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Overview of Dual-Purpose Canisters Disposal R&D

Prepared by Sandia National Laboratories technical staff, with input from consultants and other laboratories

Meeting with U.S. Nuclear Waste Technical Review Board Members and Staff

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This is a technical presentation that does not take into account the contractual limitations under the Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste (Standard Contract) (10 CFR Part 961). Under the provisions of the Standard Contract, DOE does not consider spent nuclear fuel in canisters to be an acceptable waste form, absent a mutually agreed-to contract amendment. <u>To the extent discussions or recommendations in this presentation conflict with the provisions of the Standard Contract, the Standard Contract provisions prevail</u>.

Dual-Purpose Canister Direct Disposal Background

- Dry storage is an important solution for utility spent nuclear fuel (SNF) storage
  - Dual-purpose canisters (DPCs) are loaded in fuel pools, dewatered, weld-sealed, and transferred into shielded storage casks or vaults
- Most dry-storage canisters can be moved in shielded transportation casks
- ~2,761 dry-storage canisters are now loaded with >30,000 MTU SNF
- DPCs were not designed, loaded or licensed for geologic disposal
  - After disposal, some waste packages could eventually breach and fill (or partly fill) with water, so that DPC-based packages could be flooded
  - DPC fuel baskets are designed to control criticality for short-term operations (fuel pools) or transportation accidents
  - Aluminum-based neutron absorbing materials (e.g., Boral®) could readily corrode from long-term exposure to ground water

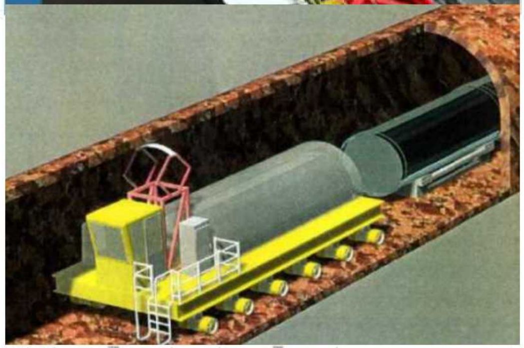
Facts About Potential Direct Disposal of SNF in DPC-Based Waste Packages

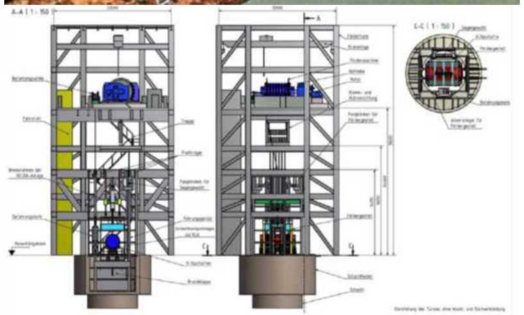
- **DPCs weigh about the same as Yucca Mountain (YM) canisters sized for 21-pressurized water reactor (PWR) assemblies.**
  - *Loaded Magnastor® canister (NAC International) 37-PWR DPC (47 MT) vs. loaded YM 21-PWR canister (≤ 49.3 MT)*
- **DPCs are about the same size as YM canisters for commercial SNF.**
  - *Magnastor canister dimensional envelope (1.80 m D x 4.87 m L → 12.4 m^3) vs. YM canister (1.69 m D x 5.39 m L → 12.1 m^3).*
- **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 be less than 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.*
  - *Creep models calibrated to recent low-stress, low-strain-rate data predict small amounts of sinking in halite, especially if interbeds are included.*

Spent Fuel and Waste Science and Technology

Engineering Challenges Can Be Met

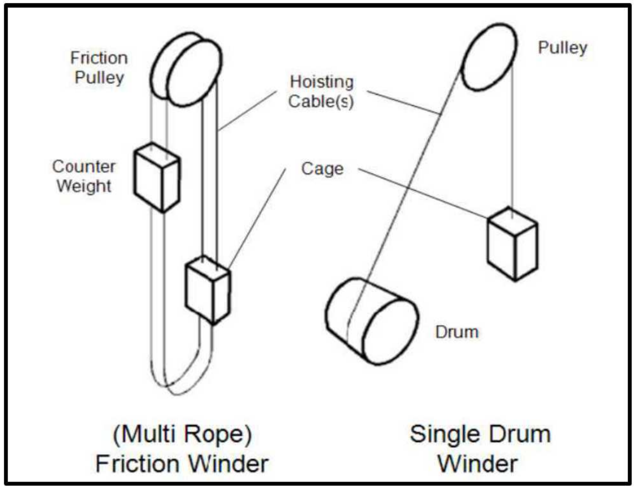
- **Handling/Packaging: Use Current Practices**
- **Surface-Underground Transport**
  - Spiral ramp (~10% grade, rubber-tire)
  - Linear ramp (>10% grade, funicular)
  - Shallow ramp (≤ 3% grade, standard rail)
  - Heavy shaft hoist
- **Drift Opening Stability Constraints**
  - Salt (a few years with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

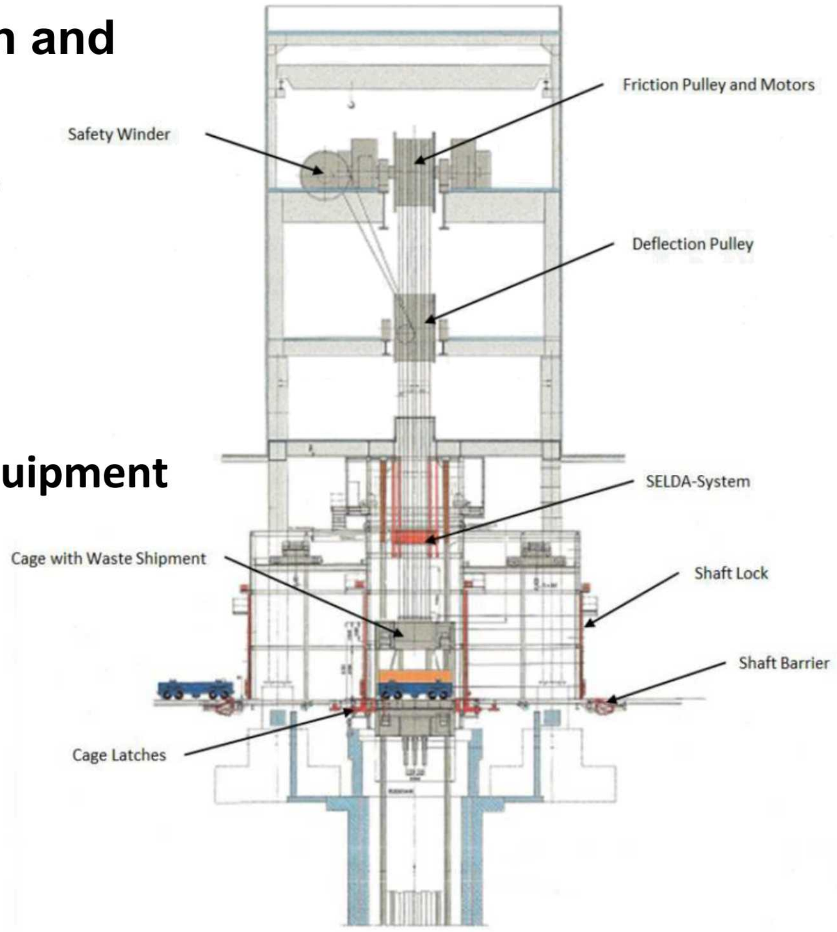




Heavy Shaft Hoist Technology

- **Hoist R&D at Gorleben, Germany: Design and testing for 85 MT capacity (BGE Tec)**
- **Payload 175 MT for DPC-based package, shielding & cart**
  - **Koepke friction hoist, 6 cables (66 mm)**
  - **Counterweight 133 MT**
  - **1 m/sec hoist speed with 800 kW winder**
  - **Order-of-magnitude cost about $30M for equipment**



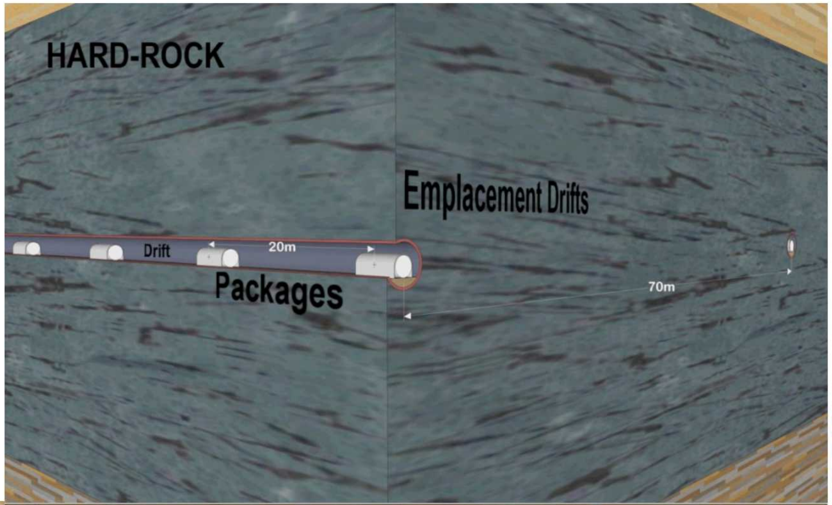


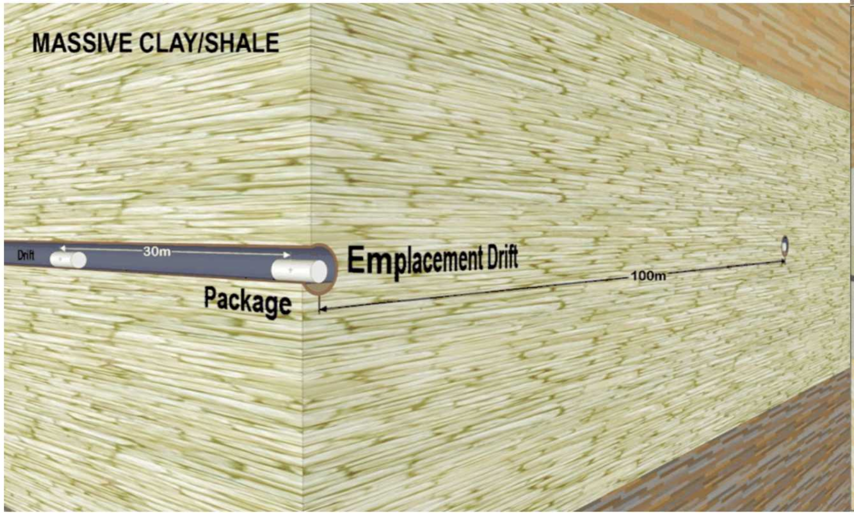
Source: Hardin et al. 2013. FCRD-UFD-2013-000170 Rev. 0.

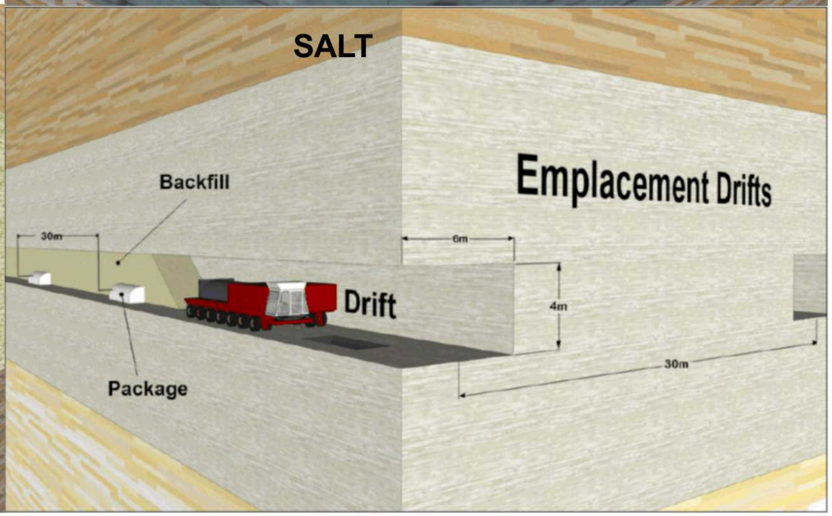
Spent Fuel and Waste Science and Technology

DPC Direct Disposal Concepts

- **Shaft or ramp transport**
- **In-drift emplacement**
- **Extended aging or repository ventilation (except salt)**
- **Backfill before closure (except hard rock unsaturated)**
- **Postclosure criticality control**



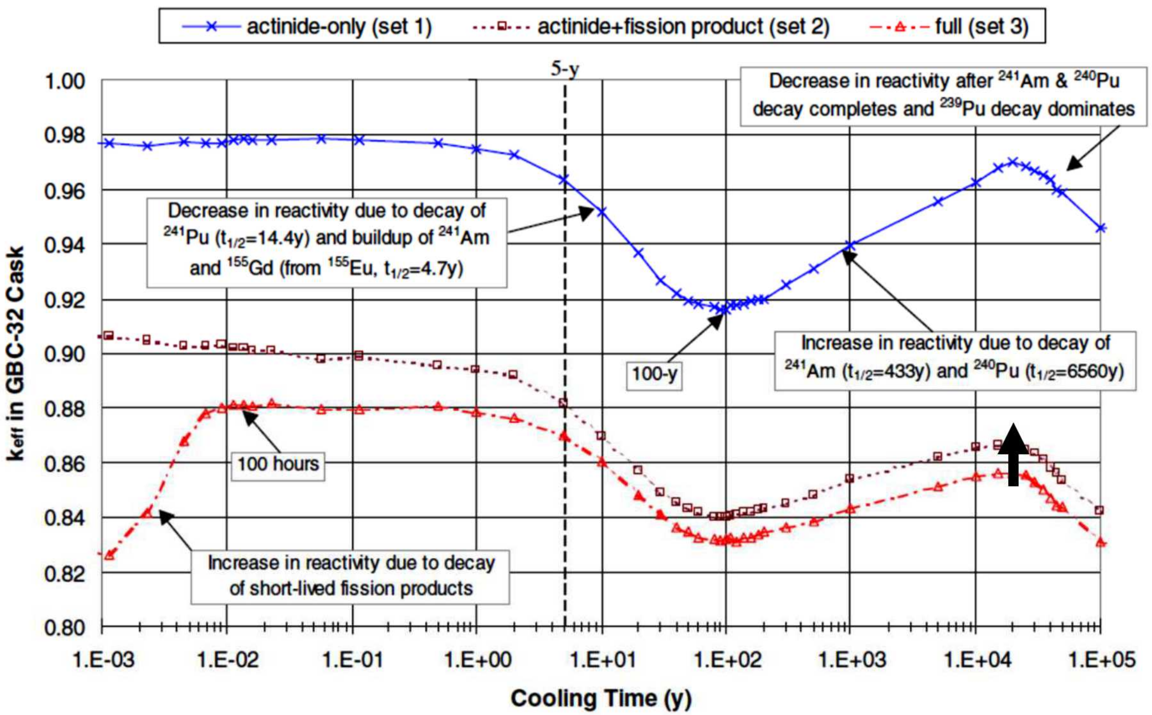




(Hardin et al. 2013. FCRD-UFD-2013-000171 Rev. 1)

Postclosure Nuclear Criticality Control

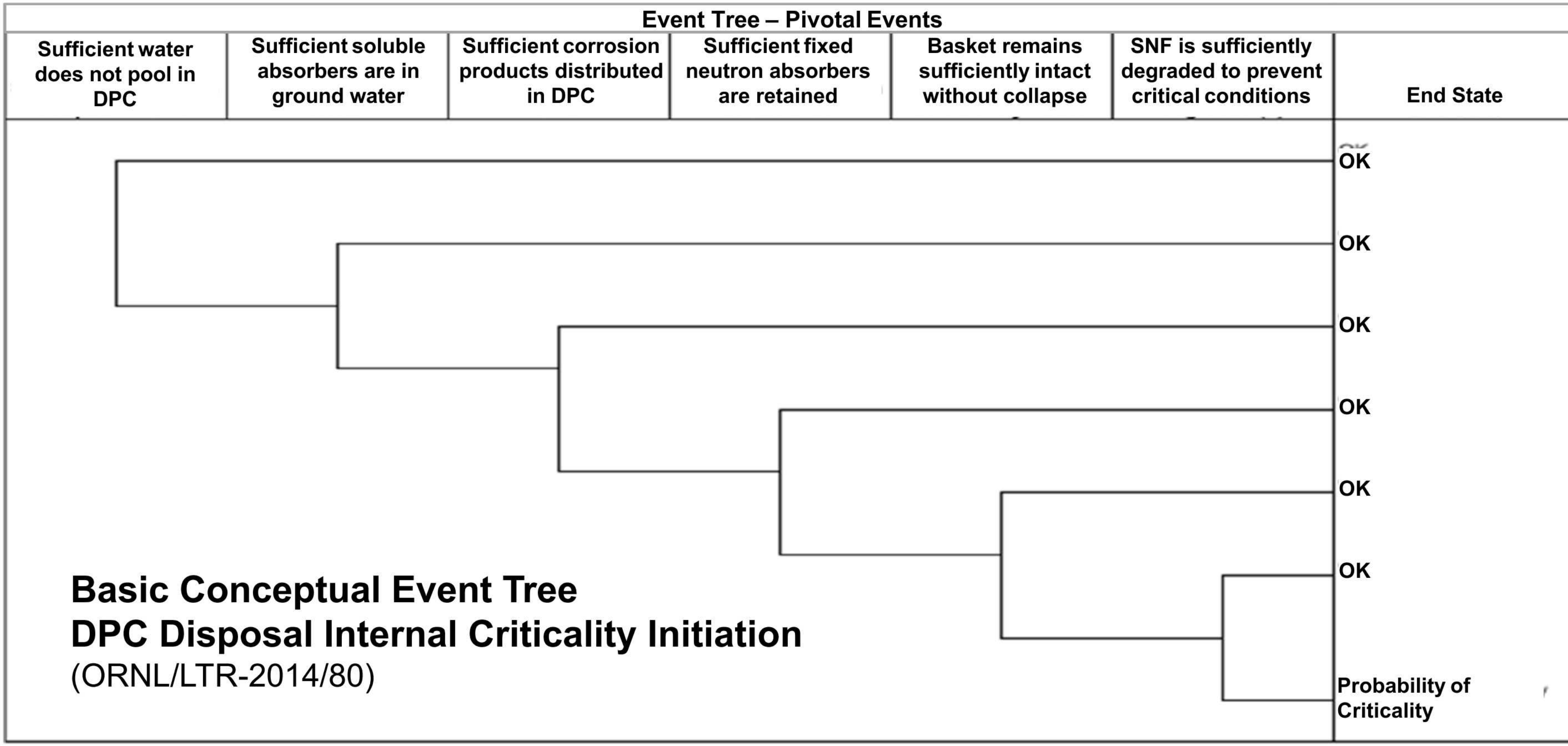
- **Disposal Environment**
  - Groundwater availability
  - Chloride in groundwater
- **Moderator Exclusion**
  - Overpack integrity
- **Moderator Displacement**
  - Fillers
- **Add Neutron Absorbers**
  - Fillers (e.g., B_4C loaded)
  - Disposal control rods (as new DPCs are loaded)
- **Criticality Analysis Methodology**
  - Burnup credit, as-loaded, stylized degradation cases
  - Peak reactivity occurs at ~25,000 years



Neutron multiplication factor (k_{eff}) vs. time
Generic burnup credit (GBC) 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)

Example Analyses 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)
- **Summary of Investigations on Technical Feasibility of Direct Disposal of DPCs** (SFWD-SFWST-2017-000045)

Summary of Previous (2012–2016) Studies on Technical Feasibility of DPC Direct Disposal

- **Technical evaluation results:**
  - Safety of workers and the public
  - Engineering feasibility
  - Thermal management
  - Postclosure criticality control

  No implementation barriers although all existing DPCs may not be disposable depending on the disposal concept

- **Most favorable concepts: salt and hard rock-unsaturated**
  - Mainly due to thermal management and postclosure criticality control
- **Additional considerations important for direct disposal:**
  - Disposal overpack reliability estimates can be improved
  - Features of existing DPC baskets will impact structural longevity
  - Investigate DPC modifications for criticality control (e.g., fillers)
  - Investigate screening postclosure criticality on low consequence in addition to low probability

Guidance from YM Criticality Topical Report (DOE YMP/TR-004Q) on Criticality Consequence Analysis

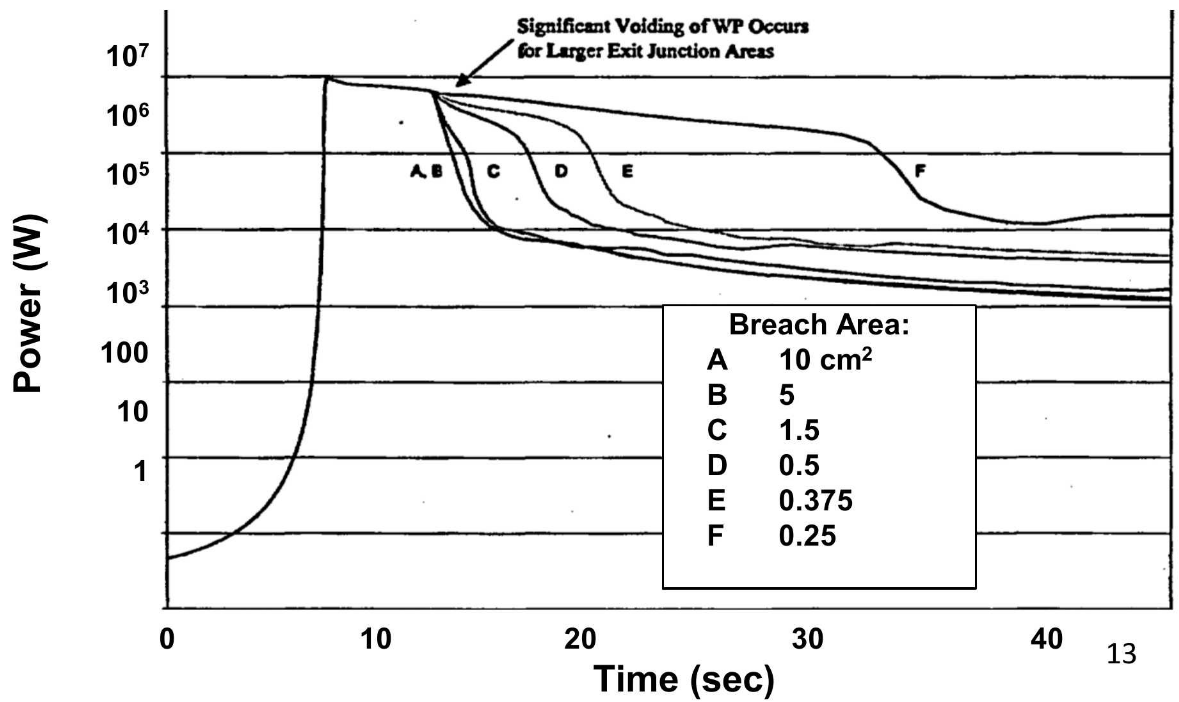
- **Potentially important effects from criticality on repository performance:**
  - Change in radionuclide inventory (from additional burnup)
  - Other effects on radionuclide transport, including
    - **Increased temperature**
    - **Fuel and container degradation (e.g., accelerated corrosion, mechanical damage, altered rates of radionuclide releases)**
- **Consider steady state and transient events**
  - Low-power events may be steady-state or pulsing
  - Transient events may be due to slow or rapid reactivity insertion
- **If postclosure criticality occurs, WF/WP degradation will likely truncate criticality event sequences**
- **Context (Rev. 02): One SNF canister design**

Background: Previous Simulations of Waste Package Criticality

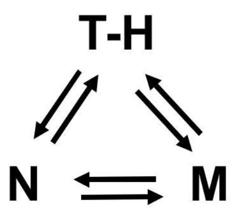
- **Criticality Consequence Analysis Involving Intact PWR SNF in a Degraded 21-PWR WP** (BBA000000-01717-0200-00057 REV 00)
- **Sensitivity Study of Reactivity Consequences to Waste Package Egress Area** (CAL-EBS-NU-000001 REV00)

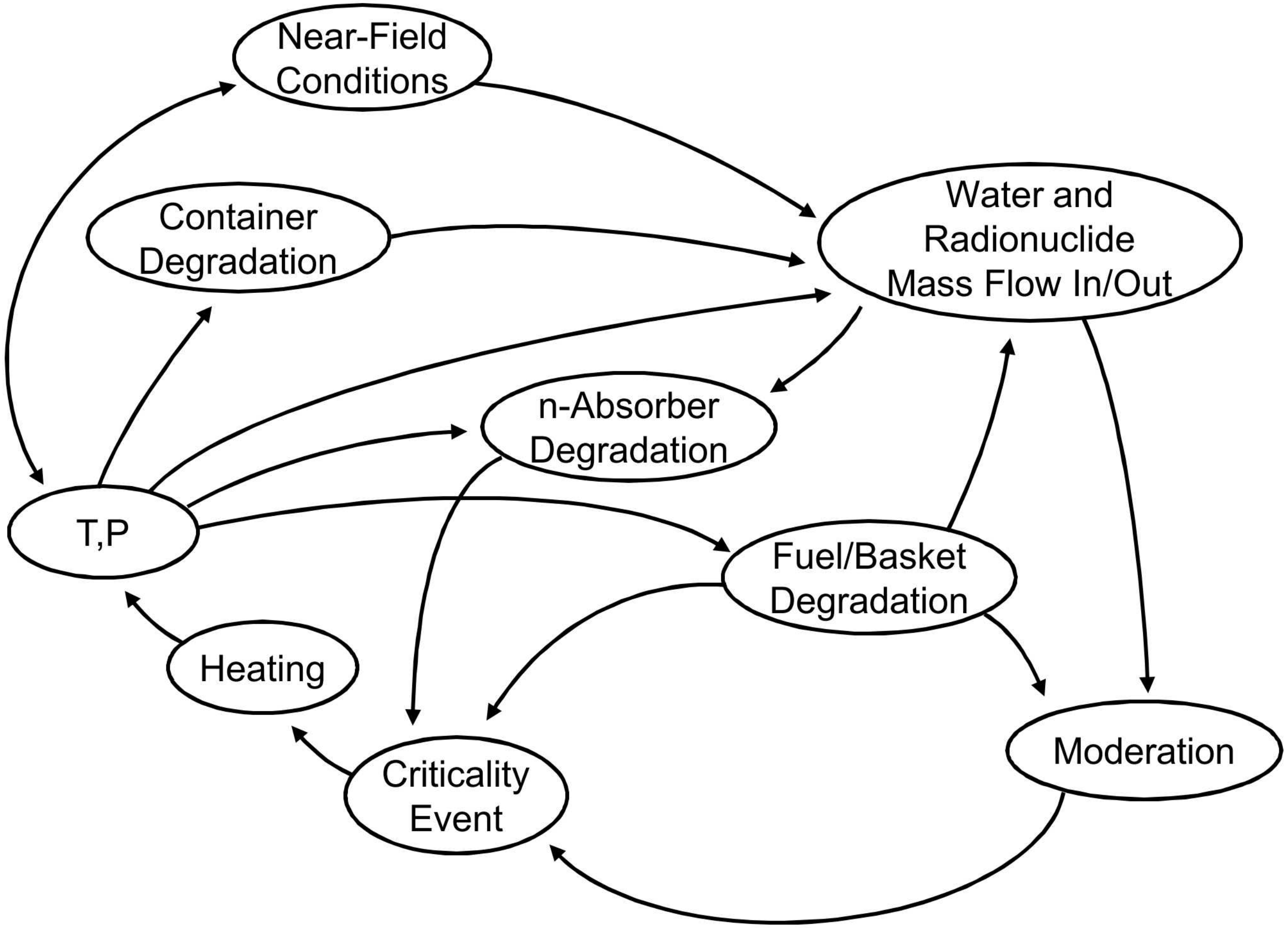
Waste Package Power vs. Time from RELAP5 Code Analysis of Fission Power Histories for Prompt (0.158 $/sec) Reactivity Insertion Rate Parameterized by Waste Package Breach Area

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



Reference Coupling Scheme (DRAFT)





Performance Assessment Approach for Criticality Consequence Analysis

- **Criticality risk = probability (i.e., incidence) × consequence**
  - ⇒ Use of system-wide assessment with variability and uncertainties
- **How will criticality be affected by repository conditions?**
  - Spatial distribution and timing of waste package containment failures
  - Groundwater composition and rate of influx in to waste packages
  - Seismic hazard (where applicable)
- **How will the waste form and canister affect the incidence of criticality?**
  - Fuel enrichment & burnup
  - Fuel degradation rate vs. basket degradation rate
  - Gradual vs. rapid episodic degradation (sediment, collapse, ground motion)
  - Early package failure/manufacturing defects
- **How can internal criticality affect the repository as a system?**
  - Temperature evolution; fuel and container degradation; radionuclide release
  - Changes to the source term

Independent 2018 Review of DPC Disposal R&D* Summary

- Regulatory engagement (e.g., 10 CFR 72.236(m))
- Develop probability + consequence screening approach
- Burnup credit advances (stable Cs-133, more work on BWR fuel, possible development of a burnup verification tool)
- Evaluate fillers
- Continue to collect as-loaded data on the existing fleet of DPCs
- Reconsider early failure/manufacture defects in disposal overpack performance
- Simulate postclosure degradation of DPCs

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

FY18-19 Planned 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