SAND2014-16041PE

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Sandia National Laboratories

Repository Science at Sandia:
WIPP, Yucca Mountain, Deep Borehole, & Beyond

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U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration

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Stages of Repository Science

- Site Selection
  - Identify potentially suitable media, evaluate and screen candidate sites
- Site Characterization
  - Experimental and field test programs to characterize long-term performance of engineered and natural components of the system
- Site Evaluation (Performance Assessment)
  - Model future performance under a range of conditions at component and full-system level, with uncertainty
- Licensing
  - EPA regulations (40 CFR 191 and 40 CFR 194) for WIPP require probabilistic estimates of repository performance for 10,000 years
  - EPA (40 CFR 197) and NRC (10 CFR 63) regulations for Yucca Mountain require probabilistic estimates of repository performance for 1 million years
  - Regulatory requirements for future repositories remain uncertain

U.S. Repository Program Status

- Commercial Spent Fuel
  - "Yucca Mountain is not a workable option" (DOE, March 3, 2010)
    - "the Secretary's judgment here is not that Yucca Mountain is unsafe or that there are flaws in the LA, but rather that it is not a workable option and that alternatives will better serve the public interest." (DOE to NRC, May 27, 2010)
  - Nuclear Waste Policy Act remains; Yucca Mountain only legal option

- DOE spent fuel and high-level waste
  - Disposal activities moved from Office of Civilian Radioactive Waste Management (OCRWM) to the DOE Office of Nuclear Energy (DOE-NE)

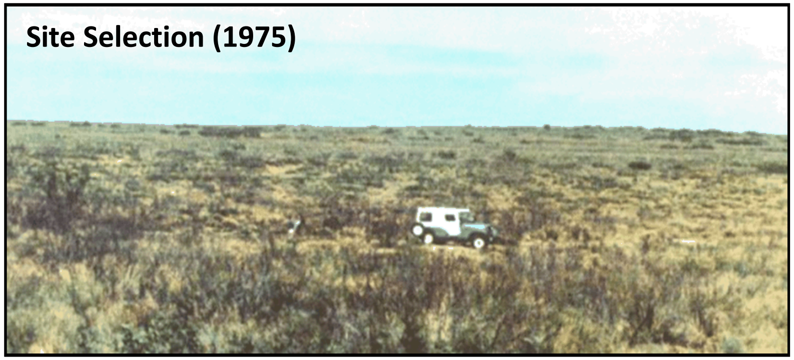
- Defense-generated transuranic waste
  - The Waste Isolation Pilot Plant (WIPP) is permanent home for transuranic waste, managed by the DOE Office of Environmental Management (DOE-EM)

SNL Leadership in Repository Science

- Waste Isolation Pilot Plant (WIPP)
  - Lead for science programs 1975-present
  - Site selection and characterization 1975-1993
  - Regulatory certification 1994-1998
  - Science in support of operations and recertification 1998-present
- Yucca Mountain
  - Contributor to site characterization 1978-2002
  - Major role in long-term performance assessment 1989-2010
  - DOE Office of Civilian Radioactive Waste Management (OCRWM) Lead Laboratory for repository science 2006-2010
  - Primary role in supporting the 2008 License Application to the NRC
- DOE-NE Used Fuel Disposition Campaign
  - Leadership responsibility 2009-present
  - Deep borehole demonstration beginning FY2015
  - Generic repository research

WIPP

Waste Isolation Pilot Plant

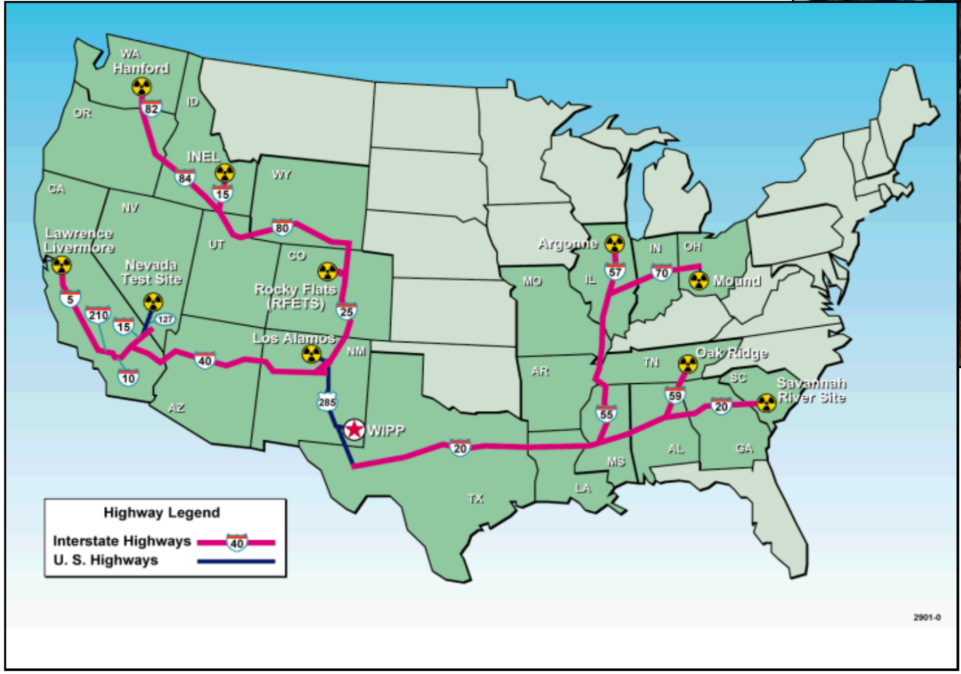

Site Selection (1975)

- Sited – 1975
- Certified by the EPA – 1998
- First Waste Receipt – March 26, 1999
- Recertification – 2004, 2009, 2014
- More than 10,000 shipments to date
- Operations on hold since Feb 14, 2014
  - Recovery plan
- Disposal operations continue: 2014 → 2055?

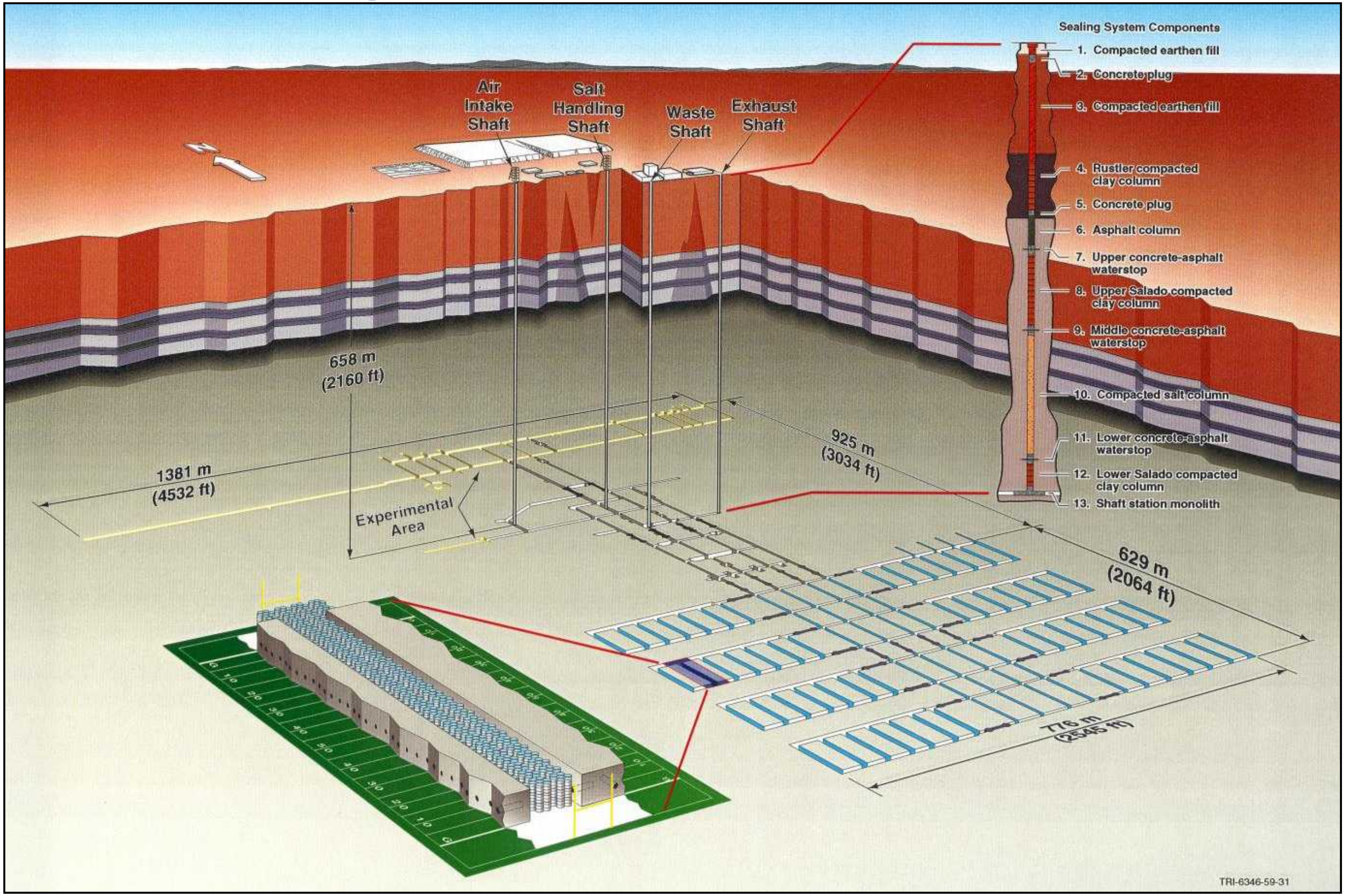

First Waste Arrival (1999)

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

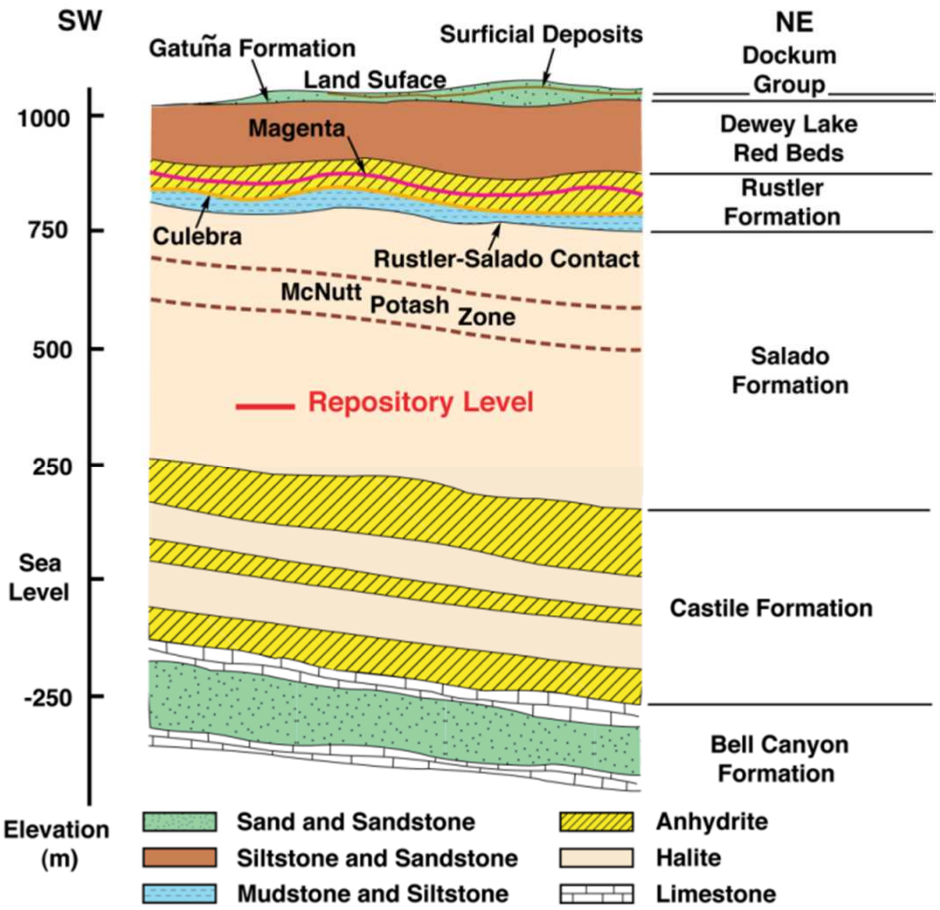


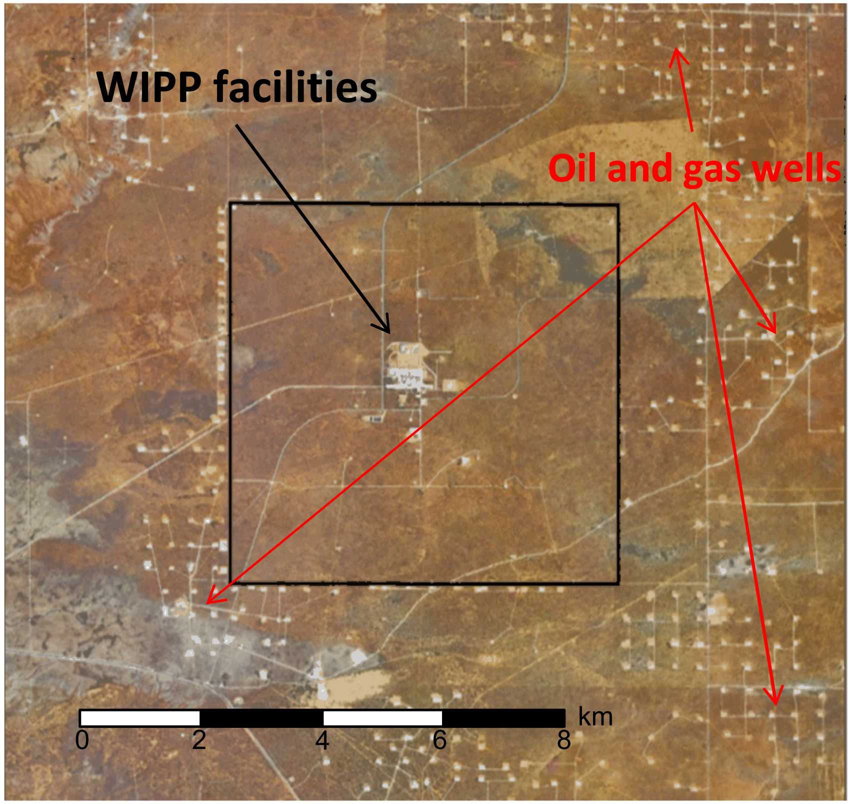
WIPP Design



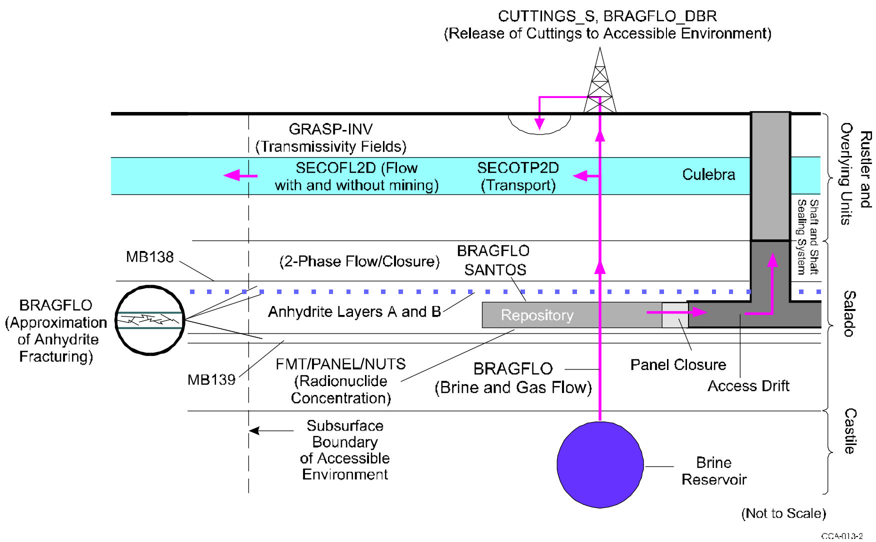
Sealing System Components
1. Compacted earthen fill
2. Concrete plug
3. Compacted earthen fill
4. Rustler compacted clay column
5. Concrete plug
6. Asphalt column
7. Upper concrete-asphalt waterstop
8. Upper Salado compacted clay column
9. Middle concrete-asphalt waterstop
10. Compacted salt column
11. 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)
629 m (2064 ft)
778 m (2545 ft)
Experimental Area
TRI-6346-59-31

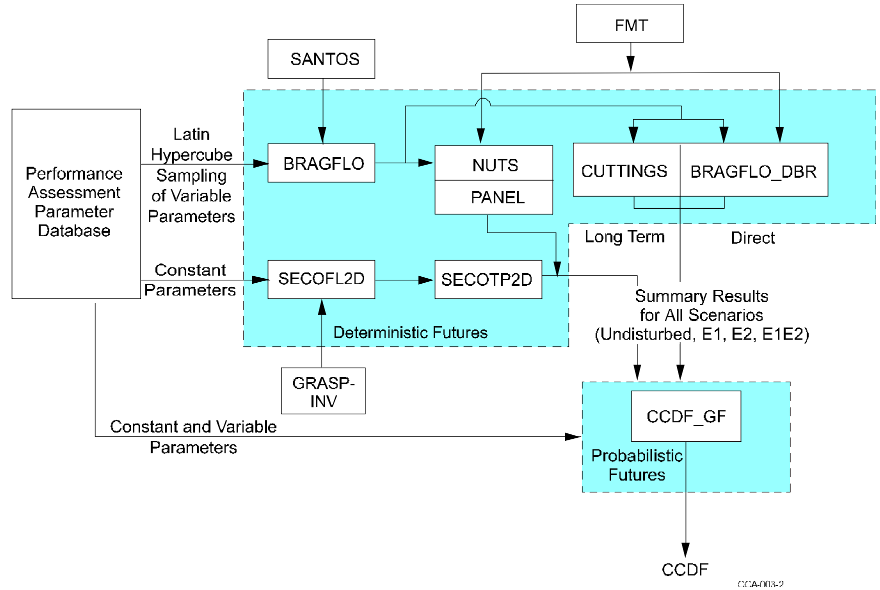
Performance Assessment for WIPP

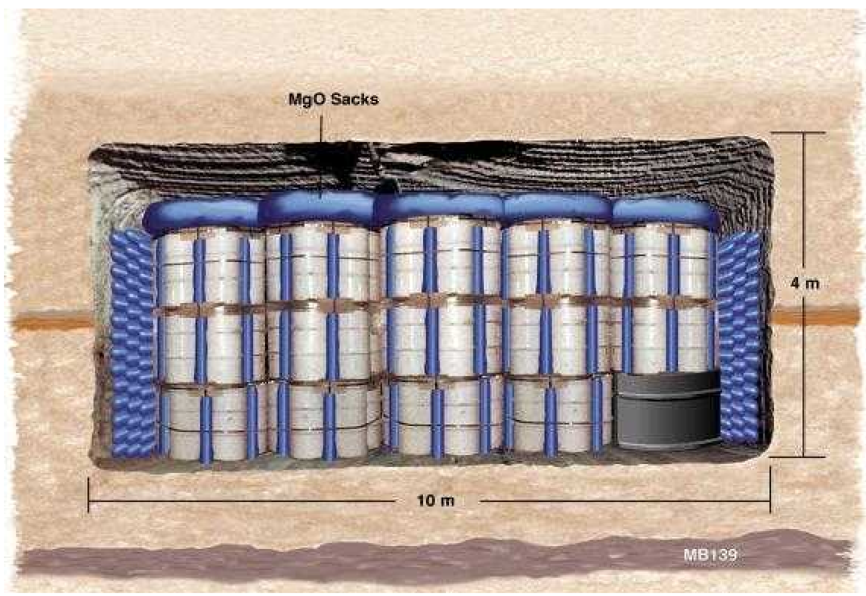


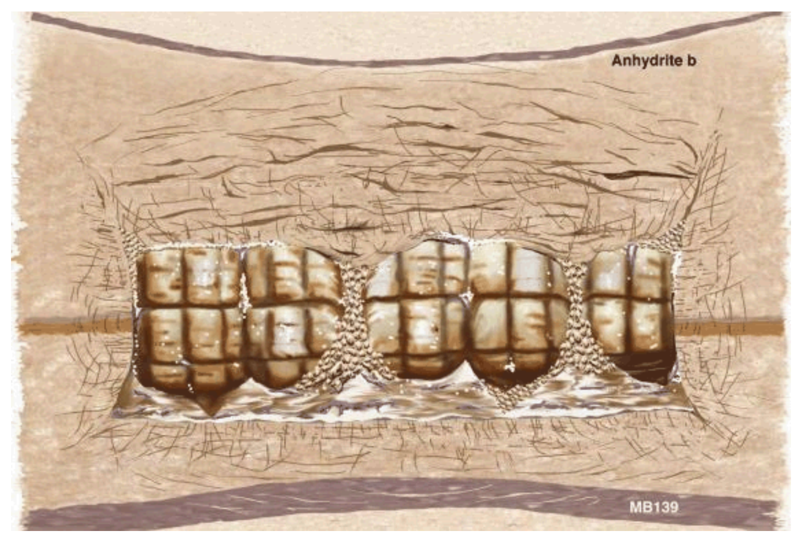


Performance Assessment for WIPP









Long-term WIPP Performance

- Geologic barriers provide long-term isolation
  - Dry climate
  - Very low permeability of salt
- No radionuclide releases to accessible environment during 10,000-year performance period without human intrusion
- Hypothetical borehole intrusions as a result of future oil and gas exploration are evaluated as part of the long-term performance assessment
  - Releases due to multiple human intrusions are well below regulatory limits

Recent WIPP Events

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

US/German Salt Collaboration

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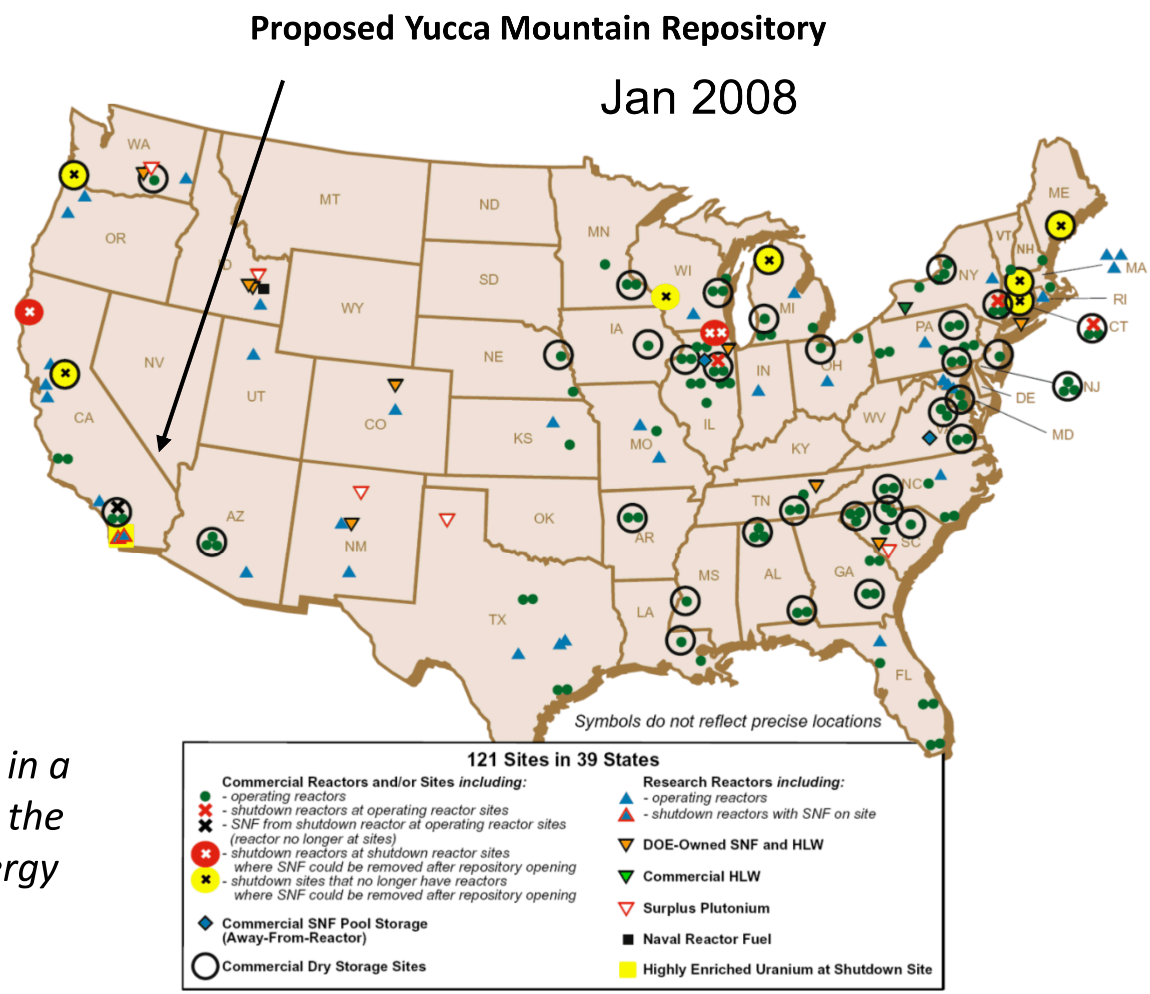
- Since 2010 German researchers and SNL have renewed collaboration on salt repository research, design, and operations

Yucca Mountain

The Yucca Mountain Mission

Current locations of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) destined for geologic disposal:

[121 sites in 39 states]()



DOE Office of Civilian Radioactive Waste Management (OCRWM) Mission was:

To manage and dispose of high-level radioactive waste and spent nuclear fuel in a manner that protects health, safety, and the environment; enhances national and energy security; and merits public confidence.

Waste for Yucca Mountain

Commercial Spent Nuclear Fuel:
63,000 MTHM (~7500 waste packages)

DOE & Naval Spent Nuclear Fuel:
2,333 MTHM
(~400 naval waste packages)
(DSNF packaged with HLW)

DOE & Commercial High-Level Waste:
4,667 MTHM
(~3000 waste packages of co-disposed DSNF and HLW)

DSNF: Defense Spent Nuclear Fuel
HLW: High Level Radioactive Waste
MTHM: Metric Tons Heavy Metal

Yucca Mountain Subsurface Design

Emplacement drifts

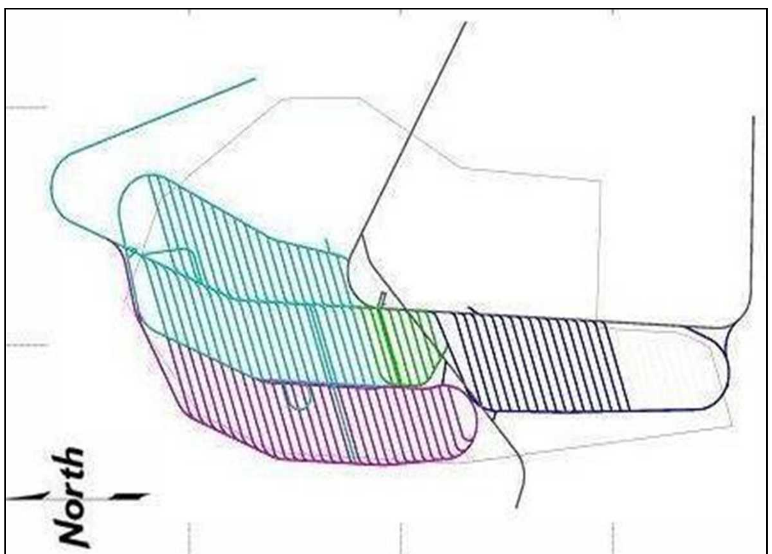
- 5.5 m diameter
- ~100 drifts, each 600-800 m long

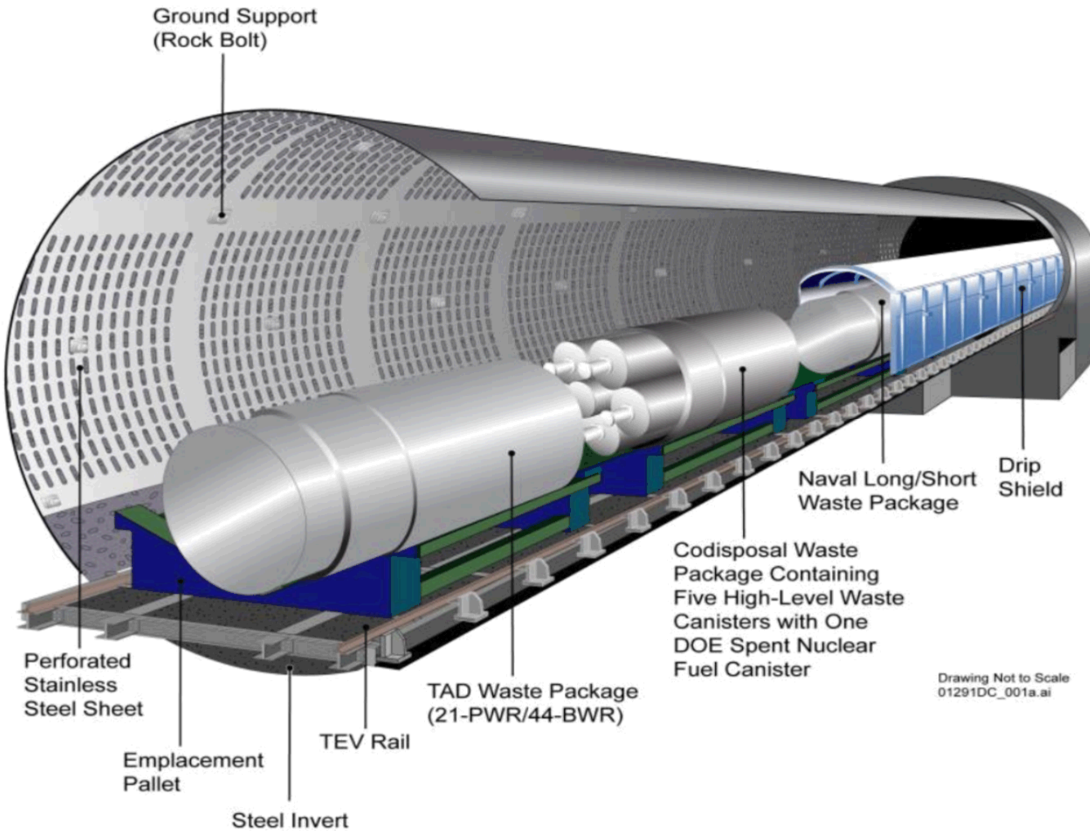
Waste packages

- ~11,000 packages
- ~ 5 m long, 2 m diameter
- outer layer 2.5 cm Alloy 22 (Ni-Cr-Mo-V)
- inner layer 5 cm stainless steel
  - Internal TAD (transportation, aging, and disposal) canisters for commercial spent fuel, 2.5 cm stainless steel

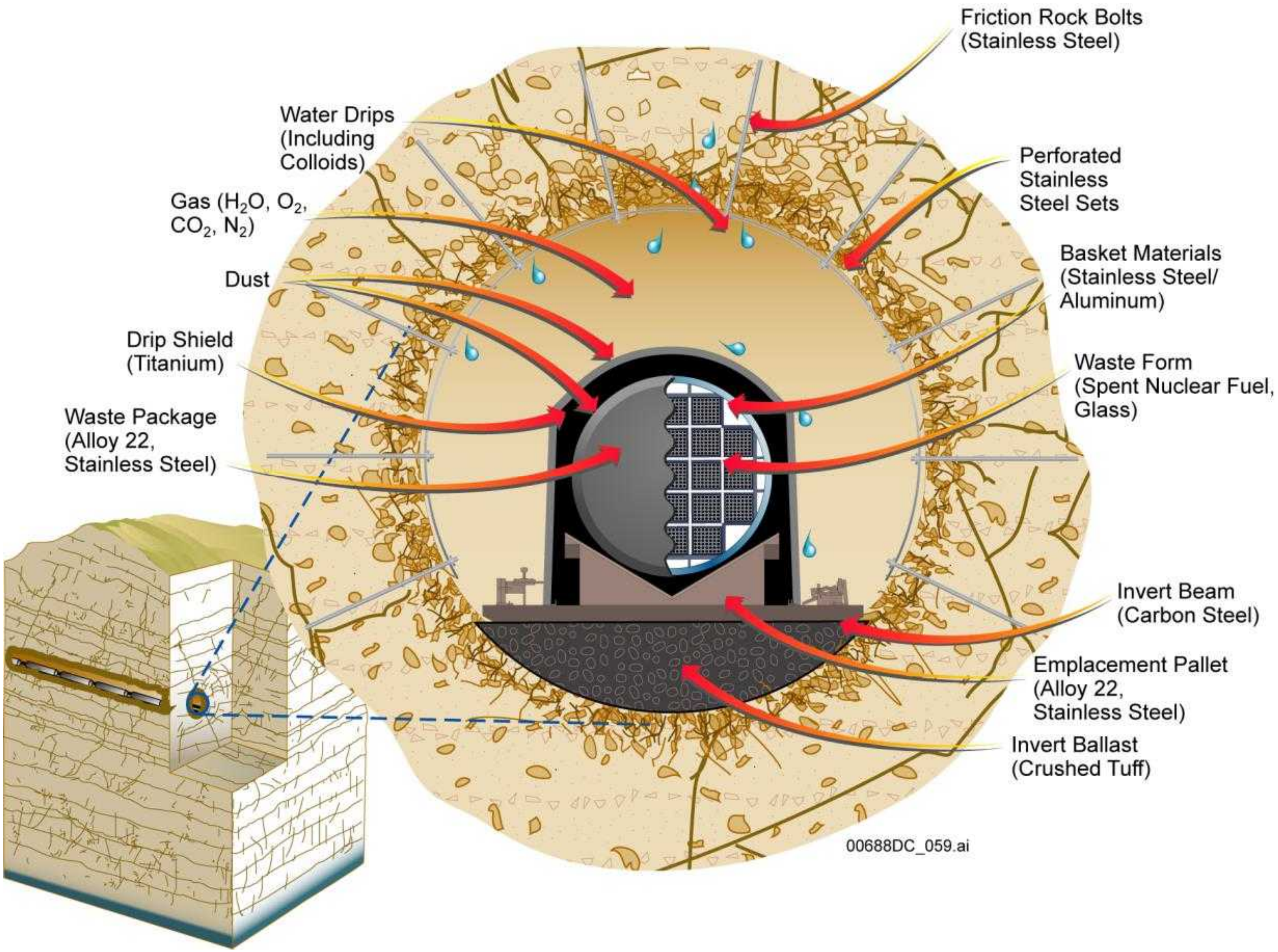
Drip shields

- free-standing 1.5 cm Ti shell





Yucca Mountain Emplacement Environment



Yucca Mountain Local Groundwater

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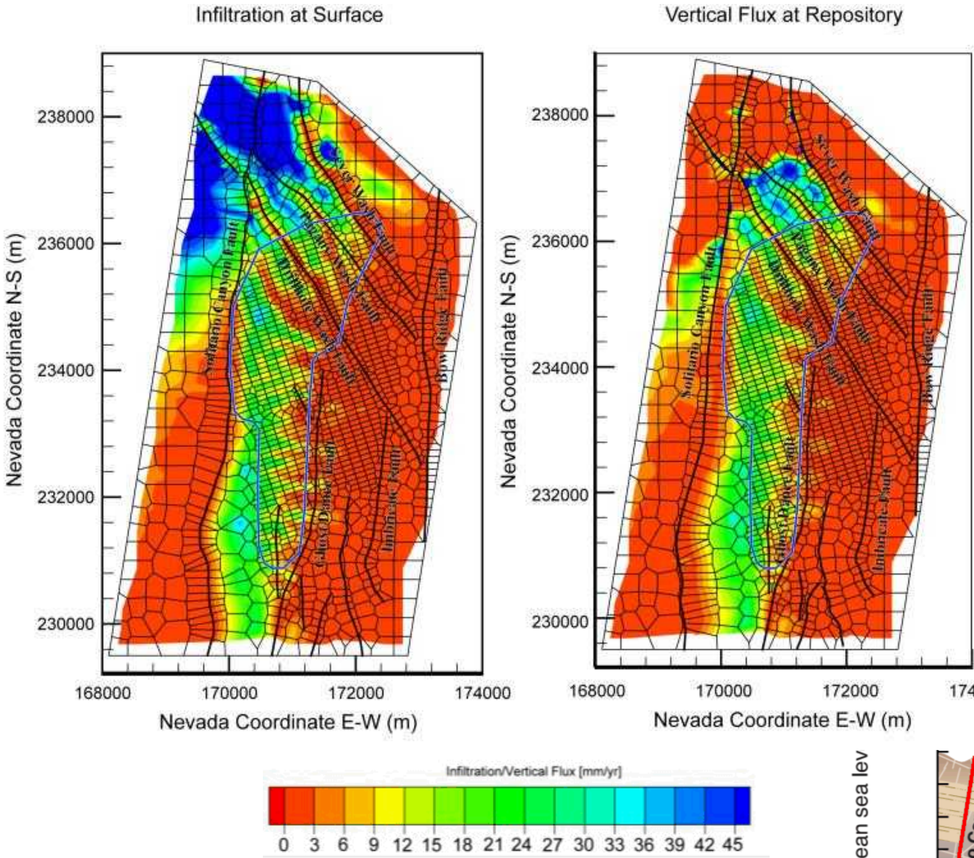
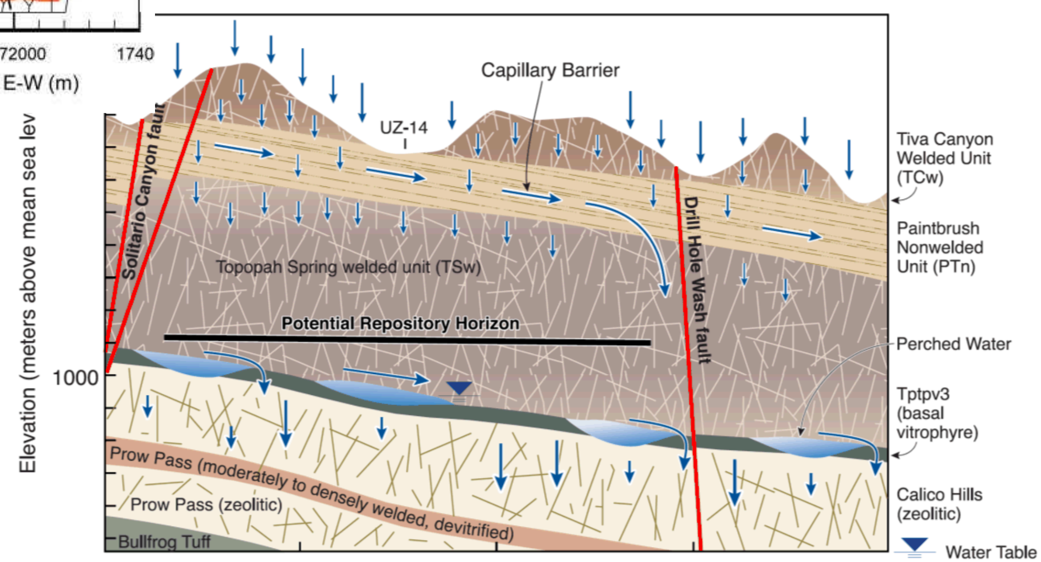
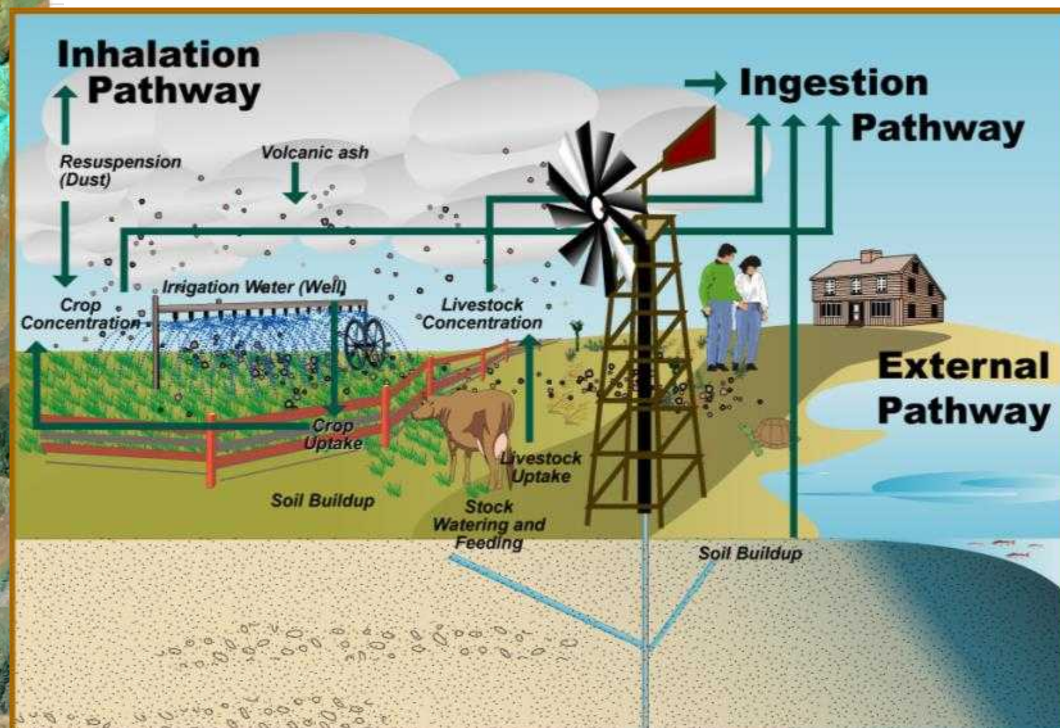


Field tests and models provide basis for understanding <u>infiltration</u> and <u>unsaturated flow</u> at Yucca Mountain

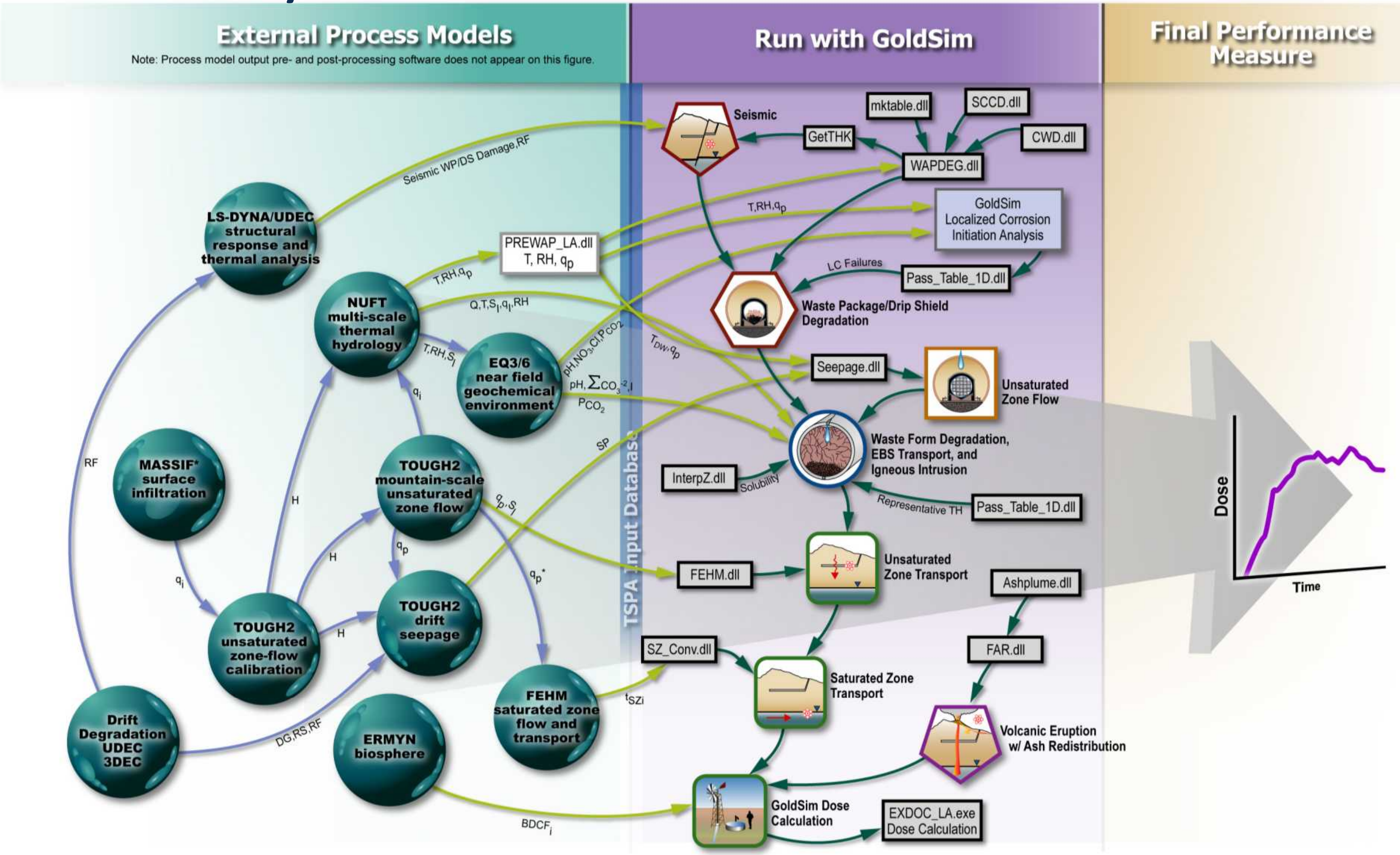


Dose to Hypothetical Future Humans

Modeled regional groundwater flow paths and hypothetical exposure pathways



Total System Performance Assessment



Output Parameters

f_S	Fraction of WPs with Seeps	q_p	Percolation Flux	q_i	Infiltration Flux	H	Hydrologic Properties
EBS	Engineered Barrier System	NO_3	Nitrate Concentration	DG	Drift Geometry	SP	Seepage Parameters
Q_S	Seep Flow Rate	T	Temperature	Cl	Chloride Concentration	RS	Rock Strength
Q	Evaporation Rate	RH	Relative Humidity	I	Ionic Strength	RF	Rockfall Size and Number
pH	pH	S_l	Liquid Saturation	t_{SZi}	Saturated Zone Transport Time		
ΣCO_3^{-2}	Carbonate Concentration	X_a	Air Mass Fraction	$BDCF_i$	Biosphere Dose Conversion Factor		
P_{CO_2}	Partial Pressure of CO_2	q_l	Liquid Flux	q_g	Gas Flux		

*Note: q_p derived from INFIL model

Legend

- Response Surface between Process Models
- Response Surface from Process Model to GoldSim
- Connection in GoldSim
- Preprocessor
- TSPA Model DLL

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Long-Term Performance of Yucca Mountain

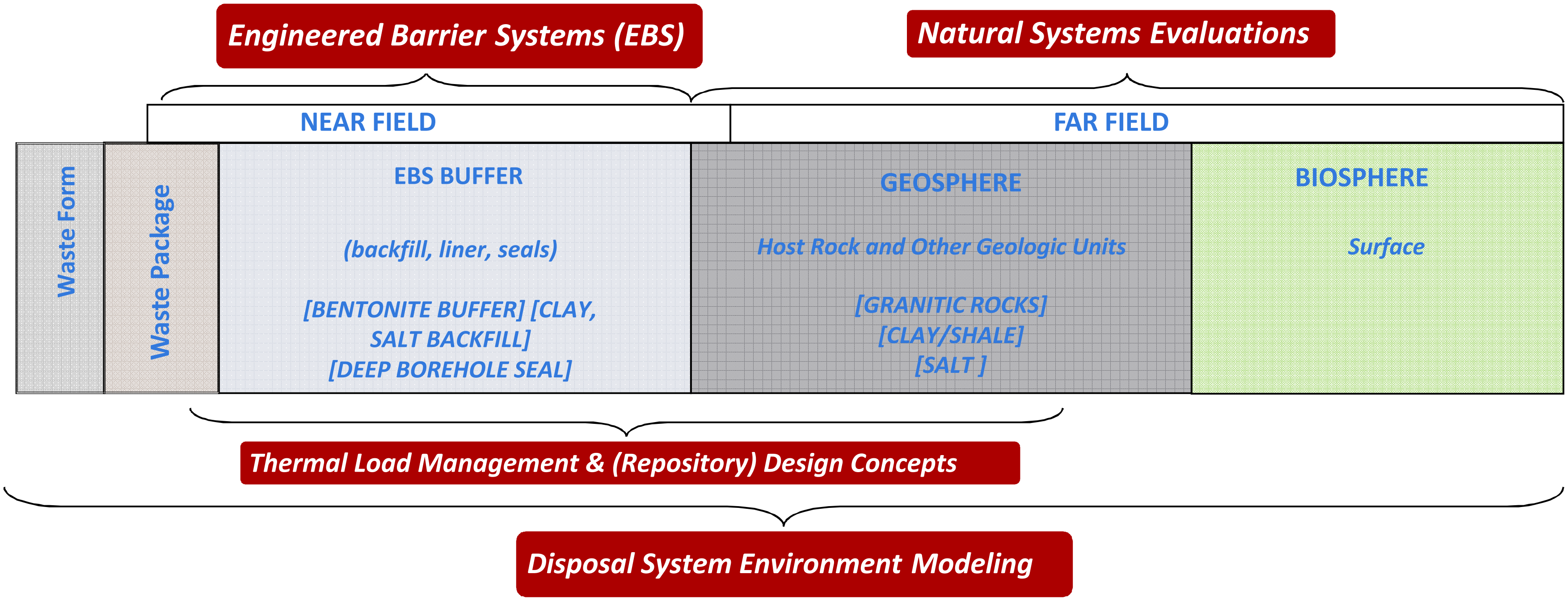
- No significant releases for 10^4 years if the site is undisturbed
  - Dry climate, little groundwater flow
  - Corrosion-resistant waste packages
- Over 10^5 years, estimated annual doses are well below natural background
- Unlikely geologic processes could cause releases and doses to humans; probability-weighted consequences are evaluated
  - Site geology indicates volcanism probability 1/10 million to 1/billion per year (mean 1.7×10^{-8}/yr)
  - seismic disruption reasonably likely over very long times; consequences are not severe
- All estimated radiation doses are within regulatory limits

Used Fuel Disposition Campaign

Generic Disposal R&D

- The Nuclear Waste Policy Act precludes site-specific repository investigations at locations other than Yucca Mountain
- All disposal research must be generic
- What can generic R&D accomplish?
  - Provide technical basis supporting multiple viable US disposal options available when national policy is ready
  - Identify and research the generic uncertainty sources that can challenge disposal concept viability
  - Increase confidence in robustness of generic disposal concepts to reduce the impact of site-specific complexity
  - Develop tools in science and engineering to address other goals

UFD Disposal Research Activities

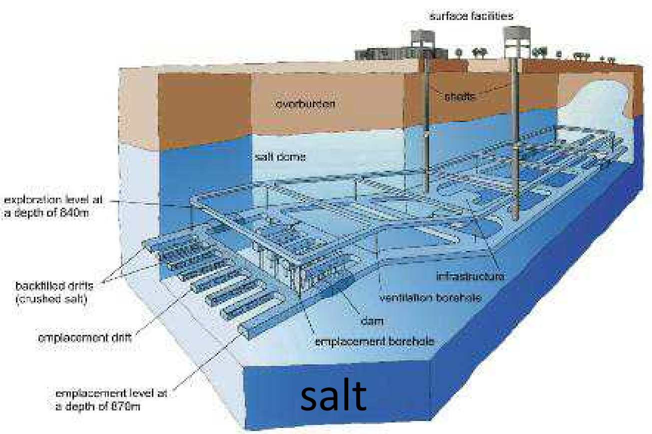


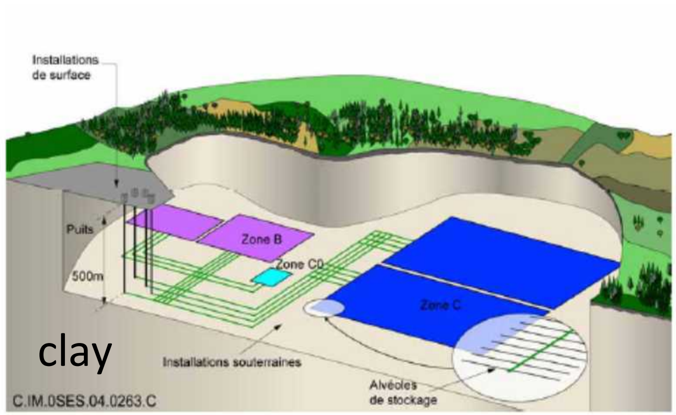
SUPPORT, ANALYSIS & EXPERIMENTAL ACTIVITIES

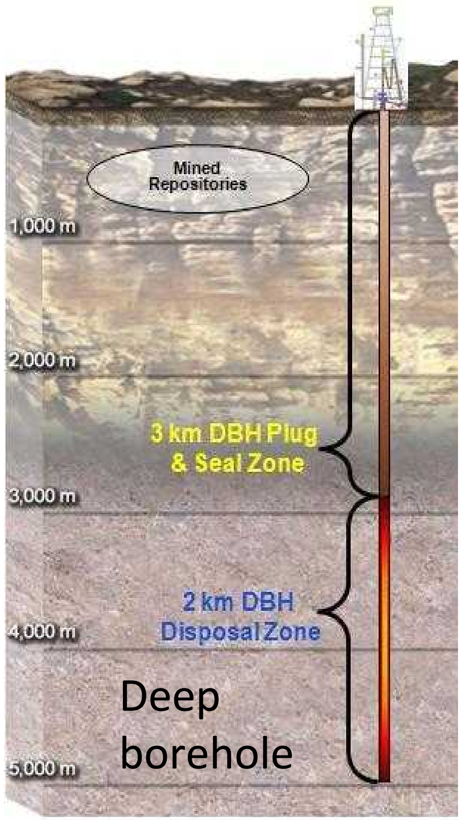
Engineered Materials Performance	**(corrosion, degradation studies)**
Features, Events & Processes	**(how R&D is organized and prioritized)**
Low Level Waste Disposition Issues	**(part of total nuclear waste consideration)**
Inventory Projections	**(LLW/HLW, used fuel, open → closed fuel cycles)**

U.S. Disposal R&D Focuses on Four Options

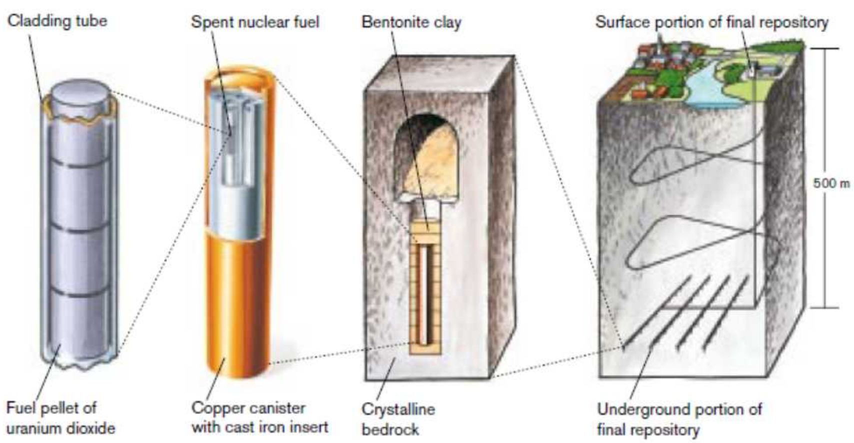
- Three mined repository options (granitic rocks, clay/shale, and salt)
- One geologic disposal alternative: deep boreholes in crystalline rocks





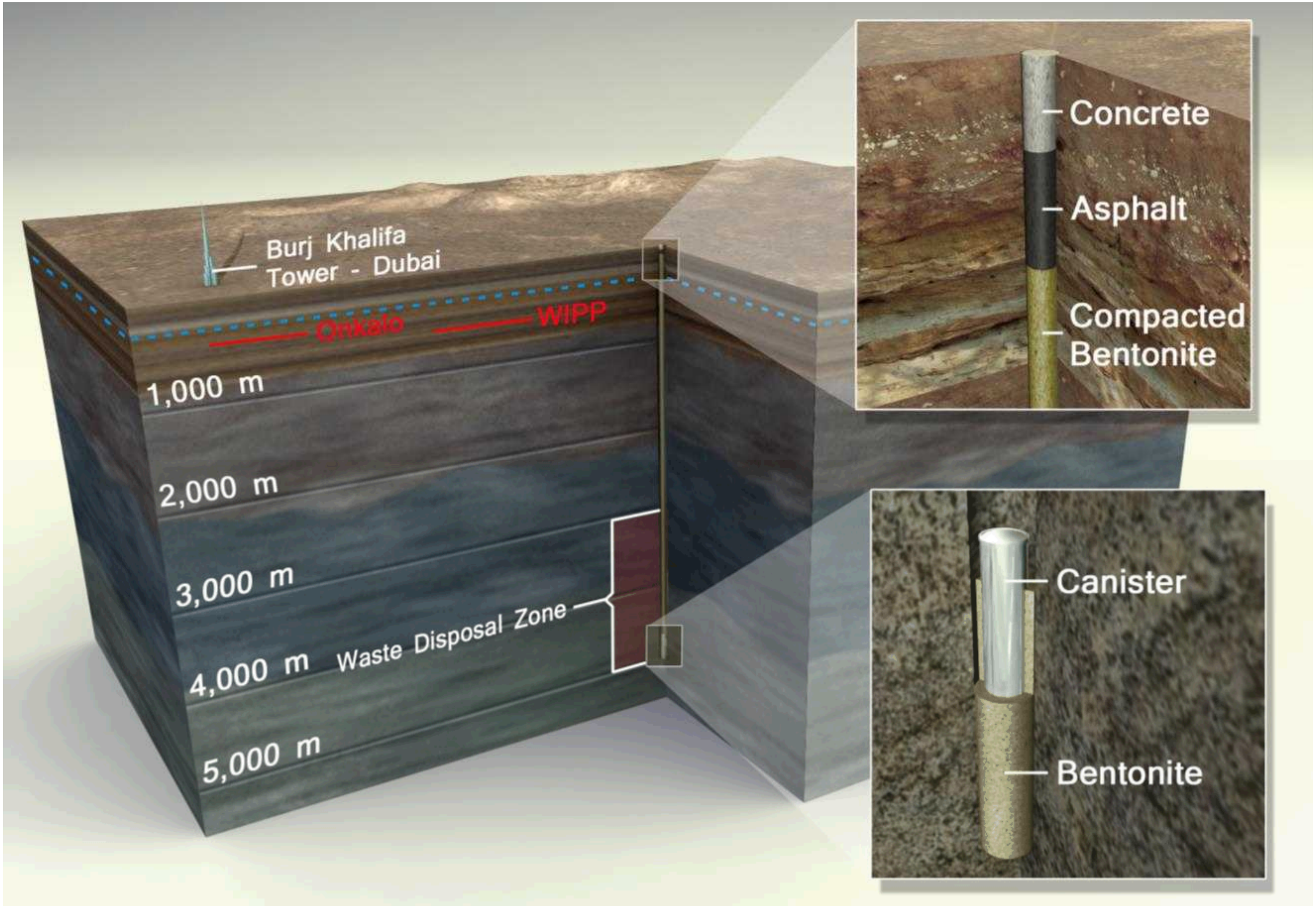


granite

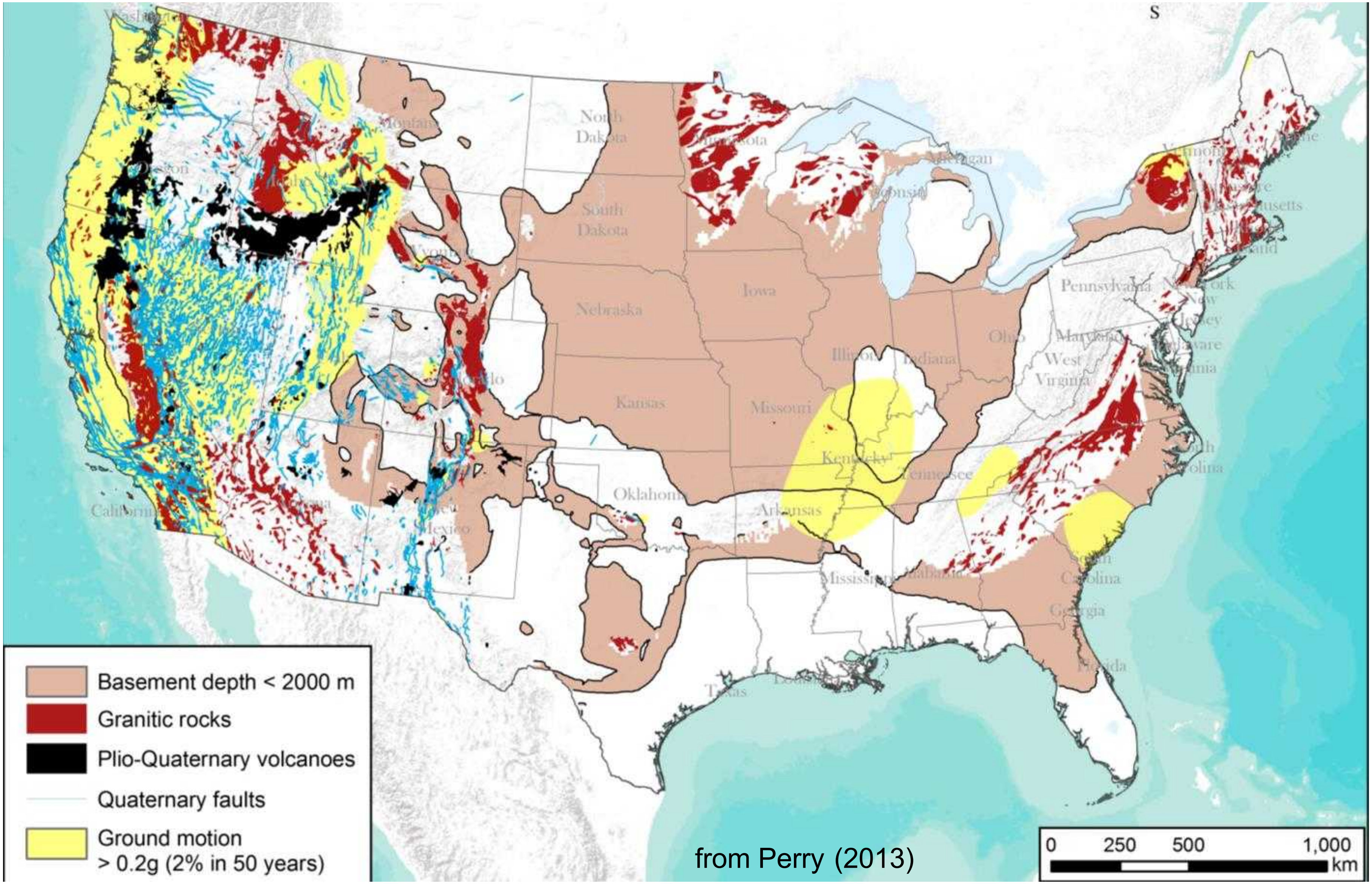


UFD: Deep Borehole Disposal

Deep Borehole Disposal Concept



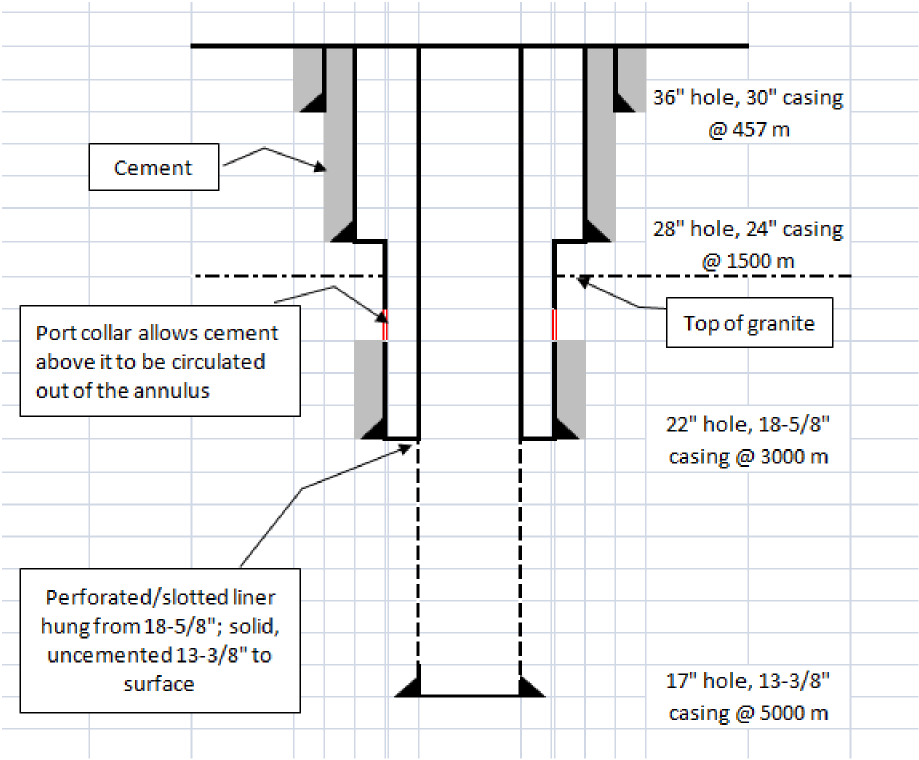
Deep Borehole Site Selection Guidelines

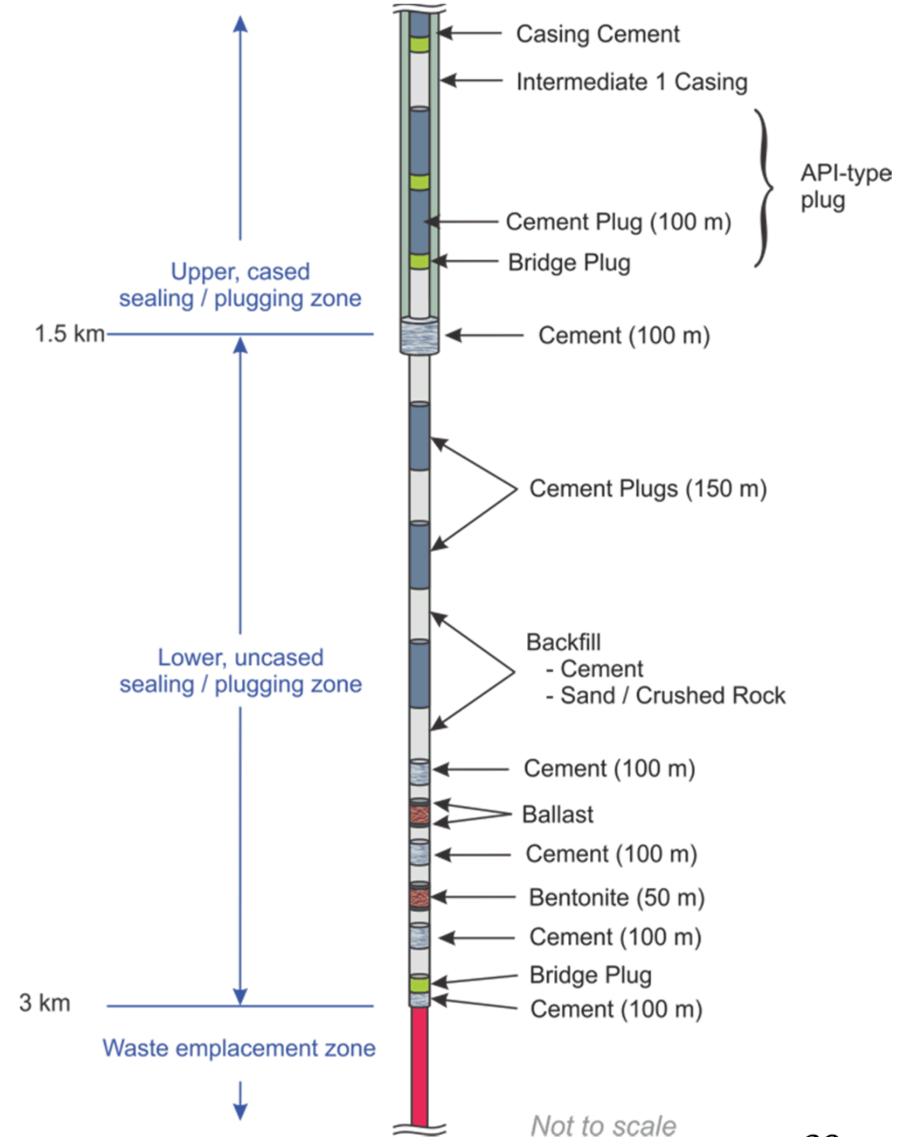


from Perry (2013)

Reference Disposal System Design

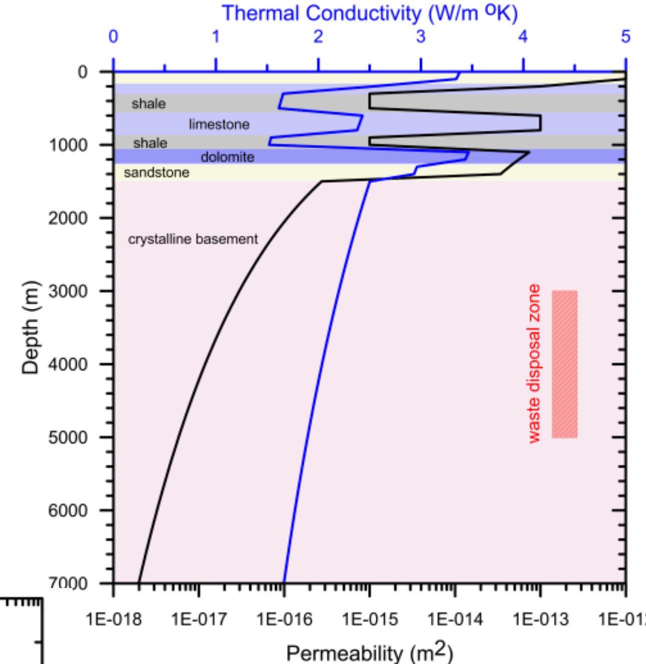
- Drilling 5 km not exceptional and 17” diameter feasible with current technology
- Dismantling/consolidation of PWR fuel rods results in fewer boreholes



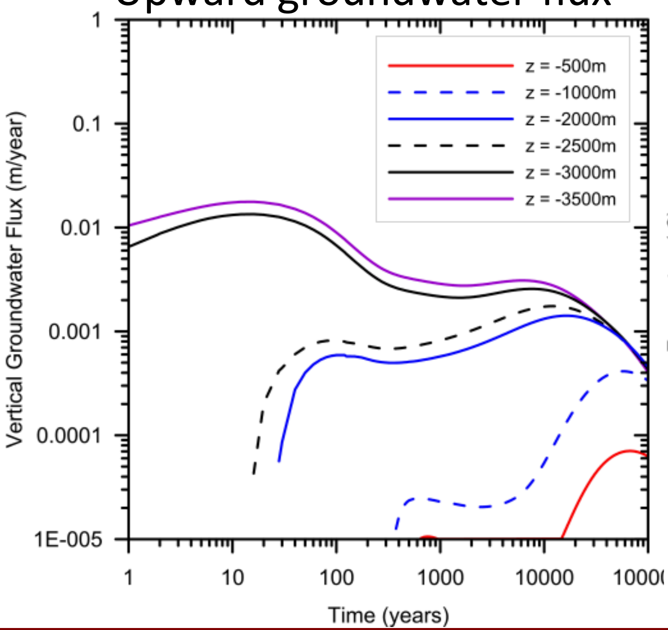


Thermal-Hydrologic Modeling

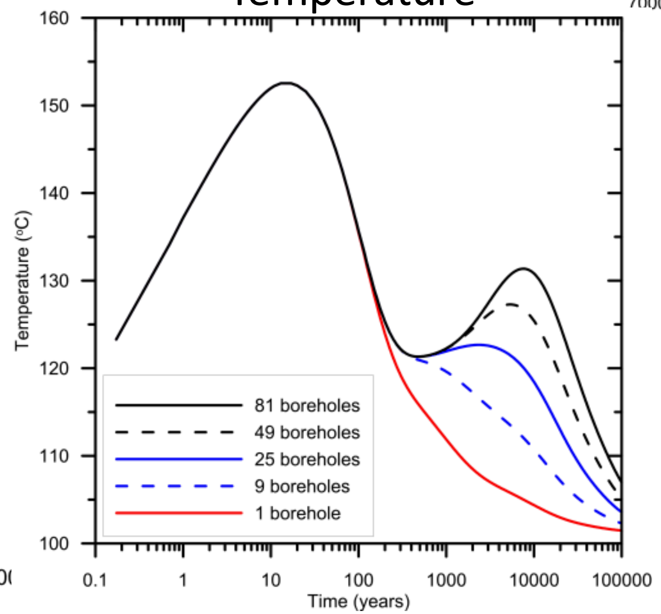
- Thermal hydrologic model concept investigation
- Central borehole at 4 km has max ΔT >50°C, <20 years after emplacement
- Multiple boreholes in a 200-m spaced array show secondary peak temperature @ 10k years



Upward groundwater flux

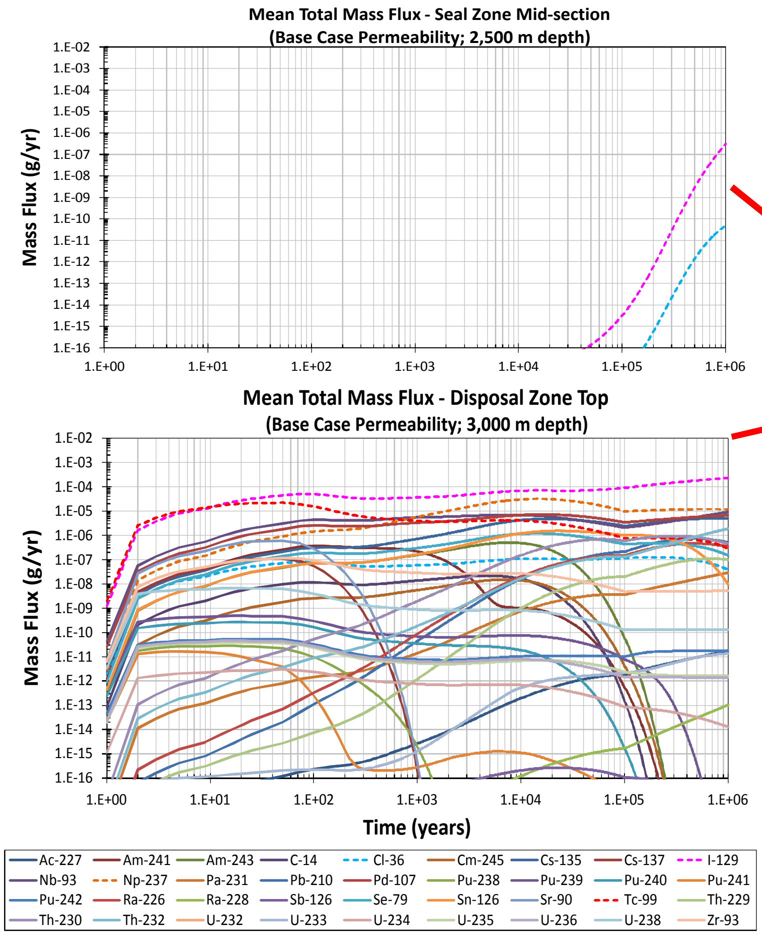


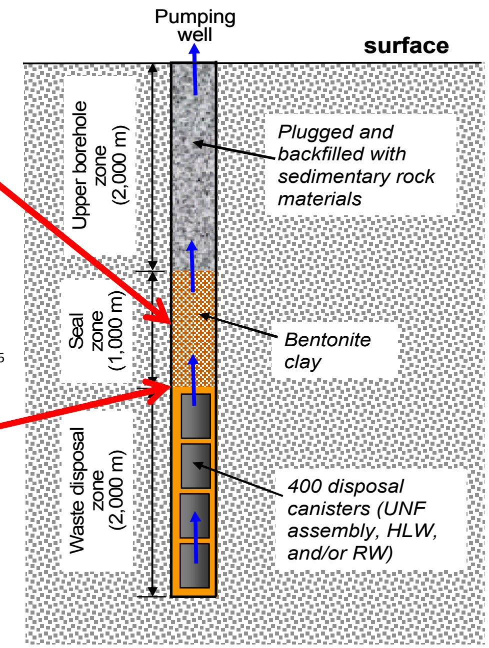
Temperature

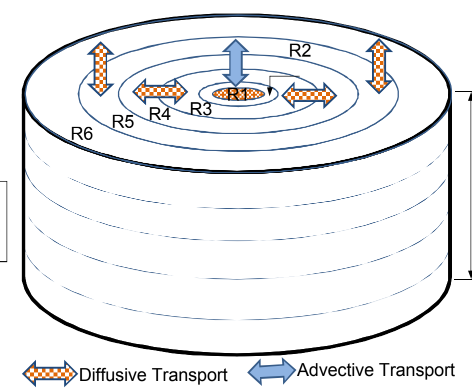


Deep Borehole PA Modeling

- <u>Thermally driven upward flow</u> in the borehole and DRZ, and diffusion of radionuclides out of the flow pathway into the host rock
- Radionuclide <u>releases highly attenuated</u> above disposal zone
- Diffusion into the host rock combined with <u>sorption of most radionuclides</u>, accounts for this high degree of attenuation
- <u>No releases to the biosphere</u> and no dose in the affected biosphere community

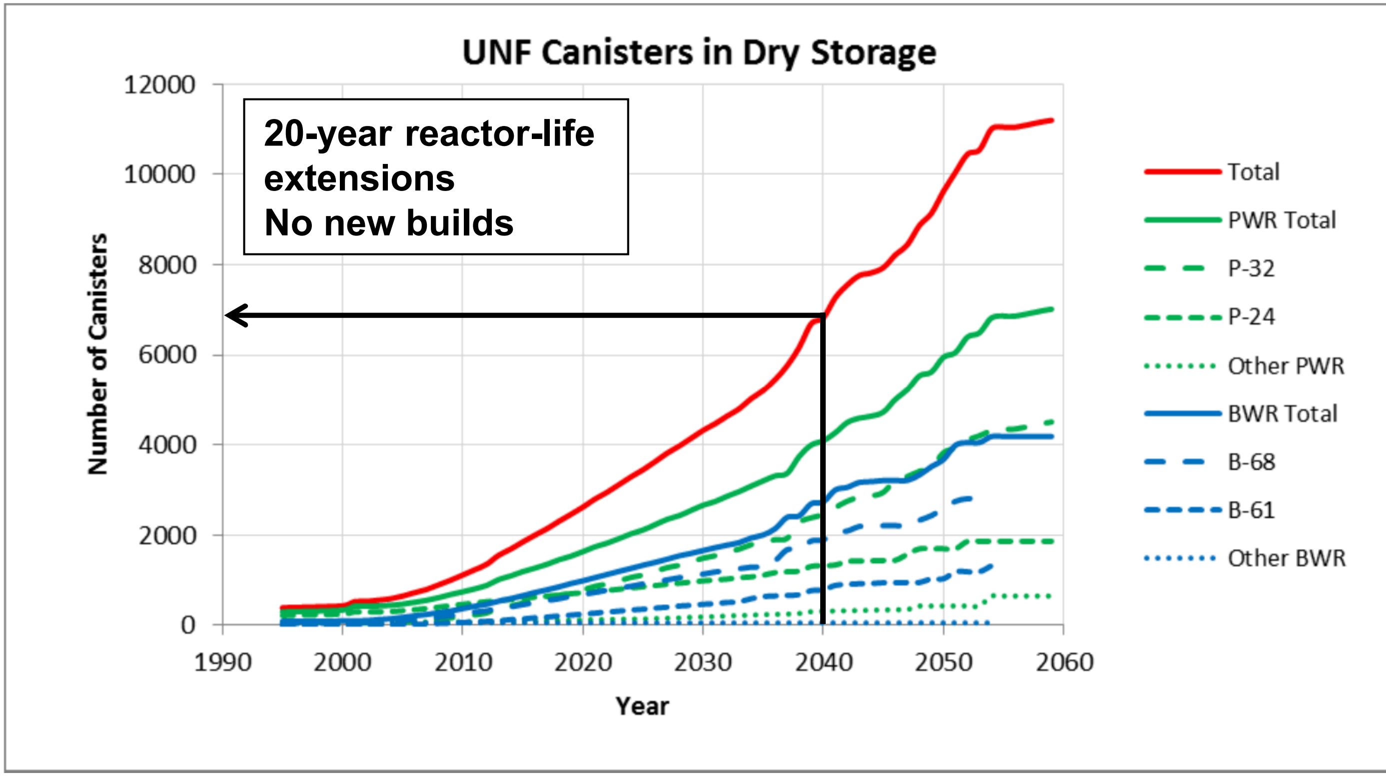






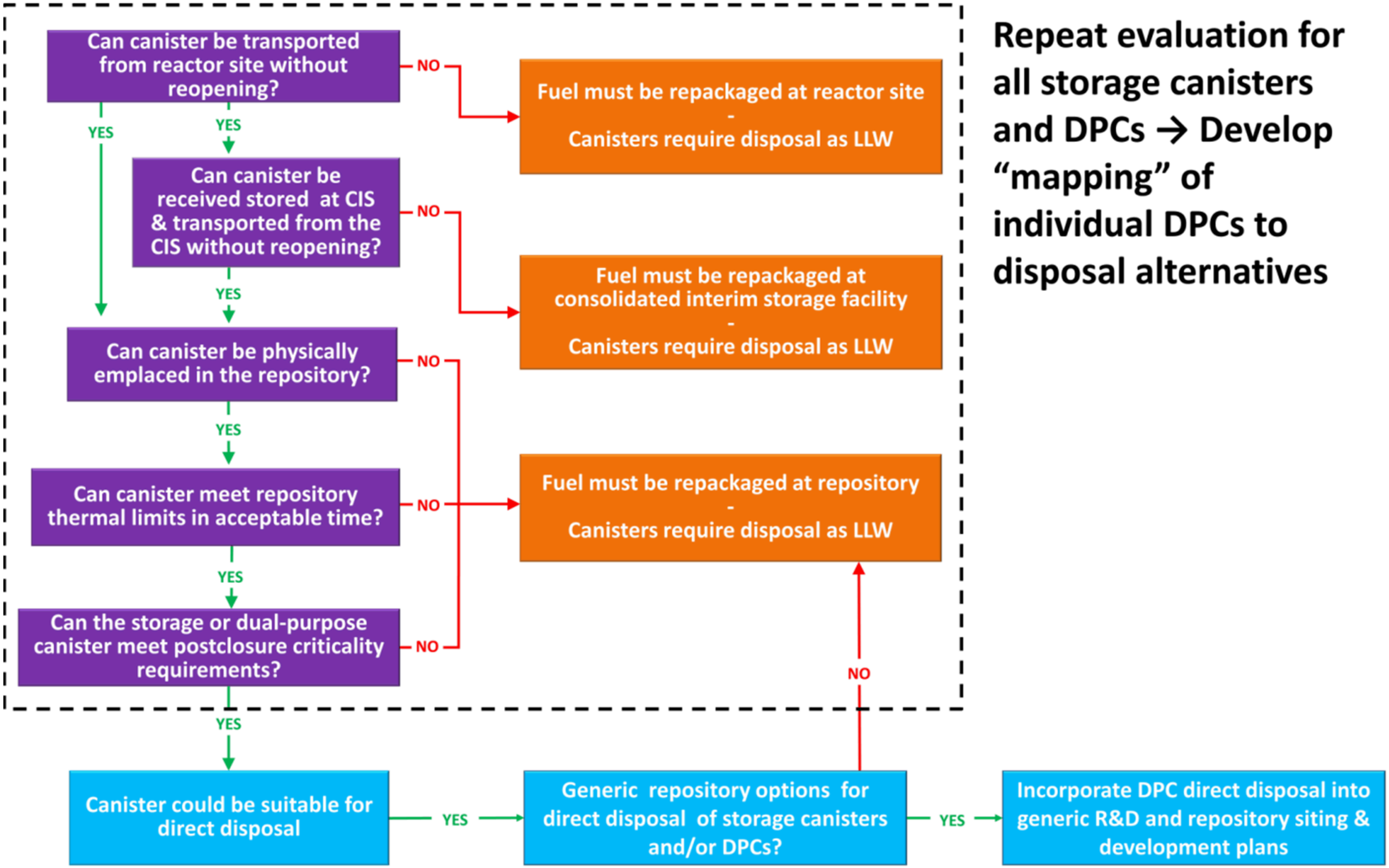
UFD: Dual-Purpose Canister Disposal

Dry Storage Projections



- 2035: >50% of US commercial used fuel will be stored in ~7,000 DPCs
- 1,900 canisters now, >10,000 possible
- 160 new DPCs (~2,000 MTHM) annualy
- At repository opening (2048) oldest DPC-fuel will be >50 years out-of-reactor
- Reactor and pool decommissioning will accelerate transfers to DPCs

Path to Direct Disposal of Existing Storage-Only and Dual-Purpose Canisters



Repeat evaluation for all storage canisters and DPCs → Develop "mapping" of individual DPCs to disposal alternatives

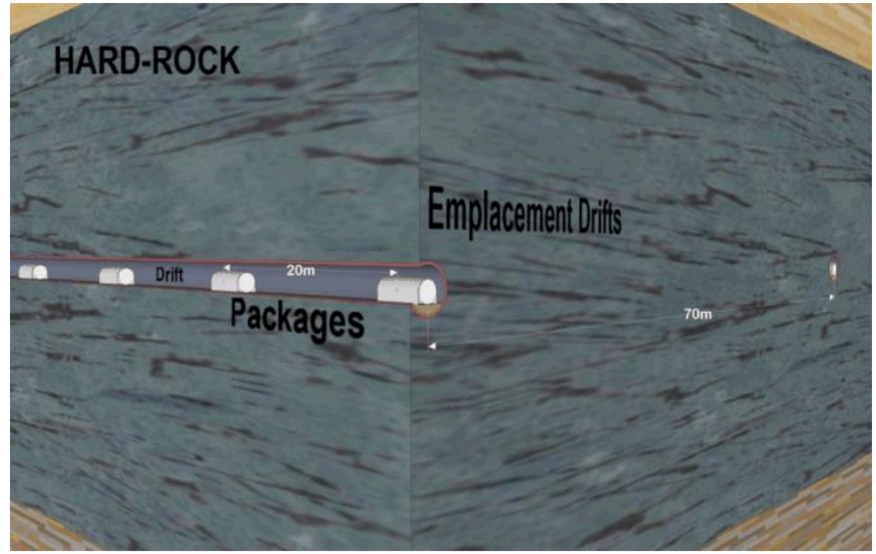
Largest, Recent DPC Designs

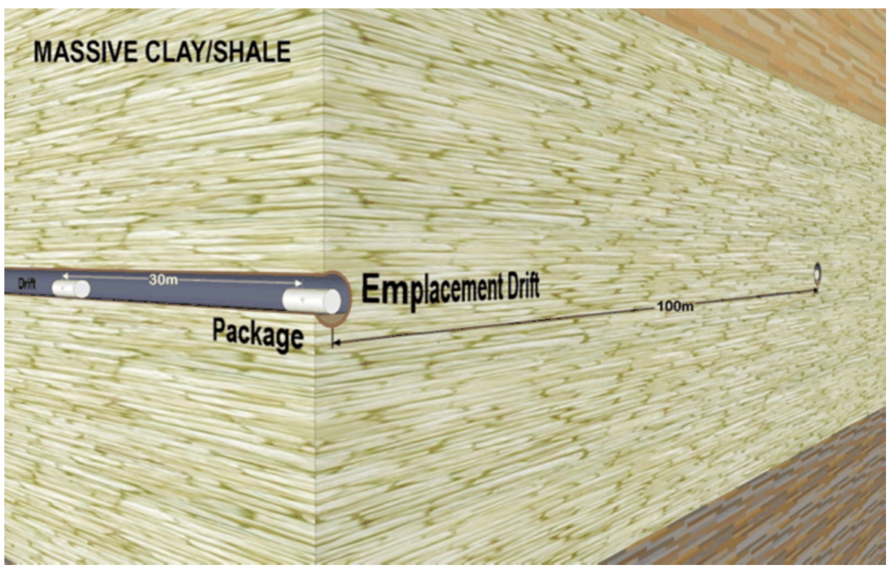
- **Example: Magnastor DPC system (NAC International)**
- **Recently brought to market**
- **Capacity 37-PWR (equiv.)**
- **Thermal limits: 35.5 kW storage/24 kW transport**
- **Fuel cool time >4 yr OoR**
- **Size evolution (free market): burnup credit analysis, heat transfer features, transportation needs.**

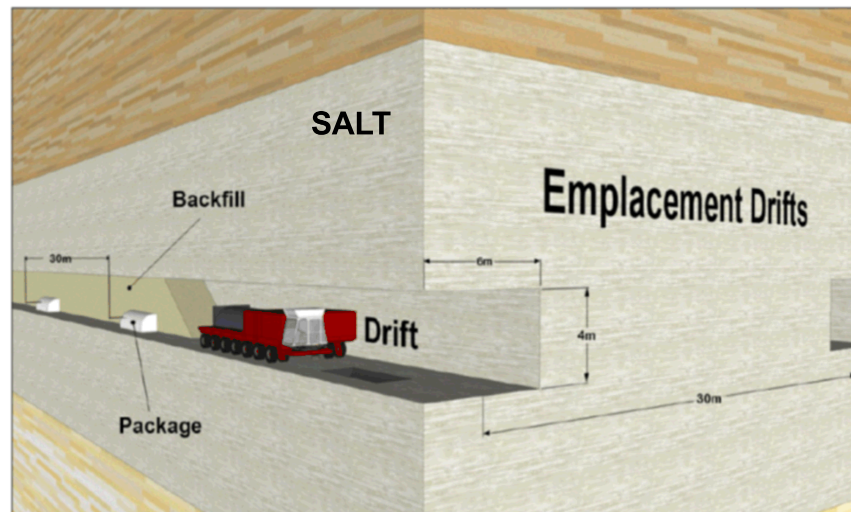
Pictures and data from NAC International website 31Mar2012

DPC Direct Disposal Concepts

- Engineering challenges are technically feasible
- Shaft or ramp transport
- In-drift emplacement
- Repository ventilation (except salt)
- Backfill prior to closure







Source: Hardin et al. 2013. FCRD-UFD-2013-000171 Rev. 0.

Update of Repository Science at SNL

Thanks!