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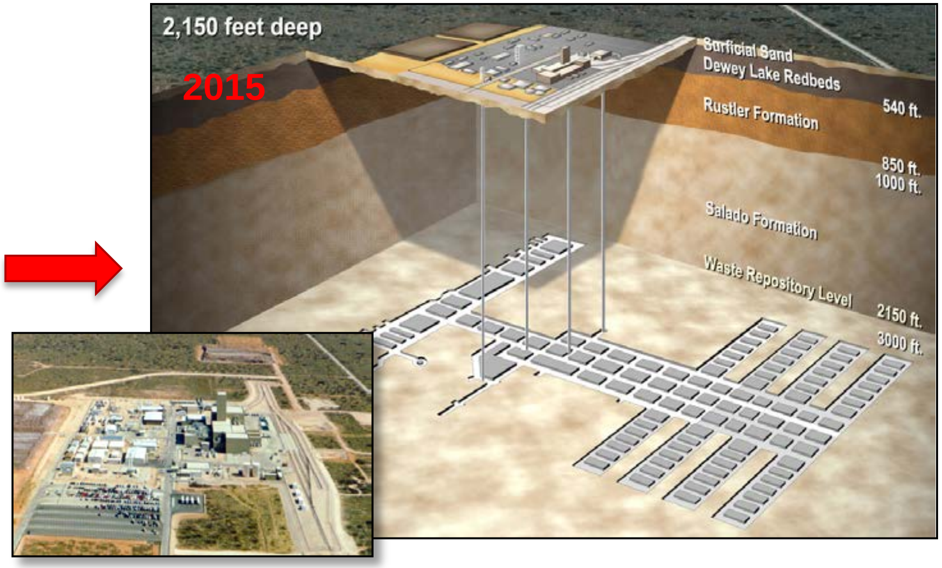

Waste Isolation Pilot Plant Overview

Peter Davies, Peter Swift, Chris Camphouse
Nuclear Energy & Fuel Cycle Programs
Sandia National Laboratories

February 17, 2015

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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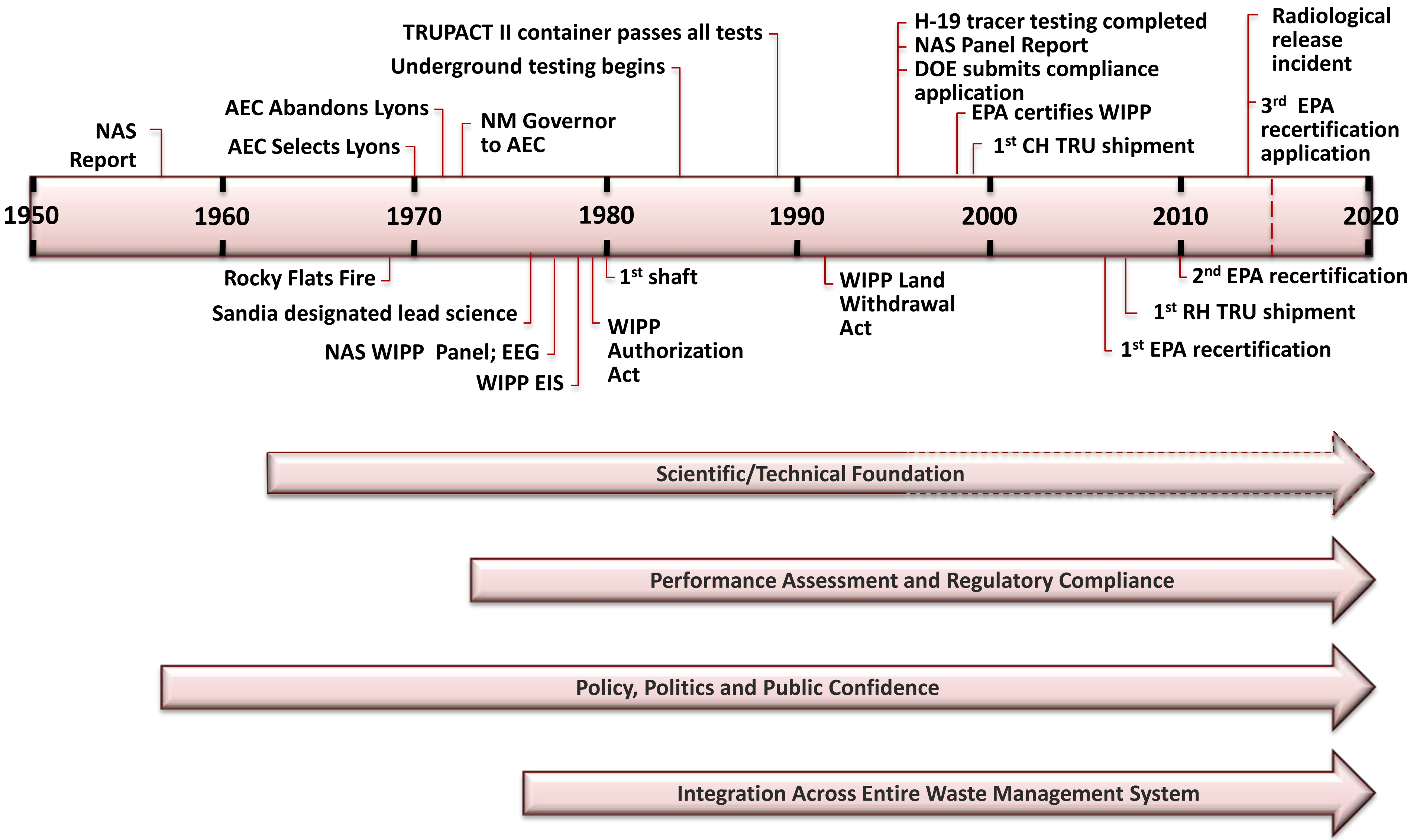
Key Themes

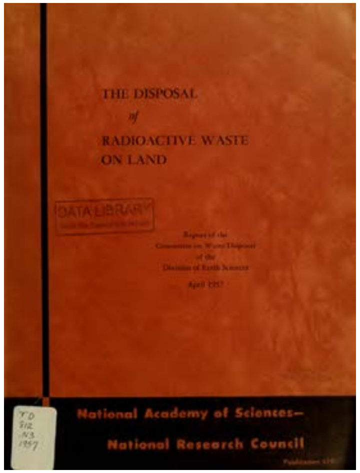
- ***Continuity*** – Development of a geologic repository requires decades of continuity of scientific, engineering and policy focus to move through a complex mix of technical, regulatory, political and public acceptance challenges.
- ***Scientific/Technical Basis*** - Building a credible, peer reviewed scientific basis for the technical and engineering foundation is a major endeavor and first step toward creating a geologic repository.
- ***Quantitative Performance Assessment*** - Scientific understanding and technical basis must be translated into quantitative/quality assured systems analysis that addresses specific regulatory requirements.
- ***Policy, Politics and Public Acceptance*** – policy, politics and public acceptance evolve over time, and multiple levels (national, state, local) are all important.
- ***Integration Across Entire Waste Management System*** – integration across waste preparation/packaging, transportation and disposal is essential for effective operations over the decadal operational life of a repository.

Continuity

Key Driving/Impacting Events



Background



- 1940s – Manhattan Project generates first significant volumes of spent nuclear fuel SNF and high-level radioactive waste (HLW)
- 1957 – NAS report *The Disposal of Radioactive Waste on Land*

INEEL 2003, Figure 3-8 (INEEL Photo # 69-6138)

- 1969 – Fire at Rocky Flats (Colorado) weapons production facility focuses attention on transuranic waste; fire waste to Idaho
- 1970 – AEC commits to remove Rocky Flats fire waste from Idaho by 1980; AEC selects salt mine at Lyons, Kansas as repository site. 1971: AEC discovers old drill holes and solution mining at Lyons site; abandons site
- 1972 – City of Carlsbad meets privately with NM governor Bruce King and potash industry; governor King invites AEC to consider NM; AEC announces interest in NM salt August 14, 1972

- 1972 thru 1979 – Political and administrative changes
  - 1974-AEC splits into NRC and Energy Research and Development Agency (ERDA)
  - 1977-ERDA becomes DOE
- 1975 – Sandia National Laboratories assumes lead science role; first site identified is found unsuitable
- 1976 – New site selected; ERDA-9 drilled; project is named Waste Isolation Pilot Plant

From DOE 1996, Appendix GCR, Figure 2-3

WIPP Transuranic Waste

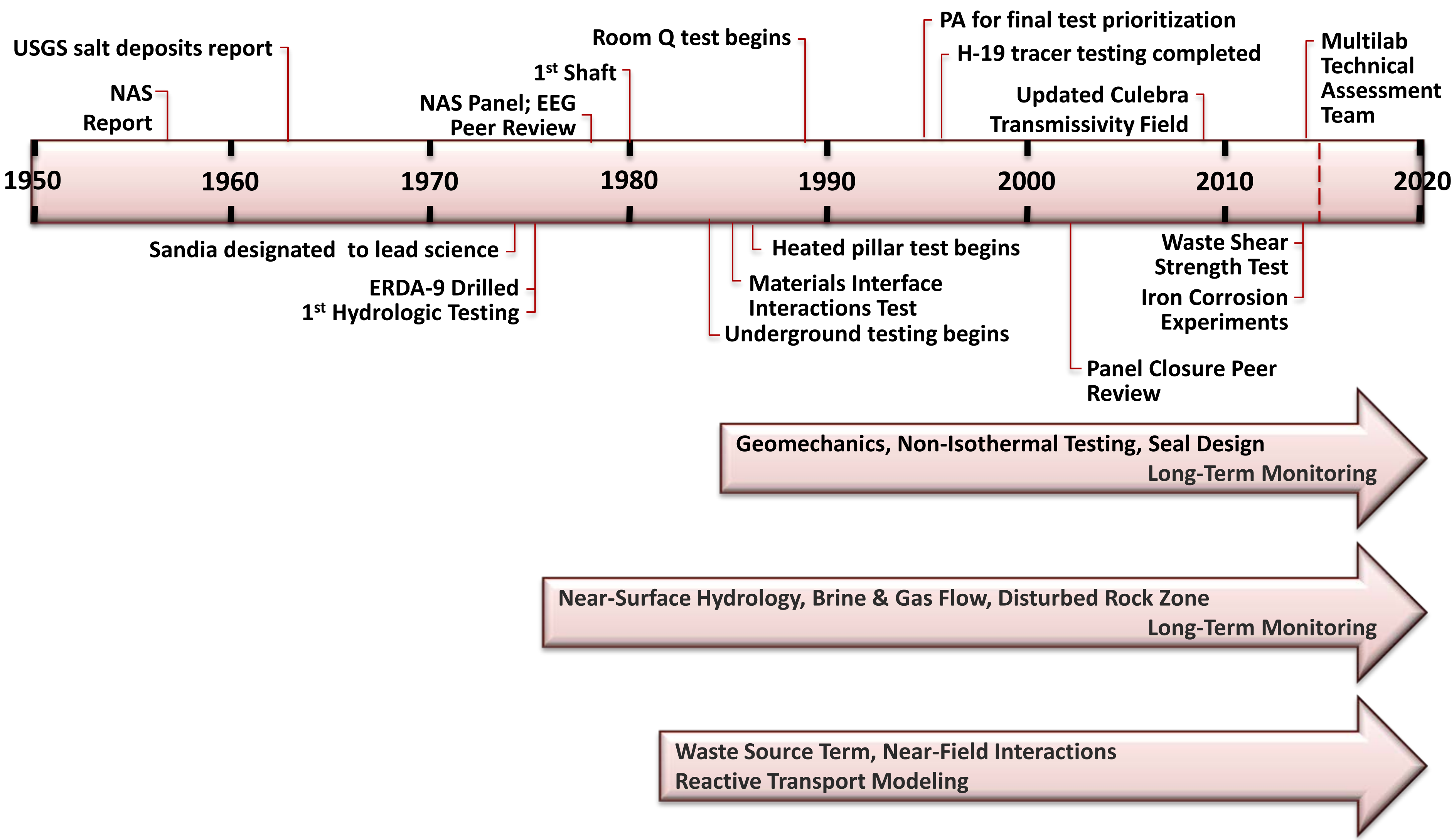
- Derived from defense-related activities
  - Laboratory and industrial trash contaminated with transuranic radionuclides
  - Primarily alpha-emitting radionuclides, relatively little gamma emission and low thermal power
  - Fewer fission products than SNF/HLW

- Defined by law:

  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 high-level radioactive waste;

Scientific/Technical Foundation

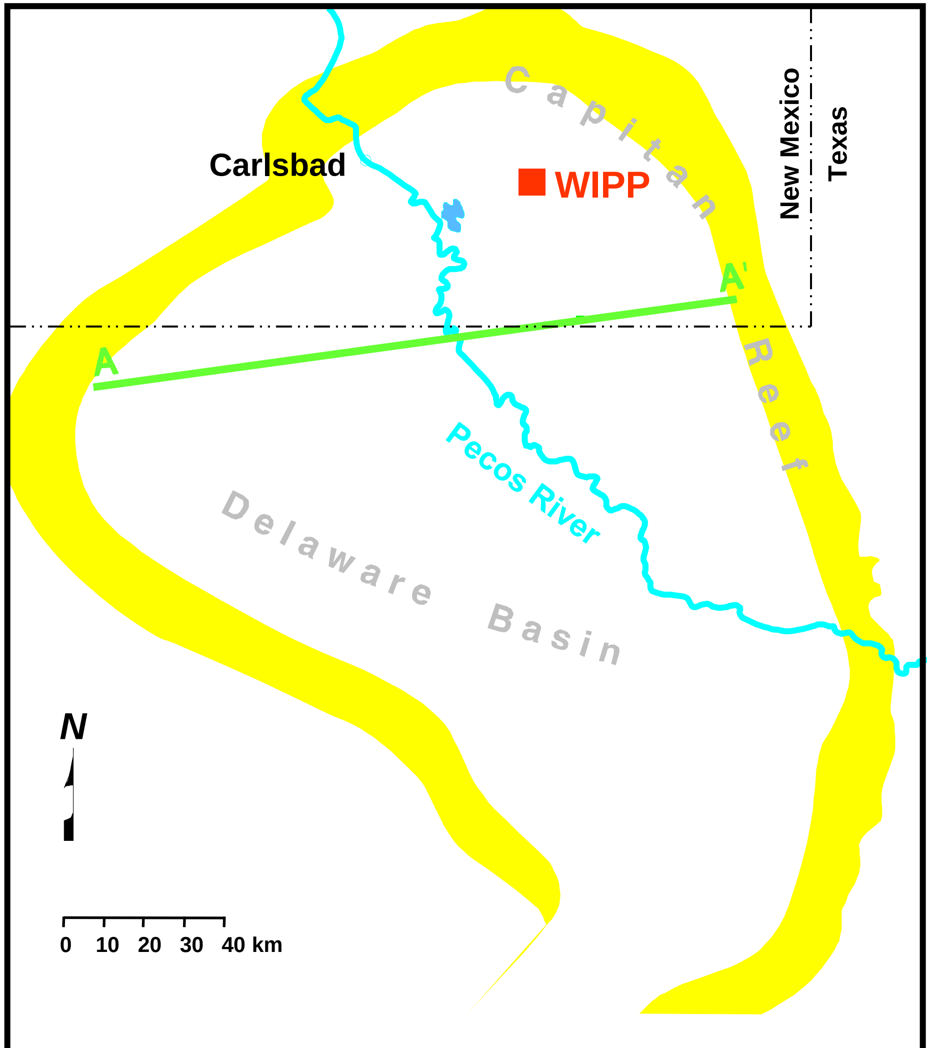
Geologic Characterization, Laboratory & In Situ Testing, Process Model Development



The Premise for Isolation in Salt

- Intact salt is essentially impermeable
- Intact salt does not contain flowing groundwater
  - Water that is present in salt formations is salt-saturated brine, and incapable of further dissolution
- Salt creep will
  - Close fractures
  - Consolidate crushed salt backfill, and allow shaft seals to function like intact rock
  - Close disposal panels and eventually surround waste with salt
- Little reliance on waste packages for isolation
  - For WIPP, no long-term post-closure function whatsoever is assumed for packages
  - Waste is assumed to be exposed to the host rock environment as soon as the repository is closed

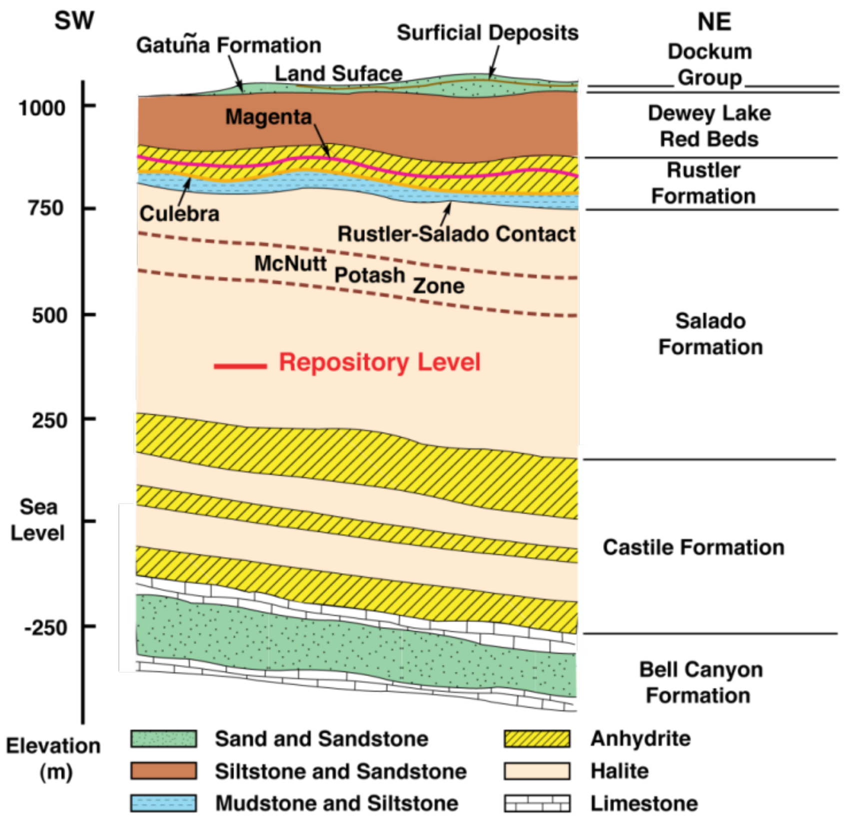
Site Geology



WIPP is located in the Delaware Basin, which is the modern geologic expression of a Permian-age (~ 255 million years) topographic depression

Basin geology is broadly characterized by carbonate reef rocks (Capitan Formation) surrounding evaporite rocks deposited in a shallow sea

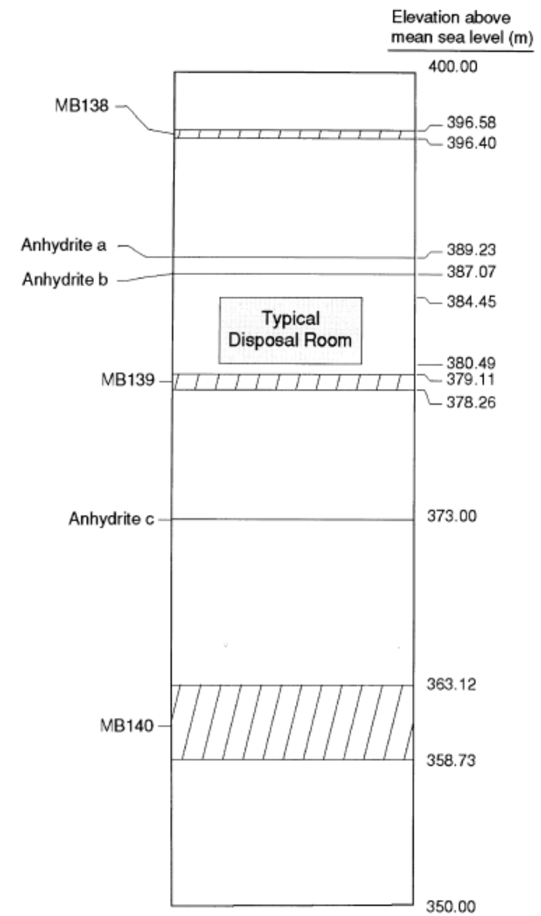
Local Stratigraphy at WIPP



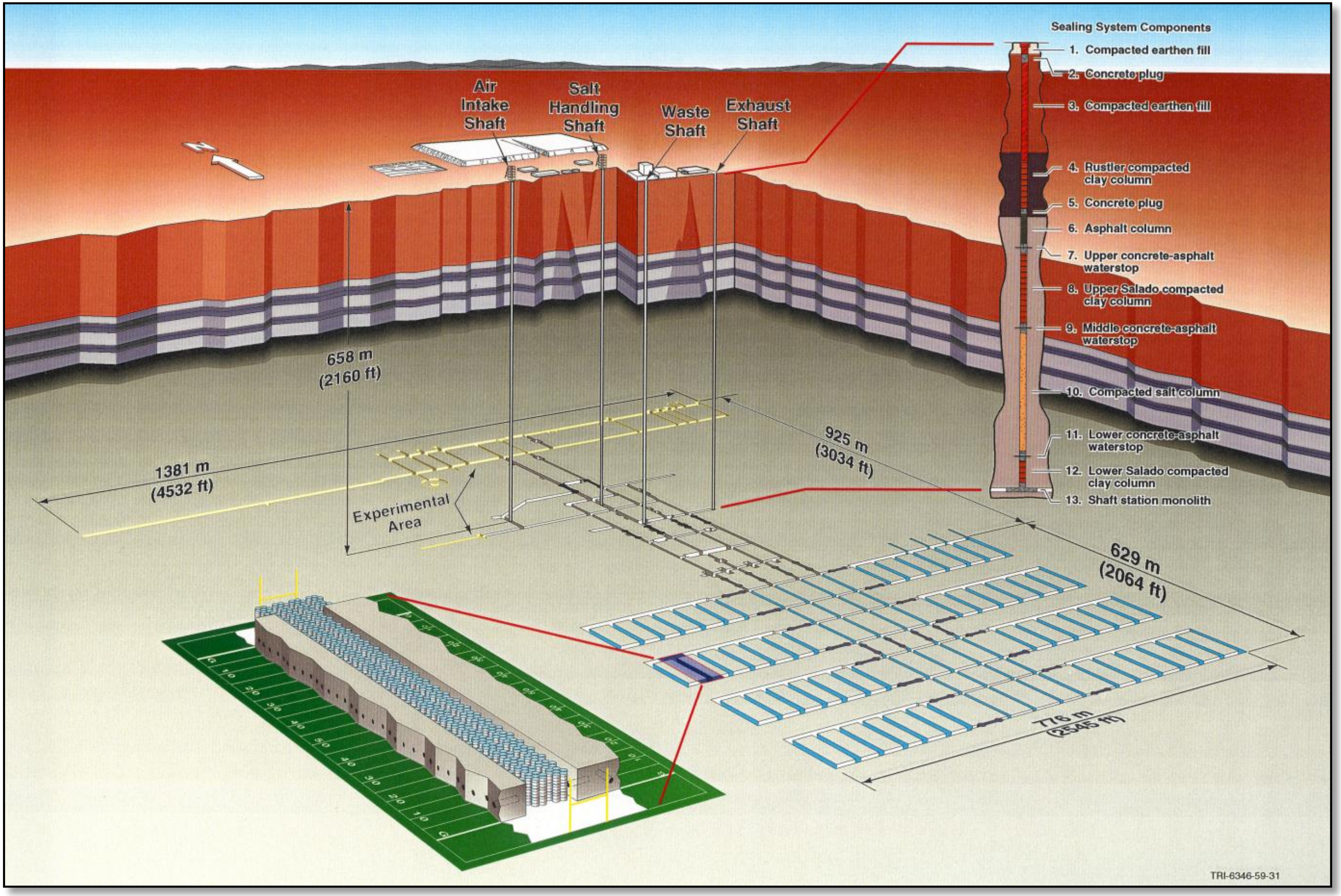
Within the Salado Fm, halite units are separated by laterally persistent interbeds of anhydrite, clay, and polyhalite.

Anhydrites "a" and "b" are thin seams 2 to 5 meters above the disposal horizon, and Marker Bed 139 (MB139) is a thicker interbed approximately 1 m below the disposal room.

Interbeds are planes of structural weakness and have relatively higher permeability than intact halite.



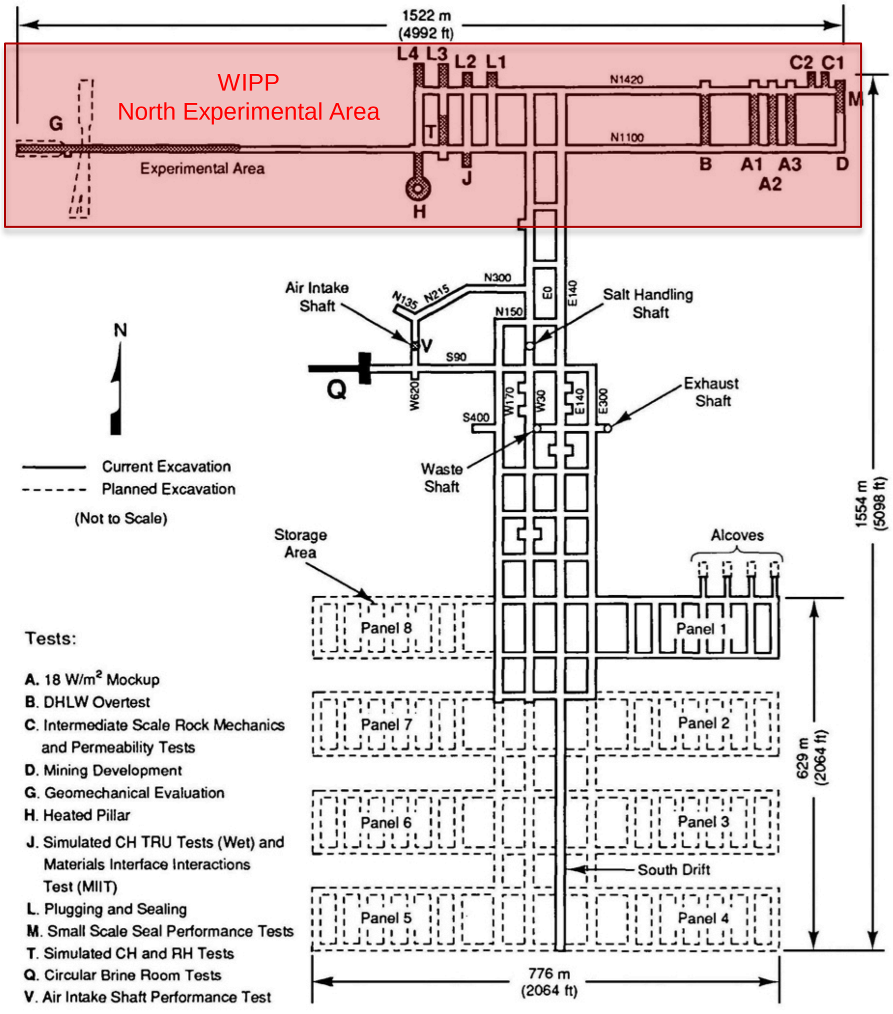
WIPP Design



Sealing System Components
1. Compacted earthen fill
2. Concrete plug
3. Compacted earthen fill
4. Rustler compacted clay column
5. Concrete plug
6. Asphalt column
7. Upper concrete-asphalt waterstop
8. Upper Salado compacted clay column
9. Middle concrete-asphalt waterstop
10. Compacted salt column
11. Lower concrete-asphalt waterstop
12. Lower Salado compacted clay column
13. Shaft station monolith
Air Intake Shaft
Salt Handling Shaft
Waste Shaft
Exhaust Shaft
658 m (2160 ft)
1381 m (4532 ft)
925 m (3034 ft)
Experimental Area
629 m (2064 ft)
776 m (2545 ft)
TRI-6346-59-31

WIPP Geomechanical & Waste Package Experiments

- 3 Primary DHLW Test Programs
  - for future Deaf Smith site
- Thermal/Structural Interactions (TSI)
  - Rooms A1-A3 (18 W/m^2 DHLW mockup)
  - Room B (DHLW overtest)
  - Room H (Heated axisymmetric pillar)
  - Room D (Isothermal Room B)
- Waste Package Performance (WPP)
  - DHLW materials tests in Rooms A1/B
    - Waste Package materials tests
    - Borehole backfill materials tests
  - Waste/package corrosion testing
    - Rooms J/T
- Plugging and Sealing Program (PSP)
  - Brine release in Rooms A1/B

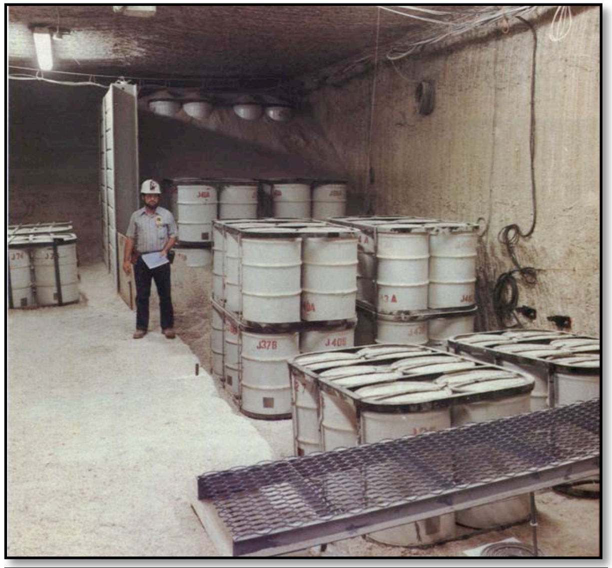


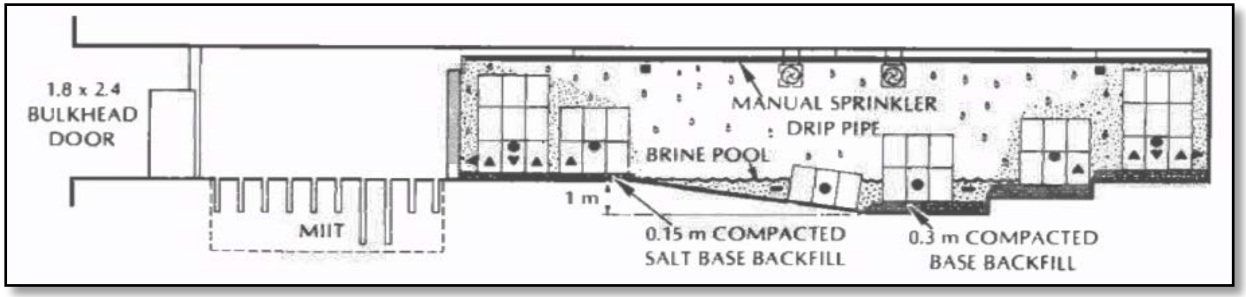
Jensen et al. (1993)

Tyler et al. (1988) provides a comprehensive summary of DHLW testing at WIPP

TRU waste package overtest ('86-'90)

- Overtest of WIPP-like conditions
  - Brine pool, 40°C, high humidity, radionuclide tracers, crushed salt
- Investigated
  - Drum corrosion
  - Backfill reconsolidation
  - Radionuclide migration





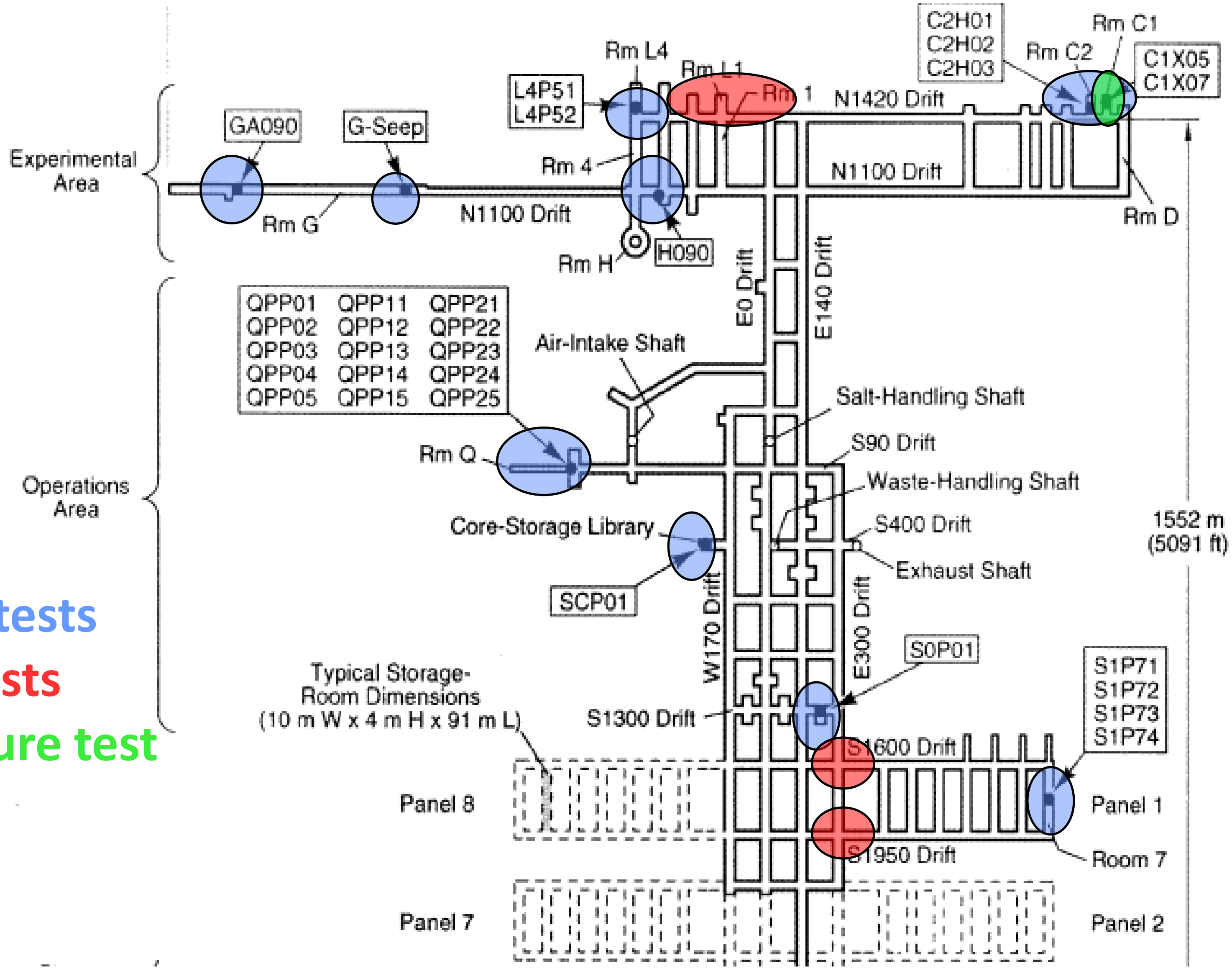
WIPP Defense High Level Waste – Heated Canister Test: Room A2 (‘85-’90)

Matalucci (1987)

WIPP Defense HLW: Room B ('85-'89)

Typical WPP DHLW canister in Room B at installation and removal
Creep closure and salt crust deposition required overcoring to remove

WIPP Brine / Gas Flow Test Locations

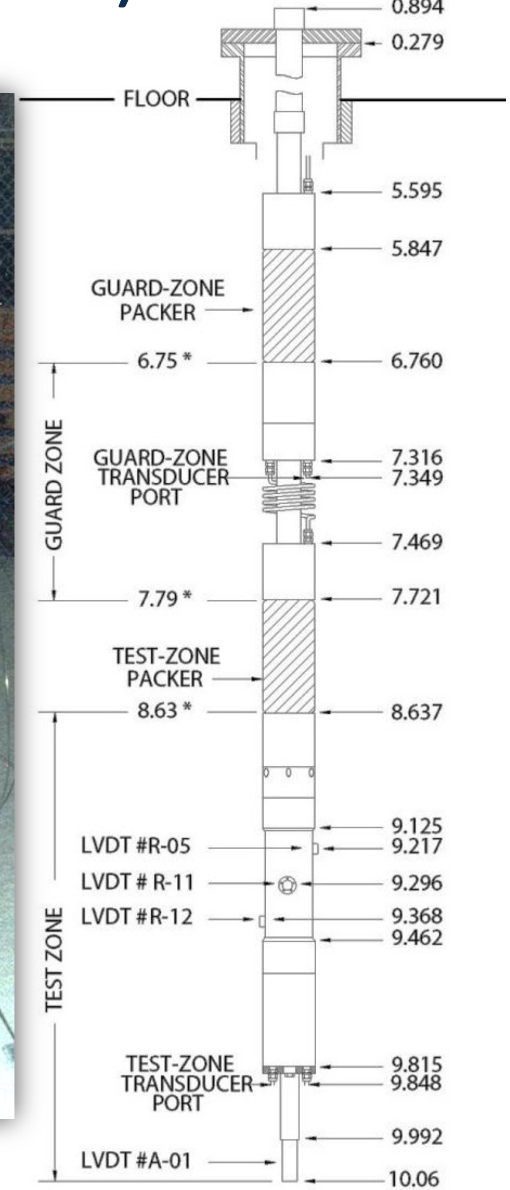


Brine flow tests

Gas flow tests

Hydrofracture test

Brine Flow Test Apparatus (‘92 – ‘95)

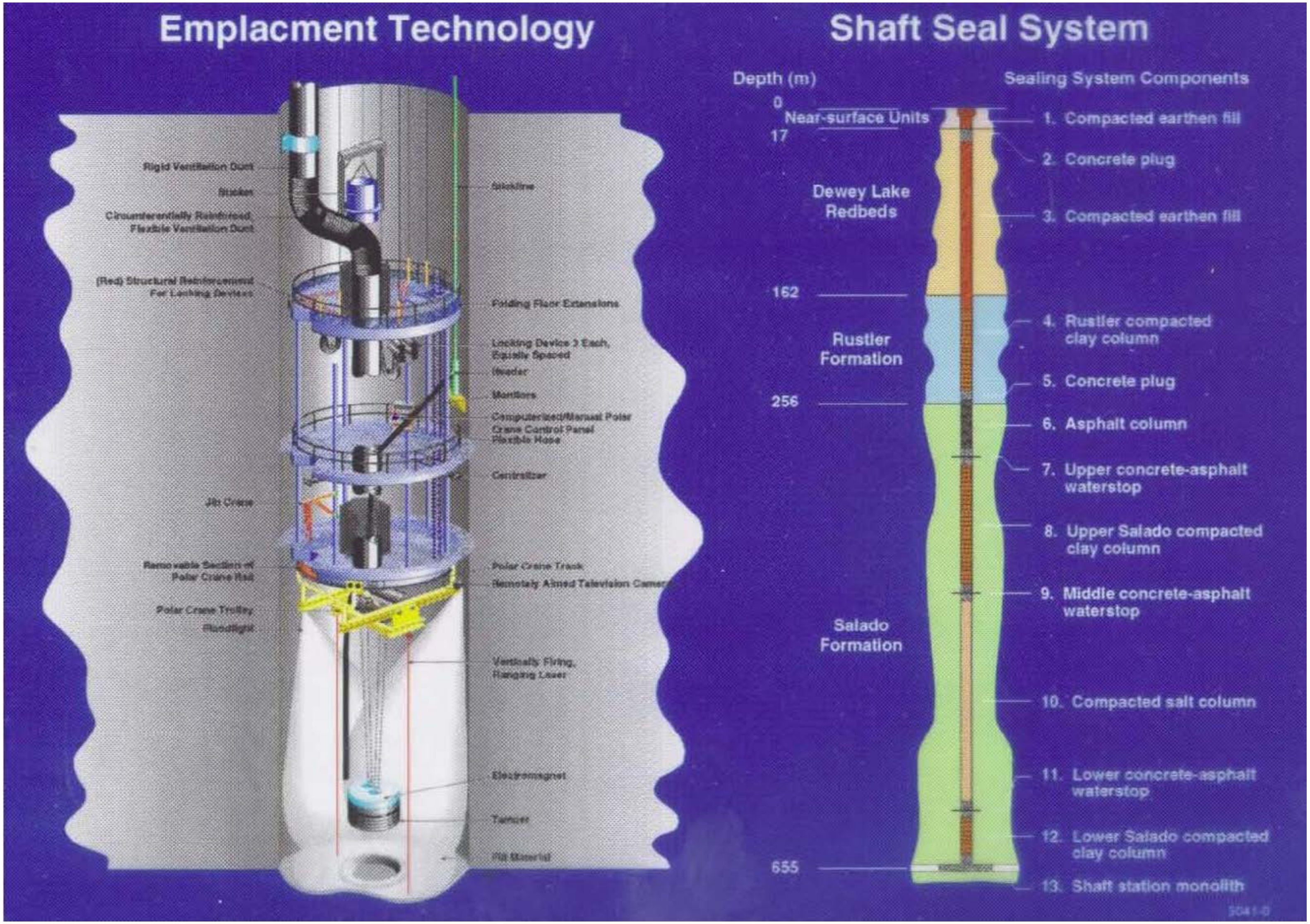


Room Q Brine Inflow Experiment ('89 - '95)

Room Q Seal Door and Instrumentation Interface

Small Scale Seals Performance Testing 1985 to 1994

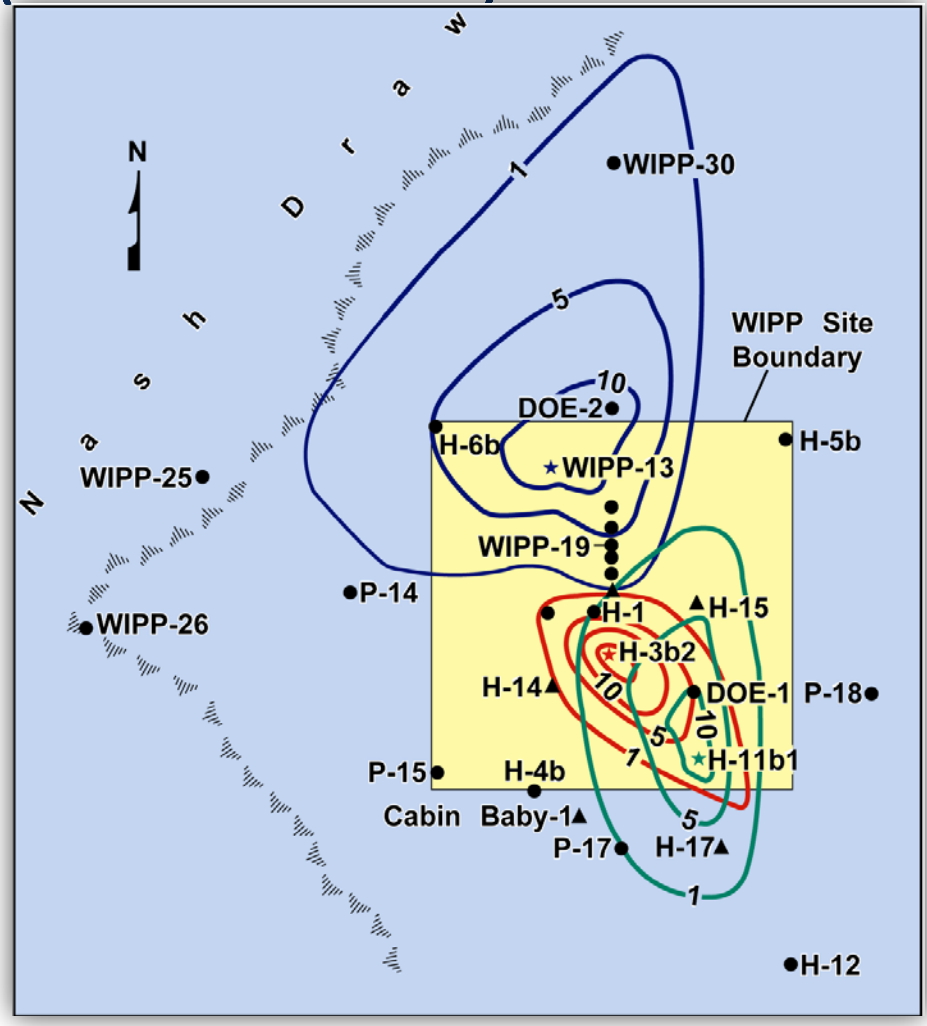
Shaft Seals System Studies



Summary of WIPP Hydrologic Testing (1976 to 1996)

- Bell Canyon tested in 5 holes from 1976-1985
- Castile tested in 5 holes from 1976-1982
- Salado tested in 7 holes from 1976-1985
- Rustler-Salado contact or Los Medaños tested in 23 holes from 1976-1987
- Culebra tested in 90 holes from 1974-2009
- Tamarisk tested in 5 holes from 1976-1987
- Magenta tested in 24 holes from 1974-2009
- Forty-niner tested in 4 holes from 1984-1989
- Dewey Lake tested in 5 holes from 1984-1996

Drawdown Responses to Large-Scale Pumping Tests in Culebra Dolomite (1995 - 1996)



Pumped wells

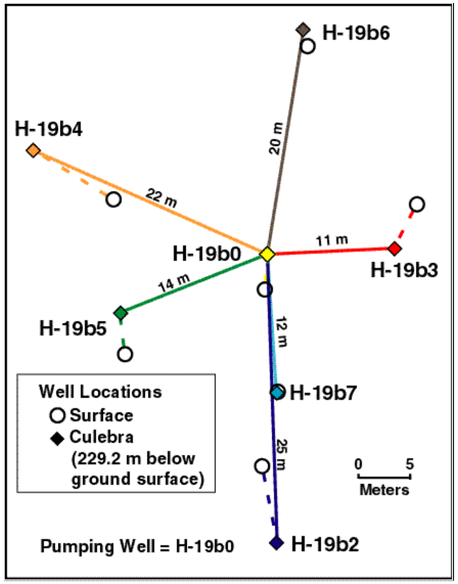
H-3b2: 62 days @ 0.3 L/s

WIPP-13: 36 days @ 1.9 L/s

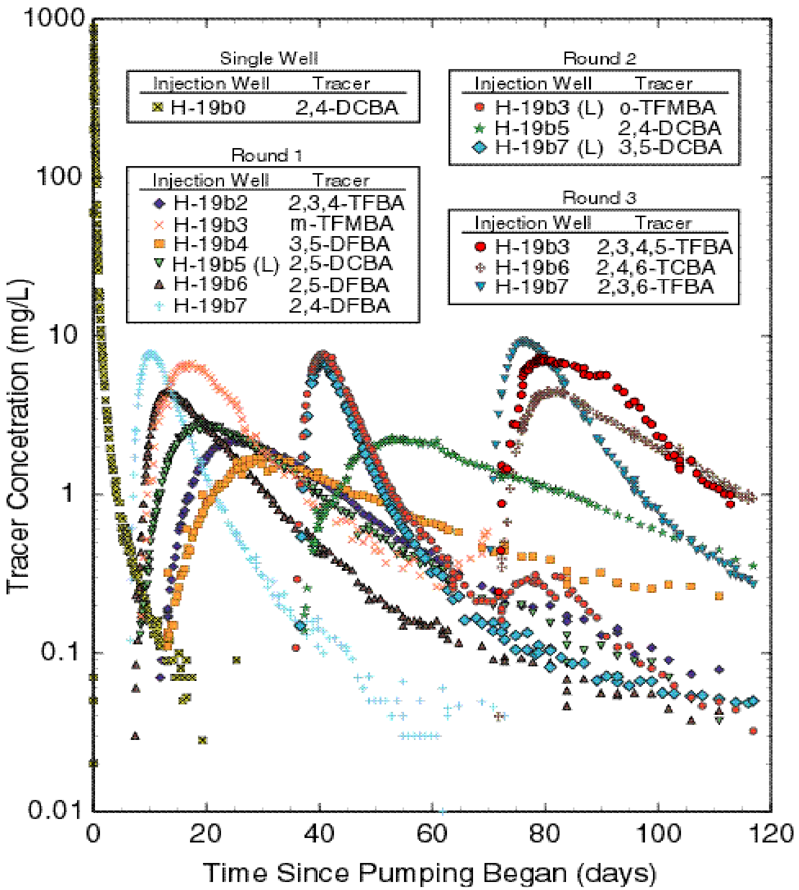
H-11b1: 63 days @ 0.4 L/s

Drawdown contours in meters

Tracer Testing in Culebra Dolomite (1980 - 1996)



Convergent Flow Tracer Test



H-19 Tracer Test Data

Waste Shear Strength Testing (2012) for 2014 Recertification Performance Assessment

- The waste shear strength is the ability of waste to resist erosion, and is one of the most important parameters in WIPP PA.

- SNL vertical flume experimental facility and the data obtained therein enabled a refinement to the WIPP waste shear strength parameter used in WIPP PA
- Surrogate degraded waste samples were used to determine lower value of shear strength uncertainty range

2012 Update of Brine Pocket Analysis for 2014 Recertification Performance Assessment

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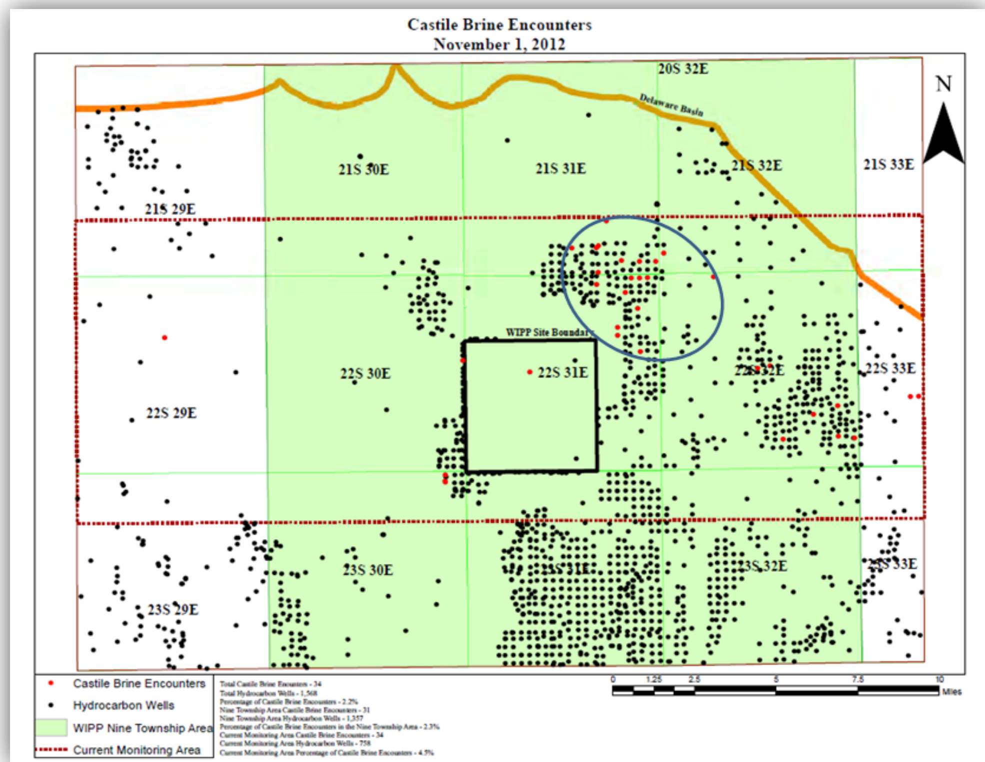
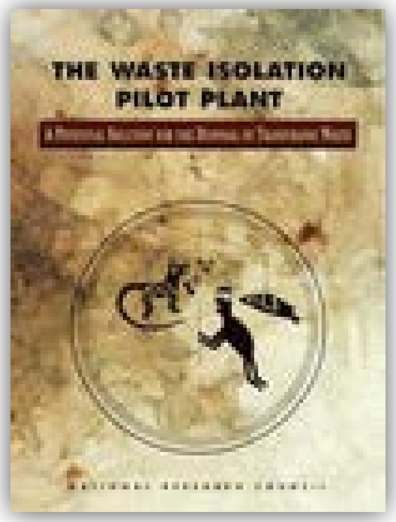
- WIPP PA includes intrusion scenarios that model borehole drilling through the repository and into underlying pressurized brine.



- A framework that provides a quantitative argument for refinement of the parameter describing the probability of a pressurized brine encounter was developed as part of the CRA-2014 PA

Technical Peer Review & International Technical Collaborations



National Research Council NAS WIPP Panel – 1978 to 1996

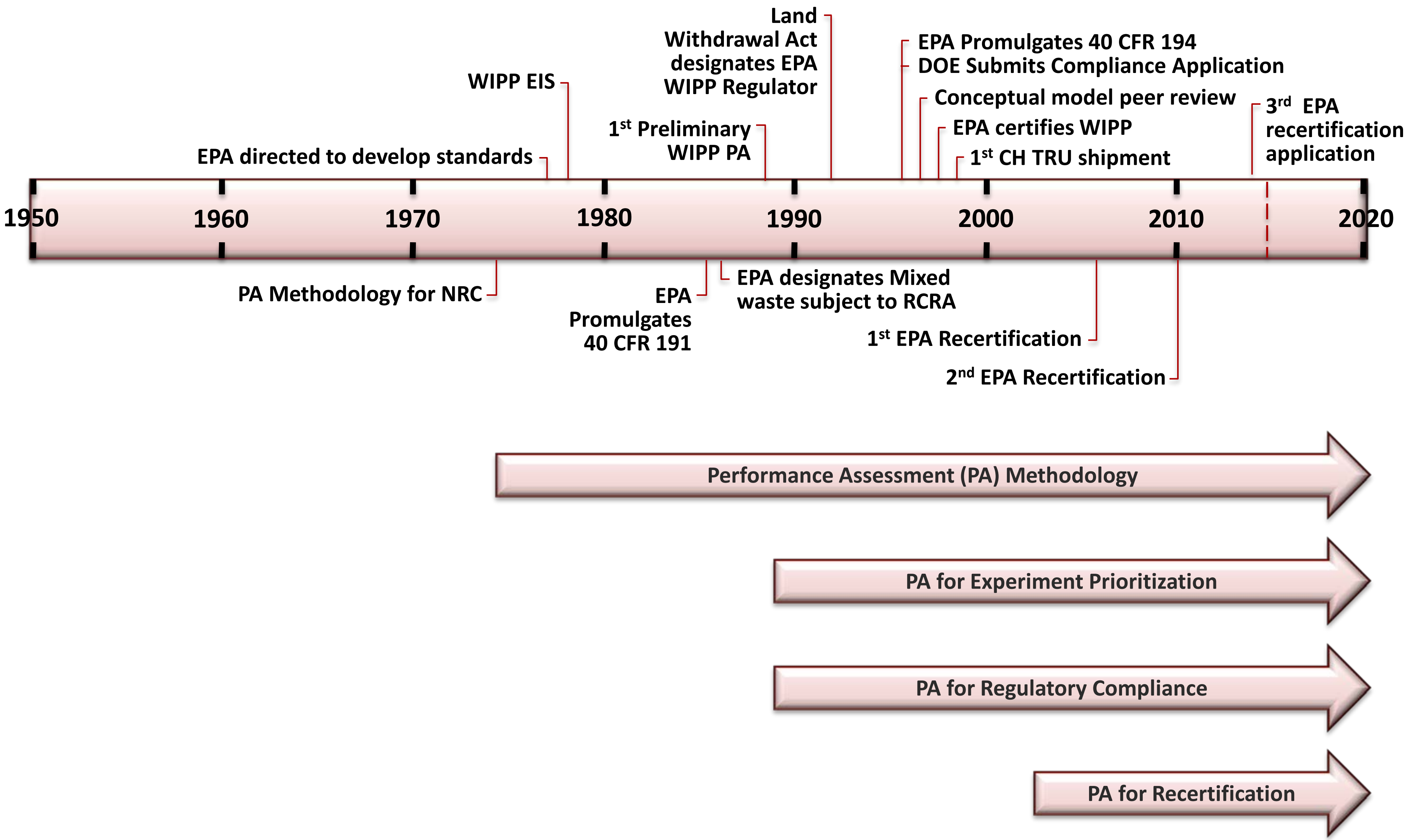
New Mexico Environmental Evaluation Group – 1978 to 2004

International Technical Collaborations – 1986 to present

- Materials Interface Interactions Tests – (Belgium, Canada, France, Germany, Japan, Sweden, and United Kingdom)
- Flow/transport in fractured rock – Aspo (Sweden); Grimsel (Switzerland)
- Salt geomechanics – (Germany)

Performance Assessment & Regulatory Compliance

Regulatory Requirements

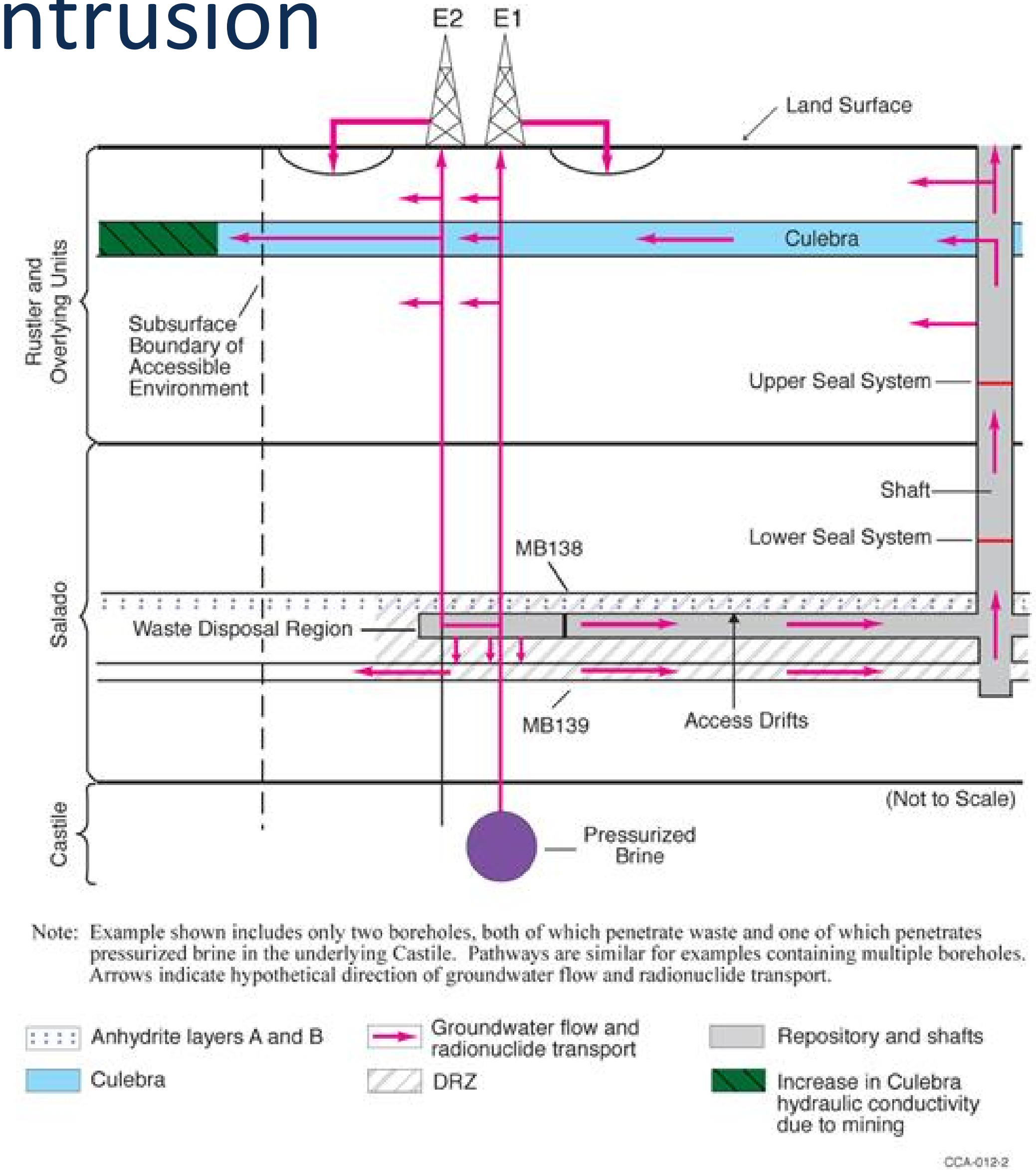


EPA's Regulatory Requirement

Key Points from 40 CFR Part 191

- *Driving scenarios* - regulatory requirements define two scenarios: "Undisturbed Performance" and performance including "all significant processes and events"
  - Undisturbed performance gets defined explicitly:
    - 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.
  - Very unlikely events ($P < 10^{-8}$/yr) may be excluded from analysis
  - Disturbed performance implicitly includes human intrusion
- *Release limit* - containment requirements, which include consequences of human intrusion, are not a dose standard
  - The metric that drives compliance for WIPP is 10,000-year cumulative release, rather than annual dose

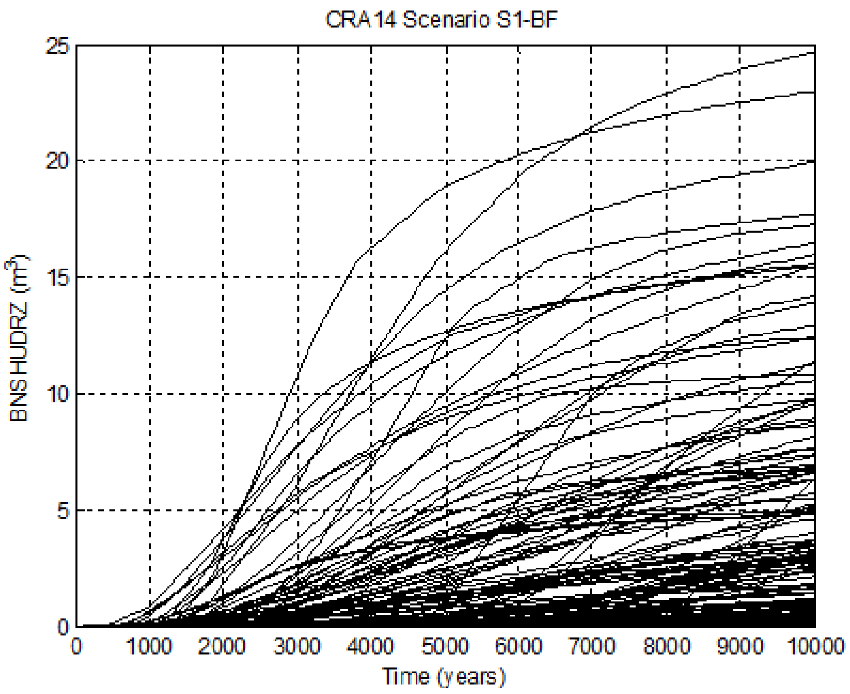
WIPP Performance Assessment – Human Intrusion



DOE 2014, Appendix PA Figure PA-9

Example of Uncertainty in WIPP Performance: Brine Flow upward through Shaft seals

10,000-year Undisturbed Performance



DOE 2014, Appendix PA, Figure PA-47

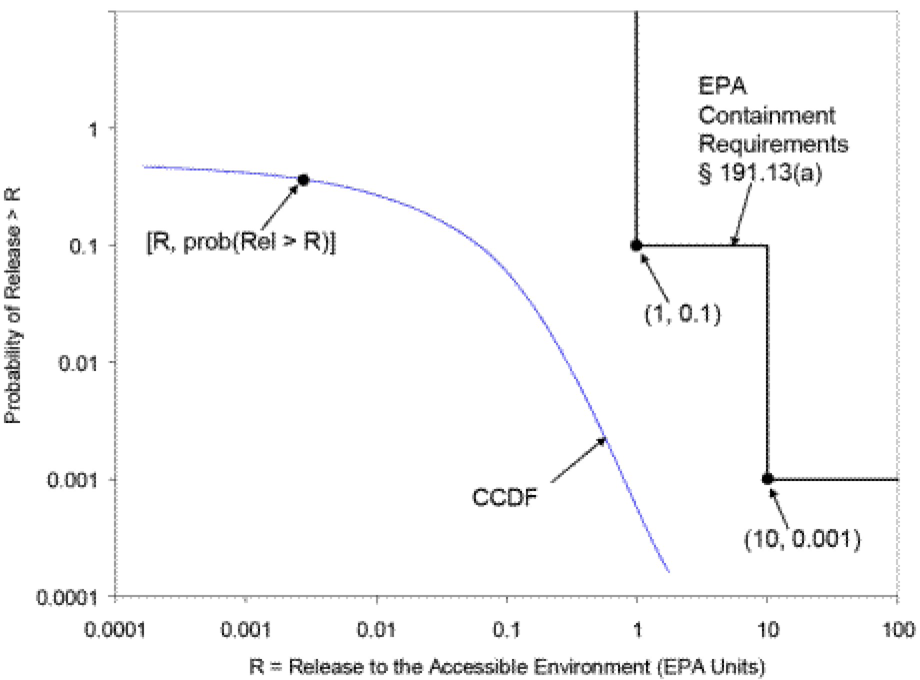
Brine flow upward in the shaft seals is a function of

- Pressure in the repository
  - Function of multiple coupled processes
- Hydrologic properties of the shaft seals
  - Permeability

EPA Containment Requirements

The EPA Containment Requirements at 40 CFR 191.13 define a *complementary cumulative distribution function* (CCDF) of allowable releases

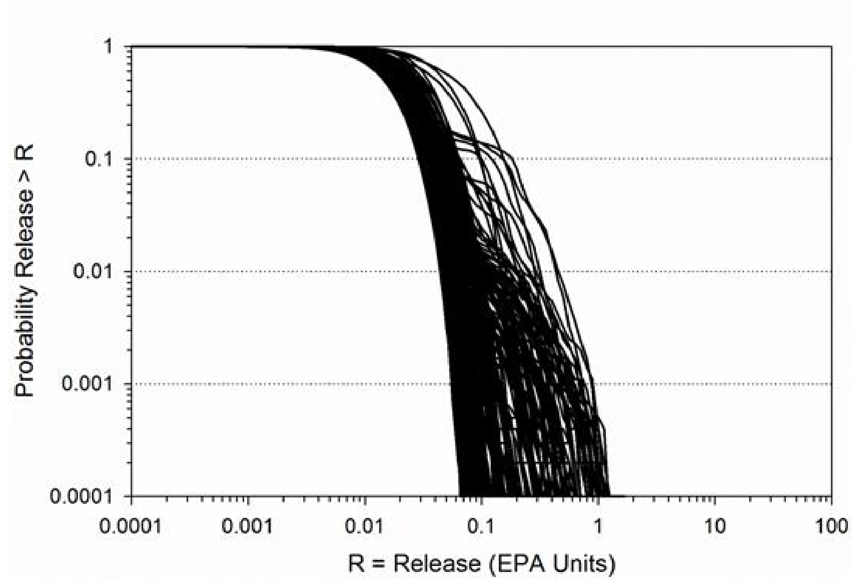
> "… cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall:
>
> - (1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 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)."

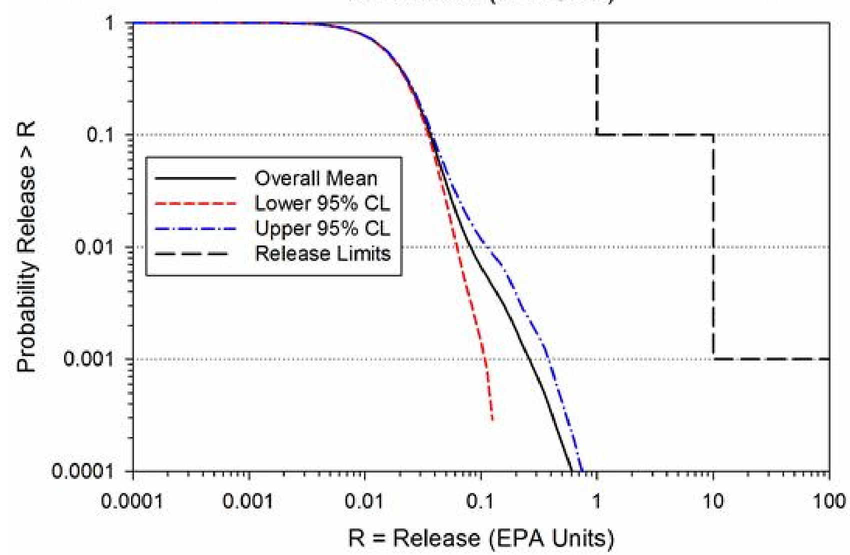


DOE 2014, Appendix PA Figure PA-2

CCDF of Total Normalized Releases From All Scenarios

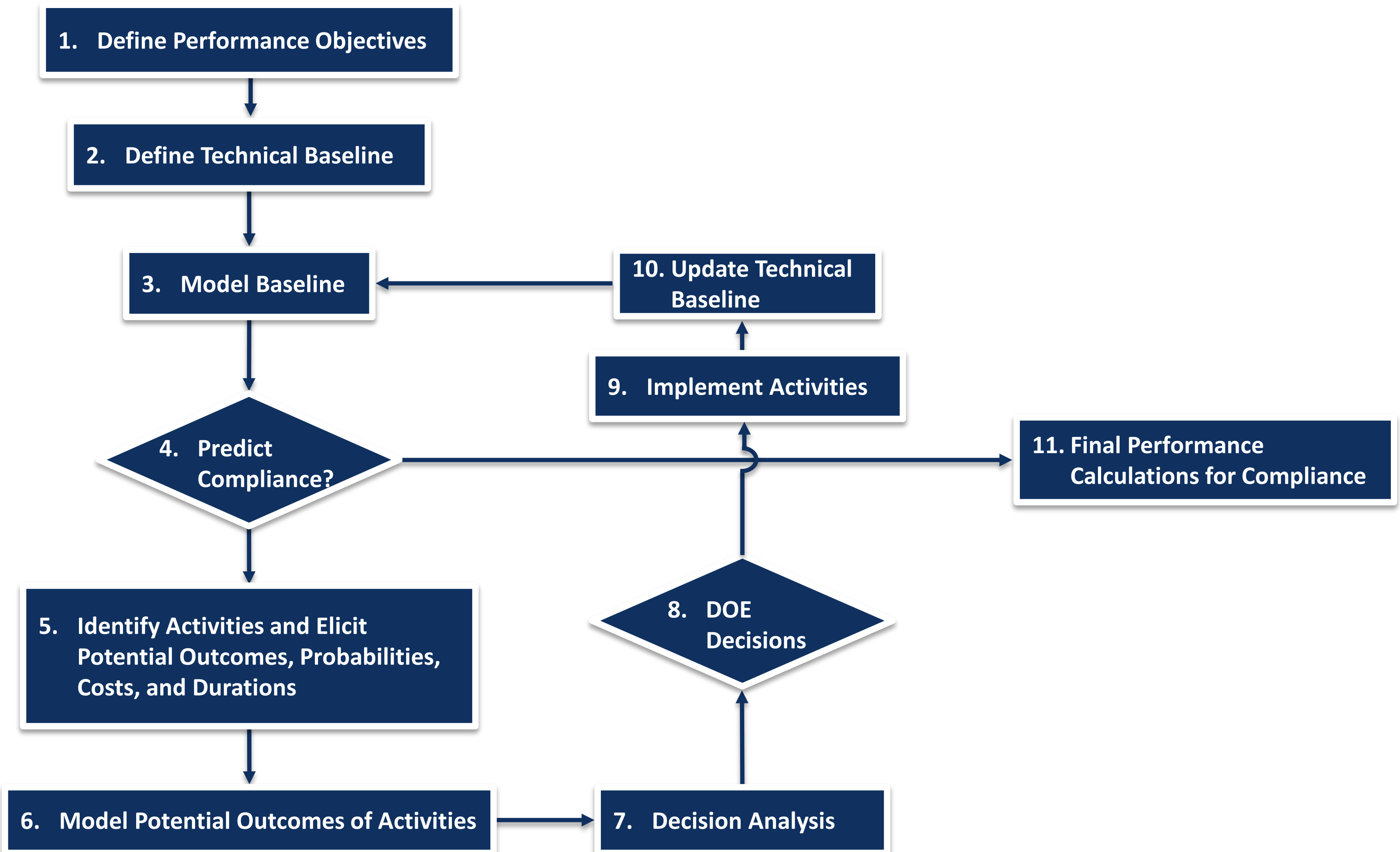
- Upper figure shows 300 individual realizations (calculated in three replicates of 100 realizations each)
- Lower figure shows regulatory limits and the overall mean CCDF, with 95% confidence intervals (derived from the Student's T distribution of the mean CCDFs from each of the three replicates)





DOE 2014, Appendix PA Figures PA-80 and PA-81

Performance Assessment for Experimental Prioritization - 1995

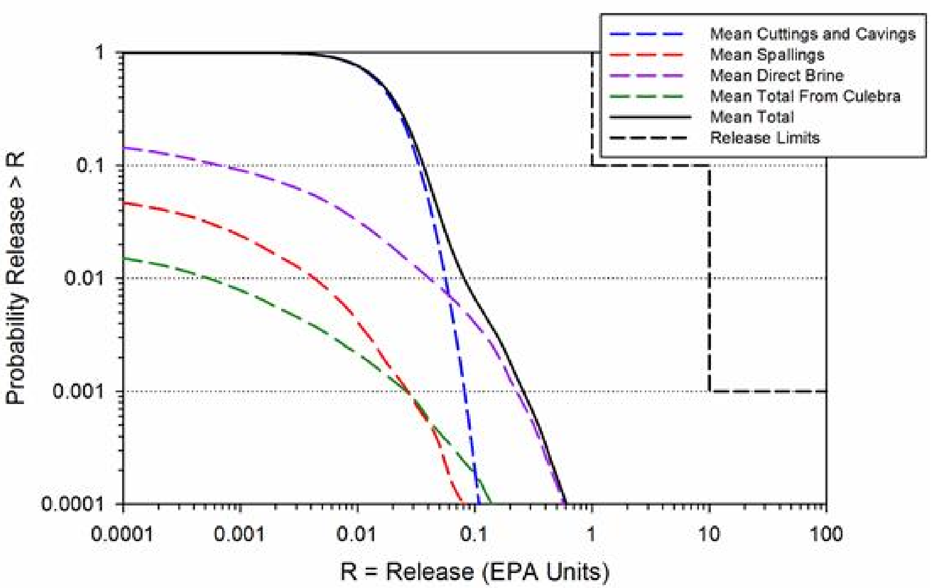


Release Mechanisms Contributing to the Overall Mean CCDF

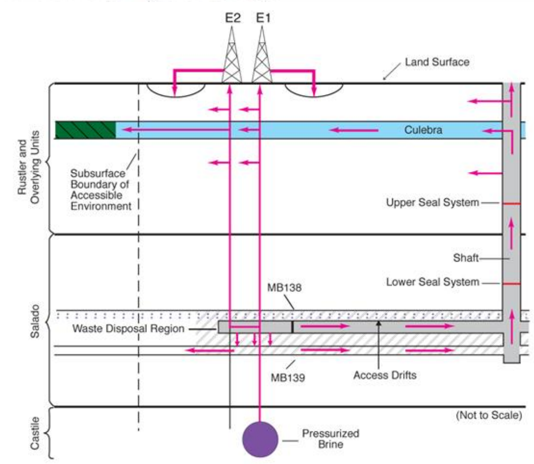
Undisturbed performance results in zero release

All releases are due to drilling intrusions

- "**Cuttings and Caving**s" are the material brought to the surface during drilling
- "**Spallings**" are solid material that is transported into the hole during depressurization and brought to the surface during drilling
- "**Direct Brine**" is contaminated brine that flows to the surface during the intrusion
- "**Culebra**" is the 10,000-year sum of radionuclides that are transported up the abandoned borehole after the intrusion event is over, and then transported laterally to the site boundary through the Culebra unit



DOE 2014, Appendix PA Figure PA-82 (above) and PA-9 (right)



Development of Advanced Modeling Capability for Future Performance Assessments

PFLOTRAN is a reactive flow and transport computer code that can be run massively parallel.

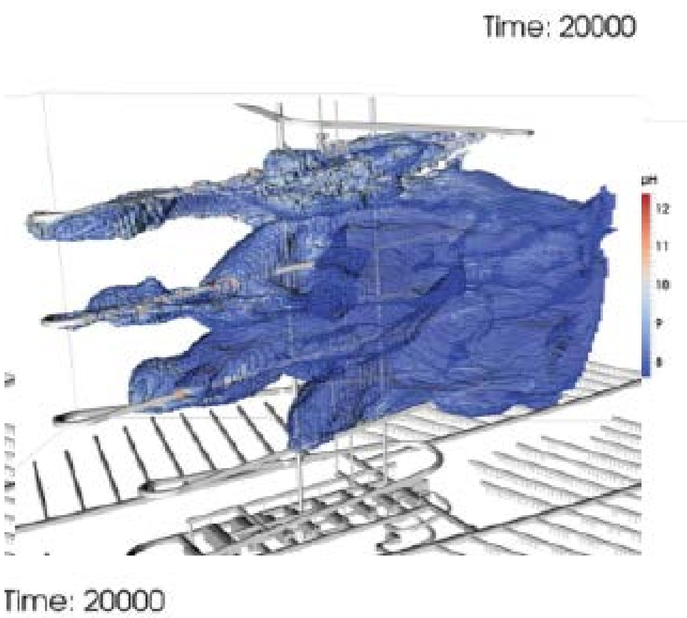


Image taken from Peter Lichtner' PFLOTRAN Shortcourse

- PFLOTRAN addresses the need for a three-dimensional code, and direct simulation of coupled processes
- Use of PLFLOTRAN in WIPP PA will enable three-dimensional representation of more complex repository geometries
- Enhancements include two-phase flow and time-dependent material properties
- PFLOTRAN PA implementation must fully satisfy stringent WIPP QA requirements

Policy, Politics and Public Confidence

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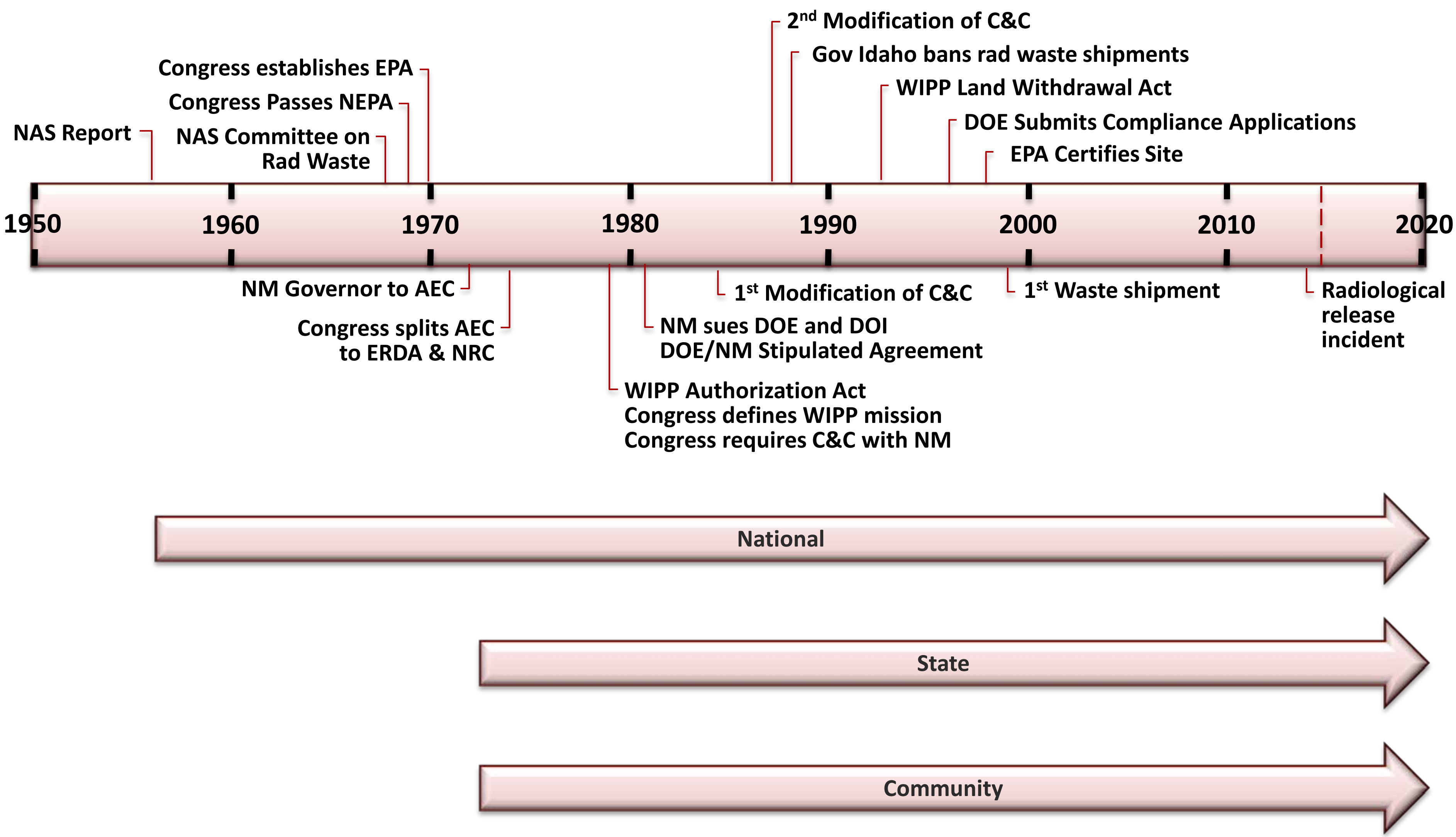
Major Events



Policy Environment and Regulatory Requirements Evolve Over Time

1969 – Congress passes National Environmental Policy Act (NEPA), first environmental law to be applied to WIPP

1970 – Congress forms EPA, which years later is designated as WIPP regulator

1971 – Congress directs AEC to stop Lyons project until safety is certified

1976 – President Ford orders ERDA demonstration disposal of radioactive waste by 1985, orders EPA to develop applicable standards

1978 – WIPP Environmental Impact Statement is project's first major analysis

1979 – Congress defines mission of WIPP as R&D facility for disposal of only TRU waste; exempts WIPP from NRC licensing; requires DOE sign "Consultation and Cooperation" (C&C) agreement with New Mexico

1985 – NRDC sues EPA to issue 40 CFR 191 as mandated in Nuclear Waste Policy Act; EPA promulgates 40 CFR 191

1992 – Congress passes WIPP Land Withdrawal Act transfers land from DOI to DOE; establishes EPA as WIPP regulator; requires 5 year recertifications; requires DOE cooperation with EEG

1997 – EPA certifies WIPP

Multiple State-Federal Interactions

1972 – Following termination of Lyons KS Project, City of Carlsbad meets privately with NM governor Bruce King and potash industry; governor King invites AEC to consider NM; AEC announces interest in NM salt August 1972

1974 – ORNL begins NM field investigations; suspended due to concerns with limiting oil drilling during Arab embargo; AEC split to NRC/ERDA; 1975 site investigation resumed; Sandia designated to lead science; brine in ERDA-6; 1976 site moved to final location; ERDA-9 drilled

1978 – NM Health & Environment Department health/safety concerns; Environmental Evaluation Group to conduct independent evaluation; neither proponent or opponent

1979 – Congress requires DOE to sign C&C agreement with NM

1981 – NM sues DOE & DOI alleging violations of federal/state laws; DOE accedes to "Stipulated Agreement" requiring geotechnical experiments; technical issue reports; State and Public review of changes; State transportation task force

1982 – DOE/NM Supplemental Stipulated Agreement requires highway funds; liability

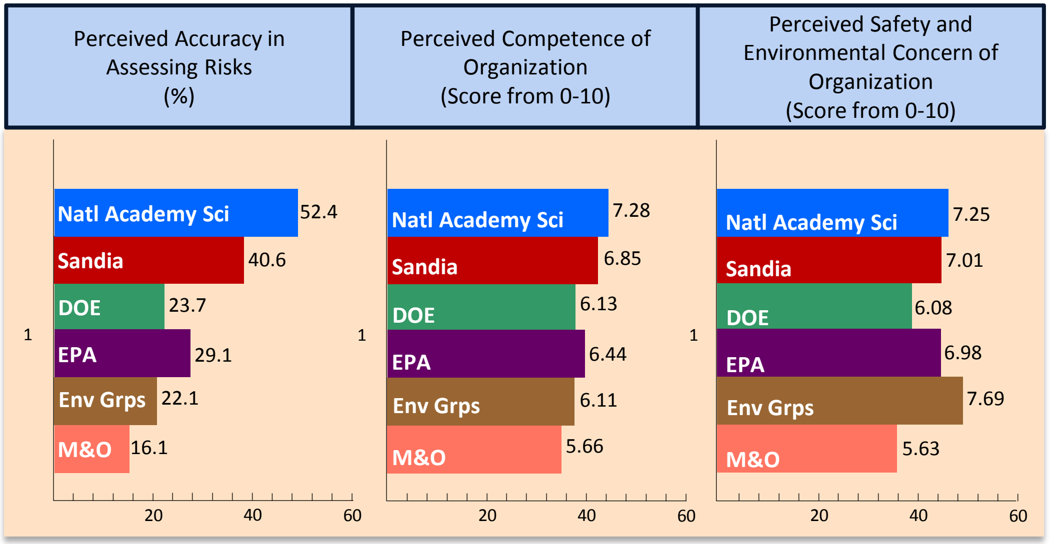
1984 – 1st modification of C&C agreement limits remote handled waste to 5.1x10E6 Ci

1987 – 2nd modification of C&C agreement use draft 40 CFR 191 as compliance framework; apply NRC and DOT regulation to TRU transportation

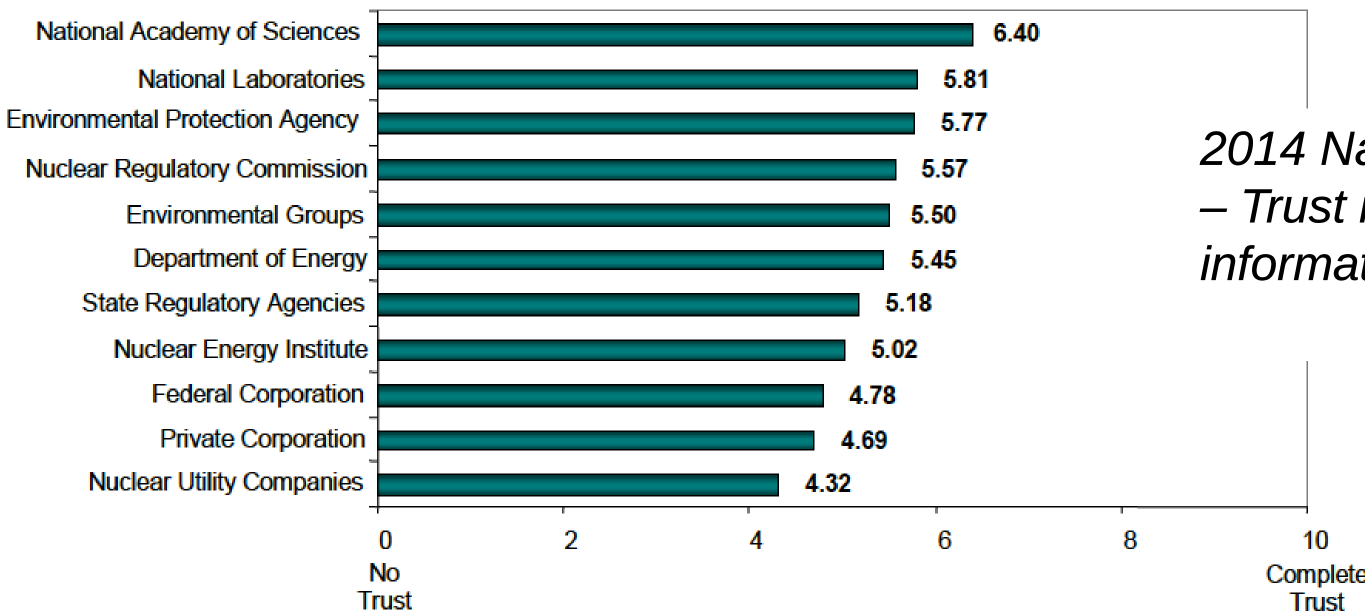
1992 – WIPP Land Withdrawal Act requires DOE cooperation with EEG; NM given $600M over 30 years

Public Confidence

1994 New Mexico survey – Perceived accuracy, competence and concern of organizations involved in WIPP performance assessment policy debate



Jenkins-Smith and Silva, 1998. *Reliability Engineering and System Safety* **59**

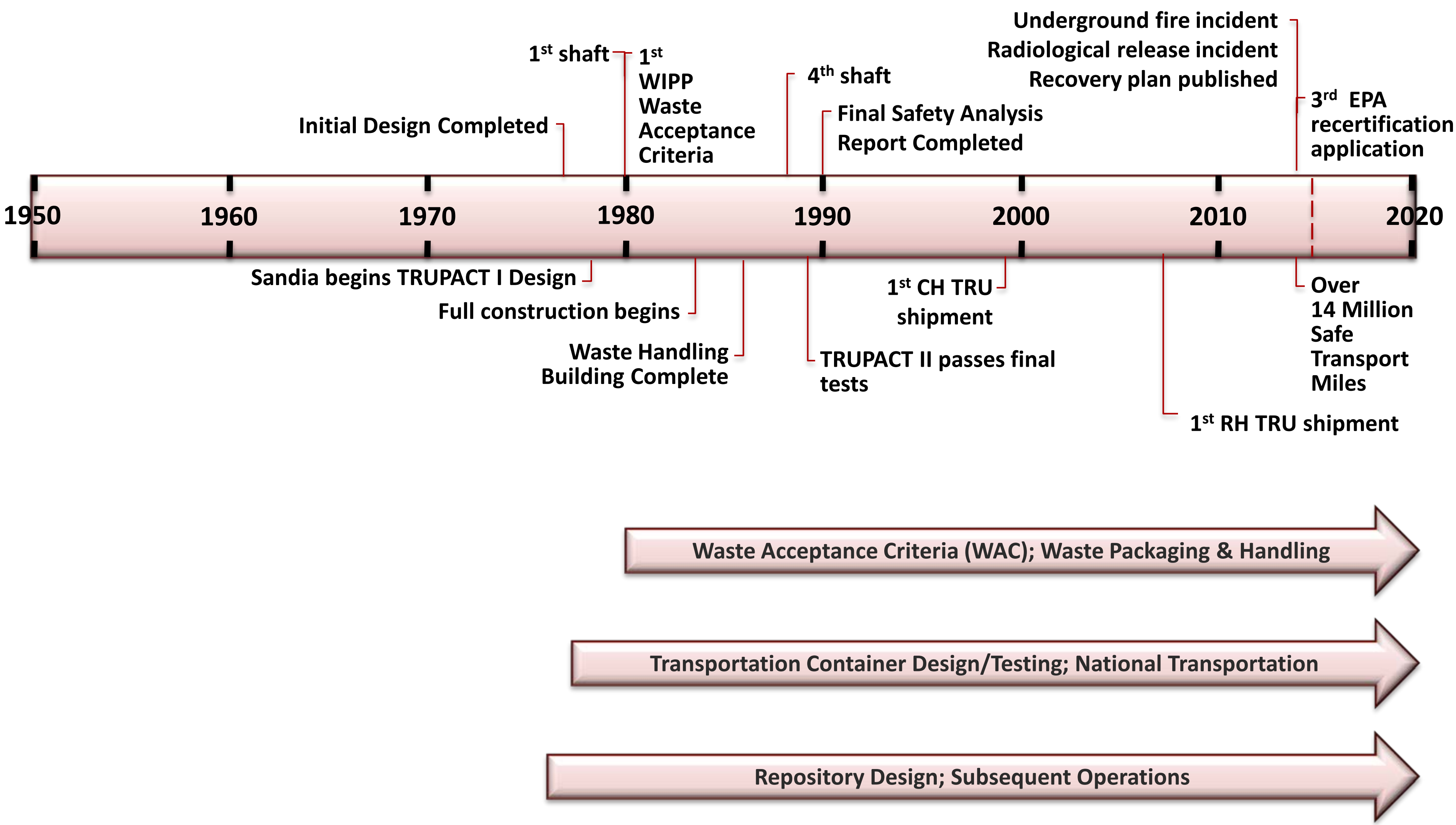


2014 National Survey – Trust in institutional information sources

Jenkins-Smith et al., 2014.
DOE FCRD-NFST-2014-000087

Integration Across Entire Waste Management System

Waste Characterization and Packaging; Transportation; Disposal



WIPP Waste

Commercial SNF; Defense HLW; TRU Waste

- 1974 – Initial screening scenarios assume 75,000 canisters HLW from commercial reactors
- 1975 – Emphasis shifts to TRU waste driven by Rocky Flats fire
- 1977-1979 – DOE considers commercial waste; initial design has separate levels for TRU and HLW
- 1979 – Interagency Review Group suggested WIPP be considered for commercial spent fuel; House Armed Services Committee apposes commercial waste; ***Congress passes law designating WIPP for defense TRU waste***

WIPP TRU Waste Inventory

- Contact Handled (CH) – Surface dose less than 200 mrem/hr
- Remote Handled (RH) – Surface dose greater that 200 mrem/hour
- Total inventory limits specified in WIPP Land Withdrawal Act – 5.1x10E6 Ci; 176,000 m3; RH-TRU waste producing dose <1000 mrem/hr

WIPP Waste

WIPP Waste Acceptance Criteria (WAC) – Rev 7.4, 2013

WAC specifies requirements for container properties; radiological properties; physical properties; chemical properties; data package requirements (CH/RH)

Flow-down of WAC Requirements:

- DOE Headquarters – provide policy and guidance for DOE environmental management sites
- DOE Carlsbad Field Office – system management; transportation fleet management; site oversight
- TRU Generator Sites – Develop/implement site-specific Transuranic Waste Authorized Methods for Payload control (TRAMPC)
- TRU Generator Sites – certify CH/RH waste payloads meet WAC criteria
- TRU Generator Sites – transmit required characterization, certification, and shipping data

WIPP TRU Waste Transportation

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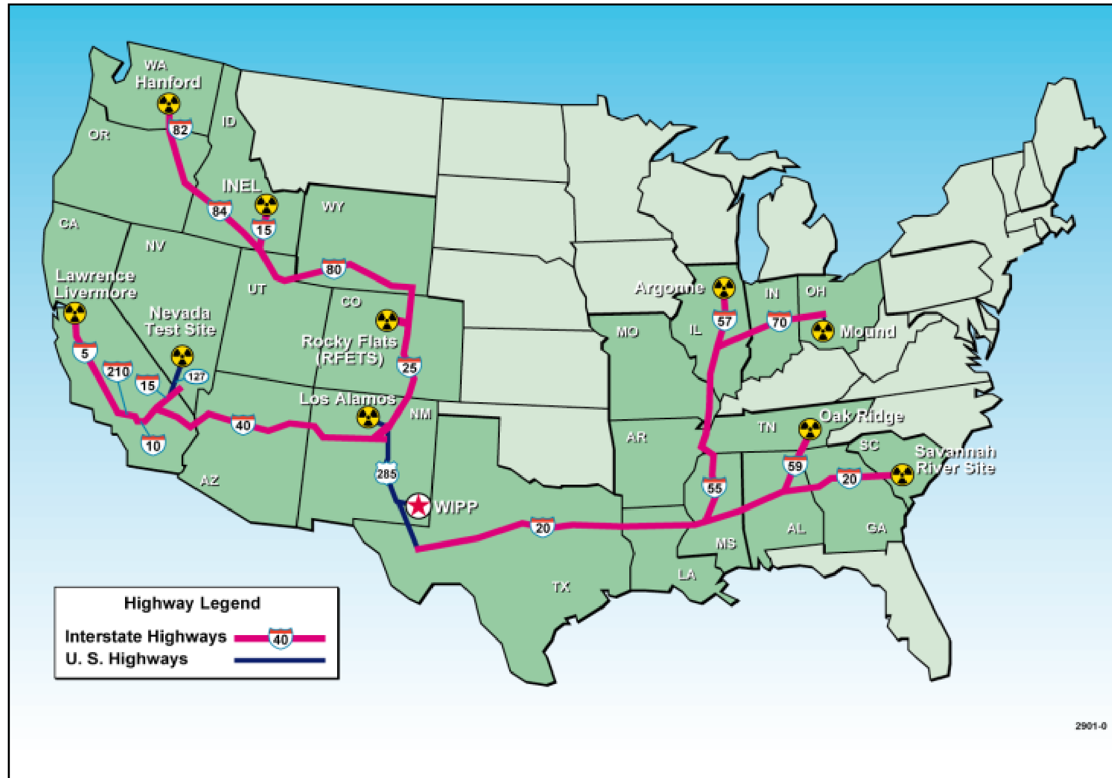
- Ten primary sites ship waste to WIPP
- All shipments by truck



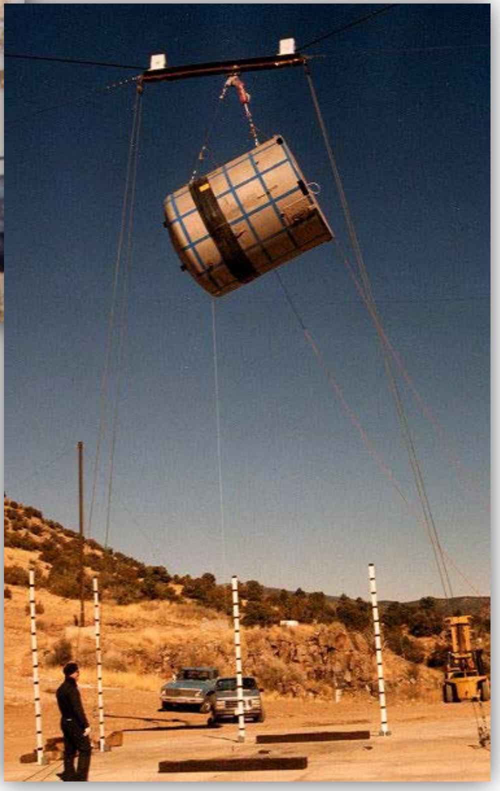
Images from http://www.wipp.energy.gov/Photo_Gallery_Images

WIPP Trupact Transportation Containers Undergo Drop, Puncture and Fire Testing

CTU-1 Puncture Drop No. 7; Pre-Drop Positioning

CTU-1 Fire No. 10; Fully Engulfing Fire

CTU-1 Puncture Drop No. 7; Post-Drop Damage



CTU-2 Free Drop No. 1; Pre-Drop Positioning

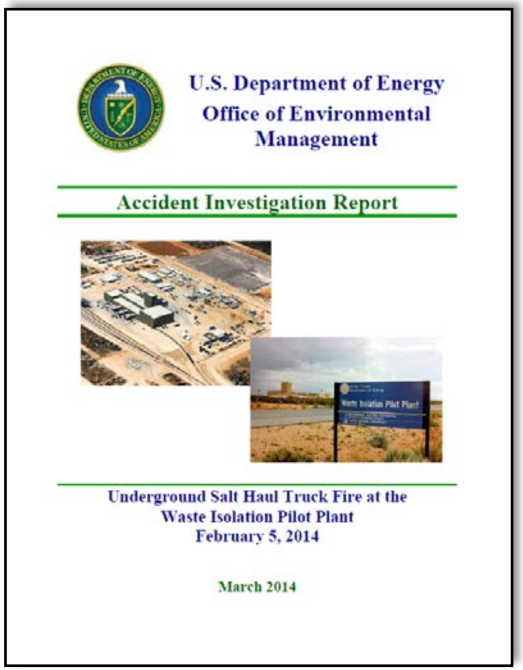
Source: TRUPACT-II Safety Analysis Report Revision 21, May 2005

Recent WIPP Events

- Mine haul truck fire Feb 5, 2014
- Radiological release Feb 14, 2014
- Investigation/Recovery continues

Key Documents for the Recent WIPP Events

Sandia National Laboratories

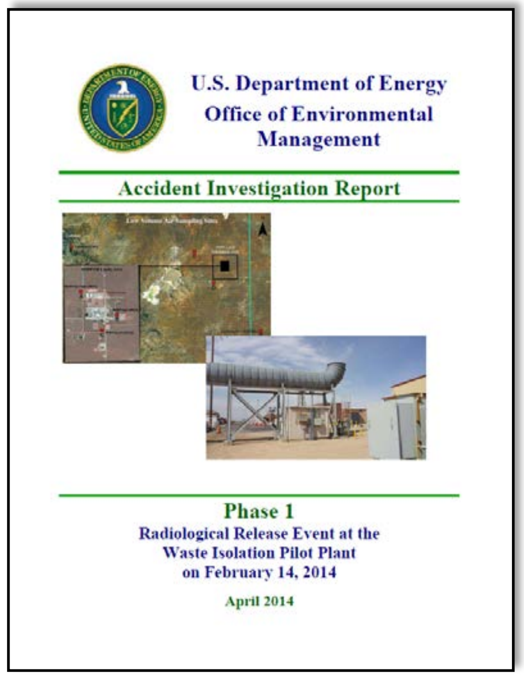

U.S. Department of Energy
Office of Environmental Management

Accident Investigation Report

Underground Salt Haul Truck Fire at the Waste Isolation Pilot Plant
February 5, 2014

March 2014

Fire Investigation Report, (March 2014)

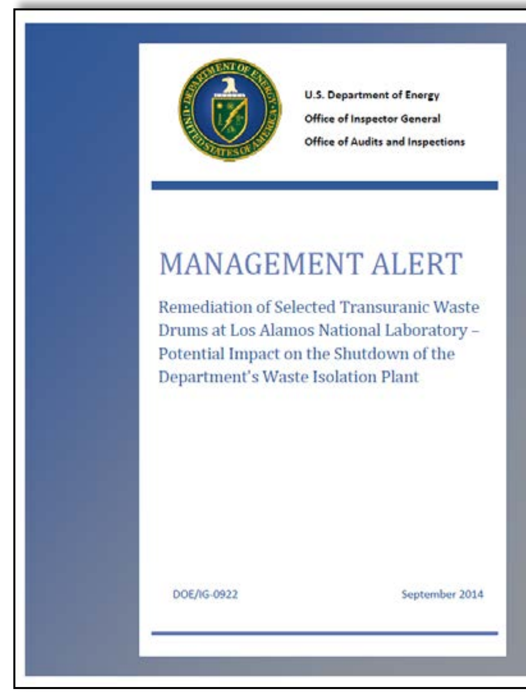

U.S. Department of Energy
Office of Environmental Management

Accident Investigation Report

Phase 1
Radiological Release Event at the Waste Isolation Pilot Plant on February 14, 2014

April 2014

Radiological Release Investigation Report, Phase 1 (April 2014)


U.S. Department of Energy
Office of Inspector General
Office of Audits and Inspections

MANAGEMENT ALERT

Remediation of Selected Transuranic Waste Drums at Los Alamos National Laboratory – Potential Impact on the Shutdown of the Department's Waste Isolation Plant

DOE/IG-0922 September 2014

DOE Inspector General's Investigation of Waste Loading at Los Alamos National Laboratory (September 2014)

All available at http://www.wipp.energy.gov/wipprecovery/recovery.html

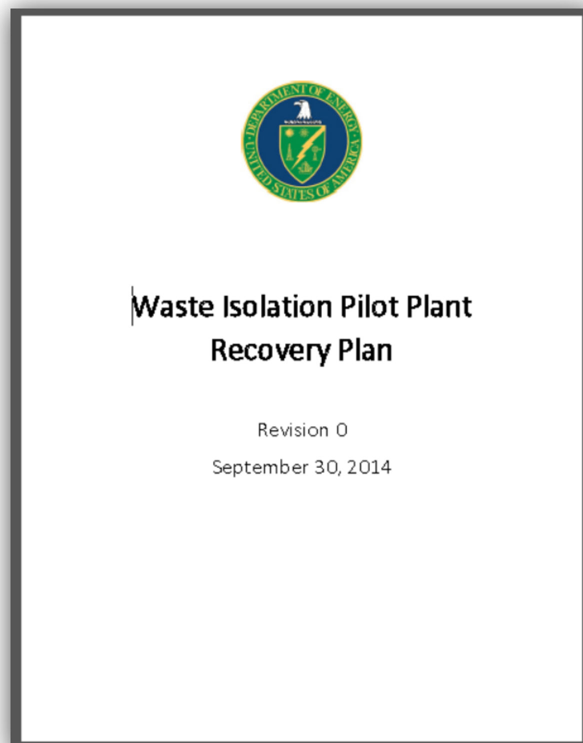
Reasonable Confidence

The Recovery Plan is intended to provide reasonable confidence for resumption of WIPP disposal operations by

- Safely isolating the waste of concern
- Initial closure of the affected waste disposal areas
- Responding to weaknesses identified by the AIB through comprehensive upgrades to programs, procedures, and training
- Upgrading equipment, infrastructure, and facilities
- Ensuring that waste generators have rigorous characterization, treatment, and packaging processes and procedures and that all waste meets the WIPP waste acceptance criteria

WIPP Recovery Plan

- Strive to resume emplacing waste during the first quarter of calendar 2016
- Undertake waste emplacement in this order
  - Site derived waste resulting from recovery activities
  - Waste containers now stored in the Waste Handling Building
  - Waste sent from the generator sites
- Focus then on completion and operation of a permanently enhanced ventilation system
- Seven key principles for Recovery
  - Safety first
  - Mine stability and underground habitability
  - Regulatory compliance
  - Decontamination
  - Ventilation
  - Workforce retraining
  - Managing waste streams



Waste Isolation Pilot Plant
Recovery Plan

Revision 0

September 30, 2014

Key Themes

- ***Continuity*** – Development of a geologic repository requires decades of continuity of scientific, engineering and policy focus to move through a complex mix of technical, regulatory, political and public acceptance challenges.
- ***Scientific/Technical Basis*** - Building a credible, peer reviewed scientific basis for the technical and engineering foundation is a major endeavor and first step toward creating a geologic repository.
- ***Quantitative Performance Assessment*** - Scientific understanding and technical basis must be translated into quantitative/quality assured systems analysis that addresses specific regulatory requirements.
- ***Policy, Politics and Public Acceptance*** – policy, politics and public acceptance evolve over time, and multiple levels (national, state, local) are all important.
- ***Integration Across Entire Waste Management System*** – integration across waste preparation/packaging, transportation and disposal is essential for effective operations over the decadal operational life of a repository.

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Key Websites: http://www.wipp.energy.gov/library/caolib.htm and http://www.wipp.energy.gov/wipprecovery/recovery.html

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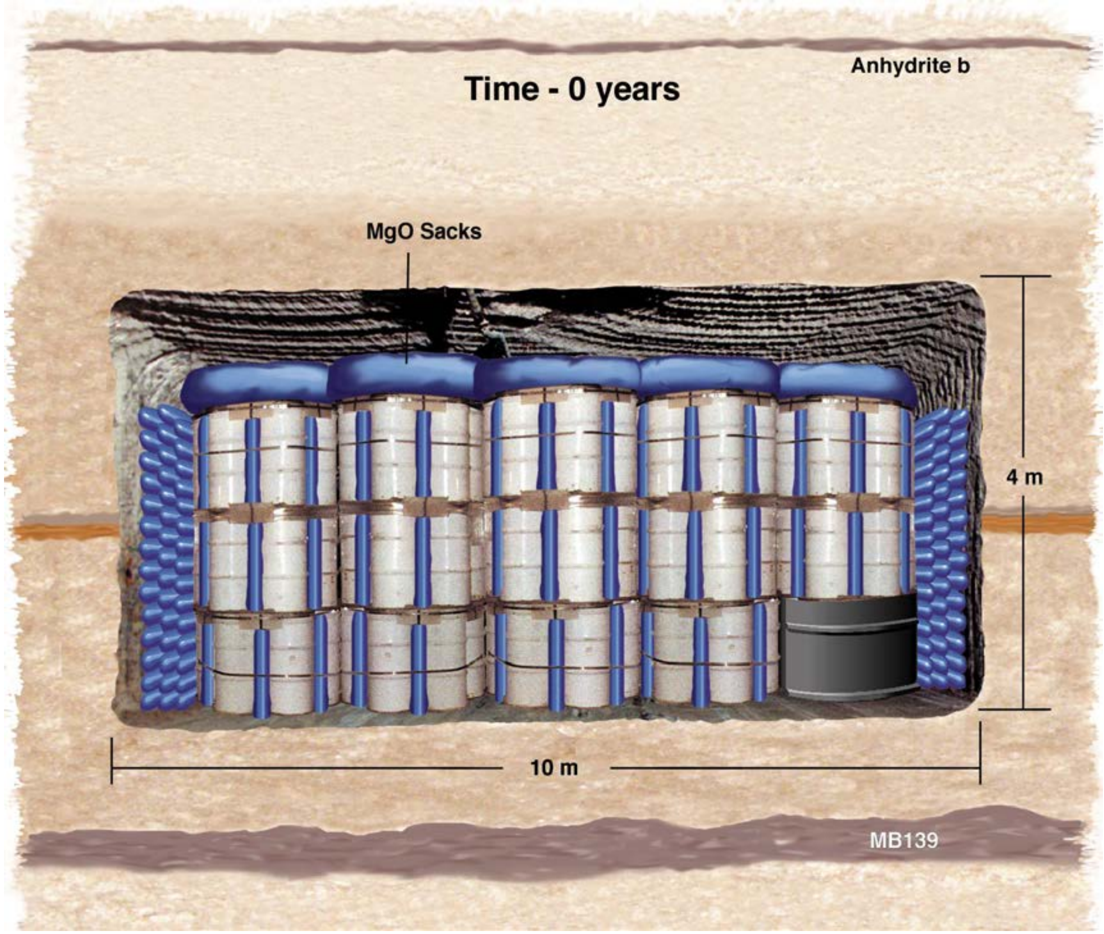
Backup Slides

Conceptual Model for Long-term Performance: Initial Conditions

Sealed Waste and Dry Backfill

- Introduced components
  - Iron waste drums, boxes
  - Mgo backfill
  - Cellulosic, plastic, rubber waste
  - Metallic waste
  - Solidified waste
  - Actinide solids
- Geologic components
  - Salado salt
  - Argillaceous anhydrite interbeds ("marker beds")
- Processes
  - Ground support
  - Ventilation

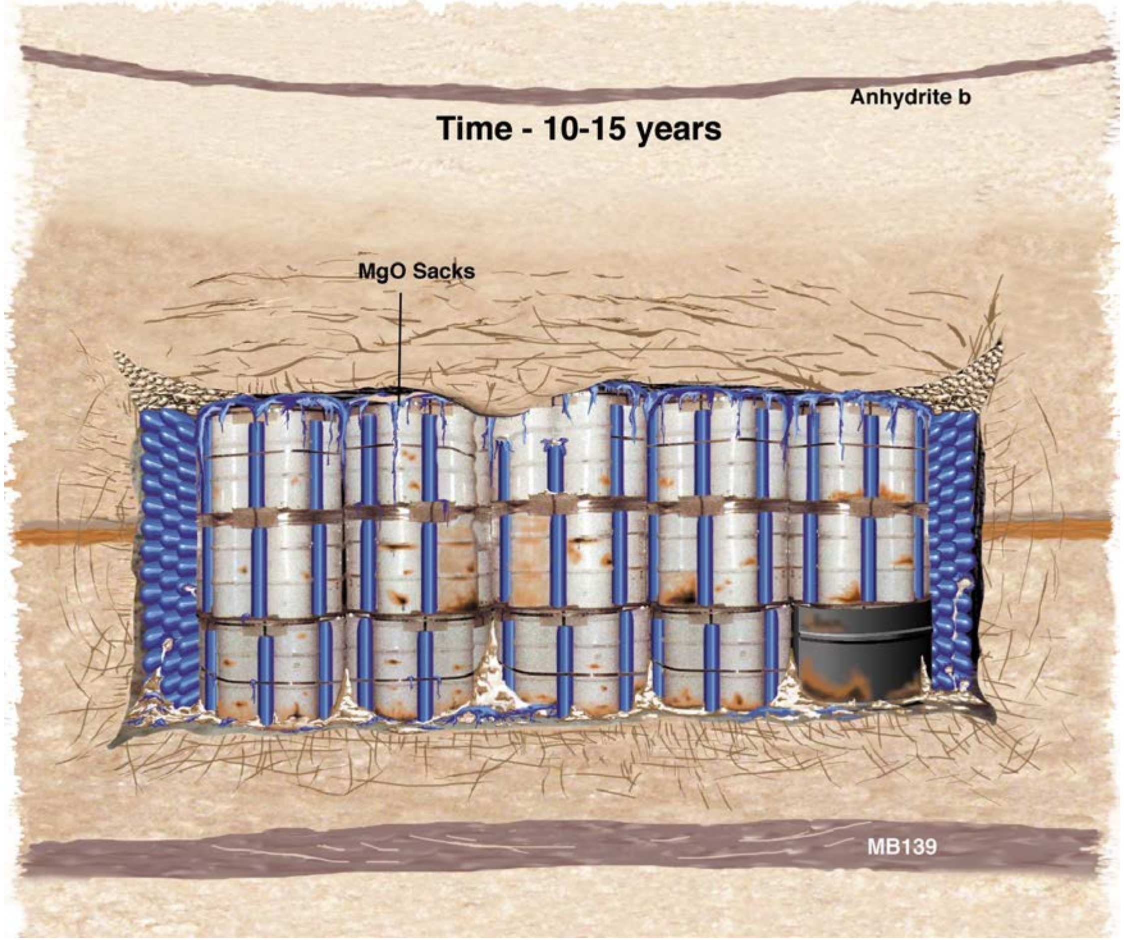


Conceptual Model for Long-term Performance: The Near Future

Rapid Salt Creep Partially Encapsulates Waste

Processes

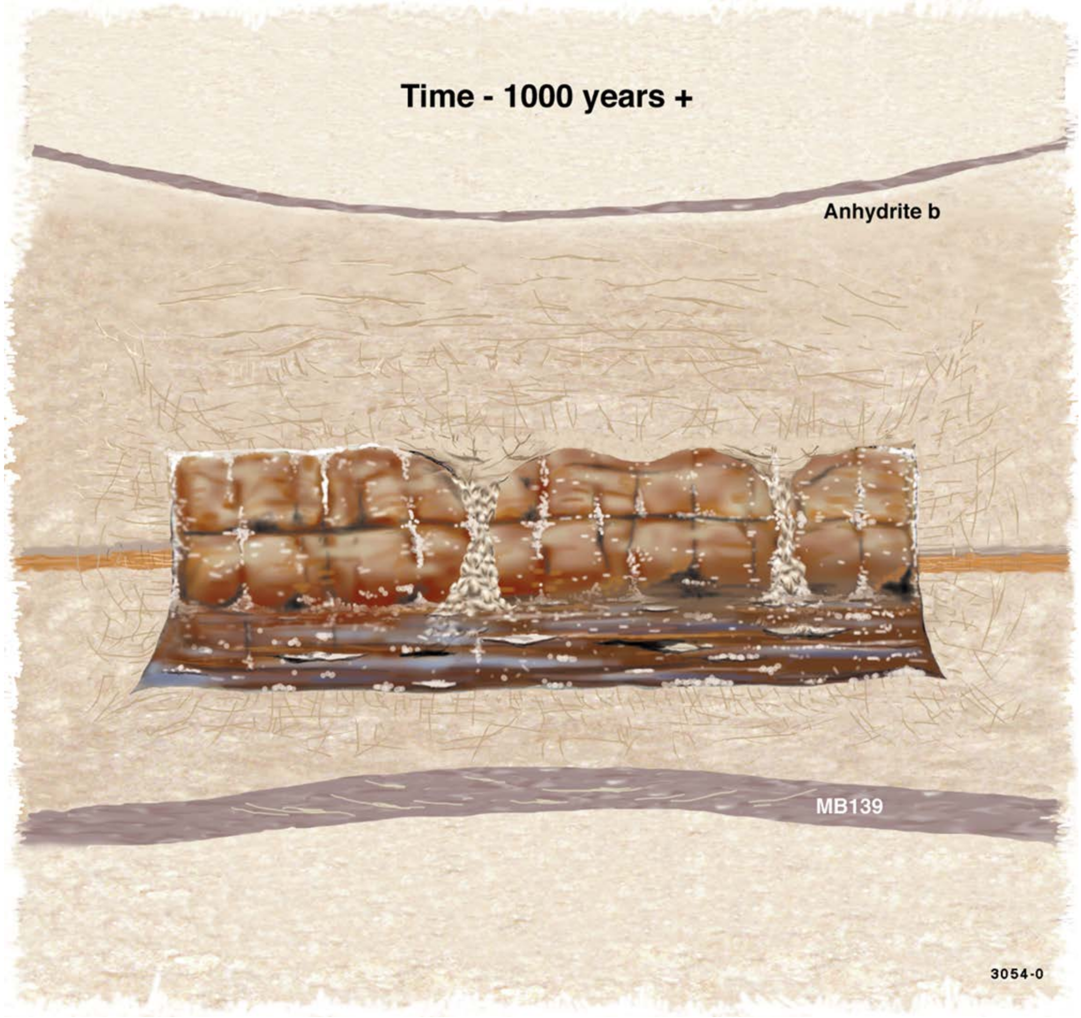
- Salt creep
- Floor heave
- Roof fall
- Collapse of salt into waste
- Disturbed-rock-zone dewatering
- Drum crushing
- Porosity, permeability reduction
- Breaching of MgO sacks
- Minor corrosion
- Degradation of organic waste



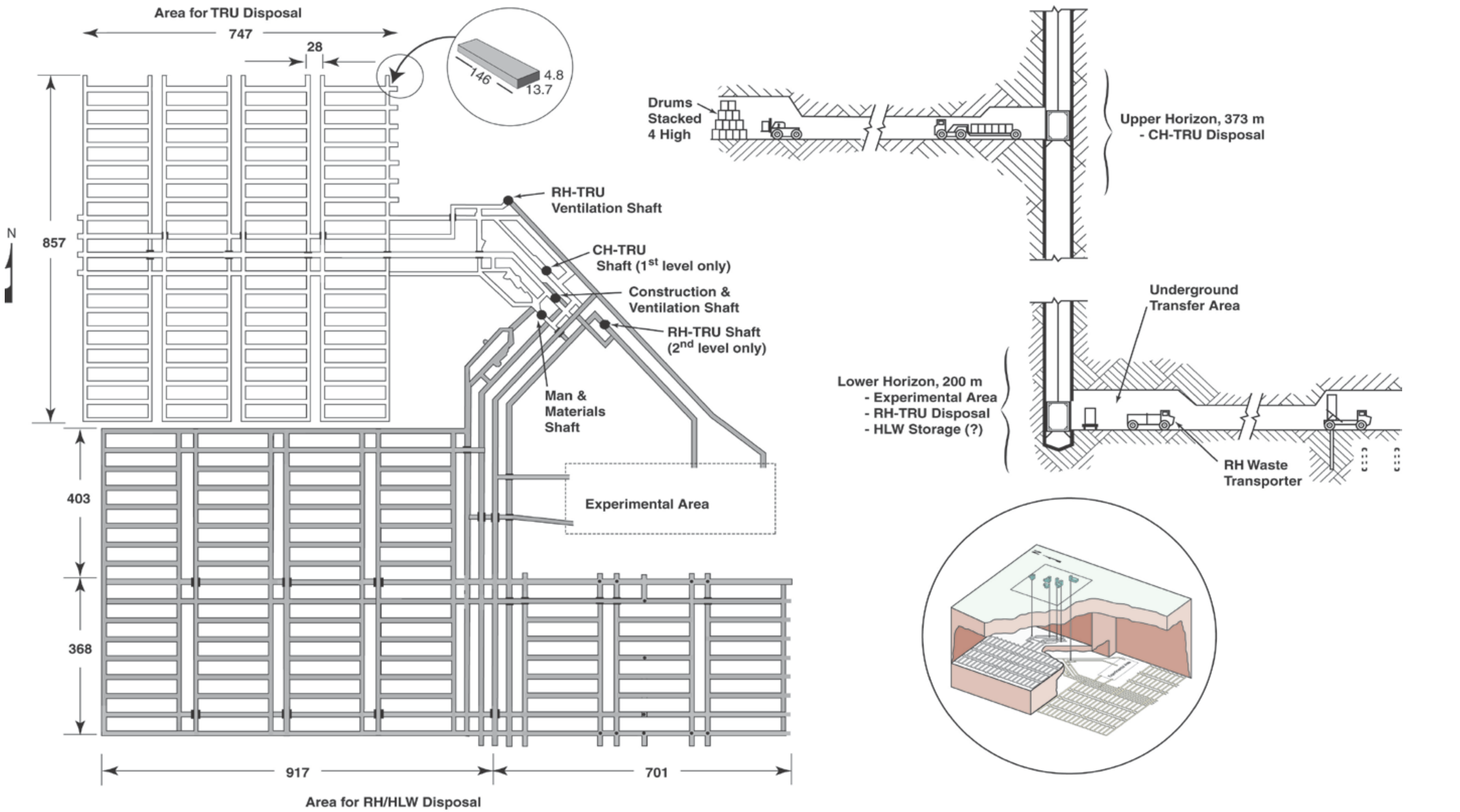
Conceptual Model for Long-term Performance: Final State?

Salt Creep Encapsulates Waste

- Processes
  - Salt creep
  - Consolidation and healing of fractures
  - Porosity, permeability reduction
  - Extensive corrosion of drums and degradation of waste
- Processes of gas generation, brine inflow, and salt creep are highly coupled
- Uncertainty remains about final extent of consolidation and brine saturation



1977 Repository Design Included Separate Levels for TRU and Defense HLW



(a) 1977 conceptual design

Compliance Recertification Application – 2014 Performance Assessment Approach

CRA-2014 PA changes are included sequentially so that compliance impacts can be reasonably isolated.

The CRA-2014 PA is comprised of 4 cases:

Case CRA14-BL
(1 Replicate: R1)
Includes:
- ROMPCS
- SDI Volume
- Updated Inventory
- Updated Solubilities (Single Brine Volume)
- Updated Drilling Parameters
- Revised Colloid Factors

Case CRA14-TP
(1 Replicate: R1)
Includes CRA14-BL changes plus:
- TAUFAIL Update
- PBRINE Revision

Case CRA14-BV
(1 Replicate: R1)
Includes CRA14-TP changes plus:
- Brine Volume Dependence

Case CRA14-0
(3 Replicates)
Includes CRA14-BV changes plus:
- Steel Corrosion Update
- Water Budget

Case CRA14-0 includes all changes in the CRA-2014 PA, and is the "formal" compliance calculation.