Fracture Parameter Values

Parameter, units	Maximum	Minimum	Median or Constant[a]
Initiation pressure (Pa)	14.8×10^6	13.8×10^6	14.3×10^6
Full fracture pressure (Pa)	17.3×10^6	16.3×10^6	16.8×10^6
Maximum porosity	—	—	initial + 1%
Maximum permeability (m^2)	—	—	10^{-9}

[a]Parameters with no maximum and minimum values are treated as constants in the performance assessment.

6.3.5.4 Disturbed Rock Zone

As discussed in Chapter 3, the DRZ is expected to generally increase fluid mobility. Because the increase in fluid mobility is not expected to be completely reversible with creep closure of the disposal rooms, performance assessment increases the permeability of a region around the repository that has constant properties through time. The modeled DRZ extends above and below the repository from the base of Marker Bed 138 to Marker Bed 139. This zone provides a permanent high-permeability region which does not impede flow between the repository and interbeds. Table 6-12 shows parameter values used in the performance assessment representation of the DRZ.

Table 6-12. DRZ Parameter Values

Parameter, units	Maximum	Minimum	Median or Constant[d]
Permeability (m^2)	—	—	10^{15}
Porosity (%)[b]	3	0.1	1.5
Specific storage (1/m)	—	—	10^{-5}
Two-phase flow:	—	—	2/3
Brooks/Corey[b]			
P_t			0
S_{br}			0
S_{gr}			0
λ	10.0	0.2	5.1
van Genuchten-Parker[b]	—	—	1/3
S_{br}			0
S_{gr}			0
m	0.91	0.17	0.836

[a]Parameters with no maximum and minimum values are treated as constants in the performance assessment.
[b]Set same as sampled halite value.

6.3.5.5 Salado Brine Outflow Model for Performance Assessment

The BRAGFLO model implemented for performance assessment could underestimate cumulative release to the accessible environment because it lacks sufficient detail to realistically portray the flow path between the waste disposal panels and the accessible environment. Rather than use BRAGFLO-calculated cumulative release, this performance assessment has implemented an alternative method for determining the quantity of brine reaching the accessible environment and its actinide concentration. This alternative technique is based on a theoretical consideration of the mass of brine that would occupy various possible flow networks for contaminated brine between the waste disposal region and the accessible environment.

The model is implemented in performance assessment by first keeping track of how much brine flows into interbeds that has been in areas where it may have become contaminated, and second by comparing that quantity of brine to a sampled parameter that represents the volume of the flow network for contaminated brine between the repository and the accessible environment. If the quantity of contaminated brine flowing into interbeds exceeds the sampled storage volume, the excess is released to the accessible environment.

Brine in the waste disposal regions of the repository and in the DRZ below these regions is assumed to be contaminated. The code NUTS is used to track brine flowing through these regions; any of this brine that enters an interbed will be accumulated (numerically) for comparison to the sampled brine storage parameter.

The volume of brine stored within a flow network is calculated by multiplying a sampled factor, called C, by a reference volume, set to be the void volume of Marker Bed 139 in a circular annulus between the repository and accessible environmental boundary. The minimum volume of the flow network between the waste disposal region and the accessible environment, accounting for possible channelized flow in fractures and likely associated fingering, is 0.1 percent of the void volume of Marker Bed 139 between the disposal panels and the accessible environment. The minimum value for C is adjusted depending on whether interbeds fracture. Due to the potential for significant storage in adjacent halite units, the maximum value for the volume of brine contained within the disposal system is fixed at twice the void volume for Marker Bed 139. Table 6-13 shows brine outflow parameter values.

Table 6-13. Brine Storage Parameter Values for Brine Outflow

Parameter, units	Maximum	Minimum	Median or Constant[a]
Minimum C, no interbed fracturing	0.05	10^{-3}	—[b]
Minimum C, with interbed fracturing	0.01	10^{-3}	—[b]
Maximum C	—	—	2
MB 139 Pore volume, m^3	1.96×10^6 times sampled interbed porosity		

[a]Parameters with no maximum and minimum values are treated as constants in the performance assessment.
[b]A constructed distribution between the maximum and minimum values was used.

6.3.6 *Rustler Formation*

Specific information about the members of the Rustler represented in performance assessment is presented below.

6.3.6.1 The Culebra Member

In undisturbed conditions, the only potential for contamination of the Culebra is through brine flow up the sealed shafts due to high repository pressure. If this happens, lateral transport of contaminants in the Culebra may occur. As the conceptual basis of the BRAGFLO model is not appropriate for predicting reasonable estimates of contaminant transport through the Culebra, performance assessment uses a different conceptual, process, and numerical model to evaluate Culebra transport. The conceptual model is two-dimensional flow through a horizontal confined aquifer with spatially variant transmissivity. The source flux of contaminants is obtained from BRAGFLO- and NUTS-calculated fluxes into the Culebra from the shaft. Parameter values used in BRAGFLO to describe the Culebra are shown in Table 6-14.

Table 6-14. Culebra Parameter Values for the BRAGFLO Model

Parameter	Maximum	Minimum	Median or Constant[a]
Permeability (m^2)	—	—	$2.65 \times 10^{-13} m^2$
Porosity (%)	—	—	14.6
Pore compressibility (1/Pa)	—	—	1.42×10^{-9}
Two-phase flow: Brooks/Corey	—	—	1.0
P_t (Pa)			1.25×10^{4}
S_{br}			0.2
S_{gr}			0.2
λ			0.7
Thickness (m)	—	—	7.7
Initial Pressure (Pa)	—	—	8.52×10^{5}
Microbial colloid free water diffusion coefficient (cm^2/sec)	—	—	0
Humic colloid free water diffusion coefficient (cm^2/sec)	—	—	1×10^{-7}
Microbial colloid release factor (%)	—	—	1
Humic colloid release factor (%)	—	—	1

[a]Parameters without maximum and minimum values are treated as constants in the performance assessment.

The SECO family of codes is used to evaluate fluid flow and transport in the Culebra. These codes capture the spatial variability of transmissivity in the Culebra by assigning different transmissivities to every element. The transmissivities assigned are calculated using an automated inverse approach to calibrate the transmissivity fields to both steady-state and transient pressure data. The technique can be broken down into three steps: unconditional simulation, conditional simulation, and automated calibration.

An unconditional simulation generates a random Culebra transmissivity field that has the same spatial correlation structure as measured transmissivities, but does not necessarily match measured transmissivities at the location of their measurements. A conditional simulation alters the random field produced during the unconditional simulation so it matches the measured transmissivities at the locations of their measurements. The automated calibration alters the conditionally simulated field so that the pressures computed by the groundwater-flow model (both steady and transient state) agree closely by least-squares with the measured pressures. When calibration is completed, a conditionally simulated transmissivity field is obtained that conforms with all head and transmissivity data at the WIPP site and may be regarded therefore as a plausible, but non-unique, version of the true distribution of transmissivity.

This process is repeated to produce the desired number of calibrated, conditionally simulated fields. For each realization executed in performance assessment, a calibrated, conditionally simulated transmissivity field is chosen for the SECO models to represent Culebra transmissivity.

6.3.6.2 Chemical Retardation of Actinides in the Culebra

Two major minerals considered to be important for adsorption in the Culebra are dolomite, because of the vast amount present in the Culebra, and clay minerals, which are typically quite powerful adsorbents. Most of the clay minerals in the Culebra are detrital in origin, deposited along bedding planes while the evaporite minerals, such as dolomite, were forming. The clay minerals are concentrated in discontinuous lenses or are present as anastomosing networks, but are generally concentrated along sub-horizontal planes. The chemical compositions of some of the clay minerals (e.g., what is now present as corrensite) were diagenetically altered, but their spatial distribution has not changed since deposition. Authigenic clay minerals are not present in appreciable quantities.

Performance assessment uses chemical retardation factors (R) calculated using the following equations:

$$R = 1 + \rho_b K_d (1-\phi)/\phi \qquad (11)$$

where K_d is the distribution coefficient for each radionuclide and ϕ and ρ_b are the porosity and bulk density of the rock, respectively. This equation can be derived from the advection-dispersion equation assuming local equilibrium for adsorption and a linear relationship between the amount of a solute adsorbed on the unit amount of the solid, S, and the concentration of the solute, C:

$$S = K_d C. \qquad (12)$$

This is the linear isotherm model. K_d values for a given actinide based on laboratory mechanistic adsorption experiments (core size: 20–100 micrometers), or laboratory column experiments (core size: up to 100 centimeters), or field tracer tests (sample size in tens of meters) should be approximately the same if the physical and chemical conditions are comparable; in other words, K_d is expected to be scale-independent.

K_d values used in performance assessment are based on the expected outcome of experiments that are currently underway. The K_d values used take credit for the bulk composition of dolomite and clay in the Culebra, but do not assume clay lining of fractures. The K_d values used are shown in the Table 6-15.

Table 6-15. Log K_d Values (m^3/g) Used for Retardation of Actinides in the Culebra

Actinide	Maximum	Minimum	Distribution
Th	-0.8	-2.1	—[a]
U	0.0	-4.0	—[a]
Np	0.2	-3.0	—[a]
Pu	1.3	-1.8	—[a]
Am	2.2	-4.0	—[a]

[a]A constructed distribution between the maximum and minimum values was used.

6.3.6.3 Colloid-Facilitated Transport of Actinides

Carrier colloids are particles which may act as substrates for sorption of actinides as well as other metals (carrier colloids with sorbed actinides are referred to in the published literature as pseudocolloids, Type II colloids, and Fremdkolloide) (see, for example, Lieser et al. [1986a, b], [1990]; Buddemeier and Hunt [1988]; Kim [1991] in the bibliography). Types of carrier colloids with the potential to transport actinides in the WIPP disposal system are discussed below.

Sterically stabilized "hard-sphere" carrier colloids are unstable "hard-sphere" carrier colloids coated with compounds capable of modifying the colloids' surface behavior so that electrostatic attraction and repulsion forces in WIPP brines are overcome, rendering them kinetically stable. Microbes are placed in this category, although their cell walls are not rigid. At the WIPP, concentrations of naturally occurring microbes are on the order of 10^9 to 10^{10} cells per liter (Francis and Gillow 1994). As microbes consume nutrients in the WIPP waste, their concentrations are likely to increase. Microbes are important for actinide transport because they may act as substrates for sorption of actinides.

"Soft-sphere" carrier colloids are flexible particles with rather indistinct particle-fluid boundaries, and are essentially dissolved macromolecules. "Soft-sphere" carrier colloids are closest in form and behavior to particles referred to as hydrophilic colloids in the traditional colloid chemistry literature (Lyklema 1978; Hiemenez 1986); examples include humic and fulvic acids (Choppin 1988; Tiller and O'Melia 1993). Humic and fulvic materials (high-molecular weight organic macromolecules) are of particular concern because of their well-known capability of complexing with metal cations, including actinides (Choppin 1988; Dearlove et al. 1990; Vlassopoulos et al. 1990; Tipping 1993; van der Lee et al. 1993). The concentrations of humic materials in deep subsurface groundwaters are typically quite small, because of the long periods of time available for oxidation of those materials. Existing information on total organic concentrations (TOCs) in Culebra groundwaters, for example, shows that TOC is on the order of 1 milligram per liter (Myers et al. 1991) which is quite low. The sources of humic materials in the disposal system are soil constituents of the WIPP waste (DOE 1994b, table 4-1, Waste Matrix Code Group 2400), and perhaps products of microbial degradation of cellulosic constituents in the waste.

Actinide intrinsic colloids (also known as true colloids, Type I colloids, and Eigenkolloide) are thought to form by condensation reactions for hydrolyzed actinide ions to form macromolecules, or "polymers," of colloidal size. The tendency for formation of one particular actinide intrinsic colloid, the Pu(IV)-polymer, is enhanced by increased concentrations of Pu(IV), temperature, and basic conditions. Examples can be found in the literature of polymeric species of most of the actinides of importance to the WIPP (see, e.g., Baes and Mesmer [1976]; Kim [1991]). It is important, however, to note the sized of polymers described in the literature. It is well known that as polyvalent metals, the actinides can form lower polymers such as dimers, trimers, tetramers, and hexamers. However, in terms of physical transport behavior, the lower polymers will behave no differently than dissolved monomeric species. In contrast, the higher polymers, such as the Pu(IV)-polymer, may reach colloidal sizes (1 nanometer to 1 micrometer) and will have different hydrodynamic properties than the subcolloidal-sized dissolved species.

In summary, sterically stabilized "hard-sphere" carrier colloids (microbes), "soft-sphere" (humic materials) carrier colloids, and actinide intrinsic colloids may be important in transport of actinides in WIPP brines.

Because the sizes of colloidal particles are significantly greater than the sizes of dissolved species, colloidal particles are transported differently. Kelley and Saulnier (1990, p. 4-10) point out that the primary distinction in transported colloid subtypes is whether the sizes of colloidal particles are larger or smaller than the mean pore throat diameter, 0.63 micrometers, of the intercrystalline pores in the Culebra matrix. Colloidal particles that are smaller than the pore throats will move into the rock matrix by physical diffusion, and will be removed from rapid transport in fractures. In contrast, colloidal particles that are larger than pore throats will be excluded from the matrix and will remain in fractures to be transported by advection and diffusion (see, e.g., Vilks [1994]). Actinide intrinsic colloids and "soft-sphere" carrier colloids (humic materials) are small enough to enter the pore throats in the Culebra, but are larger than dissolved species and have relatively reduced physical diffusion rates. Microbes are larger than the mean pore throat diameter in the Culebra, and will not diffuse into the matrix. The effective diffusion constants for the macromolecular colloidal particles have been estimated on the basis of their sizes (the free water diffusion constant for a solute in a liquid is inversely proportional to the radius of the diffusing particle: see Bird et al. [1960]; Hiemenez [1986, p. 81]). Parameters used in performance assessment to describe colloid transport are shown in Table 6-14.

6.3.6.4 Magenta Member

The Magenta is described in Section 2.1 Performance assessment models of the Magenta use the BRAGFLO geometry shown in Figure 6-6. The low permeability of the Magenta relative to the Culebra makes significant lateral transport of contaminants in the Magenta unlikely, and therefore a relatively simple model is a reasonable approximation. Magenta input parameters are included in Table 6-16.

Table 6-16. Model Parameter Values for the Magenta Member of the Rustler

Parameter	Maximum	Minimum	Median or Constant[a]
Permeability (m^2)	—	—	1.1×10^{-16}
Porosity (%)	—	—	9
Pore compressibility (1/Pa)	—	—	2.2×10^{-9}
Two-phase flow: Brooks/Corey	—	—	1.0
P_t (Pa)			1.86×10^5
S_{br}			0.2
S_{gr}			0.2
λ			0.7
Thickness (m)	—	—	8.5
Initial Pressure (Pa)	—	—	9×10^5

[a]Parameters without maximum and minimum values are treated as constants in the performance assessment.

6.3.6.5 Other Members of the Rustler Formation

The supra-Rustler units are discussed in Section 2.1. Within performance assessment, the three non-dolomite units of the Rustler are modeled as a single hydrostratigraphic interval between the Salado and the Culebra. Lateral flow in these units is exceedingly unlikely given the proximity of the Culebra and the Magenta, so properties are assigned to these units in performance assessment such that the small amounts of brine which might enter these units is diverted into the Culebra. This is accomplished by assigning zero permeability to these units in performance assessment which makes other parameters assigned to these units unimportant.

6.3.7 Dewey Lake

The Dewey Lake is discussed in Section 2.1. In performance assessment, the Dewey Lake is modeled with low permeability because the Dewey Lake does not produce water in the vicinity of the WIPP shafts or above the waste emplacement area. Dewey Lake input parameters are in Table 6-17.

Table 6-17. Dewey Lake Parameters

Parameter	Maximum	Minimum	Median or Constant[a]
Permeability (m^2)	—	—	9.33×10^{-16}
Porosity (%)	—	—	15
Pore compressibility (1/Pa)	—	—	6.67×10^{-8}
Two-phase flow: Brooks/Corey	—	—	1.0
P_t (Pa)			0
S_{br}			0.2
S_{gr}			0.2
λ			0.7
Thickness (m)	—	—	149.3
Initial Pressure (Pa)	—	—	hydrostatic, water table at 980 m, 43.3 m below top of formation.

[a]Parameters with no maximum and minimum values are treated as constants in the performance assessment.

6.3.8 Supra-Dewey Lake Units

The units overlying the Dewey Lake are discussed in Section 2.1. For performance assessment, the units overlying the Dewey Lake are represented as a single hydrostratigraphic unit, whose parameters are shown in Table 6-18.

Table 6-18. Supra-Dewey Lake Unit Parameters

Parameter	Maximum	Minimum	Median or Constant[a]
Permeability (m^2)	—	—	1×10^{-10}
Porosity (%)	—	—	17.5
Pore compressibility (1/Pa)	—	—	5.71×10^{-8}
Two-phase flow	—	—	same as Dewey Lake (see Table 6-17)
Thickness (m)	—	—	15.76
Initial pressure, 20% liquid saturation	—	—	1 atm

[a]Parameters with no maximum and minimum values are treated as constants in the performance assessment.

6.3.9 Climate Change

The historical record of climate change is discussed in Section 2.5.1. In regions with dry climates, such as present-day southeastern New Mexico, the water table (i.e., the top of the saturated zone) is at some depth below the land surface. If the climate were to become cooler and wetter, the amount of moisture that infiltrates to the water table could be somewhat greater, and consequently the water table could rise. Maximum gradients of hydraulic head are expected if the infiltration rate is sufficient to raise the water table to the ground surface at all locations. This is because the energy available to move groundwater in a basin depends on the difference in elevation between the highest and lowest positions of the water table, which in general is bounded by the difference in elevation in a groundwater basin, and also in general is only attained if the water table is close to the land surface.

For performance assessment, the maximum possible effect of climate change has been incorporated by changing the hydraulic gradient in the Culebra, which increases the rate of flow across the Culebra transmissivity fields. Heads are raised to the land surface along the northern boundary of the Culebra flow field while the head remains fixed at its present value along its southern boundary.

6.3.10 Repository and Salado Initial Conditions

The start of the long-term simulation occurs when the shaft seals are emplaced and the waste is isolated. Performance assessment uses initial conditions for the repository and Salado consistent with the following: (1) there are no gradients for flow in the Salado; (2) Salado pore pressures are elevated above hydrostatic from the surface but below lithostatic; (3) permeability and porosity are low; and (4) near the repository, excavation and waste emplacement allow partial drainage of the DRZ and Salado and subsequent evaporation of drained brine into mine air, and then removal by air exchanged to the surface.

To set the near-repository, partially drained DRZ initial condition for the long-term simulation, a simulation is executed prior to the long-term simulation. This prior calculation simulates 5 years, during which the DRZ partially drains. The initial pressure for this precursor simulation in Salado rock and the DRZ was adjusted from the 12 to 13 megapascals pressure in MB 139 by adding or subtracting a hydraulic head component. Pressure at 5 years before time zero in the excavated regions was atmospheric.

Permeability in the DRZ in 10^{-15} m^2 for all time. Porosity of these regions was set for all time at its sampled value. Porosity in lithologic units is initially liquid-saturated during the start-up simulation; the excavations are gas-saturated.

At the end of the start-up period prior to beginning the long-term simulation, waste is emplaced and parameter values for long-term material properties which have been discussed in previous tables are assigned to the waste, shaft, and other excavated areas. Any brine present in the excavated regions resulting from DRZ drainage during the start-up simulation is removed (conceptually corresponding to drying during ventilation). Waste is assigned a sampled initial brine (water) content. Pore volume in other excavated regions(e.g., seals) is set at 25 percent brine saturation.

6.3.11 Numerical Codes

Several calculational and database management codes are used to evaluate undisturbed conditions and have been mentioned in the text. BRAGFLO, SECO, and PANEL have been described previously (for example, in Sandia [1992]). These descriptions will be included in appendices in the final application. Appendix NUTS is provided as an example.

Proposed 40 CFR § 194.23 has specific documentation requirements for submittal of information regarding models and codes. These are not addressed in this draft application.

6.3.12 Performance Assessment Results

The CCDF calculated with the modeling system described previously in this section is shown in Figure 6-7. It is a mean CCDF based on 60 realizations, and it is conditional on an assumption of undisturbed performance. Although this CCDF is several orders of magnitude below the release limits stipulated in 40 CFR § 191.13(a), the DOE recognizes that it is insufficient for a demonstration of compliance with 40 CFR Part 191 and the proposed 40 CFR Part 194. As discussed in Section 6.3.1, the CCDF is not in final form because a sufficient level of confidence remains to be established in the modeling system, data, and parameters, and quality assurance has not been completed. Full justification of the models, data, and parameters will be provided in the final application. Analyses of disturbed performance, including consideration of human-initiated events and processes, will also be included in the final application.

Proposed 40 CFR § 194.34 contains specific requirements regarding the generation and submittal of CCDFs. These requirements are not addressed in this draft application.

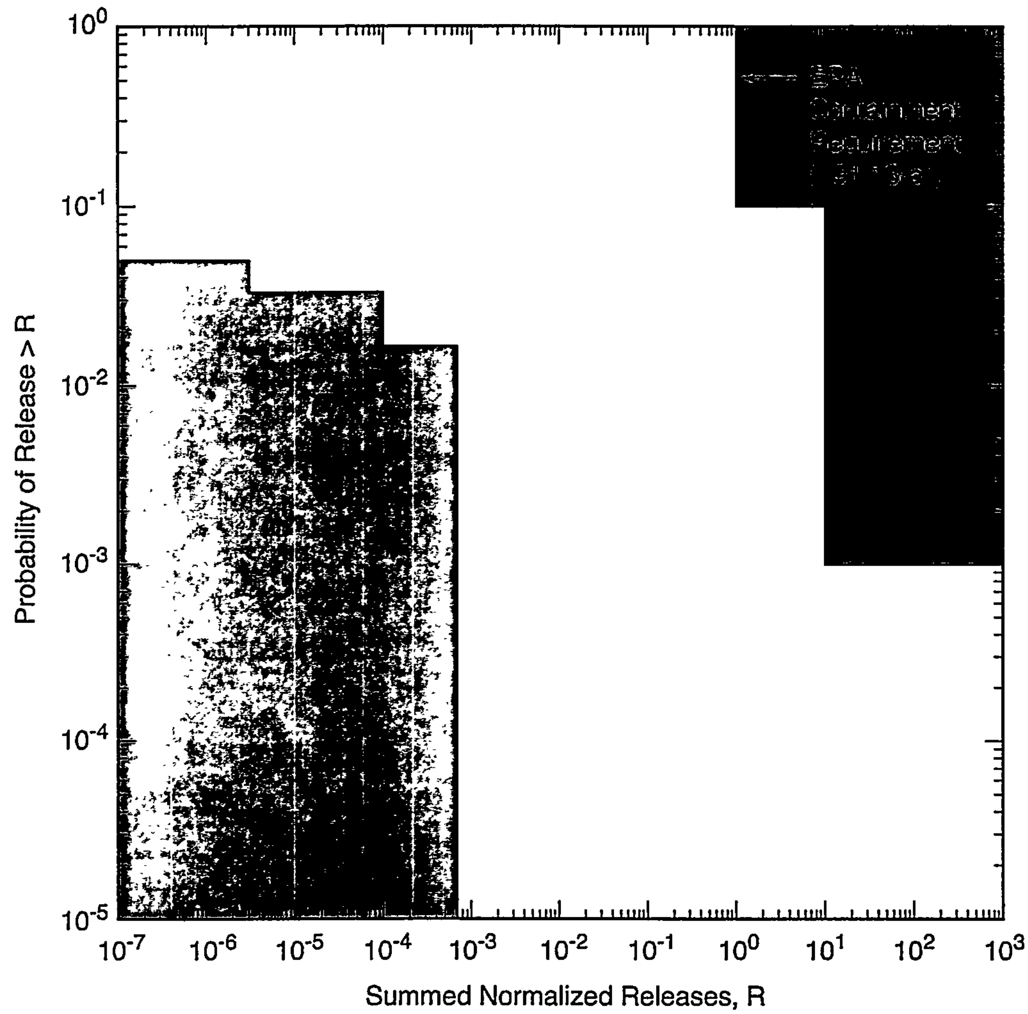

Figure 6-7. Mean CCDF Showing Probability of Cumulative 10,000-year, Normalized Radionuclide Releases from the WIPP. The CCDF is based on 60 realizations of undisturbed performance. This is a preliminary CCDF based on preliminary models and data, and does not address all requirements of 40 CFR Part 191 or proposed 40 CFR Part 194.

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7.0 ASSURANCE REQUIREMENTS

In the preamble to Title 40 Code of Federal Regulations (CFR) Part 191, the U.S. Environmental Protection Agency (EPA) points out that "there are too many uncertainties in projecting the behavior of natural and engineered components for many thousands of years—and too many opportunities for mistakes or poor judgments in such calculations—for the numerical requirements on overall system performance in Subpart B to be the sole basis to determine the acceptability of disposal systems for these very hazardous wastes." In view of this, the EPA developed assurance requirements to ensure that implementing agencies act cautiously and take steps to reduce these uncertainties. According to the EPA, these assurance requirements are considered to be an "essential complement" to the containment requirements, which, when implemented, should ensure that the level of protection desired by the EPA is achieved.

Contained in 40 CFR § 191.14 are these six separate assurance requirements:

- Active institutional controls
- Monitoring
- Passive institutional controls
- Barriers
- Resource disincentives
- Waste removal.

The following sections detail the U.S. Department of Energy's (DOE's) compliance with the assurance requirements of 40 CFR Part 191.

The EPA has proposed draft criteria for certification of compliance with 40 CFR Part 194 that include requirements not addressed in this section (EPA 1995). For example, 40 CFR Part 194 requires detailed information and plans which are not currently available. Where appropriate, the areas in this section that may require revision are identified.

7.1 Active Institutional Controls

Section 194.41 of the proposed 40 CFR Part 194 addresses active institutional controls. In particular it requires detailed descriptions of active controls, their locations, the period of time that the controls will remain active, assumptions regarding such controls and the effectiveness of those controls. While the following sections address the regulatory requirements on active controls, they do not provide the level of detail specified in the proposed rule.

Once a facility is decommissioned, positive actions (referred to as "active institutional controls") should be taken to assure proper maintenance and monitoring. The EPA has specified that no more than 100 years of active institutional control can be assumed in predictions of long-term performance. This assumption assures that future protection and control does not rely on positive actions by future generations.

Active institutional controls principally occur following shaft sealing activities, although some related activities may begin sooner. The DOE interprets this requirement to mean that control programs should be implemented as long as such controls are useful and practical, but active institutional controls cannot be considered in the performance assessment for ensuring isolation for more than 100 years.

The EPA defines active institutional controls (40 CFR § 191.12) as: "(1) controlling access to a disposal site by any means other than passive institutional controls, (2) performing maintenance operations or remedial actions at the site, (3) controlling or cleaning up releases from a site, or (4) monitoring parameters related to disposal system performance." Activities constituting active institutional controls include post-operational monitoring, decontamination and decommissioning (D&D), land reclamation, evaluation of land use in the area, maintenance of fences and buildings, and guarding the facility. There are several objectives to be accomplished by these activities: (1) to do whatever is needed to restore the land surface to as near its original condition as possible so that future generations will not preferentially select the area for some activity that will be detrimental to the disposal of wastes; (2) to provide for a facility and presence at the site during active cleanup; (3) to perform disposal system monitoring; and (4) to limit access to the site.

Section 13 of the Land Withdrawal Act (LWA) requires the DOE to submit a decommissioning plan and a post-decommissioning management plan to Congress, the state of New Mexico, the Secretary of the Interior, and the EPA Administrator by October 30, 1997. Oversight of active institutional control activities with regard to the closure and post-closure requirements of the Resource Conservation and Recovery Act (RCRA) and the New Mexico Hazardous Waste Act (NMHWA) would be the responsibility of the New Mexico Environment Department (NMED) and the EPA.

The state of New Mexico has further involvement in accordance with Section N, "Decontamination and Decommissioning," of Revision 1 of the Working Agreement for Consultation and Cooperation (DOE 1981).

Land reclamation activities would be conducted in consultation with the U.S. Bureau of Land Management (BLM) and the State Land Office (SLO) to assure that land restoration activities return the Waste Isolation Pilot Plant (WIPP) facility to a condition that is equivalent to that of surrounding lands. Section 4 of the LWA provides that the DOE, in consultation with the Secretary of the Interior and the state of New Mexico, develop a management plan by October 30, 1993, for the use of the withdrawal area until the end of the decommissioning phase. This management plan has been developed by DOE (1993b).

7.1.1 Active Institutional Control Requirements

In prescribing active institutional controls, the EPA has specified that "active institutional controls over disposal sites should be maintained for as long a period of time as is practicable after disposal" (40 CFR § 191.14[a]).

The EPA addresses the effectiveness of these controls and the length of the time period over which any such controls should be considered effective for the purposes of the performance assessment. In accordance with the final rule, the implementing agency should maintain active institutional controls for as long a period of time as is practicable. However, to be conservative, the standards require that the performance assessment should not assume that any benefits derive from active institutional controls for more than 100 years after disposal. The EPA states that assurance of isolation cannot depend on positive actions on the part of future generations; this provides additional assurance that the disposal system will protect human health and the environment in the long term (EPA 1985). This section provides an overview of the program that is currently proposed by the DOE for implementing active institutional control for the WIPP facility.

7.1.2 Objectives for Active Institutional Controls

The DOE's active institutional control program has a primary objective of addressing all requirements, including restoring the WIPP site as nearly as possible to its original condition, and thereby equalizing any preference over other areas for development by humans in the future. Restoration of the WIPP site includes any necessary remedial actions or cleanup of releases resulting from decommissioning. In addition, as part of the active institutional control program, the DOE will implement monitoring systems suitable for assessing disposal system performance if such monitoring is feasible.

7.1.3 WIPP Active Institutional Control Program

The DOE currently plans to implement the long-term active institutional control program in five steps, each of which are described in more detail below:

- Step 1 - Identification of active institutional control measures
- Step 2 - Preparation of a post-decommissioning land management plan
- Step 3 - Gathering of data necessary for implementing active institutional control measures
- Step 4 - Preparation of the active institutional control plan
- Step 5 - Implementation of active institutional control measures.

Step 1 - Identification of Active Institutional Control Measures

The first step in the process of implementing the active institutional control program is to identify measures needed to satisfy the active institutional control requirements. It is anticipated that certain characteristics of active institutional control measures, such as minimizing bias toward the site, warning of potential hazards, providing meaningful data, preserving knowledge, using state-of-the-art technology, implementing such measures for at least 100 years, addressing the standards, and deterring systematic development, will be identified and used to judge the usefulness of active institutional control programs.

Certain active institutional controls are obvious at the outset. These include site access control, site remedial actions, site maintenance, control of releases, and monitoring. Information and specifications useful in implementing these and possibly other controls will be gathered. A detailed explanation of the active institutional controls is provided in Appendix AAC, *WIPP Active Access Controls after Disposal, Design Concept Description.* This is the DOE's reference design for active institutional controls upon which planning will be based. The reference design will be reviewed periodically and updated as appropriate during WIPP disposal operations. The ongoing review and evaluation ensure that the active institutional controls implemented are appropriate for the conditions that may exist at that time. The DOE will review the reference design prior to implementation and the EPA will be consulted as part of this review.

The final disposal activity at the repository will be the closing of the waste disposal area and sealing the shafts. Upon completion of this activity, the remaining surface structures will be dismantled. All surface structures, except for the concrete Hot Cell structure and a sufficient quantity of salt tailings to support construction of the permanent marker berm, will be removed and the site regraded and planted to return the site to as near its original condition as practicable and possible. In addition, those structures erected during the disposal phase as part of the permanent marker testing program will also remain in place after decommissioning. This will include a section of the berm and at least one monolithic marker erected as a part of the program for long-term testing of materials planned to be used for the permanent marker system.

As part of the active institutional controls program, the DOE has developed a set of design criteria upon which the active institutional controls will be based. These design criteria provide a description of how the active institutional controls will be implemented. These are as follows:

- A fence line shall be established to control access to the repository's footprint area (the waste disposal area projected to the surface). A standard wire fence shall be erected along the perimeter of the repository surface footprint. The fence shall have gates placed approximately midway along each of the four sides.

- An unpaved roadway along the perimeter of the barbed wire fence shall be constructed to provide ready vehicle access to any point around the fenced perimeter, to facilitate inspection and maintenance of the fence line, and to permit visual observation of the repository footprint to the extent permitted by the lay of the land. This roadway shall connect to the paved south access road.

- To ensure visual notification, the fence line shall be posted with signs having as a minimum a legend reading "Danger—Unauthorized Personnel Keep Out" and a warning against entering the area without specific permission of the DOE (or other local authority such as the Eddy County Sheriff's Office).

- Contractual arrangements shall be developed to ensure that periodic inspection and necessary corrective maintenance is conducted on the fence line, its associated warning signs, and the roadway.

- Through direct DOE staffing support and/or contractual arrangements, procedures shall be established to provide routine periodic patrols and surveillance of the protected area by personnel trained in security surveillance and investigation.

- Processes will be developed for monitoring and controlling the long-term testing requirements of the permanent marker system.

- Processes will be developed for implementing the periodic monitoring requirements of the disposal system's monitoring program.

- Recommendations will be developed for modifications to the active institutional controls appropriate for access control and surveillance upon installation of the permanent marker system.

- Guidelines will be developed for recommending mitigating actions to be taken to address any abnormal conditions identified during periodic surveillance and inspections.

- Reports of activities associated with the post-disposal active access controls shall be prepared in accordance with regulatory requirements for submittal to the appropriate regulatory and legislative authority.

Details on meeting these criteria are found in Appendix AAC.

Step 2 - Preparation of a Post-Decommissioning Land Management Plan

Section 13(b) of the LWA requires the DOE to prepare and submit by October 30, 1997, a plan for managing the land withdrawal area after decommissioning of the WIPP facility. This plan will include a description of both the active and passive institutional controls that will be imposed after decommissioning is complete. This plan will be prepared in consultation with the Department of Interior and the state of New Mexico.

Step 3 - Gathering of Data Necessary for Implementing Active Institutional Control Measures

Once the active institutional control measures have been identified, it may be useful to gather additional data to support implementation of those measures. This includes an ongoing assessment of conditions that could affect active institutional control. Information regarding land use and population trends gathered during the Disposal Phase will be taken into account in implementing post-decommissioning surveillance.

Step 4 - Preparation of the Active Institutional Control Plan

An active institutional control plan will be prepared as part of the overall site D&D strategy (see Appendix D&D for the *Conceptual Decontamination and Decommissioning Plan for the WIPP*). This written plan, which will be initiated prior to actual plant closure, will contain all the information needed to implement the active and passive institutional controls for the WIPP facility. Active institutional control planning will take into account the most current information regarding the facility and its vicinity and will make use of state-of-the-art materials and techniques. This plan will include acceptable decontamination levels, sampling and analysis plans, and Quality Assurance and Quality Control (QA/QC) specifications. It is anticipated that this plan will incorporate the items shown in Table 7-1.

Table 7-1. Proposed Contents of the Long-Term Protection Plan Addressing Active Institutional Controls

• Active Control Plans - Access control - Maintenance - Release control - Monitoring
• Remediation and Reclamation Plans for Site - Final salt disposition - Borehole plugging or sealing - Remedial actions for spills and releases - Restoration (roads, pads, etc.)
• Final Schedules and Commitments - National Environmental Policy Act (NEPA) requirements and commitments - RCRA requirements - Federal Land Policy and Management Act (FLPMA) requirements - Waste Isolation Pilot Plant Land Withdrawal Act (LWA) management responsibilities - Other regulatory requirements
• Sampling and Analysis Strategies and Protocols
• Quality Assurance and Quality Control

Step 5 - Implementation of Active Institutional Control Measures

Most of the active institutional control measures, such as long-term site monitoring and site remedial actions, will be implemented simultaneously with plant closure and decommissioning. However, it may be possible to implement some measures earlier. For example, salt disposal may begin prior to final plant closure. Reclamation and restoration of unused disturbed surface areas has already begun. Guarding and maintenance activities, which are already in place, could evolve into an appropriate type of post-closure activity.

7.1.4 Active Institutional Control Program Review and Oversight

The working agreement for consultation and cooperation with the state of New Mexico mandates that the state be given opportunity to review all plans related to decommissioning. In addition, the facility will be operated and closed under the permitting requirements of the RCRA and the NMHWA. Both the RCRA and the NMHWA mandate a formal submittal by the DOE and review by the NMED and the EPA of the Closure and Post-Closure Plan for the facility. Additionally, it is anticipated that any plan developed to satisfy this assurance requirement will be reviewed by the Environmental Evaluation Group (EEG), the BLM, the National Academy of Science (NAS), and the SLO.

7.2 Monitoring

Requirements for monitoring of a disposal system[1] are included in the standards to the extent such monitoring can be considered meaningful in terms of detecting any detrimental and significant deviation from expected performance. The DOE interprets this standard as a requirement that a monitoring program be used with regard to addressing uncertainties associated with the long-term performance predictions and that the time period over which diagnostic data can be collected be realistic in terms of exercising active institutional control over the site. Monitoring activities at the WIPP facility would most likely include the measurement of subsidence, among other things. In addition, groundwater sampling in the Rustler Formation (hereafter referred to as the Rustler) would continue.

Disposal system monitoring is addressed in § 194.42 of the proposed 40 CFR Part 194. The proposed requirement requires that a certification application contain a level of detail not currently available. The proposed requirement also requires that specific studies be performed in support of the monitoring program.

7.2.1 Disposal System Monitoring Requirements

Regarding disposal system monitoring, 40 CFR Part 191 specifies that:

> 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 (40 Part 191.14[b]).

Within this context, if determined to be feasible, monitoring becomes one of the measures to be implemented at the WIPP facility during the active institutional control period.

[1] "Disposal system" means "any combination of engineered and natural barriers that isolate...radioactive waste after disposal" (40 CFR § 191.12).

Monitoring a disposal system is intended to address "significant concerns" associated with the performance of the isolation system. The EPA points out that monitoring approaches to address "significant concerns" should be limited to those that could provide meaningful data in a relatively short time.

The DOE will design a monitoring system that will not jeopardize the integrity of the disposal system. Many different monitoring approaches will be considered to improve confidence that the repository is performing as intended. All of these considerations will be taken into account in the design of the long-term monitoring program for the WIPP facility.

7.2.2 Objectives of Disposal System Monitoring

As a result of the specific requirements contained in § 191.14(b), the long-term monitoring program at the WIPP facility shall have the objective of detecting substantial and detrimental deviation from the expected performance of the disposal system. This monitoring will be performed with a variety of techniques designed to detect detrimental deviations without jeopardizing waste isolation. With this objective in mind, selection and specification of monitoring activities will address the four following areas of performance:

- *Hydrological*—possibilities for hydrological monitoring include, but are not limited to, a long-term assessment of the assumptions made regarding the movement of fluids through the Rustler
- *Geological*—geological performance can be assessed by monitoring subsidence at the surface
- *Geochemical*—geochemical performance may be assessed to substantiate assumptions regarding waste characteristics, brine characteristics, and waste-rock interactions
- *Structural*—structural performance would include evaluations of man-made features such as shaft seals, plugs, and human intrusion barriers.

7.2.3 Disposal System Monitoring Program

The long-term monitoring program at the WIPP facility is, in a broad sense, a continuation of preoperational and operational monitoring activities to the extent that all of these monitoring activities support the general development and refinement of knowledge about the WIPP disposal system. The DOE envisions that the implementation described in the long-term monitoring program in this section will occur in steps. The steps represent the evolution of programs from the operational to the post-operational phases.

Specific steps anticipated for the disposal system monitoring program include the following, each of which are described in more detail below:

- Step 1 - Preparation of disposal system monitoring strategic plan
- Step 2 - Identification of disposal system monitoring programs
- Step 3 - Design and implementation of operational monitoring programs

- Step 4 - Design of post-operational monitoring programs
- Step 5 - Implementation of post-operational monitoring programs
- Step 6 - Operation of the disposal system monitoring program.

Step 1 - Preparation of Disposal System Monitoring Strategic Plan

The first step involves the preparation of a planning document that can be used to direct and focus subsequent activities. This strategic plan has been issued (DOE 1993c) and summarizes monitoring requirements as derived from 40 CFR Part 191 and other applicable regulations. The strategic plan discusses the integration required to demonstrate compliance to this portion of the standard.

Step 2 - Identification of Disposal System Monitoring Programs

Based on the disposal system monitoring requirements, a conceptual design for a disposal system monitoring system was developed. The details of the system are provided in Appendix LTM. Following an evaluation of current geophysical and experimental technologies, a disposal system monitoring system was conceived composed of a subsidence network, a monitoring program, and a baseline database. The monitoring program is broken down into two subgroups, subsidence and environmental and groundwater monitoring.

Subsidence Network. Several subsidence studies have been completed and are included in the following documents:

- *Final Environmental Impact Statement* (FEIS)
- *Final Safety Analysis Report* (FSAR)
- *Methodology and Results: Preliminary Comparison with 40 CFR Part 191, Part B for the Waste Isolation Pilot Plant*
- *Backfill Engineering Analysis Report.*

These reports evaluate the potential for and predict the subsidence due to the development of the repository, drifts, and rooms. These calculations account for a range of waste volumes, waste densities, and backfill types. Subsidence was also calculated for conditions where no backfill would be used. The *Backfill Engineering Analysis Report* (BEAR) contains the most detailed data on subsidence. Contour maps included in this report detail subsidence predictions using Influence Function and National Coal Board Methods with and without backfill. The maximum subsidence was also calculated using the mass conservation method. These studies were not specifically performed to estimate subsidence for monitoring the repository performance in the long term, and they do not account for other factors that may influence subsidence such as local hydrocarbon extraction and local potash mining. A subsidence data study will predict subsidence related to repository performance and will investigate factors that influence subsidence. The goal of the study is to calculate subsidence predictions with respect to time for the repository and define the bounding limits that may indicate poor repository performance.

The Subsidence Data Study (SDS) will define the most favorable positions for any additional benchmarks and oversee their placement in the network. In order to monitor subsidence, a network of benchmarks must be placed over the area of interest. Benchmarks have been installed over and around the general vicinity of the WIPP. These benchmarks are adequate for initial data gathering. However, the current network is too coarse to provide sufficient data points to accurately define subsidence over the repository for the long term. Contour plots of expected subsidence in the BEAR show that the maximum subsidence can occur in a circular area with a radius as small as 1,000 feet (305 meters); most of the current benchmarks are 1,000 feet (305 meters) apart. Powers (1993) has recommended placing a network over the repository footprint that would extend 2,000 feet (610 meters) past the 4-square-mile (10-square-kilometer) site boundary. This would encompass the entire predicted subsidence area for angles of draw up to 45 degrees. Additional benchmarks shall be placed to increase the density over the repository. These new benchmarks shall be installed after completion of the SDS. The SDS will evaluate and determine the quantity and placement of the benchmarks to best determine subsidence.

After establishing the supplemental benchmark locations, benchmarks that meet the National Geodetic Survey (NGS) Class I, first-order standards will be installed and surveyed. All placement and survey data will be documented in the baseline database. Provisions will be made to maintain and replace benchmarks when required and to coordinate benchmark placement with the passive markers design. This coordination has been noted in the Permanent Markers Study which is included as Appendix PMR.

Subsidence Monitoring Program. The Monitoring Program consists of monitoring the subsidence network and, for a limited period, environmental and groundwater monitoring. Subsidence monitoring is accomplished with a Class I Leveling Survey. The surveys will be performed every 10 years during the operational phase and thereafter in accordance with the Disposal System Monitoring Program schedule.

The leveling surveys will be performed as described in a QA/QC procedure to ensure the data are documented and validated. The data will be included in the baseline database. A procedure will be developed to implement the monitoring program.

The Monitoring Program includes the following:

- Management of the Disposal Phase Monitoring Program
- Maintenance of monitoring procedures and QC/QA documents
- Performance of all monitoring
- Maintenance of the subsidence network
- Maintenance of the monitoring schedule
- Maintenance and storage of baseline database
- Review of data and evaluation of performance
- Eventual decommissioning of the Disposal System Monitoring Program
- Archiving of monitoring data.

Baseline Database. Establishment of environmental monitoring baselines for both radiological and nonradiological parameters was completed by compilation and publication of baseline reports. These programs have transitioned into the disposal phase; pertinent data collection continues and will continue through the life of the project. Implementation of the operational environmental monitoring is contained in the *WIPP Environmental Monitoring Plan* (EMP) (DOE 1994).

Preoperational data are contained in the following documents:

- *Statistical Summary of the Radiological Baseline Program for the WIPP*
- *Summary of the Salt Impact Studies at the WIPP, 1984–1990*
- *Study of Disturbed Land Reclamation Techniques for the WIPP*
- *Background Water Quality Characterization Report for the WIPP*

The EMP, which was transitioned from the preoperational programs, includes monitoring a comprehensive set of parameters to detect any potential environmental impact. The ecological portions of the program focus on the immediate area surrounding the facility, whereas radiological surveillance generally covers a broader geographic area, including nearby ranches, villages, and cities. This environmental monitoring will continue throughout the project's disposal and closure phases. Any impacts will be determined by a quantitative analysis comparing operational monitoring results against previously collected data. Data from ongoing environmental monitoring are published annually.

The SDS will generate subsidence predictions and compile the technical information from experiments performed during the developmental and operational phases of the WIPP. These data will be included in a database. This database will also contain data specific to the repository's geophysical, hydrological, geochemical, and structural nature at the end of the disposal phase when the repository is sealed.

The database will also contain data from previous monitoring studies and data from specific surveys and monitoring techniques performed immediately after closure of the repository. These surveys will be performed only once after closure to establish the geologic condition of the area at the start of the post-closure phase. An evaluation of geophysical methods was performed to determine which methods should be used to establish a baseline of the repository after closure. The following techniques were chosen because they meet the requirements, they are non-intrusive, they are implemented from the surface, and they provide data that are useful in interpreting the repository's geophysical, structural and hydrological condition. All post-closure monitoring techniques that would be physically conducted in the repository were excluded (see Appendix LTM for a discussion on direct repository monitoring).

The following monitoring technologies were chosen to be evaluated as candidates for disposal system monitoring:

- Subsidence surveys
- Seismic surveys

- Gravitational surveys
- Electromagnetic surveys
- Resistivity surveys
- Aerial radiological surveys.

Each of these techniques is evaluated in Appendix LTM. A determination was made to include all past data for geophysical surveys conducted during site selection and operation. At closure, several geophysical surveys will be performed to obtain baseline data on the geophysical condition of the repository and surrounding area. Seismic reflection and refraction, gravitational, electromagnetic, and resistivity surveys will be performed. No baseline environmental surveys are required since a baseline has previously been established. All data and explicit descriptions of the equipment, data reduction techniques, and procedures used will be included in the database. All sensor placements will be surveyed and recorded. Where possible, some of the original survey lines will be used. The Closure Review Study, described in Step 5 below, will also determine specific survey lines to be included.

Step 3 - Design and Implementation of Operational Monitoring Programs

Some long-term monitoring programs, such as the subsidence monitoring program, may benefit from data that are collected during operations. These data collection programs will provide data to support the design of post-operational monitoring programs and data to address the uncertainty in long-term performance predictions.

In addition, proposed 40 CFR § 194.42(b) requires DOE to address preclosure monitoring as part of the certification process. Pre-closure monitoring is not addressed in this draft application.

Step 4 - Design of Post-Operational Monitoring Programs

This step includes the detailed design and planning required to implement and operate post-operational monitoring programs. Part of this step may include the identification of data needs relative to monitoring program design and implementation. These data needs will be turned into technical directives to support the long-term monitoring programs.

Step 5 - Implementation of Post-Operational Monitoring Programs

This activity involves the actual construction, installation, and checkout of monitoring instruments. This activity also includes procedures for sample collection and analysis, as well as management of data generated by the monitoring instruments. Because the initial disposal system monitoring plan will be written at least 25 years prior to closing the facility, a review of technology, regulations, site management, safety requirements and public opinions will occur prior to implementation to assess advancements and changes over this time period. This review of the Disposal System Monitoring Plan is called the Closure Review Study (CRS) and will occur prior to closure to assure compliance and safety.

A CRS will be initiated to evaluate the Disposal System Monitoring Plan and update all aspects that are not current. This plan will review the data in the baseline database and all governing regulatory issues associated with long-term monitoring of the facility. The CRS will determine what monitoring is required, what will be monitored, what equipment and techniques will be used, and which area will be monitored. A feasibility study will evaluate technology available at that time that can be used to accomplish this task.

The CRS will update the schedules, define organizational responsibilities, and provide interface to the active institutional control activities.

Step 6 - Operation of the Disposal System Monitoring Program

Operation of monitoring programs may begin during facility operations if appropriate operational monitoring programs are identified. The total scope of the disposal system monitoring program will be included in the active institutional controls plan. The Disposal System Monitoring Program will also be included in the closure and post-closure portion of a No-Migration Determination issued by the EPA pursuant to RCRA.

7.2.4 Disposal System Monitoring Program Review and Oversight

Selection and specification of monitoring programs will be reviewed by appropriate regulatory (EPA and NMED) and oversight (NAS and EEG) organizations. Typically, disposal site monitoring becomes an integral part of decommissioning and post-decommissioning activities.

7.3 Passive Institutional Controls

Section 194.43 of the proposed 40 CFR Part 194 addresses passive institutional controls. This section requires a level of detail not formerly identified in the regulatory requirements of 40 CFR Part 191. Proposed 40 CFR § 194.25 and § 194.26 may also have an impact upon this section. These sections address future state assumptions and expert judgment but are not considered in the following text.

Passive institutional controls include markers that warn of the presence of buried nuclear waste and identify: (1) the boundary of the disposal area footprint, (2) external records about the WIPP repository, and (3) continued federal ownership. Implementation of passive institutional controls is mandated in the Assurance Requirements provisions of 40 CFR Part 191. The EPA intends for the implementing agency to provide comprehensive actions that will increase the likelihood that knowledge and information about the disposal site and its contents are passed on to future generations. For the purposes of compliance with 40 CFR Part 191, the EPA does not assume that passive controls will prevent all possibility of intrusion, but such controls will deter any systematic development of a site. The DOE will meet this requirement by installing a series of physical markers and written records to preserve knowledge of the site in perpetuity. The DOE will implement passive institutional controls in a manner that provides defense in depth. That is, the passive institutional control system will involve multiple types and multiple levels of passive controls to provide the assurance needed that human intrusion into the disposal site is unlikely. To accomplish this, the DOE intends to use several types of monuments and markers, land ownership, and written notations in land records in numerous locations. Written documentation will include information on the site, its use, and its contents, as well as stipulations on allowable land uses.

Passive institutional controls, as opposed to active institutional controls (see 40 CFR § 191.14[a]), are controls that once established, can be expected to remain effective with minimal human surveillance and maintenance, or maintenance resulting from normal governmental activities. Passive controls may be instituted at the site, a remote location, or both.

The following steps have been identified to support implementation of passive institutional controls for the WIPP:

- Step 1 - Definition of passive institutional controls appropriate for the WIPP
- Step 2 - Development of a passive institutional control implementation plan
- Step 3 - Design and implementation of pre-decommissioning passive controls
- Step 4 - Implementation of programs to collect needed information
- Step 5 - Design of post-decommissioning passive institutional controls
- Step 6 - Implementation of post-decommissioning passive institutional controls.

7.3.1 Passive Institutional Control Requirements

Unlike the other assurance requirements which provide performance standards for facilities, the EPA describes technical standards by way of specific measures (markers, records, and federal ownership) that it considers to be necessary parts of the passive institutional control program. The DOE interprets the phrase "federal ownership and regulations regarding land or resource use" to mean that the DOE or some successor agency with nuclear waste management expertise will retain administrative control over the land in accordance with Appendix C of 40 CFR Part 191. "Administrative control" means that the federal agency responsible for the land will institute regulations that impose appropriate restriction on land use and development. Regarding the WIPP facility, the DOE interprets the term "markers" to include any on-site structures engineered and constructed as a means of preserving knowledge of the location of the wastes and conveying associated hazards. The DOE interprets "records" to include any written information regarding the site and its contents, which are maintained to preserve knowledge of the site. The DOE intends to use passive institutional controls throughout the entire controlled area.

The remainder of this section details requirements for passive institutional control.

In the FEIS, the DOE commits to a final design of record maintenance and site marker systems using state-of-the-art materials and methods prior to decommissioning. The three principal components of the systems are (1) written records, (2) location markers for all shafts, and (3) visible warning markers. The component "written records" involves maintenance of written documentation of the WIPP in both federal and local public document depositories. The component "markers" consists of showing the locations of shafts with permanent surveyor markings engraved with the elevation and coordinates and firmly anchored to the shaft plug. Finally, the component "site monuments" involves a visible site monument that will serve to minimize the possibility of intrusion into the repository during the short term; it may be the most durable record of the repository in the long term.

In the proposed and final No-Migration Determination for the WIPP facility, the EPA discussed the use of passive controls as part of an overall strategy to protect a land disposal facility and to decrease the likelihood of human disruption. The EPA believes that, in the context of RCRA no-migration variance decisions, the question of human intrusion, either during operations or after closure, is best addressed through a consideration of the likelihood of intrusion, and the imposition of controls to make such intrusions unlikely events. The EPA emphasizes that this approach to human intrusion is consistent with its general approach under RCRA, both in permitting and variances. Under RCRA, the EPA typically relies on institutional controls (both active and passive) imposed through general regulatory standards and site-specific conditions (e.g., in RCRA permits) to ensure that access to a hazardous waste disposal site is appropriately restricted. EPA believes that any permanent no-migration variance for the WIPP will have to impose long-term passive institutional controls, such as land withdrawal, records, and markers—to ensure that the likelihood of human intrusion is appropriately reduced, even after active control of the facility has ceased and any permits at the site may have terminated.

The DOE is committed to retaining control over the WIPP site for as long as possible. Accordingly, an extensive system of explanatory markers and records will be instituted to warn future generations about the location and dangers of these wastes. It has not been assumed that these passive controls will prevent all possibilities of inadvertent human intrusion, because there will always be a realistic chance that some individuals will overlook or misunderstand the markers and records. (For example, exploratory drilling operations occasionally intrude into areas that clearly would have been avoided if existing information had been obtained and properly evaluated.) However, the agency assumed that society in general will retain knowledge about these wastes and that future societies should be able to deter systematic or persistent exploitation of a disposal site.

7.3.2 Objectives of the Passive Institutional Controls

As prescribed by the standards, the objective of the DOE's passive institutional control program for the WIPP is to accomplish the following:

- Ensure a record of the disposal site and its contents are preserved
- Warn those who attempt to enter the disposal site vicinity of the hazards associated with activities that would disturb the subsurface.

The DOE believes that passive institutional controls will render human intrusion sufficiently unlikely so that the possibility need not be included in the complementary cumulative distribution function.

7.3.3 Passive Institutional Control Implementation

The DOE will implement passive institutional controls in an effort to ensure that knowledge of the presence of the facility is not lost to future generations. Passive institutional controls include: (1) markers warning of the presence of buried nuclear waste and identifying the boundary of the disposal area footprint, (2) external records about the WIPP repository, and (3) continued federal ownership. The disposal area footprint is the underground waste disposal area projected to the surface. The DOE strategy is to design and implement, to the extent practicable, passive controls that will warn future generations of the dangers of intruding.

A substantial amount of work has been completed in the area of passive controls at the WIPP facility.

- *DOE Ownership.* The DOE has been successful in gaining control of the surface of the 16-section WIPP site and the subsurface to a depth of 6,000 feet (1,829 meters), including the acquisition of oil, gas, and potash leases. The area now under the control of the DOE includes the following sections in Township 22 South, Range 31 East: 15, 16, 17, 18, 19, 20, 21, 22, 27, 28, 29, 30, 31, 32, 33, and 34.

- *Land Use Controls.* Land use controls have been implemented addressing allowable uses of the withdrawal area. These are described in Appendix AAC, *WIPP Active Access Controls after Disposal, Design Concept Description.*

Beyond land ownership and implementation of use controls, which are the key preclosure passive controls, there are six steps that have been identified for the WIPP passive institutional control program.

Step 1 - Definition of Passive Institutional Controls Appropriate for the WIPP

The process of defining the passive institutional controls for the WIPP disposal site is based on the controls identified in 40 CFR § 191.12. This includes items such as records, markers, monuments, legal documentation, federal control, land use restrictions, and other methods of preserving knowledge.

The current conceptual design for post-closure passive institutional controls is described in Appendix PMR, *Permanent Marker Design Report.* The design includes:

- Large surface monuments and earthen structures to mark the repository footprint
- One or more on-site buried rooms for the long-term storage of messages describing the nature of the repository

- Small subsurface markers
- Off-site archival storage of information pertaining to the WIPP, including its potential hazards.

Three concepts for configuration of the earthen structures, arrangement of the monument markers, and placement of the archival storage rooms within the perimeter of the repository footprint are under consideration. Diagrams representing these three concepts are provided in Appendix PMR. The diagrams are Figures X-1, X-2, XI-1, and XII-1.

The first concept consists of a large earthworks configured in the shape of a trefoil centered above the repository surface's footprint center. An Information Center is also placed at the center with large monoliths arranged along the footprint perimeter and outside the trefoil. Two storage rooms are located east and west of the trefoil center. Each of these rooms is buried approximately 20 feet (6 meters) below the footprint surface. A second configuration consists of a large earthen berm enclosing the footprint perimeter. The large monoliths are arranged just inside the berm along the footprint perimeter. The locations of the Information Center and the storage rooms are geographically similar to the trefoil concept with small warning markers buried throughout the footprint surface. The third concept includes several large earthen berm-like structures arranged in a pattern intended to convey a menacing appearance. The structures "radiate" out from the footprint perimeter as outlined by the monoliths. The four corner sections are significantly larger than the other sections. Within each corner section is buried a storage room. The Information Center is located at the footprint center. Again, the small warning markers are buried throughout the footprint surface area.

The two fundamental aspects of post-closure passive institutional controls will be markers and archived records. Markers include monuments and earthworks whereas records involve long-term storage of information. Both of these aspects are discussed in greater detail in the following sections.

Markers. Two groups of experts were established to examine the issues involved with selecting, designing, and implementing an effective system of permanent markers. Hora et al. (1991) is a report by the Futures Panel (FP) discussing the "underlying physical and societal factors that would influence society and the likely modes of human-intrusion at the WIPP." The FP members also developed probabilities of various alternative futures, of inadvertent human intrusion, and in some cases, of particular modes of intrusion.

The Hora et al. report was an important reference and source of information for the preparation of Trauth et al. (1993). Trauth et al. (1993) reports the results of the Markers Panel (MP), which considered various concepts of marking the site and conveying to future generations information regarding the presence of dangerous waste material and the potential consequence of intrusion into the waste repository. The MP made estimates of the probability that components of the marker system would survive and that various future societies would comprehend the messages as a function of time. The resulting *Permanent Marker Conceptual Design Report* (Appendix PMR) is an expansion of the ideas developed by the MP.

The *Permanent Marker Conceptual Design Report* (Appendix PMR) sets forth the permanent markers system for the WIPP facility. This system involves the use of surface monuments, small subsurface warning markers, and large earthen structures marking the WIPP repository footprint on the surface.

The surface monuments are large monoliths erected on the surface. Small warning markers will be buried throughout the repository footprint. To facilitate fabrication and shipping of the monoliths, each monolith will consist of two separate stones connected by a tendon joint. The large monoliths will be engraved with Level II and III messages as described in Appendix PMR. Figure V-1 of Appendix PMR provides the dimensional characteristics of the large monoliths. Each monolith will be inscribed with the Level II and III messages in seven languages, the six official United Nations languages (English, French, Spanish, Chinese, Russian, and Arabic) and Navajo. Trauth et al. (1993) discusses in some detail the selection of these languages by the MP. The Navaho language was chosen because it represents the language of a much larger population of Native Americans indigenous to the Southwest than does the Apache language.

It is not necessary to specifically inscribe Level I messages. Such messages are conveyed by the physical form of the marker system and the effort expended in constructing it. In addition, each monolith will be inscribed with a diagram (Figures IV-2 and IV-4 of Appendix PMR) depicting two concepts. The first concept is comprised of four frames illustrating the danger of digging or drilling into the repository and releasing the radioactive and toxic waste. The second concept illustrates the decay of the radioactive material (decreasing size of the trefoil and improving disposition of the icon) over many thousands of years by depicting the precession of the earth's north pole through the major constellations (Ursa Minor, Ursa Major, Draco, and Cygnus) and the bright star, Vega.

The monoliths will be quarried from granite or other dimensional stone and shipped by rail to the WIPP site. Monolith locations will be excavated to at least 5 feet (1.5 meters) into the caliche. After emplacing the base monolith, the upper monolith will be placed over the base tendon and the excavation will be backfilled. This will provide for suitably supporting the base monolith within the caliche deposit or the Gatuña Formation even under conditions in which the overlying layer of sand is removed through erosion or other weathering phenomena.

The small warning marker is shown in Figure V-2 of Appendix PMR. The Level II message placed on the small subsurface warning markers will also be in the seven languages listed above. However, each marker will have the message in only one of the seven languages. Warning markers will be placed throughout the repository footprint and within the berm. The warning markers will be made of a diversity of materials and thus improve the likelihood that at least some of the markers will endure for a 10,000-year period.

The small buried warning markers will be spaced to provide a reasonable expectation of their discovery by any organized effort to explore at depths of the repository footprint; however, they will be buried at a depth below that which would be encountered from deep plowing and the protocol governing amateur archaeologists in New Mexico, but above the caliche. Based on discussions with local drilling operators, the standard procedure for a drilling crew to follow is to remove the surface soil down to the caliche layer over an area sufficiently large to set up the drilling rig and a mud pit. Nominally this area is 50,000 square feet (4,648 square meters). By placing the small warning markers above the caliche at intervals of a few feet, several of the warning markers should be unearthed during the soil clearing operation. This provides a reasonable likelihood that at least one of the warning markers would be discovered by a drilling crew.

The inclusion of a berm or berm-like structure in the permanent marker design is based upon the following arguments (see Appendix PMR for more detail):

- The surface footprint of the repository should be essentially outlined by some enduring structure
- The structure should be sufficiently massive to provide reasonable assurance that it will endure for 10,000 years
- The structure's profile should minimize the likelihood that it can become buried by shifting sands or that characteristics of the profile may lead to fabrication stresses affecting the ability of the structure to retain its configuration
- It should be constructable without the need for high-tech equipment or processes
- Its construction materials should be reasonably available to the WIPP site and have little intrinsic value
- Its cost should be competitive with other alternatives, i.e., its cost should not be disproportionately high for the advantages it provides
- To the extent practicable, the nature of the structure should lend itself to testing over a period of 2–5 decades.

A berm-like configuration is proposed to be used to define the repository footprint. A berm satisfies the criteria listed above to a greater extent than any of the other configurations proposed. Each of the conceptual design configurations described below makes use of a berm configuration. Although the individual configurations may have an outwardly different appearance, their construction consists of similar materials and material placement. Figure VIII-1 of Appendix PMR depicts the general cross-sectional berm construction configuration. The core base material to be used is salt remaining from the excavation of the repository. The design capacity of the repository of 6,200,000 cubic feet (175,600 cubic meters) of waste will provide a significant amount of mined salt remaining after closure. The salt is proposed to be used to form the core of the berm(s). Although the salt would be susceptible to water and wind erosion, using it as a base core material with other material applied over the salt will effectively protect the salt.

A practical and locally available protective covering for the salt core is the caliche soil found locally up to 15 feet (4.6 meters) below the surface. Large quantities are available. The caliche is reasonably impervious to water penetration in the semiarid environment of the WIPP. Studies of the locale report that even at the height of an ice age, the annual rainfall is not expected to more than double its current 13 inches (33 centimeters) per year average (DOE 1980).

A third layer of berm material will be comprised of riprap quarried near Carlsbad, New Mexico. This will provide protection for the caliche from wind erosion. It will also provide for runoff of rainwater to the surrounding desert without water erosion of the caliche layer. The final layer of berm material will consist of a mixture of riprap and native soil. This should support local vegetation and add another erosion-resistant characteristic to the overall berm configuration.

During the disposal phase of the WIPP, testing will be conducted to determine what combination of rock sizes, soil types, and vegetation provide the best likelihood of success, at least in the near term (100 years). This will include evaluations of the optimal thicknesses of the various materials used to construct the berms.

To provide a distinctive magnetic signature for the berm, large permanent magnets buried in the berm can be used. Large strontium ferrite permanent magnets buried within the berm at intervals of 246–328 feet (75–100 meters) would give a signal detectable with current state-of-the-art airborne equipment 328 feet (100 meters) above the magnets. The individual magnets would be approximately 3.3 feet (1 meter) in length and 1.5 foot-by-1.5 foot, (0.5 meter-by-0.5 meter) in cross-section. Should future climatic conditions cause sand shifts so extensive that the berm and monoliths become covered (which is not expected), future generations conducting magnetic surveys of the area should still be able to detect a magnetic anomaly resulting from the permanent magnets. The magnetic signal's geometric form will provide strong indication that it could only have been man-made. This should inspire any organization capable of magnetic surveying to investigate this anomaly further prior to initiating any planned drilling activities in the local area enclosed by the magnetic signature.

Bellus and Eckeman (1994) provides a description of the use of trihedrals fabricated from metal as a means of providing a radar reflective signature unique from the surrounding terrain. Figure VIII-2 of Appendix PMR illustrates the basic trihedral configuration. Current ground-penetrating radars operate below 100 megahertz. Much of the communication allocations occupy frequencies below 100 megahertz; therefore, radars operating below this range must use filters to avoid problems with communications bands. Bellus and Eckeman report that recent experience in the Middle East with SeaSat operating at 1.2 gigahertz produced excellent images of roads and structures buried under the desert.

The dimensional characteristics of a trihedral facet that will give a peak Radar Cross-Section (RCS) are three times the wavelength of the incident radar signal. Assuming a radar operating at 1 gigahertz, a trihedral with facets measuring 3 feet (0.9 meters) on a side will be optimal. This according to Bellus and Eckeman (1994) will provide a peak RCS of 17 decibels per square meter per square meter. The typical peak terrain RCS is -15 decibels per square meter per square meter. The difference in RCS strength operating at 1 gigahertz is 32 decibels per square meter per square meter. This will give a highly visible signal. The trihedrals will be fabricated from stainless steel and placed within the berm at the surface of the salt core. To provide a unique radar signature, the trihedrals will be grouped in sets of four spaced approximately every 300 feet (91 meters) around in the berm as shown in Figure VIII-3 of Appendix PMR. In addition, four trihedrals will be placed around each of the buried rooms to provide a unique radar signature at the room location. One trihedral will be placed adjacent to each room exterior wall approximately midway along the wall. During the testing period conducted throughout the disposal phase and for some period after decommissioning, buried bare stainless steel trihedrals and trihedrals encased in concrete should be evaluated for performance of their respective RCS. Encasing the trihedral in concrete reduces the likelihood of its being efficiently salvaged and also may add to the effective lifetime of the trihedral by the protective concrete covering.

Records. The *Permanent Marker Conceptual Design Report* (Appendix PMR) sets forth the post-closure records management system for the WIPP facility. The post-closure records management system that will be implemented to preserve information on the WIPP facility involves the use of on-site rooms for long-term storage of messages and archival storage of WIPP information offsite.

The on-site room or rooms for containing the Level IV message and associated diagrams will be designed to endure for the 10,000-year period of the permanent marker system. The design characteristics contributing to this longevity are the material and environmental conditions associated with construction and location. The room or rooms will be made of granite with a minimum number of joints. Individual walls, the floor, and the roof will be comprised of single granite slabs joined only at the perimeter locations. The internal walls will each be made of three sections to provide redundancy of the information provided. Figure VI-1 of Appendix PMR is an isometric view of the planned buried storage room containing the Level IV message. The magnets shown in the figure are to permit locating the rooms magnetically. Figures VI-2 through VI-4 of Appendix PMR show views of the building from the top, the side, and the end. They include overall dimensional characteristics. The configuration minimizes the risk of failure due to chemical interactions between the construction material, the joining materials, and the environment.

In each of the conceptual design configurations, at least one room is buried. In addition, the Information Center will be located on the surface providing access to the information contained in the buried rooms. This should limit the incentive to excavate the buried rooms by future generations. Details regarding the location of the buried storage rooms containing identical information will be in the Information Center. It is anticipated that distribution of archival information regarding the WIPP site in local, state, federal, and international repositories will also preclude the need for future generations to excavate and enter any of the buried rooms for a significant number of years. If, through societal changes, calamities, or loss of the archival information, society cannot determine what the buried room(s) contain, then it is assumed that at least one of the rooms will be entered and observed. If a decision is made to construct the permanent marker system immediately after closure of the WIPP, active controls established and funded by the U.S. Government should preclude entry into any of the buried rooms for at least 100 years. A delay in construction of the permanent marker system may present a potential risk of the disturbance of the buried rooms. However, a significant effort will be required to fully excavate the rooms, and even occasional surveillance by local law enforcement personnel should thwart any significant damage to the rooms by vandalism or souvenir hunters.

The message texts contained within the buried rooms are to be engraved on the walls in the arrangement similar to that for the Information Center shown in Figure VII-1 of Appendix PMR. To provide redundancy, additional granite slabs engraved with the message text and the diagrams are held in place against the interior walls. The room entrance is a single plug in one wall. The tapered plug weighs approximately 1,600 pounds (727 kilograms). Its removal will require the efforts of more than a single individual in all likelihood. The opening is small so that the room contents cannot be removed easily by an unorganized group or individuals intent on vandalism. Although some damage could be inflicted by vandals, the granite composition of the message carrying materials provides the greatest opportunity for preventing complete destruction of the information contained within the buried room.

A significant part of the overall system is the archiving of important information remote from the repository. The archived material will include information that is important to defining the location, design, content, and hazards associated with the WIPP. The amount of information will be more extensive than that available within the permanent marker system at the repository footprint location. The information, however, will be widely distributed in a number of locations, including some locations worldwide.

The initial form of the information should be on archival quality paper and high-quality microfilm. Jensen (1993) describes a specification which prescribes that the archival quality paper contain fibers from cotton, linen, and/or bleached chemical pulp with any other type pulp making up less than 5 percent of the fiber content. In addition the pH is specified as 7.5–10 with a minimum 2 percent calcium carbonate alkaline reserve. Microfilm specifications will be consistent with those recommended by recognized authorities such as the National Archives.

Specific documents which will be included in the archived information portfolio include:

- Detailed maps describing the exact location of the repository
- The FSAR and the addenda which describes the disposal phase of the WIPP
- The FEIS for WIPP and the Supplement(s) to the Environmental Impact Statement
- The No-Migration Variance Petition and the No-Migration Determination for Disposal
- The RCRA Permit
- The Certification of Compliance with 40 CFR Part 191 and associated application
- Environmental and ecological background data collected during the preoperational phase of WIPP and summaries of data collected during the disposal and decommissioning phases of WIPP
- Records of the waste containers' contents and disposal locations within the WIPP repository
- Drawings defining the construction and configuration of the repository and shafts
- Drawings, procedures, and the design report(s) describing how the waste was emplaced; how the repository was decommissioned, closed and sealed; and how the shafts were backfilled and sealed.

The organization identified as the recordholder responsible for the permanent storage of this information is the National Archives. In addition, other locations for this information will include publicly funded organizations which may expend the resources necessary to preserve the documents in well-controlled environments. However, the most likely strategy for long-term protection of the information is through widespread distribution. The information will be submitted to the following facilities and organizations for archiving:

- Library of Congress
- Within the states of New Mexico and Texas
  - The state archives
  - The state library
  - The city libraries of population centers exceeding 15,000 within 150 miles of Carlsbad
- The state libraries of the remaining 48 states
- The local office of the Bureau of Land Management
- The local office of the Bureau of Mines
- The local office of the Bureau of Reclamation
- The national library and national archives of the nations worldwide which possess nuclear weapons and/or operate nuclear power generating plants
- The archive of the United Nations
- The national archive and libraries of the signatory nations to the nuclear non-proliferation treaty
- The U.S. Nuclear Regulatory Commission
- The 53 federal regional depository libraries
- The American Nuclear Society.

This list of receiving organizations will be reviewed and expanded, as appropriate, as the time of the actual transfer of the information approaches.

Location and hazards information will be submitted to various federal and state of New Mexico mapping agencies to ensure that the WIPP location and drilling or mining restrictions are identified on widely distributed maps used by almost all public and private organizations. These agencies include:

- BLM
- U.S. Geological Survey
- Library of Congress
- National Archives and Records Service
- Defense Mapping Agency
- International Boundary Commission
- Federal Highway Administration
- New Mexico State Highway Department Planning and Research Division, Cartography Section.

To ensure widespread location information of the WIPP site and the hazards associated with the emplaced waste, detailed maps and descriptions of the hazardous material will be sent to national and international professional societies of cartographers and geographers. Weitzberg (1982) suggests the following organizations and societies receive this location and hazards information:

- The American Congress on Surveying and Mapping
- The American Society of Cartographers
- The Commission for the Geological Map of the World
- The International Cartographic Association
- The American Geographical Society
- The Association of American Geographers
- The International Geographical Union
- The Society of Women Geographers
- The American Geological Institute
- The American Geophysical Union
- The American Society of Professional Geographers
- The National Geographic Society
- The Federal Aviation Administration.

Step 2 - Development of a Passive Institutional Control Implementation Plan

Once the appropriate passive institutional controls have been defined, a strategy will be prepared that includes final design, construction, and implementation. The strategy will identify site-specific information needs and approaches to obtaining needed technical and non-technical information.

There are some passive institutional control activities that can be implemented prior to the end of operations. For example, once wastes are permanently placed in the repository, appropriate notations can be made in land records.

Step 3 - Design and Implementation of Predecommissioning Passive Controls

Predecommissioning passive controls, such as land records, will be implemented and evaluated to the extent possible. For example, the effectiveness of DOE's land management plans will be assessed periodically to assure only acceptable land use is in effect.

Step 4 - Implementation of Programs to Collect Needed Information

Programs may be necessary to support implementation of passive institutional control activities with site-specific information. These program needs will be identified during the development of a passive institutional control implementation strategy Step 2.

Planned Evaluations. Upon closure of the WIPP at the conclusion of the Disposal Phase, active controls will be implemented to control access to the site. In addition, monitoring systems will be managed to detect significant deviations in repository performance. With active control provided over the site, the schedule for construction of the permanent marker system is a management option which could be extended for decades. In that the design of the permanent marker system has a 10,000-year lifetime goal, it is prudent that the DOE conduct some testing of the construction materials planned for use as permanent marker material.

Berms. One aspect of the testing is the construction of a section of the berm. The overall size (height and width) of the test section of the berm will match the design of the permanent marker berm. However, the test berm length will be shorter than the full-sized berm. A section approximately 164–328 feet (50–100 meters) long will be sufficient to test a number of different configurations. Included within the test section will be varying thicknesses of the salt core, the caliche layer, and the top layer of riprap and soil material. The DOE will construct a section of the berm for the purpose of evaluating materials and construction techniques. Actual construction and testing will be initiated during the Disposal Phase to provide sufficient time for testing.

The major subjects to be addressed during this testing program are as follows:

- Evaluating a system for unloading and moving large quantities of material from the railroad spur to the permanent marker site
- Assessing the performance and required maintenance of the railroad spur—this may impact a decision of whether to conduct periodic maintenance of the spur or refurbish it when constructing the permanent marker system
- Surveying representative monuments within a 150-mile (240-kilometer) radius of the WIPP to more extensively evaluate the climatic environmental affects on granite
- Identifying a suitable local source of caliche and establishing the required contractual and regulatory agreements to obtain and move the caliche in the quantities required
- Identifying a suitable local source of riprap and establishing the required contractual and regulatory agreements to obtain and move the riprap in the quantities required
- Determining what, if any, configuration changes may have significant impacts on the cost of constructing the large berm
- Evaluating various berm surface materials (e.g., size of rocks, types of soil, types of vegetation) for durability, resistance to animal burrowing, and success in supporting vegetation overgrowth.

Monuments. Another aspect of passive controls to be evaluated during testing is monuments. The major considerations that will be evaluated include the following:

- Procuring, shipping, erecting test monuments, and evaluating long-term environmental effects of wind, rain, and shifting sand for various types of dimensional stone
- Evaluating the magnetic signature provided by sample permanent magnets buried within the berm to determine optimum locations and spacing

- Evaluating the affects of various soils used as protective backfill for dimensional stone
- Evaluating the effects of chemical interaction with the backfill material
- Evaluating the environmental effects on the berm caused by wind, rain, and shifting sand
- Evaluating the effects of plant root intrusion into the berm and potential for salt dissolution and berm slumping
- Evaluating the effectiveness of sample radar reflectors buried within the berm at various distances
- Developing cost estimates for various options of configurations and materials tested.

Messages. Messages will also need to be evaluated during the testing program. The primary aspects of the messages program to be evaluated include the following:

- Evaluation of message text by presenting it to groups indigenous to the countries whose language is represented in the message
- Evaluation of message text by presenting it to linguists to assess the likelihood that the messages will continue to be understood through time.

Step 5 - Design of Post-Decommissioning Passive Institutional Controls

This activity will use results derived from information gathering programs in Step 4 to make final decisions on passive institutional control measures. Passive control implementation plans will be included as a portion of the WIPP long-term protection strategy and will include maintaining federal ownership, markers and monuments, surface modifications and controls, permanent written records, legal records, and land use identification and restriction.

Step 6 - Implementation of Post-Decommissioning Passive Institutional Controls

The final step involves constructing and installing the post-decommissioning passive institutional control measures. Additionally, a system for reviewing and approving the markers and other passive measures would be established.

7.4 Multiple Barriers

Section 194.44 of the proposed 40 CFR Part 194 addresses the use of barriers. In particular it addresses the use of engineered barriers and imposes additional requirements. It requires that the DOE perform cost-versus-benefit evaluations of potential barriers and dictates the manner in which these evaluations are performed. If the rule is promulgated as proposed, this section will be revised as necessary to reflect the new requirements.

Section 8(g) of the LWA addresses waste form modifications and the use of natural and engineered barriers. The DOE interprets the term "natural barriers" to include the salt formation, its favorable characteristics, and the geohydrologic setting. Engineered barriers include, for example, the repository, closure systems, and seals that serve to substantially delay the movement of contaminants to the accessible environment.

The WIPP facility will incorporate multiple engineered barriers, including plugs, seals, and, if appropriate, backfill. The DOE has recently determined that salt backfill emplaced during disposal operations for the purposes of filling voids or mitigating fires is not needed and has deleted this material from the base facility design. In the event that a function is identified for a material around the waste (such as a gas getter, sorbent material, or a pH buffer), the specification and development of this material as an engineered alternative will be subjected to a design development process in which the specific performance criteria are determined and material characteristics are engineered to meet these criteria. As a part of the WIPP's incorporation of multiple barriers, an Engineered Alternatives Task Force (EATF) evaluated optional additional engineering measures for the WIPP facility. The findings of the task force are summarized in the *Evaluation of the Effectiveness and Feasibility of the Waste Isolation Pilot Plant Engineered Alternatives,* July 1991. The DOE is conducting another review of engineered alternatives, including engineered barriers, as the result of an agreement between the DOE and the EPA. Not all engineered alternatives meet the definition of an engineered barrier, although many do. The review will update the EATF activity and augment it with more in-depth and comprehensive analyses of the relative benefits and detriments of the alternatives. Benefits and detriments at the waste generation and storage sites will be evaluated as well as those at the WIPP. Guidance regarding this study as provided by the EPA in its proposed rule, 40 CFR Part 194, will be followed. This evaluation is due for completion in late 1995; results of the study are planned to be included in the final compliance package.

7.4.1 Multiple Barrier Requirements

By requiring the use of both engineered and natural barrier types as an assurance requirement, the EPA intends to ensure that the impacts of the failure of any one barrier type will be minimized.

Requirements for multiple barriers are as follows:

- The EPA requires that both engineered and natural barriers be used (40 CFR Part 191). Barriers are designed to impede the movement of radionuclides into the accessible environment.

- The LWA states that "the Secretary shall use both engineered and natural barriers, and waste form modifications, at WIPP to isolate transuranic waste after disposal to the extent necessary to comply with the final disposal regulations." The DOE interprets this to mean that implementation of any combination of engineered and natural barriers and waste form modifications necessary for containment will be sufficient to comply with this requirement.

- In the second modification to the Consultation and Cooperation Agreement with the State of New Mexico (DOE 1987), the DOE commits to the use of both engineered and natural barriers. In particular, it states on page 5 that "the barriers shall include, as a minimum, properly designed backfill, plugs and seals in the drifts and at the entries to the panels, and plugs and seals in the shafts and boreholes."

7.4.2 Objectives of Multiple Barriers

The primary objective for the implementation of multiple barriers at the WIPP facility is to provide a disposal system that isolates the radioactive wastes to the levels required by 40 CFR Part 191. This is being accomplished by a design that includes multiple types of barriers. Current research and development programs being conducted by Sandia National Laboratories (SNL) are supporting this design effort.

7.4.3 Multiple Barrier Implementation

The baseline design for the WIPP facility includes the concept of multiple barriers for isolation and containment of mixed TRU waste. Barriers considered include natural barriers (hydrological, geological, and geochemical conditions), engineered alternatives barriers (plugs and repository seals), and, if needed, additional engineered barriers such as waste packaging and waste form modifications. The effectiveness of these barriers is being modeled by the performance assessment to demonstrate the ability of the system to meet the EPA standards.

7.4.4 Multiple Barrier Review and Oversight

Oversight and review of the WIPP engineered barriers will continue to be performed by the NMED, the EEG, and the NAS. In accordance with the LWA, the EPA will review WIPP engineered barriers as part of its certification of compliance with the standards.

7.5 Resource Characteristics Evaluations

The EPA specifies that locations containing recoverable resources should not be used unless it can be shown that the favorable characteristics of the location compensate for the greater likelihood of being disturbed in the future. At the WIPP site, the intent of this assurance requirement was met during site screening and selection. The DOE has issued a finding (Appendix IRD) that the decision-making process adequately considered the likelihood of the location being disturbed in the future for resources. The results of this finding are discussed below.

7.5.1 Resource Consideration Requirements

The EPA discourages the location of repositories in areas in which valuable natural resources are present.

The purpose of the requirement is to provide assurance that site selection actions further reduce the likelihood of future intrusion into the repository by preferring those sites without currently recognized resources. Sites containing resources are acceptable provided the potentially favorable characteristics of the site outweigh any increased risks.

7.5.2 Objectives of Resource Considerations

The WIPP site selection occurred prior to promulgation of the standards. Resource considerations were included in the site selection process for the WIPP and are documented in the WIPP FEIS. The objective of the program for demonstrating compliance with the resource considerations requirement is to document the rationale used in the decision-making process.

7.5.3 Resource Consideration Implementation

The WIPP site was selected prior to promulgation of the standard. Resource considerations were, however, included in the site selection process for the WIPP and are documented in the WIPP FEIS (DOE 1980). The FEIS describes a four-step decision-making process that was applied to siting the repository. This process is summarized below:

- Step 1 - Bedded salt was selected as the most promising geologic medium, and geographic regions that contain extensive bedded salt formations were identified. This was accomplished by gathering and evaluating existing information concerning rock types and their geographic distribution. Desirable criteria were identified and the most favorable regions were identified.

- Step 2 - A literature review was performed to narrow the number of regions identified in Step 1. Once a region was selected, candidate sites within the region were chosen. Selection criteria were used to compare the sites. Those sites which satisfied the most criteria were selected for further evaluation. Resource-conflict considerations were applied on a broad scale at this stage of the process.

- Step 3 - The candidate sites identified in Step 2 were subjected to further investigations covering geology, hydrology, archaeology, demography, and biological resources. The results of all the site evaluations were compared, and the site that best met the selection criteria was selected for additional site characterization. At this stage, the types and quantities of natural resources present at the site were considered in detail.

- Step 4 - In this final step, a detailed system analysis was performed. This analysis addressed the specific geologic environment, the waste forms, the disposal facility design, and the potential failure modes in respect to radiation safety and environmental impact.

The rationale for selecting the WIPP site is further documented in a summary report titled *Implementation of the Resource Disincentive in 40 CFR Part 191.14(e) at the Waste Isolation Pilot Plant* (DOE 1993a). This report, which is included as Appendix IRD, documents that the presence of resources has been considered in major project decisions.

Analysis of the performance of the repository is underway to determine what measures (such as engineered alternatives, additional experiments, or waste restrictions), if any, are required to assure that the WIPP will comply with the 40 CFR Part 191 containment requirements, even in the event that inadvertent intrusion into the repository occurs. The results of these analyses will be discussed in the final compliance documentation.

7.5.4 Resource Considerations Review and Oversight

The resource considerations report was issued in September 1991 and distributed to the EEG, the EPA, and the NMED. Comments have been addressed and DOE issued a revised report in February 1993. The final report is included in Appendix IRD.

7.6 Waste Removal

Assurance is required that it will be technologically feasible to locate and recover the waste for a reasonable period of time after disposal. In promulgating the standards, the EPA stated that "*any* current concept for a mined geologic repository meets this requirement *without* any additional procedures or design features" (EPA 1985, p. 38082, emphasis added).

The WIPP facility is a mined repository. No additional actions other than documentation to meet this assurance requirement are considered necessary. The rationale for this assurance requirement is to preclude use of some disposal technologies that would not permit future generations to recover the wastes should they decide to do so. Recovery need not be easy or inexpensive, but only possible.

7.6.1 Waste Removal Implementation

"To meet this assurance requirement, it only need be technologically feasible (assuming current technology levels) to be able to mine the sealed repository and recover the waste—albeit at substantial cost and occupational risk" (EPA 1985). To illustrate that waste removal is feasible, Appendix WRAC describes a system using available mining technologies.

After determining the existing repository condition, the mining and waste removal operations will be designed to minimize the amount of contamination and exposure to allow limited human access for assessments, equipment retrieval, and repairs. All operations will be designed to reduce or eliminate human involvement. Any radiological work will be performed using standard industry practices and approved procedures.

Mining operations will use standard equipment to sink the shafts and excavate the drifts and support rooms. Smaller scale mining equipment will be used to perform the removal. Minor modifications to the equipment will enable the vehicles and support equipment to be remotely controlled and handle the waste material not usually associated with mining activities.

Sampling will be implemented to ensure that the contact-handled (CH) and remote-handled (RH) wastes are still segregated from one another sufficiently to allow separate removal. If commingling has occurred, then it may be necessary to manage all of the waste as RH. If wastes are not commingled, RH and CH wastes will be retrieved in separate operations.

The removal concept is composed of the following five phases:

- Phase 1 - Planning and permitting
- Phase 2 - Initial above ground setup and shaft sinking
- Phase 3 - Underground excavation and facility setup: setup of underground ventilation, radiation control, packaging areas, decontamination areas, maintenance, remote control center, and personnel support rooms
- Phase 4 - Waste location and removal operations: mining waste removal, packaging, package surveying and decontamination, transportation to surface, staging for off-site transportation, and off-site transportation
- Phase 5 - Closure: D&D of the facility.

Each of the five phases is summarized below and described in detail in Appendix WRAC.

Removal of the waste after the repository is sealed is possible. Since the repository was initially mined to provide the repository rooms, access to the waste can be accomplished using the same mining technologies. Location and removal is also possible using the same equipment modified to operate remotely. The requirement to remove most of the waste eliminates the need to prove that all waste residues have been removed. Packaging the removed waste and decontamination of the containers can be accomplished with standard automation techniques.

Phase 1 - Planning and Permitting (P&P)

The need to remove waste would initiate the P&P phase. Permitting requirements will be based on governing regulations at the time removal is authorized. The P&P program will identify all permits and research the available technologies at that time to determine the appropriate removal techniques and the waste and repository conditions. After initial research is completed, a plan will be drafted to itemize and schedule all removal activities.

Phase 2 - Initial Above Ground Setup and Shaft Sinking

Aboveground support buildings will be required to house the exhaust fans and filters, administration, maintenance support facilities, control center waste staging and decontamination areas, and warehouse (containers).

A shielded area will be required to handle and store the RH transuranic (TRU) containers and casks prior to off-site shipment. Shafts will be appropriately located and sunk.

Phase 3 - Underground Excavation and Facility Setup

After the shafts are completed, drifts will be run and ventilation paths will be established using air control regulators. Support rooms will be excavated for maintenance, control rooms, and packaging areas. Air locks will be constructed to isolate the clean areas from the contaminated areas. All equipment required for removal, packaging, and all related support equipment will be installed.

Excavation will be in two phases. Initial excavation will not contact waste but will mine support rooms and haulage drifts that provide ventilation and access to the waste panels. The second phase will remove the waste.

Phase 4 - Waste Location and Removal Operations

The CH TRU and RH TRU waste removal will be performed in separate operations. The CH TRU waste will be removed by mining the area where this waste was emplaced. The CH TRU waste and all surrounding rock will be removed and transported to the packaging areas without disturbing the RH TRU waste. The CH TRU waste can be removed many ways using standard equipment. Appendix WRAC contains a brief description and feasibility of using various mining techniques for waste removal.

The RH TRU waste will be removed by excavating the rock salt around the waste and removing it in as intact condition as possible. This waste may be placed in a waste container at the work place and then transported to the packaging area. The RH TRU waste will be removed after the CH TRU waste is excavated. Equipment will be set up to remove and excavate the materials around the waste. Waste will be loaded into a container and moved to the packaging area. The container may be decontaminated at the packaging area, if possible, or overpacked prior to shipment above ground. After decontamination is completed, the RH TRU waste is transported to the surface and is warehoused in a shielded area prior to off-site shipping. Radiation surveying and decontamination procedures will be similar to the CH TRU operations.

Phase 5 - Closure

After waste is removed from the repository, the facility will be decommissioned per the current regulations at that time.

7.6.2 Waste Removal Review and Oversight

The WIPP is a mined geologic repository and, as such, meets the requirement without any additional design requirements since current technology can be used to retrieve the waste if the need arises. Proposed 40 CFR § 194.46 requires DOE to submit a plan for removal of waste. A plan is not included in this draft application.

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8.0 INDIVIDUAL AND GROUNDWATER PROTECTION REQUIREMENTS

The quantitative release limits set forth in the Containment Requirements provisions of Title 40 Code of Federal Regulations (CFR) § 191.13 are one of three long-term numerical performance requirements contained in 40 CFR Part 191. The Waste Isolation Pilot Plant (WIPP) must also comply with numerical performance standards contained in the individual and groundwater protection requirements. This section describes the U.S. Department of Energy's (DOE's) demonstration of compliance for the WIPP with both the individual and groundwater protection requirements. A description of undisturbed performance and the conceptual models to support the compliance demonstration associated with these requirements are described in Chapter 6.

Some of the requirements of the U.S. Environmental Protection Agency's (EPA's) proposed rule 40 CFR Part 194 that may affect the information presented in the chapter have not been implemented. These areas are identified where appropriate.

8.1 Individual Protection Requirements

The individual protection requirements are contained in § 191.15 of the long-term disposal regulations. Section 191.15(a) requires that:

> Disposal systems for waste and any associated radioactive material shall be designed to provide a reasonable expectation that, for 10,000 years after disposal, undisturbed performance of the disposal system shall not cause the annual committed effective does, received through all potential pathways from the disposal system to any member of the public in the accessible environment, to exceed 15 millirems (150 microsieverts).

"Undisturbed performance" is defined in 40 CFR Part 191 to mean "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" (§ 191.12). "Undisturbed performance" is the same as the "base case" for scenario selection purposes.

The method used to evaluate compliance with the individual protection requirements is related to that developed for assessing compliance with the containment requirements. The base-case scenario for the containment requirements describes undisturbed conditions. If the evaluation of the base-case behavior shows contaminants will reach the accessible environment, the resulting dose to exposed individuals may be calculated and compared to the 15-millirem annual committed effective dose standard specified in § 191.15.

Based on the scenario development process described in Chapter 6, two potential pathways for groundwater flow and radionuclide transport are possible in the undisturbed disposal system:

- In the first path, a pressure gradient between the waste disposal panels and the Culebra Dolomite Member (hereafter referred to as the Culebra) causes brine and radionuclides to migrate from the waste disposal panels to the base of the shafts and up the shafts toward the Culebra.

- The second path for brine and radionuclide migration from the undisturbed repository is laterally through anhydrite interbeds toward the subsurface boundary of the accessible environment in the Salado Formation.

Although these are possible pathways, the modeling analyses reported in Chapter 6 indicate only the first is a potential pathway during the 10,000-year period of interest specified in the regulation.

The proposed 40 CFR Part 194 specifies further requirements. Doses must be estimated for an individual who resides at the location in the accessible environment where that individual would be expected to receive the highest exposure from radionuclide releases from the disposal system (proposed 40 CFR § 194.51). In addition, all potential pathways for exposure associated with the undisturbed performance of the repository must be assessed (proposed 40 CFR § 194.52). As provided by the future state assumptions of proposed 40 CFR § 194.25, unless otherwise specified, it shall be assumed that current conditions continue into the future.

Formal dose calculations, as required by 40 CFR § 191.15, have not been performed for the purposes of this draft Compliance Certification Application. If the final compliance calculations indicate releases to the accessible environment under undisturbed conditions, formal dose calculations will be developed and presented. However, using the exposure pathway analyses presented in the Supplemental Environmental Impact Statement (SEIS) for the WIPP (DOE 1990), bounding doses for the releases reported in Chapter 6 may be estimated.

The analyses presented in the SEIS identify the "stock pond–to–cow–to–man" pathway as being the most important, in terms of delivering the maximum exposure to an individual. This pathway consists of a hypothetical well pumping water from the Culebra to a stock water tank. Cattle then drink the water and are subsequently consumed by humans. Under present-day conditions for undisturbed performance, this pathway dominates all others by orders of magnitude.

The SEIS analysis is supported by Sandia National Laboratories (SNL) report *Systems Analysis, Long-Term Radionuclide Transport, and Dose Assessments, Waste Isolation Pilot Plant (WIPP) Southeastern New Mexico* (Lappin et al. 1990). Lappin et al. (1989) reports concentrations of radionuclides in the Culebra at the stock-well location and lists the resulting dose levels for the "stock pond–to–cow–to–man" pathway. Doses of less than 10^{-8} millirem per year may be derived by extracting the peak concentrations of radionuclides for the highest release reported in Chapter 6 (the total over all radionuclides is equal to 10^{-3} picocuries per liter), by assuming that the total concentration is due to plutonium, and by scaling linearly to a dose estimate based on SEIS information.

The estimated bounding dose of less than 10^{-8} millirem per year is much lower than the annual dose that is received from background sources, which is about 100 millirem per year. In addition, the bounding dose estimate is based on concentrations expected to occur at the WIPP site boundary and not at the nearest location where present-day potable water is believed to first be available in the Culebra (about 3 miles [5 kilometers] from the WIPP facility). Furthermore, this is not a mean estimate; it is based on the largest release observed in the 60 realizations performed. The mean value is about 1/60th of the 10^{-8} millirem-per-year estimate. The bounding dose estimate indicated from the releases reported in Chapter 6 is many orders of magnitude below the background doses and the § 191.15 standard of 15 millirem per year. Based on this bounding analysis (and conditional on the finalization of the Chapter 6 analyses), the DOE believes that compliance with the individual protection standard can be demonstrated. The DOE has not yet conducted the formal calculation required in 40 CFR § 194.55.

8.2 Groundwater Protection Requirements

The groundwater protection requirements are contained in Subpart C of 40 CFR Part 191. In particular § 191.24(a)(1) requires that:

> *General.* Disposal systems for waste and any associated radioactive material shall be designed to provide a reasonable expectation that 10,000 years of undisturbed performance after disposal shall not cause the levels of radioactivity in any underground source of drinking water, in the accessible environment, to exceed the limits specified in 40 CFR Part 141 as they exist on January 19, 1994.

The "levels of radioactivity" specified in 40 CFR Part 141, as of January 19, 1994 were:

1. Combined ^{226}Ra and ^{228}Ra (§ 141.15[a]): 5 picocuries per liter
2. Gross alpha particle activity, including ^{226}Ra but excluding radon and uranium (§ 141.15[b]): 15 picocuries per liter

The base-case analysis of the undisturbed performance of the WIPP presented in Chapter 6 shows that the total concentration of all radionuclides reaching the accessible environment is 10^{-3} picocuries per liter.

Information regarding the concentrations of naturally occurring radionuclides in groundwater in the vicinity of the WIPP is presented in Section 2.4.4.4.2 and in Table 2-9. The data in Table 2-9 indicate background concentrations in excess of the levels of radioactivity specified in 40 CFR Part 141. The range of the mean values shown for ^{226}Ra is about 19 to 140 picocuries per liter (6.9×10^{-4} to 52×10^{-4} becquerels per gram). The mean ^{228}Ra concentration shown in Table 2-9 is about 26 picocuries per liter (9.6×10^{-4} becquerels per gram).

The DOE has not yet performed the formal compliance assessment required by 40 CFR § 194.55.

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GLOSSARY OF TERMS

40 CFR PART 191. *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes.* This regulation sets environmental radiation protection standards for management (Subpart A) and disposal (Subparts B and C) of spent nuclear fuel and high-level and transuranic radioactive wastes.

40 CFR PART 194. This regulation, required by the LWA, will provide EPA's criteria for certifying compliance with the final disposal standards.

40 CFR PART 261. *Identification and Listing of Hazardous Waste.* This part identifies those solid wastes which are subject to regulation as hazardous wastes under Parts 262–265, 268, 270, 271, and 124 of Title 40 of the Code of Federal Regulations.

40 CFR PART 264. *Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities.* This subpart establishes minimum national standards which define the acceptable management of hazardous waste.

40 CFR PART 264. Subpart G. This subpart of 40 CFR Part 264 defines closure and post-closure requirements pertaining to hazardous waste management units.

40 CFR PART 264. Subpart X. This subpart specifies requirements that apply to owners and operators of facilities that treat, store, or dispose of hazardous waste in miscellaneous hazardous waste management units.

40 CFR PART 268. This regulation restricts the land disposal of hazardous waste and specifies treatment standards and/or treatment technologies that must be met or applied before hazardous wastes may be land disposed. Section 268.6 provides for petitioning to allow land disposal of untreated hazardous waste if it can be demonstrated to a reasonable degree of certainty that there will be no migration of hazardous constituents from the disposal unit for as long as the waste remains hazardous.

40 CFR PART 270. This regulation establishes provisions for the Hazardous Waste Permitting Program under Subtitle C of RCRA. This regulation and the associated State of New Mexico regulation require the permitting of the WIPP as a hazardous waste management unit.

ACCESSIBLE ENVIRONMENT. "(1) [T]he atmosphere, (2) land surfaces, (3) surface waters, (4) oceans, and (5) all of the lithosphere that is beyond the controlled area." (40 CFR § 191.12)

ACTINIDE. An element in the actinide series beginning with element 89 and continuing through element 103. All the transuranic nuclides considered in this document are actinides.

ACTINIDE SOURCE TERM. The fraction of the total radionuclide inventory of a disposal room or repository that can be mobilized for transport.

ACTIVE INSTITUTIONAL CONTROL. (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. (40 CFR § 191.12)

ACTIVITY. A measure of the rate at which a material emits nuclear radiation, usually given in terms of the number of nuclear disintegrations occurring in a given length of time. The unit of activity used in this document is the curie (Ci).

ADSORPTION. (1) Bonding, frequently ionic, of a substance to soil or some other medium. A substance is said to be adsorbed if the concentration in the boundary region of a soil particle is greater than in the interior of the continuous phase. (2) Adherence of gas molecules, or of ions or molecules in solution, to the surface of solids with which they are in contact.

AIR LOCK. An intermediate chamber between zones of different static pressure.

ALARA. As Low As Reasonably Achievable; radiation protection program for minimizing personnel exposures.

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 radiation.

ALTERNATIVE CONCEPTUAL MODELS. An alternative set of assumptions that describe the same system for the same purpose and are consistent with the existing information.

ALTERNATIVE CONTAINER MATERIALS. Container materials, other than mild steel, that reduce and/or eliminate gas generation from corrosion in the range of expected Waste Isolation Pilot Plant environments.

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

ANNUAL COMMITTED EFFECTIVE DOSE. The committed effective dose resulting from a 1-year intake of radionuclides released plus the annual effective dose caused by direct radiation from facilities or activities subject to Subparts B and C of 40 CFR Part 191. (40 CFR § 191.12)

ANOXIC CORROSION. Corrosion of metals in the absence of oxygen by anaerobic bacteria.

ANTICLINE. A fold of rocks whose core contains the stratigraphically older rocks; it is convex upward.

AQUIFER. An underground geological formation or part of a formation that is capable of yielding a significant amount of water to a well or spring. (40 CFR § 191.12)

ARENACEOUS. Of the texture or character of sand.

ARGILLACEOUS ROCKS. Rocks containing appreciable amounts of clay, especially shale.

ARTESIAN. Refers to water confined underground under pressure so that it will rise in a well. Sometimes the word is used to mean that the water flows out at the surface, but that, strictly speaking, is "flowing artesian."

BACKFILL. Material placed around the waste containers, filling the open space in the disposal room.

BACKGROUND (RADIATION). Radiation in the human environment from naturally occurring elements, from cosmic radiation, and from fallout.

BARRIER. "[A]ny material or structure that prevents or substantially delays movement of water and/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." (40 CFR § 191.12) Barriers also prevent or delay the movement of hazardous constituents.

BASE CASE. The base case for the Waste Isolation Pilot Plant performance assessment is the behavior of the repository in the absence of human intrusion. Also called the "undisturbed performance" of the repository.

BASELINE INVENTORY REPORT. Baseline waste inventory report for all nuclear wastes in the DOE complex.

BELL CANYON FORMATION. A sequence of rock strata that form the uppermost formation of the Delaware Mountain Group (Early Permian). It is immediately below the Castile Formation at about 4,000 feet below the surface. May contain some oil and gas.

BENTONITE. A commercial term applied to expansive clay materials containing montmorillonite (smectite) as the essential mineral.

BETA PARTICLE. A negatively charged particle emitted in the radioactive decay of certain nuclides; a free electron.

BIODEGRADATION. The process of consumption by microbial substances—usually organic materials such as cellulosics.

BIOLOGICAL HALF-LIFE. The time required for an organism to eliminate half the amount of a radionuclide ingested or inhaled.

BOREHOLE. (1) A hole drilled from the surface for purposes of geologic or hydrologic testing, injection, or exploration for resources; sometimes referred to as a drillhole. (2) A man-made hole in the wall, floor, or ceiling of a subsurface room used for verifying geology, making observations, or emplacing canisters of remote-handled transuranic waste.

BRAGFLO. The name of the computer model Sandia National Laboratories uses to determine effects of gas on the flow of brine through the repository and up an intrusion borehole.

BRINE. Saline water containing calcium (Ca), sodium (Na), potassium (K), chlorides (Cl), and minor amounts of other elements located in deep sedimentary basins.

BRINE POCKET. *See* BRINE RESERVOIR.

BRINE RESERVOIR. A volume of brine of limited extent trapped within fractures and/or intergranular pore spaces of a host rock and usually pressurized relative to normal formation fluids. Such pockets may exist under various conditions of stress and solute concentration. Pressurized brine pockets have been observed in the Castile Formation.

BUFFERED HUMID CONDITIONS. Under long-term conditions, the absolute (and relative) humidities within the Waste Isolation Pilot Plant are expected to be buffered by the activity of water in adjacent portions of the Salado Formation.

CALCITE. Calcium carbonate ($CaCO_3$).

CALIBRATE. To vary parameters of an applied computational model within a reasonable range until differences between observed data and computed values are minimized.

CALICHE. A limy material commonly found in layers on or within the surface of stony soils of arid or semiarid regions. It occurs in the form of gravels, sands, silts, and clays cemented together by calcium carbonate (lime) or as crusts at the surface of the soil.

CAMBRIAN. The first oldest period of the Paleozoic Era.

CANISTER. As used in this document, a container, usually cylindrical, for remotely handled TRU waste. The waste will remain in this canister during and after burial. A canister affords physical containment but not shielding; shielding is provided during shipment by a cask.

CAPITAN REEF. A buried fossil limestone reef of Permian age that rings the Delaware Basin except in the south.

CARBONATES. A compound containing the radical CO_3^{+2}, for example, a calcium and magnesium mineral such as $CaMg(CO_3)_2$, dolomite.

CARLSBAD POTASH DISTRICT. The area east of Carlsbad and north and west of the Los Medaños site formally designated by the U.S. Geological Survey as having potentially economic grades of potash mineralization.

CASK. A massive shipping container providing shielding for highly radioactive materials and holding one or more canisters.

CASTILE FORMATION. A formation of evaporite rocks (mainly anhydrite with a few halite interbeds) of Permian age that immediately underlies the Salado Formation in which the WIPP disposal level may be built. May contain brine pockets.

CAVINGS. During exploratory drilling, waste that erodes from the borehole wall in response to the upward-flowing drilling fluid within the annulus formed by the drill pipe and the borehole wall.

CENTRAL BASIN PLATFORM. The geological region covering an area of several hundreds of square miles separating the Delaware and Midland basins.

CERTIFICATION. Any action taken by the Administrator of the U.S. Environmental Protection Agency under Section 8(d) of the WIPP Land Withdrawal Act.

CENTRAL MONITORING ROOM (CMR). A room at the WIPP facility equipped to monitor alarm functions and provide reliable communications.

CENTRAL MONITORING SYSTEM (CMS). A computer system that monitors the WIPP facility instrumentation; operated from the Central Monitoring Room.

CERTIFIER. In the context of 40 CFR Part 191, the "certifier" is the U.S. Environmental Protection Agency which must certify whether the Department of Energy has demonstrated that the Waste Isolation Pilot Plant is in compliance with the requirements of the standard.

CHEMICAL SOURCE TERM. The fraction of the hazardous constituents inventory that can be mobilized for transport.

COLLOIDAL SOLUTION. A liquid colloidal suspension is often referred to as a solution. Since colloidal particles are larger than molecules, it is technically incorrect to call such "dispersions" solutions; however, this term is used widely in the literature.

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION. A graphical representation of the probability of exceeding the radionuclide release limits specified in 40 CFR Part 191 (ordinate) compared to the consequences of exceeding the limits (abscissa). The consequence measure for releases, as defined by the Containment Requirements of 40 CFR Part 191, is the normalized sum of releases of individual radionuclides.

COMPLIANCE EVALUATION. The assessment of compliance of a mined geologic waste repository. Titles 40 CFR Part 191 and 40 CFR § 268.6 require such evaluations be made to demonstrate that a reasonable degree of certainty (40 CFR § 268.6) or a reasonable expectation (40 CFR Part 191) that the performance standards will be met.

COMPUTATIONAL MODEL. The computational model is the implementation of the mathematical model. The implementation may be through analytical or numerical means. Often the analytical solution is numerically evaluated (e.g., numerical integration or evaluation of complex functions); hence, both solution techniques are typically coded on the computer. Consequently, the computational model is often called a computer model.

COMPUTER MODEL. A computer code to implement a corresponding mathematical model either by evaluating an analytical solution or by using a numerical technique.

CONCEPTUAL MODEL. A set of assumptions, usually qualitative, used to describe and represent a system for some analytical purpose. For a physical system, these assumptions address the system's geometry and dimensionality, initial and boundary conditions, time dependence, material properties, internal processes, and any other characteristics relevant to its behavior. The assumptions should be consistent with one another and with the known properties of the system within the context of its intended analytical purpose.

CONDITIONAL DISTRIBUTION FUNCTION. A summary representation of risk. A display of information pertaining to events that may occur, the likelihood of their occurrence, and the consequences of their occurrence. Families of conditional distribution functions are used to display complementary cumulative distribution functions and can be used to infer the relative accuracy of the complementary cumulative distribution function.

CONFIRMATION. For the purposes of this document, a term used to indicate support or establishment of certainty and/or validity of models used in reference to specific performance issues of the repository over any specific time frame of interest. In general, laboratory and field experiments at the Waste Isolation Pilot Plant and elsewhere are conducted to provide data in support of this type of activity, such as for the gas generation model. Confirmation is used in a mechanistic sense and is not intended to have specific legal implications (*see* VALIDATION).

CONSERVATIVE. As a term used with predictions or estimates, "conservative" means leaning on the side of pessimism. A conservative estimate is one in which the uncertain inputs are used in a way that maximizes an adverse impact.

CONSULTATION AND COOPERATION AGREEMENT. An agreement that affirms the intent of the Secretary of Energy to consult and cooperate with the State of New Mexico with respect to State public health and safety concerns. The term "Agreement" means the July 1, 1981, Agreement for Consultation and Cooperation, as amended by the November 30, 1984, "First Modification," the August 4, 1987, "Second Modification," and the March 22, 1988, modification to the Working Agreement.

CONTACT-HANDLED WASTE. Transuranic waste that has a measured radiation dose rate at the container surface of 200 millirems per hour or less and can be safely handled without special equipment when placed in containers.

CONTAINMENT. The retention of radioactivity within prescribed boundaries, such as within a waste package. In this document, containment usually refers to retention within a system to exclude its release to the biosphere in unacceptable quantities or concentrations.

CONTAMINATION. Undesirable radioactive material present on outside surfaces. This contamination can be either transferable or fixed. Radiation penetrating the walls of a waste package from within is not contamination.

CONTROLLED AREA. The 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 5 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. (40 CFR § 191.12)

CORROSIVITY. The tendency of a metal to deteriorate by chemical attack.

CREEP. A very slow, usually continuous, time-dependent movement of soil or rock; refers to the geologic phenomenon experienced as the gradual flow of salt under compressive loading.

CREEP CLOSURE. Closure of underground openings, especially openings in salt, by plastic flow of the surrounding rock under lithostatic pressure.

CULEBRA DOLOMITE. The lower of two layers of dolomite within the Rustler Formation that are locally water bearing.

CULTURAL RESOURCE SITES. Human-associated ruins of archaeologic significance.

CURIE. A quantitative measure of radioactivity equal to 3.7 x 10^{10} disintegrations per second.

CUTTINGS. During exploratory drilling, waste contained in the cylindrical volume created by the cutting action of the drill bit through the waste. This volume is approximated by the cross-sectional area of the drill bit multiplied by the repository thickness.

DAUGHTER PRODUCT. A nuclide that results from radioactive decay. Thus radium-226 decays to radon-220, which in turn decays to polonium-216. The radon is the daughter of the radium, and polonium is its daughter.

DECAY, RADIOACTIVE. The decrease in the number of radioactive nuclei present in a radioactive material due to their spontaneous transmutation. Also, the transmutation of a radionuclide into another nuclide by the emission of a charged particle.

DECOMMISSIONING. Actions taken upon abandonment of the repository to reduce potential environmental, health, and safety impacts, including repository sealing as well as activities to stabilize, reduce, or remove radioactive materials or demolish surface structures.

DECOMMISSIONING PHASE. The term "decommissioning phase" means the period of time beginning with the end of the disposal phase and ending when all shafts at the Waste Isolation Pilot Plant repository have been backfilled and sealed.

DECONTAMINATION. The removal of unwanted material (especially radioactive material) from the surface or from within another material.

DEFENSE HIGH-LEVEL WASTE (DHLW). High-level radioactive waste generated as a result of DOE's national defense activities and programs.

DEFENSE WASTE. Nuclear waste deriving from the manufacture of nuclear weapons and the operation of naval reactors. Associated activities such as the research carried on in the weapons laboratories also produce defense waste.

DELAWARE BASIN. An area in southeastern New Mexico and adjacent parts of Texas where a sea deposited large thicknesses of evaporites some 200 million years ago. It is partially surrounded by the Capitan Reef.

DELAWARE MOUNTAIN GROUP. A set of three formations that underlie the Castile Formation at the Los Medaños site. The uppermost of these is the Bell Canyon Formation.

DERIVED AIR CONCENTRATION (DAC). Equals the Annual Limit on Intake (ALI) (of a radionuclide) divided by the volume of air inhaled by Reference Man in a working year (i.e., 2.4×10^3 m^3). The unit of DAC is becquerels per cubic meter.

DESATURATE. To remove liquid from a material to reduce the degree of saturation. If all the liquid is removed from pores and cracks, the material is said to be completely dried.

DESIGN BASIS EARTHQUAKE (DBE). An earthquake that is the most severe design basis accident of this type and that produces the vibratory ground motion for which safety class items are designed to remain functional.

DESIGN BASIS TORNADO (DBT). A tornado that is the most severe design basis accident of that type applicable to the area under consideration.

DEVONIAN WOODFORD SHALE. This is a Devonian-age geological marker about 15,600 feet deep that separates the Silurian era from the Mississippian era.

DEWEY LAKE (REDBEDS). Uppermost geologic formation layered on top of the Rustler Formation.

DIFFUSION, MOLECULAR. Movement of a contaminant due to the cumulative effect of the random motions of molecules.

DISCHARGE POINT (OR AREA). In groundwater hydraulics, the point (or area) where water comes out of an aquifer onto the surface.

DISPOSAL. The term "disposal" means permanent isolation of transuranic waste from the accessible environment with no intent of recovery, whether or not such isolation permits the recovery of such waste. Disposal of waste in a mined geologic repository occurs when the waste has been emplaced and all the shafts to the repository are sealed.

DISPOSAL FACILITY. A facility or part of a facility into which hazardous waste is intentionally placed and in which hazardous waste will remain after closure.

DISPOSAL PHASE. The term "disposal phase" means the period of time during which transuranic waste is disposed of at the Waste Isolation Pilot Plant, beginning with the initial emplacement of transuranic waste underground for disposal and ending when the last container of transuranic waste is emplaced underground for disposal.

DISPOSAL ROOM. An excavated cavity in the Waste Isolation Pilot Plant underground in which transuranic waste will be emplaced during disposal operations.

DISPOSAL SYSTEM. The disposal system is any combination of engineered and natural barriers that isolate transuranic waste after disposal. For the purposes of the Waste Isolation Pilot Plant, this will include the combination of the repository/shaft system and the controlled area.

DISSOLUTION. The process whereby a space or cavity in or between rocks is formed by the solution of part of the rock material.

DISTURBED ROCK ZONE. That portion of the geologic barrier of which the physical and/or chemical properties may have changed significantly as a result of underground construction activities.

DOLOMITE. A sedimentary rock consisting mostly of the mineral dolomite: $CaMg(CO_3)_2$. It is commonly found with limestone.

DOME (BRECCIA PIPE). A type of hill found near the Los Medaños site; under at least a few of these hills lies a roughly cylindrical volume of breccia pipes (rock reconstituted of coarse rock fragments).

DOME, SALT. A diapiric or piercement structure with a central, nearly circular salt plug, generally 1–2 kilometers in diameter, that has risen through the enclosing sediments from a deep mother bed of salt. In the continental United States, salt domes are located in the Gulf Coast states.

DOSE. A general term indicating the amount of energy adsorbed per unit mass from incident radiation.

DOSE CONVERSION FACTOR. A numerical factor used in converting radionuclide uptake (curies) in the body to the resultant radiation dose or dose commitment (rem or man-rem).

DOSE EQUIVALENT. The product of absorbed dose and appropriate factors to account for differences in biological effectiveness due to the quality of radiation and its spatial distribution in the body; the unit of dose equivalent is the "rem" ("sieverts" in SI units). (40 CFR § 191.12)

DOSE RATE. The rate at which dose is delivered.

DRIFT. A horizontal passageway in a mine.

E1, E2. These are potential human intrusion scenarios used in computer modeling for compliance purposes.

EFFECTIVE DOSE. The sum over specified tissues of the products of the dose equivalent received following an exposure of, or an intake of radionuclides into, specified tissues of the body, multiplied by appropriate weighting factors. This allows the various tissue-specific health risks to be summed into an overall health risk. The method used to calculate effective dose is described in Appendix B of 40 CFR Part 191. (40 CFR § 191.12)

EFFLUENT. Wastewater or airborne emissions discharged into the environment.

EMPLACEMENT. At the Waste Isolation Pilot Plant, the placing of radioactive wastes in the repository.

ENGINEERED ALTERNATIVES. Potential modifications to the design or operation of the WIPP or to waste forms that, if adopted, will provide increased assurance that the WIPP will perform in compliance with environmental protection and safety requirements.

ENGINEERED BARRIERS. Backfill, seals, and any other man-made barrier components of the disposal system.

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

EVENT. A phenomenon that occurs instantaneously or within a short time interval relative to the time frame of interest.

FAULT. A surface or zone of rock fracture along which there has been displacement.

FAULT TREE. A tree-like cause-and-effect diagram of hypothetical events. Analysis of fault trees is used to investigate failures in a system or concept.

FEDERAL FACILITIES COMPLIANCE ACT. An amendment, promulgated in 1992, to the Solid Waste Disposal Act. Title I of the act grants the U.S. Environmental Protection Agency administrative enforcement authority against any department, agency, or instrumentality of the executive, legislative, or judicial branch of the federal government. In regard to mixed wastes, sovereign immunity for federal agencies is waived, consistent with a schedule provided in the act. In addition, the act requires that the DOE prepare an inventory of mixed wastes and mixed waste treatment capacities and technologies. For those mixed wastes for which treatment capacities or technologies do not exist, the Department must prepare plans for the development of the capacities or technologies.

FILTER BANK. An arrangement of air filters in series and/or parallel.

FINAL SAFETY ANALYSIS REPORT (FSAR). A safety document providing a concise but complete description and safety evaluation of the site, the design, normal and emergency operations, potential accidents, and predicted consequences of such accidents, and the means proposed to prevent such accidents or to mitigate the consequences of such accidents. An FSAR documents the adequacy of safety analysis for a nuclear facility to ensure that the facility can be constructed, operated, maintained, shut down, and decommissioned safely and in compliance with applicable laws and regulations.

FISSILE. Describes a nuclide that undergoes fission on absorption of neutrons of any energy.

FISSILE MATERIAL. Fissile material means any material consisting of or containing one or more fissile radionuclides. Fissile radionuclides are plutonium-238, plutonium-239, plutonium-241, uranium-233, and uranium-235.

FISSION. The splitting of a heavy nucleus into two approximately equal parts, each the nucleus of a lighter element, accompanied by the release of a large amount of energy and generally one or more neutrons. Fission can occur spontaneously, but it usually follows the absorption of neutrons.

FISSIONABLE. Describes a nuclide that undergoes fission on absorption of a neutron with energy over some threshold energy.

FLOWPATH. The path traveled by a "zero-charged," "floating" particle released into a groundwater flow field.

FLUVIAL. Pertaining to streams.

FORMATION (GEOLOGIC). The basic rock-stratigraphic unit in the local classification of rocks. It consists of a body of rock (usually sedimentary) generally characterized by some degree of internal lithologic homogeneity or distinctive features.

FORTY-NINER MEMBER. Upper anhydrite and mud stone layer of Rustler Formation.

GAMMA RAYS. Short wavelength electromagnetic radiation emitted in the radioactive decay of certain nuclides. Gamma rays are the same as gammas or gamma particles.

GAS GENERATION MODEL. A computational model that can simulate and/or predict the rate and quantity of gases generated by waste transformation processes in a disposal room of the decommissioned repository.

GAS GENERATION RATE. The combined gas production rate from all species of gases produced as a result of transuranic waste transformations such as corrosion, microbial degradation, and/or radiolysis at any given time. The rate of gas production throughout the history of the repository is expected to vary depending on repository conditions with respect to humidity, total or partial brine inundation, competitive reactions that absorb specific gases, and the ability of the repository to retain the gases generated. The term is also applied to individual gases.

GATUÑA. A geologic formation covering the Dewey Lake Formation in a wide ranging area. It is basically Pleistocene in age and of medium to coarse brown soil.

GENERATOR AND/OR STORAGE SITES. Refers to the Department of Energy sites nationwide where transuranic wastes are generated and/or stored as a result of activities associated with nuclear weapons production.

GEOMORPHOLOGY. The study of landscape development.

GETTERS. Substances that sorb gases, such as carbon dioxide (CO_2), and may be added with other potential backfill materials to mitigate the pressure buildup in the repository and radionuclide mobility.

GLOVE BOX. A sealed box in which workers, remaining outside and using gloves attached to and passing through openings in the box, can safely handle and work with radioactive materials.

GROUNDWATER. Water below the land surface in a zone of saturation. (40 CFR § 191.12)

GROUT. A mortar or cement slurry (of high water content) used to plug potential fluid-flow paths in geologic or engineered structures.

GUADALUPIAN. Geological group of rocks below the Castile about 4,100 feet to about 8,000 feet below the surface. Contains the Bell Canyon, Brushy Canyon, and Cherry Canyon formations.

GYPSUM. A mineral consisting of hydrous calcium sulfate: $CaSO_4 \cdot 2H_2O$. It is soft and, when pure, white.

HALF-LIFE. The time required for the activity of a group of identical radioactive nuclei to decay to half its initial value.

HALITE. The mineral rock salt: NaCl.

HAZARDOUS CONSTITUENT. Those chemicals identified in Appendix VIII of 40 CFR Part 261.

HAZARDOUS MATERIAL. Any material that has been determined to be capable of posing a risk to health, safety, or property.

HAZARDOUS WASTE. A hazardous waste as defined in 40 CFR § 261.3.

HEAD, HYDRAULIC. *See* HYDRAULIC POTENTIAL.

HEADSPACE GASES. The free gas volume at the top of a closed container (between the container lid and the waste inside the container) or containment, such as a drum or bin, containing TRU mixed or simulated waste. The gas may be generated from biological, chemical, or radiolytic processes; this would include contributions from volatile organic compounds (VOCs) present in the waste.

HEALTH PHYSICS. The science concerned with the recognition, evaluation, and control of health hazards from ionizing radiation.

HEAVY METAL. All uranium, plutonium, or thorium placed into a nuclear reactor. (40 CFR § 191.12)

HEPA FILTER. A high-efficiency particulate air filter usually capable of 99.7 percent efficiency as measured by a standard photometric test using 0.3-micron droplets (aerodynamic equivalent diameter) of dioctylphthalate (DOP).

HIGH-LEVEL WASTE. Radioactive waste resulting from the reprocessing of spent fuel. Discarded, unreprocessed spent fuel is also high-level waste. It is characterized by intense, penetrating radiation and by high heat-generation rates. Even in protective canisters, high-level waste must be handled remotely.

HORIZON. In geology, an interface indicative of a particular position in a stratigraphic sequence. For instance, the waste-emplacement horizon in the Salado Formation at the Waste Isolation Pilot Plant is the level about 650 meters (2,150 feet) deep where openings are mined for waste disposal.

HOST ROCK. The rock unit, in this case the Salado Formation, in which the radioactive waste is to be emplaced.

HOT CELL. A heavily shielded compartment in which highly radioactive material can be handled, generally by remote control.

HUMAN INTRUSION. Inadvertent human disruptions of a mined geologic repository that could result in loss of containment of the waste. The most severe disruption would occur through inadvertent, intermittent intrusion by exploratory drilling (into the repository) for resources (40 CFR Part 191, app. C).

HUNDRED-YEAR STORM. A storm that, on a statistical basis, is expected to recur only once every hundred years.

HYDRAULIC CONDUCTIVITY. A quantity defined in the study of groundwater hydraulics that describes the ability of rock to transmit groundwater. It is measured in feet per day or equivalent units. It is equal to the hydraulic transmissivity divided by the thickness of the aquifer.

HYDRAULIC GRADIENT. A quantity defined in the study of groundwater hydraulics that describes the rate of change of head with distance.

HYDRAULIC POTENTIAL (OR HYDRAULIC HEAD). Hydraulic pressure corrected for the potential energy of elevation. In an aquifer it is equivalent to the highest level of a column of water that the pressure in the aquifer will support. It is measured relative to a specified level, which in this document is sea level.

HYDRAULIC TRANSMISSIVITY. A measure of the ability of rock to transmit groundwater. It is measured in square feet per day or equivalent units.

HYDRAULIC TRANSPORT. The transport of dissolved substances by groundwater.

HYDRAULICS, HYDROLOGY. These two terms tend to be used interchangeably, but technically they are not the same. Hydraulics is an engineering discipline; hydrology is the related science. Hydraulics deals with the flow of water. Hydrology deals with water: its properties, circulation, and distribution, from the time it falls as rainwater until it is returned to the atmosphere through evapotranspiration or flows into the ocean.

HYDROLOGIC MODELING. The process of using a mathematical representation of a hydrologic system (as embodied in a computer code) to predict the flow of groundwater and the movement of dissolved substances.

IMPLEMENTING AGENCY. The Environmental Protection Agency for those implementation responsibilities for the Waste Isolation Pilot Plant Land Withdrawal Act. The Department of Energy is the implementing agency for any other disposal facility and all other implementation responsibilities for the WIPP (under 40 CFR Part 191) not given to the EPA. (40 CFR § 191.12)

IN SITU. In the natural or original position. The phrase is used in this document to distinguish in-place experiments, rock properties, and so on, from those measured in the laboratory.

INADVERTENT HUMAN INTRUSION. Used in this text to denote an unintentional breach of the repository.

INJECTION WELL. A well into which fluids are injected.

INSTITUTIONAL CONTROLS. Human actions to control a waste management facility such as the WIPP. Institutional controls are described as "active" and "passive." Active institutional controls are defined in 40 CFR § 191.12 as: (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. Passive institutional controls are defined in 40 CFR §191.12 as:

(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.

INTENSITY, EARTHQUAKE. A measure of the effects of an earthquake on humans and structures at a particular place. Not to be confused with magnitude.

INTERNATIONAL SYSTEM OF UNITS. The version of the metric system which has been established by the International Bureau of Weights and Measures and is administered in the United States by the National Institute of Standards and Technology. The abbreviation for this system is "SI." (40 CFR § 191.12)

INTERSTITIAL BRINE. Brine distributed in the pore space (voids) of a rock mass.

ION EXCHANGE. A phenomenon in which chemical species in one phase or material exchange with similar species in another phase.

IRRADIATION. Exposure to any form of radiant energy.

ISOTOPE. A species of atom characterized by the number of protons and the number of neutrons in its nucleus. In most instances an element can exist as any of several isotopes, differing in the number of neutrons, but not the number of protons, in their nuclei. Isotopes can be either stable isotopes or radioactive isotopes (also called radioisotopes).

KELVIN. A unit of temperature equal to Centigrade degrees. $1K = 1°C$. Abbreviated K.

LAMBDA FUNCTION (λ). $\lambda = f(1-p_1p_2)$ is a measure of drilling intensity where p_1 is the probability of markers still being in place and p_2 is the probability that the markers will deter drilling, and f is the frequency of attempted inadvertent intrusions.

LAND WITHDRAWAL ACT. Public Law 102-579, which withdraws the land at the Waste Isolation Pilot Plant site from "entry, appropriation, and disposal"; transfers jurisdiction of the land from the Secretary of the Interior to the Secretary of Energy; reserves the land for activities associated with the development and operation of the Waste Isolation Pilot Plant; and includes many other requirements and provisions pertaining to the protection of public health and the environment.

LANGBEINITE. A mineral, $K_2Mg_2(SO_4)_3$, used in the fertilizer industry as a source of potassium sulfate.

LATIN HYPERCUBE SAMPLING. A Monte Carlo sampling technique that divides the range of each variable into intervals of equal probability and samples from each interval.

LEACHATE. Means any liquid, including any suspended components in the liquid, that has percolated through or drained from hazardous waste.

LEACHING. The process of extracting a soluble component from a solid by the percolation of a solvent (in this report, water) through the solid.

LEONARDIAN. The geologic formation from 8,000 feet to 11,400 feet below the surface. Middle of the Permian zone.

LEVEL-LINE SURVEY. A cross-country survey in which changes in elevation with respect to sea level are very carefully measured.

LITHOLOGY. The study and examination of rocks.

LITHOSTATIC PRESSURE. Subsurface pressure due to the weight of overlying rock or soil.

LONG TERM. Refers to the 10,000 years after shaft sealing for which performance assessment calculations and models assess the behavior of the repository with respect to compliance with 40 CFR Part 191 and 40 CFR § 268.6.

LOS MEDAÑOS. In this report, the area in southeastern New Mexico surrounding the site proposed for the WIPP repository. In Spanish it means "dune country."

LOWER EXPLOSIVE LIMIT. The minimum concentration of gas or vapor in air below which a substance does not burn when exposed to an ignition source.

MAGENTA DOLOMITE. The upper of two layers of dolomite within the Rustler Formation that are locally water-bearing.

MAGENTA MEMBER. The upper dolomite member that also contains some minor amounts of nonpotable water.

MAGNITUDE, EARTHQUAKE. A measure of the total energy released by an earthquake. Not to be confused with intensity.

MALAGA BEND. A sharp bend in the Pecos River 20 miles southeast of Carlsbad, New Mexico, and directly east of the town of Malaga. The discharge points of the Rustler aquifers are a series of brine seeps and springs nearby.

MAN-REM. A unit of population dose.

MARKER BEDS (MB). MBs are well defined layers of rock that mark distinct divisions in major geological strata or geological time frames.

MATHEMATICAL MODEL. The mathematical representation of a conceptual model (i.e., the algebraic, differential or integral equations) that predict quantities of interest of a system and any constitutive equations of the physical material that appropriately approximate system phenomena in a specified domain of the conceptual model.

MAXIMALLY EXPOSED PERSON. A hypothetical person who is exposed to a release of radioactivity in such a way that the person receives the maximum possible individual dose or dose commitment. For instance, if the release is a puff of contaminated air, the maximally exposed person is the individual at the point of largest ground-level concentration who stays there during the whole time of the cloud passage. The use of this term is not meant to imply that there is such a person, but only that thought is being given to the maximum exposure a person could receive.

MAXIMUM INDIVIDUAL DOSE. The highest dose delivered to the whole body or to an individual organ that a person can receive from a release of radioactivity. The hypothetical person who receives this dose, the maximally exposed person, is one whose location and activities maximize the dose. For instance, the person may be at the point of maximum concentration of a radioactive cloud for the whole time it takes to pass.

MEAN. The average value. For a given set of n values, the mean is the sum of their values divided by n.

MEDIAN. The median of a set of data is the value such that half of the observations are less than that value and half are greater than that value.

MEGAPASCAL (MPA). Pascal times 10^6.

MERCALLI INTENSITY. A scale of measurement of earthquake intensity.

MESCALERO CALICHE. An informal name for the layer of white calcium containing rock of varying thickness found overlaying the Rustler in the WIPP area.

METHANOGENESIS. The generation of methane through the decomposition of organic matter in wastes.

MIGRATION. In the context of 40 CFR § 268.6, "migration" means the movement of hazardous constituents beyond the boundary of a hazardous waste management unit in concentrations exceeding applicable regulatory levels.

MISCELLANEOUS HAZARDOUS WASTE MANAGEMENT UNIT. A waste management unit where hazardous waste is treated, stored, or disposed of, and that is not a container, tank, surface impoundment, pile, land treatment unit, landfill, incinerator, boiler, industrial furnace, underground injection well, or unit eligible for a research, development, and demonstration permit. (40 CFR § 260.10)

MISSISSIPPIAN. Geologic formation from 15,000 to 15,600 feet. Geologic age when petroleum and natural gas formed about 300 million years ago.

MIXED WASTE. Mixed waste contains both radioactive and hazardous components, as defined by the Atomic Energy Act and the Resource Conservation and Recovery Act, respectively.

MODEL VALIDATION. The process of ensuring (through sufficient testing of a model using actual site data), that a conceptual model, and corresponding mathematical and computer models, correctly simulate a physical process with sufficient accuracy.

MODEL VERIFICATION. The process of ensuring (e.g., through tests on ideal problems) that a computer code (computational model) correctly performs the necessary functional operations (such as solving the mathematical model). Given that a computer code correctly solves the mathematical model, the physical assumptions of the mathematical model must then be checked through validation.

MONTE CARLO SAMPLING. A random sampling technique used in computer simulations to obtain approximate solutions to mathematical or physical problems. Monte Carlo sampling is used in conjunction with Latin Hypercube techniques to sample a range of variables. The range is divided into intervals of equal probability, and one value is randomly selected from each interval. The selected values from each interval are combined to generate vectors. The procedure ensures that the distribution tails are sampled; also, it is more efficient than simple random sampling.

MUNSON DAWSON MODEL. A simulation model developed to help predict the behavior, particularly the rate of room closure, of Waste Isolation Pilot Plant underground openings.

NASH DRAW. A shallow valley, approximately 5 miles wide, open to the southwest located to the west of the WIPP site.

NATURAL BACKGROUND RADIATION. Radiation in the human environment from naturally occurring elements and from cosmic radiation.

NATURAL BARRIERS. The repository host rock and surrounding geologic structures and formations. The natural barriers extend from the engineered barrier to the compliance boundary.

NEUTRON. An elementary particle that has approximately the same mass as the proton but lacks electric charge, and is a constituent of all nuclei having mass number greater than one.

NEW MEXICO HAZARDOUS WASTE ACT. The New Mexico legislation which establishes the state hazardous waste management program. The state law is no less stringent than the federal law.

NEW MEXICO HWMR-7. The New Mexico Hazardous Waste Management Regulations implement the provisions of the New Mexico Hazardous Waste Act. The regulations are consistent with the federal RCRA regulations, 40 CFR Parts 260 through 270.

NO-MIGRATION. Adequate isolation of RCRA-regulated constituents such that "no-migration" of hazardous-waste constituents beyond the unit boundary occurs for as long as the wastes remain hazardous.

NO-MIGRATION DETERMINATION. In the context of the Test Phase, the term "no-migration determination" means the Final Conditional No-Migration Determination for the Department of Energy Waste Isolation Pilot Plant published by the Environmental Protection Agency on November 14, 1990 (55 Fed. Reg. 47700), and any amendments thereto, pursuant to the Solid Waste Disposal Act (42 U. S. C. 6901 et seq.). The Department of Energy has decided not to pursue the testing activities in the WIPP underground for which the conditional No-Migration Determination was made.

NUCLIDE. Isotope.

NUCLIDE INVENTORY (RADIONUCLIDE INVENTORY). A list of the kinds and amounts of radionuclides in a container or a source. Amounts are usually expressed in activity units: curies or curies per unit volume.

ORDER OF MAGNITUDE. A factor of ten. When a measurement is made with a result such as 3×10^7, the exponent of 10 (here 7) is the order of magnitude of that measurement. To say that this result is known to "within an order of magnitude" is to say that the true value lies between (in this example) 3×10^6 and 3×10^8.

ORDOVICIAN. Rock zone between 16,900 feet and 18,200 feet below the surface and also denotes geologic time 425–500 million years ago.

OVERPACK. A container put around another container. In the WIPP, overpacks would be used on damaged or otherwise contaminated drums, boxes, and canisters that it would not be practical to decontaminate.

OXIC CORROSION. Oxidation of metals by molecular oxygen (O_2).

PACKAGING. The assembly of components necessary to ensure compliance with packaging requirements. It may consist of one or more receptacles, absorbent materials, spacing structures, thermal insulation, radiation shielding, and devices for cooling or absorbing mechanical shocks. The vehicle, tie-down system, and auxiliary equipment may be designated as part of the packaging.

PALEOZOIC. Major geological age from 229 million years to 600 million years. Denotes a wide range of geological strata from different subgeological ages, i.e., Permian, Pennsylvania, Mississippi, etc.

PANEL. A group of several underground rooms connected by drifts. Within the Waste Isolation Pilot Plant, a panel consists of seven rooms connected by drifts at each end.

PANEL. Sandia National Laboratory computer code name for a program which simulates the process of waste mobilization.

PASCAL (PA). A unit of pressure obtained by dividing force (in Newtons) by area (in meters squared).

PASSIVE INSTITUTIONAL CONTROLS. "(1) [P]ermanent 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." (40 CFR § 191.12)

PENNSYLVANIAN. This is a geologic period of approximately 285 million years ago. Pennsylvanian rocks are found about 12,800 to 15,000 feet below the Los Medaños surface. Contains oil and natural gas.

PERFORMANCE ASSESSMENT. A term used to denote quantitative activities carried out to evaluate the long-term ability of the Waste Isolation Pilot Plant to effectively isolate the waste, to ensure long-term health and safety of the public by complying with 40 CFR Part 191 and 40 CFR § 268.6, and to supply data/information to the compliance analysis for demonstrating regulatory compliance. The final analysis of compliance will consist of a qualitative assessment of the quantitative results of the performance assessment.

PERFORMANCE-BASED WASTE ACCEPTANCE CRITERIA. Waste-acceptance criteria based on the results of performance assessment models, operational assessments, and possible conditions which may be imposed as a part of the regulatory process.

PERFORMANCE-BASED WASTE ENVELOPE. The bounding characteristics of wastes acceptable for the Waste Isolation Pilot Plant, based on the expected repository performance.

PERFORMANCE-BASED WASTE INVENTORY. That portion of the waste inventory which will meet the performance-based waste acceptance criteria.

PERMEABILITY. In hydrology, the capacity of a rock sediment or soil to transmit fluids under specified conditions.

PERMIAN BASIN. A region in the Central United States where, during Permian times 280 to 225 million years ago, there were many shallow seas that laid down vast beds of evaporites. The Delaware basin is a part of the Permian basin.

pH. A term used to describe the hydrogen-ion activity or concentration of a solution.

PHYSIOGRAPHY. A description of the natural features of the surface of the earth.

PLUTONIUM. A metallic, radioactive actinide, symbol Pu, atomic number 94, in the transuranium series of elements; used as a nuclear fuel, to produce radioactive nuclides for research, and as the fissile agent in nuclear weapons.

PLUTONIUM EQUIVALENT CURIE (PE CI). A term developed for use at the WIPP to provide a uniform basis among various radioactive wastes to perform comparative human health consequence analyses resulting from inhalation. The PE Ci concept has strict limits of applicability. It is utilized herein as a means of expressing the transuranic activity content of TRU waste packages.

POINT SOURCE. A source of effluents that is small enough in dimensions that it can be treated as if it were a point. The converse (not used in this document) is a diffuse source. A point source can be either a continuous source or a source that emits effluents only in puffs or for a short time.

POLYHALITE. An evaporite mineral: $K_2MgCa_2(SO_4)_4 \cdot 2H_2O$. It is a hard, nearly insoluble mineral with no economic value.

POPULATION DOSE. The sum of the radiation doses received by the individual members of a population.

POROSITY. The percentage of porous rock that consists of open space.

POST-CLOSURE PHASE. A designated period of time beginning with the end of the Decommissioning Phase and extending through the end of the regulatory time frame of 10,000 years. Performance assessment modeling of repository behavior will address this time frame with the exception of possible human intrusion events which will not be modeled until 100 years after decommissioning.

POTASH. A potassium compound, especially as used in agriculture or industry.

POTENTIOMETRIC SURFACE. A subsurface map of the hydraulic potentials of an aquifer. It is usually represented in figures as a contour map, each point estimating how high the water would rise in a well tapping that aquifer at that point.

PRECAMBRIAN ROCKS. The deepest rock zone under WIPP (18,000 feet) and the oldest at +600 million years.

PROCESS KNOWLEDGE. The detailed knowledge of the processes and materials that generated the wastes in the DOE system.

PROJECT TECHNICAL BASELINE. The Project Technical Baseline document includes the technical facts, approaches, and assumptions necessary to support demonstrations of compliance with 40 CFR Part 191 Subparts B and C, 40 CFR § 268.6, and 40 CFR Part 264, Subpart X. As such, the document will serve as a basis for the conceptual model of the WIPP repository by explaining the parameters affecting the performance of the repository. It will include the compliance database consisting of technical data supporting compliance demonstrations.

PUBLIC LAW 96-164. The U.S. Department of Energy National Security and Military Applications of Nuclear Energy Act of 1980. Public Law 96-164 directed the Department of Energy to proceed with the design and development of the Waste Isolation Pilot Plant.

PUBLIC LAW 102-579. *See* LAND WITHDRAWAL ACT.

QUALITY ASSURANCE. The planned and systematic actions necessary to provide adequate confidence that a structure, system, or component will perform satisfactorily in service.

QUALITY ASSURANCE PROJECT PLANS (QAPP). Documents that ensure site-specific waste characterization activities meet the data quality objectives.

QUALITY CONTROL. Those quality assurance activities that provide a means to control and measure the characteristics of a structure, system, or component to established requirements.

RAD. A unit of absorbed dose. Related to, but not the same as "rem."

RADIOACTIVE MATERIAL. Matter composed of or containing radionuclides, with radiological half-lives greater than 20 years, subject to the Atomic Energy Act of 1954, as amended. (40 CFR § 191.12)

RADIOGRAPHIC EXAMINATION. The nondestructive technique that enables a qualitative evaluation of the contents of a waste container.

RADIOLYSIS. Chemical decomposition by the action of radiation.

REAL-TIME RADIOGRAPHY. A nondestructive, nonintrusive examination technique that enables a qualitative (and in some cases semiquantitative) evaluation of the contents of a waste container. Real-Time Radiography utilizes x-rays to inspect the contents of the waste container and allows the operator to view events in progress (real time). Real-Time Radiography is used to examine and verify the physical form of the waste for certain waste forms, identify individual waste components, and verify the absence of certain noncompliant items, as applicable.

REASONABLE. (1) Not conflicting with reason, (2) not extreme or excessive, (3) having the faculty of reason, or (4) possessing sound judgment.

RECHARGE POINT (OR AREA). In groundwater hydraulics, the point (or area) where surface water enters an aquifer.

REGULATORY GUIDE. One of a series of official NRC guides prescribing standards for nuclear facilities. They cover a variety of subjects such as what constitutes acceptable meteorological data or acceptable methods for calculating radiation dose.

RELEASE. Movement of regulated substances into the accessible environment as defined in 40 CFR Part 191 or beyond the unit boundary as defined for 40 CFR § 268.6.

REM. Roentgen equivalent in man—a special unit of dose equivalent which is the product of absorbed dose, a quality factor which rates the biological effectiveness of the radiation types producing the dose, and other modifying factors (usually equal to one). If the quality and modifying factors are unity, 1 rem is equal to 1 rad: 100 rem = 1 sievert (SI units). Also expressed in terms of millirem (mrem): 1 rem = 1,000 mrem.

REMOTE-HANDLED WASTE. Transuranic wastes that have a measured radiation dose rate at the container surface of between 200 mrem per hour and 1,000 rem per hour and, therefore, must be shielded for safe handling.

REPOSITORY. The portion of the Waste Isolation Pilot Plant underground system within the Salado Formation, including the access drifts, waste panels, and experimental areas, but excluding the shafts.

REPOSITORY/SHAFT SYSTEM. The Waste Isolation Pilot Plant underground workings, including the shafts, all engineered and natural barriers, and the altered zones within the Salado Formation and overlying units resulting from construction of the underground workings.

RESERVES. Mineral resources that can be extracted profitably by existing techniques and under present economic conditions.

RESISTIVITY. Measure of electrical resistance in a fluid such as brine.

RESOURCE CONSERVATION AND RECOVERY ACT PERMIT APPLICATION. An application, which is submitted by the owner/operator of a hazardous waste management unit to the state (if authorized by the Environmental Protection Agency) or to the Environmental Protection Agency, for a Resource Conservation and Recovery Act permit to operate the unit.

RESOURCES. Mineralization that is concentrated enough, in large enough quantity, and in a physical and chemical forms such that its extraction is currently or potentially feasible and profitable.

RETRIEVABLE. Describes storage of radioactive waste in a manner designed for recovery without loss of control or release of radioactivity.

ROENTGEN. The international unit of x-radiation or gamma radiation equal to the amount of radiation that produces in 1 cubic centimeter of dry air at 0° and standard atmosphere pressure, ionization of either sign equal to 1 electrostatic unit charge.

ROOM. An excavated cavity within a panel in the underground. Within the Waste Isolation Pilot Plant, a room is about 10 meters wide, 4 meters high, and 91 meters long.

RUSTLER FORMATION. The evaporite beds, including mudstones, of probable Permian age that immediately overlie the Salado Formation.

SALADO FORMATION. A geologic formation of Late Permian age in southeastern New Mexico. At the Waste Isolation Pilot Plant site, it is composed of salt beds with minor amounts of anhydrite (45 numbered anhydrite marker beds: Marker Bed 101 through Marker Bed 145) and clay. It is the host unit for the Waste Isolation Pilot Plant repository.

SAN SIMON SINK. The central, most depressed area of San Simon Swale.

SAN SIMON SWALE. A broad depression about 15 miles east of the Los Medaños site, open to the southeast.

SANCHO. Sandia National Laboratory computer code name for a program which deals with geomechanical closure of rooms and affects on gas generation.

SATURATED. A condition in which all connected pores in a given volume of material contain fluid.

SCENARIO. A combination of naturally occurring or human-induced events and processes that represent realistic future changes to the repository, geologic, and geohydrologic systems that could cause or promote the escape of radionuclides and/or hazardous constituents from the repository.

SEAL. An engineered barrier designed to isolate the waste and to impede groundwater flow in the shafts.

SEDIMENTARY. Rocks formed by the accumulation of sediments, usually in ancient seas.

SEISMIC RISK ZONE. A designation of a geographic region expressing the maximum intensity of earthquakes that could be expected there.

SENSITIVITY ANALYSIS. Methods for computing the effect of changes in the input parameters on the model predictions.

SHAFT. A man-made hole, either vertical or steeply inclined, that connects the surface with the underground workings of a mine.

SHAFT PILLAR. The cylindrical volume of rock around a shaft from which major underground openings are excluded in order that they not weaken the shaft.

SHALLOW-DISSOLUTION ZONE. A zone of residual material at the interface of the Rustler and Salado formations left after dissolution of the salt. It is highly permeable and often contains brine.

SI UNIT. A unit of measure in the International System of Units. (40 CFR § 191.12)

SIEVERT. The SI unit of effective dose. It is equal to 100 rem or one joule per kilogram. (40 CFR § 191.12)

SITE CHARACTERIZATION. The process of making geologic and environmental studies to identify potential sites for mined geologic repositories. Detail site characterization goes further: all additional data are collected that would be necessary if a license application were to be submitted.

SLUDGE. Refers to de-watered contact-handled transuranic wastes containing both organic and inorganic constituents that must meet the Waste Acceptance Criteria for shipment and disposal at the Waste Isolation Pilot Plant repository. High sludges are contact-handled transuranic waste where the sludge component constitutes 50 percent or more of the waste volume; low sludges are the same type of waste containing less than 50 percent by volume of sludge.

SOLUBILITY. The ability or tendency of one substance to blend uniformly with another (e.g., solid in liquids, liquid in liquid, gas in liquid, and gas in gas). Solids vary from 0 to 100 percent in their degree of solubility in liquids depending on the chemical nature of the substance(s); to the extent that they are soluble, they lose their crystalline form and become molecularly or ionically dispersed in the solvent to form a true solution. Liquids and gases are often said to be miscible in other liquids and gases rather than soluble.

SOLUTE. A substance which is dissolved in another substance called the solvent. The solute is uniformly dispersed in the solvent either molecularly or ionically.

SOLVENT. A substance capable of dissolving another substance (solute) to form a uniform dispersed mixture (solution) at the molecular or ionic level. Solvents are, accordingly, characterized as either polar or non-polar. Water is strongly polar; hydrocarbon solvents are non-polar.

SORPTION. The binding on a microscopic scale of one substance to another, such as by adsorption or ion exchange. In this document, the word is especially used in the sorption of solutes onto aquifer solids.

SOURCE TERM. The kinds and amounts of radionuclides that make up the source of a potential release of radioactivity. *See* NUCLIDE INVENTORY.

SPALLINGS. During exploratory drilling, waste surrounding the eroded borehole that is transported by waste-generated gas escaping to the lower pressure borehole.

SPECIFIC ACTIVITY. Radioactivity per unit weight of radioactive material.

STANDARD WASTE BOX (SWB). A waste container measuring approximately 6 by 4.5 by 3 feet high, with rounded ends.

STRATA. Geologic term for layering of the earth's crust. The crust was generally laid down in layers during geological epochs.

STRATIGRAPHIC. Involves the science and study of the origin, composition, and proper sequence in which various rock strata were layered during various geological ages. Used in this text to describe geological layered formations above and below the WIPP repository and their physical characteristics.

STUDY AREA. The region about the Los Medaños site studied in the evaluation of that site.

SWIPE SAMPLES. The presence of radioactive contaminants may be ascertained by applying a Kim-wipe™ or equivalent to the surface of the potentially contaminated item and measuring the radioactivity of the Kim-wipe™.

SYLVITE. A mineral, KCl, used as a fertilizer.

TAMARISK MEMBER. Middle anhydrite layer of Rustler Formation.

TECTONIC ACTIVITY. Movement of the earth's crust such as uplift and subsidence and the associated folding, faulting, and seismicity.

THERMAL FIELD. The field or set of temperatures throughout a volume. Use of the term usually connotes temperatures that differ from point to point.

THERMAL GRADIENT. The rate of change of temperature in the direction of increasing temperature.

TRANSMISSIVITY. For a confined aquifer, the product of hydraulic conductivity and aquifer thickness.

TRANSURANIC NUCLIDE. A nuclide with an atomic number greater than that of uranium (92). All transuranic nuclides are produced artificially and are radioactive.

TRANSURANIC PACKAGE TRANSPORTER (TRUPACT)-II. Package designed to transport contact-handled TRU mixed waste to the WIPP site. It is a cylinder with a flat bottom and a domed top that is transported in the upright position.

TRANSURANIC WASTE. The term "transuranic waste" means waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes per gram of waste, with half-lives greater than 20 years, except for: (1) high-level radioactive waste, (2) waste that the Secretary has determined, with the concurrence of the Administrator, does not need the degree of isolation required by the disposal regulations, or (3) waste that the Nuclear Regulatory Commission has approved for disposal on a case-by-case basis in accordance with 10 CFR 61.

TREATMENT. Means any method, technique, or process, including neutralization, designed to change the physical, chemical, or biological character or composition of any hazardous waste so as to neutralize such waste, or so as to recover energy or material resources from the waste, or as to render such waste non-hazardous, or less hazardous; safe to transport, store, or dispose of; or amenable for recovery, amenable for storage, or reduced in volume.

TREND. A general tendency or course of geologic material.

TRUE SOLUTION. A uniformly dispersed mixture at the molecular or ionic level, of one or more substances (solute) in one or more substances (solvent). Solutions that exhibit no change of internal energy upon mixing and have complete uniformity of cohesive forces that are true.

TYPE A PACKAGING. Means a packaging designed to retain the integrity of containment and shielding required by this part under normal conditions of transport as demonstrated by the tests set forth in 49 CFR § 173.465 or 173.466, as appropriate.

UNCERTAINTY ANALYSIS. (1) An evaluation to determine the uncertainty in model predictions that results from imprecisely known input variables. (2) Determination of the degree of uncertainty in the results of a calculation based on uncertainties in the input parameters and underlying assumptions. Such an analysis requires definition of a system, description of the uncertainties in the factors that are to be investigated, and the characteristics of the system that are to be simulated.

UNDISTURBED PERFORMANCE. "[T]he 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." (40 CFR § 191.12)

UNINTERRUPTIBLE POWER SUPPLY (UPS). A power supply that provides automatic, instantaneous power, without delay or transients, on failure of normal power. It can consist of batteries or full-time operating generators. It can be designated as standby or emergency power depending on the application. Emergency installations must meet the requirements specified for emergency.

UNIT BOUNDARY. In the context of 40 CFR § 268.6, the unit boundary is that the point at which "migration" occurs if hazardous constituents pass that point in concentrations exceeding health-based levels.

VOLATILE ORGANIC COMPOUNDS (VOCs). RCRA-regulated organic compounds which readily pass into the vapor state and are present in contact-handled transuranic mixed waste.

VUGS. Small open cavity in a rock.

WASTE ACCEPTANCE CRITERIA. A set of conditions established for permitting transuranic wastes to be packaged, shipped, managed, and disposed of at the Waste Isolation Pilot Plant.

WASTE CHARACTERIZATION. Sampling, monitoring, and analysis activities to determine the nature of the waste.

WASTE CHARACTERIZATION PROGRAM. The processes of contact-handled transuranic waste analysis to support the No-Migration Determination, Part B of the Resource Conservation and Recovery Act permit application, other permits, transportation requirements, and the experimental program requirements. These analyses include documentation of waste generation processes, visual characterization of waste components, Real-Time Radiography analysis, and passive-active neutron waste assay for radionuclide content. Waste matrix and headspace gas chemical analyses are also part of the characterization program.

WASTE FORM. A term used to emphasize the physical and chemical properties of the waste.

WASTE MATRIX. The material that surrounds and contains the waste and to some extent protects it from being released into the surrounding rock and groundwater. Only material within the canister (or drum or box) that contains the waste is considered part of the waste matrix.

WOLFCAMPIAN. Lower member of Permian age in Southeastern New Mexico.

WORKING AGREEMENT. Appendix B of the Agreement of Consultation and Cooperation, which sets forth the working details of that Agreement.

X-RAY. Any of the electromagnetic radiations of the same nature as visible radiation but of any extremely short wavelength (less than 100 angstroms) that is produced by bombarding a metallic target with fast electrons in vacuum or by transition of atoms to lower energy states, and that has the properties of ionizing a gas upon passage through it, of penetration various thicknesses of all solids, of producing secondary radiations by impinging on materials bodies, of acting on photographic films and plates as light does, and of causing fluorescent screens to emit light.