U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Criticality Task Force Meeting

DOE data needs for EST – Criticality related

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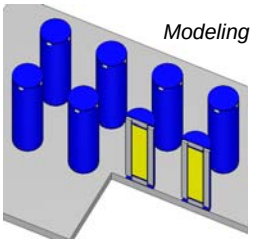
Purpose

- **Open discussion on information collection needs for extended storage and transportation (EST) related to criticality (Note that data being requested has much broader area of applicability [e.g., Aging Management])**
  - Data uses to justify subcriticality after extended dry cask storage
  - Modeling and margins
  - Example applications of additional data
  - Proposed path forward and actions

Data

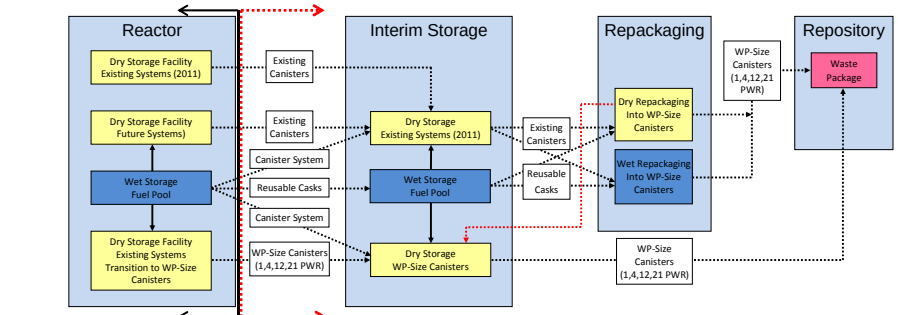
Modeling



Safety

Source: Holtec International

Data is used to support technical justification from time discharged from reactor to final disposal



Site data available *Data DOE has collected*

- DOE needs to consider entire waste management system and be able to meet regulations after taking ownership of the spent fuel
- If fuel needs to be repackaged after leaving site, DOE will have to develop subsequent licensing bases
- DOE will need similar data and design information used in spent fuel pool, storage cask, and transportation cask licensing

Database for Storage, Transportation, and Disposal

- **Operating history data:**
  - **Need credible resource for selecting input data for out-of-reactor nuclear safety analyses involving CSNF**
    - **Burnup credit**
    - **Source terms (decay heat, radiological)**
    - **Off-site dose calculations**
    - **Fuel/cladding integrity studies**
- **Fuel assembly data:**
  - **Many design variants each with different features, hardware, and reactivity levels**
  - **Need this information to go with operating history data**
  - **Reconfiguration analyses (EST and disposal) and associated impacts**

- **All use some level of "bounding" data and configurations**
  - **Simplifies and reduces amount of analyses and subsequent technical justification**
  - **Different data is used for different evaluations to meet different requirements (i.e., bounding for one is not bounding for all)**
  - **Need data to prove parameters selected for evaluations are appropriately bounding**

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Extended storage and subsequent transportation of Dual-Purpose Canisters (DPCs)

- **Criticality analyses for transport after extended storage are similar to disposal considerations**
  - Changes to package and internal components due to extended storage and subsequent transportation need to be accounted for in design basis analyses
    - *Credit for flux traps unlikely if confinement is lost*
    - *Used fuel material reconfiguration (criticality and shielding issues)*
    - *Impacts on misload analyses*
  - Some storage canisters loaded crediting soluble boron
    - *No soluble boron available for transportation analyses*
- **Conclusions of prior studies investigating the impacts on k_{eff} of fuel reconfiguration during transport and direct disposal of DPCs indicate that demonstrating criticality control after EST is a principle challenge**
  - *Effects of Fuel Failure on Criticality Safety and Radiation Dose for Spent Fuel Casks, NUREG/CR-6835, September 2003.*
  - *Feasibility of Direct Disposal of Dual-Purpose Canisters: Options for Assuring Criticality Control*, 1016629, EPRI, 2008.
  - *The Potential of Using Commercial Dual Purpose Canisters for Direct Disposal*. Department of Energy, Office of Civilian Radioactive Waste Management,TDR-CRW-SE-000030 Rev 00, November 2003.

Need to maximize burnup credit and reduce excess margin

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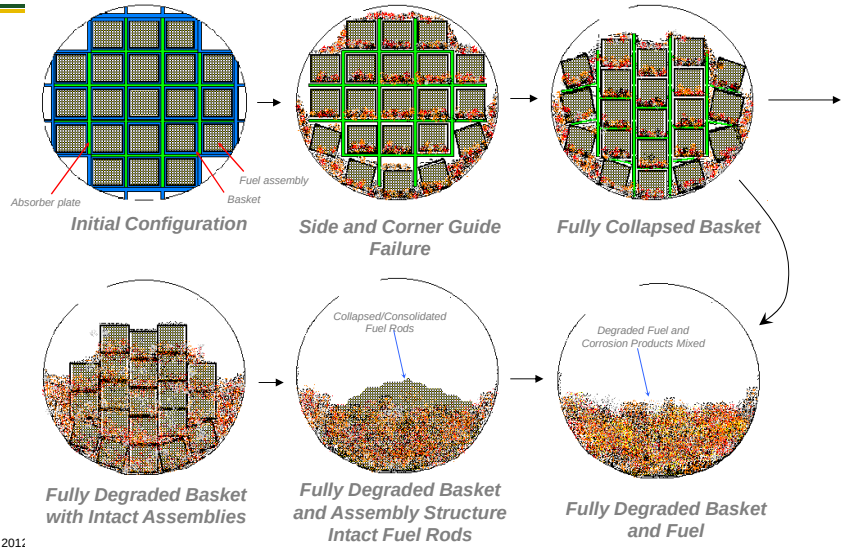
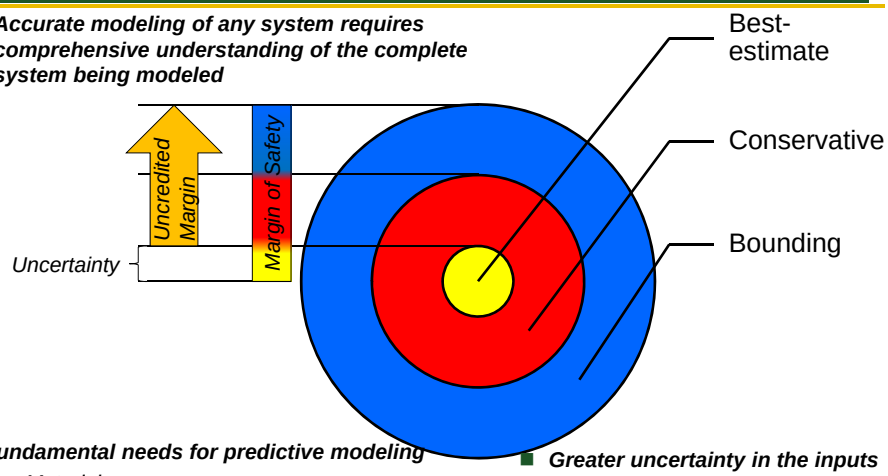
Reconfiguration scenarios that need to be evaluated for design basis (what's credible after EST?)



May 2011

Choice of predictive modeling parameters for used fuel and excess margin

- ***Accurate modeling of any system requires comprehensive understanding of the complete system being modeled***

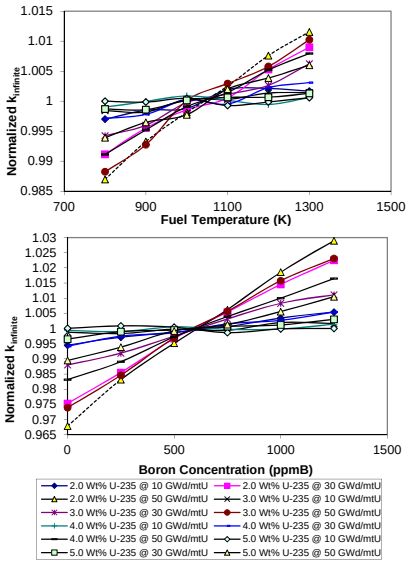


- ***Fundamental needs for predictive modeling***
  - *Materials*
  - *Geometry*
  - *Time dependent changes*

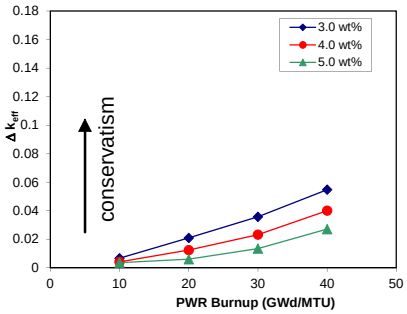
- ***Greater uncertainty in the inputs and longer period of prediction***
  - → *Larger margins*
  - → *Lower loading density*
  - → *Increased costs*

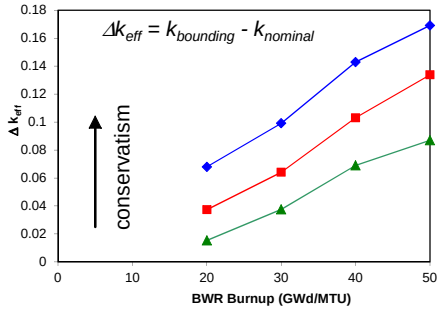
Operating history parameters are needed to simulate effects of reactor power production

- ***Typical operating history parameters***
  - *Power density*
  - *Fuel temperature*
  - *Moderator temperature*
  - *Soluble boron concentration with time (PWRs)*
  - *Void fraction (BWRs)*
  - *Axial effects*
  - *BPRAs*
  - *Cycle length*
  - *Cycle down time*
  - *Etc.*
- ***Parameters selected without regard to correlation (can't have high temperature and low power density at same time)***



Representative net effects on discharge reactivity based on choice of fuel depletion parameters





Potential benefits of comprehensive operating history database
Improved accuracy in safety margin estimates
Improved technical basis for parameter selection
Reduced conservatism in analyses
Reduced potential for RAIs in license applications if parameters are selected based on a comprehensive database
Reduced potential for such parameters being cited as licensing conditions for loading spent fuel assemblies

Example areas that uncredited margin can be reduced

- **Actual cask k_{eff} versus loading curve based on uniform assembly characteristics**
  - **Increases standard loading, provides flexibility in accident analysis sequences, as well as conditional probability of criticality given misload.**
- **Axial burnup and void profiles**
  - **Most bounding PWR profiles come from a few assemblies (pre-1997 database) that have limited representation of the population.**
  - **Similar BWR axial profile database does not exist, limiting burnup credit to relatively low burnup values where single axial zone is bounding.**
- **Use of actual BPRA characteristics instead of bounding characteristics**

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Direct Disposal of DPCs for demonstrating disposal criticality control

- **Current criticality safety licensing uses design basis approach assuming all assemblies in canister are identical and at the design-basis limits**
  - Need capability to account for design basis configuration changes after extended storage
- **Alternative licensing strategy could be to perform canister specific criticality safety calculations for DPCs**

Parameter	Value	Source
Fuel dimensions	--	TVA Data
Power (MW/assembly)	--	Actuals from TVA data
Cycle length (d)	--	Actuals from TVA data
Outage between cycles (d)	--	Actuals from TVA data

Additional data being requested

Source: EPRI 2008. Feasibility of Direct Disposal of Dual-Purpose Canisters Options for Assuring Criticality Control

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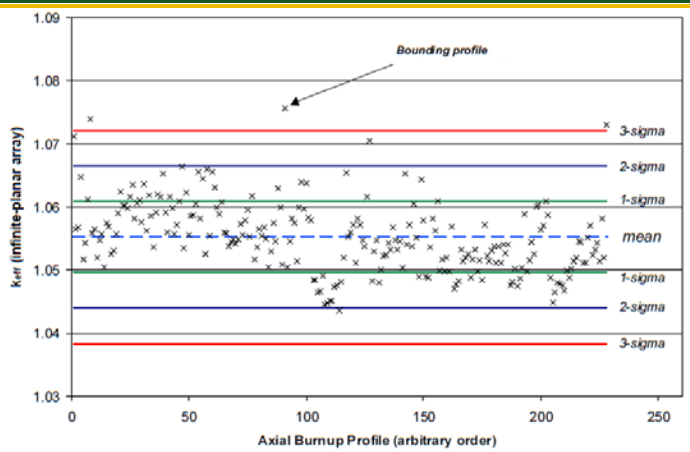
Example PWR Bounding Axial Burnup Profile



- ***Additional data on burnup profiles will allow more representative profiles to be selected***

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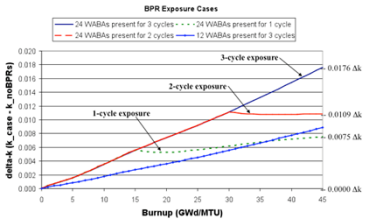
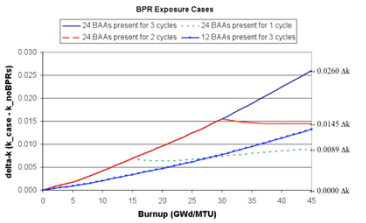
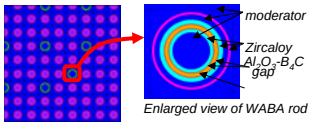
Burnable Poison Rods

- **Investigated effect of BPRs on reactivity for various BPR designs & exposure conditions**



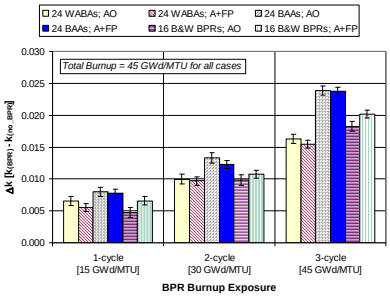




Enlarged view of WABA rod

Lower-right quadrant of W17x17 assembly with 24 WABA rods present

NUREG/CR-6761



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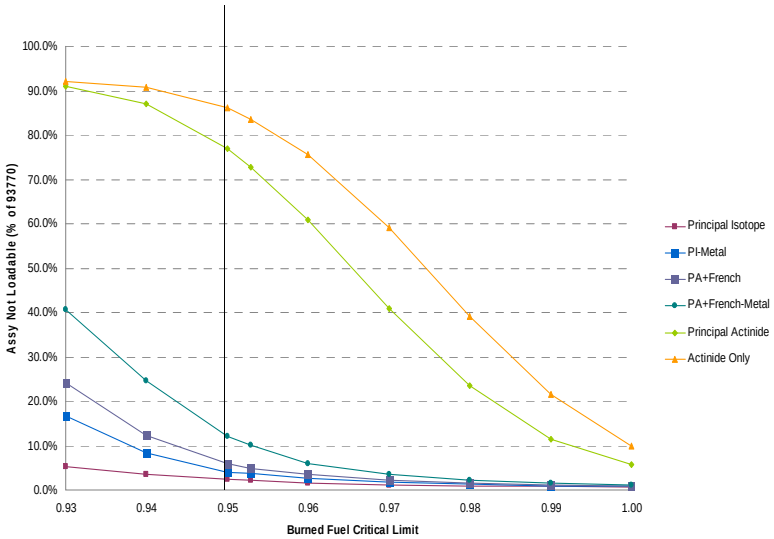
k_{eff} margin benefits on loading curves



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Summary

- ***Data requested is subset of what is used to support core reload and spent fuel pool analyses and is typically available in core design reports (core conditions are known at all times)***
- ***What's bounding for criticality safety evaluations isn't the same as what is bounding for shielding, dose, or thermal evaluations.***
  - *Neutron spectrum effects on source terms (shielding, decay heat, criticality*
  - *Axial and radial effects*
  - *Hydrogen uptake by cladding during irradiation*
- ***DOE needs to know main spent fuel characteristics for waste management system planning (e.g., repository design, spent fuel receiving systems, spent fuel handling systems, etc.)***
  - *Existing data (GC-859) is being collected for this purpose*
- ***Access to operating history data is desired to support efforts to determine and justify more realistic safety margins***
  - *Effort to collect and consolidate data will be done separately from the GC-859 data collection activity*

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Proposed path forward and actions

- **UFD to coordinate with NEI on a voluntary data collection effort**
  - Through NEI, we would like to determine which utilities are ready and willing to participate
- **UFD has developed a prioritized list of requested data, recognizing that utilities may not have ready access to all of the data we would like**
- **Need to move forward with collecting the data that are available, and adjust process and list of requested data, as needed**
- **Other actions?**

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BACKUP

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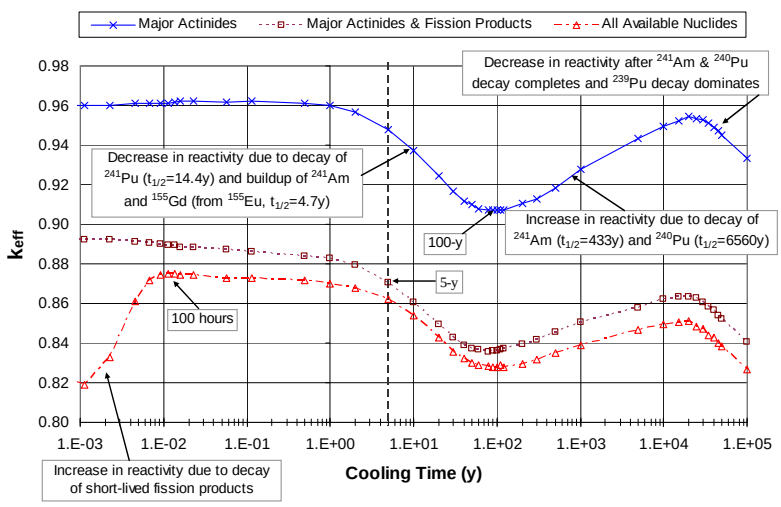
Reactivity of CSNF as a Function of Time



GC-859 data is insufficient to justify reduction in excess conservatism

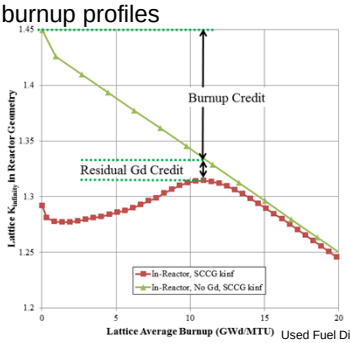
- **NRC Staff guidance on burnup credit for transport (ISG-8 Rev. 2) states that calculated SNF isotopic compositions**

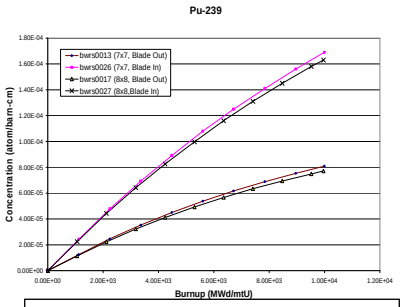
  "*should be calculated using fuel design and in-reactor operating parameter values that appropriately encompass the range of design and operating conditions for the proposed contents*"
- **Design and operating history parameters must be justified as bounding for k_{eff} calculations**
- **Excessive Conservatism in the Postclosure Criticality Analysis *Contention [10 C.F.R. 2.309(f)(1)(i)]***

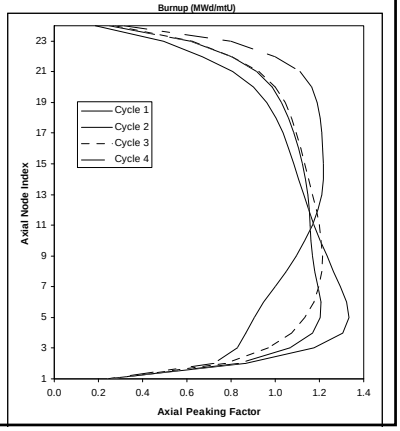
  "*The postclosure criticality analysis described in Section 2.2.1.4.1.1 of the License Application (LA) Safety Analysis Report (SAR) provides a substantial safety margin, is excessively conservative, and will unnecessarily lead to the expectation that disposal control rod assemblies be inserted in some fuel assemblies at nuclear power plants prior to shipment to disposal.*"

BWR criticality analyses

- **BWRs**
  - Various Gd rod loadings
  - Various radial and axial enrichments
  - Part length rods
  - Blade usage
  - Void history profile
  - Axial burnup profiles







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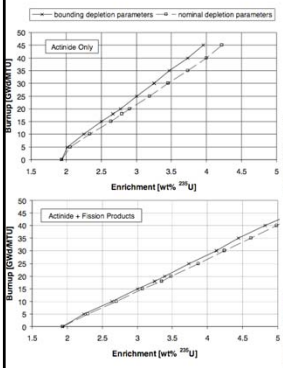
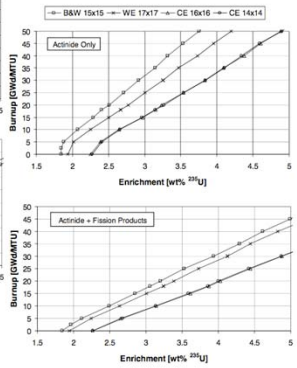
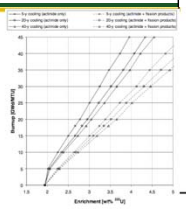
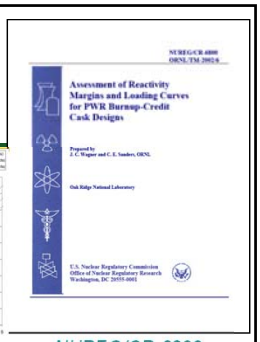
Reactivity Margins

- **Examined impact of depletion & criticality analysis assumptions on loading curves**









NUREG/CR-6800

Table 13 Summary table of Δk values due to variations in calculational assumptions for a typical discharge burnup and enrichment combination (40 GWd/MTU; 4.0 wt % ^{235}U) in the GBC-32 cask

Modeling parameter/ characteristic	Assumptions used for comparison[1]		Δk values*	
	Base assumption	Bounding assumption	Actinide-only	Actinide + fission products
Fuel temperature during depletion	850 K	1100 K	0.0045	0.0031
Moderator temperature during depletion	595 K	610 K	0.0083	0.0088
Soluble boron concentration during depletion	600 ppm	1000 ppm	0.0042	0.0038
Specific power during depletion	40 MW/MTU	60 MW/MTU	< the statistical uncertainty	0.0008
Total of all depletion parameters listed above	All values listed above	All values listed above	0.0185[5]	0.0154
BPRs during depletion	None	Inserted for first 20 GWd/MTU of burnup	0.0080	0.0062
CRs during depletion	None	Fully-inserted for first 5 GWd/MTU of burnup	0.0062	0.0070
Axial-burnup variation	Uniform	Reference profile from Table I	0.0111	0.0337
Horizontal-burnup variation	Uniform	20% gradient	0.0023	0.0021
ICFs	None	Set 1 ICFs from Table 8	0.0325	0.0482

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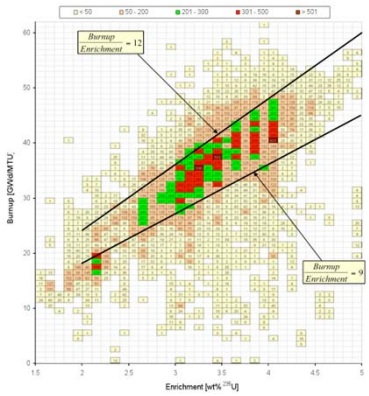
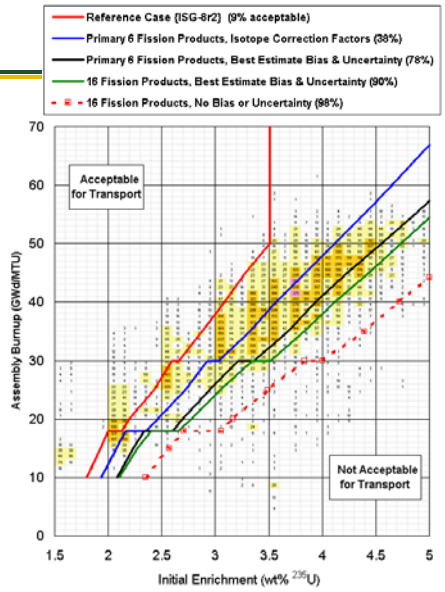
Reactivity Margins



US PWR discharge data through 1998



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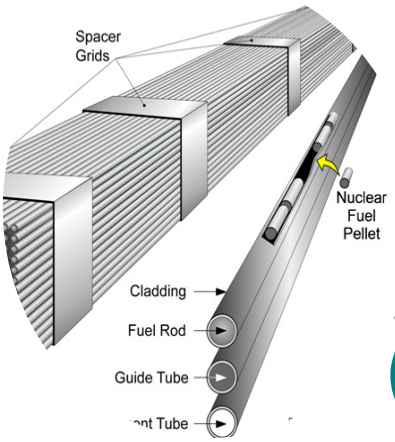
Data is applied differently to support separate requirements



Storage
10 CFR 50 and 72

- Confinement
- Radiation protection
- Retrievability
- Subcriticality

Transport
10 CFR 71

- Containment
- Release fraction
- Structural integrity
- Subcriticality

Disposal
?

- Subcriticality
- Performance assessments

Modeling of Component Aging Effects

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Areas of application (high-value impact from improved precision)

- **Criticality safety**
- **ALARA considerations**
- **Self-protection for security evaluations**
- **Corrosion/degradation models (thermal and radiolytic)**
  - **Aging management**
  - **Effects on concrete and steel casks**
  - **Deliquescence**
  - **Identification of credible configurations**
    - **Likelihood of component failure**

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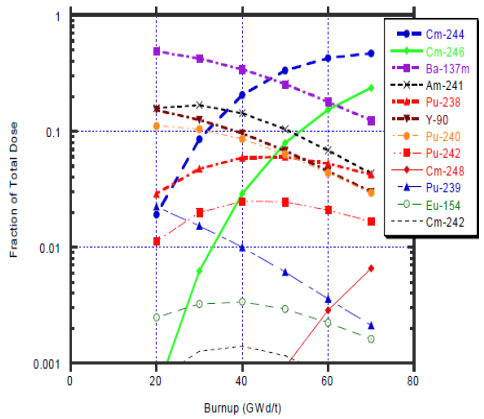
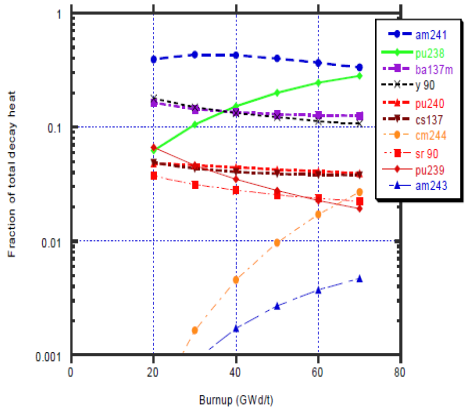
Example of change in nuclide importance to dose and decay heat with burnup



Fraction of total dose in transport cask (100y cooling)



Fraction of decay heat (100y cooling)