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Spent Fuel and Waste Science and Technology (SFWST)

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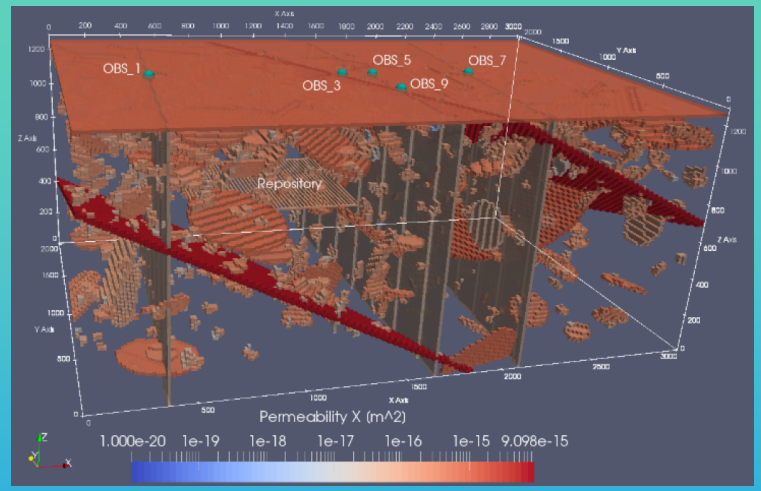

DOE's Disposal Research Activities: Geologic Disposal Safety Assessment (GDSA) and Direct Disposal of Dual-Purpose Canisters (DPCs)

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Las Vegas NV

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This is a technical presentation that does not take into account the contractual limitations or obligations under the Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste (Standard Contract) (10 CFR Part 961). For example, under the provisions of the Standard Contract, spent nuclear fuel in multi-assembly canisters is not an acceptable waste form, absent a mutually agreed to contract amendment.

To the extent discussions or recommendations in this presentation conflict with the provisions of the Standard Contract, the Standard Contract governs the obligations of the parties, and this presentation in no manner supersedes, overrides, or amends the Standard Contract.

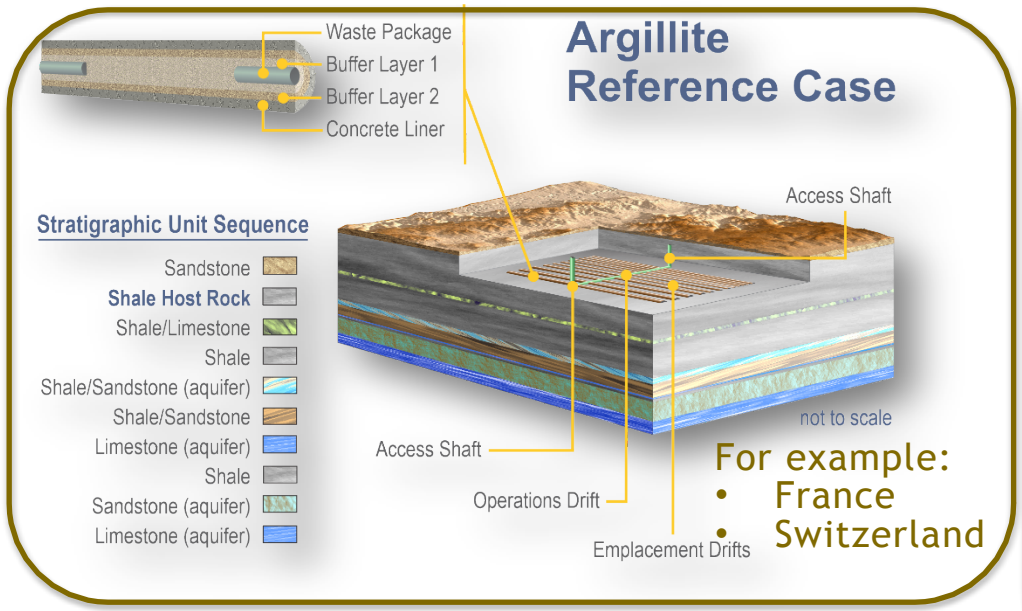
This presentation reflects technical work which could support future decision making by DOE. No inferences should be drawn from this presentation regarding future actions by DOE, which are limited both by the terms of the Standard Contract and Congressional appropriations for the Department to fulfill its obligations under the Nuclear Waste Policy Act including licensing and construction of a spent nuclear fuel repository.

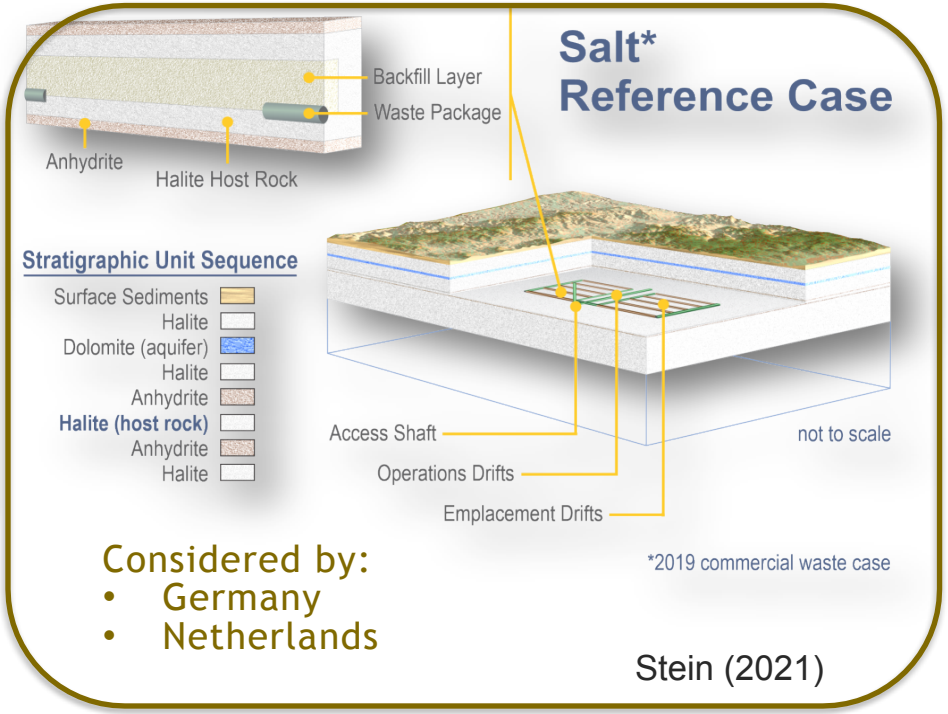
Outline

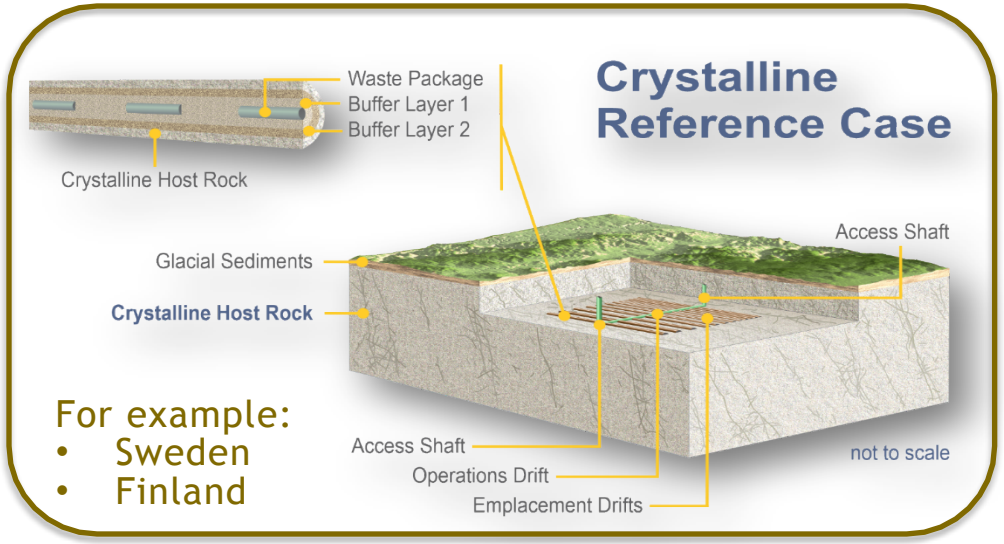
- **Disposal Research Overview**
- **Geologic Disposal Safety Assessment (GDSA) Framework**
  - **Overview and Capabilities**
  - **Applications**
    - **Mined Repositories**
    - **Deep Borehole Disposal**
- **Direct Disposal of Commercial Spent Nuclear Fuel (CSNF) in Dual-Purpose Canisters (DPCs)**
  - **Overview and Projected Inventory**
  - **R&D to Support Options for Direct Disposal of DPCs**
  - **Independent Technical Review (ITR)**

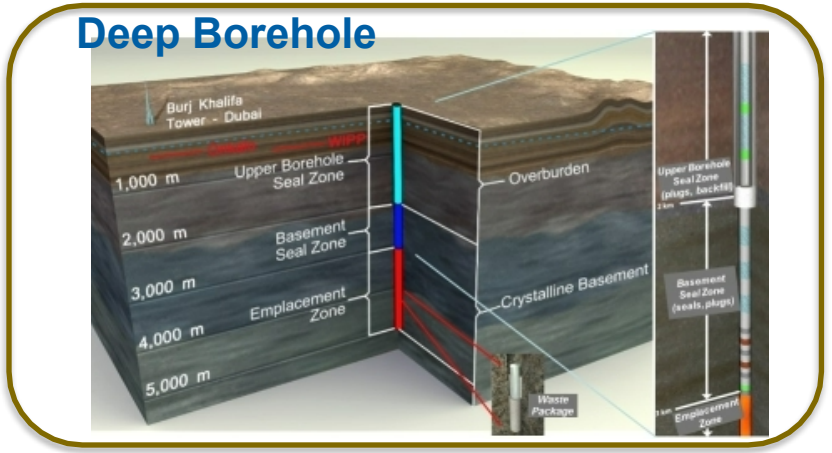
Disposal Research Overview

- 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
- Utilize international experience and develop U.S. program capabilities









Geologic Disposal Safety Assessment (GDSA) Framework

Next Gen Workflow

DAKOTA
Explore and predict with confidence.

Input Parameters
- Parameter database

Uncertainty Sampling and Sensitivity Analysis
DAKOTA
Explore and predict with confidence.

Computational Support

Processing
VoroCrust
python
dfnWorks

Visualization
ParaView
Parallel Visualization Application
python

Multi-Physics Simulation and Integration
PFLOTRAN

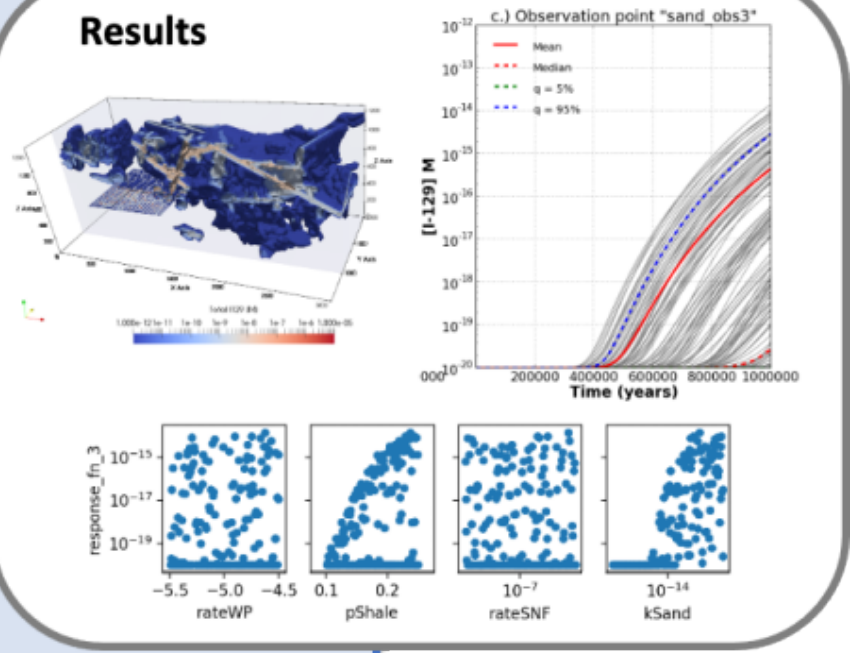
Source Term and EBS Evolution Model
- Inventory
- Decay, ingrowth
- WF degradation
- WP degradation
- Radionuclide release
- Thermal, mechanical
- Gas generation

FMDM

Flow and Transport Model
- Advection, diffusion, dispersion
- Discrete fracture networks
- Multiphase flow
- Sorption, solubility, colloids
- Isotope partitioning
- Decay, ingrowth
- Thermal effects
- Chemical reactions

Biosphere Model
- Exposure pathways
- Uptake/ transfer
- Dose calculations

Results



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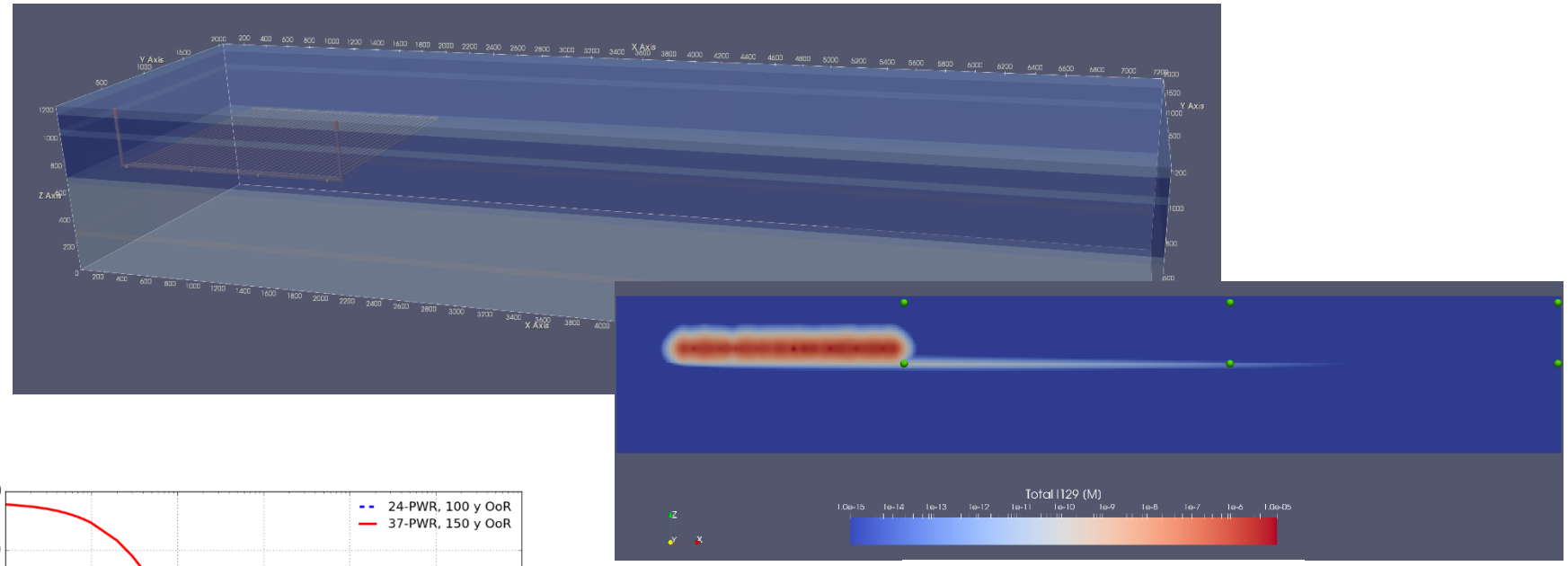
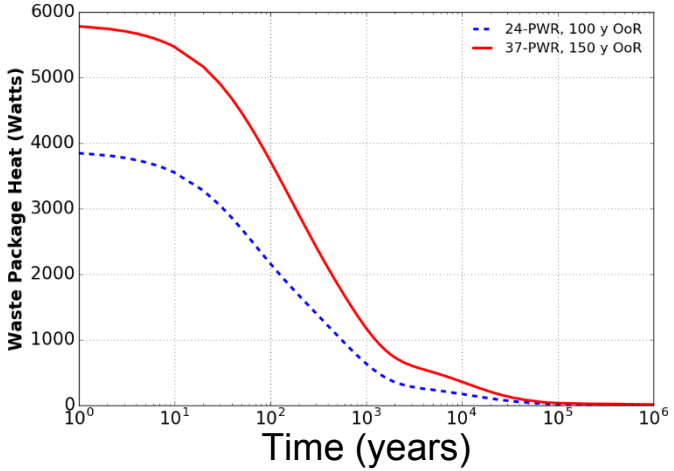
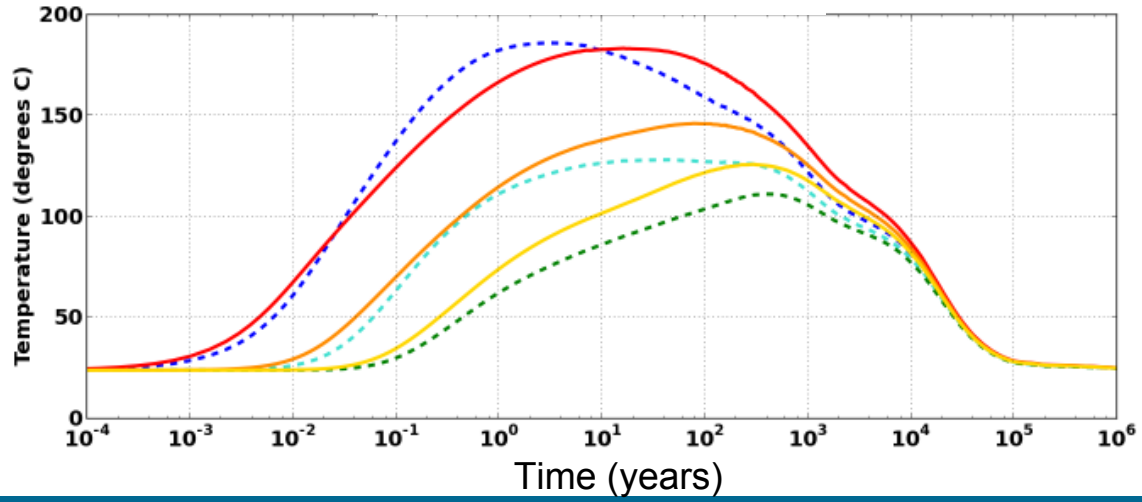
GDSA Applications – Mined Repositories

- **Crystalline**
  - 4-, 12-pressurized water reactor (PWR) assemblies
  - *Stein et al. (2021), Swiler et al. (2021)*
- **Bedded Salt**
  - 12-, 24- & 37-PWR
  - *LaForce et al. (2020), Mariner et al. (2015)*
- **Argillite (Shale)**
  - 4-, 12-, 24- & 37-PWR
  - *Mariner et al. (2017); Sevougian et al. (2019)*
- **Unsaturated Alluvium**
  - 24- & 37-PWR
  - *LaForce et al. (2021)*

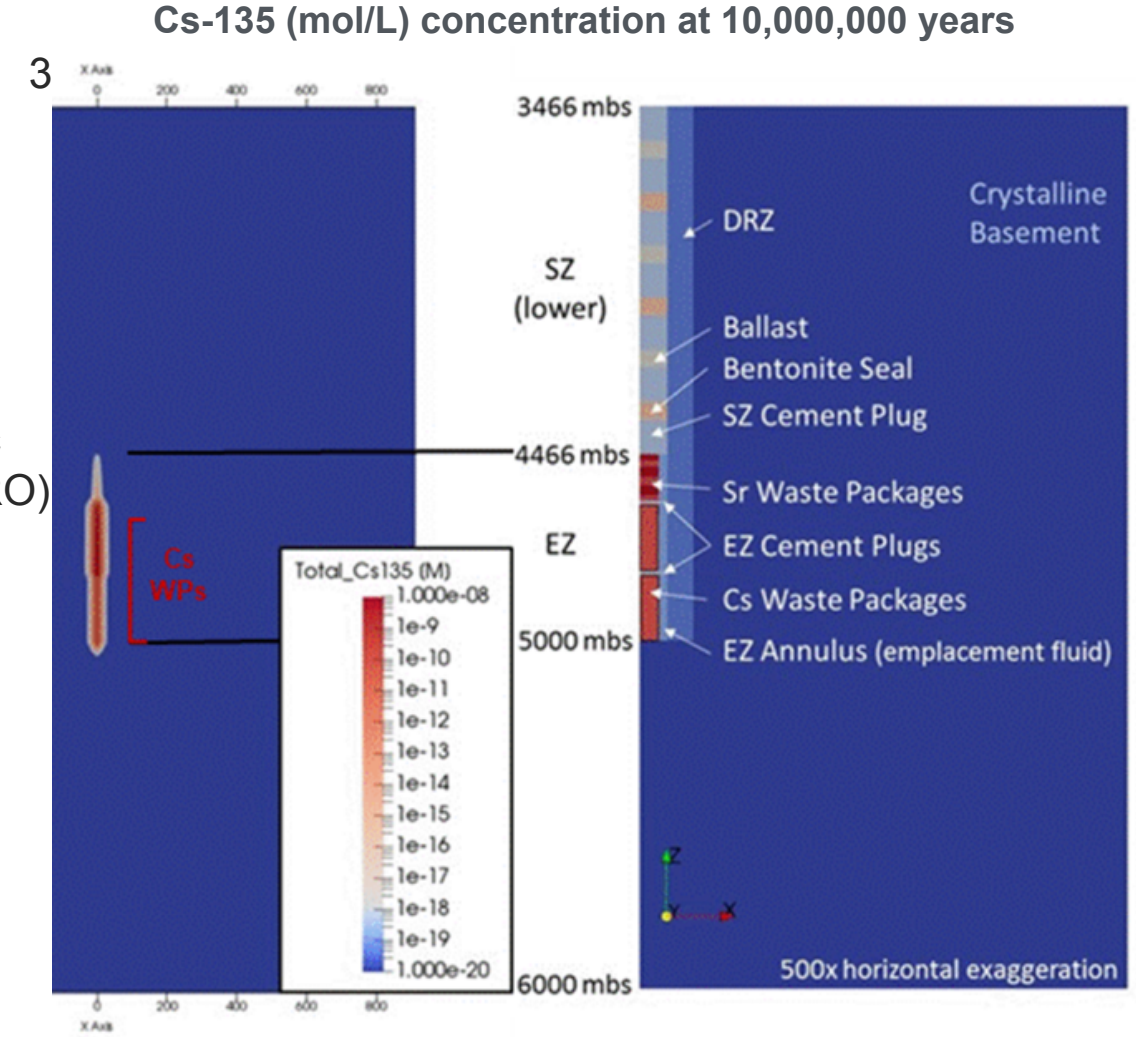




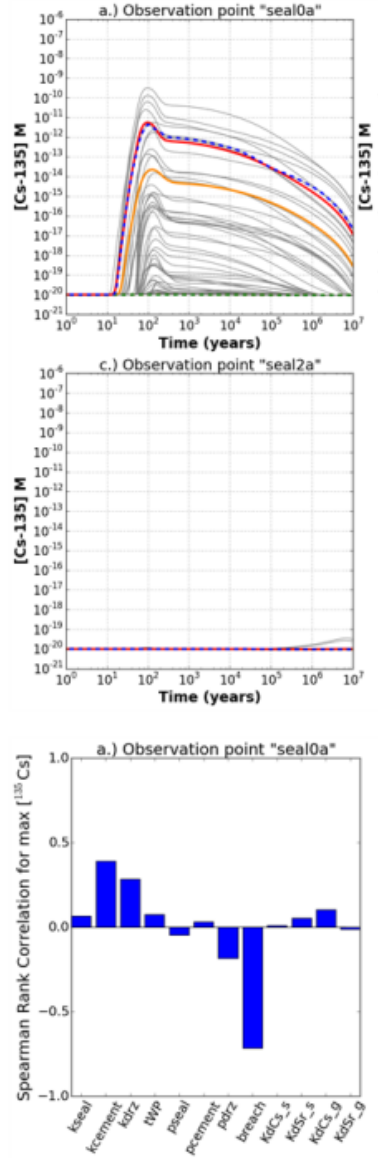


GDSA Applications – Deep Borehole Disposal

- **DOE Deep Borehole Field Test**
  - Feasibility of disposal of Cs-Sr capsules in -5 km deep vertical borehole
  - *Freeze et al. (2016), Freeze et al. (2019a), Hardin et al. (2019), Kuhlman et al. (2019)*
- **Australia Deep Borehole Field Demonstration**
  - Collaboration with Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Australian Nuclear Science and Technology Organisation (ANSTO)
  - *Mallants et al. (2020), Freeze et al. (2021a)*
- **Israel Intermediate-Depth Borehole Demonstration**
  - Collaboration with Israel Atomic Energy Commission (IAEC) and Nuclear Research Center Negev (NRCN)
  - *Freeze et al. (2020)*

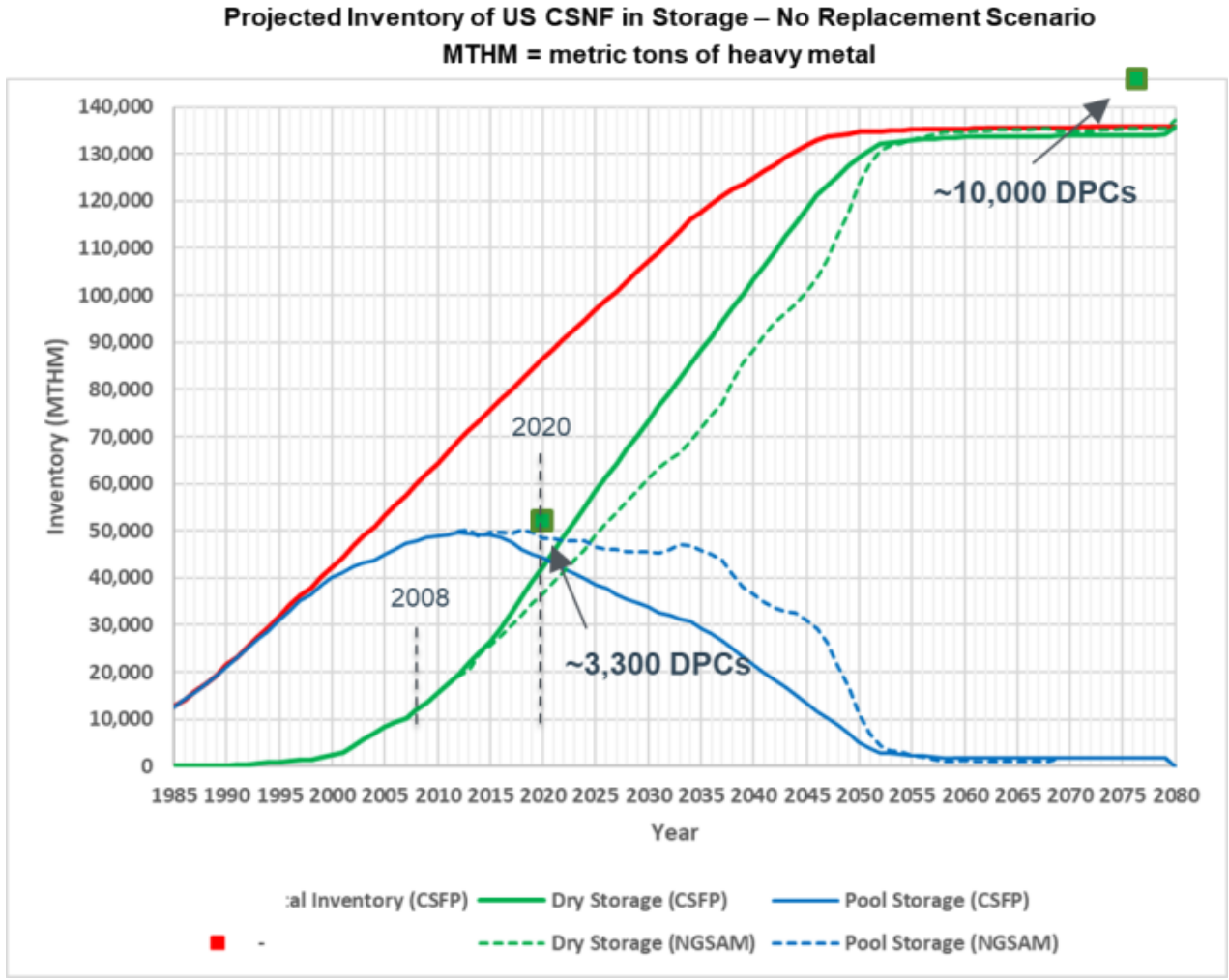


Source: Freeze et al. (2016), Freeze et al. (2019a)



DPC Direct Disposal R&D – Overview and Projected Inventory

- Investigate the feasibility of repository disposal of commercial SNF (CSNF) in dual-purpose canisters (DPCs) in overpacks
  - The term DPC is used here to collectively refer to the large multi-assembly canisters currently loaded with CSNF for dry storage
- DPCs are designed and licensed for storage and transportation of SNF (hence "dual purpose"), but not with consideration for ultimate geologic disposal
  - Direct disposal of CSNF in DPCs is an alternative to repackaging CSNF into disposal-ready canisters
  - Repackaging cost could be on the order of $20 billion (Freeze et al. 2019b)
- Projected inventory of CSNF in dry storage
  - December 2020: ~42,000 MTHM in ~3,300 DPCs
  - By 2075: ~140,000 MTHM in ~10,000 DPCs



Source: adapted from Freeze et al. (2021b, Figure 2-3) and Peters et al. (2020, Figure 2-13)

DPC Direct Disposal R&D - Activities

- The direct disposal of DPCs should consider:
  - Operational (Pre-closure) and Post-closure Safety
    - Geologic Disposal Safety Assessment (GDSA) generic reference cases
  - Engineering Feasibility
    - DPC waste packages (WPs) only 10-20% larger size and weight than Yucca Mountain transportation, aging, and disposal (TAD) WPs
  - Thermal Management
    - Media-dependent WP and drift spacing, aging/cooling
    - DPC WPs are 32(37) PWR / 68(89) BWR whereas TAD WPs are 21 PWR / 44 PWR
  - Post-Closure Criticality
    - DPC fuel baskets are designed to control criticality for short-term operations (fuel pools, dry storage, transportation)
    - After disposal (1,000-100,000 yrs), some packages could eventually breach and flood
      - Groundwater is a moderator
      - Aluminum-based neutron absorbing materials readily corrode from long-term exposure to groundwater
    - Eventual fuel and package degradation → potential critical configuration

Prior R&D (Hardin et al. 2015, SNL 2021) suggests achievable for multiple geologic media
- salt
- clay
- crystalline
- unsaturated

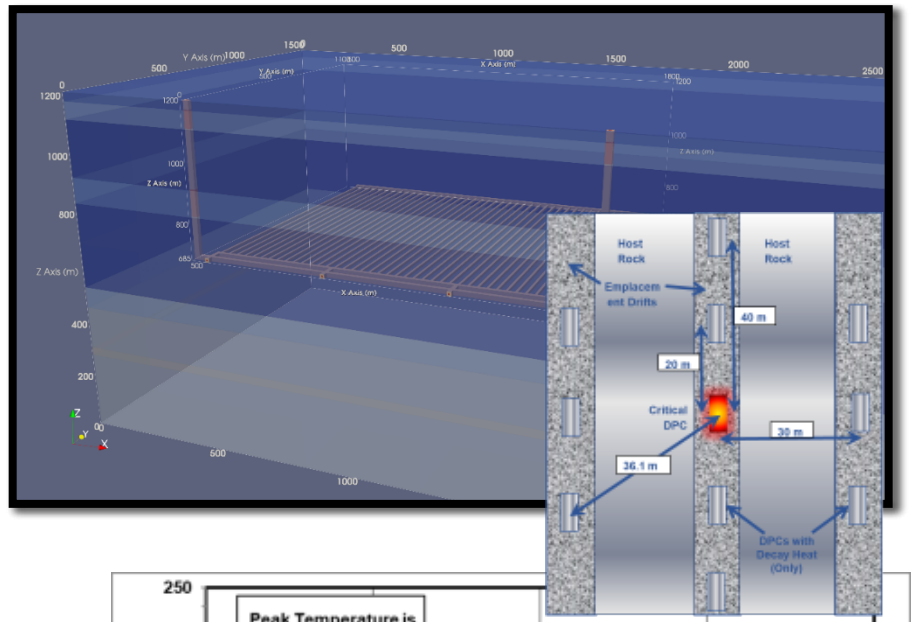
Focus of ongoing R&D

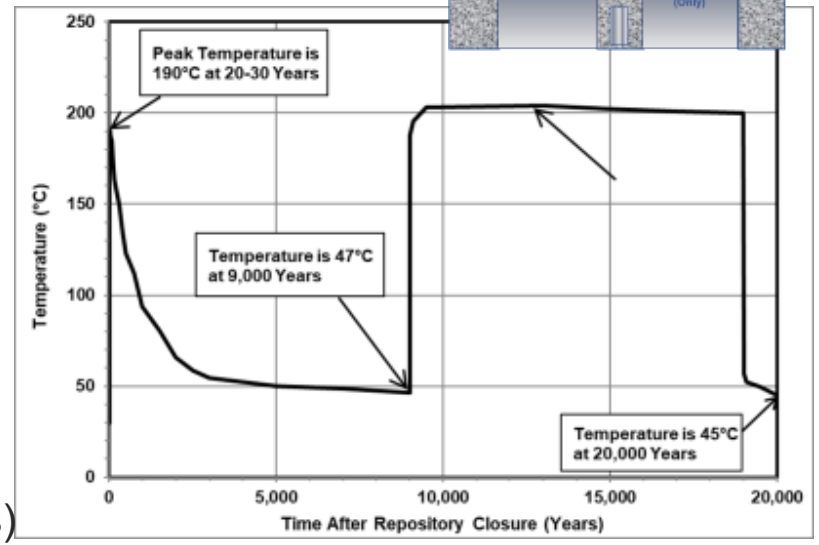
Post-Closure Criticality Ongoing R&D

- DPC Disposal Without Modification

  [Already Loaded and Future Loaded DPCs]

  - Reactivity margin
    - As-loaded analyses (early-loaded DPCs, burnup credit, etc.)
      - More applicable to BWRs and older, smaller PWRs
    - Insufficient groundwater to flood packages
      - e.g., High-performance overpack or unsaturated conditions
    - High-salinity groundwater/brine (Cl limits reactivity)
  - Criticality Consequence Studies
    - Post-closure performance assessments using PFLOTRAN-based GDSA Framework coupled to neutronics calculations
    - Repository Concepts
      - Hypothetical saturated shale
      - Hypothetical unsaturated alluvium
    - Criticality Scenarios
      - Steady-State: low power (50 W - 4 kW) long duration (1000's of years)
      - Transient: high power (10^2 - 10^5 MW) short duration (0.01 to 10 seconds)





Post-Closure Criticality Ongoing R&D

- DPC Disposal With Modification

  [Already Loaded DPCs]

  - Injectable Fillers – liquids that solidify to exclude/displace the groundwater moderator
    - Cements – e.g., calcium phosphates
    - Molten Materials – low melting point metals, alloys, glasses

  [Future Loaded DPCs]

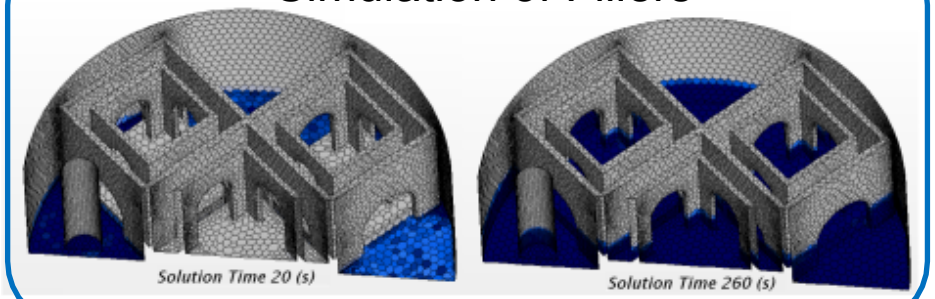
  - Fuel Assembly Modification
    - Disposal criticality control features (with advanced neutron absorbers (ANAs) – e.g., BSS or Ni-Cr-Mo-Gd)
      - PWR assembly control rods
      - BWR fuel assembly rechanneling
    - Zone loading
  - Basket Redesign
    - Addition of built-in corrosion-resistant neutron absorbing features (chevron insets, absorber plates)

Laboratory Filler Experiments

Phosphate-Based Cements

Low Melting Point Metals

Simulation of Fillers



DPC Direct Disposal Independent Technical Review (ITR)

- **ITR Objective**
  - Review representative technical reports and other information and provide input to ongoing and potential future R&D
- **ITR Members**
  - Carl Chagnon, Orano Federal Services, Review Team Manager
  - Adam H. Levin, AHL Consulting, ITR Chair
    - Licensing, Nuclear Engineering, Nuclear Physics
  - Robert W. Andrews, INTERA Inc.
    - Post-Closure Performance Assessment
  - Sven O. Bader, Orano Federal Services
    - Licensing, Nuclear Engineering, Nuclear Physics
  - Robert Sindelar, Savannah River National Laboratory
    - Corrosion of Fuel, Canister, and Basket Materials
  - Marek Zreda, University of Arizona
    - Geohydrology
- **DOE is currently evaluating ITR observations**

Summary of DPC Direct Disposal R&D

R&D Topical Areas:

- Safety
- Engineering challenges
- Thermal management

Achievable for multiple geologic media (e.g., salt, clay, crystalline, unsaturated)

- Post-Closure criticality

Focus of ongoing R&D

Ongoing R&D is summarized in SNL (2020) and SNL (2021)

Technology		Applicable to Currently Loaded DPCs	Applicable to Future Loaded DPCs
Reactivity Margin	PWR	Yes	No
	BWR	Yes	Yes
Criticality Consequence Analysis		Yes	Yes
Injectable Fillers	Cements	Yes	Yes
	Metals	Yes	Yes
Fuel Assembly Modifications	PWR Control Rods	No	Yes
	BWR Rechannel	No	Yes
	Zone Loading	No	Yes
Basket Redesign	Chevron Inserts	No	Yes
	Absorber Plates	No	Yes
Dry Particle Fillers		not currently addressed by SFWST R&D	
Repackaging		not currently addressed by SFWST R&D	

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Questions?