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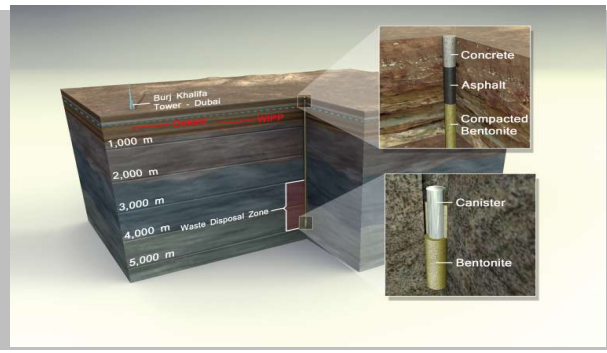

Disposal Research Activities

Kevin McMahon
Sandia National Laboratories

Presented to the
SNL-BAM Workshop
October 6-8, 2014
Albuquerque, NM

U.S. DEPARTMENT OF ENERGY | NNSA

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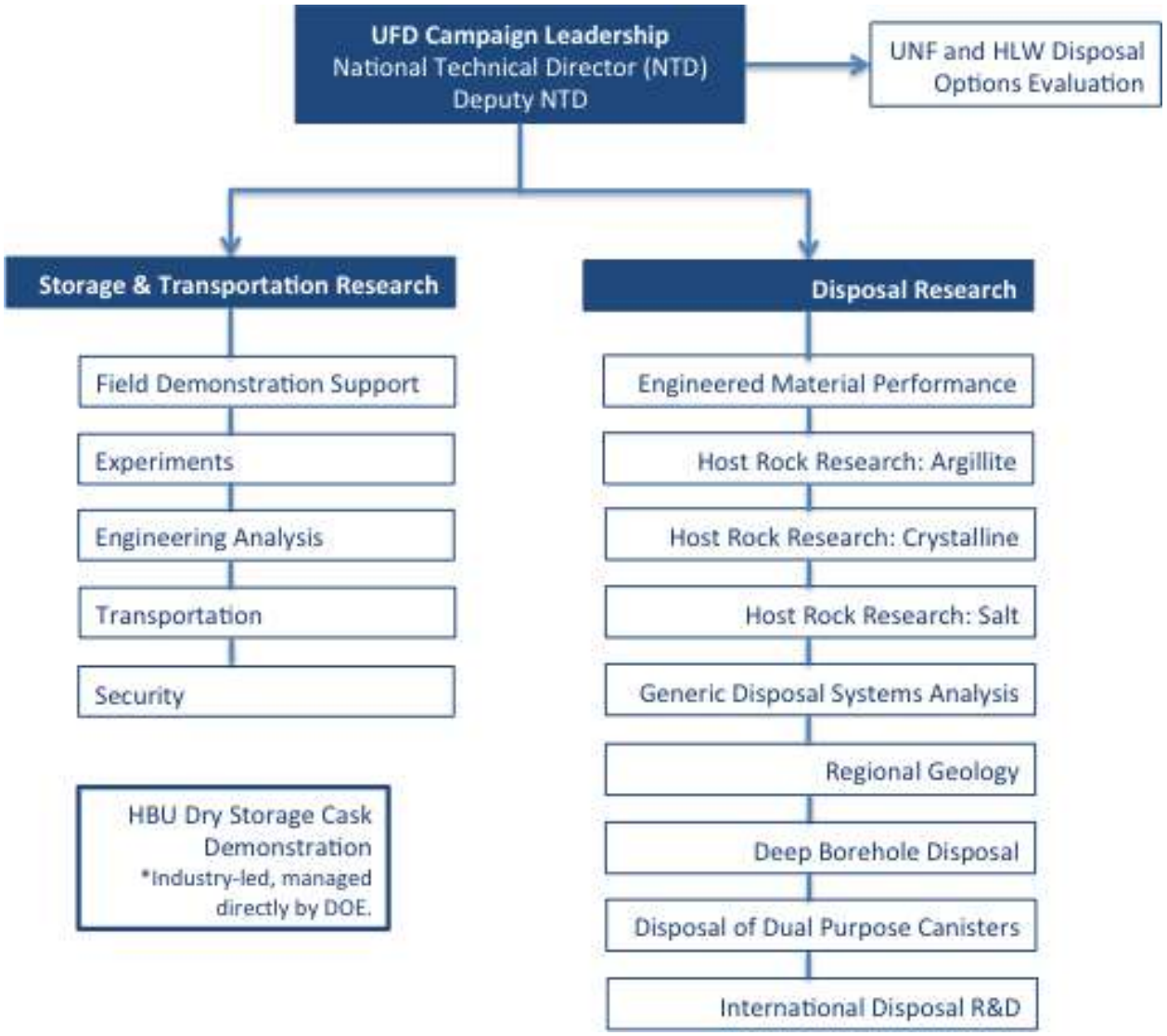
Outline

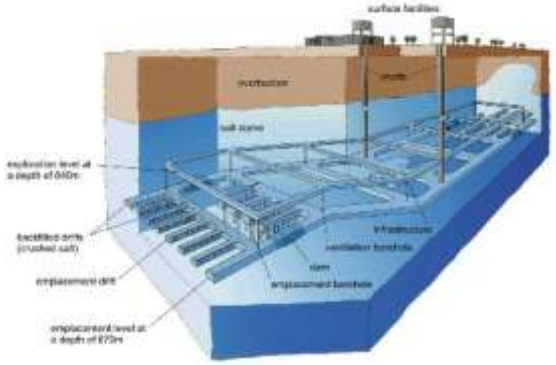
- Disposal Research as part of the Used Fuel Disposition (UFD) Campaign
- Focus and Technical Challenges for Disposal Research
- Disposal Options Being Considered
  - Deep borehole
  - Crystalline Host Rock
  - Argillite Host Rock
  - Salt Host Rock
- Work Supporting Disposal Options
  - Dual Purpose Canisters (DPC)
  - Regional Geology
  - Generic Disposal Systems Analysis
  - International Collaborations
- Conclusions

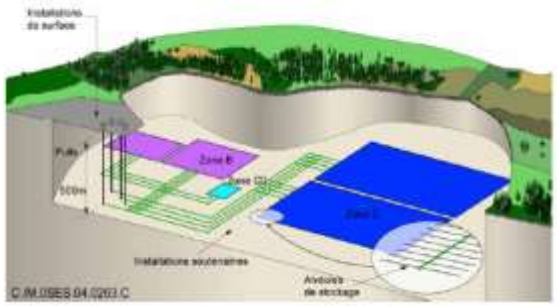
UFD Campaign Structure

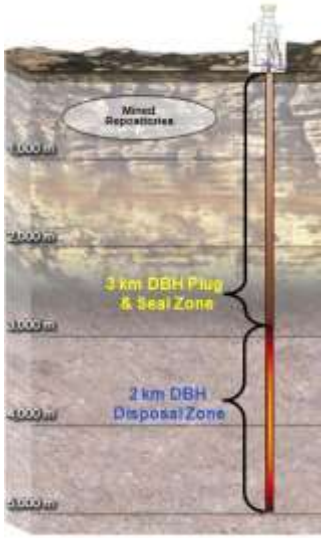


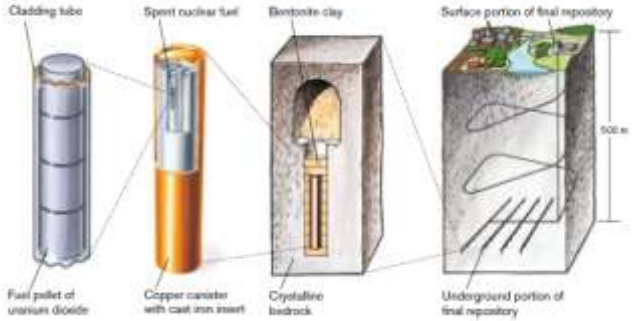
R&D Focus for SNF and HLW Disposal

- Provide a sound technical basis for multiple viable disposal options in the US
- Increase confidence in the robustness of generic disposal concepts
- Develop the science and engineering tools needed to support disposal concept implementation





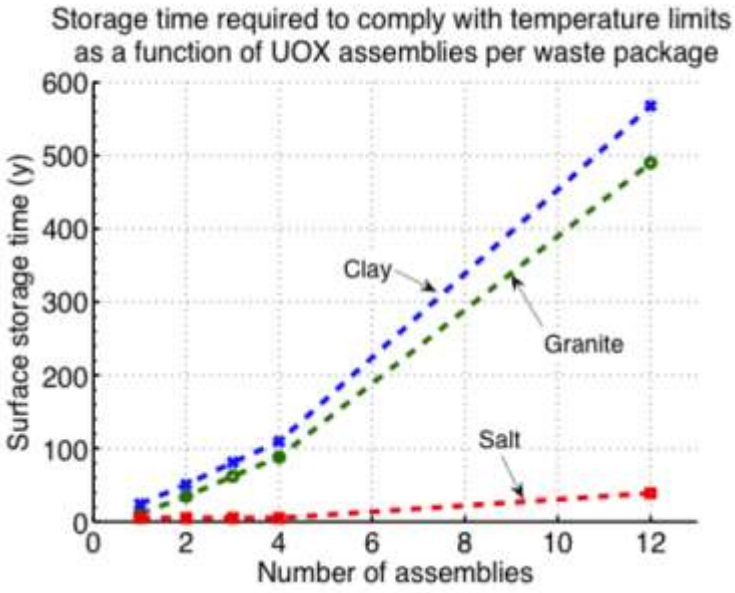




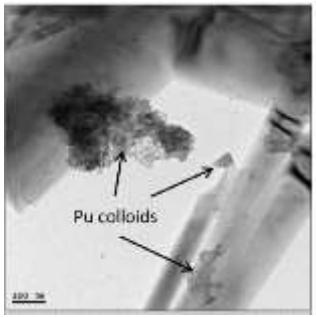
Three mined repository options (crystalline rocks, argillite rocks, and salt)
One geologic disposal alternative: deep boreholes in crystalline rocks

Technical Challenges and Opportunities for Disposal Research

- Building confidence in multiple repository concepts without site-specific data
- Developing tools for characterizing complex natural and engineered systems
- Identifying constraints on disposal options
  - E.g., different media pose different thermal limits, constraining repository design and waste package size
- Matching engineered barriers to geologic environments
  - E.g., Alloy-22 packages in oxidizing environments, copper packages in reducing environments
- Opportunities for international collaboration
  - France, Germany, Sweden, Switzerland, Korea, Japan, China, Czech Republic, Canada, Finland, UK …

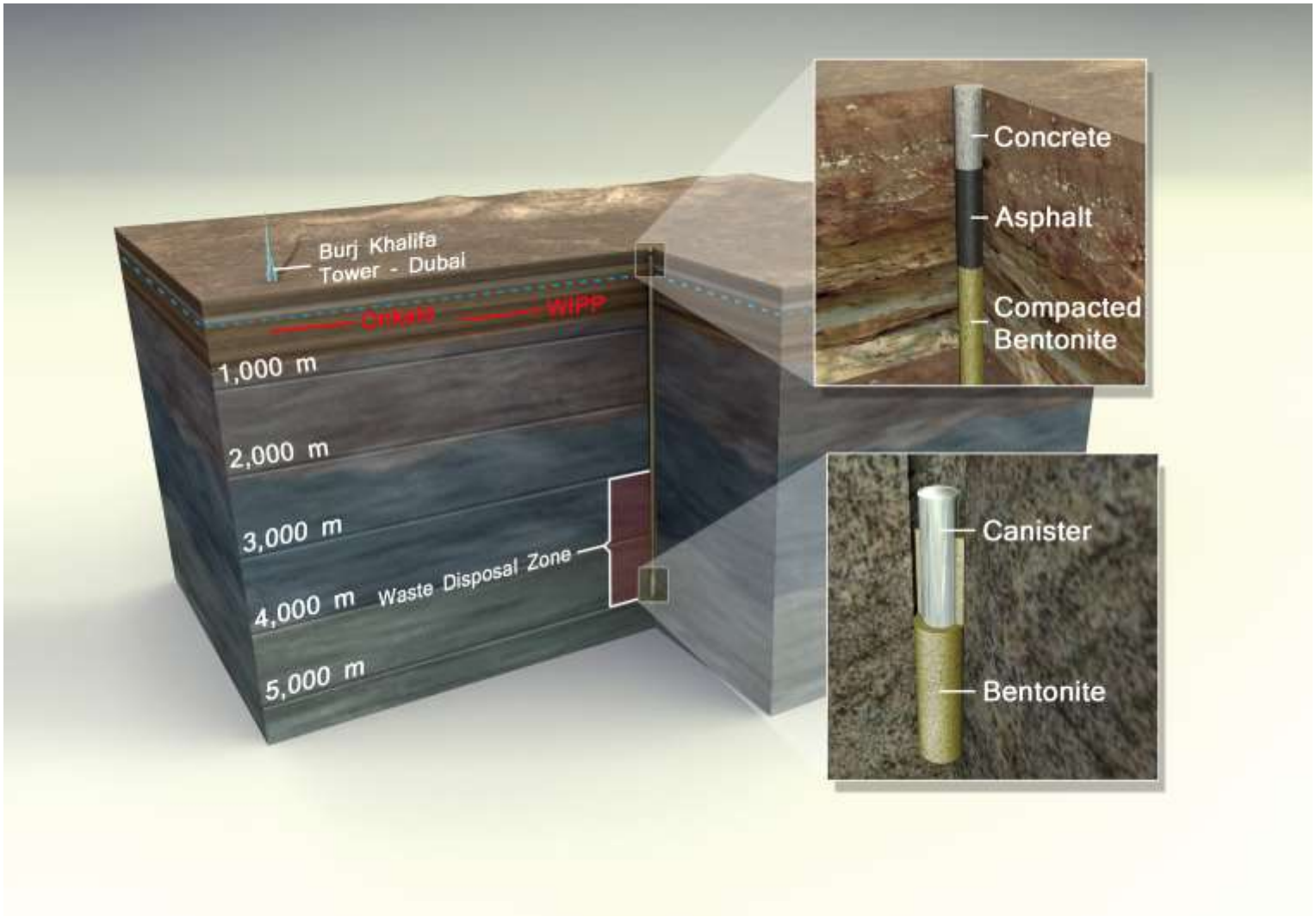


Minimum decay storage durations to limit peak PWR waste package surface temperature to 100°C (granite, clay) or 200°C (salt). (Hardin et al., 2011, Generic Repository Design Concepts and Thermal Analysis (FY11), FCRD-USED-2011-000143)



TEM of intrinsic Pu(IV) nano-colloids sorbed to goethite at 25° C for 103 days (Wang et al., 2011; Natural System Evaluation and Tool Development—FY11 Progress Report, FCRD-USED-2011-000223)

Deep Borehole Disposal Concept

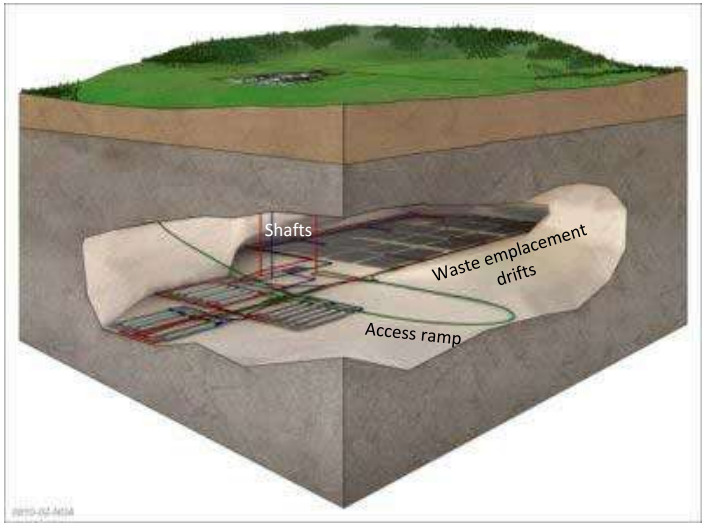


Deep Borehole Disposal Considerations

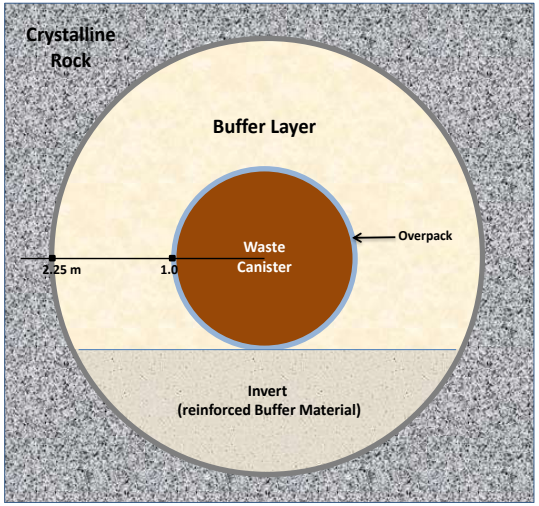
- **Multiple factors indicate the feasibility and safety of the deep borehole disposal concept**
- **Demonstration site selection guidelines indicate that large areas with favorable geological characteristics exist in the conterminous U.S.**
- **Groundwater characterization should focus on aspects of the system critical to demonstrating safety of the deep borehole disposal system:**
  - **Groundwater age and history**
  - **Salinity and geochemistry**
  - **Potential for vertical fluid movement**
  - **Permeability in the host rock and disturbed rock zone**
  - **Borehole seals integrity and durability**

Crystalline Host Rock Disposal R&D

- **Objectives**
  - Advance our understanding of long-term disposal of used fuel in crystalline rocks and to develop necessary experimental and computational capabilities to evaluate various disposal concepts in such media.
- **Focuses**
  - Better characterization and understanding of fractured media and fluid flow and transport in such media
  - Designing effective engineered barrier systems for waste isolation. Especially, the work will take into consideration the implication of the disposal of dual purpose canisters in crystalline rocks.

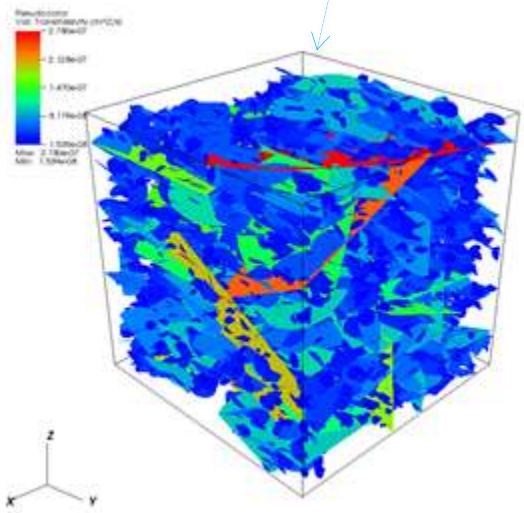


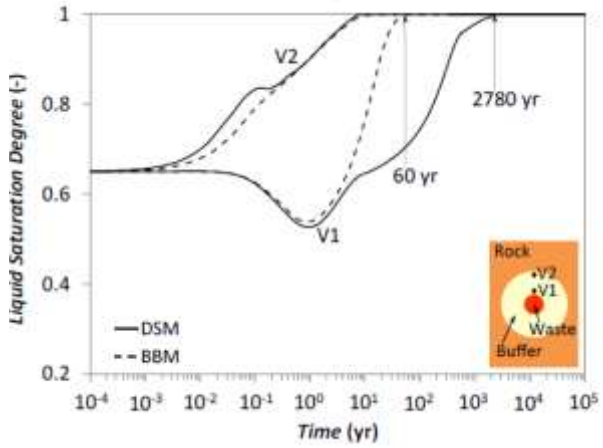
http://www.bbc.com/news/uk-england-cumbria-21253673

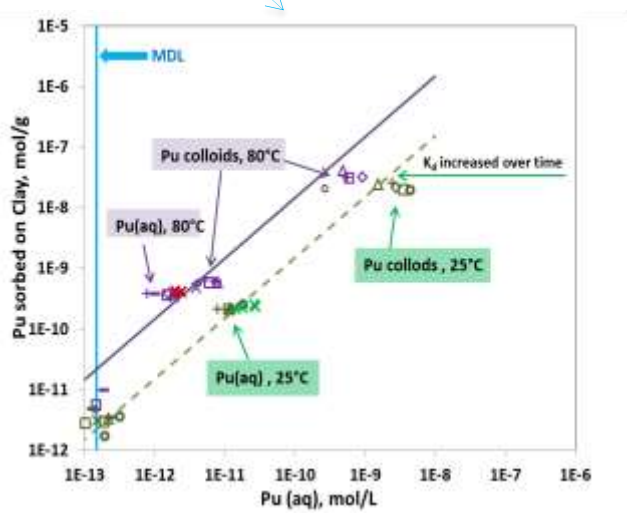


Crystalline Host Rock Disposal R&D –
FY14 Accomplishments

- A R&D plan was developed for used fuel disposal in crystalline rocks. A total of 31 research topics have been identified.
- A generic reference case for crystalline disposal media has been established.
- The capability of a discrete fracture network model was demonstrated using fracture parameters from a testing site.
- A thermo-hydrologic-mechanical (THM) model has been applied to an engineered barrier system.
- Significant progress has made in understanding radionuclide interactions with buffer and granitic materials.
- International collaboration has been actively pursued (e.g., DECOVALEX, KAERI, Sweden URL).



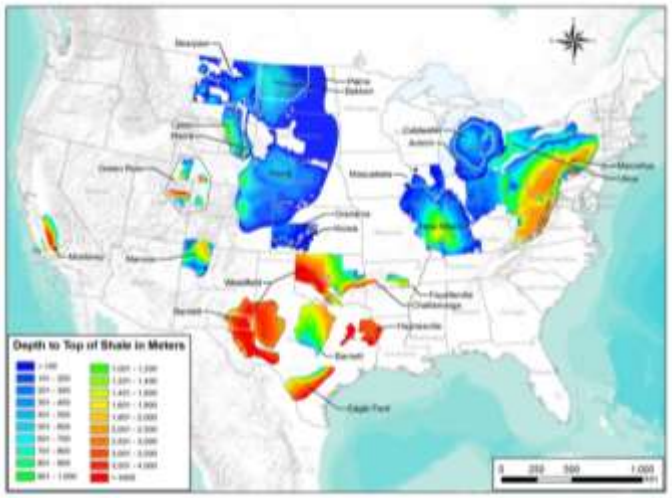


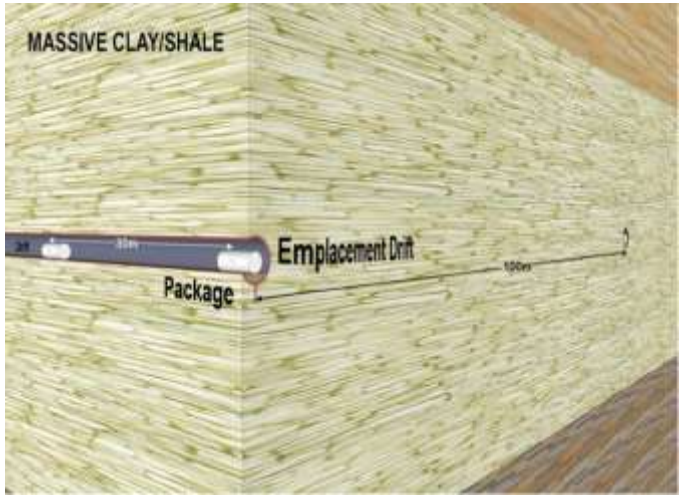


Argillite Host Rock Disposal

Overall Description

- **Scope**
  - **An integrated assessment of various aspects of nuclear waste disposal research in clay-bearing host rock media:**
    - **Development of a reference case for argillite**
    - **Geochemical evaluation of interactions relevant to EBS materials (clay, metal) under repository conditions:**
      - Thermodynamic modeling and hydrothermal experiments
      - Thermodynamic database assessment: clay minerals and sorption
    - **Coupled Thermal-Hydrological-Mechanical-Chemical (THMC)**
      - Development and validation of constitutive relationships for permeability, porosity and effective stress
      - Discrete fracture network (DFN) approach for fractures in argillaceous rock
      - Transport in clay and clay rock
    - **Corrosion modeling For used fuel degradation: Application to Argillite Rock Environments**

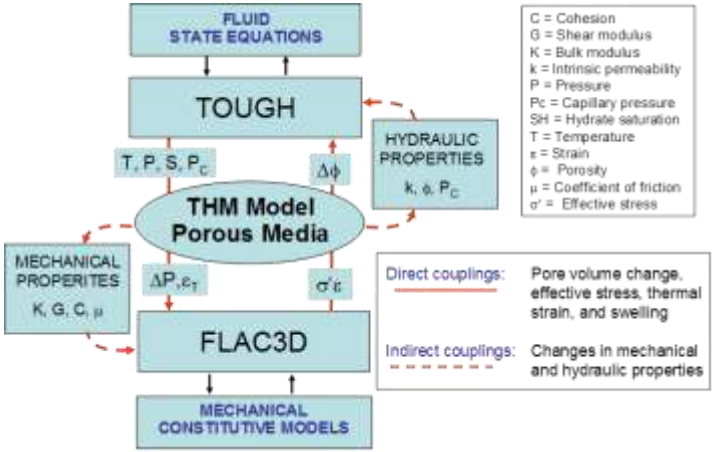


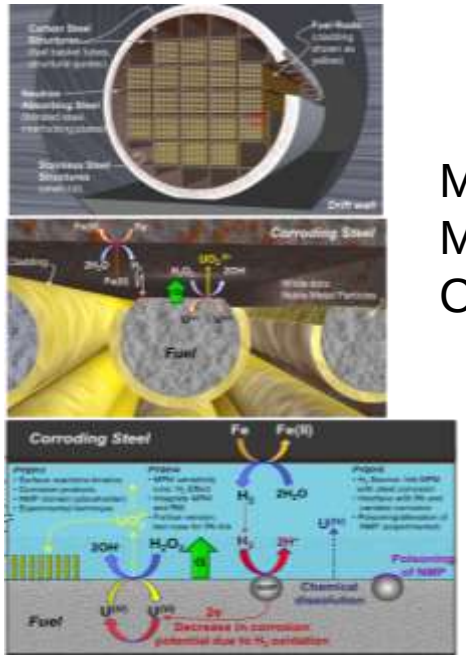


Argillite Host Rock Disposal

Examples of Model Development

- **THM coupled models for clay**
  - International Collaborations: THM Modeling of Underground Heater Experiments
- **Discrete Fracture Network (DFN) approach for fractures in argillite**
  - Excavation damaged zone (EDZ) and natural fracturing
  - Rigid-Body-Spring Network (RBSN) modeling approach for mechanical damage
- **Modeling and experimental investigations on barrier material interactions and stability**
- **ANL Mixed Potential Model (MPM) for used fuel matrix degradation**
  - Development towards integration with performance assessment (PA)

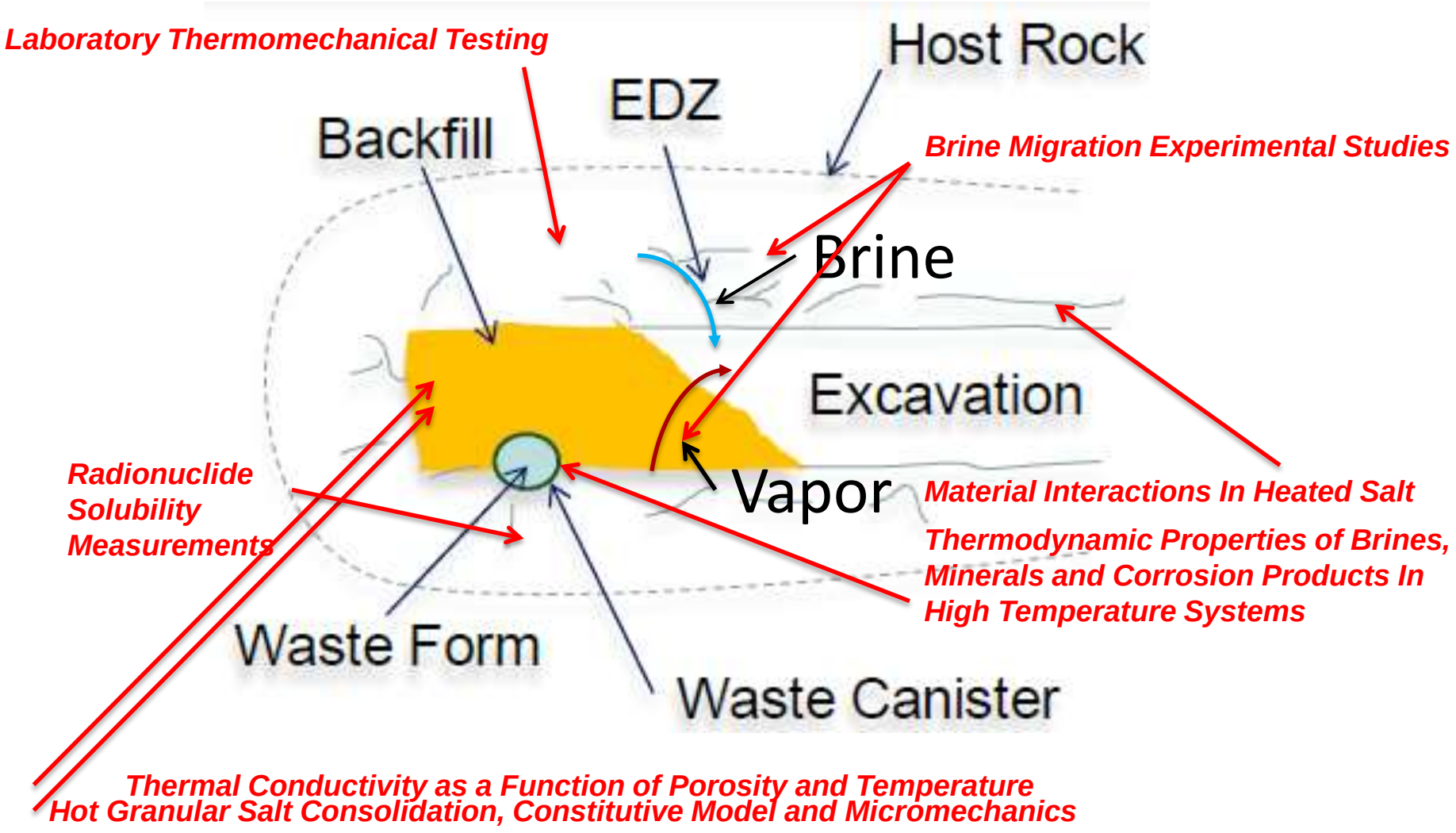




MPM Model Concept

Salt Host Rock RD&D:

Schematic of Features of a Backfilled Repository Room



Salt Host Rock RD&D:

Schematic of Features of a Backfilled Repository Room

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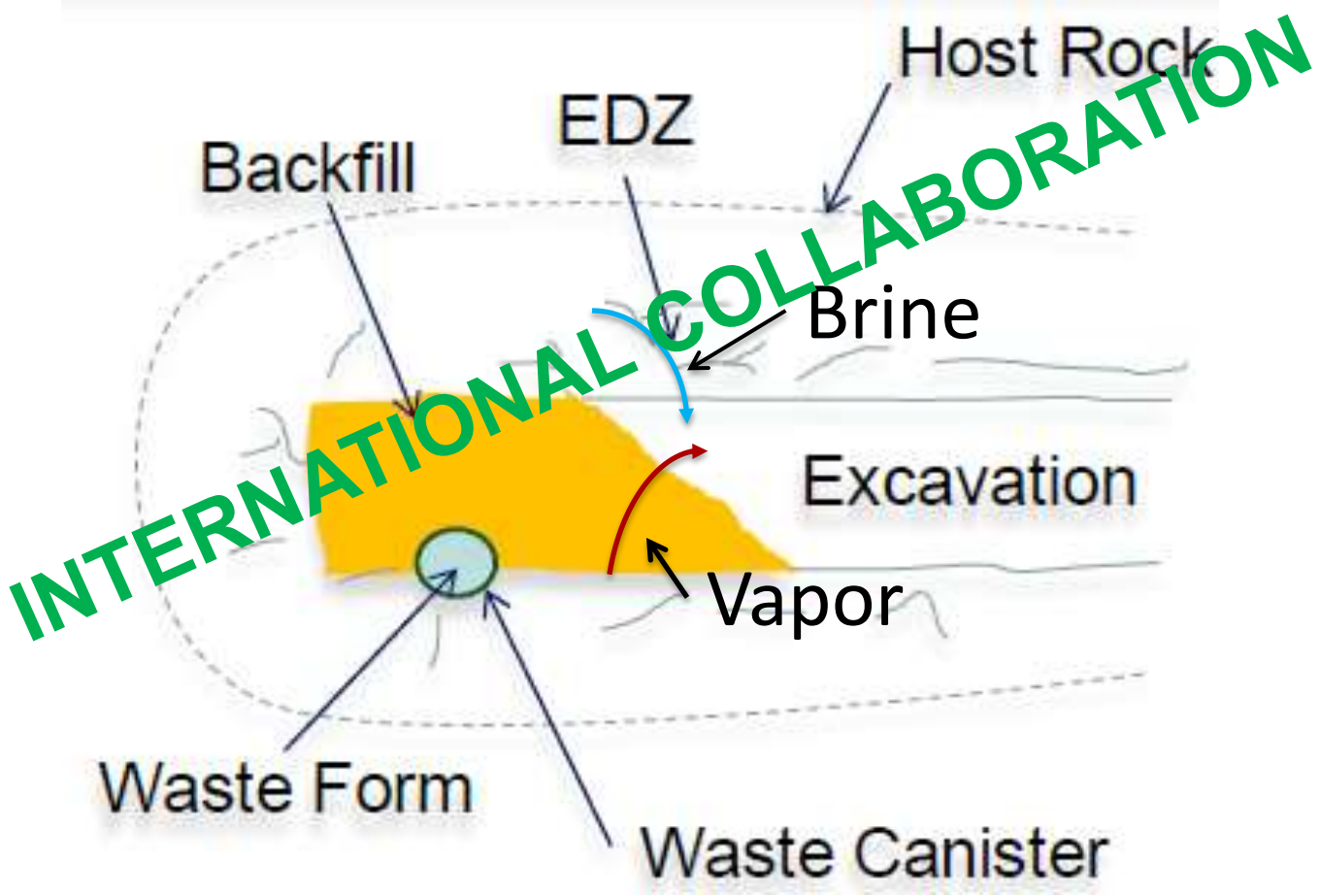
Total System Model Development (TSMD) Modification

Generic Salt Repository Benchmarking

FMEP Model Development (FEBA) Modification



INTERNATIONAL COLLABORATION

Salt Host Rock Disposal RD&D

Field Studies

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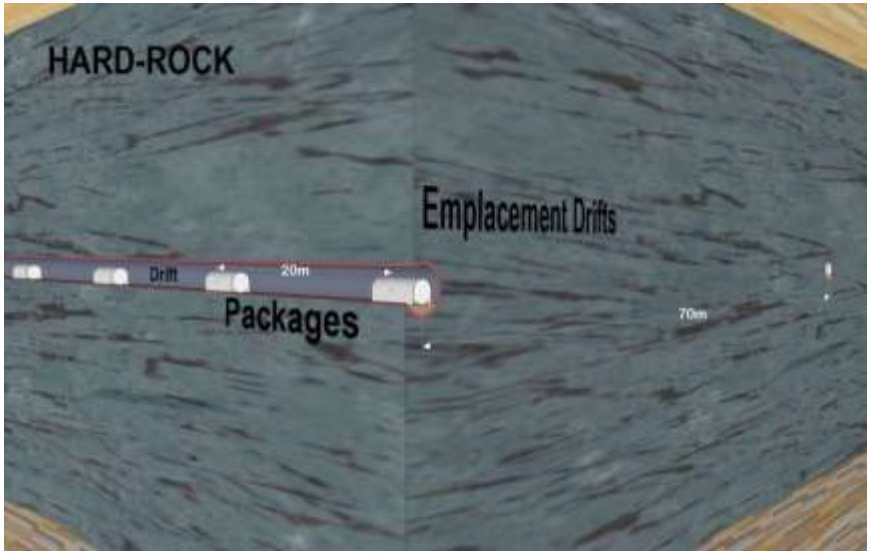
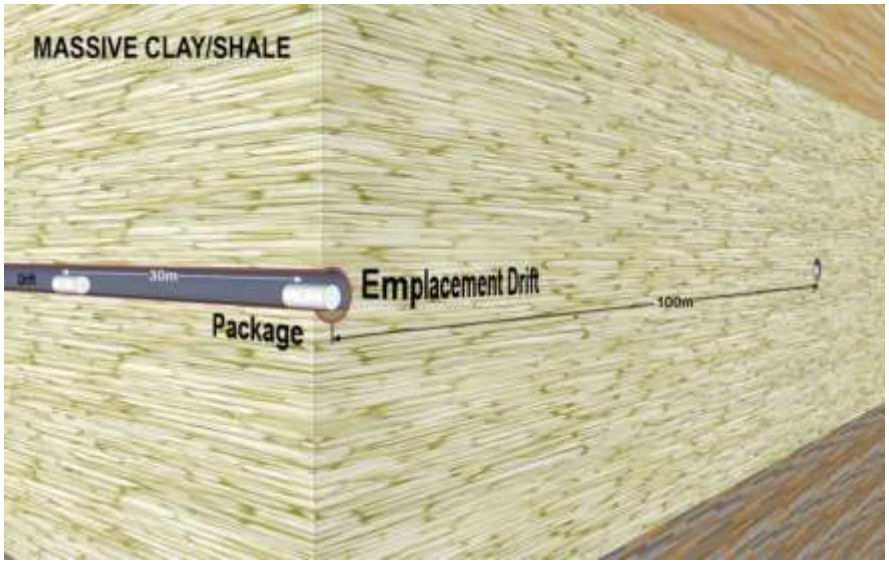
General Objectives

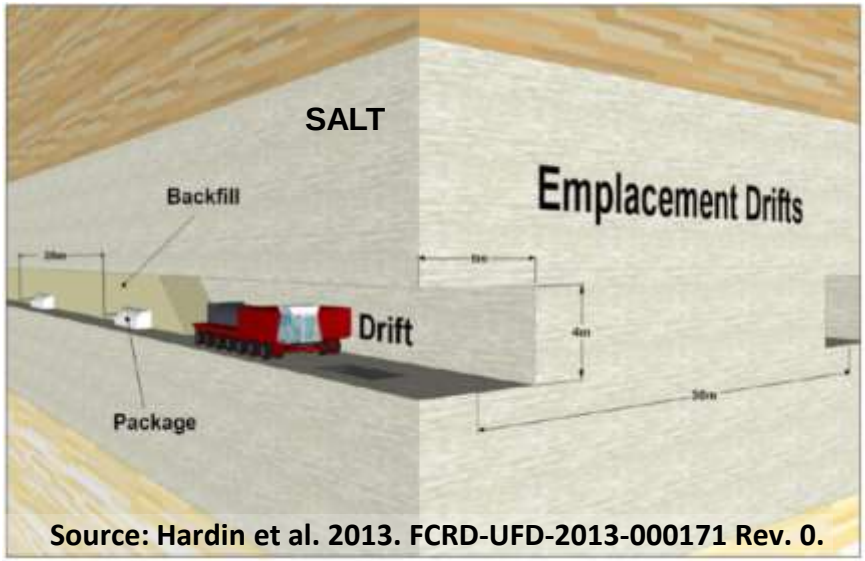
- ***Develop technology and methodology for rock characterization and testing***
- ***Better understand, model and test relevant processes***
- ***Better understand various components of engineering barrier system***
- ***Provide quantitative data for safety assessment calculations***
- ***Test and optimize full-size repository components and operating procedures (demonstration)***
- ***Optimize repository construction techniques***
- ***Training and benchmarking***
- ***Promote international co-operation***
- ***Build confidence in scientific and technical community***
- ***Contribute to public trust and confidence***

DPC Direct Disposal Concepts

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

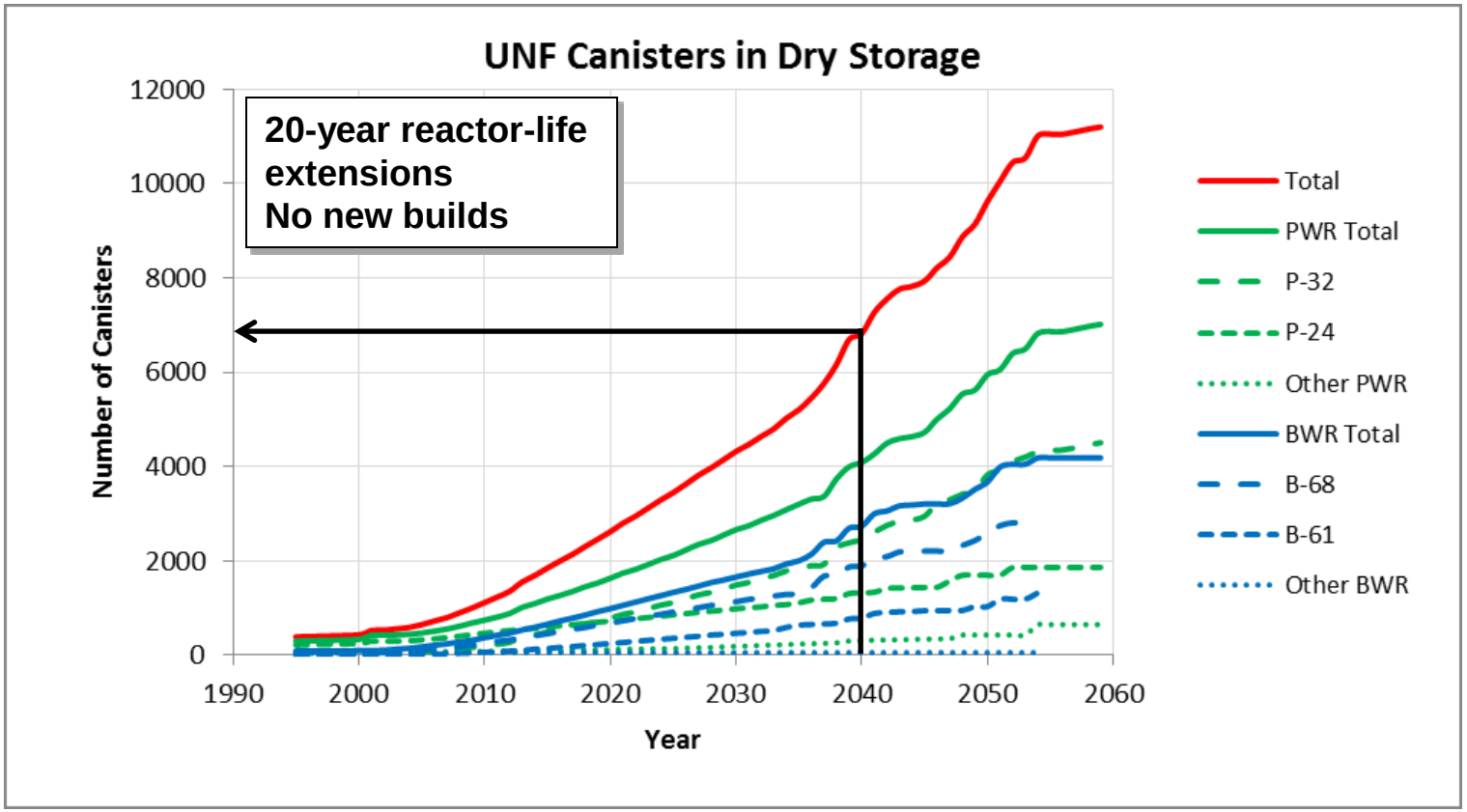






Source: Hardin et al. 2013. FCRD-UFD-2013-000171 Rev. 0.

Dry Storage Projections (TSL-CALVIN)



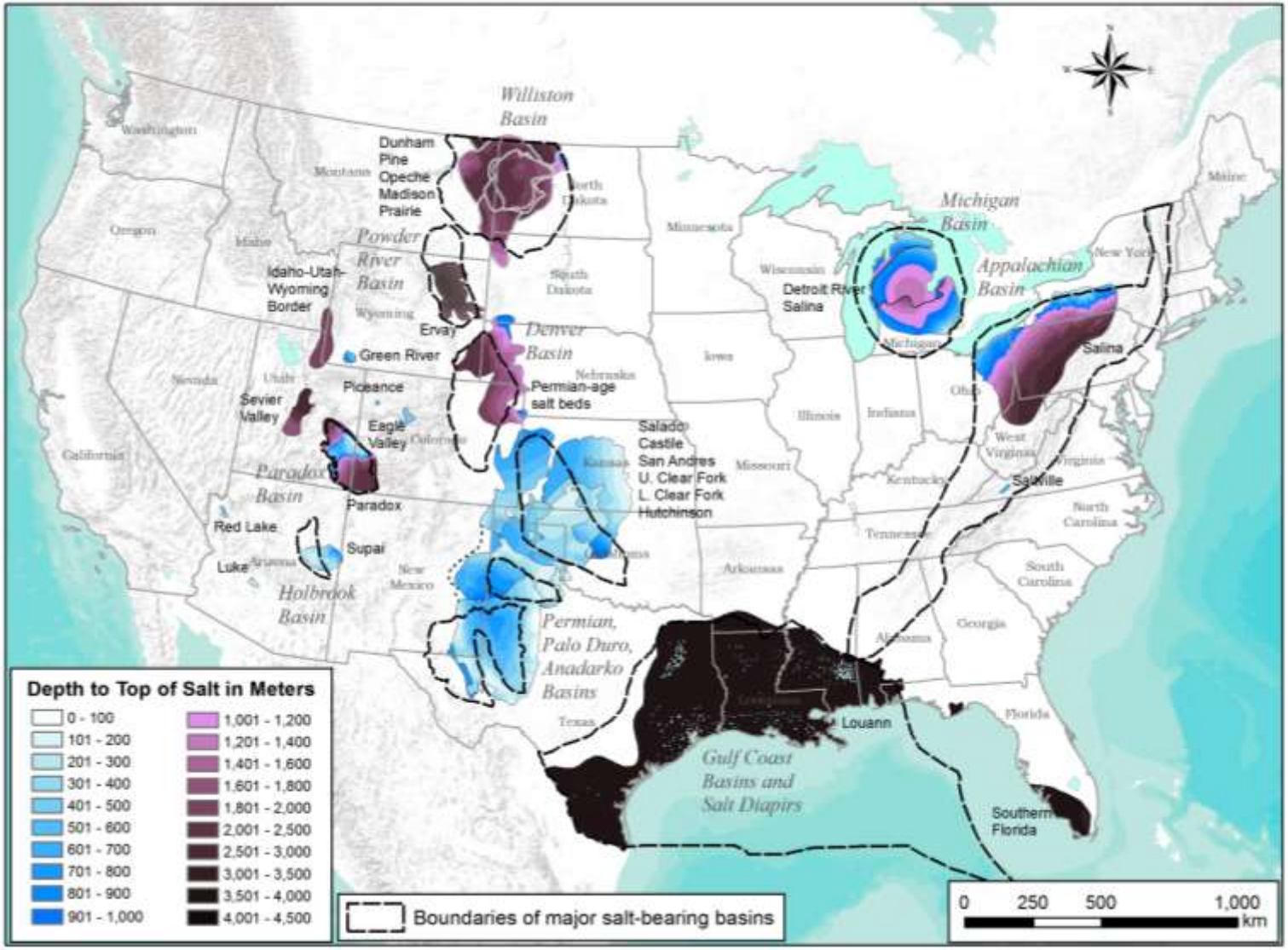
- **2035: > 50% of commercial used fuel in the U.S. will be stored in ~7,000 DPCs**
- **>1,900 canisters now, >10,000 possible with existing reactor fleet**
- **160 new DPCs (~2,000 MTHM) per year**
- **Reactor and pool decommissioning will accelerate fuel transfers to DPCs**
- **At repository opening (~2048) the oldest DPC-fuel is >50 years out-of-reactor**

Regional Geology

- We are building a GIS spatial database that combines data for alternative host rocks and other natural and cultural features in order to evaluate and communicate potential siting options
- Simple geologic characteristics such as depth to formations may be used to evaluate the potential for repository siting in specific regions
- Other relevant formation data (e.g., heterogeneity, geochemistry, permeability) will be added to the database in the future
- A web-based interactive tool is planned to communicate basic geologic and siting information for different regions of the U.S.

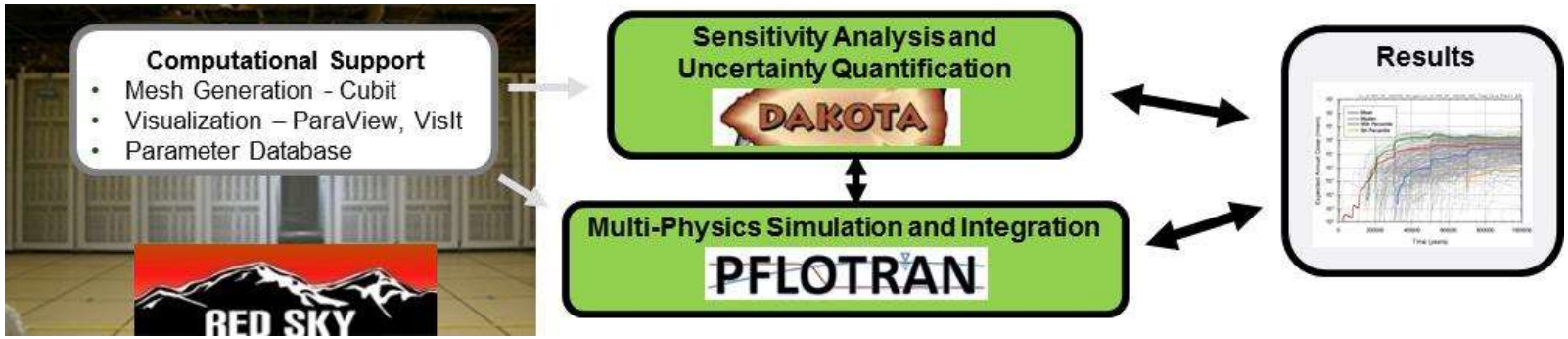
Comparative Depth of (Bedded) Salt

Regional Geology Example



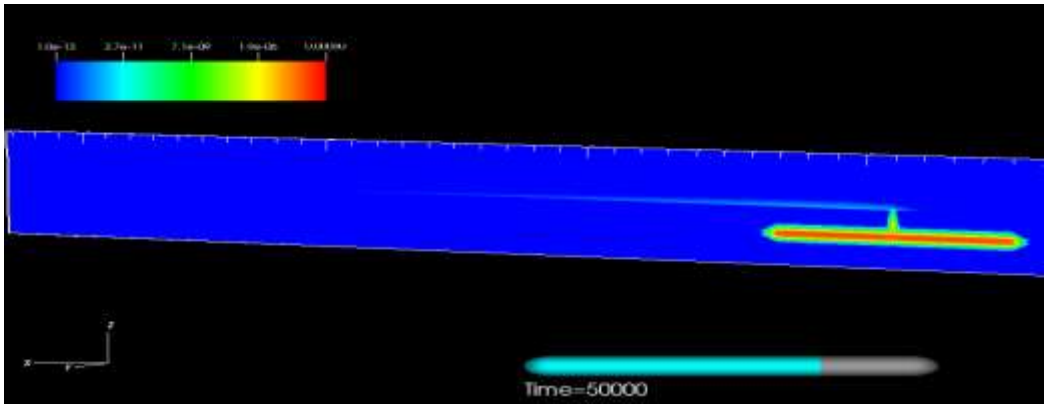
Generic Disposal System Analysis

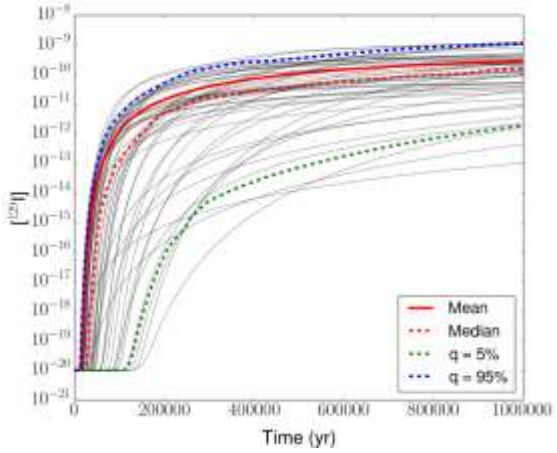
- Scope
  - Development and implementation of an enhanced performance assessment (PA) modeling capability, applicable to a range of disposal options (salt, granite, clay, deep borehole)
- Technical Challenges
  - Application of high-performance computing (HPC)-enabled PFLOTRAN code for efficient simulation of 3D integrated multi-physics (thermal-hydro-chemical (THC)) over a range of spatial scales
  - Representation of spatially-variable THC-driven source term



Generic Disposal System Analysis
Continued

- Accomplishments
  - Development of generic repository reference cases
    - salt, clay and granite
  - Conceptual model for complex, integrated THC source term
    - waste degradation, radionuclide solubility and mobility
  - Probabilistic THC simulations and sensitivity analyses
    - Salt reference case with spatially-varying waste degradation, decay heat, fluid flow, radionuclide mobilization and transport, coupled biosphere





International Collaborations in Disposal Research

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Key Issues Tackled in Current and Planned Portfolio

- **Near-Field Perturbation**
- **Engineered Barrier Integrity**
- **Radionuclide Transport**
- **Demonstration of Integrated System Behavior**

International Cooperative Initiatives

- **DECOVALEX -** research collaboration and model comparison activity for coupled processes simulations (currently 10 partners)
- **Mont Terri -** research partnership for the characterization and performance assessment of a clay/shale formation (currently 15 partners)
- **Colloid Formation and Migration -** research investigation of colloid formation/bentonite erosion, colloid migration, and colloid-associated radionuclide transport (currently 9 partners)
- **FEBEX -** *in situ* full-scale heater test conducted in a crystalline host rock with bentonite backfill (currently 10 partners)
- **SKB Task Forces -** collaboration in the area of conceptual and numerical modeling of performance-relevant processes in natural and engineered systems (currently 12 partners)

International Collaborations in Disposal Research (continued)

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Bilateral Collaborations

- **KAERI Underground Research Tunnel (KURT)** - *in situ* borehole characterization and methods for measuring streaming potential (SP) to characterize groundwater flow in a fractured formation
- **German Federal Ministry of Economics and Technology (BMWi)** - model benchmarking and data exchange for salt repositories at WIPP and Gorleben
- **MoU between ANDRA and DOE** - collaborative work in clay/shale disposal at the LSMHM Underground Laboratory near Bure

Countries With Collaboration Partners Include

Finland, Sweden, France, Belgium, Peoples Republic of China, Switzerland, Japan, Canada, United Kingdom, Germany, Republic of Korea, Spain, Republic of China (Taiwan)