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Direct Disposal of Commercial Spent Nuclear Fuel Dual-Purpose Canisters — Ongoing DOE Studies

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

John Scaglione, Oak Ridge National Laboratory,
ScaglioneJM@ornl.gov
Laura Price, Sandia National Laboratories
llprice@sandia.gov

Notices

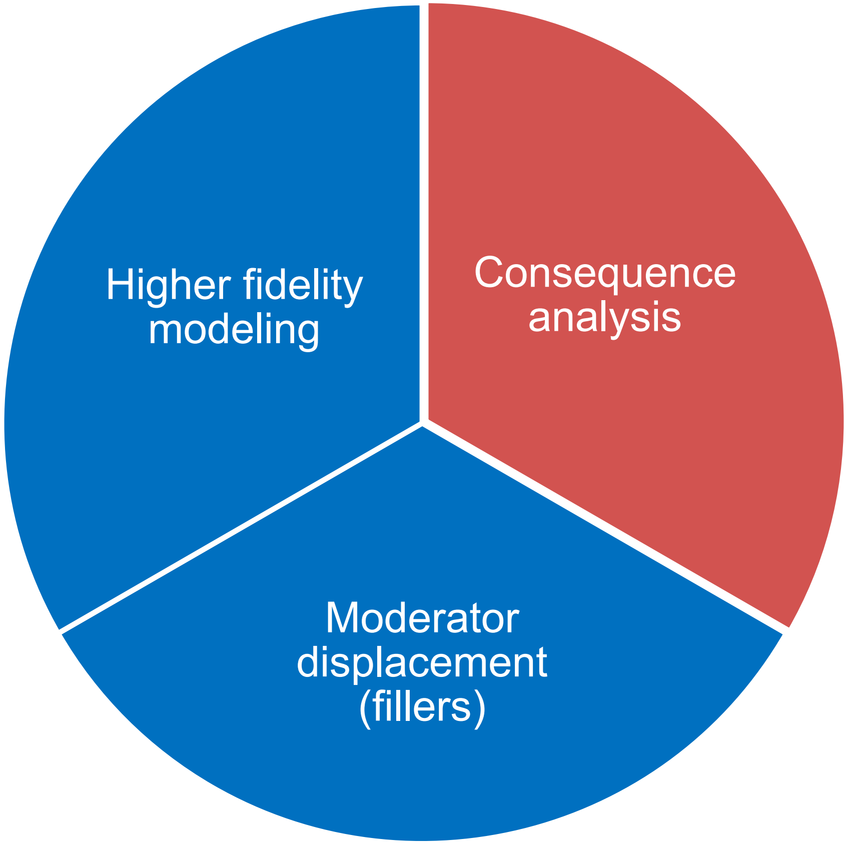
This is a technical presentation that does not take into account the contractual limitations under the Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste (Standard Contract) (10 CFR Part 961). Under the provisions of the Standard Contract, DOE does not consider spent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

Background

- As of 10/02/2018 there are 2,954 dry storage systems in use in the US containing 125,147 spent fuel assemblies
- ~200 new dual-purpose canisters (DPCs) are being loaded per year
- Addressing criticality over disposal time periods (e.g., 10,000+ years) is necessary to support a repository performance assessment that includes disposal of DPCs

One of the remaining challenges to direct disposal of DPCs is addressing the potential for criticality during the repository performance period

- Probability analysis
  - More detailed modeling to recover uncredited margins (e.g., burnup credit and as-loaded analysis)
  - Addition of filler to displace moderator from being between fuel rods
- Evaluation of consequences of criticality on repository performance assessment (PA)
  - Steady-state
  - Transient

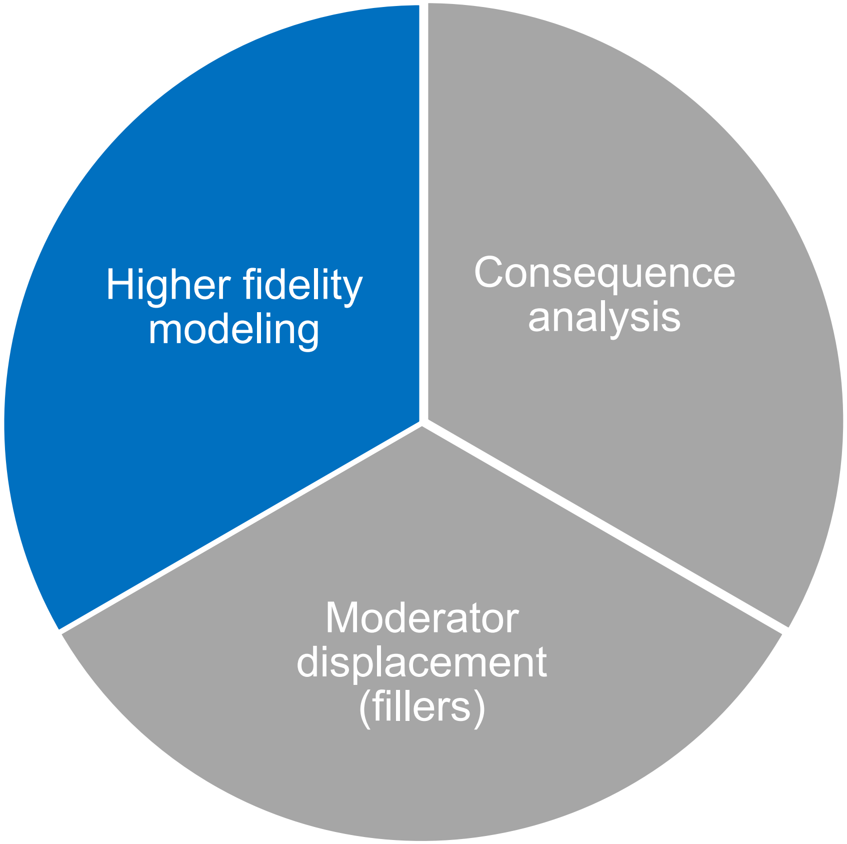

Higher fidelity modeling

Consequence analysis

Moderator displacement (fillers)

Options to consider besides repackaging

Option 1: Higher fidelity (better) modeling



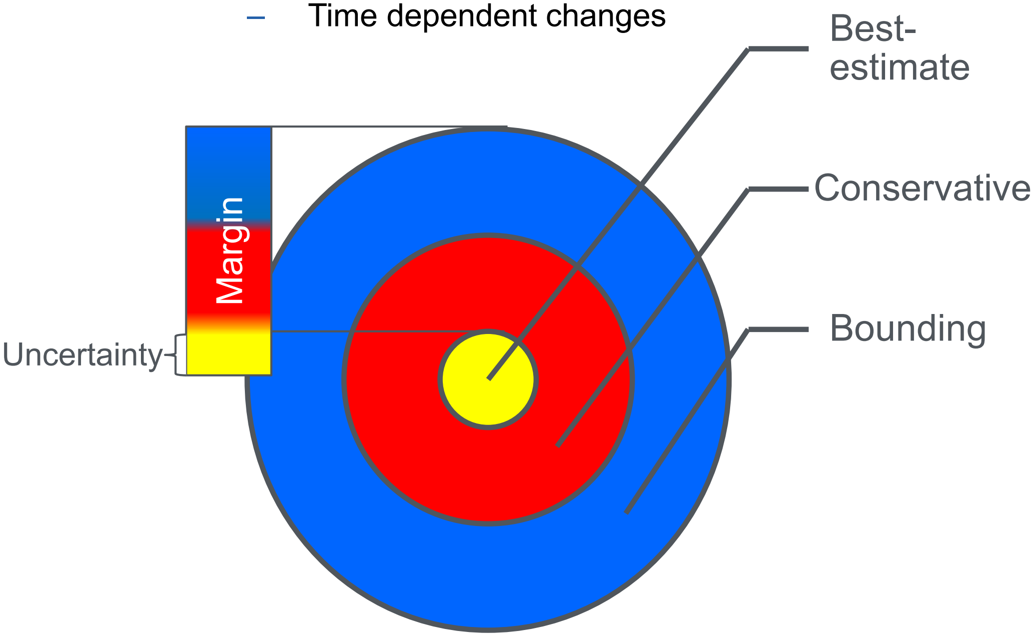
Detailed DPC modeling is being performed to improve accuracy in results used to assess criticality probability and reduce uncredited margins

- Margin = Design licensing basis – (best-estimate plus uncertainty)
- Actual loaded DPCs have considerable margin

Data Specificity	Example data types
High-level (Bounding analysis)	Average data, reactor type, annual power, cycle dates
Moderate (Conservative analysis)	Assembly specific initial enrichment, burnup, cycles assembly in reactor, discharge date, storage location (GC-859 form)
Detailed (Best-estimate analysis)	Assembly location in core, flux spectrum, operating history (axial profiles [burnup, moderator density, fuel temperature], soluble boron), flux control, pin power maps

Fundamental needs for predictive modeling

- Materials
- Geometry
- Time dependent changes



Greater uncertainty in the inputs and longer period of prediction
→ Larger margins
→ Increased costs

The capability to analyze each loaded DPC for suitability for direct disposal has been developed

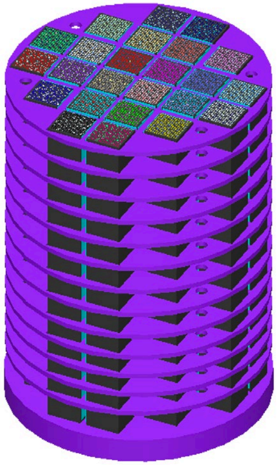
- Used Nuclear Fuel-Storage, Transportation, & Disposal Analysis Resource and Data System (UNF-ST&DARDS)
  - Integrates a relational database with analysis capabilities to enable automated characterization of eventually all spent fuel assemblies and casks (e.g., criticality, dose rates, containment, and temperatures) in the domestic inventory
- Explicit as-loaded criticality analysis of each loaded DPC
  - Loading maps used to develop models with actual assembly attributes
  - Burnup credit using 29 actinides and fission products
  - Component credit (e.g., discharged burnable poison rod assemblies inserted in guide tubes)
  - Other credit based on design specifics, and host media specifics (e.g., Cl-35 in salt repository)

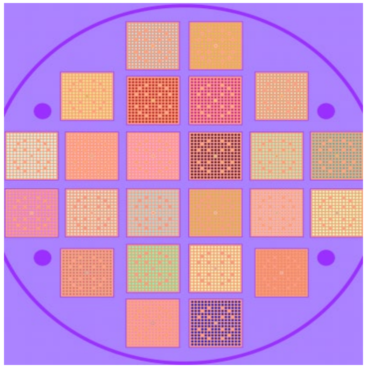
As-loaded criticality analysis scoping results show that some DPCs still have criticality potential after uncertainties are reduced

- Scoping analysis results based on current modeling and material degradation assumptions (DPC design specific)

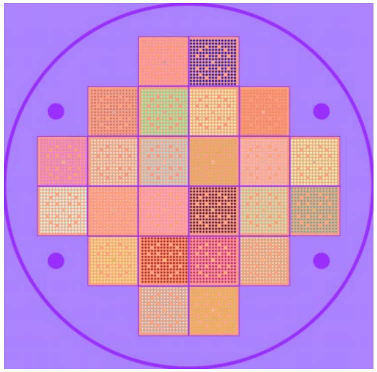
Description	**Value**
Total DPCs analyzed	616
Total DPCs below subcritical limit with loss of neutron absorber (design-basis loading)	0 (0%)
Total DPCs below subcritical limit with loss of neutron absorber (as-loaded)	473 (~76%)
Total DPCs below subcritical limit with loss of neutron absorber and carbon steel structures (as-loaded)	420 (~68%)

Tube and disk design with carbon steel disks



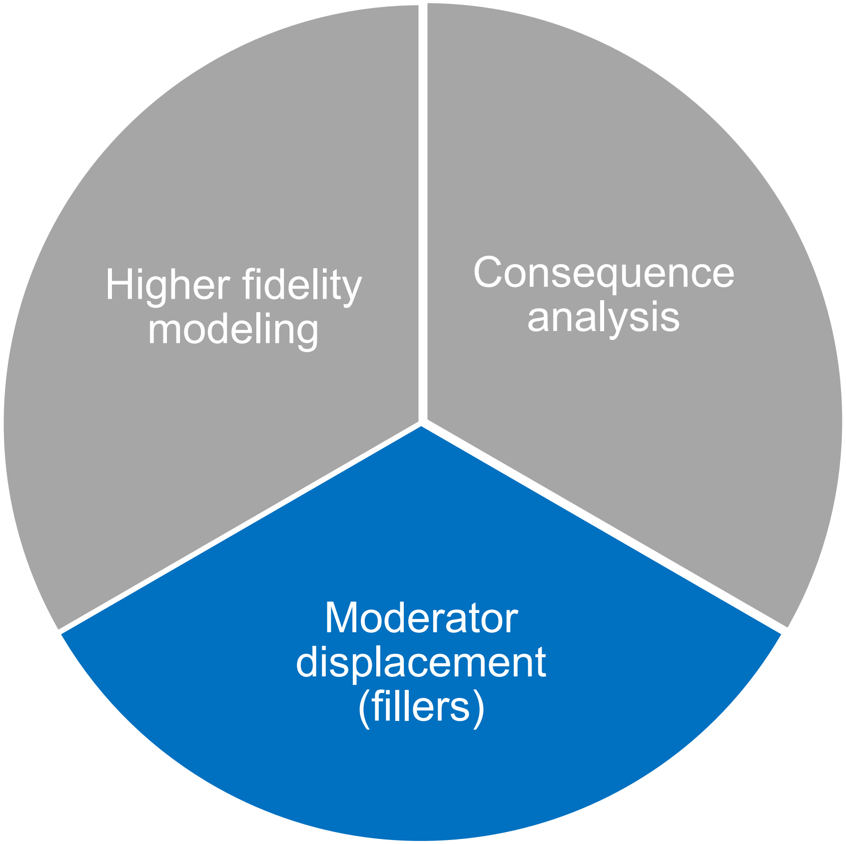


Loss of neutron absorber



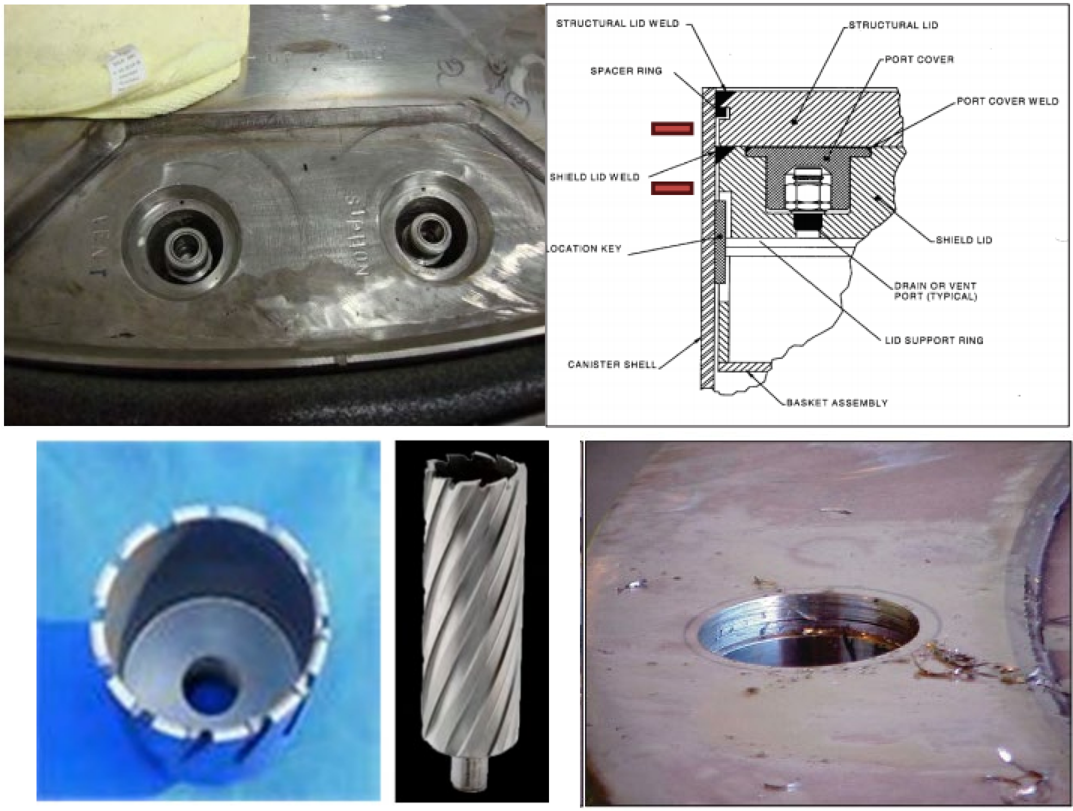
Loss of neutron Absorber + carbon steel disk

Option 2: Moderator Displacement (fillers)



Filler work is performed to assess whether DPC internal void volume can be filled through vent/drain ports with suitable material

- Adding filler material to displace regions for future moderator intrusion is being considered as an option to prevent post-closure criticality
- Two classes of filler materials are now being investigated
  - Cement slurry materials
  - Low temperature metals and alloys
- Prior research and demonstrations exist on filling open canisters (prior to installing lids)

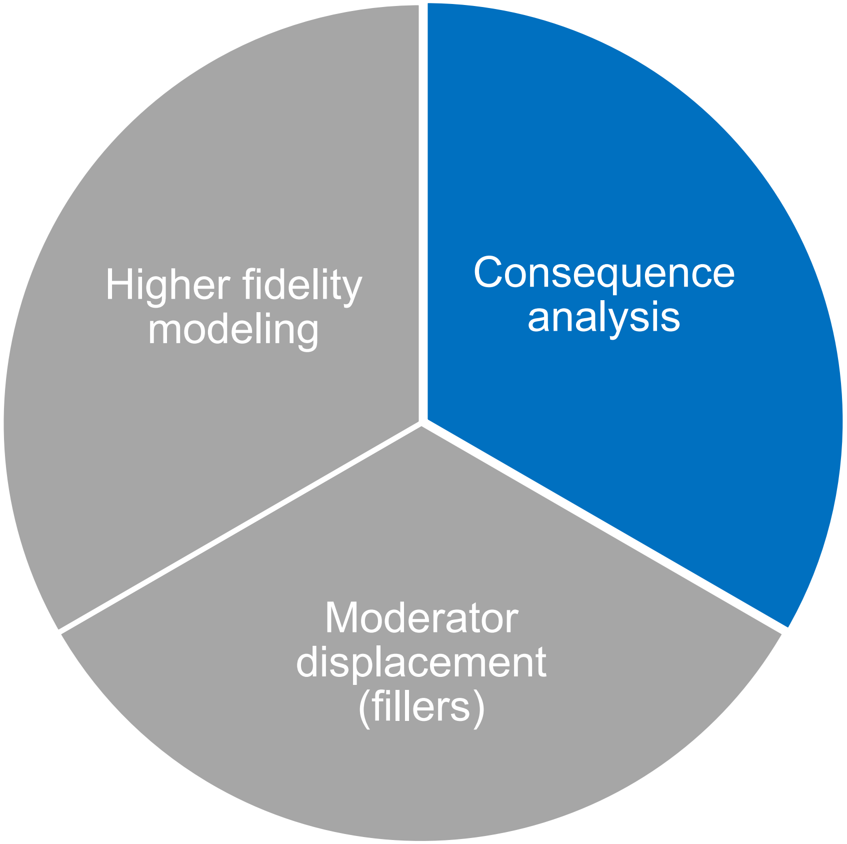


Pictures of vent and drain ports

A Multiphysics simulation capability is being developed to support and assess DPC filling process

- Stage 1 - Single physics with validation experiments (unit testing)
  - Flow simulation (under development) to determine injectability, void filling, filling time, filling method (pump vs. gravity)
  - Thermodynamic simulation (not started) to understand solidification behavior
  - Heat transfer (first phase completed) to understand temperature distribution, waste package temperature
- Stage 2: Multiphysics with validation experiments (scaled DPC testing)
  - Multiphysics coupling (flow + thermodynamic + heat transfer) to develop a predictive tool

Option 3: Consequence analysis



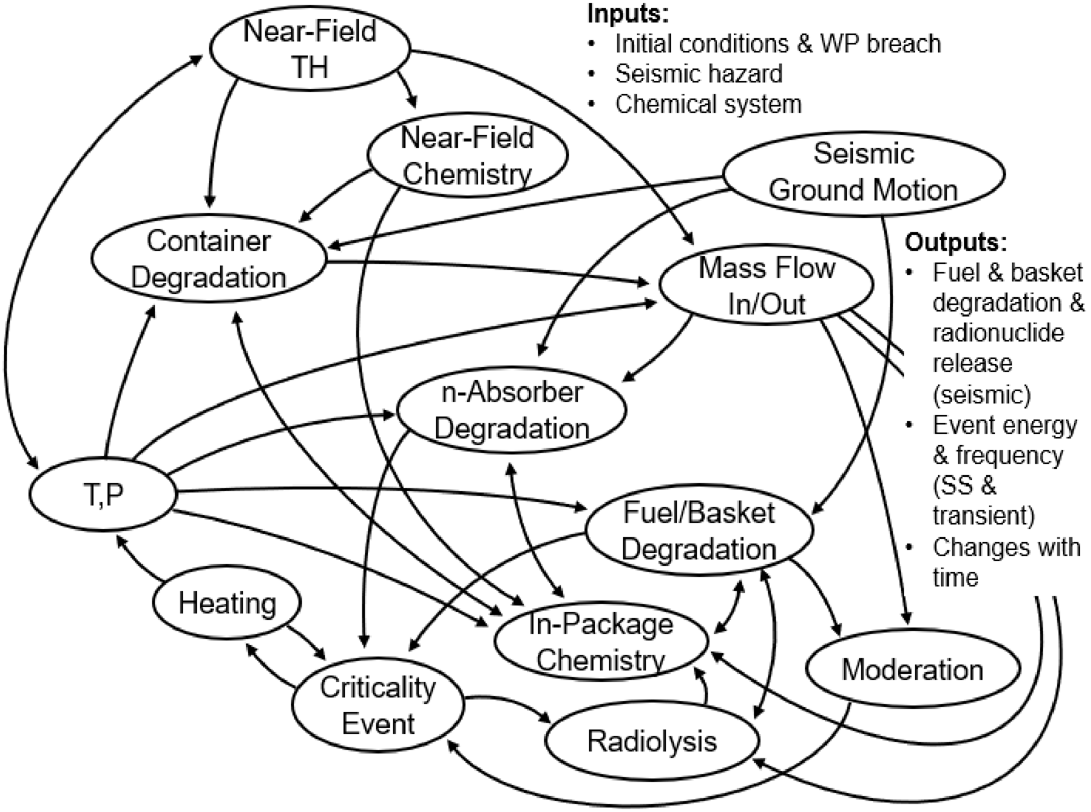
Higher fidelity modeling

Consequence analysis

Moderator displacement (fillers)

Geologic repository criticality event consequence modeling is complex and changes over time

- Changing repository conditions
  - Temperature, humidity, and chemistry (affects degradation)
  - Water movement (moderator and transport mechanism)
- Changing waste package conditions
  - Material degradation (barriers and basket)
  - Changing of geometry (basket degradation)
- Changing spent fuel conditions
  - Waste form degradation (cladding and assembly structure)
  - Isotopic concentrations (decay and buildup)



Inputs:
- Initial conditions & WP breach
- Seismic hazard
- Chemical system

Near-Field TH

Near-Field Chemistry

Seismic Ground Motion

Container Degradation

Mass Flow In/Out

n-Absorber Degradation

T,P

Fuel/Basket Degradation

Heating

In-Package Chemistry

Criticality Event

Radiolysis

Moderation

Outputs:
- Fuel & basket degradation & radionuclide release (seismic)
- Event energy & frequency (SS & transient)
- Changes with time

Conceptual illustration of interdependent processes affecting repository performance modeling

DPC criticality consequence analyses is important for understanding impacts on geologic repository performance

- Consequences of a criticality event on repository performance parameters include power/heat, duration of event(s), changes in radionuclide inventory, and impacts on near field environment
  - Quasi-steady state (oscillates between critical and subcritical states)
  - Transient
- Impact on repository performance is measured by change in dose from the transport of radioactive nuclides to the accessible environment
- Activities are in progress to develop a generic (non-site specific) PA model with the capability to include effects of DPC criticality events in the overall simulation to either screen criticality events out of the PA on basis of low consequence, or to include it in the PA
- Multiphysics modeling of DPC criticality can be used to inform magnitude of repository parameter perturbations in PA model from a critical event

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Objective

- Develop an approach to modeling the consequences of criticality on repository performance
  - Screen criticality from PA on the basis of consequence OR
  - Included in PA, if criticality cannot be excluded from PA.

Phased Approach

- Two phases, scoping and execution
- We are in first phase, completion January 2019
- Approach will be built on DOE’s *Disposal Criticality Analysis Methodology Topical Report*
- Focus on the consequences of criticality in a dual-purpose canister, not the probability of occurrence
- Include uncertainty and variability as appropriate
- Examining only in-package criticality
- May adopt bounding assumptions in some instances

Some Previous Criticality Consequence Calculations

- Performance Assessment of the Direct Disposal in Unsaturated Tuff of SNF and HLW Owned by the U.S. DOE – SNL, 1995
  - Inventory increased about 1% over 10,000 years of criticality
  - All packages, steady-state temperature just below boiling
- Second Waste Package Probabilistic Criticality Analysis: Generation and Evaluation of Internal Criticality Configurations – CRWMS, 1996
  - Total curies increased about 24% over 10,000 years of criticality
  - Very conservative; does not imply 24% increase in dose
- Criticality Consequence Analysis Involving Intact PWR SNF in a Degraded 21 PWR Assembly Waste Package – CRWMS, 1997
  - Transient event, negligible inventory increase, no effect on other waste packages or overall integrity of the repository

Some Previous Criticality Consequence Calculations (cont’d)

- Sensitivity Study of Reactivity Consequences to Waste Package Egress Area – OCRWM, 1999
  - Examined pressure, temperature, power output as a function of waste package egress area
- System-Level Performance Assessment of the Proposed Repository at Yucca Mountain Using the TA Version 4.1 Code – CNWRA, 2004
  - Dose in steady-state case increased by a factor of three, dose in transient case increased by an order of magnitude
  - Found the risk from criticality to be small because the conditional dose is below the standard, and probability of the event is expected to be low

Cases to be Considered

- Alluvium, unsaturated, quasi-steady-state
- Alluvium, unsaturated, transient
- Shale, saturated, quasi-steady state
- Shale, saturated, transient

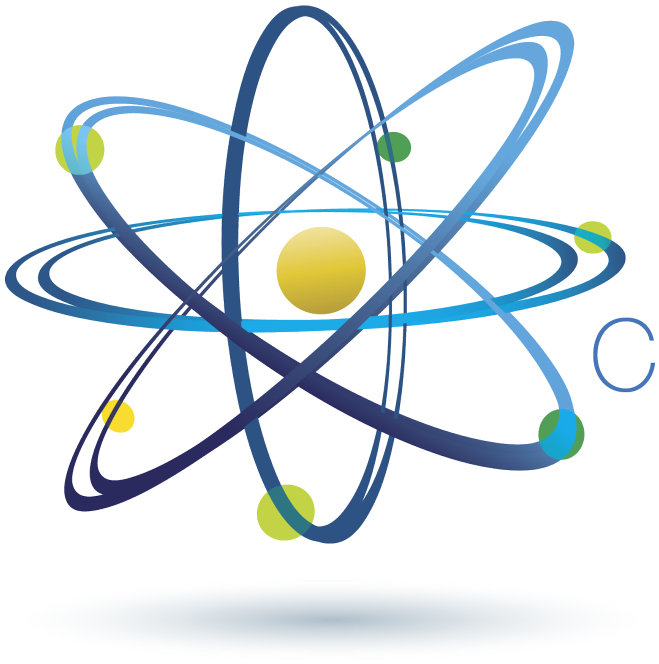
Parameters and phenomena to be included

- As-loaded inventory
- Corrosion and corrosion products
- Burnup credit (where possible)
- Shut-off mechanism for criticality
- Temperature
- Pressure
- Fission and activation product generation
- Radiolysis
- Chemical effects
- Mechanical effects from transient events

Strategy

- Identify DPCs to be modeled
- Develop conceptual models of how criticality occurs and progresses over time
- Employ a computational performance assessment model for each conceptual model
- Calculate time-dependent outputs of interest for each model
  - Temperature
  - Inventory
  - Radiolysis and chemical effects
  - Mechanical damage
- Run model with and without criticality event, compare output

Questions?



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