An Overview of the WIPP Performance Assessment

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Presentation to the Nuclear Waste Technical Review Board

January 12, 1994
Washington DC
Outline of the Presentation

1) The Regulations 40CFR191 and 40CFR268.6
2) PA Methodology
3) Present Status of the WIPP PA
4) Lessons Learned from WIPP PA
### 1985 RULE

**TITLE 40, CODE OF FEDERAL REGULATIONS**

**SUBCHAPTER F—RADIATION PROTECTION PROGRAMS**

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

**Subpart A—Environmental Standards for Management and Storage**

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**Subpart B—Environmental Standards for Disposal**

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**KEY**

- Strike-through = deletions
- **Boldface** = additions
- Vertical bar = rearrangement of sequence
191.15 Individual protection requirements.

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

(a) Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes 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 dose equivalent, received through all potential pathways from the disposal system, to any member of the public in the accessible environment, to exceed 25 15 millirems (150 microsieverts) to the whole body or 75 millirems to any critical organ. All potential pathways (associated with undisturbed performance) from the disposal system to people shall be considered, including the assumption that individuals consume 2 liters per day of drinking water from any significant source of ground water outside of the controlled area:

(b) Annual committed effective doses shall be calculated in accordance with Appendix B of this part.

(c) Compliance assessments need not provide complete assurance that the requirements of §191.15 (a) of this subpart will be met. Because of the long time period involved and the nature of the processes and events 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 §191.15(a) will be achieved.

(d) Compliance with the provisions in this section does not negate the necessity to comply with any other applicable Federal regulations or requirements.
191.17 Alternative provisions for disposal.

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

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

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

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

191.18 Effective date.

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

191.17 Alternative provisions for disposal.

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

191.18 Effective date.

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

Subpart C-Environmental Standards for Ground-Water Protection

191.21 Applicability.

(a) This Subpart applies to:

(1) Radiation doses received by members of the public as a result of activities subject to subpart B of this part; and
(2) Radioactive contamination of underground sources of drinking water in the accessible environment as a result of such activities.

(b) This Subpart does not apply to:

(1) Disposal directly into the oceans or ocean sediments;

(2) Wastes disposed of before the effective date of this subpart; and

(3) The characterization, licensing, construction, operation, or closure of any site required to be characterized under § 113(a) of Public Law 97-425.

191.22 Definitions.

Unless otherwise indicated in this subpart, all terms have the same meaning as in subparts A and B of this part.

Public water system means a system for the provision to the public of piped water for human consumption, if such system has at least fifteen service connections or regularly serves at least twenty-five individuals. Such term includes

(1) any collection, treatment, storage, and distribution facilities under control of the operator of such system and used primarily in connection with such system; and

(2) any collection or pretreatment storage facilities not under such control which are used primarily in connection with such system.
Total dissolved solids means the total dissolved (filterable) solids in water as determined by use of the method specified in 40 CFR Part 136.

Underground source of drinking water means an aquifer or its portion which:

(1) supplies any public water system; or

(2) contains a sufficient quantity of ground water to supply a public water system; and

(i) currently supplies drinking water for human consumption; or

(ii) contains fewer than 10,000 milligrams of total dissolved solids per liter.

191.23 General provision

(a) Determination of compliance with this subpart shall be based upon underground sources of drinking water which have been identified on the date the implementing agency determines compliance with subpart C of this part.

191.24 Disposal standards

(a) Disposal systems.

(1) 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 141 as they exist on the effective date of this subpart.
Environmental Standards for Management And Disposal
(40 CFR 191)

Subpart A
Management & Storage Standards
(191.03)
Dose Limits to Public During Operation of Repository

Subpart B
Release Limits up to 10,000 yr for all Scenarios
(191.13)
Assurance Design & Control Philosophy
(191.14)
- Multiple Barriers
- Natural Resources
- Recoverability
- Monitoring
- Institutional Controls

Subpart C
Groundwater Protection
(191.24)
Containment Limits to Underground Sources of Drinking Water for 10,000 yr for Undisturbed Scenario

Disposal (Long-Term Environmental Criteria)
Management & Storage (Operational Environmental Criteria)
As Defined by 40 CFR 191, Performance Assessment Is...

"An analysis that:

1. Identifies the processes and events that might affect the disposal system;

2. Examines the effects of these processes and events on the performance of the disposal system, and

3. Estimates the cumulative releases of radionuclides, considering the associated uncertainties, caused by all significant processes and events.

These estimates shall be incorporated into an overall probability distribution of cumulative releases to the extent practicable."
Long-Term Performance Assessment Is also Applicable to 40 CFR 268.6

Regulatory performance measure is concentrations of specific hazardous materials at the unit boundary

- Volatile Organic Compounds (VOCs)
- Heavy Metals (HMs)

Regulatory boundary is different for 40 CFR 268.6 and 40 CFR 191
Accessible Environment and Disposal unit Boundaries

Not to Scale

Maximum Controlled Area 40 CFR 191

<table>
<thead>
<tr>
<th>40 CFR 191</th>
<th>Accessible Environment</th>
</tr>
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<tr>
<td>40 CFR 268</td>
<td>Disposal Unit</td>
</tr>
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Repository/Shaft System

40 CFR 191 Land Withdrawal Boundary

Santa Rosa and Gavina Formations

Dewey Lake Redbeds

Rustler Formation

Salado Formation

Castle Formation

TRI-6330-7-9

6342-106-0
PAs for Long-Term Requirements of 40 CFR 268.6 and 40 CFR 191 Will:

Cover the same time period (10,000 years)

Use the same data and conceptual models to describe the disposal system

Use comparable computational models to simulate performance
Methodology for Performance Assessment of TRU Repositories

System Description
- Waste Characteristics
- Facility Characteristics
- Site Characteristics

Scenario Development/Screening

Scenario Probability Estimates

Consequence Modeling
- GW Flow
- Source Term
- Geosphere RN Transport
- Biosphere RN Transport
- Dose to Man

Final Results
- Identify Main Radionuclides, Parameters, and Scenarios

EPA Standard (40 CFR 268.6) RCRA

EPA Standard (40 CFR 191)
191.13 (Containment)
191.16 (GW Protection)

EPA Standard (40 CFR 191)
191.15 (Individual Protection)
1994 Modeling System (Codes)

CCDFPERM (Intrusion Probability/CCDF Construction)

CUTTINGS (Release of Cuttings to Accessible Environment)

Withdrawal Well

GRASP-INV (Transmissivity Fields)

SECO2D/SECO_TP (Flow/Transport)

Upper Shaft Seal System

Lower Shaft Seal System

Access Drift

BRAGFLO (2-Phase Flow/Closure)

Panel

Anhydrite Layers A and B

MB138

MB139

BRAGFLO (Approximation of Anhydrite Fracturing)

BRAGFLO (Brine Flow)

PANEL (Radionuclide Concentration)

Brine Reservoir

Subsurface Boundary of Accessible Environment

Not to Scale

TRI-6342-3401-1
Data Bases

Secondary Data Base
Site Geometry
Distribution

CAMDAT
QA
Mesh
Boundary Conditions
Material Properties
Heads and Velocities
Concentrations
Pathway and Release

Necessary Input

Computer Module

Data Produced

- Stratigraphy
- Parameter Distributions
- Hydrologic Parameters
- Geologic Parameters
- Facility Design
- Waste Properties
- Hydrologic Parameters
- Geologic Parameters
- Waste Properties
- Concentrations
- Releases

Mesh Generation
Monte Carlo Sampling
Hydrologic Modeling
Repository/Shaft Modeling
Groundwater Transport Modeling
Compliance Evaluation

Local Mesh
Vector 1 Vector m
\( x_{1,1} \ldots x_{1,m} \)
\( x_{2,1} \ldots x_{2,m} \)
\ldots
\( x_{n,1} \ldots x_{n,m} \)
Pressure Contours
Source Concentrations
Pathway
Release Concentrations

CCDF Compared with Release Limits

TRI-6334-94-0
WIPP PA Uses Iterative Monte Carlo Methodology


- Provide interim guidance to project
- Allows early peer review

Monte Carlo Technique

- Multiple deterministic simulations using sampled values
- Facilitates parameter sensitivity analyses at full system scale
- 40 CFR 191.13 requires consideration of uncertainty in performance measure
Deterministic Analyses Are Part of the Monte Carlo Methodology

Multiple deterministic analyses are the basis for uncertainty and sensitivity analyses

Single deterministic analyses in WIPP PA

- Valuable for benchmarking and code verification with test problems
- Can be used for rapid turn-around for specific parametric variation studies, but multiple simulations are preferable
Present Status of the
WIPP PA
Sources of Uncertainty in System Performance Assessments

Future states of the system
Models used to assess consequences
Model parameters and data
Barrier Effect Display, 1992 PA
Showing Effects of Physical and Chemical Retardation and Markers

Probability of Release > R

Summed Normalized Releases, R

Total, Single Porosity + Cuttings, $K_d = 0, \lambda_0$

Total, Dual Porosity + Cuttings, $K_d = 0, \lambda_0$

Total, Dual Porosity + Cuttings, $K_d \neq 0, \lambda_0$

EPA Containment Requirement (191.13(a))

Total Discharge from Borehole + Cuttings, $\lambda_0$
### Summary of Importance of Sampled Parameters in the 1992 WIPP PA
(Conditional on Assumptions of 1992 PA)

<table>
<thead>
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<th>Parameters</th>
<th>1991 Rank</th>
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<tr>
<td><strong>Critically Important Parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Drilling Intensity</td>
<td>1</td>
<td>Y*</td>
<td>na</td>
</tr>
<tr>
<td>2. Borehole Fill Permeability</td>
<td>2</td>
<td>Y</td>
<td>na</td>
</tr>
<tr>
<td>3. Shaft Seal Permeability (Long-Term)</td>
<td>3</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td><strong>Very Important Parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Permeability of Intact Anhydrites</td>
<td>5</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>5. Permeability of Intact Halite</td>
<td>4</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>6. Initial Water Content of Waste/Backfill</td>
<td>8</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>7. Radionuclide Solubility Limits</td>
<td>6</td>
<td>Y</td>
<td>na</td>
</tr>
<tr>
<td>8. Fracture Spacing in Culebra</td>
<td>14</td>
<td>Y</td>
<td>na</td>
</tr>
<tr>
<td>9. Sorption in Culebra Matrix (K_s)</td>
<td>7</td>
<td>Y</td>
<td>na</td>
</tr>
<tr>
<td><strong>Important Parameters (order of listing is not significant)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas Generation Model Parameters (6)</td>
<td>N</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Two-Phase Relative Permeability Model</td>
<td>N</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Porosity of Intact Anhydrite</td>
<td>N</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Shaft Seal Permeability (Short-Term)</td>
<td>N</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Disturbed Rock Zone Porosity</td>
<td>N</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Metal (and Glass) Content of Waste</td>
<td>N</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Combustible (Cellulosic) Content of Waste</td>
<td>Y</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Culebra Transmissivity Fields</td>
<td>Y</td>
<td>na</td>
<td></td>
</tr>
<tr>
<td>Culebra Matrix Porosity</td>
<td>Y</td>
<td>na</td>
<td></td>
</tr>
<tr>
<td><strong>Less Important Parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remaining 21 Sampled Parameters</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

* Y (yes) indicates a parameter is important with respect to the listed regulation. N (no) indicates that sensitivity with regard to the regulation is the primary reason for the ranking. NA (not applicable)
"Less Important" Parameters Sampled in the 1992 PA (Conditional on Assumptions of 1992 PA)

Climatically-Varying Recharge Factor
Fracture Porosity in Culebra
Porosity of Clay Lining Fractures in Culebra
Radionuclide Sorption in Clay Fracture-Linings in Culebra (6 elements)
Residual Brine Saturation in Halite
Residual Brine Saturation in Anhydrite
Residual Gas Saturation in Halite
Residual Gas Saturation in Anhydrite
Two-Phase Flow Model Exponent
Castile Brine Reservoir Pressure
Castile Brine Reservoir Area
Castile Brine Reservoir Storativity
Porosity of Backfill in Drifts, Experimental Regions, and Shafts Below Seal
Drift and Panel Seal Permeability
Far-Field Pressure in Salado Formation
Shaft Seal Vertical Thickness
Examples of Important Sources of Conceptual Model Uncertainty in the 1992 PA

<table>
<thead>
<tr>
<th>Conceptual Model</th>
<th>191.13</th>
<th>268.6</th>
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<tbody>
<tr>
<td>VOC Source Term and Transport</td>
<td>na*</td>
<td>Y</td>
</tr>
<tr>
<td>Spalling</td>
<td>Y</td>
<td>na</td>
</tr>
<tr>
<td>Pressure-Dependent Fracturing of Anhydrite</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Darcy Flow in Low Permeability Mediums (e.g., Halite)</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Dual-Porosity Transport in Culebra</td>
<td>Y</td>
<td>na</td>
</tr>
<tr>
<td>Sorption in Culebra Matrix</td>
<td>Y</td>
<td>na</td>
</tr>
<tr>
<td>Gas-Generation Model</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Actinide Source Term Model</td>
<td>Y</td>
<td>na</td>
</tr>
<tr>
<td>Confined Aquifer Model for Flow in the Culebra</td>
<td>Y</td>
<td>na</td>
</tr>
</tbody>
</table>

Others...

* NA (not applicable) indicates a conceptual model does not apply to the listed regulation. Y (yes) and N (no) indicate whether or not conceptual model uncertainty is important with respect to the listed regulation.
Performance Assessment Information Flow

System

Subsystem

Components

Repository/Shaft/Borehole Models

Salado Formation

Reference Stratigraphy

Material Properties of Undist. Fm

Material Properties of DRZ

Waste/Backfill

Waste Properties

Backfill Properties

40CFR191 Source Term

RCRA Source Term

Repository/Waste Interactions

Creep Closure/Expansion

Waste-Form Backfill Compaction

Pressure Dependent Fracturing

Gas Generation

Brine/Gas Flow

Human Intrusion

Material Properties of Borehole

Castile Brine Reservoir

Intrusion Probability

Repository Shaft Design

Repository Design

Panel/Drift Seals

Shaft Seals

Groundwater Flow and Transport Models

Groundwater Flow Model

Regional Hydrogeology

Rustler/Dewey Lake Hydrogeology

Radionuclide Transport Model

Physical Retardation

Chemical Retardation

Cuttings/Cavings Model

Drill Cuttings

Erosion/Cavings

Spallings

Exposure Pathways Models

Radon

Pressure Dependent Fracturing of Anhydrite
For 268.6, PA Does Not yet Calculate a Regulatory Performance Measure

Regulatory measure is VOC (and HM) concentration at unit boundary

VOC source term and transport not modeled in 1992 PA or in 1994 preliminary runs

Gas migration is reported as a nonregulatory performance measure

- Potentially a conservative bounding calculation
- Migration past unit boundary has no regulatory significance
- Preliminary 1994 undisturbed calculations show all gas remaining within unit boundary in 46 of 50 realizations
Maturation of PA Process

**PA Modeling Sophistication**

*PSA/# = Probabilistic System Assessment/# perams sampled

**Sensitive Parameters**

Protection of sensitive parameters includes:

- Brine inflow
- Gas Generation
- Human Intrusion Scenarios

**Guidance to Test Program**

- Study: Brine Inflow, EPA Regulation
- Do Engineered Alternatives Study
- Do Dual Porosity, Retardation & Solubility Studies

**Pre 1989**

- 1-D Flow
- No Retardation
- No Gas Effects
- No PSA*
- Manual Dataflow

**1989**

- 1-D Flow/Trans
- No Retardation
- No Gas Effects
- PSA/12
- Auto Dataflow

**1990**

- 2-D Flow/Trans
- No Retardation
- No Gas Effects
- PSA/29
- Auto Dataflow

*PSA* indicates Probabilistic System Assessment.
Maturation of PA Process (Continued)

1991
- 2-D Flow/Trans
- Geostatistics
- Retardation
- Gas Effects
- PSA/45
- Auto Dataflow

1992
- Coupled Process
  in Waste Panel,
  Geostatistics
  in Culebra,
  Full
  Repository for
  Undisturbed
  PSA/55

1994
- Fracture Approximation,
  Full Repository for
  Intrusion Scenarios,
  Rustler/Dewey Lake
  stratigraphy included

Sensitive
Parameters
- Previous list plus
  Intrusion Rate (Poisson)
  Cor/Inun Gas Gen Rate
  Salado/MB Perm
  Culebra T-fids & BCs

Guidance to
Test Program
- Do fracture study
  Regional GW model
  Gas Generation
  Model

- Continue ongoing studies,
  Support Conceptual Models
  QA (Software, Data,
  Parameters, Analysis)

*PSA/# = Probabilistic System Assessment/# perams sampled
Rip’s Lessons Learned From WIPP PA

- Iterative PA analyses must be used to guide R & D needs
- Human Intrusion is dominant (only) release pathway for 40CFR191
- Calculational complexity is both good and bad
- Methods are available to treat data uncertainty
- For data spatial variability is still a problem
- Conceptual model uncertainty is the largest remaining problem
- A definition of future states for Human Intrusion are needed
- A figure of merit for 40CFR268.6 (RCRA) is needed
- The international community is at approximately the same level of development for PA