NRC RESEARCH IN SUPPORT OF BURNUP CREDIT REGULATORY GUIDANCE

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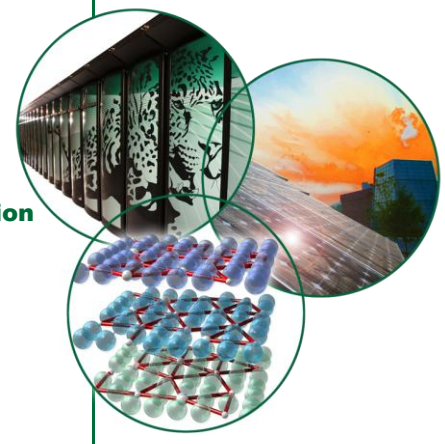
Oak Ridge National Laboratory



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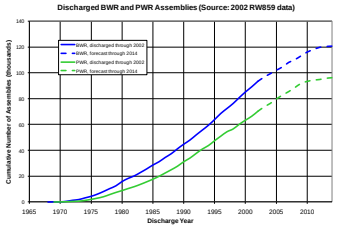
Introduction



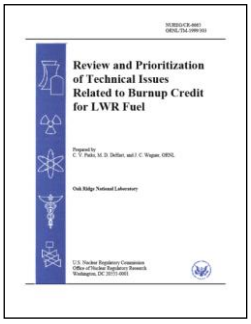
- Increasing spent nuclear fuel (SNF) inventories necessitate expanding and optimizing SNF storage and transport capacity
- Credit for fuel burnup can enable more cost-effective, higher-density storage and transport of SNF
- Potential benefits of burnup credit have motivated
  - Numerous technical studies, 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
- 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, 1999

- 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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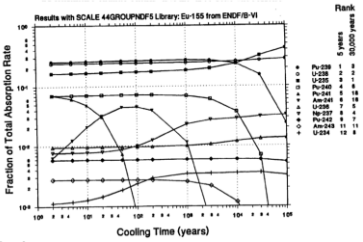

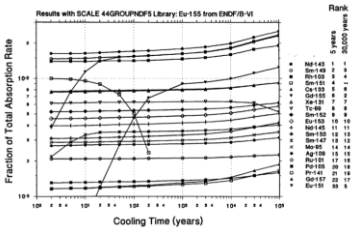

Reactivity Equivalencing, 2000

- Investigated the practice of equating the reactivity of spent fuel to the reactivity of fresh fuel, referred to as *reactivity equivalencing for PWR SFP conditions*
- Looked at normal and accident conditions, as well as various storage configurations
- Demonstrated practice to be acceptable, when used properly
- Demonstrated inaccurate and non-conservative reactivity estimates when used improperly

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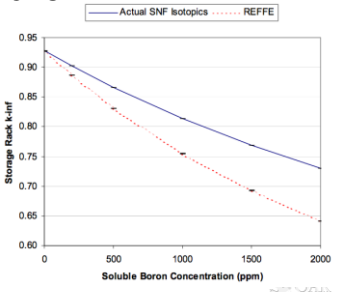
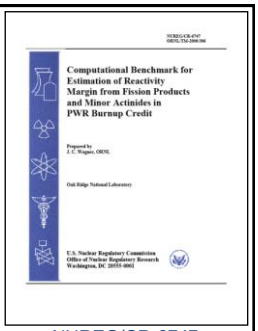


Computational Benchmark, 2001

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



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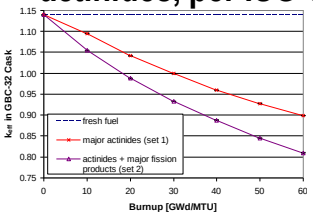
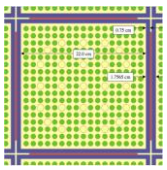
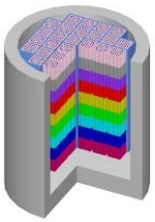






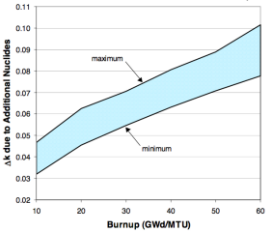
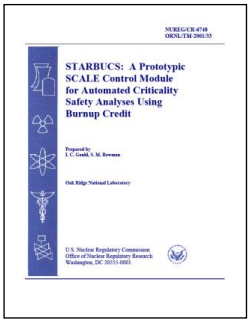


Table 15 Individual components of the reduction in k_{eff} as a function of burnup and cooling time for fuel of 5 wt % ^{235}U initial enrichment

	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%

SCALE BUC Sequence, 2001

- 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 study burnup credit issues



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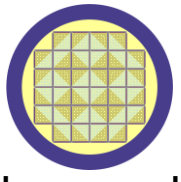
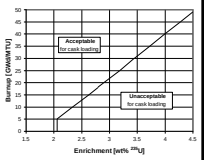
GBC-32 cask with horizontal burnup modeled

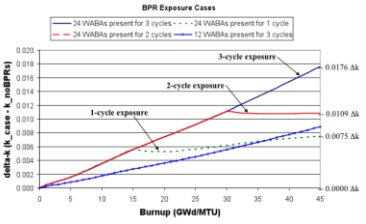


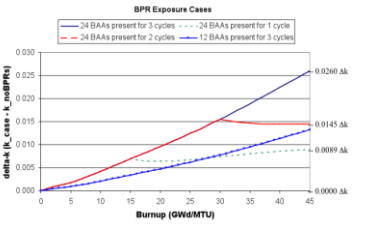


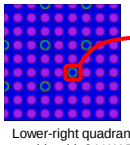
Illustrative loading curve

Burnable Poison Rods, 2002

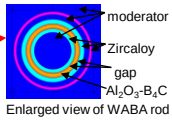
- Investigated effect of BPRs on reactivity for various BPR designs & exposure conditions







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



Enlarged view of WABA rod

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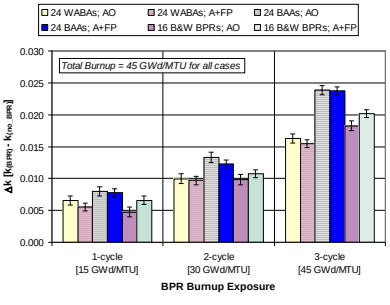
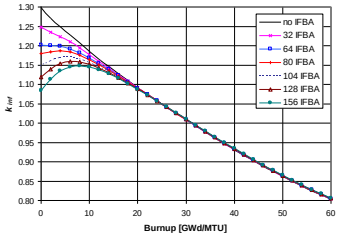
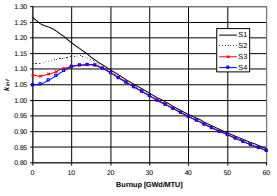
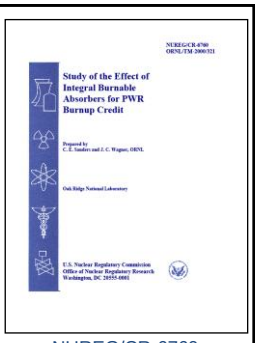


Integral Burnable Absorbers, 2002

- Investigated effect of IBAs on reactivity, ZrB_2, UO_2-Gd_2O_3, UO_2-Er_2O_3, Al_2O_3-B_4C







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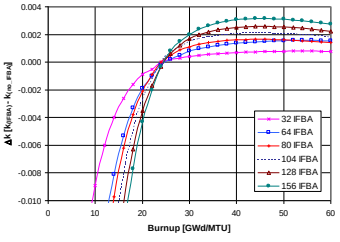
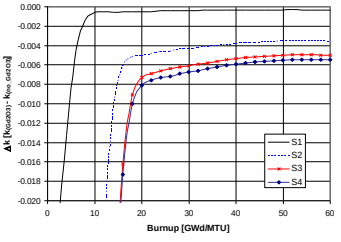
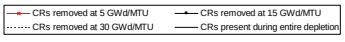
UO_2-Gd_2O_3

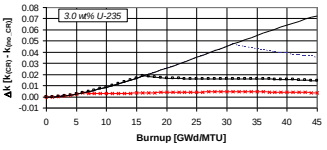


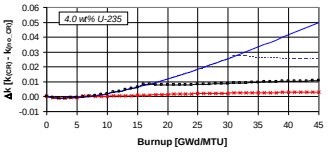


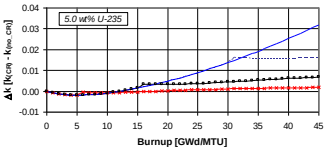
Control Rods, 2002

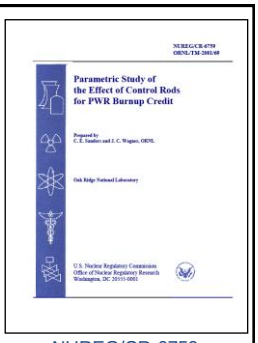
- Investigated effect of CRs on reactivity for CR/APSR designs & exposure conditions
- W, B&W, and CE designs considered











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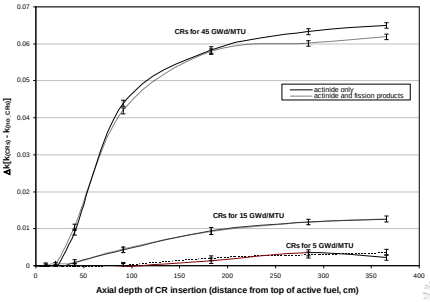
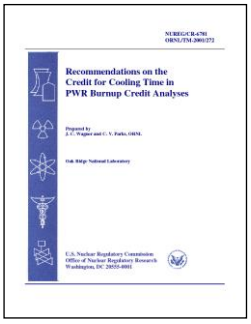


Cooling Time, 2003

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



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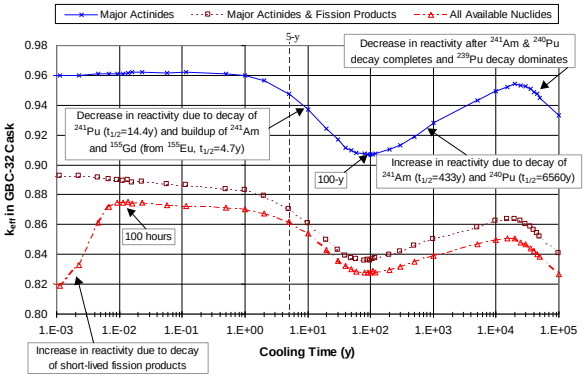

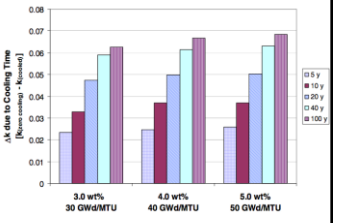

Axial Burnup, 2003

- 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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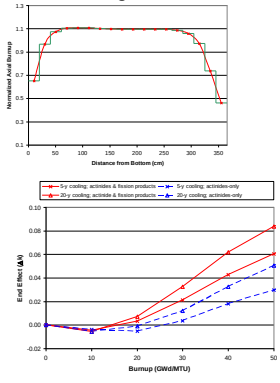
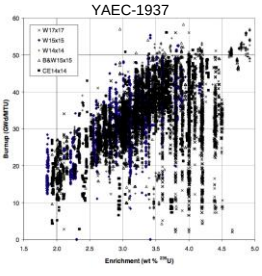
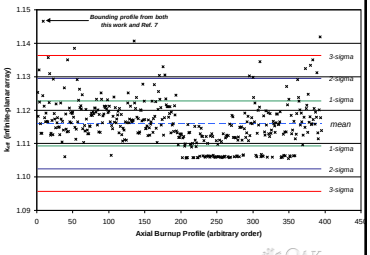
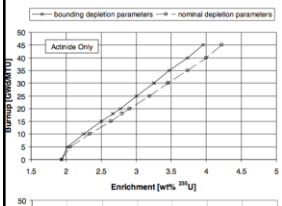


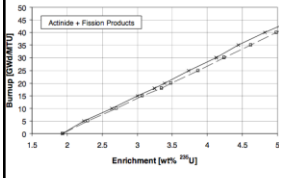


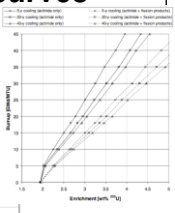


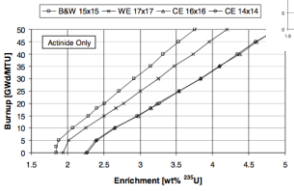
Reactivity Margins, 2003

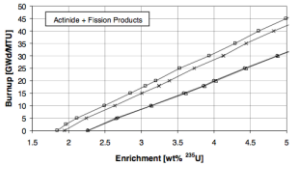
- Examined impact of depletion & criticality analysis assumptions on loading curves

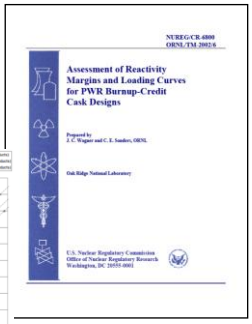












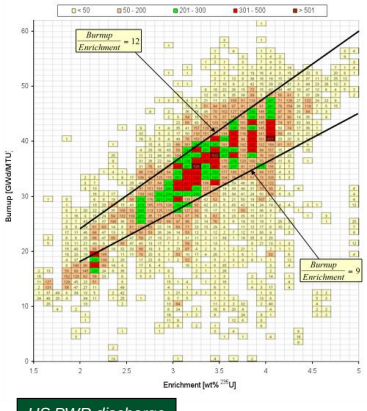
NUREG/CR-6800

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

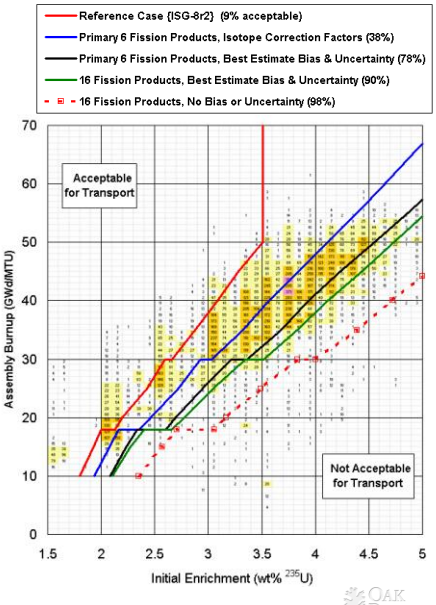
Modeling parameter/ characteristic	Assumptions used for comparison[1]		Δk values*	
	Base assumption	Bounding assumption	Actinide-only	Actinide + fission products
Fuel temperature during depletion	850 K	1100 K	0.0045	0.0031
Moderator temperature during depletion	595 K	610 K	0.0083	0.0088
Soluble boron 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 4	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

Reactivity Margins, (cont'd)

- Quantified large impact of ICFs
- Confirmed need for FP credit

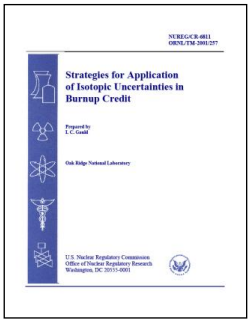


US PWR discharge data through 1998



Isotopic Validation, 2003

- 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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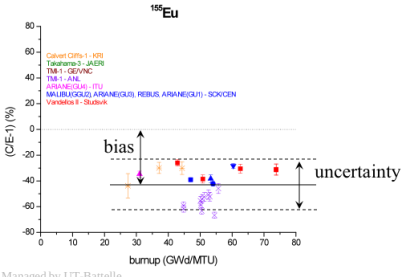
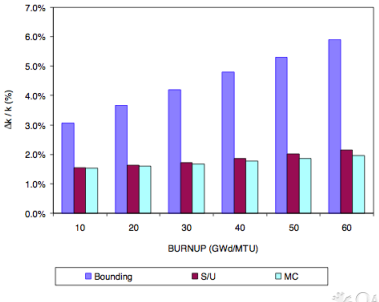
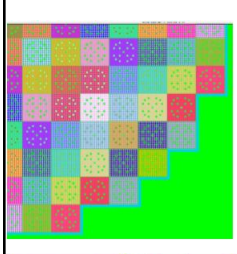
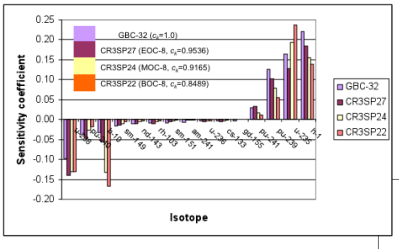


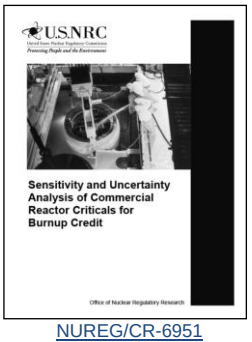


Applicability of CRCs, 2008

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







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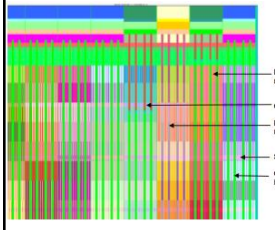
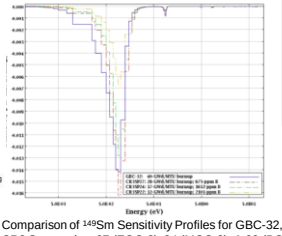
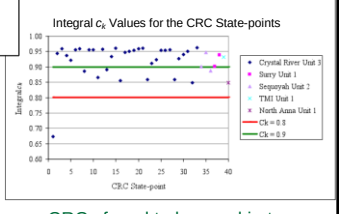




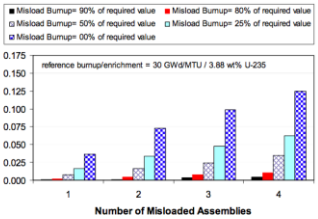
Comparison of ^{149}Sm Sensitivity Profiles for GBC-32, CR3 State-points 27 (EOC-8), 24 (MOC-8), & 22 (BOC-8)

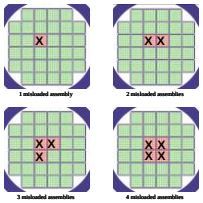


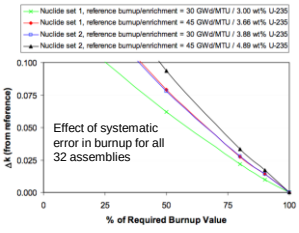
- CRCs found to be good in terms of applicability
- Issue of configuration uncertainties not addressed

Assembly Misloading, 2008

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







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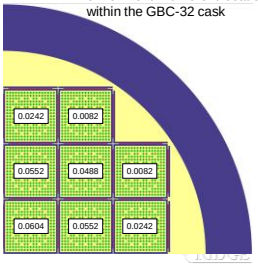
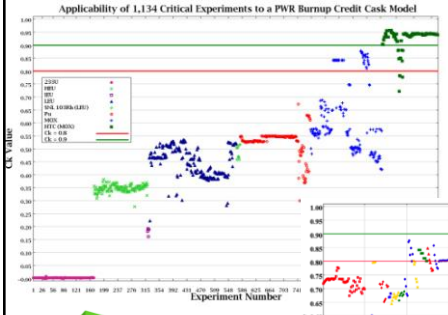
Δk effect of misloading a single fresh assembly with 5 wt% ^{235}U enrichment in different locations within the GBC-32 cask

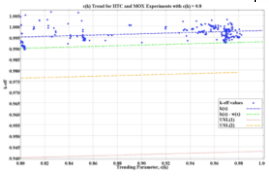


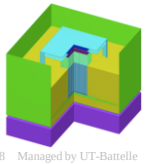
NRC Research in Support of Burnup Credit Regulatory Guidance

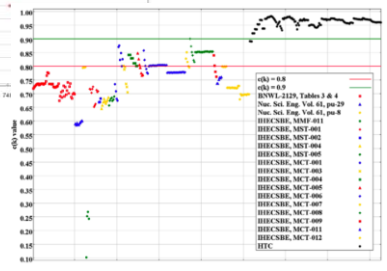
Criticality Validation–HTC data

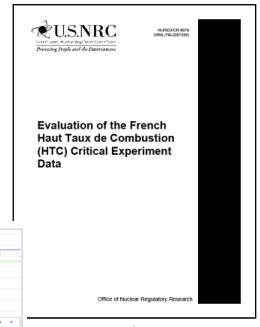
- Examined applicability/usefulness of French critical experiments (Valduc) for actinide validation
  - 156 configurations designed to mimic 4.5 wt% ^{235}U initial enrichment fuel burned to 37.5 GWd/MTU in storage & transport conditions











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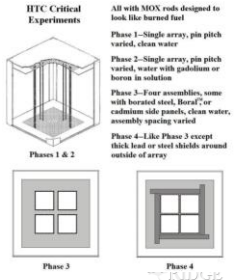
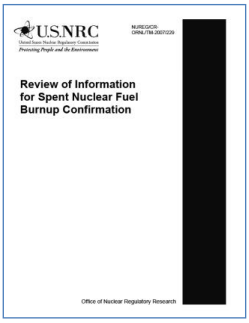


NRC Research in Support of Burnup Credit Regulatory Guidance

Burnup Confirmation, 2009

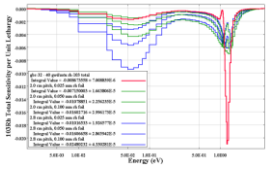
- Reviewed information and issues relevant to pre-shipment burnup measurements when using burnup credit in PWR SNF storage & transport casks
- The report provides a review of:
  - Role of burnup measurements in the regulatory guidance (ISG-8) for demonstrating compliance with burnup loading criteria
  - 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



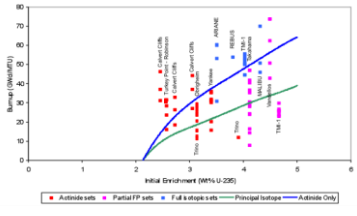
NUREG/CR-6998

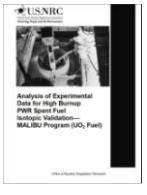
Current Focus – FP Validation

- Methods and data for criticality validation



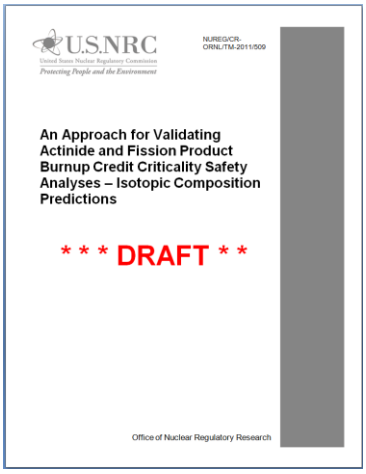
- Methods and data for isotopic validation



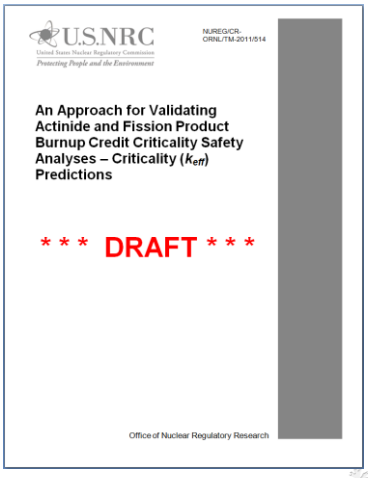


Current Focus – FP Validation

- Methods and data for isotopic validation



- Methods and data for criticality validation



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
  - http://www.oecd-nea.org/science/wpncs/buc/bibliography

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
- Work on BWR BUC bases has been started
- 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

Closure – questions & discussion

- Thank you for your attendance and attention!

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  - Don Mueller, muellerde@ornl.gov