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Feasibility of Direct Disposal of Dual-Purpose Canister From a Criticality Perspective

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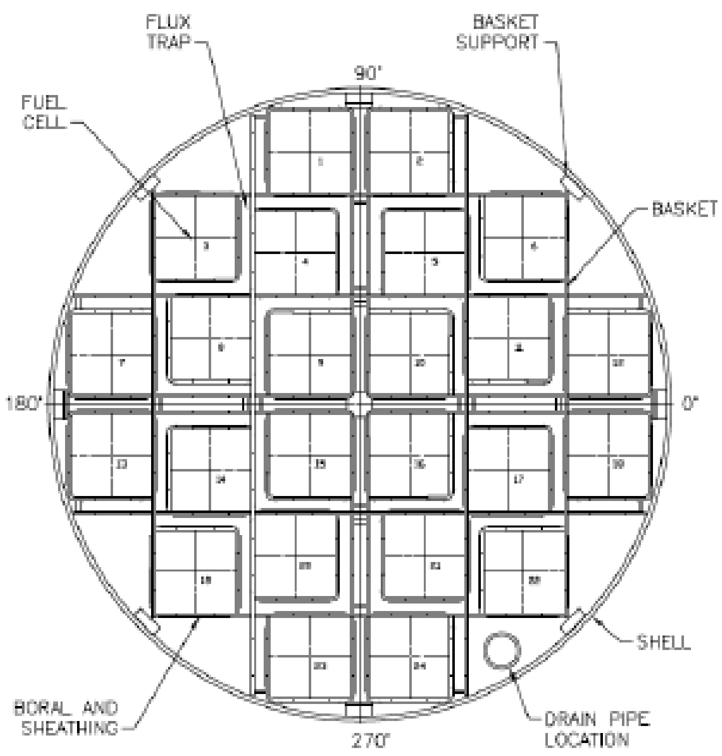
Outline

- **Dual-purpose canister (DPC) concept for used nuclear fuel (UNF)**
- **Motivation for direct disposal of DPCs**
- **Potential criticality analysis approaches for direct disposal of DPCs**
- **Criticality studies with dissolved aqueous species in the groundwater**
- **As-loaded canister-specific criticality analysis**
- **Conclusion**

Used nuclear fuels are stored in a basket built as a honeycomb of cellular elements positioned within a canister

- **Fuel basket structure and canister are typically made of stainless steel**
  - Coated carbon steel has also been used
- **Neutron absorber (such as Boral®) plates are typically attached to the basket cells**
  - Neutron absorbers are comprised of a chemical form of the neutron absorber nuclide (such as B-10 in B_4C) and a matrix (such as Al or stainless steel) that holds the absorber nuclide
- **Canisters are typically dual-purpose as they are designed for storage and transportation**
- **The canister is placed in different overpacks for storage, transportation, and disposal (if they are disposed of)**



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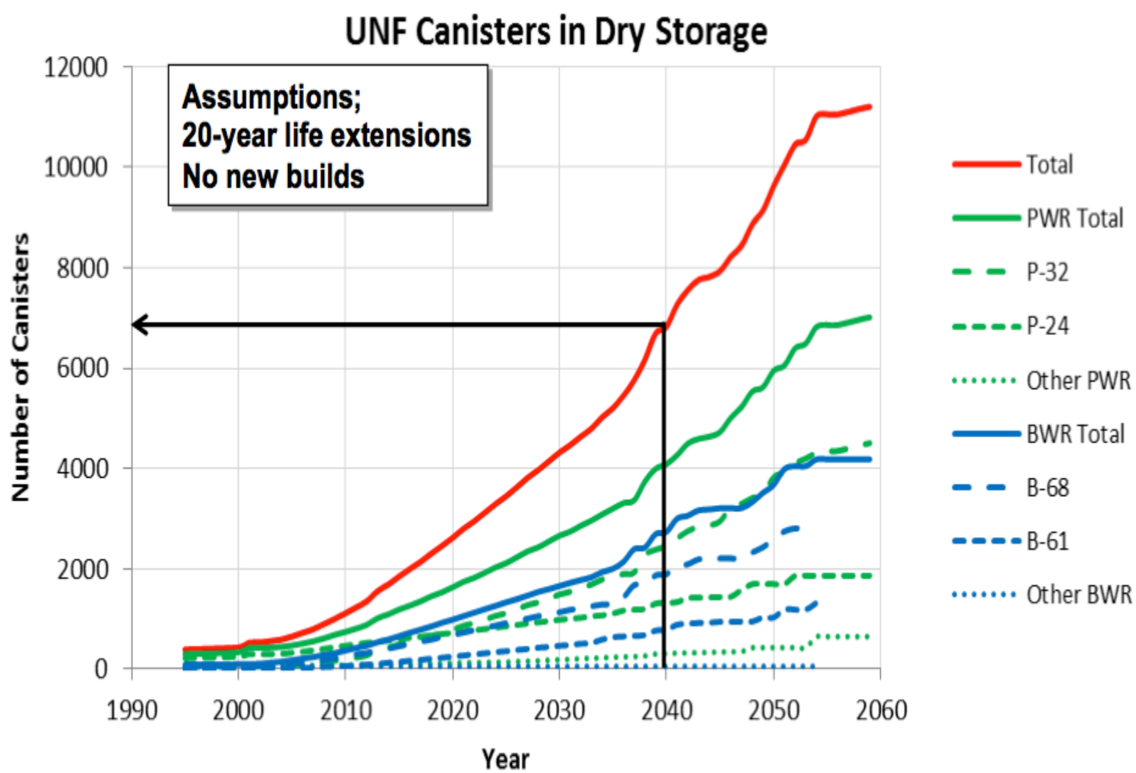
Used nuclear fuels will eventually be disposed of in a geological repository yet to be determined

- **Current used fuel disposition campaign research is focused on investigating the feasibility of direct disposal of existing canister systems (DPCs)**
- **Why evaluate direct disposal of large DPCs?**
  - Less fuel handling
  - Less repackaging (facilities, operations, new canister hardware)
  - Lower worker dose
  - Less secondary waste (e.g., no separate disposal of existing DPC hulls)
  - Less cost



Sometime before 2040 more than half of the commercial SNF in the U.S. will be stored in ~7,000 DPCs at power plants or decommissioned sites.

One of the principal challenges to direct disposal of DPCs is the potential for criticality over repository time frames (10,000 years or more)

- **DPC criticality in a repository requires groundwater (also called moderator) infiltration and material and structural degradation**
- **Two approaches are examined to address the potential criticality concern:**
  - **First approach:** Various dissolved aqueous species are investigated to determine whether they can provide any reactivity suppression
  - **Second Approach**: Inherent uncredited criticality margins in DPCs are quantified and credited
    - Storage and transportation Certificates of Compliance are based on established bounding loading specifications using design-basis limits
    - Because of the diverse UNF population, it is not possible to load a DPC with UNF that represent exactly the design-basis limits, thereby providing some amount of unquantified, uncredited safety margin
    - The uncredited safety margin associated with actual loading is investigated to offset reactivity increases from flooding and associated basket material degradation

Potential DPC degradation may include gradual loss of neutron absorber to complete loss of basket structure

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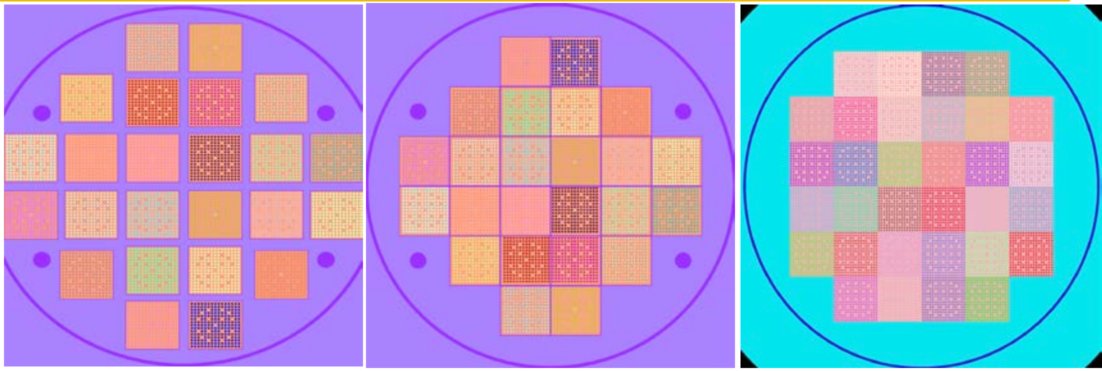
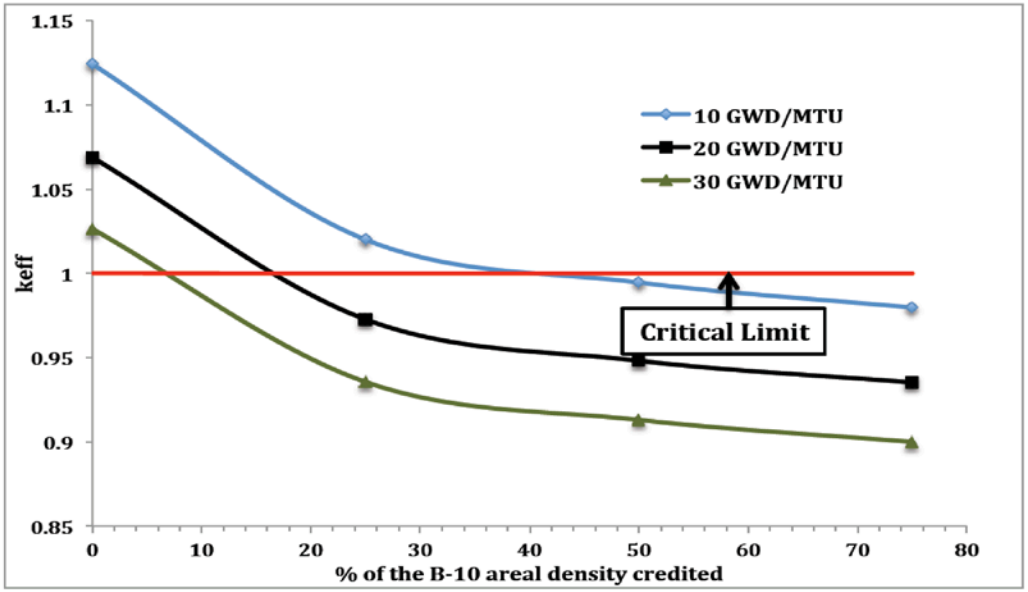
- **Three potential degradation scenario end-states are considered**
  - Gradual loss of neutron absorber (measured by B-10 areal density)
  - Loss of coated carbon steel basket supports
  - Complete loss of basket
- **Criticality control options considered**
  - Burnup credit (NUREG/CR-7109)
  - Actual as-loaded cask configuration
  - Credit for materials in solution (e.g., salt)
- **ORNL's SCALE code is used for criticality studies. As-loaded, site specific calculations are performed using UNF-ST&DARDS (See abstract #608)**



Degradation models used for criticality study



Reactivity impact of B^{10} areal density variation

Geochemistry of the repository will determine the composition of groundwater

- **The dissolved aqueous species available in the groundwater widely vary depending on the geochemistry of the repository concepts under considerations (salt, crystalline rock, clay/shale, sedimentary rock, and hard rock)**
- **The following dissolved species are commonly available in varying quantity in the repository concepts under consideration**
  - Ca, Li, Na, Mg, K, Fe, Al, Si, Ba, B, Mn, Sr, Cl, S, Br, N, and F
- **The quantity of the dissolved species can vary from less than 1 mg/liter (for example, Li in Opalinus clay*) to more that 150,000 mg/liter (For example, Cl in a salt repository**)**

*Y. Wang et. al., "Integrated Tool Development for Used Fuel Disposition Natural System Evaluation – Phase I Report," Prepared for U.S. Department of Energy Used Fuel Disposition, FCRD-UFD-2012-000229 SAND2012-7073P, 2012.
**J. Winterle et. al., "Geological Disposal of High-Level Radioactive Waste in Salt Formation." Center for Nuclear Waste Regulatory Analyses, San Antonio, Texas, March 2012.

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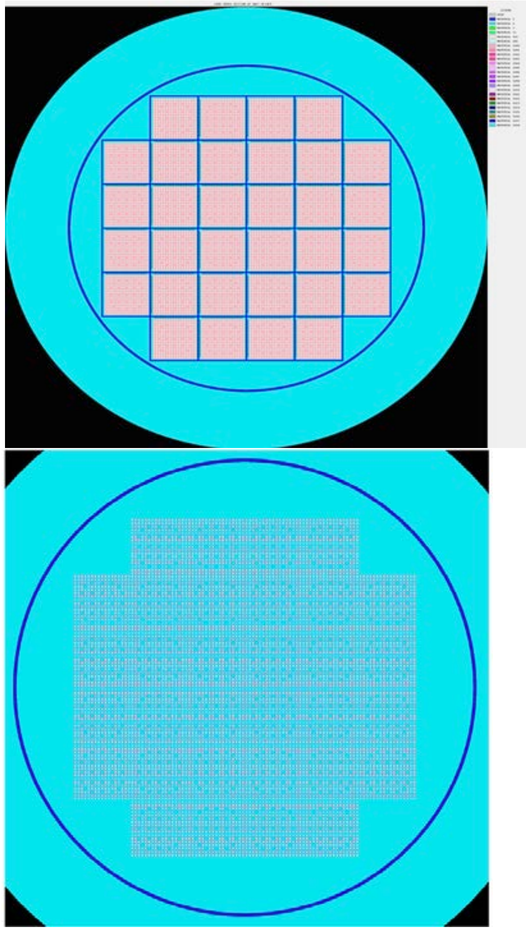
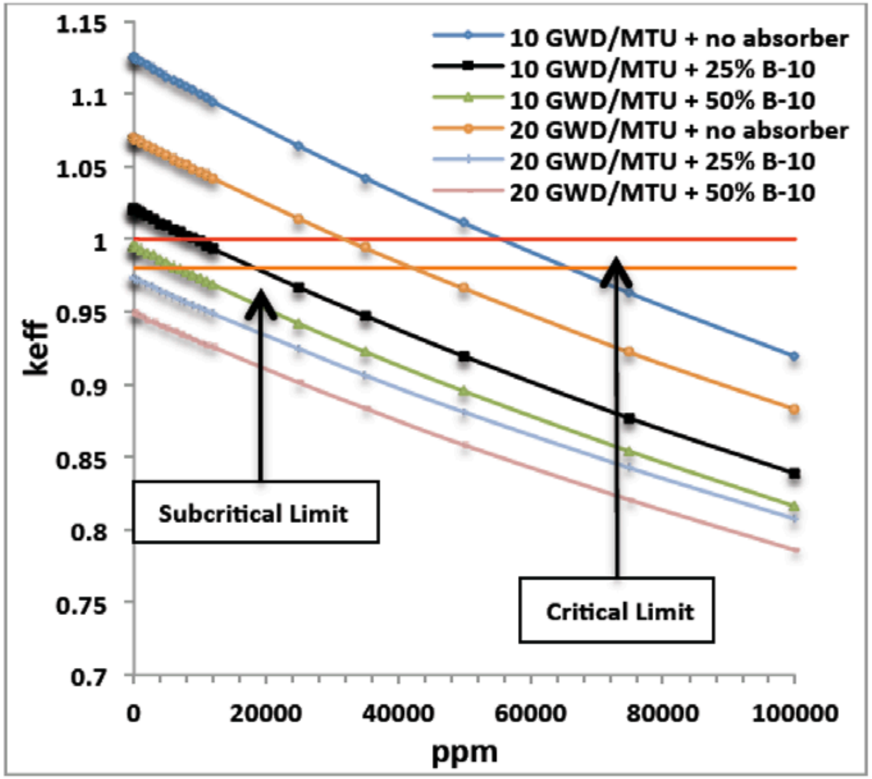
Dissolved species present in the groundwater may offset the reactivity increases due to loss of neutron absorber and basket structure

- **Various dissolved species present in the groundwater across the repository concepts may have twofold impact on reactivity**
  - They can act as neutron absorber (For example, Cl-35 isotope in Cl and Li-6 isotope in Li)
  - They can displace moderator (water) which is essential for criticality
- **The objective of this work is to investigate the neutron absorption characteristics of different dissolved species that can potentially be available in various geological media**
- **Studies are performed by varying the quantity of the following dissolved species in groundwater**
  - Ca, Li, Na, Mg, K, Fe, Al, Si, Ba, B, Mn, Sr, Cl, S, Br, N, and F

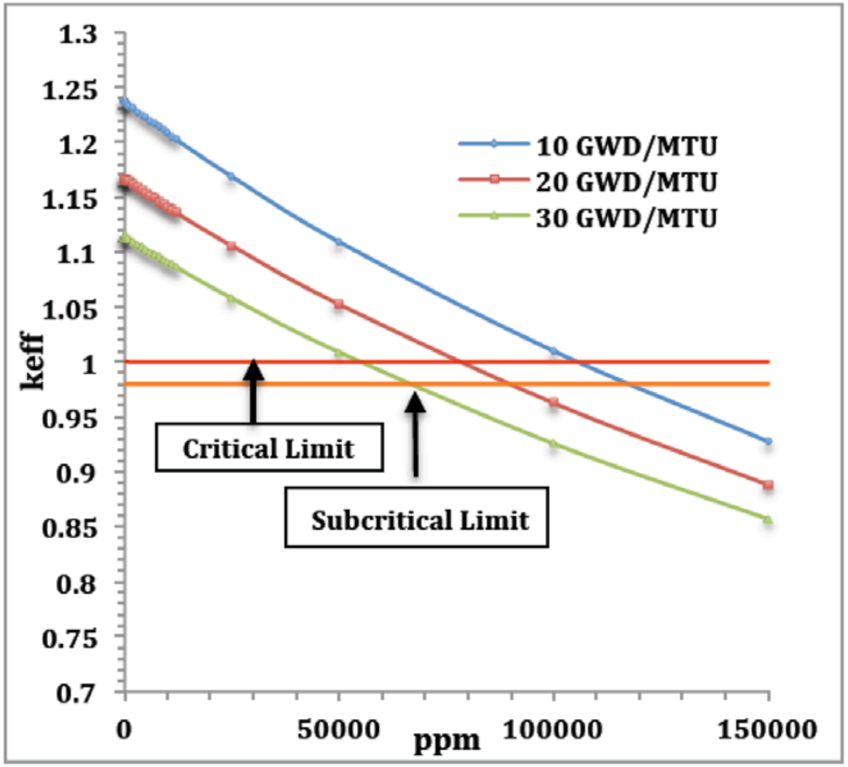


Cross-section views of the Holtec International's MPC 32 used for the ground water studies with gradual loss of neutron absorber and degraded basket

Cl, Li, and B have significant impact on reactivity, while other species provide insignificant reactivity suppression



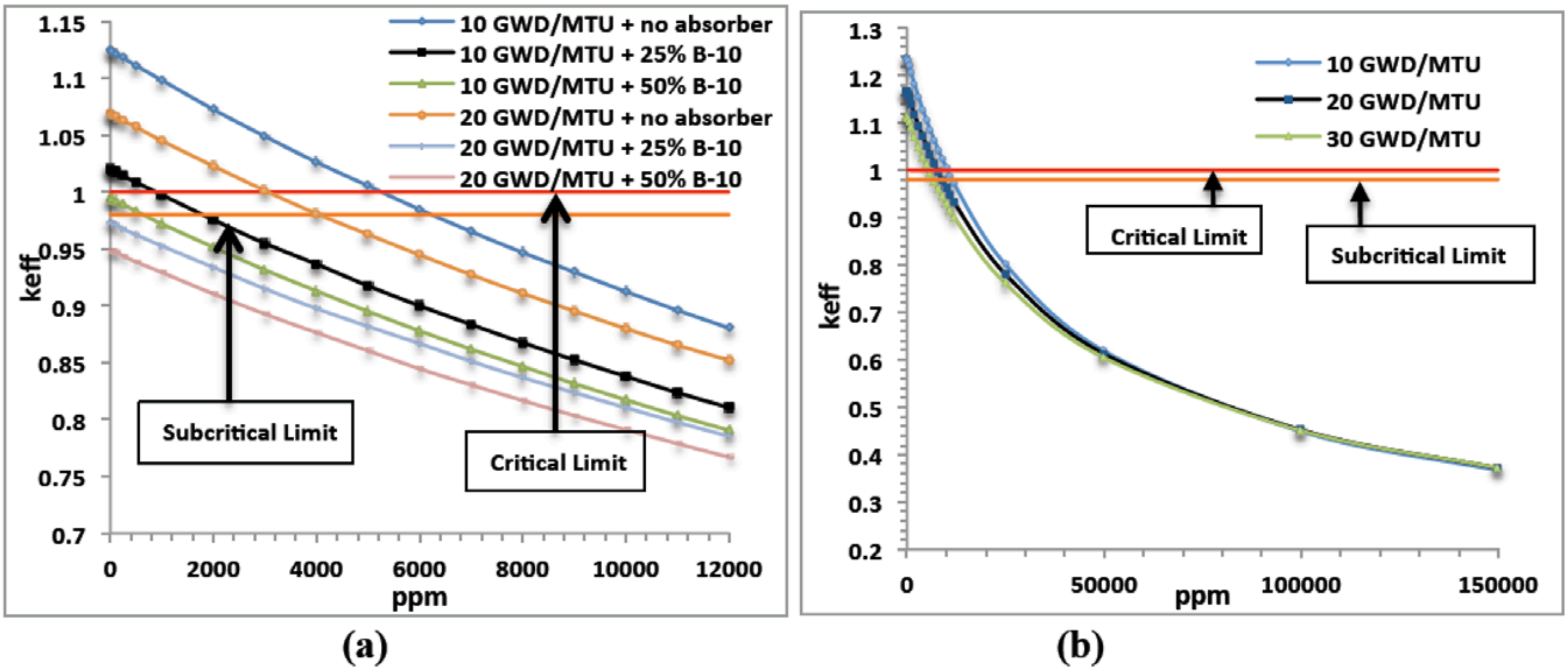
(a)



(b)

(a) Reactivity impact of chlorine concentration in groundwater for different levels of neutron absorber; (b) reactivity impact of chlorine concentration in groundwater for degraded basket configuration.

Cl, Li, and B have significant impact on spent nuclear fuel reactivity, while the other species provide insignificant reactivity suppression



(a) Reactivity impact of lithium concentration in groundwater for different levels of neutron absorber; (b) reactivity impact of lithium concentration in groundwater for degraded basket configuration.

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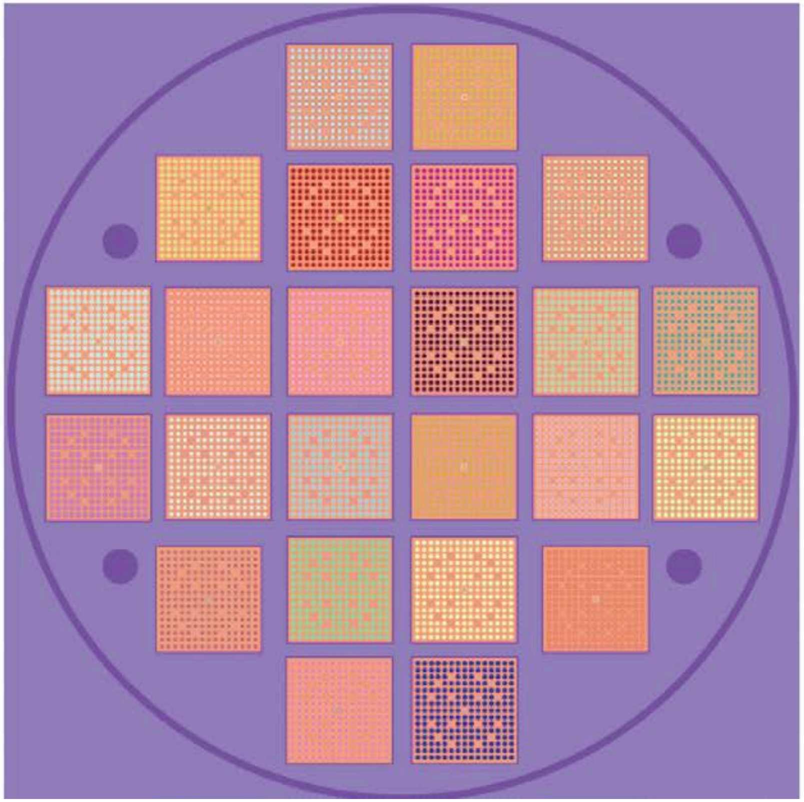
Only Cl is expected to be present in sufficient amounts to suppress reactivity in the geological media under consideration

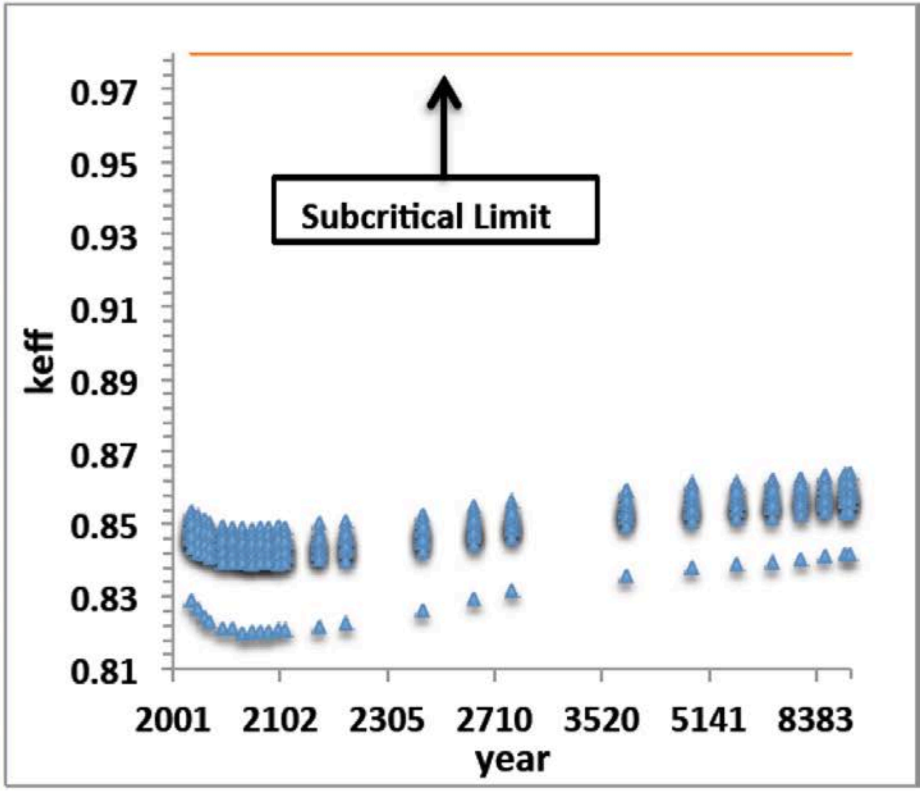
- **In addition to salt repository concepts, Cl is also available (in moderate quantity) in clay*, granite* and crystalline rock****
  - The quantity of Cl varies between the geological media
- **Literature reviews show that Li and B may also be available in small quantity in some geological media***
- **Other commonly available dissolved aqueous species may not yield a significant neutron absorption effect, but together may provide a significant moderator displacement effect (not studied here)**

*Y. Wang et. al., “Integrated Tool Development for Used Fuel Disposition Natural System Evaluation – Phase I Report,” Prepared for U.S. Department of Energy Used Fuel Disposition, FCRD-UFD-2012-000229 SAND2012-7073P, 2012.
**C.F. Jove Colon et. al. “Disposal Systems Evaluations and Tool Development – Engineered Barrier System (EBS) Evaluation,” Prepared for U.S. Department of Energy Used Fuel Disposition Campaign, SAND2010-8200, 2011.

Margin obtained by analyzing the canister-specific loading can offset reactivity increase from flooding and basket material degradation

- **Site A: 20 as-loaded DPCs (24 assemblies) are analyzed**
  - Full flooding with pure water
  - **Configuration one: Loss of absorber panels**





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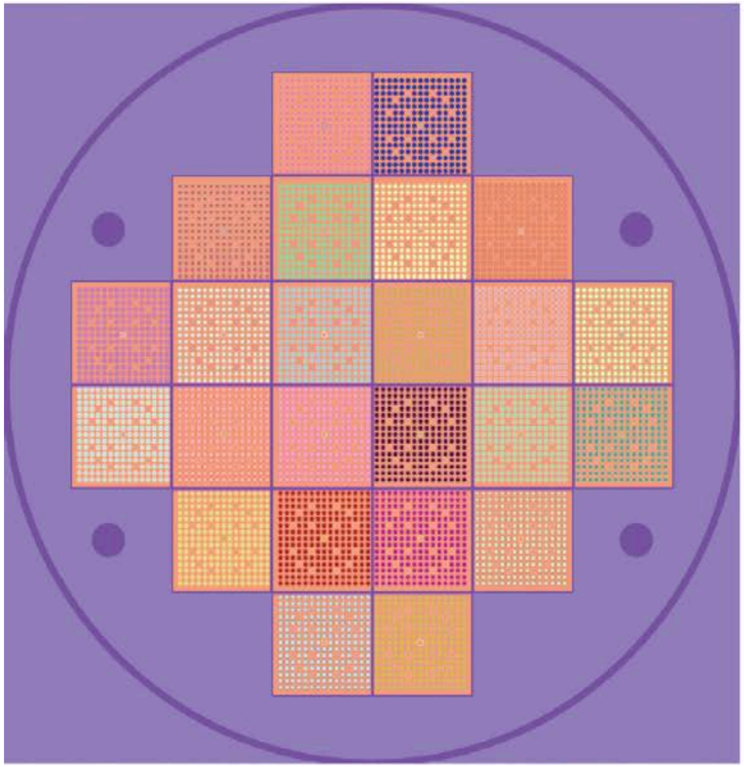
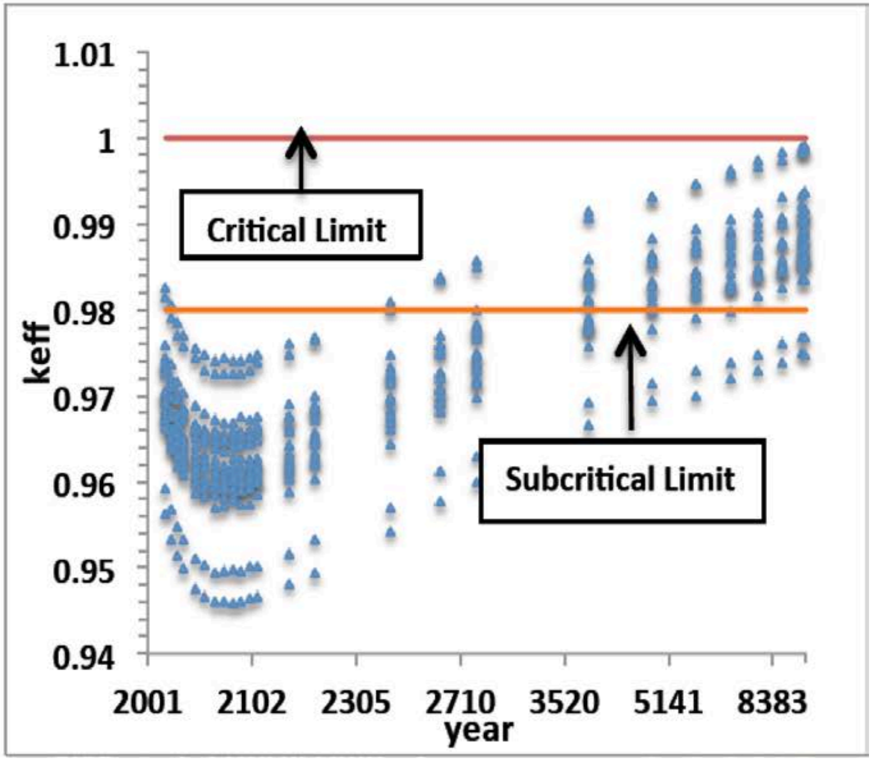
Margin obtained by analyzing the canister-specific loading can offset reactivity increase from flooding and basket material degradation

- **Site A: 20 DPCs (24 assemblies) are analyzed**
  - Full flooding with pure water
  - **Configuration two: Loss of absorber panels and coated carbon steel spacer disks**





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The uncredited margin associated with actual fuel loading compared with the licensing limits can offset reactivity increase over repository time frame

Number of canisters analyzed for Site A	20
Configuration one: Loss of neutron absorber panels	
Number of canisters with k_{eff} > 0.98 with design basis analyses	**20**
Number of canisters with k_{eff} > 0.98 with cask specific analyses in the year 9999	0
Max k_{eff}	0.86381
Configuration two: Loss of neutron absorber panels and spacer disks	
Number of canisters with k_{eff} > 0.98 with design basis analyses	**20**
Number of canisters with k_{eff} > 0.98 with cask specific analyses in the year 9999	18
Max k_{eff}	0.99901
Approximate Cl requirement	10,000 ppm

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DPC disposal criticality safety demonstration may require both canister-specific evaluations and credit for neutron absorbers present in the groundwater

- **Direct Disposal of DPCs has many potential benefits**
  - Criticality is a challenge
- **If chlorine from the repository environment is in the groundwater, there may be substantial criticality benefits**
  - It may be difficult to benchmark this analysis with current criticality experiments
- **Using actual as-loaded cask models (instead of design basis models), provides another significant criticality benefit**
- **Additionally, criticality consequence analyses can be used to determine the impact of one or more criticality events on the repository performance.**

Future repository criticality safety demonstrations may need to consider both groundwater neutron absorber credit and cask-specific evaluations