Overview of Dilute and Dispose Waste Form Criticality Analysis for Disposal at the Waste Isolation Pilot Plant

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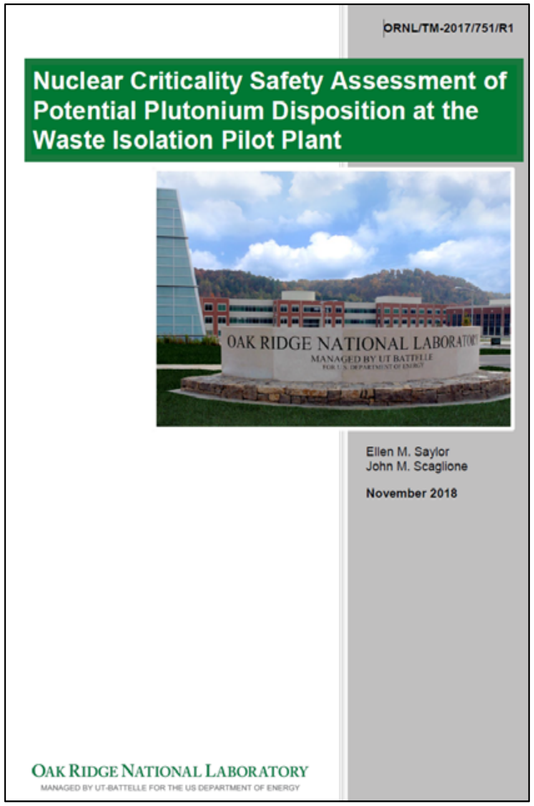
Criticality events of the Dilute and Dispose waste form can be screened out of the WIPP performance assessment on the basis of low probability

- A design basis approach was used in the evaluations considering criticality control overpacks (CCOs) and room closure in combination with other repository features, events, and processes
  - Numerous parametric analyses accounting for geometry and material composition changes
  - 380 fissile gram equivalents (FGE) ^{239}Pu per CCO
  - Accounts for both wet and dry scenarios
  - Accounts for material degradation over time
- Neutron absorbers (i.e., B_4C) integrated within the Dilute and Dispose waste form ensures subcriticality for bounding design basis configurations
- Technical report documenting the ORNL criticality analysis was finalized in November 2018


ORNL/TM-2017/751/R1

Nuclear Criticality Safety Assessment of Potential Plutonium Disposition at the Waste Isolation Pilot Plant

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OAK RIDGE NATIONAL LABORATORY
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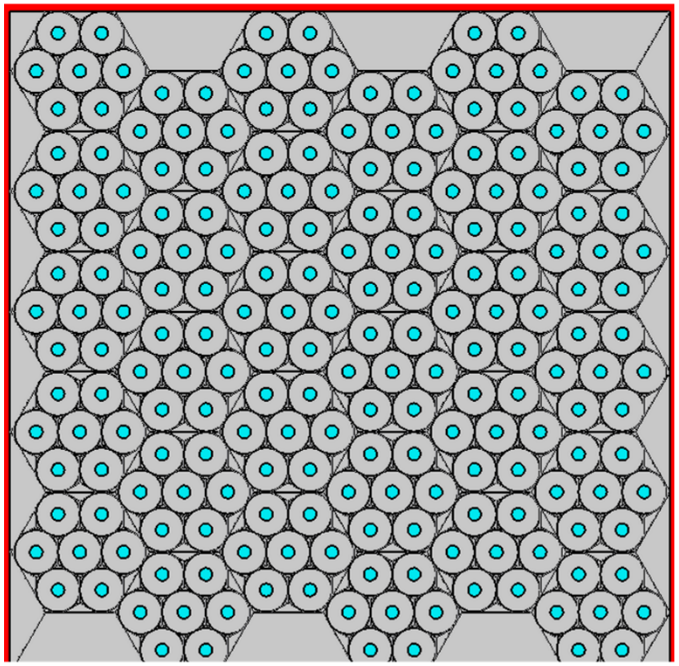
Outline

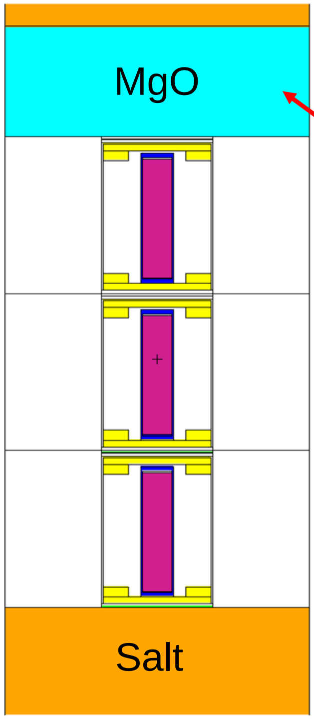
- Background
- Container and room model description
- Analysis approach and considerations
- Results
- Conclusions

Different criticality evaluations for the CCO have been performed for initial storage, transportation, and initial WIPP emplacement

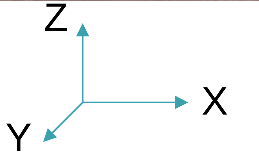
- Different methodologies and modeling approximations are appropriate because each area of application (i.e., storage, transportation, initial emplacement) is based on different timeframes, different environments, and different potential scenarios/upset conditions
- Documents reviewed prior to this work include:
  - *Consideration of Nuclear Criticality When Disposing of Transuranic Waste at the Waste Isolation Pilot Plant*, SAND99-2898
  - *Nuclear Criticality Safety Evaluation for Contact-Handled Transuranic Waste Containers at the Waste Isolation Pilot Plant*, WIPP-016
  - *CCO Criticality Analysis for TRUPACT-II and HalfPACT*, Document Number 01937.01.M009-01 (supports TRUPACT-II SAR)
  - *Comparison of Plutonium Disposition Alternatives: WIPP Diluted Plutonium Storage and MOX Fuel Irradiation*, Highbridge Associates Inc.
- The focus of the disposal criticality assessment work was after waste emplacement and based on changes to the as-emplaced conditions that could potentially occur throughout the repository's performance period (10,000 y)

Configuration scenario development starts with room collapse and salt exerting pressure on waste containers





57 rows
Six 7-packs per row
Total of 7182 drums per room



- Force from salt will be from x and z directions
- Force in y direction is from container movement

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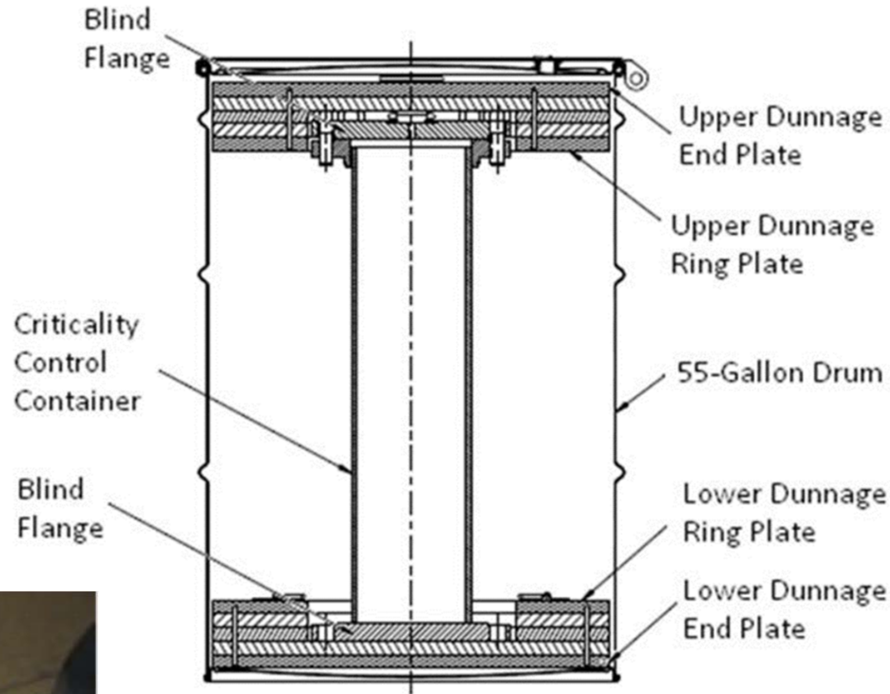
Container description

Relevant CCC dimensions (inches)

Outer diameter	6.6
Wall thickness	0.28
Flange thickness	1.0
Flange diameter	11.02
Cavity height	27



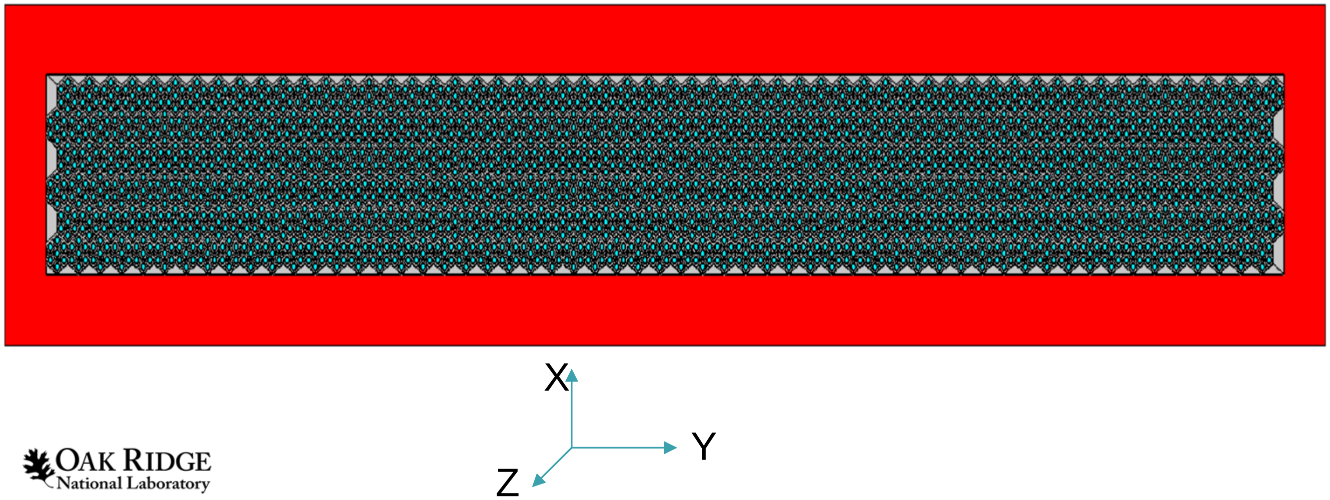
Criticality control overpack

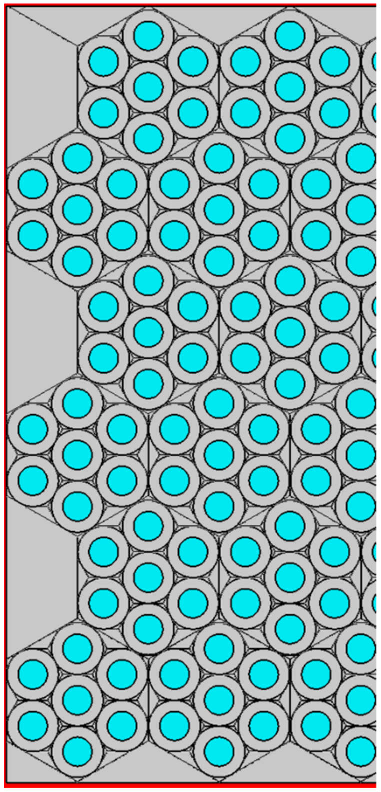
Source: Saylor and Scaglione 2018. *Nuclear Criticality Safety Assessment of Potential Plutonium Disposition at the Waste Isolation Pilot Plant,* ORNL/TM-2017/751/R1.

Photo with CCO lid and upper dunnage removed
Source: Incorporated, P. (Mar. 2011). Criticality Control Overpack 30-Foot Free Drop Post-Test Summary Report. Tech. rep. 8448-R-001, Rev. 1. Ogden UT: Petersen Incorporated.

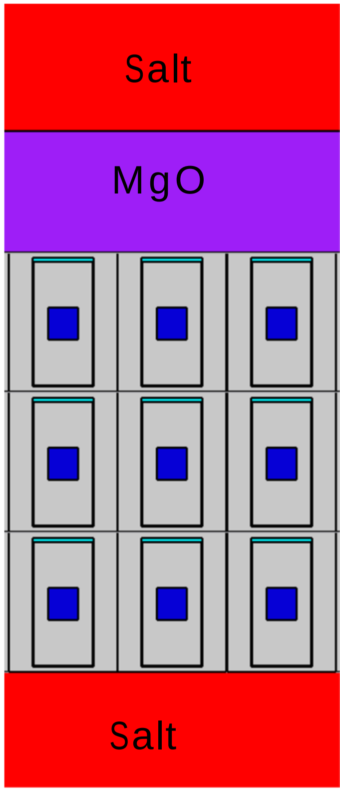
Full room configuration models used for all in-situ (internal to room) configurations

- Room of 7-packs in hexagonal lattice
  - 57 rows of staggered 7-packs, six 7-packs per row
  - Total of 7182 drums
  - Emplaced configuration is 3 high, but 2 high, and 1 high configurations also evaluated





Edge view



Side view

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Extensive parametric analyses were conducted to assess changes in neutron multiplication associated with variations in materials and geometry

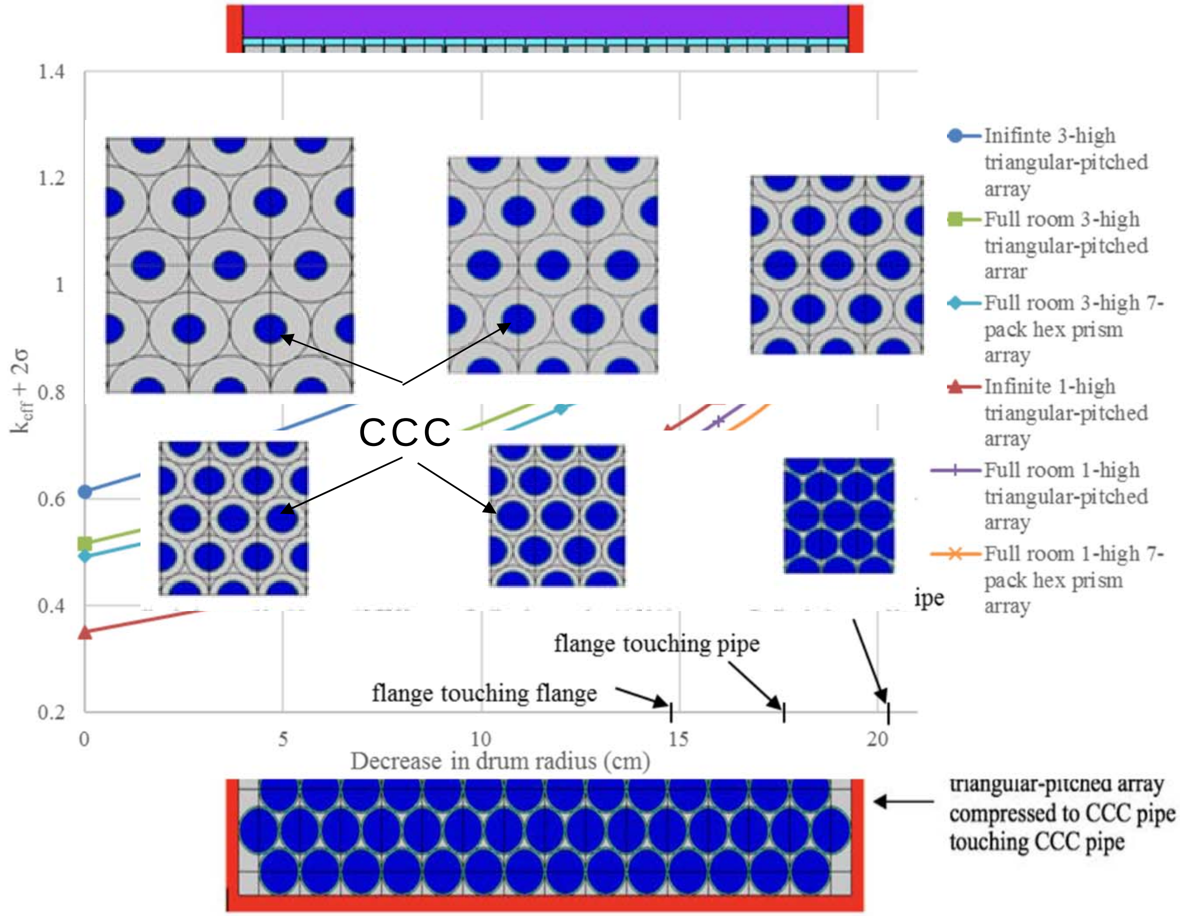
- Geometry
  - Reflectors around CCC and waste form
  - Waste form location within a CCC
  - Changes in vertical and radial spacing between waste form units (accounts for CCC corrosion/degradation)
- Waste form
  - Ratio of inorganic material to fissile material (380 fissile gram equivalent ^{239}Pu)
  - Hydrogenous content within the waste form
  - Amount and distribution of B_4C neutron absorber
  - Amount and distribution of beryllium
  - Bulk density variation within a CCC
- Results of sensitivity analyses were used to create design basis configurations
  - Reconfigured dry scenario
  - Reconfigured wet scenario (including subsequent dryout)

- Three configuration classes evaluated to quantify system sensitivity
  - Infinite array (triangular-pitched array infinite in the x and y directions)
  - Triangular-pitched array room model
  - 7-pack hexagonal array room model

Waste form compositions varied to bound actual classified composition

After room collapse, the limiting configuration for CCO containers is a full room model loaded with CCCs in a triangular pitch

- Under time/pressure the limiting configuration is a pure drum hexagonal array (i.e., drums collapse under pressure and CCCs move closer together)
- Neither the carbon steel of the 55-gallon drum nor the plywood dunnage (top and bottom of drum) are modeled, stainless steel of CCC is modeled
  - Each CCC has 380 g Pu as PuO_2 in 3800 g of concrete-like mix (10% water) plus 400 g polyethylene (modeled as CH_2)



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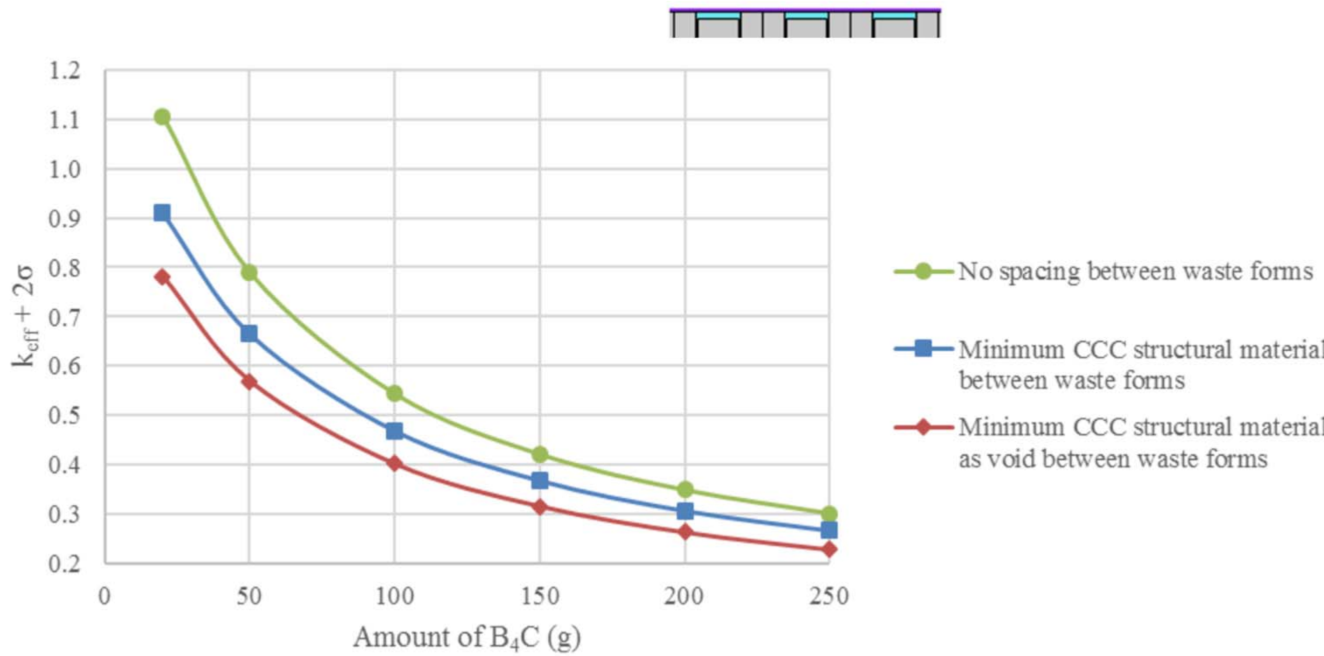
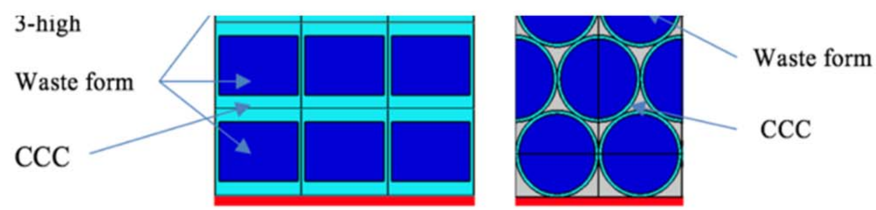
To account for changes in vertical spacing, sensitivity analyses were modeled to account for CCC degradation before the waste form degrades

- Vertical range starts as initial emplaced to fully touching vertically and radially
- Account for brine saturation and dry out
- Account for partial corrosion product and nothing between waste form
- Some models have the stainless steel of CCC completely omitted





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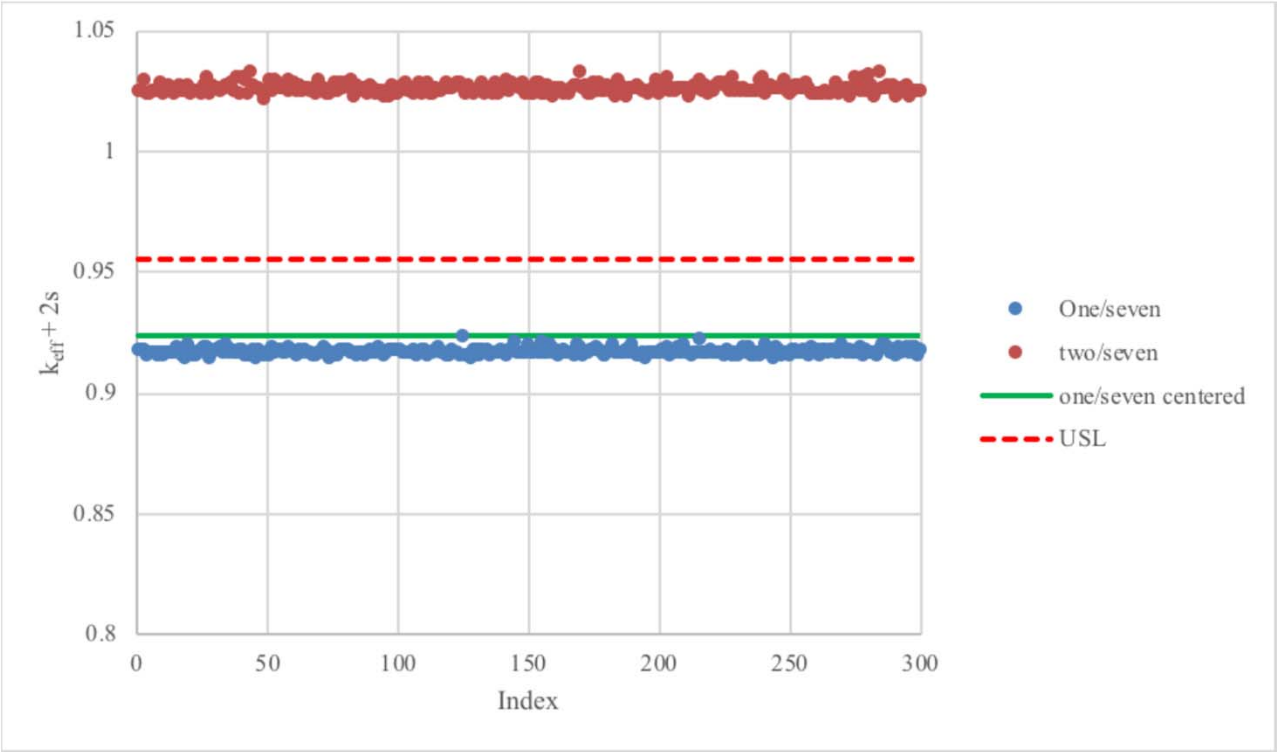
Analysis was also performed to investigate the potential omission of B_4C being added to the waste form

- Container modeled as missing B_4C
- Stochastic analysis performed varying the location of non-B_4C containers per 7-pack
  - 7-pack hexagonal array room model configuration
  - Results indicate that system remains subcritical even if one container per 7-pack does not contain B_4C
- Clusters of non-B_4C 7-packs also investigated to determine minimum number needed to affect room k_{eff}
- USL = 1.0 + bias – bias uncertainty – administrative margin



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The Dilute and Dispose waste form packaged in CCOs does not impact the current WIPP external criticality screening justification

- Previous work[1,2] analyzed 21 FGE metric tons of ^{239}Pu and predicted that no more than 110 kg of ^{239}Pu could reach the Culebra, which would result in concentrations 4 times lower than the 3 kg/m^3 limit
  - Regarding additional amounts of ^{239}Pu, Dr. Rechard states: "dissolved Pu concentrations predicted by the WIPP thermodynamic model are **solubility-limited, not inventory limited**, i.e., independent from inventory."[2] (bold-added)
- A new assessment[3] reaffirmed the prior conclusions that a critical concentration cannot be reached in areas external to the repository rooms
- The external criticality screening argument is based on
  - The amount of fissile material transported over 10,000 y is predicted to be small,
  - There are insufficient spaces in the advective pore space to provide sufficient thickness for precipitation of fissile material, and
  - There is no credible mechanism to counteract the natural tendency of the material to disperse during transport and instead concentrate fissile material in a small enough volume for it to form a critical concentration[1]

[1]Rechard et. al., *Considerations of Nuclear Criticality When Disposing of Transuranic Waste at the Waste Isolation Pilot Plant*, SAND99-2898, April 2000.
[2]Rechard et. al., *FEP Qualitative Screening Argument, RNT-1: Nuclear Criticality in Near Field and Far Field, SWCF-A: 1.2.07.3:PA:QA:TSK:RNT-1*, August 1996.
[3]Rechard, R., Sanchez, L., Stein, E. and Xiong, Y. 2018. *Low Probability of Criticality Following Disposal of Surplus Plutonium at the Waste Isolation Pilot Plant*. Sandia National Laboratories, Carlsbad, NM. ERMS 570596.

Conclusions of this work support a qualitative low-probability rationale for criticality FEP screening for the Dilute and Dispose waste form in CCOs

- Multiple configurations have been analyzed considering room collapse scenarios under both dry and wet environments
  - Potential number of geometric configurations is infinite so a design basis approach was used
- The demonstration of subcriticality is made through quantitative calculations, and the rationale for probability of a criticality event is based on observations that bounding configurations are subcritical, thereby making criticality not credible
- Existing conclusions regarding the low probability for external criticality remain the same, even with the new higher mass of plutonium allowed per CCO based on the dissolved plutonium solubility concentration being solubility limited, not inventory limited