Used Fuel Disposition Campaign

Fuel Cycle Technologies

DPC Direct Disposal Feasibility Evaluation: Concept Development and Analysis

E. Hardin & D. Clayton, Sandia National Laboratories

J. Scaglione & R. Howard, Oak Ridge National Laboratory

J. Carter, Savannah River National Laboratory

J. Blink, Lawrence Livermore National Laboratory

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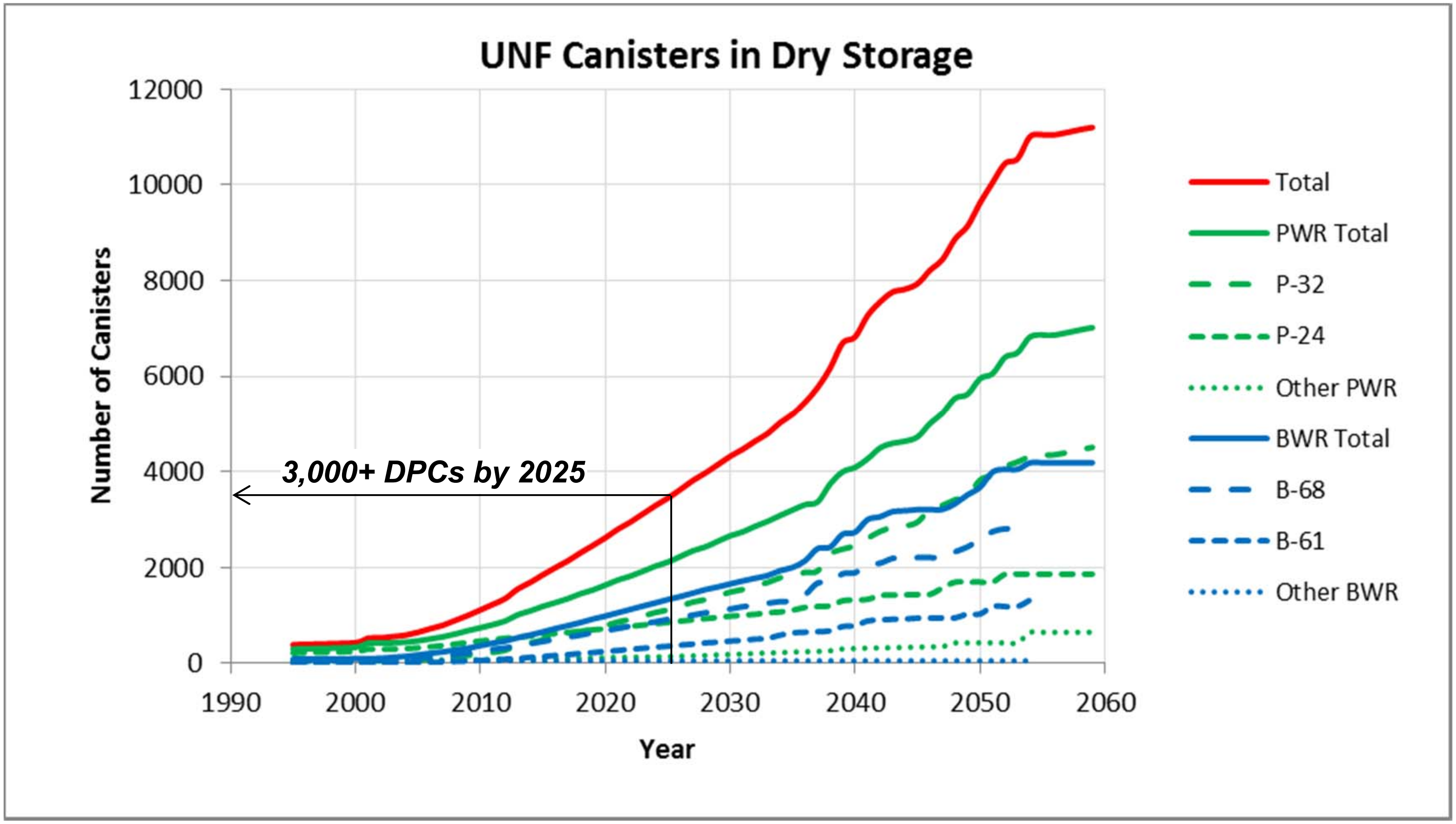
Context for This Study

This is a technical presentation that does not take into account the contractual limitations under the Standard Contract. Under the provisions of the Standard Contract, DOE does not consider spent fuel in canisters to be an acceptable waste form, absent a mutually agreed to contract modification. To ensure the ability to transfer the spent fuel to the government under the Standard Contract, the individual spent fuel assemblies must be retrievable for packaging into a DOE-supplied transportation cask.

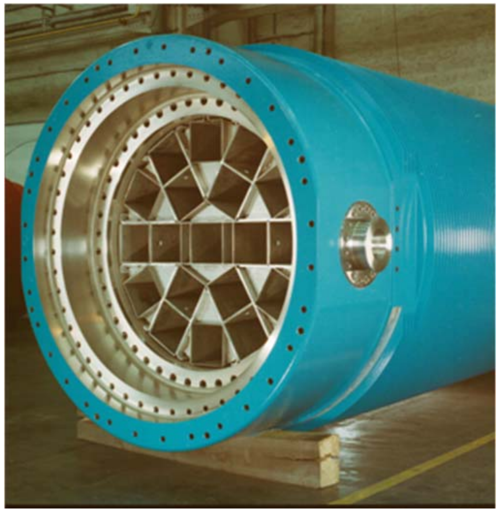
Projected Accumulation of DPCs TSL-CALVIN Simulator



Assume Presently Used DPC Types, No Fuel Shipments from Existing ISFSIs, and 20-yr Life Extensions for the Currently Operating Reactor Fleet.

Previous Work on Direct Disposal of Existing DPCs

- **EPRI reports (2008)**
  - Thermal and waste isolation performance
  - Evaluation of principal/partial analysis methods
  - Partial waste package flooding, loading variations and control rod displacement
- **Bechtel-SAIC Co. (2004)**
  - Principal issue is postclosure criticality (burnup credit; use reactor records)
  - Other issues (facilities, equipment, operations) don't impact "disposability"
- **Multi-Purpose Canister (DOE 1994)**
  - Concept of operations, and comparison with alternatives
- **German DIREGT Concept (e.g., Graf & Filbert 2012)**
  - Direct disposal of CASTOR V casks in salt
  - Phased effort considering shaft conveyance, package handling, and criticality



CASTOR V Cask

DPC Direct Disposal Concept Development Challenges

- **Generic (non-site specific)**
  - Accommodate a wide range of geology
  - Concepts may involve long-term repository operations (e.g., >100 yr)
- **Postclosure Criticality Analysis**
- **Thermal management in all operations**
- **Transport and Handling of Large, Heavy Packages**
  - Conveyance (shaft vs. ramp) and underground transport
- **Underground Structures (e.g., long-term stability, large openings, cementitious materials, backfill/plugs/seals)**

SFR ILW rock vaults, Forsmark, Sweden

Flexible Disposal Concepts for Direct Disposal of DPCs

Objectives:

- **Safe disposal options for a range of geologic settings**
- **Find engineering solutions likely to be feasible**
  - Package transport and emplacement
  - Long-term repository operations (e.g., opening stability through closure)
- **Heat dissipation to meet temperature limits**
- **Options for excluding (or including) postclosure criticality**

Constraints:

- **Burnup to 60 GW-d/MT**
- **Capacity 32-PWR (and BWR equivalent) or larger**
- **Surface storage + repository operations ≤ 150 yr**
- **Underground handling and transport are shielded**
- **Dose-based (e.g., Part 63) regulatory framework**
- **Cladding temperature ≤ 350°C after emplacement**
- **Engineered material and host rock temperature limits**

DPC Disposal Concept Development

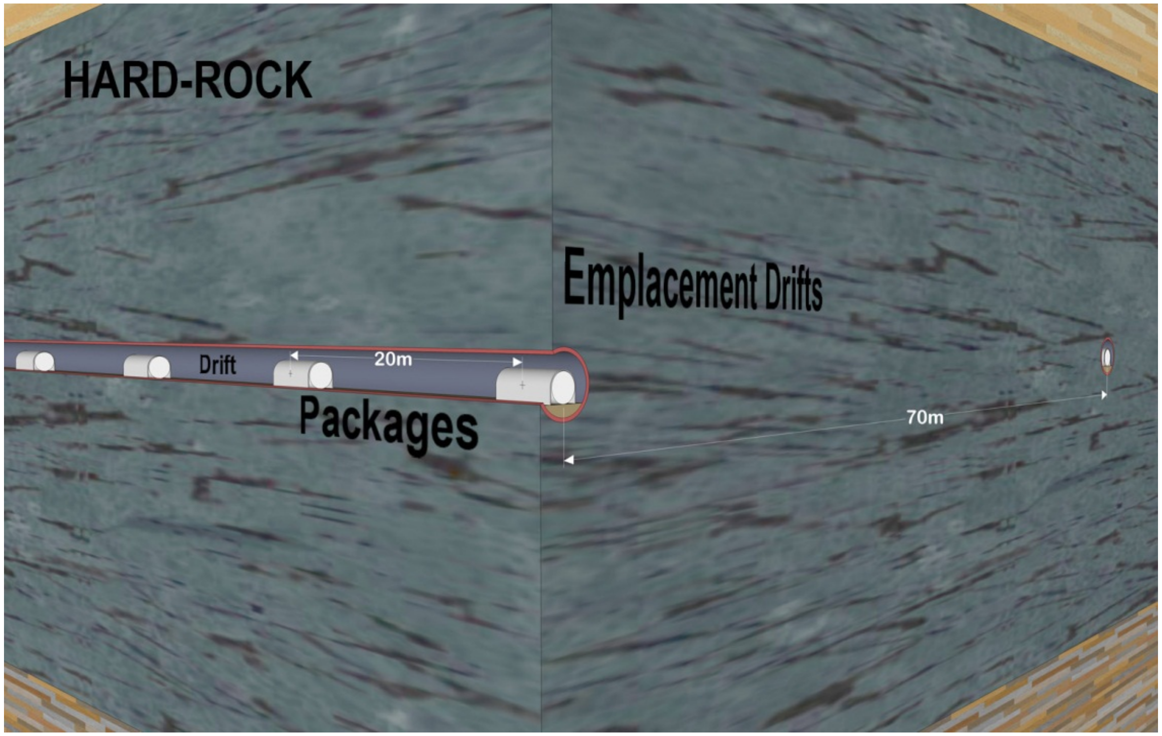
1. *Crystalline enclosed*
   - *1.1) KBS-3V* *1.2) KBS-3H* *1.3) In-Drift*
2. ***Generic salt repository (enclosed)***
   - ***2.1) In-alcove or in-drift*** ***2.2) Borehole***
3. *Clay/shale enclosed*
4. ***Sedimentary unbackfilled "open" mode***
5. ***Sedimentary backfilled "open" mode***
6. ***Hard-rock "open" emplacement***
   - ***6.1) Unbackfilled, unsaturated*** ***6.2) Backfilled***
7. ***Cavern retrievable concept***
   - ***7.1) Surface casks*** ***7.2) Subterranean***
8. *(Deep borehole concept)*

Disposal Concepts Being Considered for Large, Hot Waste Packages

Note: "Open" modes can be ventilated to remove heat prior to perma-nent closure, and air spaces may remain open after closure also.

Hard-Rock Unsaturated, Unbackfilled Open Concept

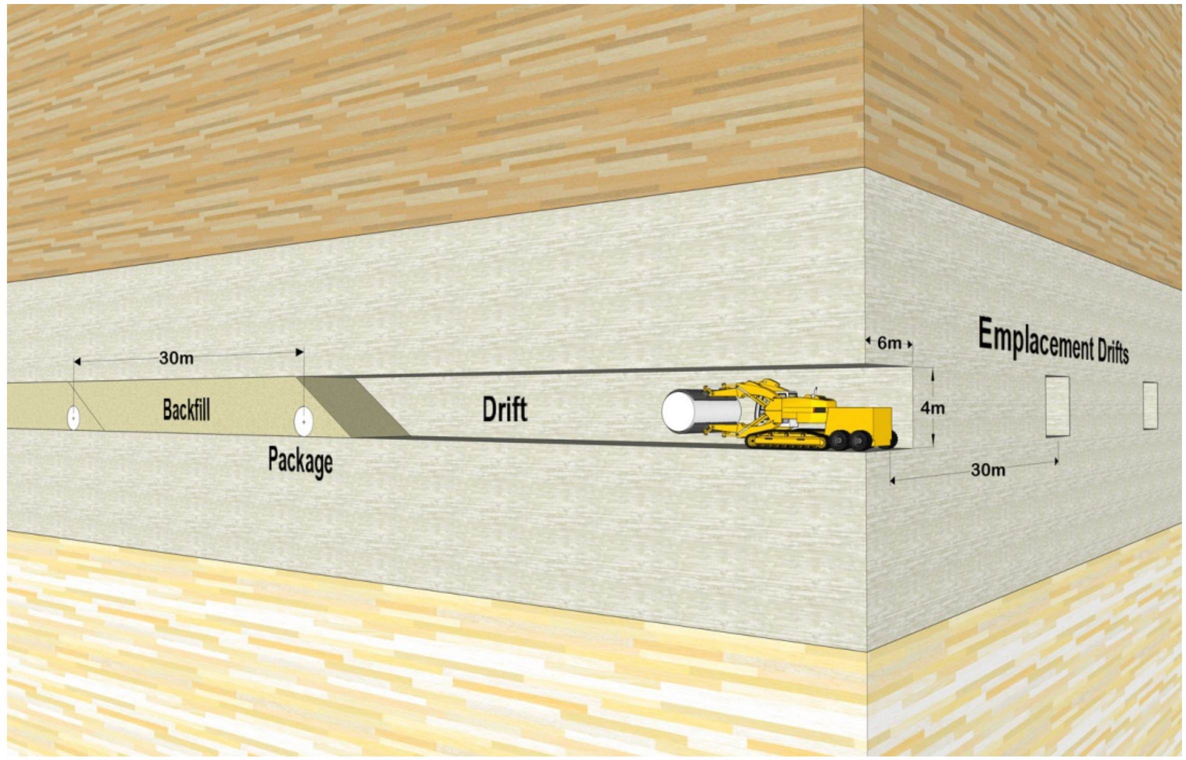
- LA Design Selection Study (1998)
- Unsaturated setting
- In-drift emplacement, 32-PWR or larger
- Corrosion resistant waste packaging
- Ventilation, then closure at <150 yr OoR
- Additional engineered barrier(s) at closure
- Openings stable during postclosure thermal peak (~500 yr)



(after Hardin et al. 2012)

Generic Salt Repository Concept

- 32-PWR or larger canisters, 50 to 70 yr out-of-reactor
- Crushed salt backfill
- Bedded or domal salt
- Shaft vs. ramp access (→175 MT payload)
- Handling equipment and conveyance development needed
- Salt has higher temperature tolerance (200°C) than other sedimentary media

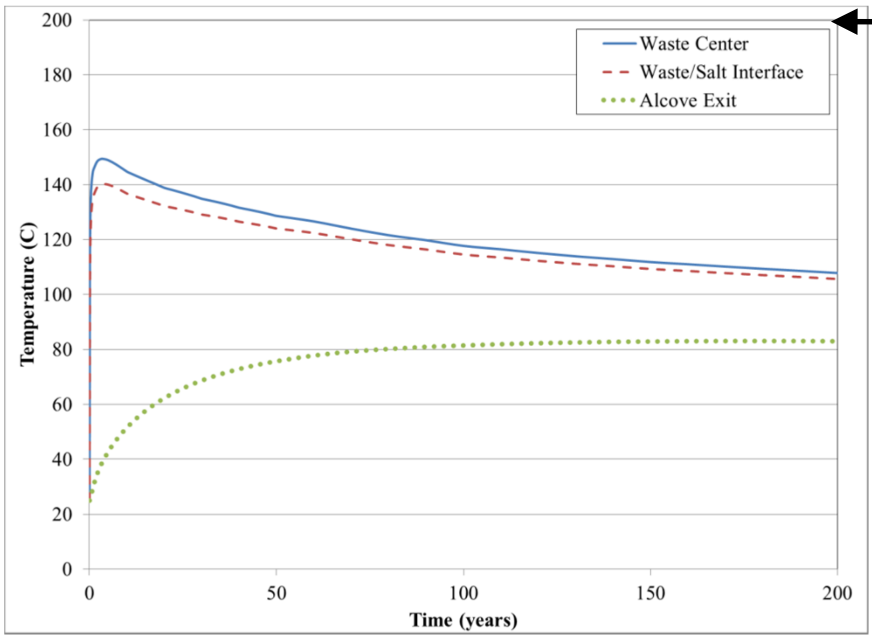


(after Hardin et al. 2013)

Temperature Histories in a Salt Repository: High-Burnup Fuel Can Be Accommodated

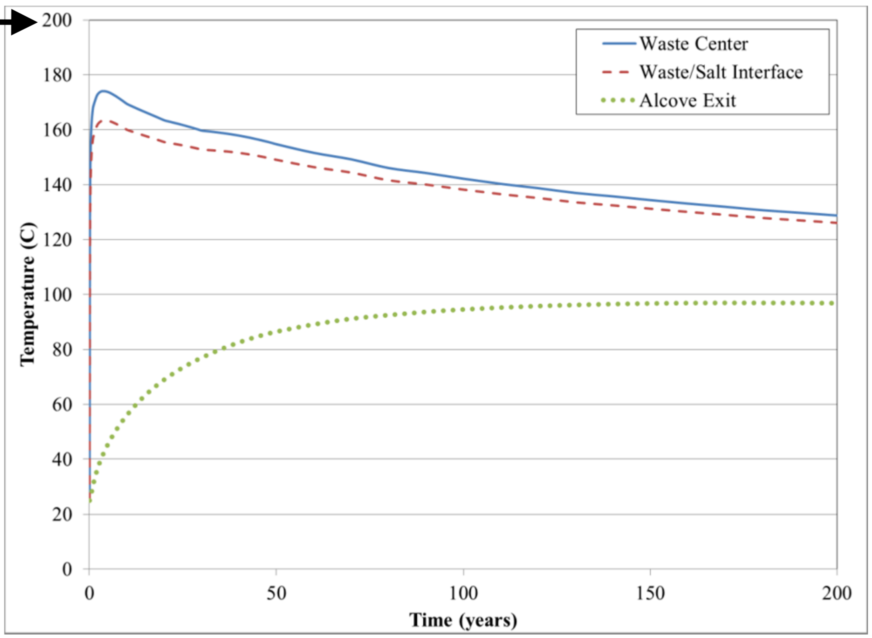
32-PWR Packages, 30-m Spacings

40 GW-d/MT
50 years OoR (10.2 kW)



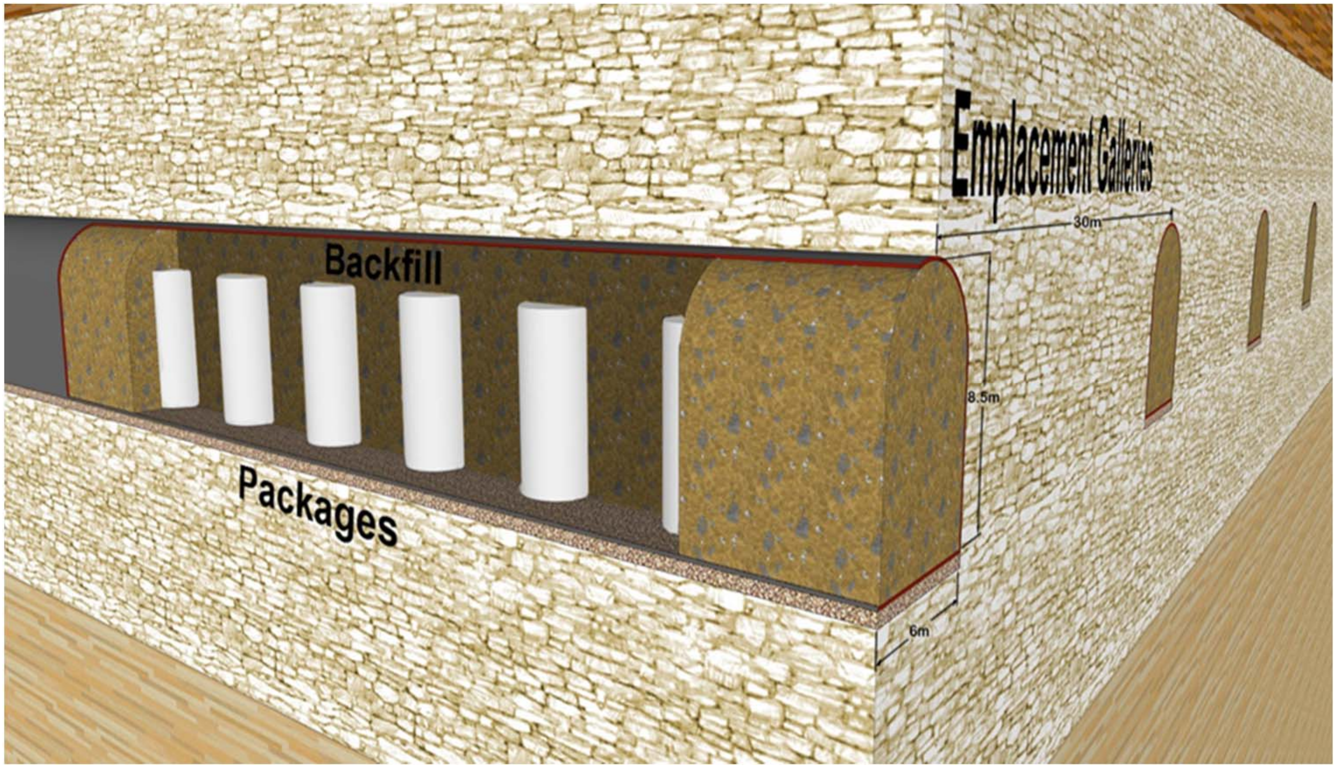
200°C

60 GW-d/MT
70 years OoR (11.8 kW)



Widely accepted peak temperature for bedded and domal salt: 200°C

Cavern-Retrievable Storage-Disposal Concept



- Use existing dry storage systems
- Large galleries
- Extended ventilation (>100 yr)
- Unsaturated settings preferred
- Engineered barrier(s) installed at closure: development needed

(Concept from McKinley, Apted et al. 2008; figure from Hardin et al. 2013)

Postclosure Criticality Analyses

- Use full burnup credit
- Boron "loss"
- Flux trap collapse in ~10^3 to 10^6 yr
- Represent groundwater salinity
- Cases: as-loaded, loss of absorber, basket collapse, saline water

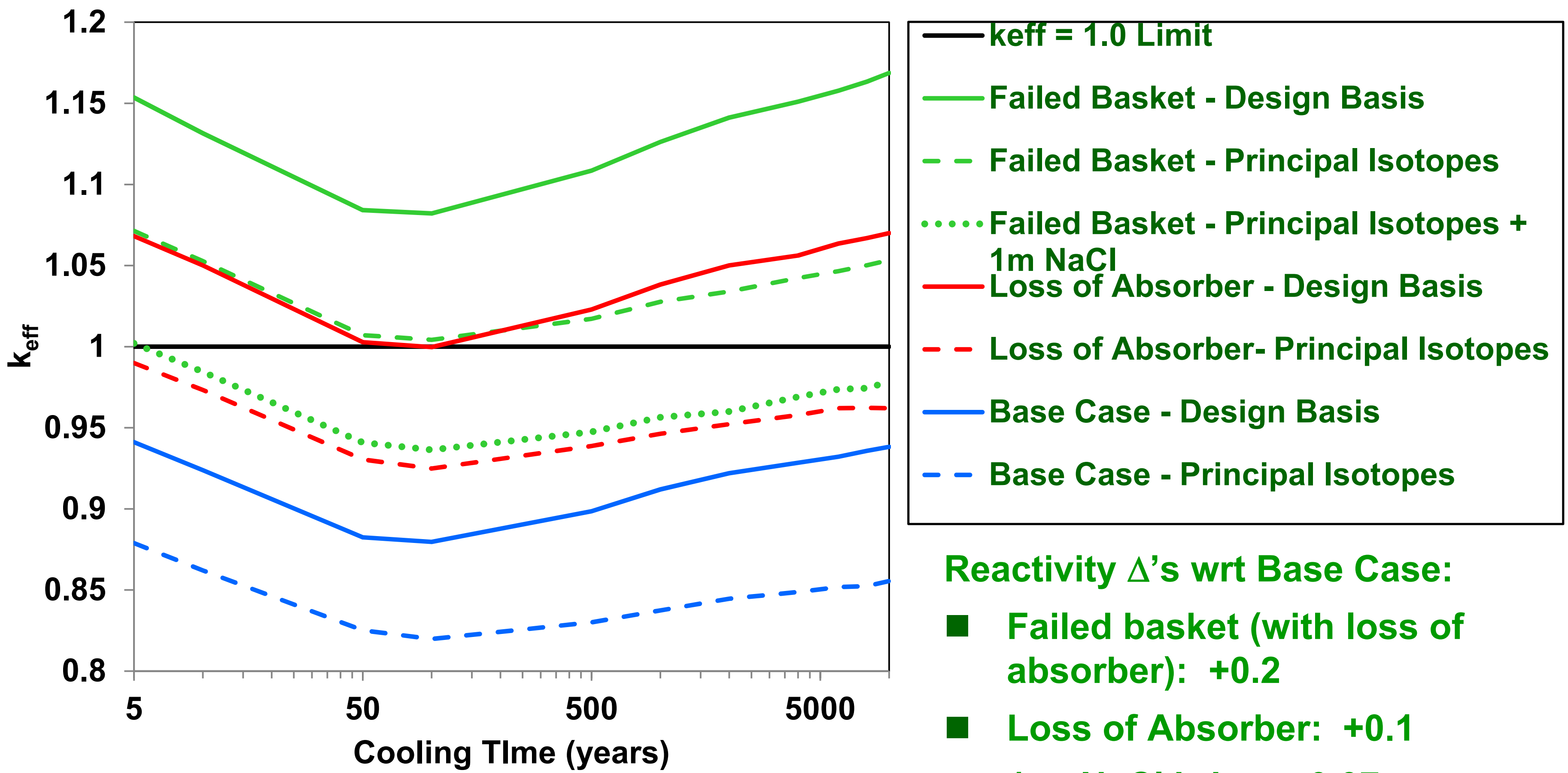
	Canister Contents
2,000+ Existing Canisters	***1. Actual fuel inventory*** ***2. Moderator displacement***
Future DPCs optimized loading, moderator displacement, corrosion resistant components	***3. Loading optimization*** ***4. Moderator displacement*** ***5. Corrosion-resistant control element inserts (other components?)***

(after Machiels 2008; Machiels and Wells 2009)

Analysis Method

1. ***Probabilistic approach***
   a) ***Level of flooding***
   b) ***Time-dependent reactivity***
2. ***Sufficient credit for burnup with appropriate treatment of uncertainties associated with fuel composition and nuclide parameters***

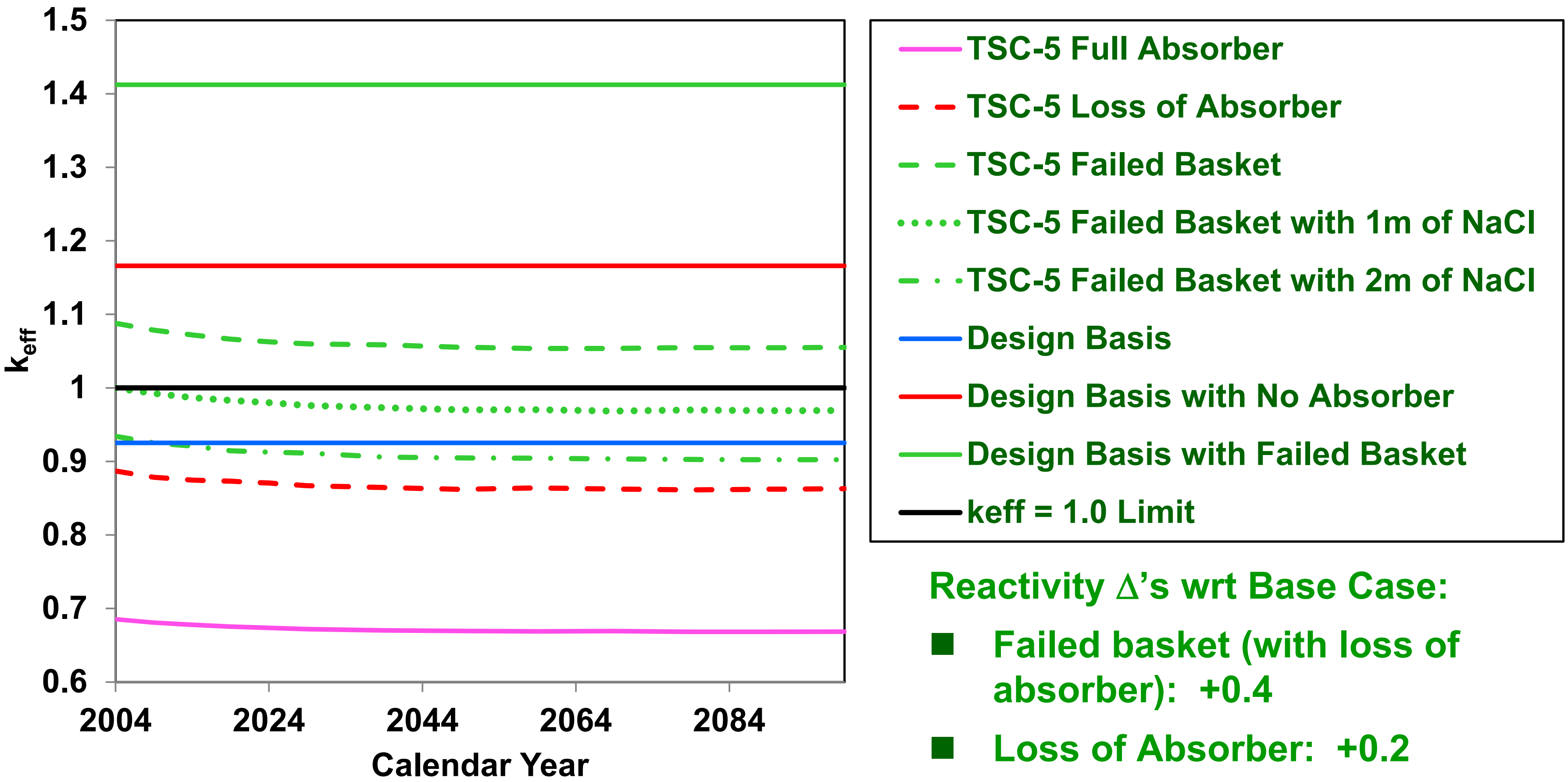
k_{eff} vs. Cooling Time
Holtec MPC32, Sequoyah 4 (49 GWd/MTU)



Reactivity Δ's wrt Base Case:

- Failed basket (with loss of absorber): +0.2
- Loss of Absorber: +0.1
- 1 m NaCl brine: -0.07

Maine Yankee TSC-5 (NAC-UMS-24)
Design Basis and As-Loaded Configurations



Reactivity Δ's wrt Base Case:

- Failed basket (with loss of absorber): +0.4
- Loss of Absorber: +0.2
- 2 m NaCl brine: -0.15

Summary

- **Preliminary Result: No "Showstoppers"**
  - ***Example: Salt disposal concepts are likely feasible, with thermal and postclosure criticality margins***
  - Other media also under investigation
- **Scope Remaining in Current Study:**
  - Evaluate shaft hoists and operational safety
  - Research high-temperature buffer/backfill materials (e.g., swelling properties and/or low permeability stable to 150°C)
  - Postclosure criticality evaluations
  - Preliminary evaluation report: "Quick Look" (FY13)
  - Focused issue studies and final evaluation (FY14-15)

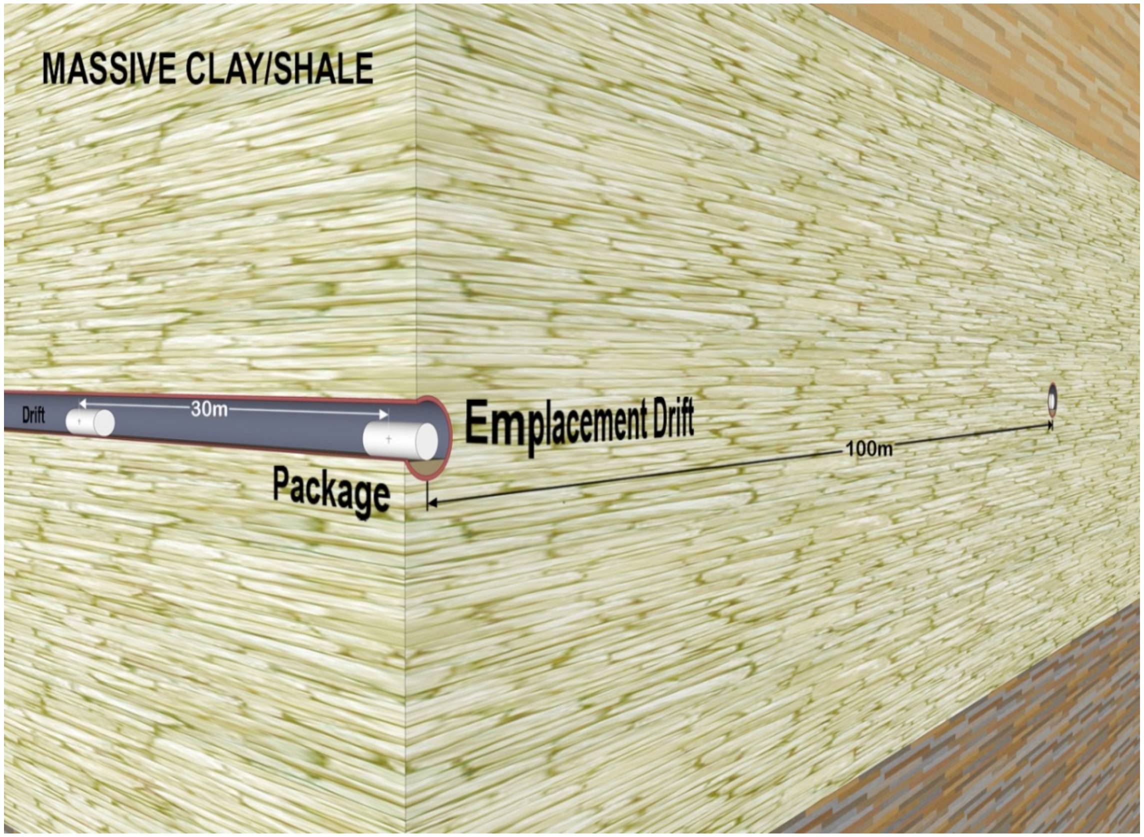
Backup Slides

Outline: Feasibility Study for Direct Disposal of Spent Fuel in Dual-Purpose Canisters

- **Introduction**
  - Previous work on dual-purpose and multi-purpose canister (DPC and MPC) disposal
  - DPC direct disposal challenges
- **Concept Development**
  - Hard Rock Unsaturated Repository
  - Salt Repository
  - Sedimentary Repository
  - Cavern Retrievable Storage/Disposal
- **Thermal Management Summary (post-closure)**
- **Postclosure Criticality**
- **Transport and Handling of Heavy Unshielded Packages**
- **Preliminary Results & Ongoing Activities**

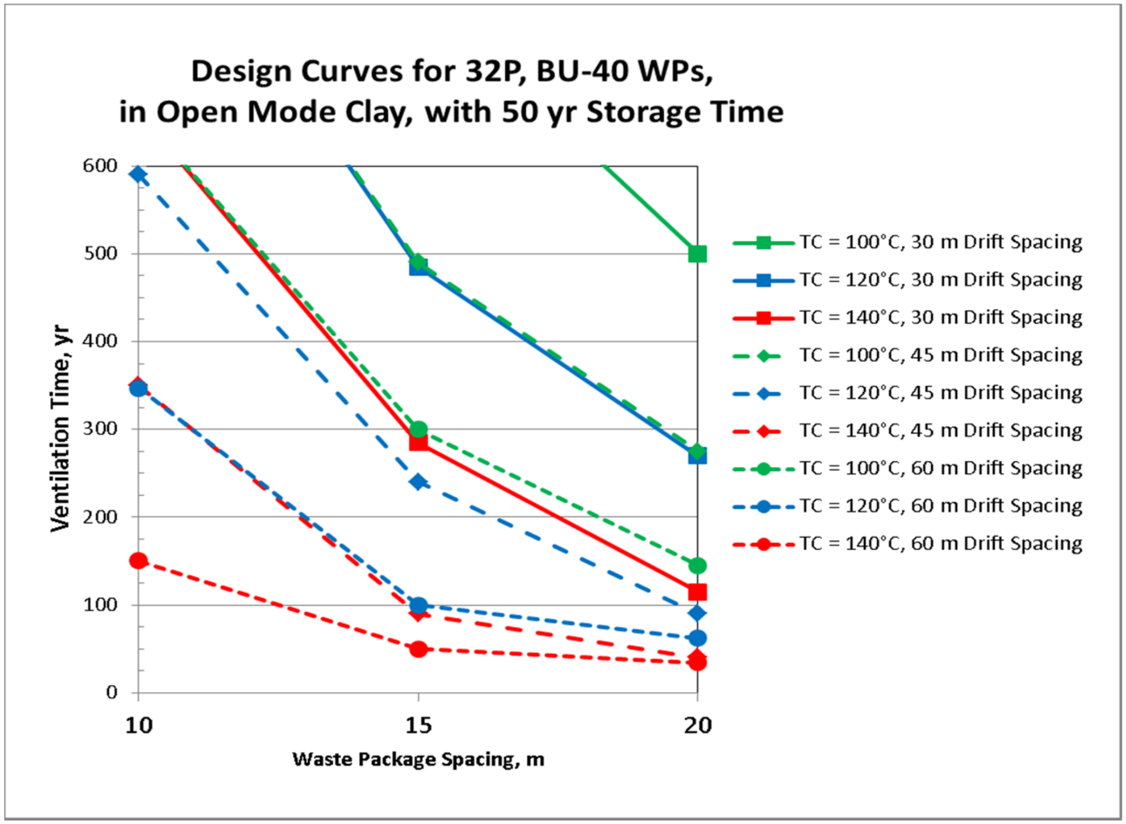
Sedimentary Unbackfilled Open Concept

- Massive, soft clay/shale medium
- In-drift, ventilated
- 32-PWR or larger packages; closure at ≥ 150 yr out-of-reactor
- Packaging for handling and limited containment
- Repository segments isolated by backfilling and/or sealing
- Possible local heating of host rock >100°C



(after Hardin et al. 2012)

Sedimentary Concept Thermal Management Tradeoffs: Ventilation (Closure) Time vs. Repository Spacings and Temperature Limit



Effect of Rock Wall Temp. Constraint (100 to 140°C; K_{th} = 1.75 W/m-K)

(Source: Greenberg et al. 2013)

Summary of Thermal Analysis for Sedimentary Concepts:

- **Rock Peak Temp. < 100°C Requires Closure at > 150 yr OoR or Spacing >> 20 m**
- **Backfill Adds >100 C° to Peak Temperatures at the Waste Package Surface**

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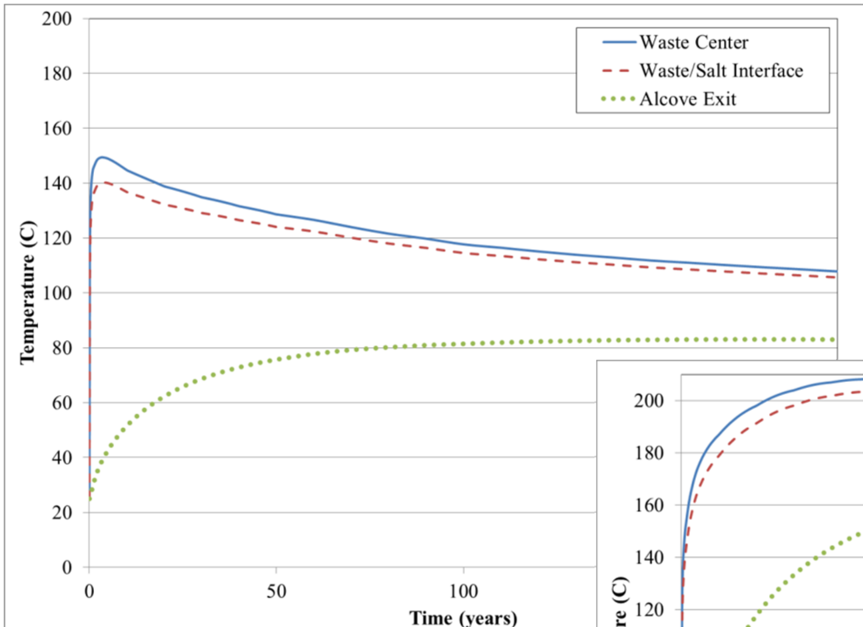
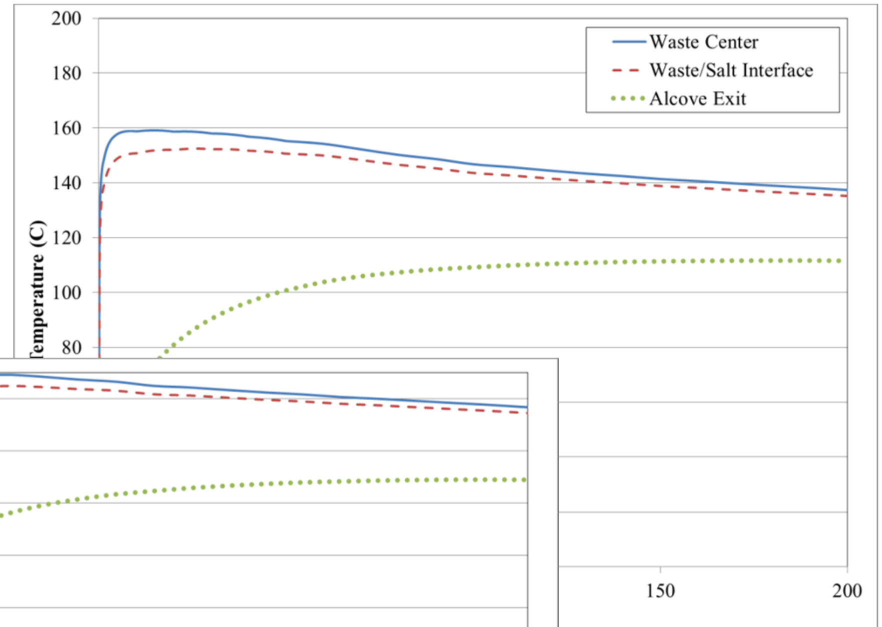
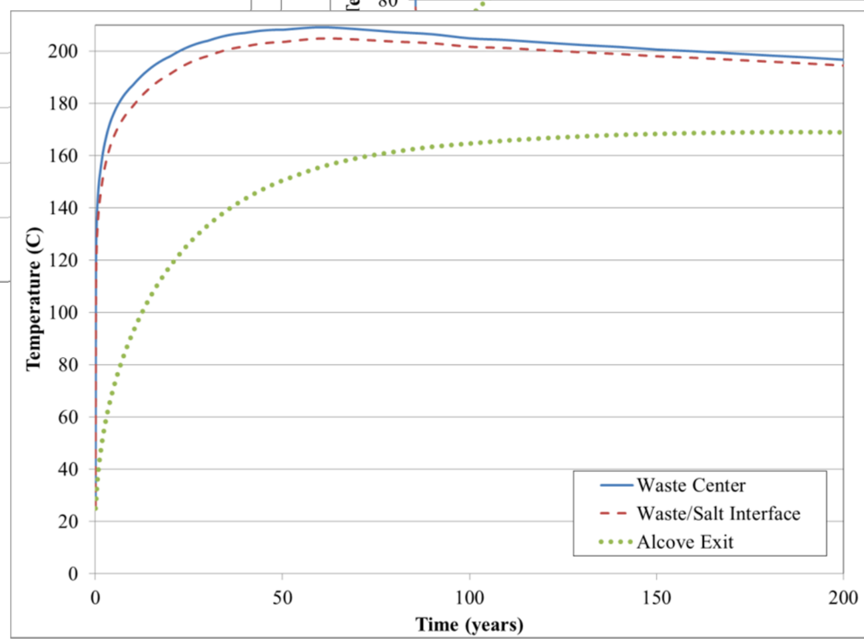
Salt Repository Waste Package Spacing
(32-PWR, 40 GW-d/MT, 50 years OoR)

30 m



25 m

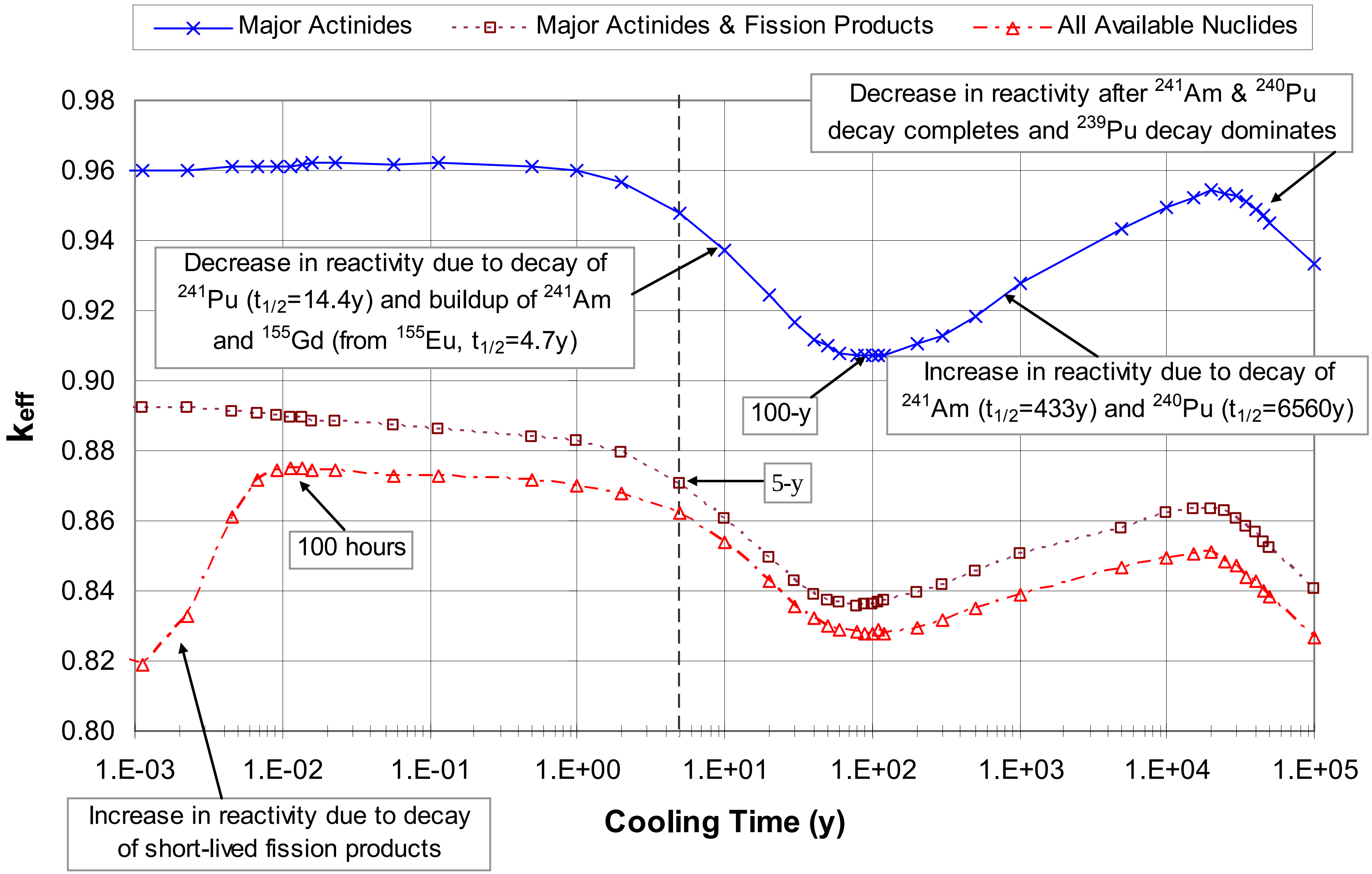




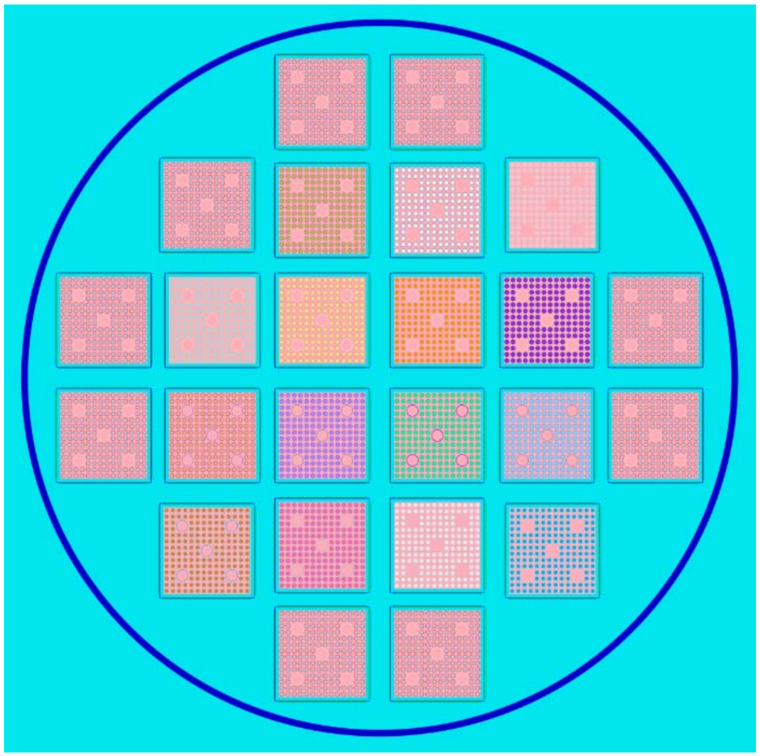
20 m

30-m spacing (x & y) → Disposal area ~200 acres per 10,000 MTU

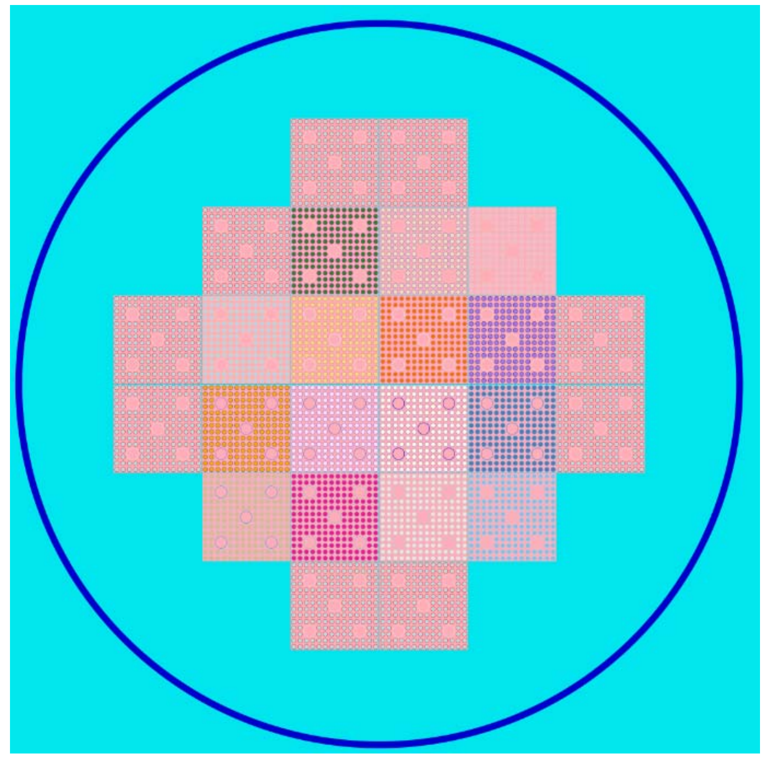
Reactivity of UNF vs. Time



Basket Configurations for NAC-UMS-24 System: Maine Yankee



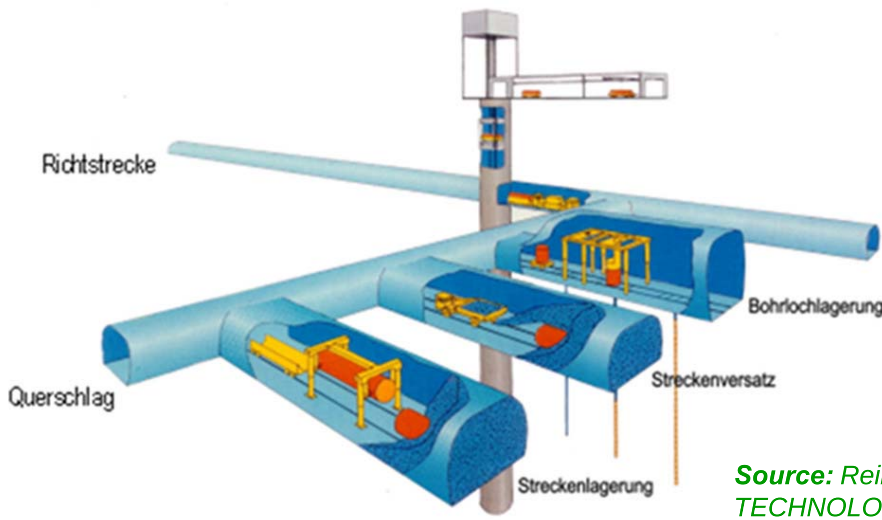
Intact Basket

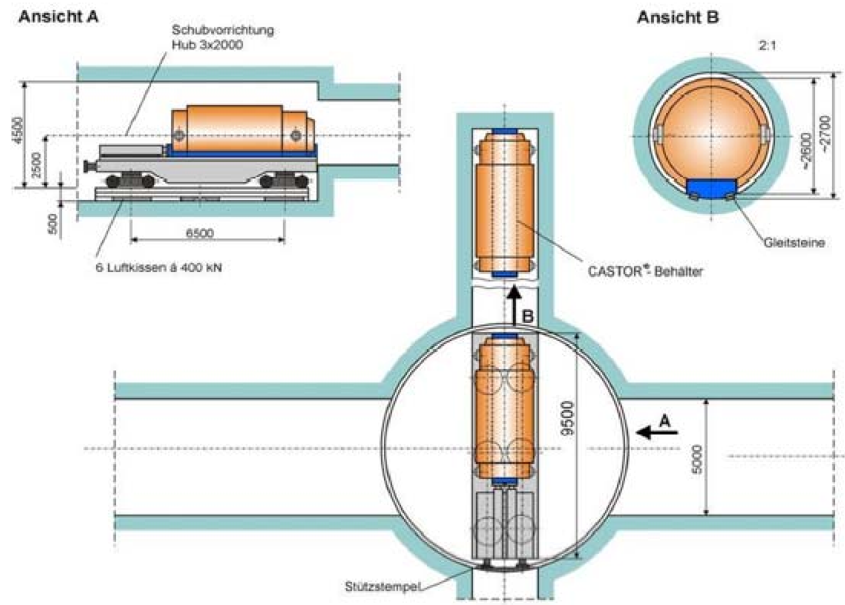


Collapsed Basket

Shaft Conveyance in Salt Repositories
German DIREGT Concept (DBE Tec)

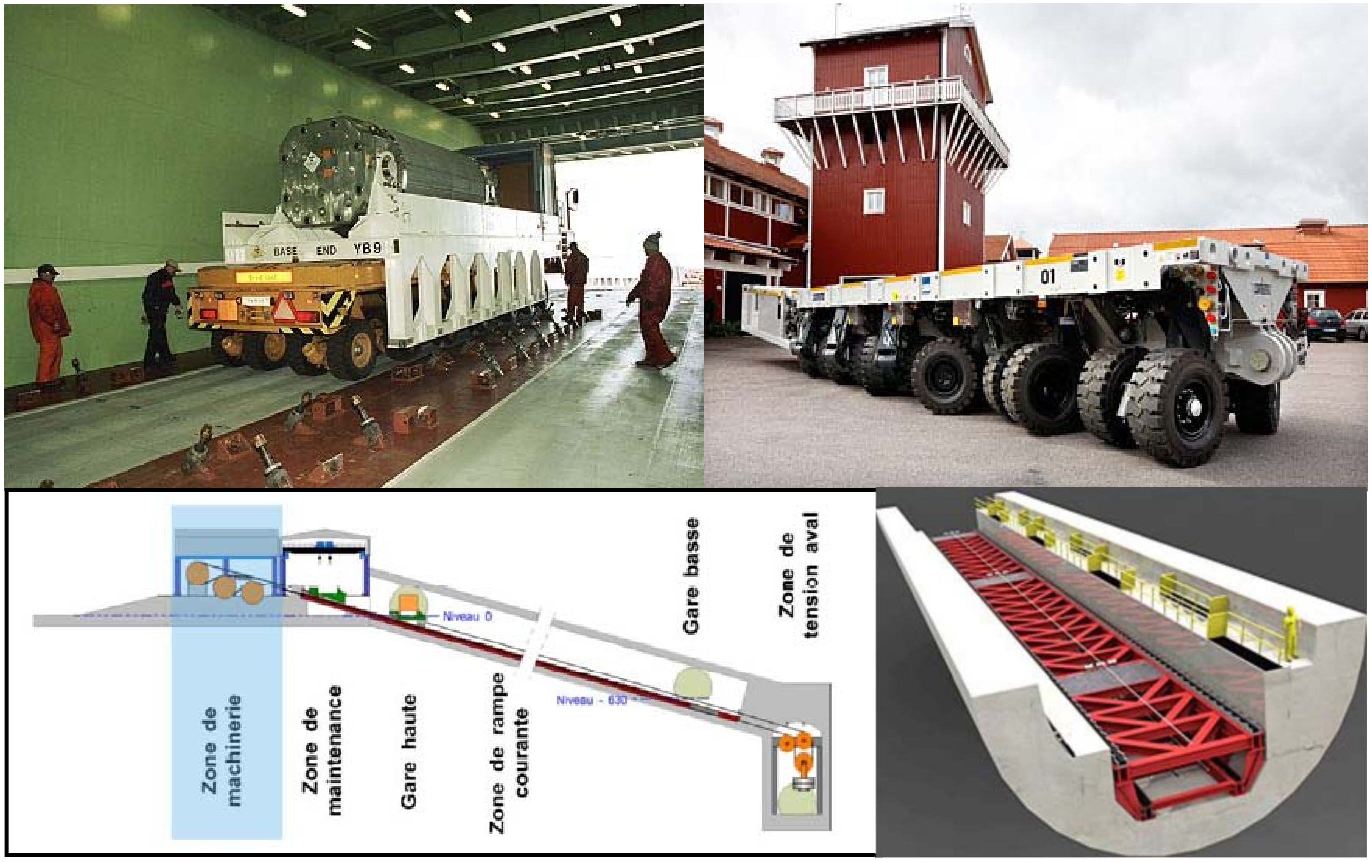
- Based on existing cast iron storage/transport cask (CASTOR V, ~120 MT containing 10 MT SNF)
- Shaft diameter: ~8 m; hoist payload ~175 MT
- Underground transfer station; in-drift or borehole emplacement





Source: *Reinhold Graf, Dr. Klaus-Jürgen Brammer (GNS), Wolfgang Filbert (DBE TECHNOLOGY GmbH).* ***Direkte Endlagerung von Transport- und Lagerbehältern - ein umsetzbares technisches Konzept.*** *Jahrestagung Kerntechnik 2012, Stuttgart, 24.05.2012.*

Ramp Conveyance



(upper left) SKB's SNF transport from m/s Sigyn to CLAB (upper right) Cometto demonstration, SKB, Äspö, Sweden (right) Conceptual view of funicular railway system

- **Ramp Concepts**
  - Shallow (~2%)
  - Deep (~10%)
- **Transporters**
  - Rail (≤2.5%)
  - Rubber-tired (≤ 15%)
- **Powered**
  - Self-powered
    - *Diesel*
    - *Battery*
  - Electric (pantograph)
- **Performance**
  - 90 MT payload (Äspö) but essentially unlimited payloads
  - ~30 m/min
  - Self-leveling
- **Hazards**
  - Fire
  - Runaway

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