Development of Technical Basis for Burn-up Credit Regulatory Guidance in the United States

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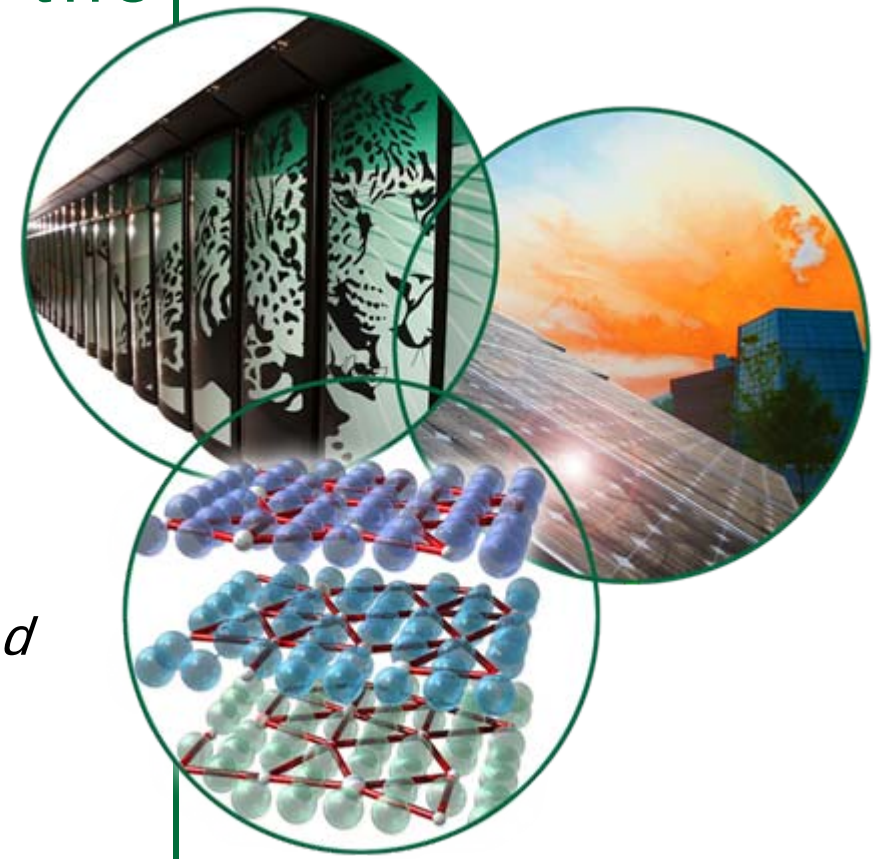

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U.S. DEPARTMENT OF ENERGY

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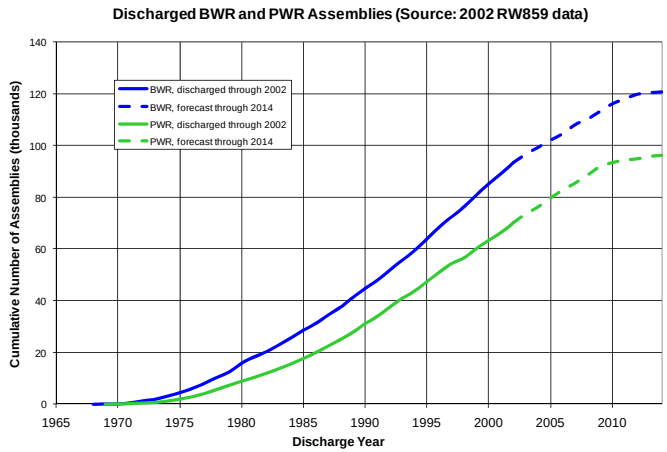
Introduction



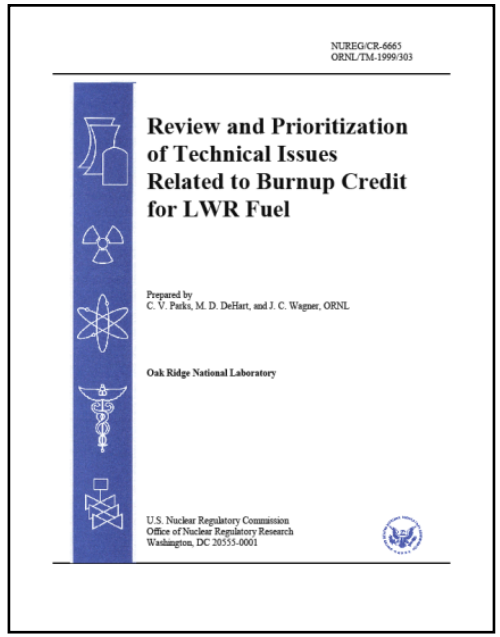
- Increasing spent nuclear fuel (SNF) inventories necessitate expanding and optimizing SNF storage and transport capacity
- Credit for fuel burnup can enable more cost-effective, higher-density storage and transport of SNF
- Potential benefits of burnup credit have motivated
  - Numerous technical studies, domestically and internationally
  - Use in storage, transport and disposal license applications
- PURPOSE: inform audience about NRC sponsored research (at ORNL) relevant to *Spent Nuclear Fuel Criticality Analysis*

Introduction

- In 1999, the US NRC initiated a research program with ORNL to develop guidance and technical bases for allowing and expanding the use of burnup credit in PWR SNF storage and transport applications
  - NRC guidance (or recommendations) issued as Interim Staff Guidance 8 (or ISG-8).
- The research program attempted to systematically address technical issues in the pursuit of expanding regulatory guidance for the use of burnup credit
- The program produced a number of publically available reports and supported revised guidance

Baseline Report

- Reviewed application areas
- Reviewed previous technical studies
- Reviewed/identified parameters/phenomenon
- Reviewed technical and licensing issues
- Proposed research and prioritization
- Status of burnup credit programs in other countries



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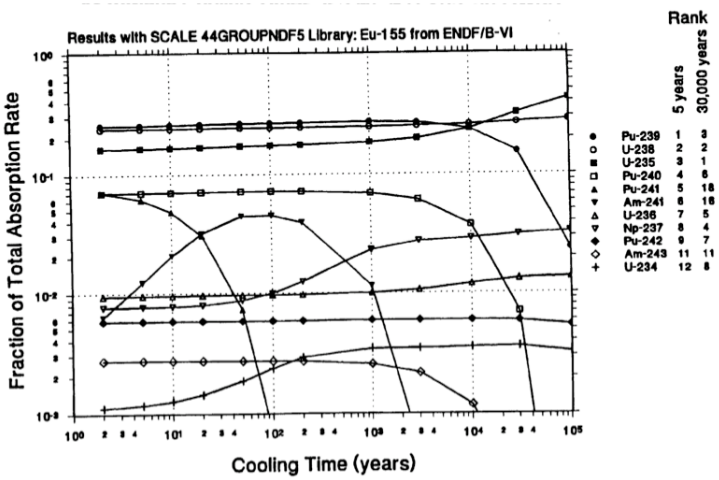
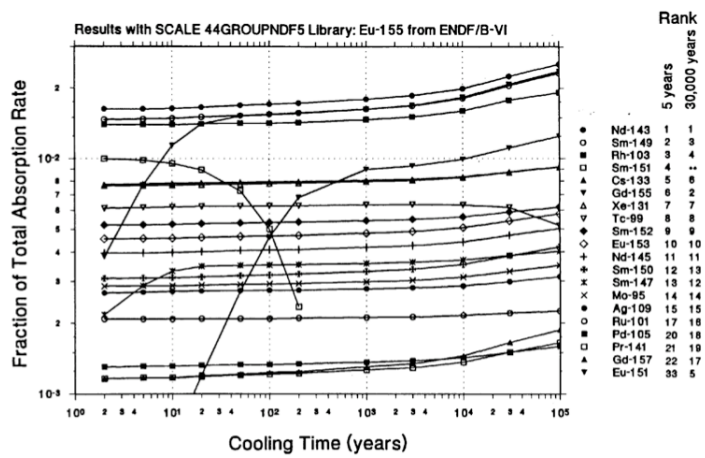
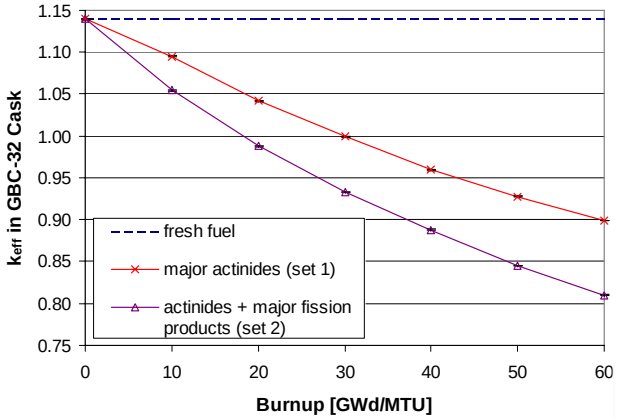
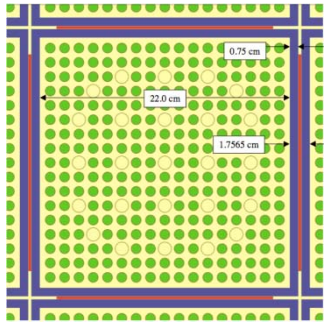


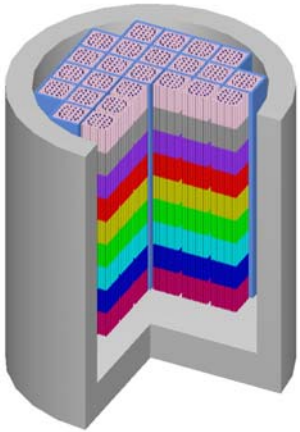


Computational Benchmark

- Defined representative high-capacity cask
- Estimated additional reactivity margin available from fission products and minor actinides, per ISG-8 recommendation







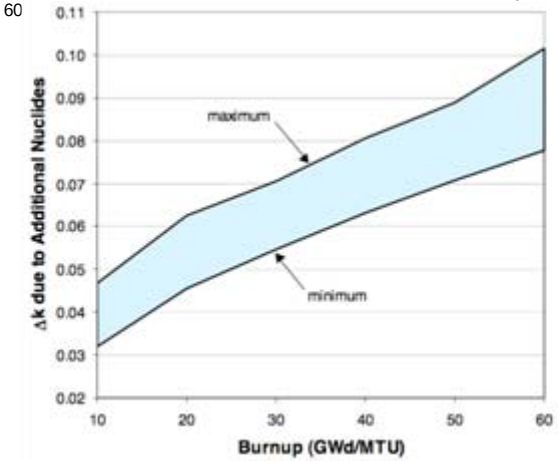


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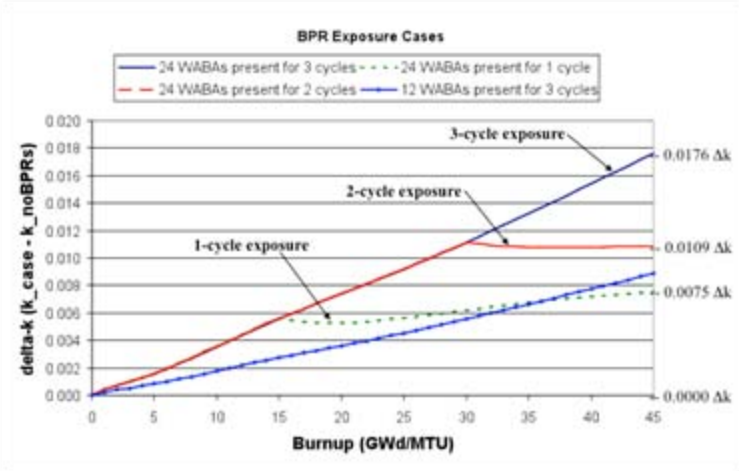
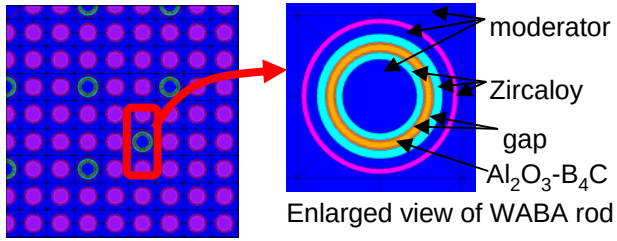
Table 15 Individual components of the reduction in k_{eff} as a function of burnup and cooling time for fuel of 5 wt % ^{235}U initial enrichment

	Δk values due to the various nuclide sets			Contribution to total reduction in k_{eff}	
Burnup (GWd/MTU)	Major actinides (set 1)	Additional nuclides (set 3)	Total (set 2)	Major actinides (set 1)	Additional nuclides (set 3)
0-year cooling time					
10	0.04286	0.03563	0.07849	54.61%	45.39%
20	0.08854	0.05156	0.14010	63.20%	36.80%
30	0.12911	0.06144	0.19055	67.76%	32.24%
40	0.16453	0.06806	0.23259	70.74%	29.26%
50	0.19746	0.07552	0.27298	72.33%	27.67%
60	0.22739	0.08263	0.31002	73.35%	26.65%
5-year cooling time					
10	0.04334	0.04538	0.08872	48.85%	51.15%
20	0.09339	0.06249	0.15588	59.91%	40.09%
30	0.13712	0.07054	0.20766	66.03%	33.97%
40	0.17538	0.07856	0.25394	69.06%	30.94%
50	0.20939	0.08761	0.29700	70.50%	29.50%
60	0.24198	0.09395	0.33593	72.03%	27.97%

Burnable Poison Rods

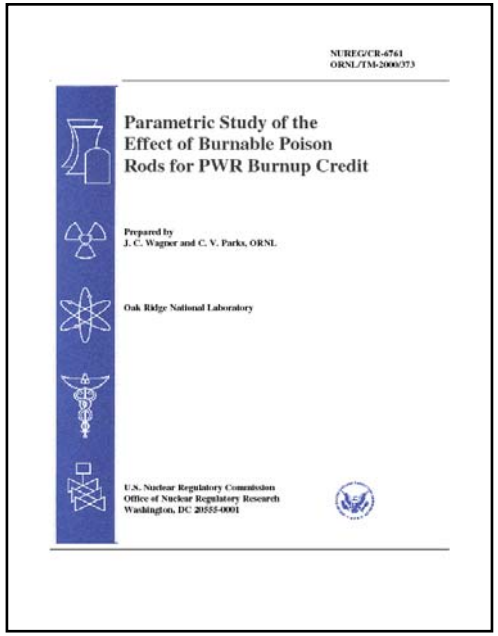
- Investigated effect of BPRs on reactivity for various BPR designs & exposure conditions





Enlarged view of WABA rod

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



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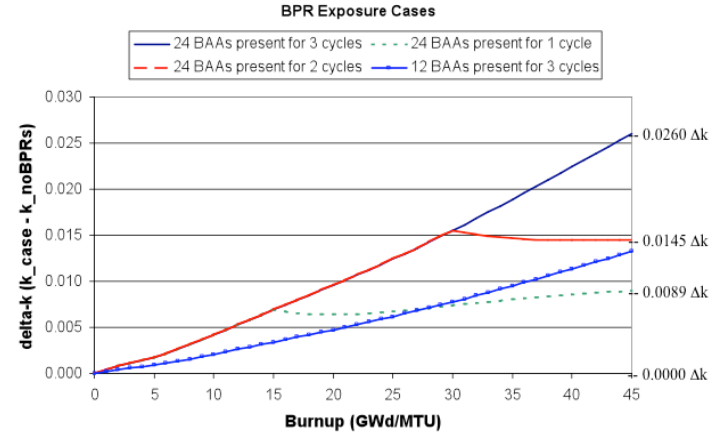
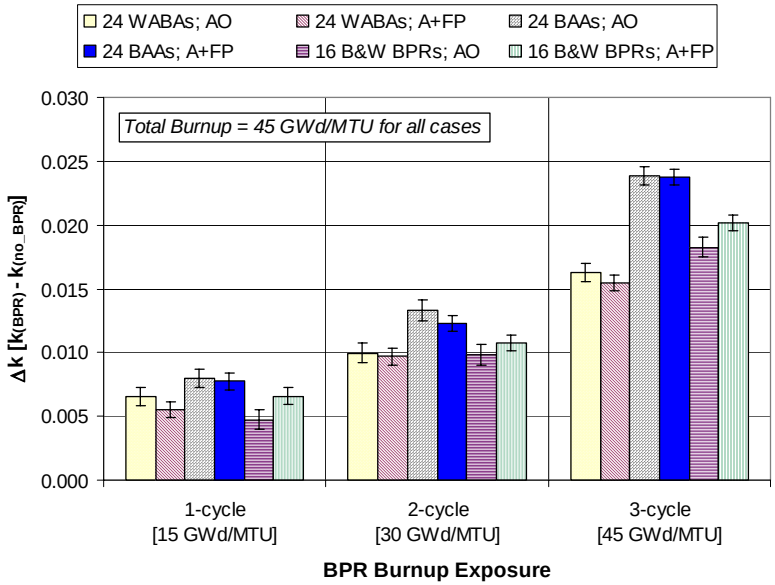
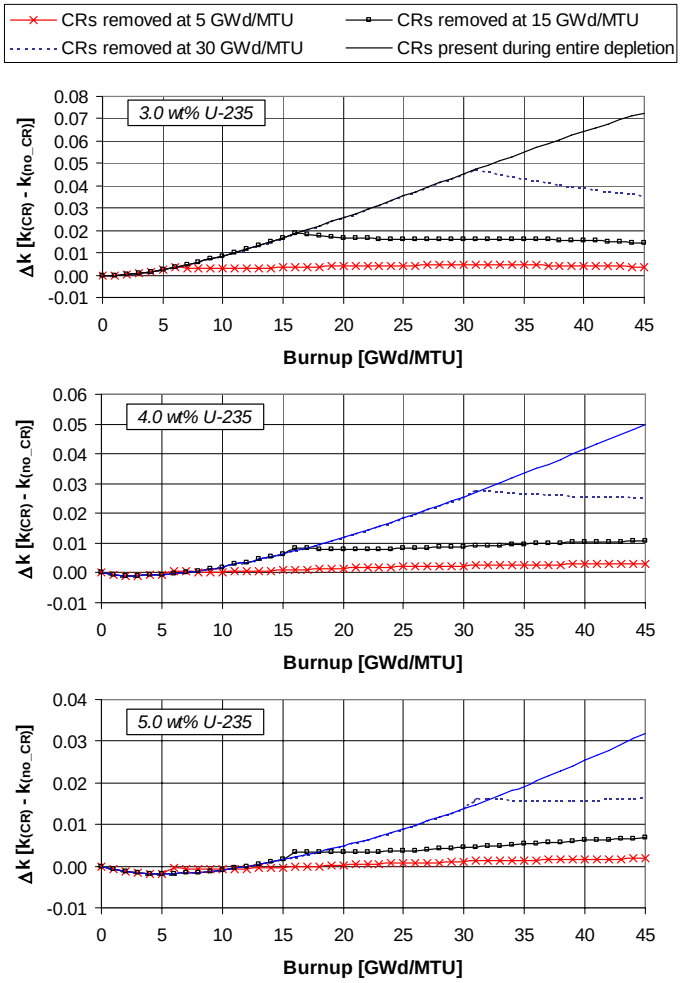


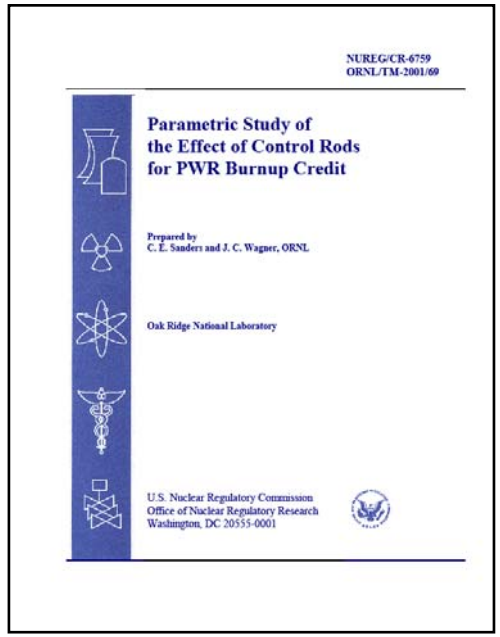


Control Rods

- Investigated effect of CRs on reactivity for CR/APSR designs & exposure conditions



- W, B&W, and CE designs considered



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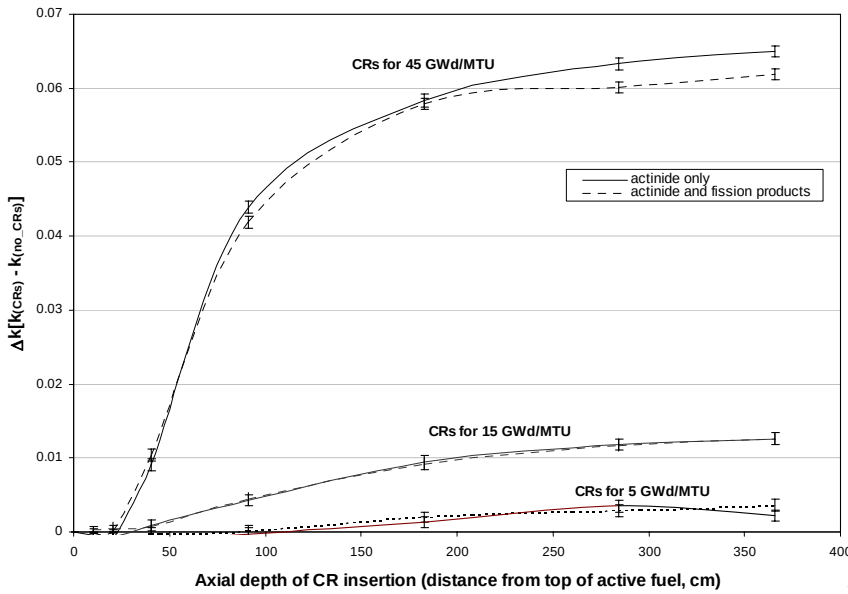
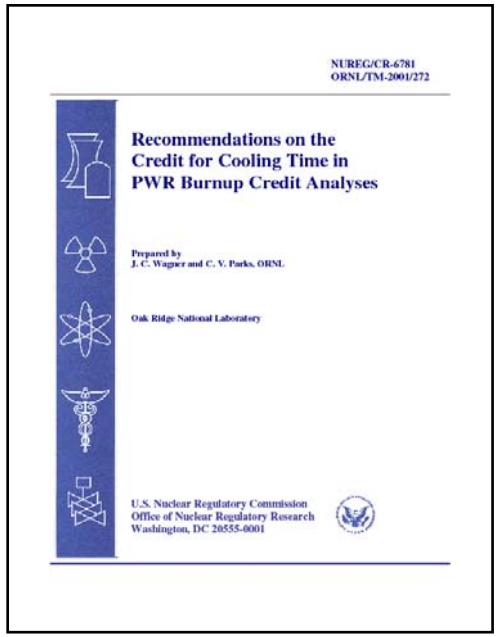


Cooling Time

- Examined reactivity behavior as a function of cooling time to assess the possibility of modifying guidance recommendation



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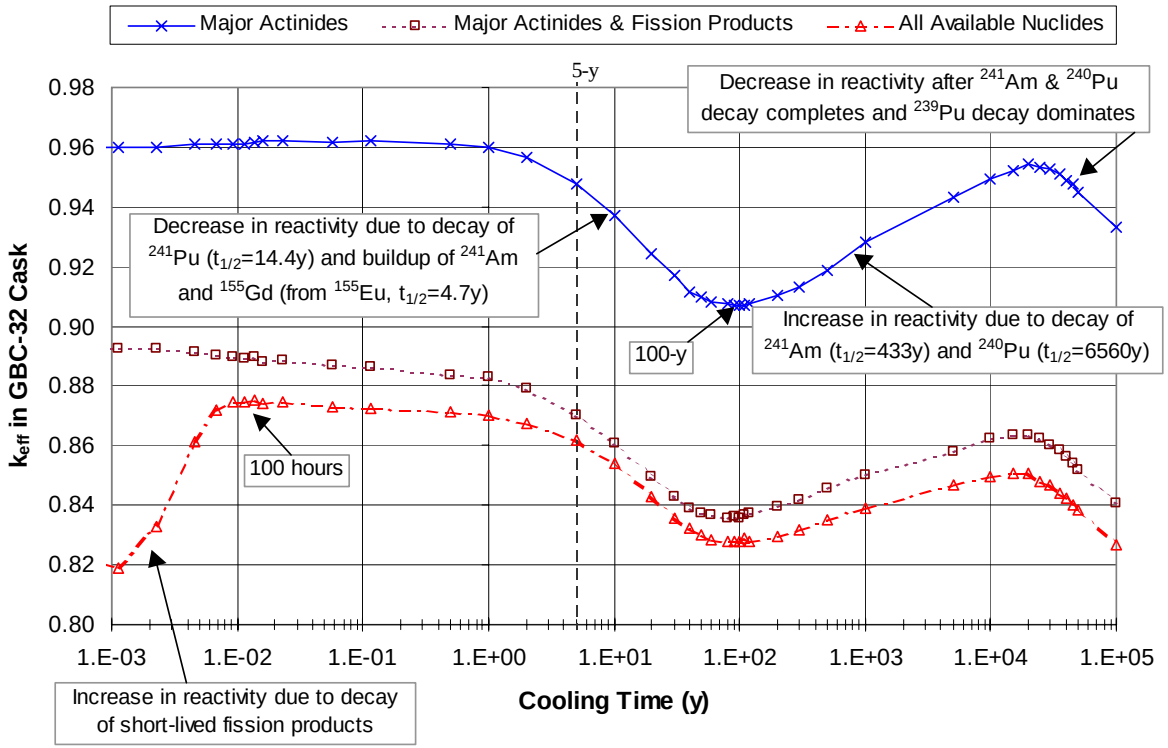
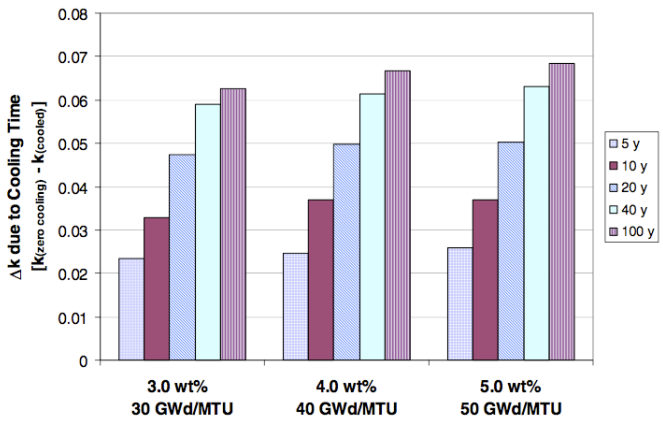
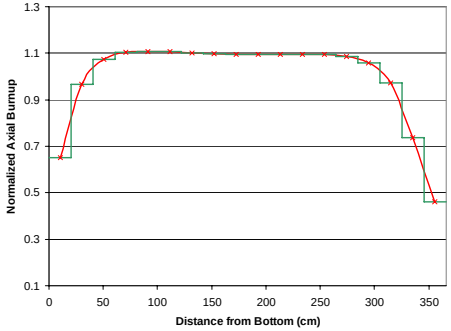
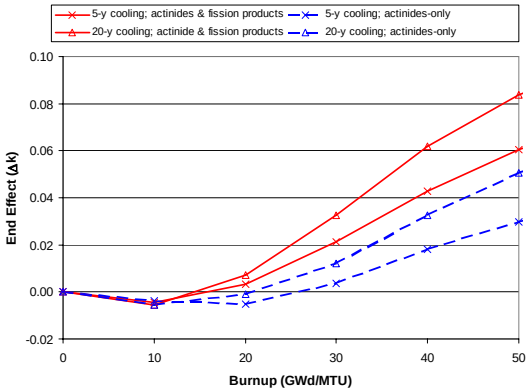




Axial Burnup

- Examined effect of axial burnup on reactivity
- Examined available database of profiles to
  - Identify profiles that maximize, k_{eff}
  - *Assess its* adequacy for use in safety analyses
  - Investigate existence of trends with fuel type and/or reactor operations





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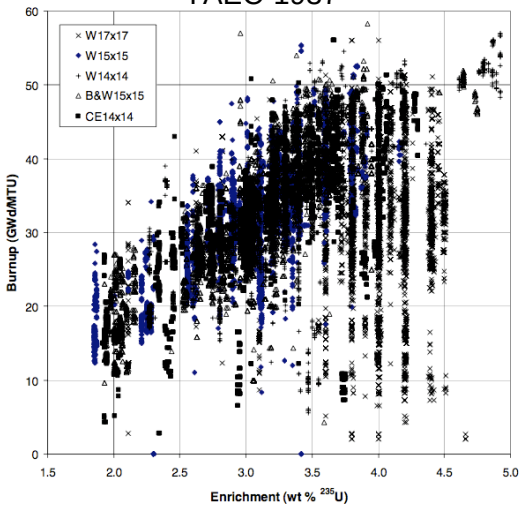

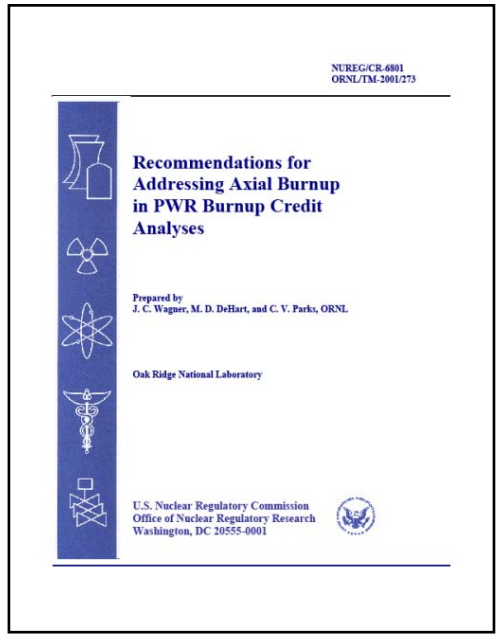

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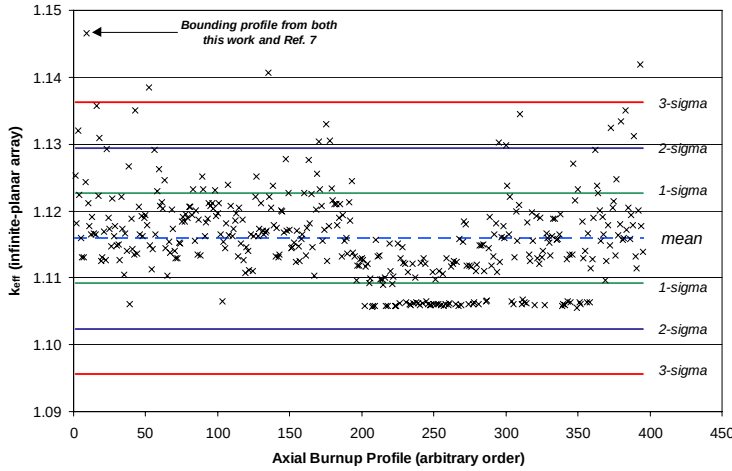
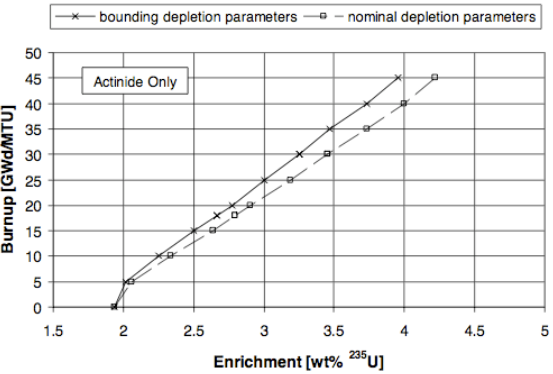
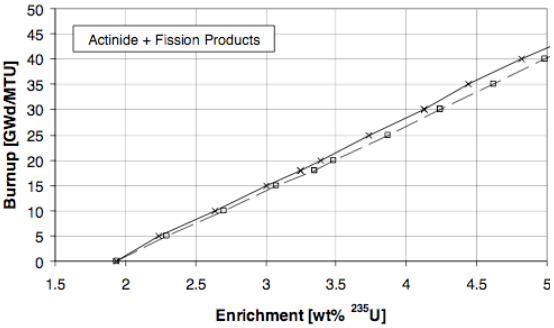
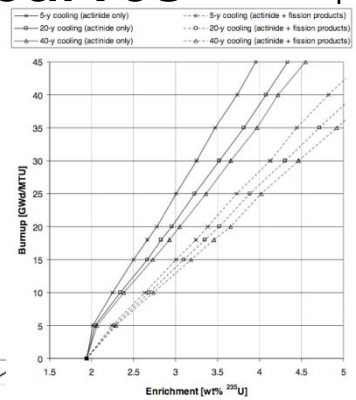


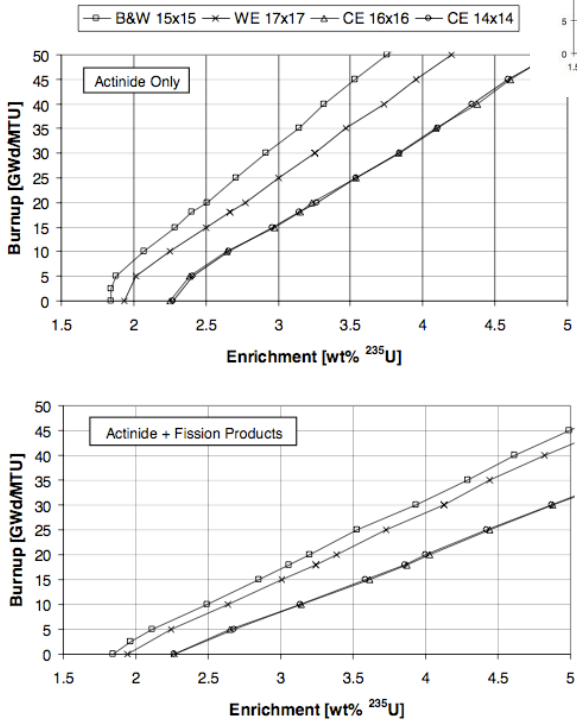
Reactivity Margins

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









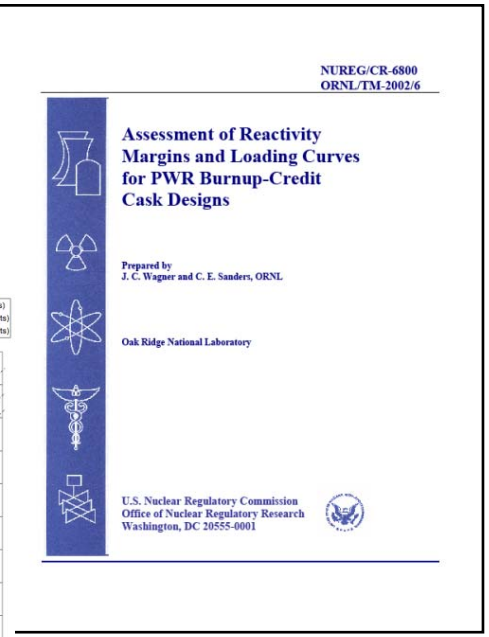


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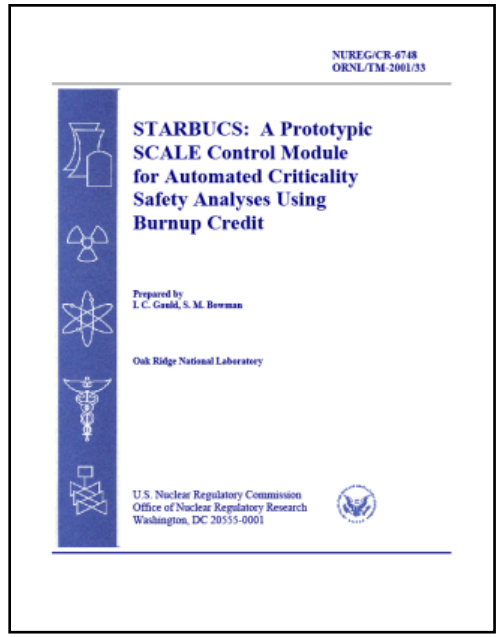
Table 13 Summary table of Δ*k* values due to variations in calculational assumptions for a typical discharge burnup and enrichment combination (40 GWd/MTU; 4.0 wt % ^{235}U) in the GBC-32 cask

Modeling parameter/ characteristic	Assumptions used for comparison†		Δ*k* 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‡	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 1	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

SCALE BUC Sequence

- STARBUCS sequence to automate burnup credit analyses for UO_2 SNF systems
- Performs integrated depletion analysis, cross-section processing, and Monte Carlo calculations for 3-D systems
- Relevant input options to represent
  - Irradiation conditions
  - Cooling time
  - Nuclides relevant to burnup credit
  - Axial and radial variation of burnup
  - Isotopic composition uncertainties
- Used extensively at ORNL to generate loading curves and impact of assumptions



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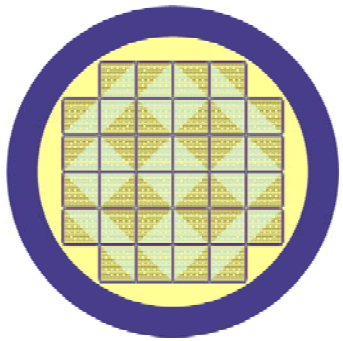
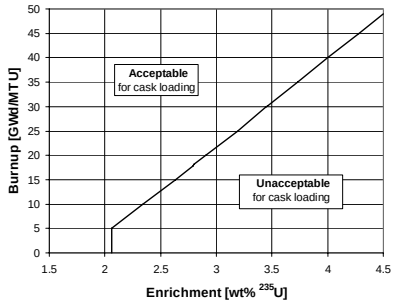
GBC-32 cask with horizontal burnup modeled

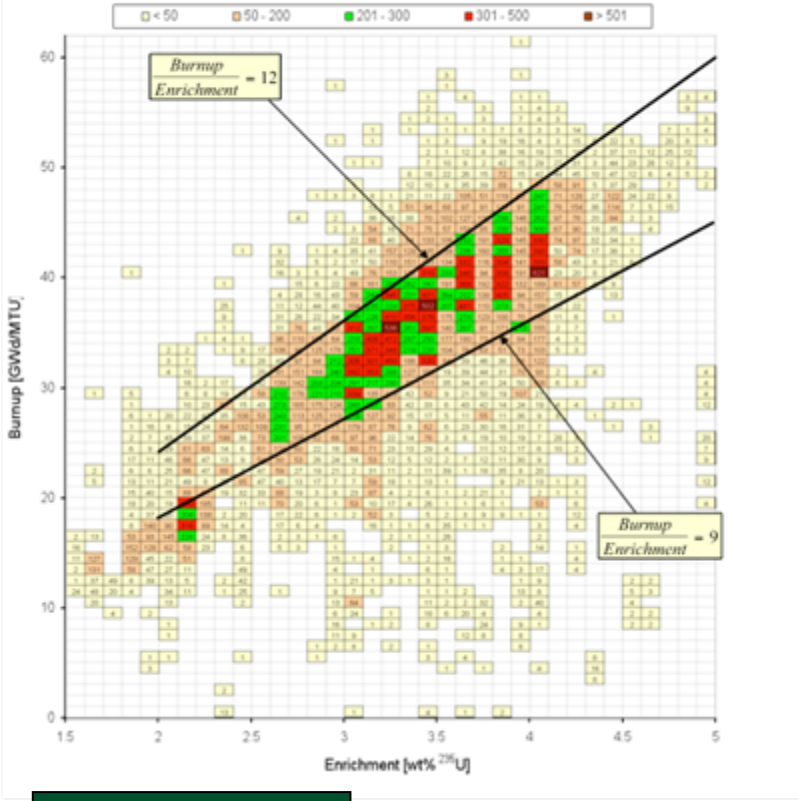




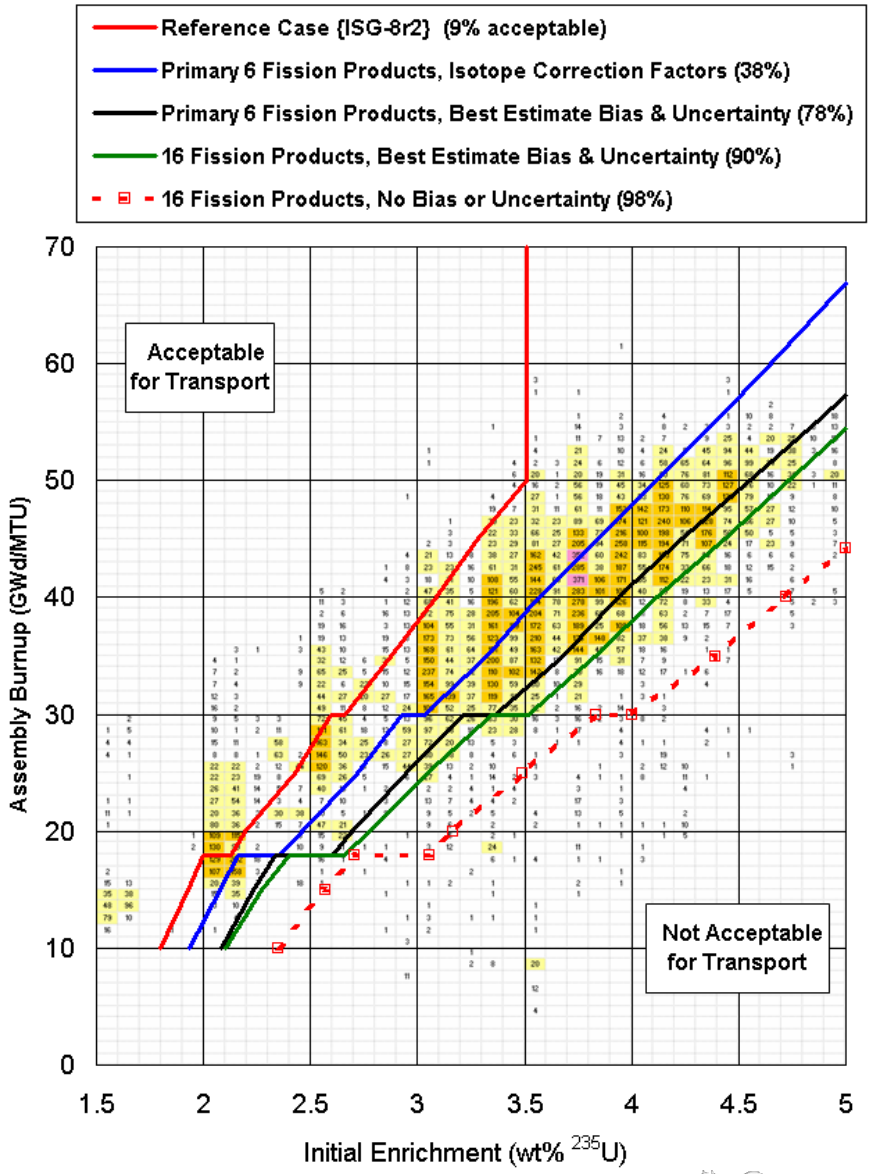
Illustrative loading curve

Reactivity Margins

- Examined impact of analysis assumptions on loading curves
- Quantified large impact of ICFs
- Confirmed need for FP credit

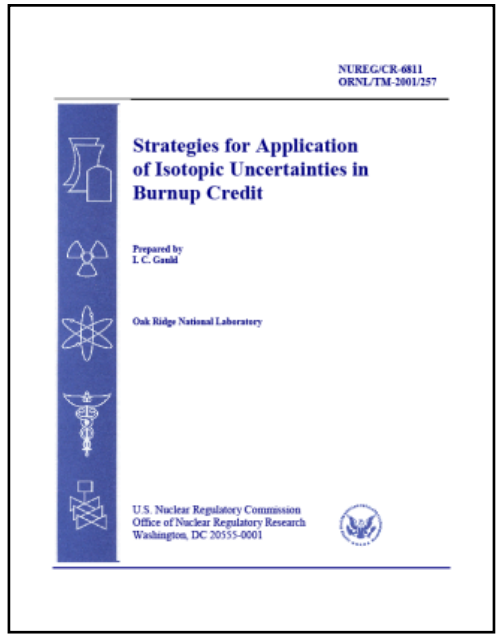


US PWR discharge data through 1998



Isotopic Validation

- Examined strategies for addressing uncertainties in predicted isotopic comps.
  - Reviewed/applied methods and data
    - Bounding methods
    - Best estimate methods
      - Monte Carlo sampling
      - Sensitivity coefficient analysis
      - Direct isotopic differencing



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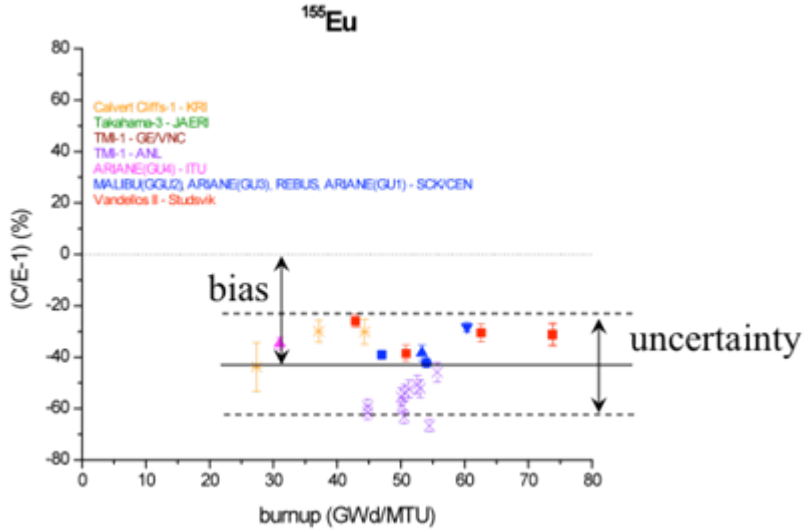
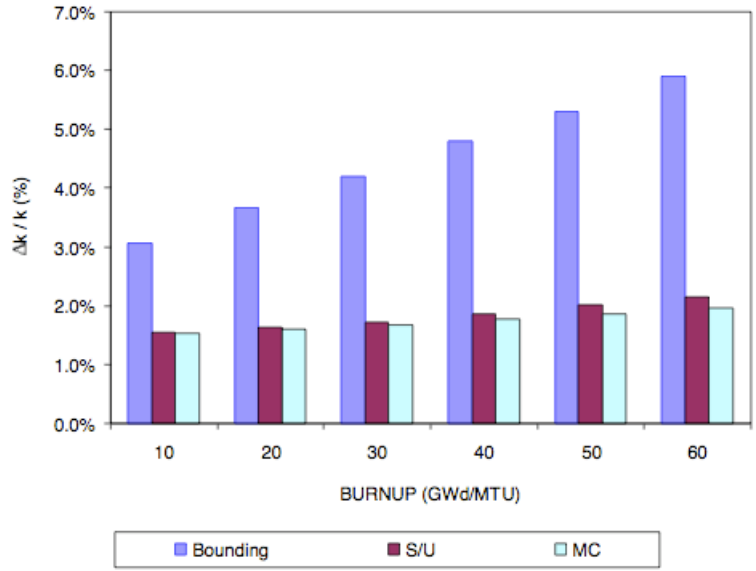
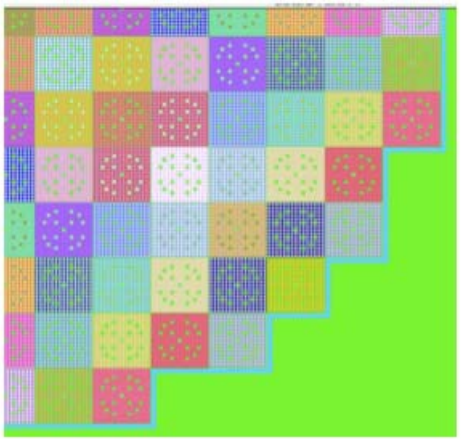
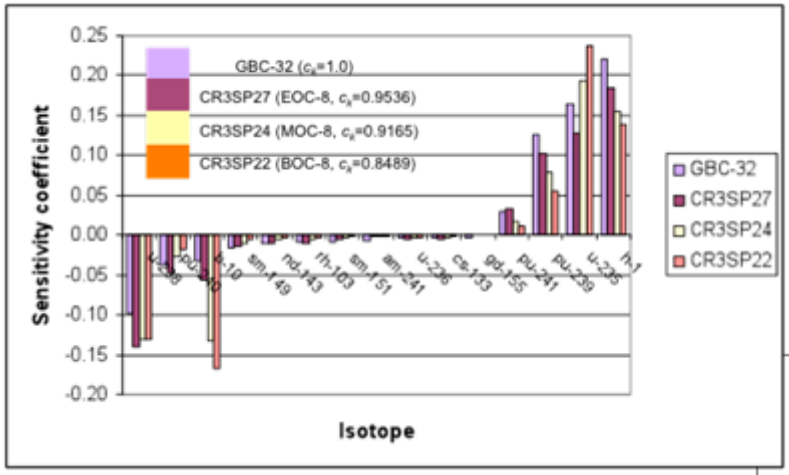


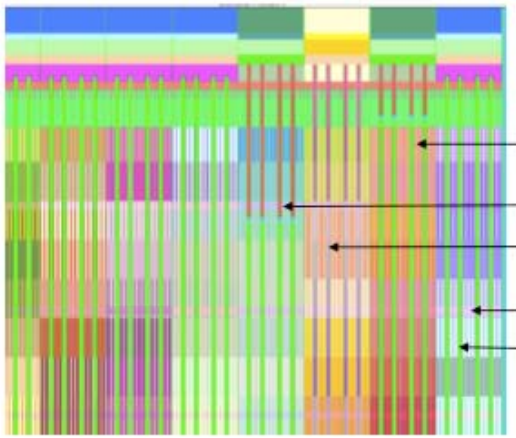


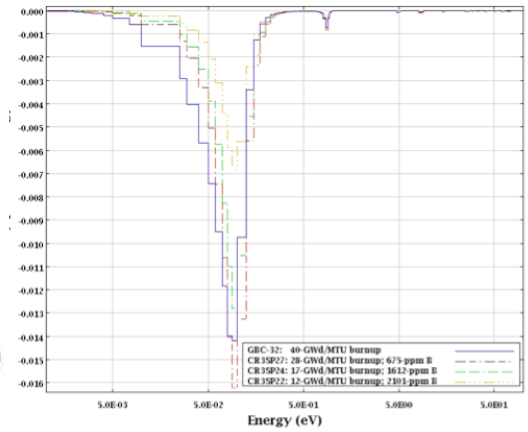
Applicability of CRCs

- Examined neutronic similarities between a SNF cask and 40 CRC state-points

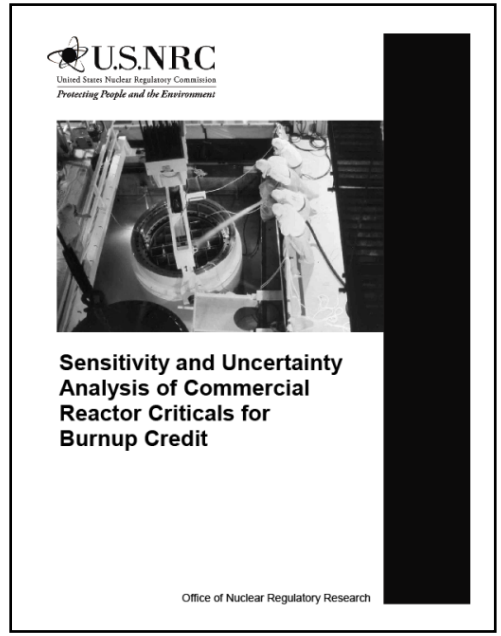








Comparison of ^{149}Sm Sensitivity Profiles for GBC-32, CR3 State-points 27 (EOC-8), 24 (MOC-8), & 22 (BOC-8)



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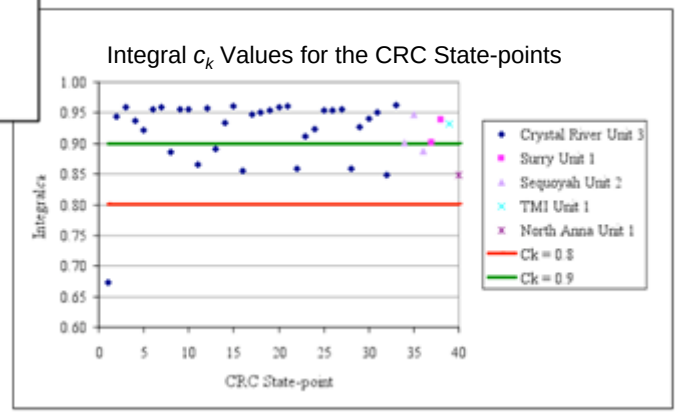
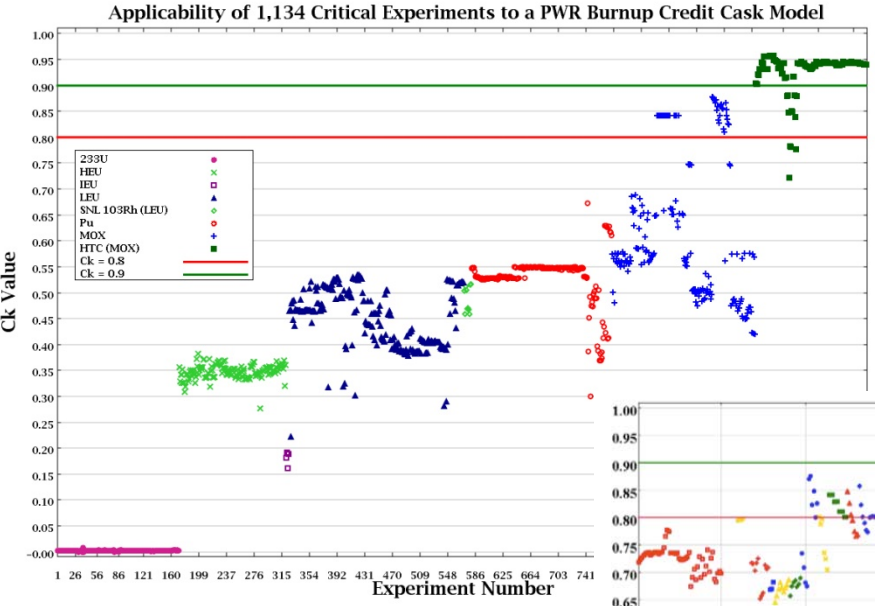
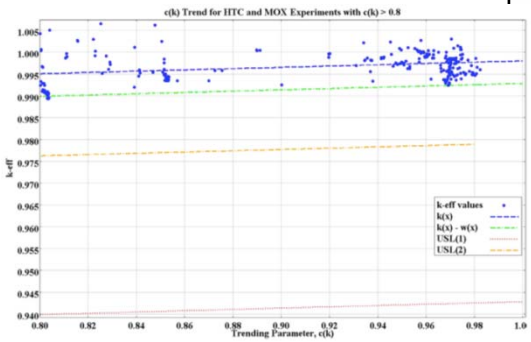


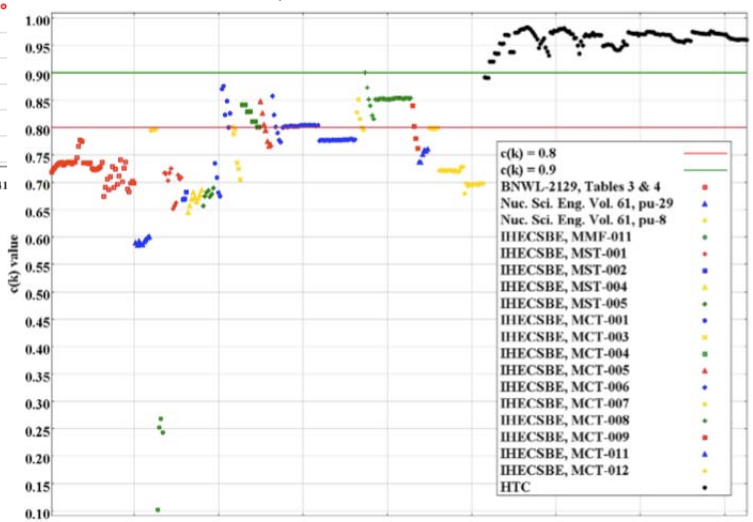
- CRCs found to be good in terms of applicability
- **Issue of configuration uncertainties not addressed**

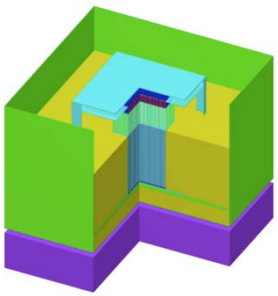
Criticality Validation & HTC data

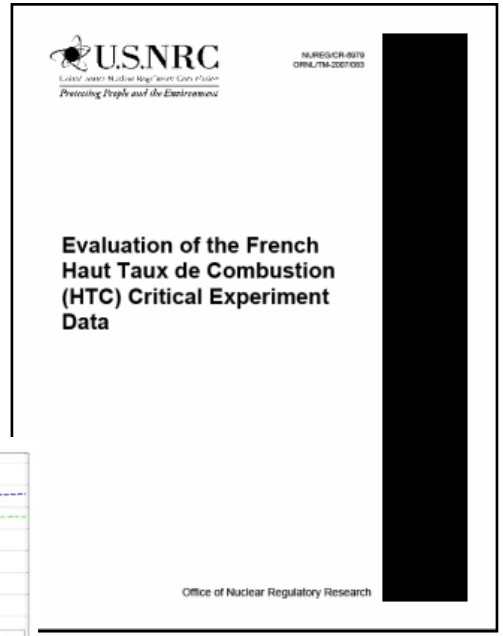
- Examined applicability/usefulness of French critical experiments (Valduc) for actinide validation
  - 156 configurations with designed to mimic 4.5 wt% ^{235}U initial enrichment fuel burned to 37.5 GWd/MTU in storage & transport conditions











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HTC Critical Experiments

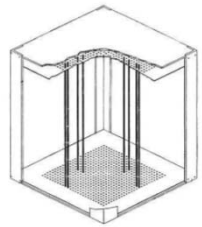
All with MOX rods designed to look like burned fuel

Phase 1–Single array, pin pitch varied, clean water

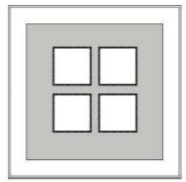
Phase 2–Single array, pin pitch varied, water with gadolium or boron in solution

Phase 3–Four assemblies, some with borated steel, Boral™ or cadmium side panels, clean water, assembly spacing varied

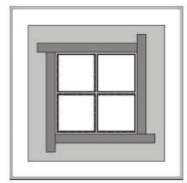
Phase 4–Like Phase 3 except thick lead or steel shields around outside of array



Phases 1 & 2



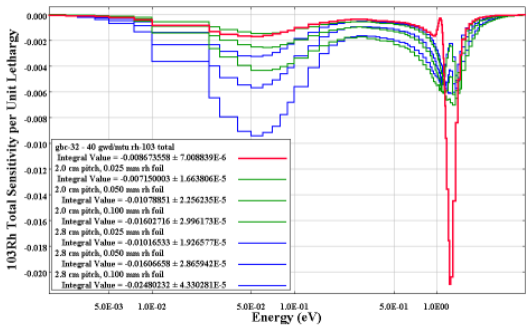
Phase 3

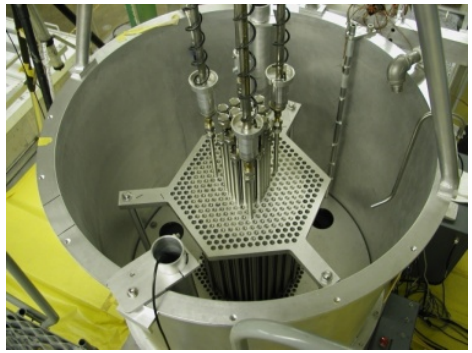


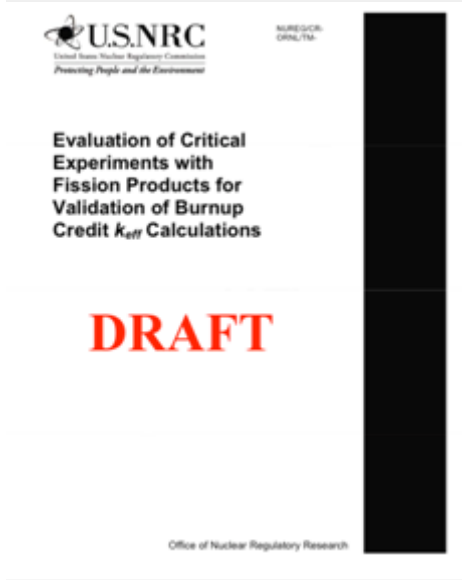
Phase 4

Current Focus – FP Validation

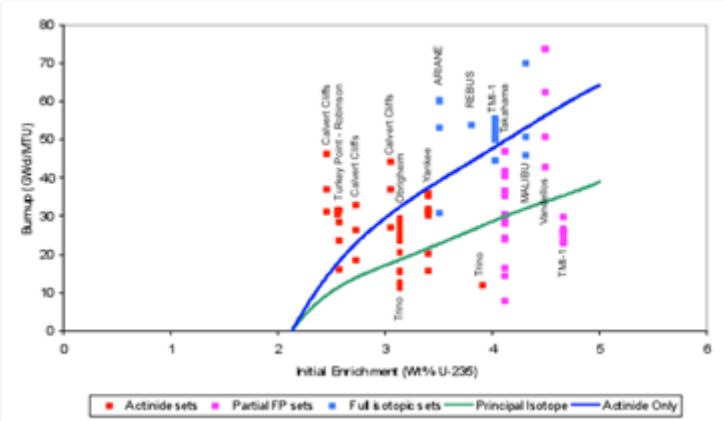
- Methods and data for criticality validation

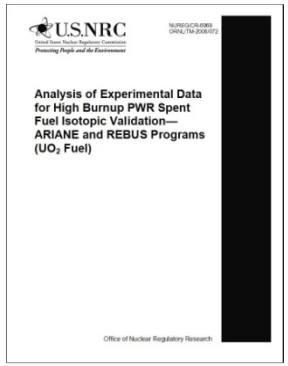


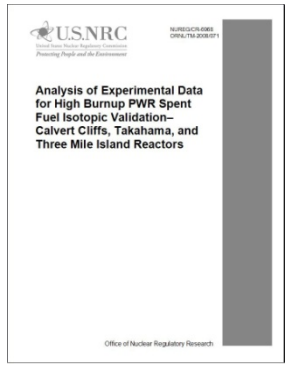


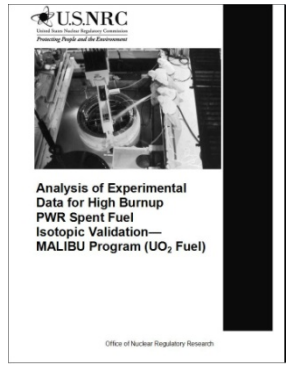


- Methods and data for isotopic validation



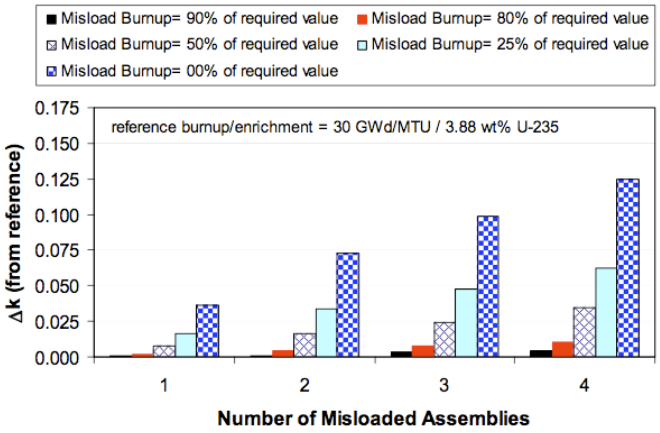


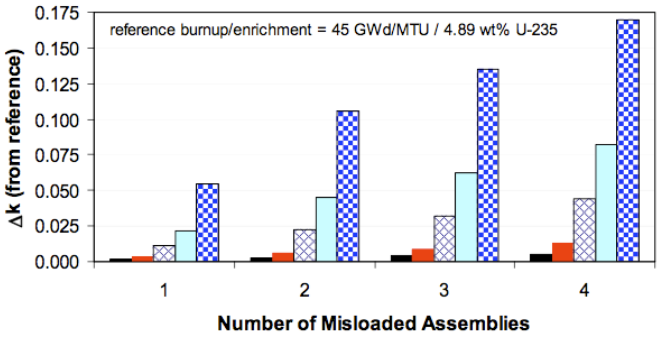


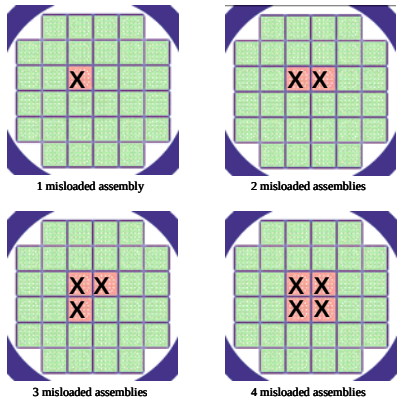


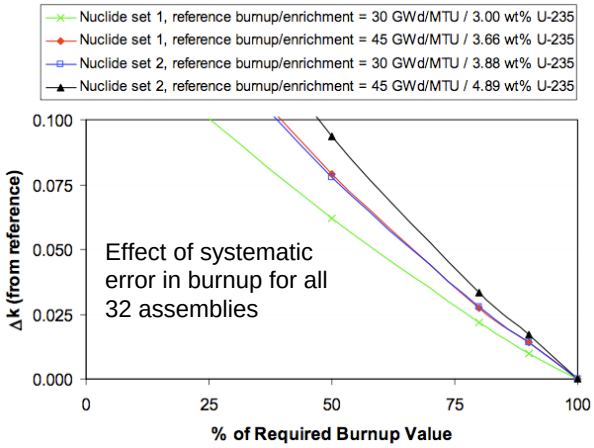
Assembly Misloading

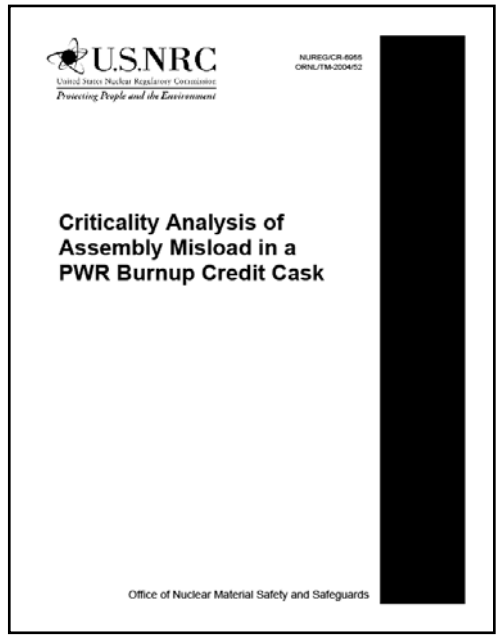
- Examined effect of fuel misloading on k_{eff}
- A variety of fuel-misloading configurations were investigated to understand impact











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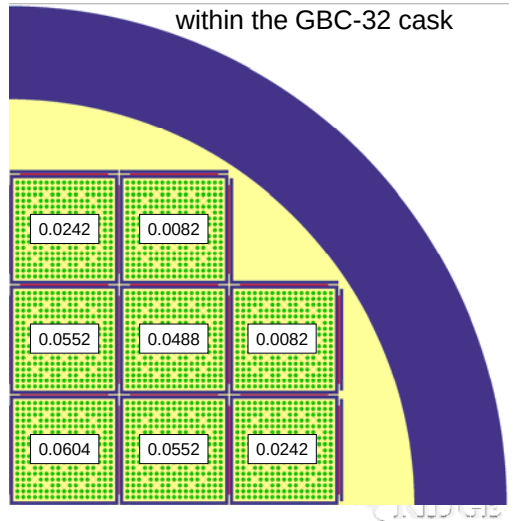
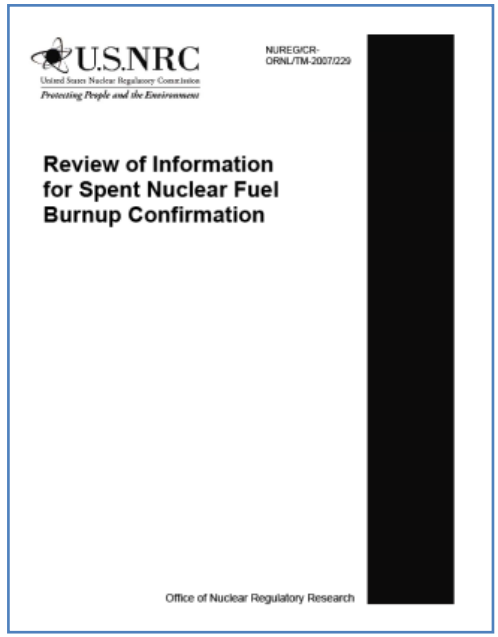
Δk effect of misloading a single fresh assembly with 5 wt% ^{235}U enrichment in different locations within the GBC-32 cask



Burnup Confirmation

- Reviewed information and issues relevant to pre-shipment burnup measurements when using burnup credit in PWR SNF storage & transport casks
- The report provides a review of:
  - Role of burnup measurements in the regulatory guidance (ISG-8) for demonstrating compliance with burnup loading criteria
  - Burnup measurement capabilities and experience
  - Accuracy of utility burnup records
  - Fuel movement and misloading experience
  - Consequences of misloading assemblies in casks designed for burnup credit
- The report also provides observations based on the review



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Other Technical Resources

- OECD/NEA Expert Group publications
- Meeting proceedings and journal articles
- Technical reports from US DOE and other organizations
- Regulatory guidance/standards from safety authorities
- ANSI/ANS-8.27-2008: Burnup Credit for LWR Fuel

- Burnup credit bibliographies:
  - http://www.ornl.gov/sci/radiation_transport_criticality/BUCPublications..htm
  - See: http://www.nea.fr/html/science/wpncs/buc/index.html

Concluding Remarks

- US NRC initiated and maintained a research program to address burnup credit technical issues with the goal of allowing and expanding the use of burnup credit in PWR SNF storage and transport applications
- A great deal of work has been performed by ORNL and others in the US and abroad, particularly for PWR SNF
- Hopefully this work is and will be useful to others for
  - Learning and understanding issues
  - Reducing redundant work, thereby enabling focused efforts on remaining important technical issues