Used Fuel Disposition Campaign

Criticality Aspect of the DPC Direct Disposal

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UFD Working Group Meeting
June 9-11, 2015

Outline

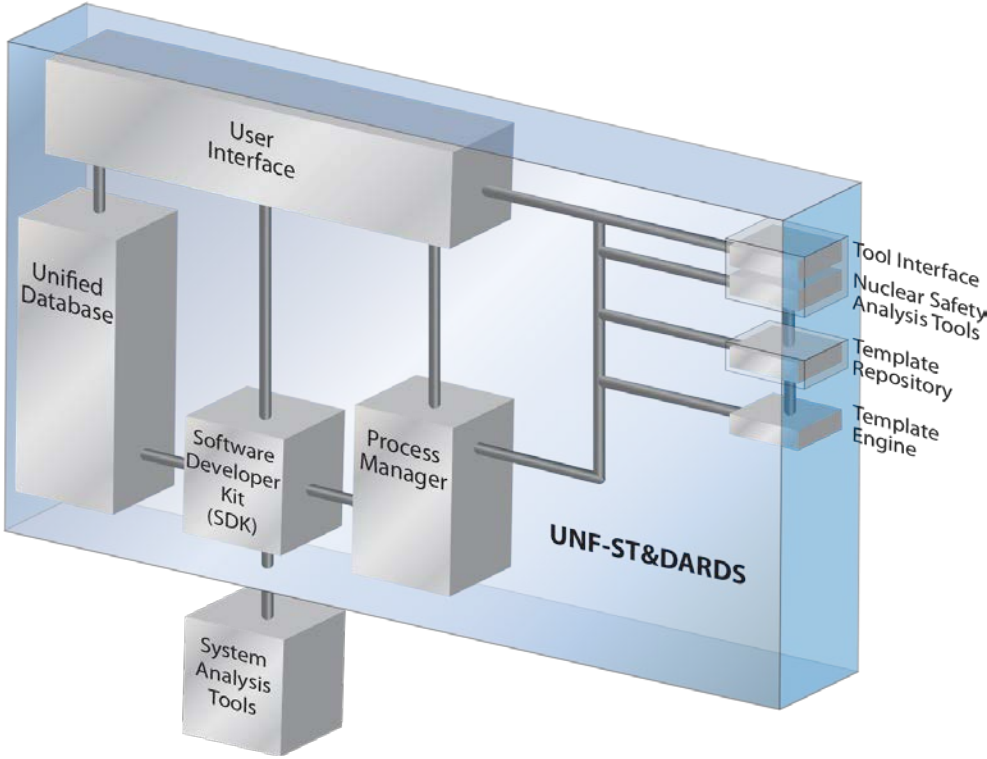
- As-loaded analysis to support direct disposal of DPC
- As-loaded analysis with Cl credit
- As-loaded analysis with filler materials
- Conclusion and future work

Several new criticality analyses were carried out in FY15 to support the feasibility of direct disposal of DPCs

- **Criticality scoping assessment to support the feasibility of DPC direct disposal started in FY13**
- **Objective is to evaluate available margins, options and parameters of importance to support the feasibility of direct disposal of DPCs from criticality perspective**
- **M4FT-15OR0816013 – issued on December 19, 2014**
  - Validation basis for Cl reactivity suppression in groundwater
- **M4FT-15OR0816011 - issued on March 30, 2015**
  - Updated all criticality results with a set of 29 principal isotopes from criticality analysis topical report
  - Three new sites including a boiling water reactor (BWR) site (additional 36 DPCs) were analyzed
  - Reactivity impact Cl applied to as-loaded DPCs
  - Reactivity impact of filler material applied to as-loaded DPCs

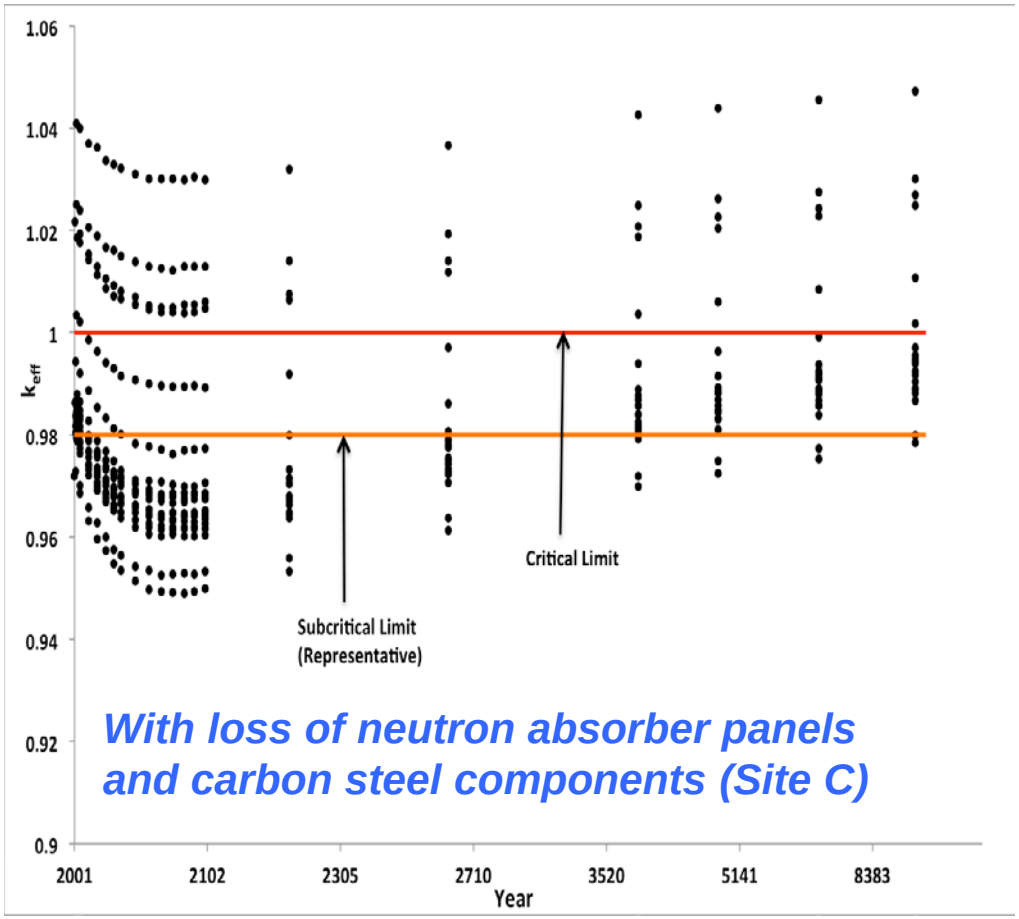
A new tool has been developed to perform as-loaded analyses to quantify realistic safety margins

- **Used Nuclear Fuel- Storage, Transportation & Disposal Analysis Resource and Data System (UNF-ST&DARDS) is used for as-loaded analyses**
- **UNF-ST&DARDS uses template based process for automated analyses**
  - Templates are being developed for various degradation scenarios to support disposal criticality analysis
- **ORNL's SCALE code is used for criticality analyses**



Criticality analyses were performed for loaded DPCs at eight sites using as-loaded configuration

- **215 loaded DPCs at eight sites were analyzed**
  - Six DPC types including 24-assembly baskets (flux trap design) and 32-assembly basket
  - One BWR site analyzed
- **Two degradation scenarios were considered**
  - Loss of neutron absorber panels (seven sites)
  - loss of carbon steel components and neutron absorber panels (one site)
- **Representative subcritical limit**
  - k_{eff} <0.98 was used in this study as a representative acceptance criteria for as-loaded calculations



75% of analyzed DPCs are below the representative subcritical limit with as-loaded analysis (fresh water)

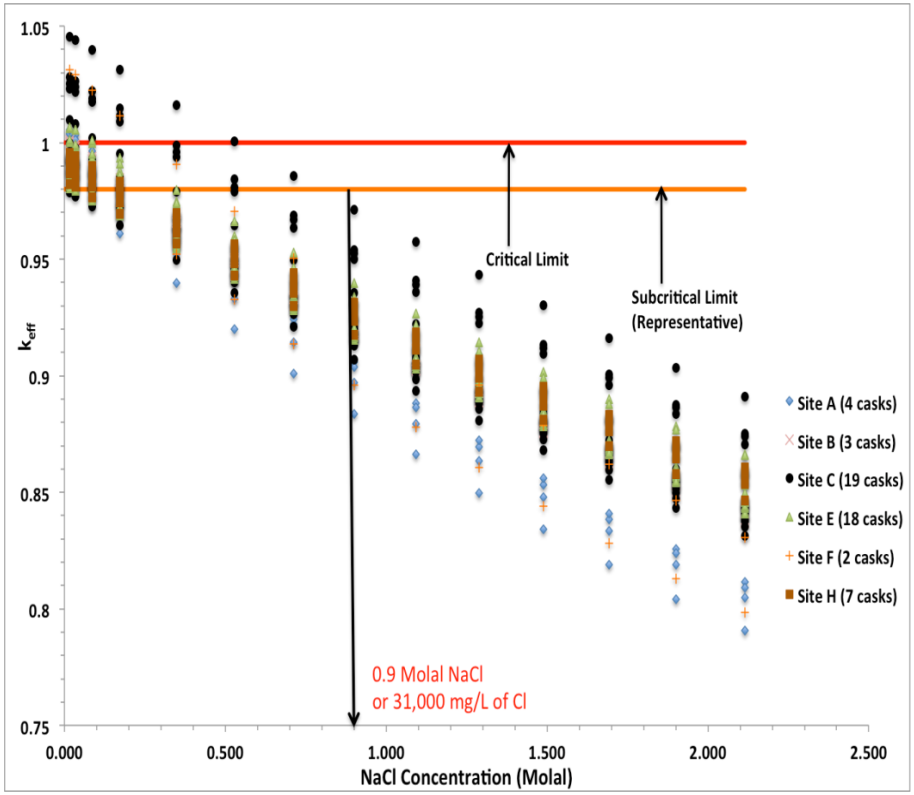
Description	Value
Total DPCs analyzed	215
Total DPCs that fail subcriticality with loss of neutron absorber (design-basis loading)	215 (100%)
Total DPCs that fail subcriticality (as loaded)	
Loss of neutron absorber	34 (16%)
Loss of neutron absorber and carbon steel structures	53 (34+19) (25%)

What else can be credited?

1. ***Components such as burnable poison rod assemblies (BPRAs)***
2. ***Aqueous species in groundwater such as Chlorine***
3. ***Preconditioning with filler materials***

Cl is expected to present in all the geological media under consideration and provides noticeable reactivity reduction

- **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)**



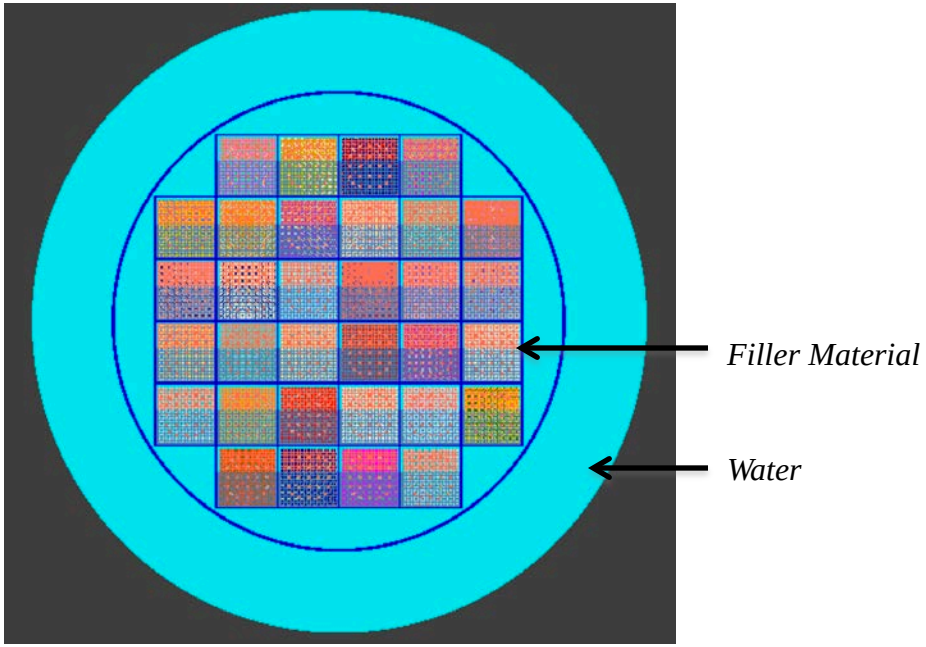
*Y. Wang et. al., "Integrated Tool Development for Used Fuel Disposition Natural System Evaluation – Phase I Report," Prepared for U.S. Department of Energy Used Fuel Disposition, FCRD-UFD-2012-000229 SAND2012-7073P, 2012.
**C.F. Jove Colon et. al. "Disposal Systems Evaluations and Tool Development –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

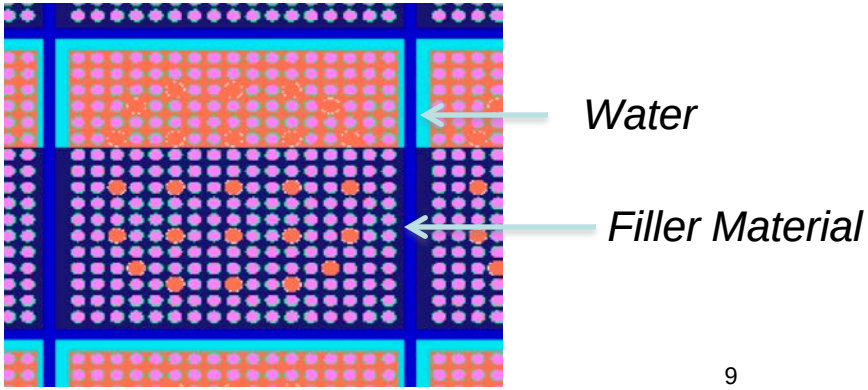
A dedicated set of criticality experiments to validate Cl credit is required

- **Extensive literature search has been conducted**
  - Experiments involving Cl (in PVC, plexiglas) were only found in International Handbook of Evaluated Criticality Safety Benchmark Experiments (ISCBEP)
- **Identified 11 best applicable experiments through statistical analysis (similarity coefficients)**
  - Small sample size doesn't provide good statistics
- **Other validation options explored**
  - Sensitivity and uncertainty analysis of nuclear data to predict biases for individual nuclides (NUREG/CR 7109)
  - Cross-section adjustment within cross-section covariance data using TSURFER (SCALE) to estimate the bias and bias uncertainty of the application systems (loss of absorber and loss of basket)
  - A dedicated series of criticality configurations for generating Cl validation data using Sandia's critical experiment facility

Filler materials can also be used to prevent flooding of the DPCs during the repository time frames

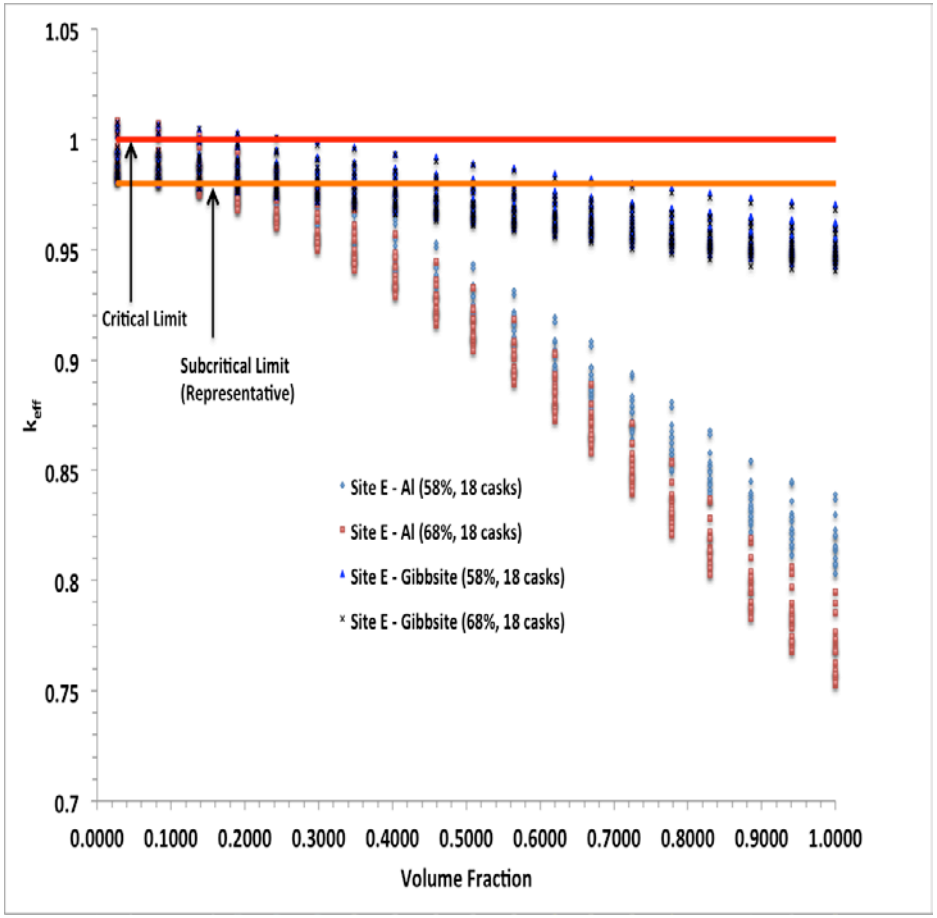
- The moderator displacement aspect of the filler materials was investigated using as-loaded DPCs at Site E (with loss of neutron absorber)
- Aluminum was used as a representative filler material that only provides water displacement
- Gibbsite ($Al(OH)_3$), which is a mineral of aluminum and can potentially form from aluminum in the presence of water over the repository performance period, was also considered
- 58% and 68% volumetric mixtures of filler materials were considered





Filler materials should occupy substantial DPC volume to provide criticality control over repository time frames

- About 34% volume (58% volumetric mixture) is required to be filled (uniformly) by aluminum slurry to maintain k_{eff} below 0.98 for all the DPCs at Site E in the year of 9999
- However, if the aluminum turns into gibbsite (or other similar materials that react with water to form a hydrogenous compound) over the repository time frames, about 72.5% volume would be required to be filled



DPC disposal criticality safety demonstration may require both canister-specific evaluations and Cl credit

- **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**
- **Preconditioning measures such as adding filler materials to fill the canister void region and displace the moderator could be another option to mitigate post-closure criticality**

Near future work to support DPC criticality licensing

- **Only ~10% of the currently loaded DPCs were evaluated**
  - Need to analyze more high density (e.g., 32-assembly or higher) DPCs
- **Currently we are incorporating GC-859 into UNF-ST&DARDS which will provide loading maps of many loaded DPCs**
  - Need to develop disposal criticality templates to utilize all these loading maps
- **Misload analysis methodology to support full burnup credit for as-loaded configurations needs to be developed**
- **Full (actinides + fission products) BWR burnup credit methodology needs to be developed**
- **Development of an integrated criticality consequence methodology**