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Overview of Past R&D and Recommendations for Future R&D

U.S. Nuclear Waste Technical Review Board Fall Meeting
October 24, 2018
Albuquerque, New Mexico

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Outline

- **DPC background**
- **Examples of DPCs in current use**
- **Projected accumulation of DPCs**
- **Benefits from direct disposal**
- **History of DOE’s R&D program for DPC direct disposal**

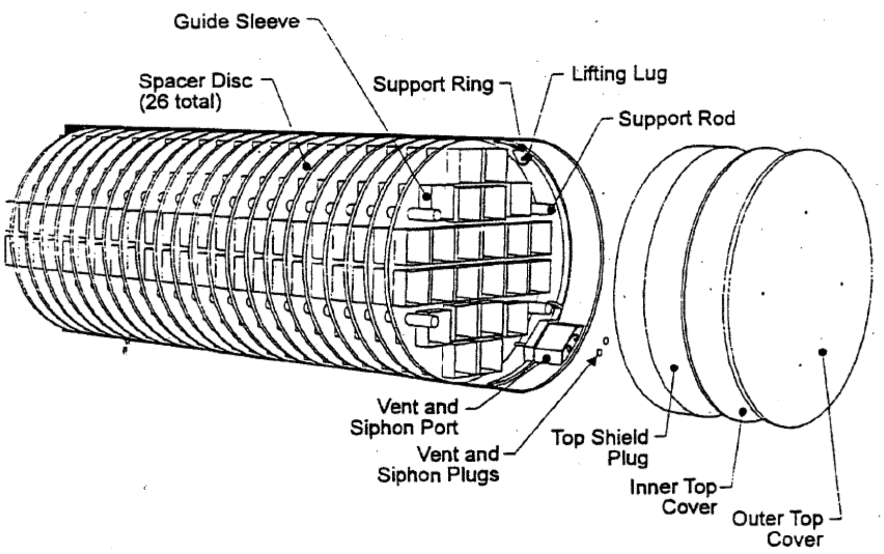
- **Results from previous DPC disposal feasibility study**
- **Screening of criticality from dose assessment, on low probability**
- **Low-consequence screening background**
- **Independent expert review**
- **Approach to injectable fillers**
- **Summary of ongoing and planned R&D activities**

Dual-Purpose Canister – Direct Disposal Background

- **Dry storage is an important solution for utility spent nuclear fuel (SNF) management**
  - Dual-purpose canisters (DPCs) are loaded in fuel pools, dewatered, weld-sealed, and transferred into shielded storage casks or vaults
- **DPCs are designed/licensed for storage and transportation**
- **>90% of dry storage inventory (~30,000 MTU) is in DPCs**
- **DPCs were not designed, loaded, or licensed with consideration for ultimate geologic disposal**
  - Safety of workers and the public
  - Postclosure criticality control
  - Thermal management
  - Engineering feasibility

Typical DPC Canister/Cask System – NUHOMS®

- NUHOMS® (TransNuclear/Orano) horizontal storage systems
- ~1/3 of existing U.S. DPC fleet
- NUHOMS line varies with capacity, PWR & BWR fuel types
- Shell is welded SS304; basket and plug materials vary



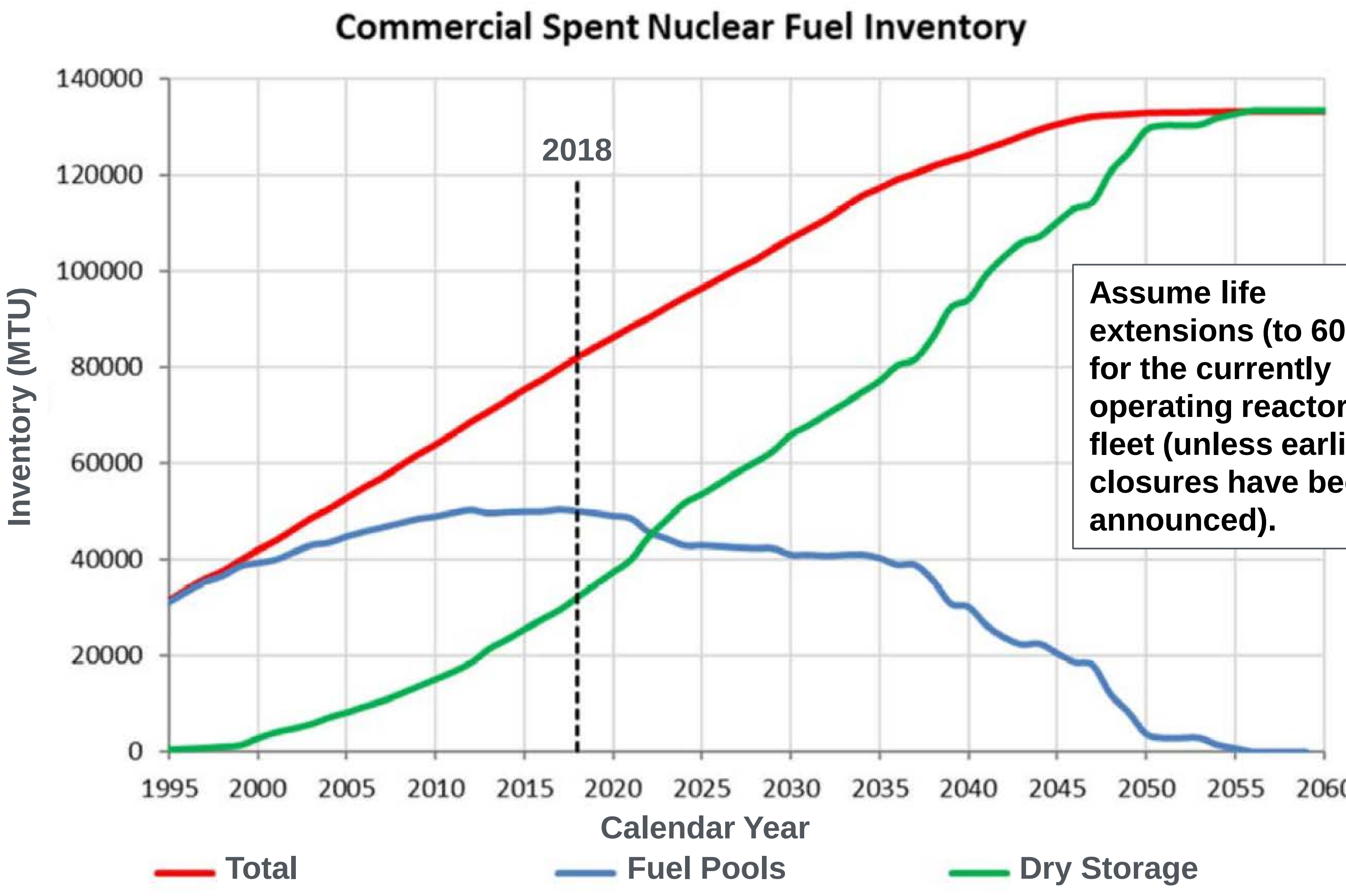
Cutaway of canister and basket

Typical, Recent Large DPC System Designs – Example: Magnastor®

- **Magnastor® DPC vertical storage system (NAC International)**
- **Capacity 37-PWR (or BWR equivalent)**
- **Weight: ~50 MT loaded**
- **Diameter: 1.77 m**

Pictures and data from NAC International website

Spent Fuel Projection – Accumulation in Pools and DPCs (MTU)



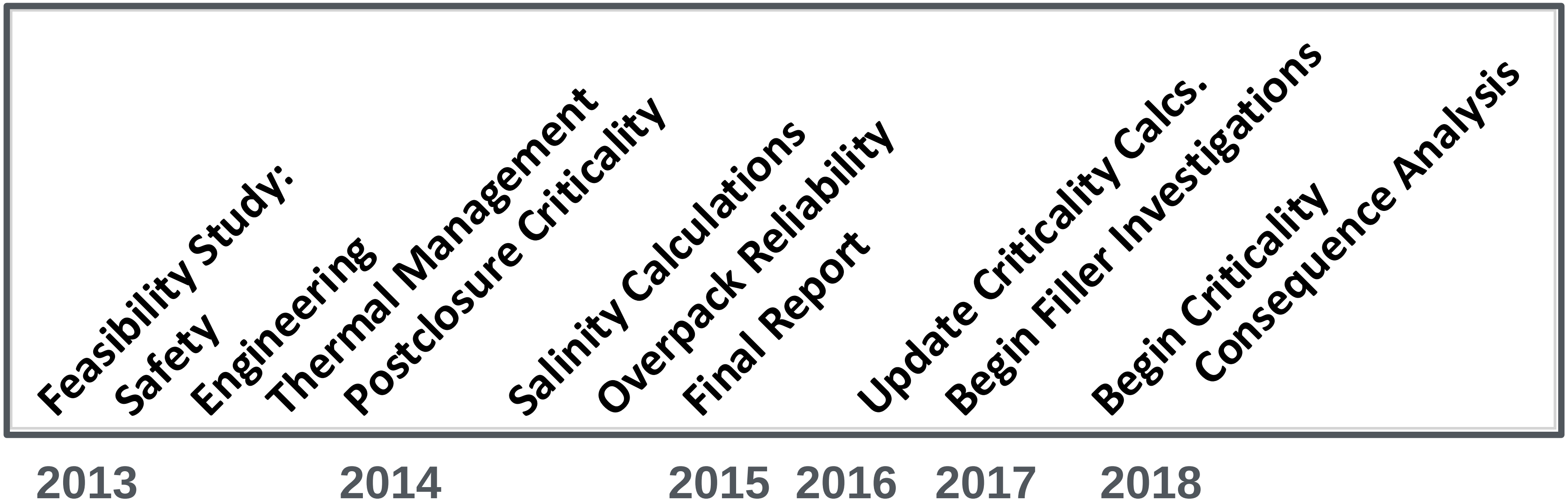
Assume life extensions (to 60 yr) for the currently operating reactor fleet (unless earlier closures have been announced).

Potential Benefits from Direct Disposal of SNF in DPCs of Existing Designs

- **Less collective worker dose**
  - More than 250 mRem/canister to load DPCs → Re-packaging by analogy
- **Less LLW produced (DPC hulls)**
- **Reduce the complexity of fuel management operations**
  - Facilities, staging, re-blending, new canisters, etc.
- **Reduce risk from fuel damage caused by additional handling**
- **Significant financial savings (e.g., 10 to 20% of overall disposal cost for commercial SNF)**

Substantial cost savings could be achieved by: 1) direct disposal of all DPCs; or 2) direct disposal of some DPCs and early transition to <u>multi-purpose canisters</u> (storage-transport-disposal).

SFWST Campaign DPC Direct Disposal R&D



- **First budgeted FY2013**
- **Initial approach: technical feasibility with low-probability screening of criticality**
- **Current R&D:**
  - DPC fillers for criticality control
  - Postclosure criticality consequence analysis
  - As-loaded DPC criticality modeling

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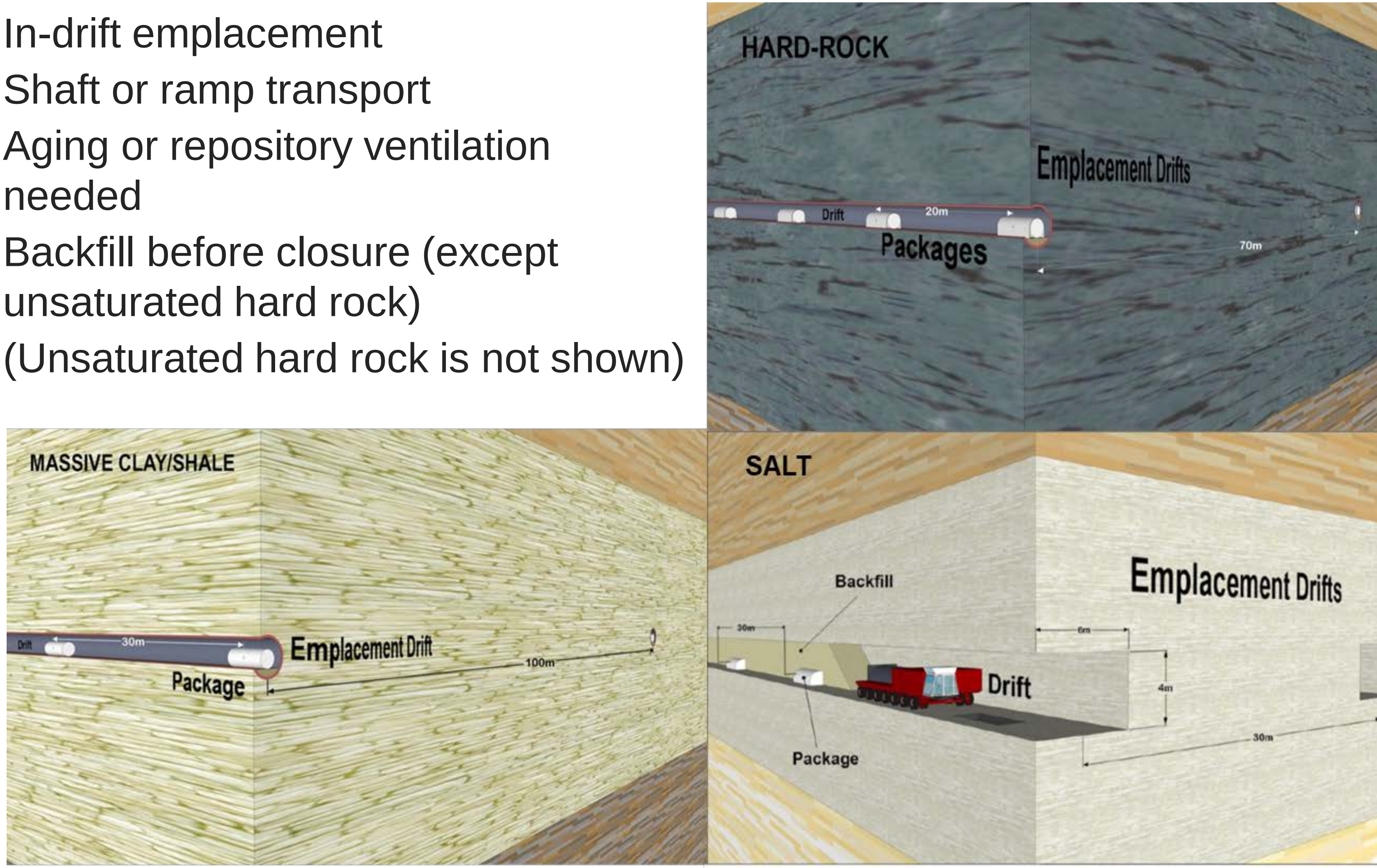
Summary of Previous (2013–2017) Technical Feasibility of DPC Direct Disposal

- **Technical evaluation results:**
  - Safety of workers and the public
  - Postclosure criticality control
  - Thermal management
  - Engineering feasibility
- **Disposal is possible with all geologic settings evaluated**
  - Thermal management and postclosure criticality constraints vary for geologic settings
- **Additional considerations:**
  - Disposal overpack reliability estimates can be improved
  - DPC basket designs impact structural longevity after package breach
- **Major recommendations:**
  - Investigate fillers for existing DPCs
  - Investigate screening postclosure criticality on low consequence

DPC Direct Disposal Concepts

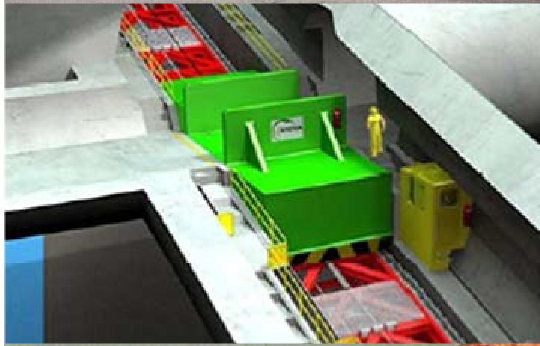
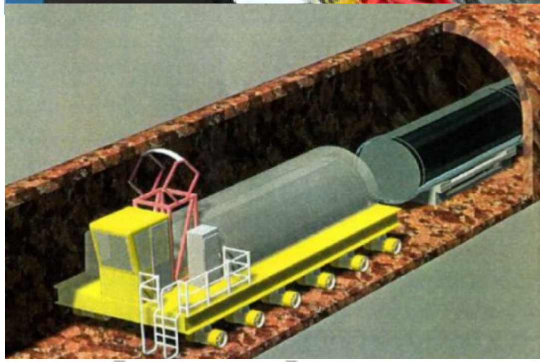
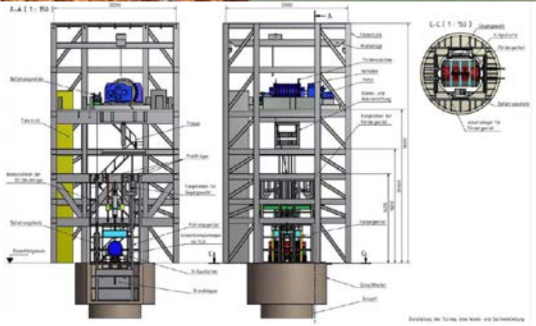
- In-drift emplacement
- Shaft or ramp transport
- Aging or repository ventilation needed
- Backfill before closure (except unsaturated hard rock)
- (Unsaturated hard rock is not shown)



(Hardin et al. 2013. FCRD-UFD-2013-000171 Rev. 1)

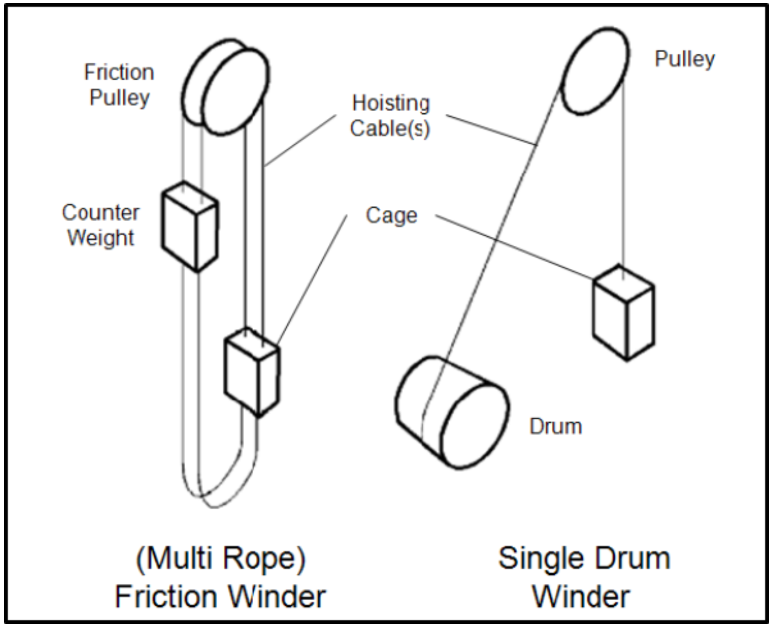
Engineering Challenges Can Be Met

- **Handling/Packaging: Use Current Practices**
- **Surface-Underground Transport**
  - Spiral ramp (~10% grade, rubber-tire)
  - Linear ramp (>10% grade, funicular)
  - Shallow ramp (≤ 3% grade, standard rail)
  - Heavy shaft hoist (up to 175 MT payload)
- **Drift Opening Stability Constraints**
  - Salt (a few years with little attention or heating; longer with rock bolts and maintenance)
  - Hard rock (50 years or longer)
  - Sedimentary (50 years may be feasible, or longer depending on geologic setting)

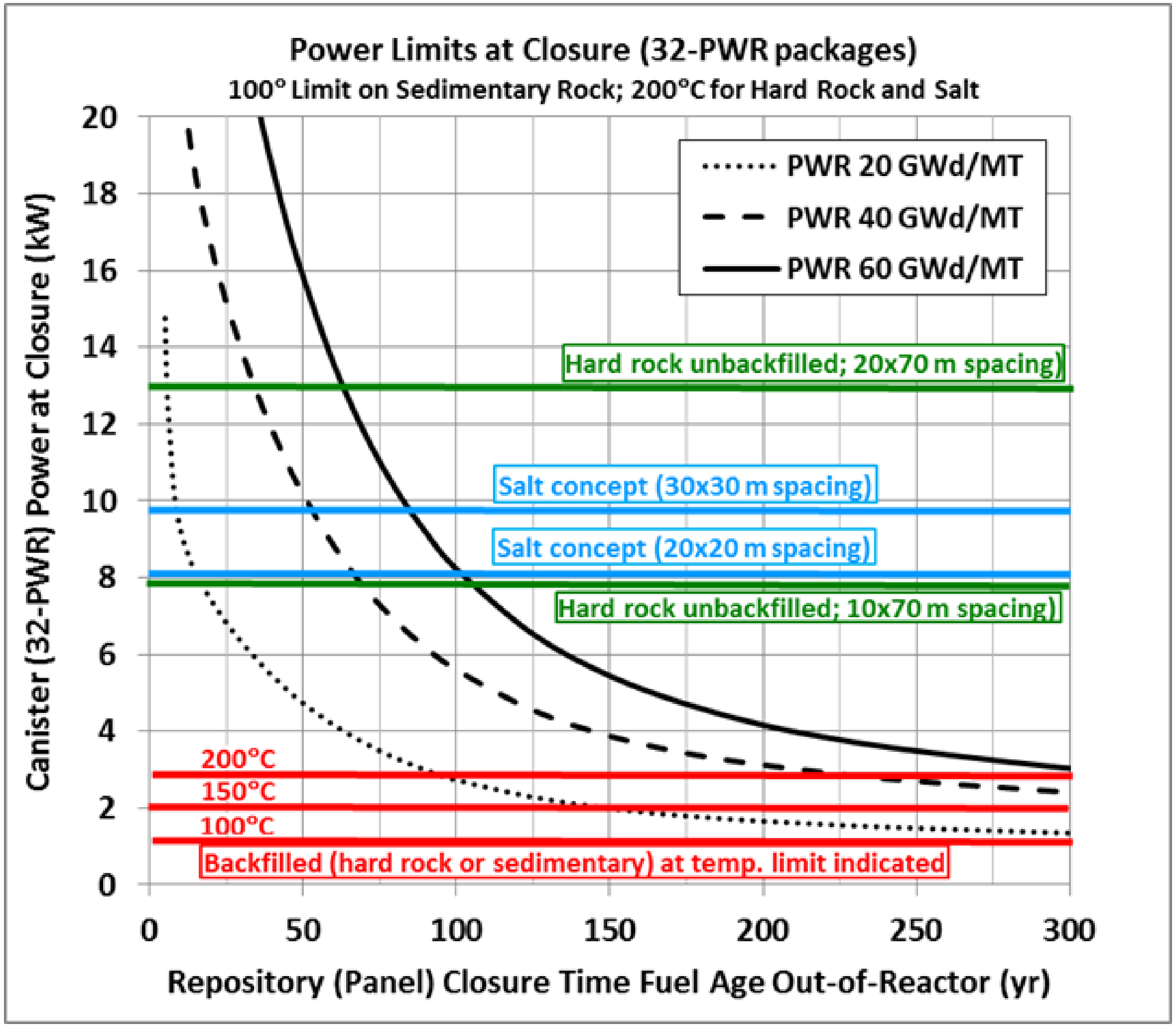
Heavy Shaft Hoist Technology

- **Hoist R&D at Gorleben, Germany**
  - Design and testing for 85 MT capacity (BGE Tec)
- **Payload of 175 MT studied for German "DIREGT" concept**
  - Similar to weight of DPC + overpack + shielding + cart
  - Koepke friction hoist, 6 cables (each 66 mm ϕ)
  - Counterweight 133 MT
  - 1 m/sec hoist speed with 800 kW winder
  - Order-of-magnitude cost about $30M for equipment



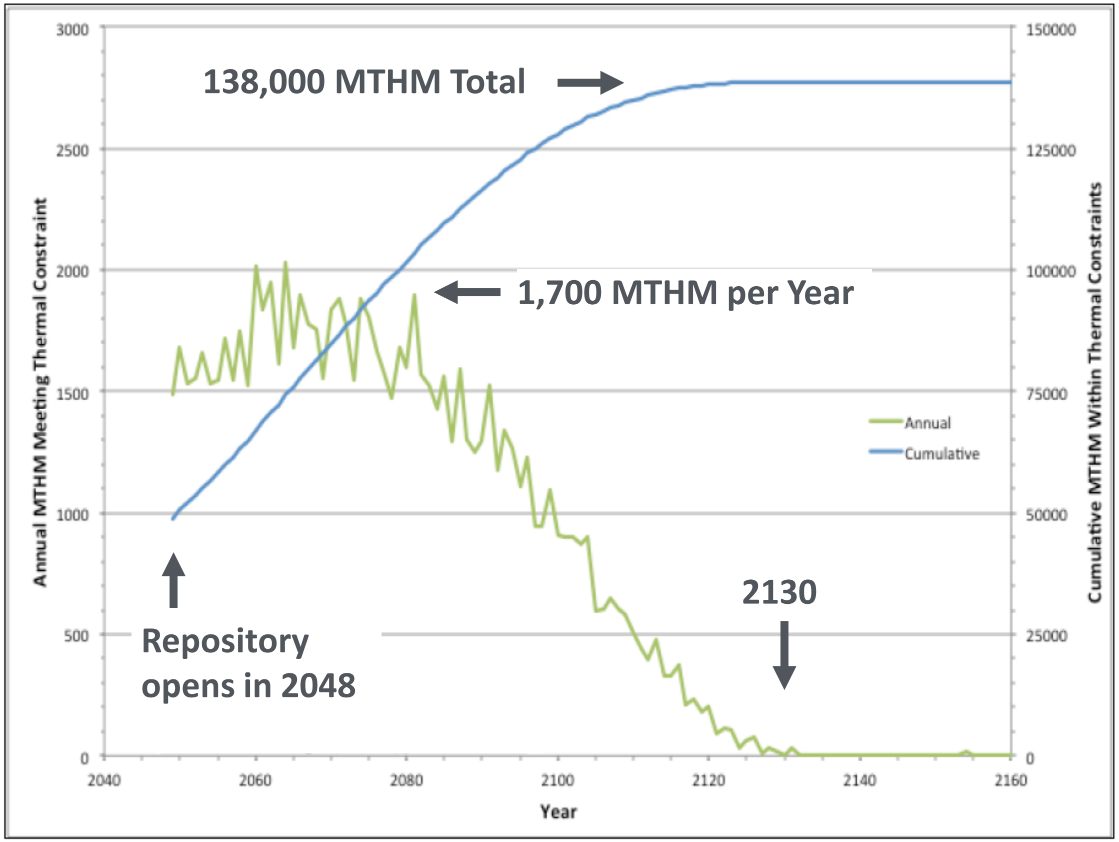
Thermal Management for DPC Disposal Concepts

- SNF burnup (black curves) crossing points give aging time to meet peak temperature targets for 32-PWR size packages
- Heat dissipation is best for salt and unsaturated/ unbackfilled concepts
- Backfill constraints dominate (where backfill is used)



Aging Analysis for 10 kW Emplacement Power Limit

- TSL-CALVIN* logistics simulator
- 10 kW limit would be typical for salt and unbackfilled concepts
- 1,700 MTHM/yr throughput would keep pace with cooling to 10 kW
- Disposal of >98% of projected SNF by 2130



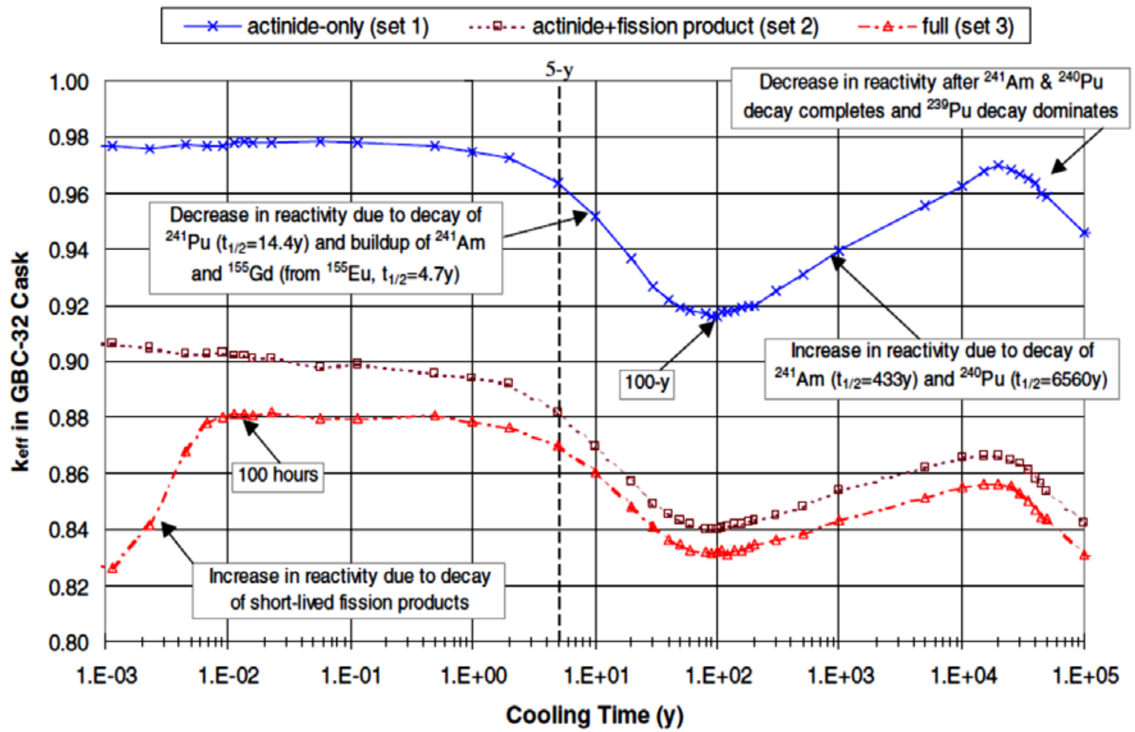
b) Amount of SNF

SNF emplaced per year (MTHM) vs. calendar year

* Nutt et al. 2012. *Transportation Storage Logistics Model – CALVIN (TSL-CALVIN).* FCRD-NFST-2012-000424.

Postclosure Nuclear Criticality Control

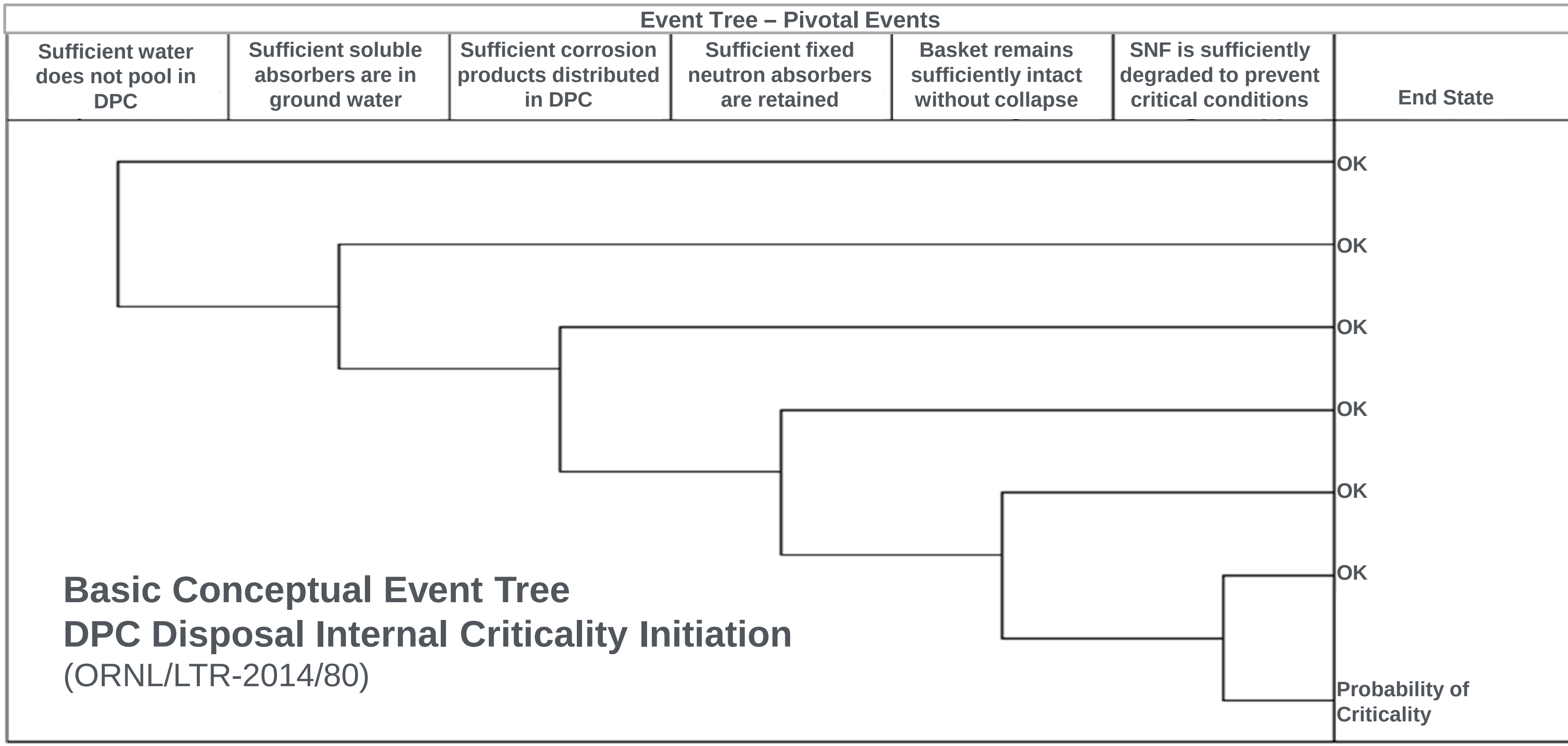
- **Disposal Environment**
  - Groundwater availability
  - Chloride in groundwater
- **Moderator Exclusion**
  - Overpack integrity
- **Moderator Displacement**
  - Fillers
- **Add Neutron Absorbers**
  - Fillers (e.g., B_4C loaded)
  - Disposal control rods (new DPCs only)
- **Criticality Analysis Methodology**
  - Burnup credit, as-loaded, stylized degradation cases
  - Peak reactivity occurs at >10,000 years



Neutron multiplication factor (k_{eff}) vs. time
Generic burnup-credit 32-PWR cask
PWR fuel (4% enriched, 40 GW-d/MT burnup)

Wagner and Parks 2001 (NUREG/CR-6781, Fig. 3)

DPC Disposal Criticality Initiators (low probability screening)



Basic Conceptual Event Tree
DPC Disposal Internal Criticality Initiation
(ORNL/LTR-2014/80)

Summary of Recommendations from 2013-2017 Feasibility Study (1/2)

- **Safety**
  - General attributes of a safe repository also apply for DPCs*
  - Performance assessment models need to discern differences*
  - May need to use cementitious materials for large underground openings and extended service lifetime
- **Engineering Feasibility**
  - Consider fuel condition if extended aging is needed*
  - Develop transporter and emplacement system concepts
  - Start corrosion testing for packaging materials
  - Update disposal overpack reliability
  - Confirm long-term underground stability
- **Thermal Management**
  - Continue R&D for high-temperature low-permeability backfill (e.g.,150ºC)*
  - Investigate sinking of heavy, heat-generating packages in plastic media*
  - Develop thermally driven process models (e.g., clay)*

* Underway or planned in FY18-19 R&D program.

Summary of Recommendations from 2013-2017 Feasibility Studies (2/2)

- **Postclosure Criticality Control**
  - Continue analysis of “as loaded” DPCs for degraded, flooded conditions*
  - Document stylized degradation scenarios*
  - Develop models of in-package (fuel, basket) degradation including effects from radiolysis*
  - Advance burnup credit analysis for BWR fuel*
  - Conduct R&D on fillers for moderator exclusion and neutron absorption*

* Underway or planned in FY18-19 R&D program.

Independent 2018 Review* of DPC Disposal R&D Summary

- Develop probability + consequence screening approach
- Simulate postclosure degradation of DPCs
- Continue to collect as-loaded data on existing DPCs
- Evaluate fillers
- Pursue burnup credit advances (e.g., for BWR fuel)
- Regulatory engagement (e.g., 10 CFR 72.236(m))
- Reconsider early failure/manufacture defects in disposal overpack performance
- Other items (Cs-133 burnup credit, probabilistic k_{eff}, burnup verification tool) are under discussion

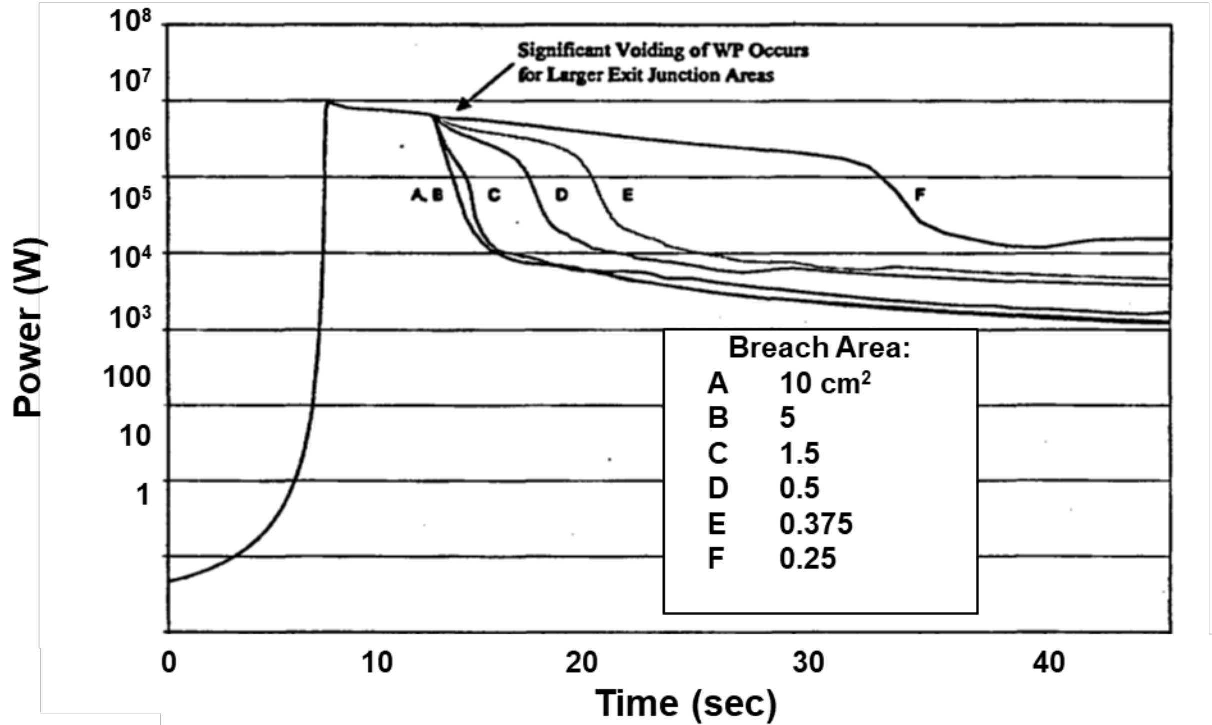
* Alsaed, A. 2018. SFWD-SFWST-2018-000491 Rev. 0.

Background: Previous Simulations of Waste Package Criticality

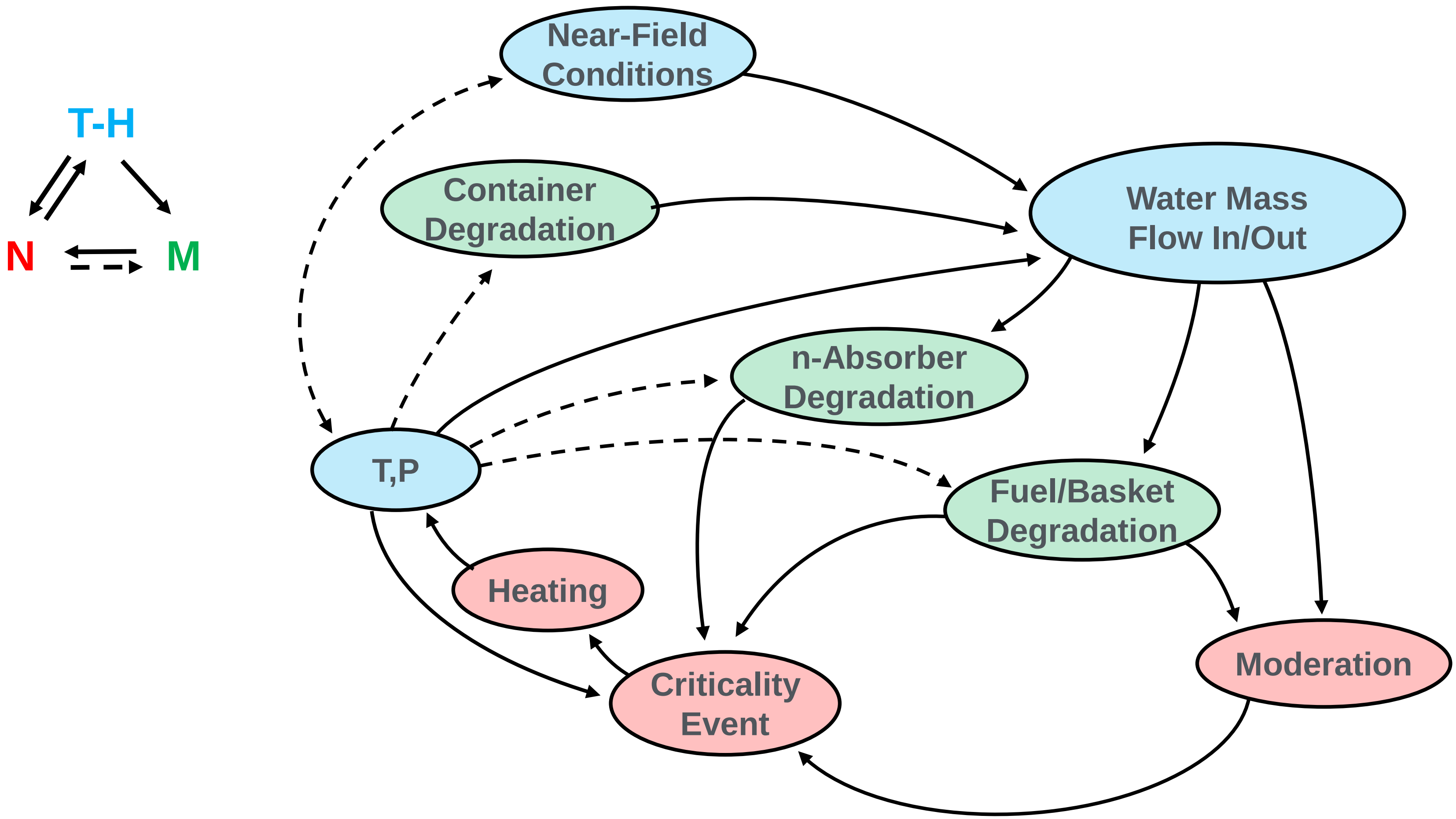
- **Example Calculations:**
  - Criticality Consequence Analysis Involving Intact PWR SNF in a Degraded 21-PWR WP (BBA000000-01717-0200-00057 REV 00)
  - Sensitivity Study of Reactivity Consequences to Waste Package Egress Area (CAL-EBS-NU-000001 REV00)

Waste Package Power vs. Time from RELAP5 Code Analysis of Fission Power Histories for Prompt (0.148 $/sec) Reactivity Insertion Rate Parameterized by Waste Package Breach Area

(CAL-EBS-NU-000001, Figure 6-5)



Reference Coupling Scheme (Current State of the Art)



Dashed lines signify ad hoc input or loosely coupled processes

Perspective on Past and Present Filler Options for Existing U.S. DPCs

- **Cut DPC Lids Off?**
  - Skiving (wet) selected among various methods (DOE investigation)
  - Steel shot dry-filler test, Framatome-Cogema (Cogar 1996)
  - Glass bead dry-filler test, Atomic Energy of Canada Ltd. (Forsberg 1997)
  - Filling must be done dry
  - Requires weld-resealing the canister dry
- **Alternative: Criticality Control Features (EPRI 2008)**
  - Cut DPC lids off, insert disposal control rods
  - Rearrange fuel assemblies and/or de-rate capacity
- **Alternative: Injectable Fillers**
  - Cut off covers over existing DPC vent/drain ports

Cogar, J. 1996. Waste Package Filler Material Testing Report. BBA000000-01717-2500-00008 Rev 01. OCRWM.

Forsberg, C.W. 1997. Description of the Canadian Particulate-Fill Waste Package (WP) System for Spent Nuclear Fuel (SNF) and its Applicability to Light-Water Reactor SNF WPs with Depleted Uranium Dioxide Fill. ORNL/TM-13502.

EPRI (Electric Power Research Institute) 2008. Feasibility of Direct Disposal of Dual-Purpose Canisters: Options for Assuring Criticality Control. #1016629.

Filler Attributes (Liquid or Slurry Emplaced)

- **Injectable** – ~6,000 L through a 0.75-in ϕ DPC drain tube in a few hours
- **Void Filling** – Penetrate limber holes, assemblies, baskets
- **Compatible** – Limited gas generation or chemical attack
- **Durable** – 10,000+ yr chemical/physical lifetime before or after waste package breach (natural analogues)
- **Reactivity Control** – Displace ground water or incorporate neutron absorber, or both
- **Safe** – Does not endanger workers or members of the public
- **Practical** – Reasonable weight, possibility of retrieving fuel
- **Low Cost** – Relative to alternative DPC disposal alternatives

Summary of FY18-19 Planned F&D Activities

- **Planned Activities:**
  - Technical/Programmatic Solutions for Direct Disposal of SNF in DPCs
  - Probabilistic Post-Closure DPC Criticality Consequence Analysis
  - DPC Filler and Neutron Absorber Degradation R&D
  - Multi-Physics Simulation of DPC Criticality
- **Expected Outcomes:**
  - DPC disposition alternatives, R&D and resource needs
  - Generic (non-site specific) preliminary PA model
  - Evaluate feasibility for candidate filler materials
  - Mechanistic multi-physics coupled models

Questions?

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Backup Slides

DPC Terminology

- **Canister** ≡ Sealed, unshielded vessel containing spent fuel, for use with various overpacks. Typically welded closure.
- **Dual-Purpose Canister** ≡ Dry storage canister that has been, or can be, licensed by the NRC for transportation also. Three major U.S. vendors: Transnuclear/Orano, Holtec, and NAC International.
- **Storage Cask** ≡ Shielded container for stationary storage. Typically stationary, with bolted closure.
- **Transportation Cask** ≡ Shielded container for transporting SNF in canisters (or as “bare” fuel assemblies). Bolted closure.
- **Transfer Cask** ≡ Used locally to transfer unshielded canisters from fuel pools to storage casks, or from storage casks to transport casks.
- **Multi-Purpose Canister** ≡ A canister that can be licensed for storage, transportation, and disposal.

Facts About Potential Direct Disposal of SNF in DPC-Based Waste Packages

- DPCs weigh about the same as Yucca Mountain (YM) canisters sized for 21-pressurized water reactor (PWR) assemblies.

  Loaded Magnastor® canister (NAC International) 37-PWR DPC (~50 MT) vs. loaded YM 21-PWR canister (≤ 49.3 MT)

- DPCs are about the same size as YM canisters for commercial SNF.

  Magnastor canister dimensional envelope (1.77 m D x 4.87 m L → 12.4 m³) vs. YM canister (1.69 m D x 5.39 m L → 12.1 m³).

- DPC-based waste packages could be lowered down a shaft with a large hoist.

  A DPC package (~70 MT) with shield (+75 MT) + carriage would compare to the 175 MT payload for the "DIREGT" conceptual hoist design (BGE Tec).

- DPC-based packages could be disposed of in a salt repository.

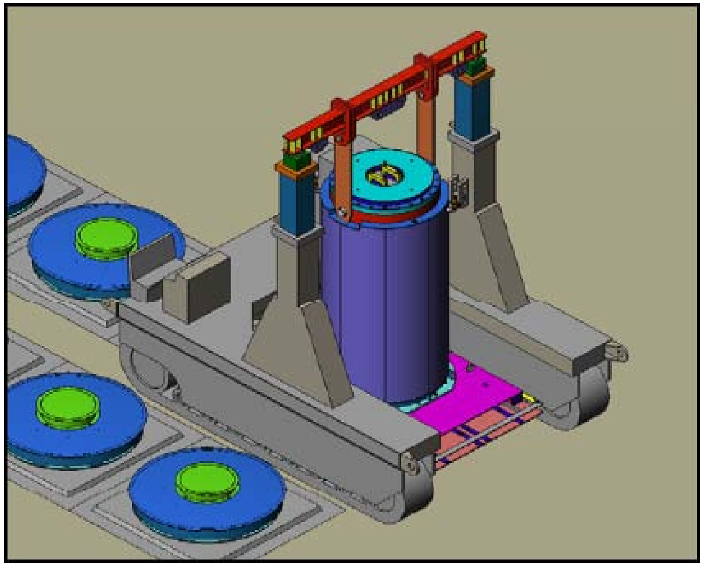
  Size and weight are reasonable challenges for transport underground.

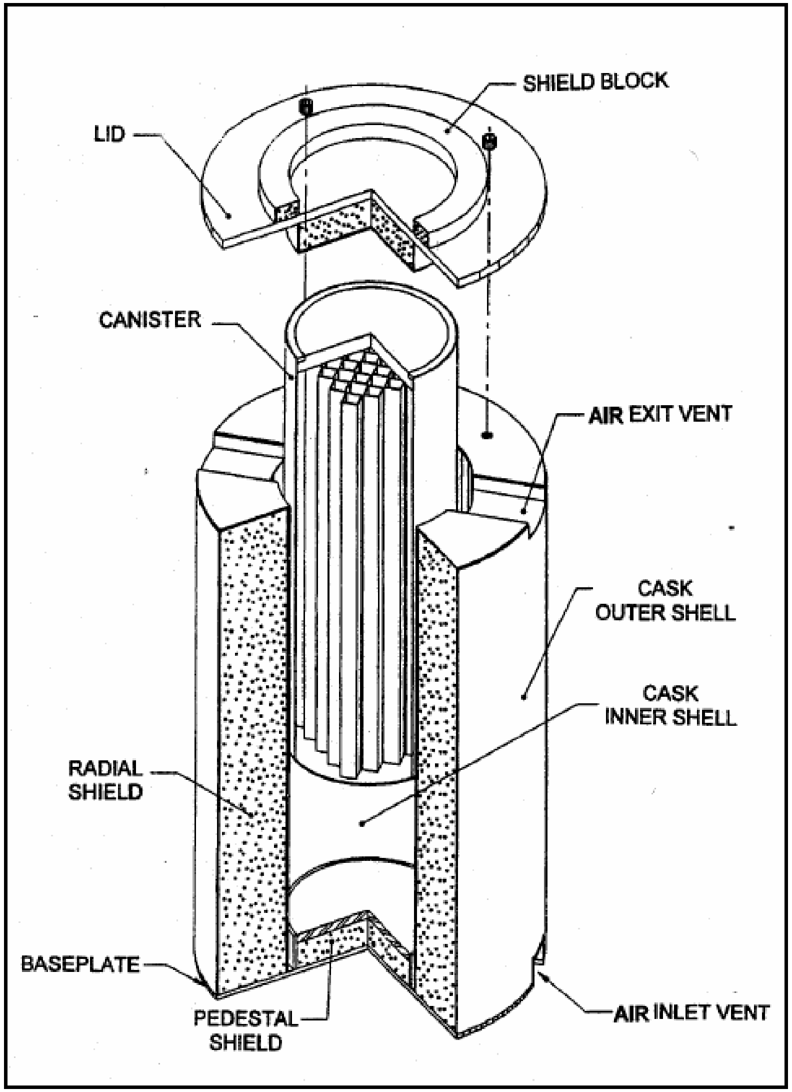
  Thermal management may require some aging but 98% of commercial fuel could be emplaced by 2130 in a salt repository.

  Creep models calibrated to recent low-stress, low-strain-rate data show that package sinking in halite could be limited, especially with interbeds.

Dual-Purpose Canisters in Subterranean Storage

- Holtec HI-STORM 100U® subterranean canister overpack system (32 PWR/ 68 BWR)
- HI-STORM 100® shielded overpack with bolted closure, and welded stainless “multi-purpose” canister
- HI-TRAC ® transfer cask (125 ton max.)
- Mitigates aircraft crash hazard





Pictures from EPRI Spent Fuel Storage Handbook

Example Work Products Supporting Low-Probability FEP Screening

- **Yucca Mountain License Application**
  - *Screening of Criticality FEPs for LA* (ANL-DS0-NU-000001 REV00A)
  - *Commercial SNF Waste Package Misload Analysis* (CAL-WHS-MD-00003 REV00A)
  - *Commercial SNF Igneous Scenario Criticality* (ANL-EBS-NU-000009 REV00)
  - *Commercial SNF Loading Curve Sensitivity Analysis* (ANL-EBS-NU-000010 REV 00)
- **Feasibility Study 2013-2017**
  - *Summary of Investigations on Technical Feasibility of Direct Disposal of DPCs* (SFWD-SFWST-2017-000045)