Review of NRC Guidance on Burnup Credit for Transport and Dry Cask Storage

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Introduction

- **Separate and distinct licensing staff and regulations govern**
  - **Pool storage (10 CFR 50)**
  - **Transport and dry cask storage (10 CFR 71 & 72)**
  - **Disposal (10 CFR 63)**
- **Technical issues the same but regulatory approach and concerns often different**
- **Talk will focus on burnup credit (BUC) for transport of spent nuclear fuel (SNF)**

Introduction: Pool Storage

- **Burnup credit for PWR fuel storage used since early 1980s**
  - **Decision to allow BUC based largely on resistance to allowing credit for the boron in pools under potential accident scenarios**
- **Informal guidance on pool storage provided by memo of Kopp (NRC, retired) [1]**
- **Focus seems to be on evaluating overall safety of the pool**
  - **Some implicit consideration for the boron presence**
  - **Separate assessment of the individual sources of uncertainty not typically required**

Introduction: Disposal

- **Regulations for disposal allow:**
  - **Postclosure criticality to be considered in light of probability of occurrence and the consequences to the total system performance**
  - **Preclosure will require prevention of criticality**
- **Safety evaluation report (SER) indicates acceptance of general approach proposed by licensee:**
  - **Postclosure BUC for PWR and BWR fuel**
  - **Credit for actinides and fission products**
- **Open items of SER relate to specific approach to be used for validation**

Introduction: Transport

- **DOE Topical Report (TR) for transportation submitted May 1995 [2]**
- **TR revisions submitted along with technical reports providing background information. Not approved.**
- **Interim Staff Guidance 8 (ISG-8): *Burnup Credit in the Criticality Safety Analyses of PWR Spent Fuel in Transport and Storage Casks***
  - **Revision 0 - May 1999 [3]**
  - **Revision 1 - July 1999 [4] http://www.nrc.gov/OPA/reports/isg8r1.htm**
- **ISG-8 recommendations included in NRC Standard Review Plan for transport (March 2000) [5]**
  - **Previous guidance and recommendations for fresh fuel safety analysis remain intact**

References

[1] *Guidance on the Regulatory Requirements for Criticality Safety Analysis of Fuel Storage at Light-Water Reactor Power Plants*, NRC memorandum from L. I. Kopp to T. Collins, August 19, 1998, U.S. Nuclear Regulatory Commission.

[2] *Topical Report on Actinide-Only Burnup Credit for PWR Spent Nuclear Fuel Packages*, DOE/RW-0472, Rev. 0, U.S. Department of Energy, Office of Civilian Radioactive Waste Management (May 1995). - Revision 1 issued May 1997. Revision 2 issued September 1998.

[3] *Spent Fuel Project Office Interim Staff Guidance - 8, Rev. 0 - Limited Burnup Credit*, U.S. Nuclear Regulatory Commission, May 13, 1999.

[4] *Spent Fuel Project Office Interim Staff Guidance - 8, Rev. 1 - Burnup Credit in the Criticality Safety Analyses of PWR Spent Fuel in Transport and Storage Casks*, U.S. Nuclear Regulatory Commission, July 30, 1999.

[5] *Standard Review Plan for Transportation Packages for Spent Nuclear Fuel - Final Report*, U.S. Nuclear Regulatory Commission, NUREG-1617, March 2000.

[6] *Regulations for the Safe Transport of Radioactive Material, 1996 Edition*, IAEA Safety Standards Series No. ST-1, International Atomic Energy Agency (1996).

Overview of ISG-8

ISG-8 Recommendations (6 areas)

- **Limits for the Licensing Basis**
- **Code Validation**
- **Licensing-Basis Model Assumptions**
- **Loading Curve**
- **Assigned Burnup Loading Value**
- **Estimate of Additional Reactivity Margin**
- **Full text available at http://www.nrc.gov/OPA/reports/isg8r1.htm**

Recommendation 1: Limits for Licensing Basis

- **Actinide compositions**
- **PWR UO_2 fuel**
  - **Average assembly burnup value of 40 GWd/MTU or less**
  - **Cooling time of 5 years (fixed)**
  - **Intact assemblies that have not used burnable absorbers (BAs)**
  - **Maximum initial enrichment limited to 5 wt %**
- **Loading offset for initial enrichments >4.0 wt %**
  - **Increase burnup loading value by 1 GWd/MTU over licensing basis value for each 0.1 wt % over 4.0 wt %**
  - **Example: To obtain credit for 4.2 wt % fuel burned to 40 GWd/MTU requires an assigned burnup value of 42 GWd/MTU**
- **Requested use of specifications outside these ranges should be accompanied by adequate justification**

Licensing Basis Recommendation: Comments

- **Limits on initial enrichment, burnup, and use of loading offset are a result of the lack of chemical assay data for PWR SNF beyond 40 GWd/MTU and 4.0 wt % (only one measurement above 3.4 wt %).**
- **Assemblies with BAs excluded due to lack of chemical assay data and lack of technical studies**
- **Limited to actinides due to large level of uncertainty related to fission products.**
- **Cooling time limited to value of 5 y because**
  - **No current need to ship with less cooling time**
  - **Concerns over complexity of loading curves for multiple times**
  - **Transport of fuel with cooling times beyond 5 y provides reactivity margin with well-known uncertainty**

Loading Offset Example

Initial Enrichment (wt % 235U)	Safety Analysis Burnup (GWd/MTU)	Loading Burnup (GWd/MTU)
4.0	40	40
4.25	40	42.5
4.5	40	45
4.75	40	47.5
5.0	40	50

Recommendation 2: Code Validation

- Derive isotopic bias and uncertainty from applicable fuel assay measurements
  - Only actinides established via such validation should be used in predicting k-eff
- Derive k-eff bias and uncertainty from applicable benchmark critical experiments
  - Guidance on validation techniques exist but adequacy of experiments still requires substantial judgement
- Bias and uncertainties should be applied to ensure conservatism, particularly given the lack of cask-type SNF experiments

Recommendation 3: Licensing-Basis Model Assumptions

- **Use fuel design and in-reactor operating parameters that provide conservative SNF k-eff in cask.**
- **Cask models, analysis assumptions, and code inputs should allow adequate representation of the physics; e.g.**
  - **Axial and horizontal variation of the burnup within a spent fuel assembly**
  - **Modeling that can account for the local reactivity effects at the fuel ends**

Recommendation 4: Loading Curve

- **Applicant should prepare a loading curve(s) that provides, as a function of initial enrichment, the assigned burnup value above which fuel assemblies may be loaded in a cask.**
- **Loading curves based on 5-y cooling time and only fuel cooled 5 y or longer should be loaded in a cask approved for burnup credit.**

Recommendation 5: Assigned Burnup Loading Value

- Cask applicant should provide administrative procedures to ensure that the cask user will load with fuel that is within specifications approved during licensing.
- Procedures should include an assembly measurement that confirms the reactor record assembly burnup.
  - May be calibrated to the reactor records for a representative set of assemblies.
  - For record confirmation, measurement should provide agreement within a 95% confidence interval based on the measurement uncertainty.
- Assigned burnup loading value should be the confirmed reactor record value as adjusted downward for uncertainties in the records and the measurement.

Recommendation 6: Estimate of Additional Reactivity Margin

- Applicant should provide design-specific analyses that estimate the reactivity margin available from nuclides not included in the licensing safety analysis.
- The margin estimates should be verified using experimental data (e.g., limited assay data) and computational benchmarks (e.g., OECD problem sets) that demonstrate the performance of the codes and data used by the applicant.
- Margin estimates should be provided over full range of loading curve(s).
- Margin estimates should be assessed against estimates of uncertainties not evaluated in the models or validation process
  - Potential added uncertainty from lack of SNF cask criticals
  - Potential non-conservatisms in modeling

Comparison of regulatory requirements for PWR BUC

Issue	Current regulatory guidance	
	Spent fuel pools	Transport and dry storage
Nuclides credited	All nuclides except ^{135}Xe, with depletion uncertainty equal to 5% of the reactivity decrement	Select actinides-only, with conservative biases applied to the concentrations.
Modeling – fuel	Equivalent fresh fuel enrichments	Explicit isotopic content
Modeling – burnup distributions	Consideration of axial burnup distribution	Bounding consideration of axial and horizontal burnup distributions
Validation requirements	Criticality code validation with fresh fuel isotopics	Validation of criticality and depletion methodologies for the specific isotopics credited
Maximum allowable burnup	None specified	No credit for burnup beyond 40 GWd/MTU
Maximum allowable initial enrichment	5.0 wt % ^{235}U	4.0 wt % ^{235}U (5.0 wt % with burnup "penalty")
Fixed burnable absorbers	Acceptable	Not acceptable
Integral burnable absorbers	Acceptable	Not acceptable
Requirement for burnup measurements	No	Yes
Cooling time	All cooling times allowed	5-year cooling time

NRC Research Program on BUC (Storage and Transport)

OBJECTIVES:

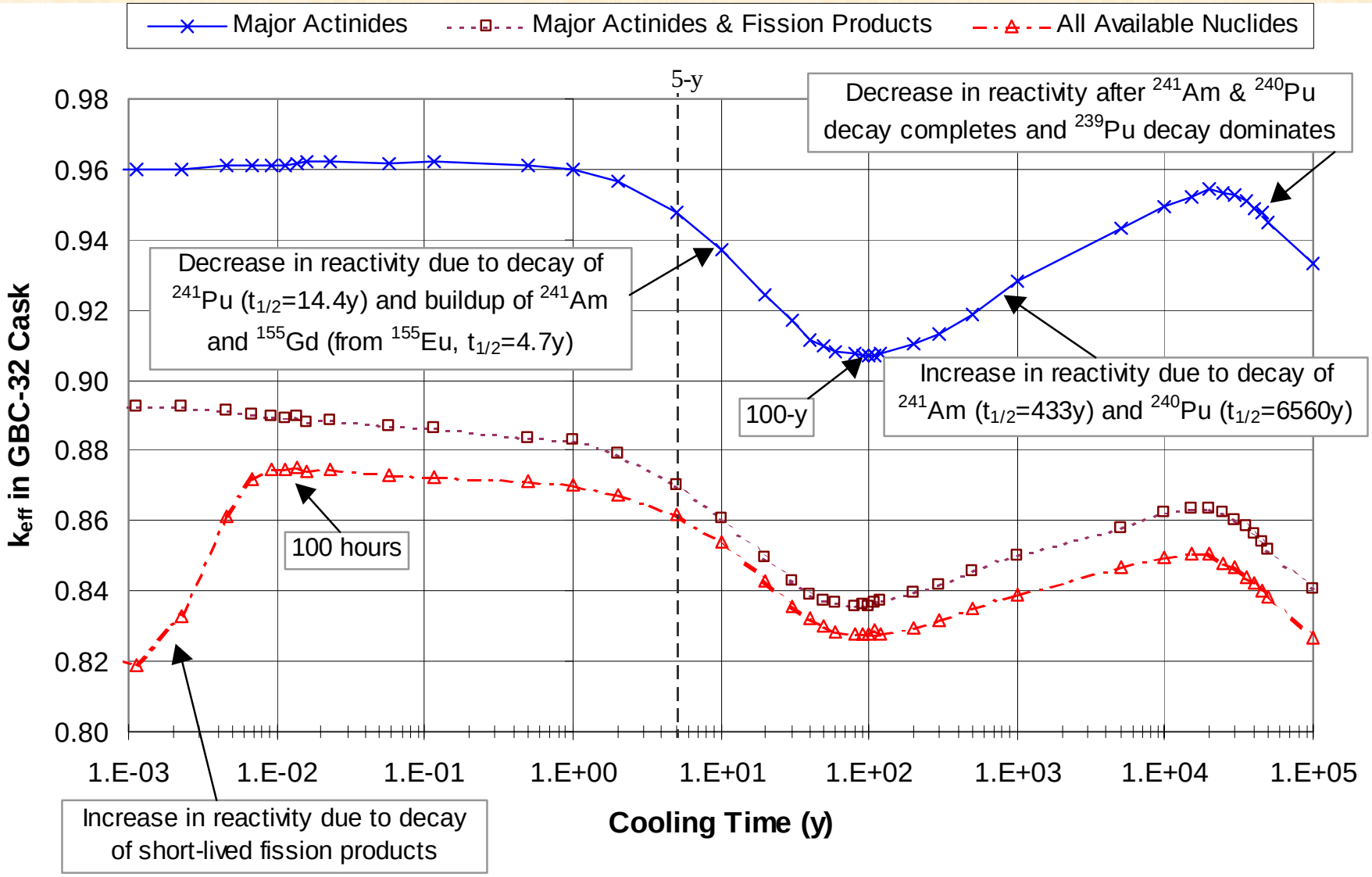
- Assure understanding of phenomena and parameters that impact subcritical margins.
- Develop technical bases and recommendations to improve guidance and expand criteria for ISG-8.

FOCUS AREAS:

- Technical basis for cooling times other than 5 years
- Technical basis for allowing assemblies exposed to burnable absorbers.
- Guidance for selection of axial burnup profile.
- Technical basis for modification or removal of loading offset.

Cooling Time

Reactivity Effect of Cooling Time



Cooling Time Issue: Observations

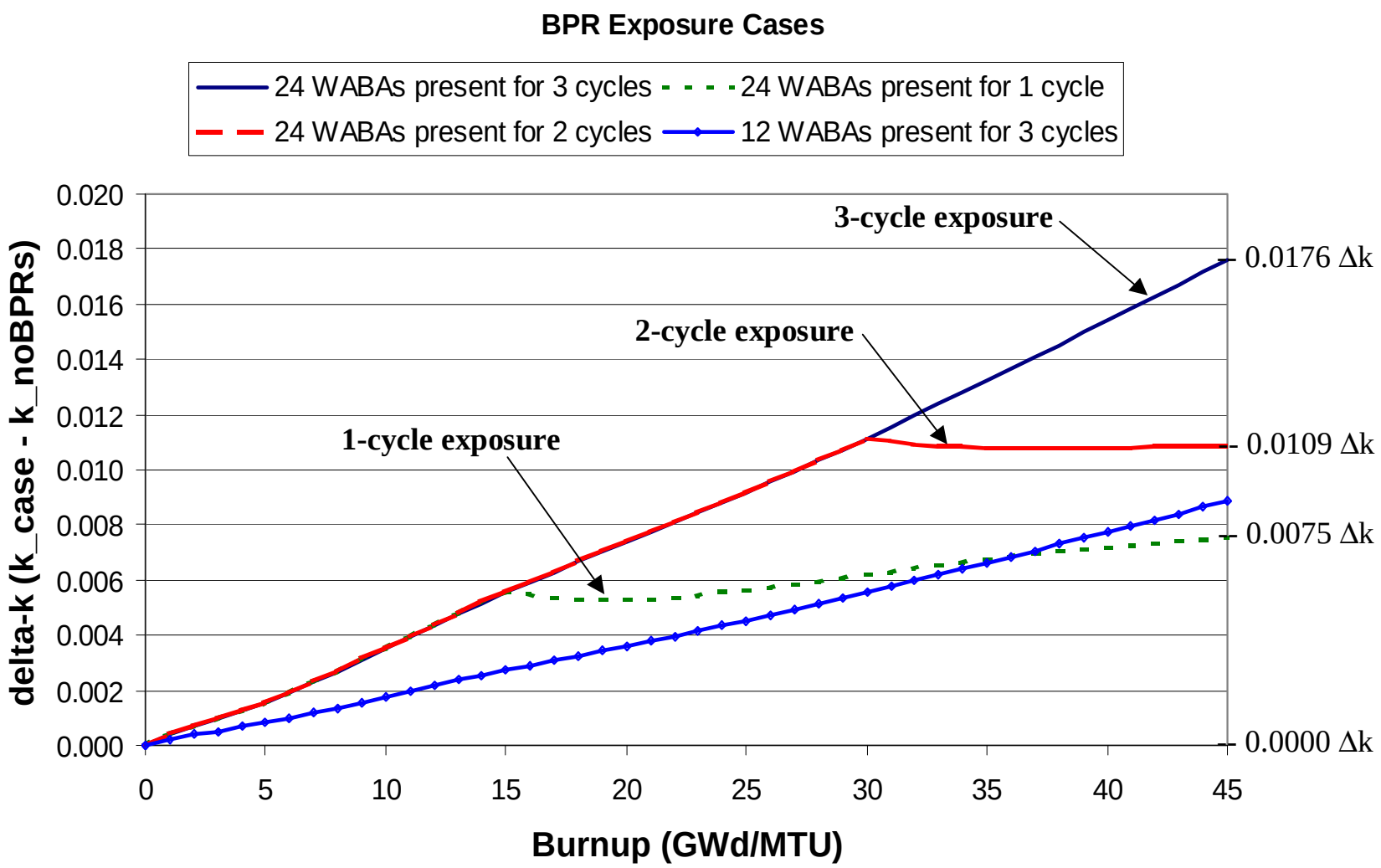
- Time frames of interest for dry storage and transport cask not firm – practical time of 200 y (10 storage licensing periods) assumed upper limit.
- Minimum actinide-only estimates of k-eff (ISG-8 assumption) exceed maximum k-eff for best estimate prediction (with fission products considered).
- Cooling time of 40 y provides reactivity equivalent to that of 200 y.
- Best estimate k-eff value at 10-y cooling time not exceeded at longer cooling times.
- Recommendation: Modify current regulatory guidance to allow cooling times from 1 to 40 years.

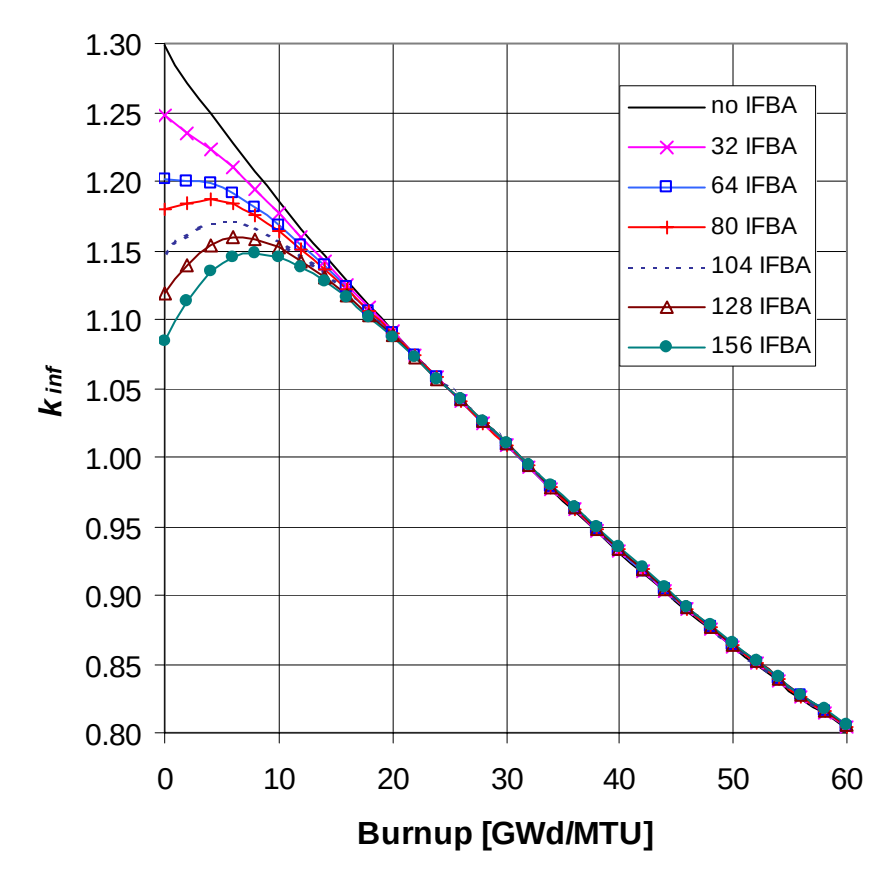
Burnable Absorbers (BAs) and Control Rods (CRs)

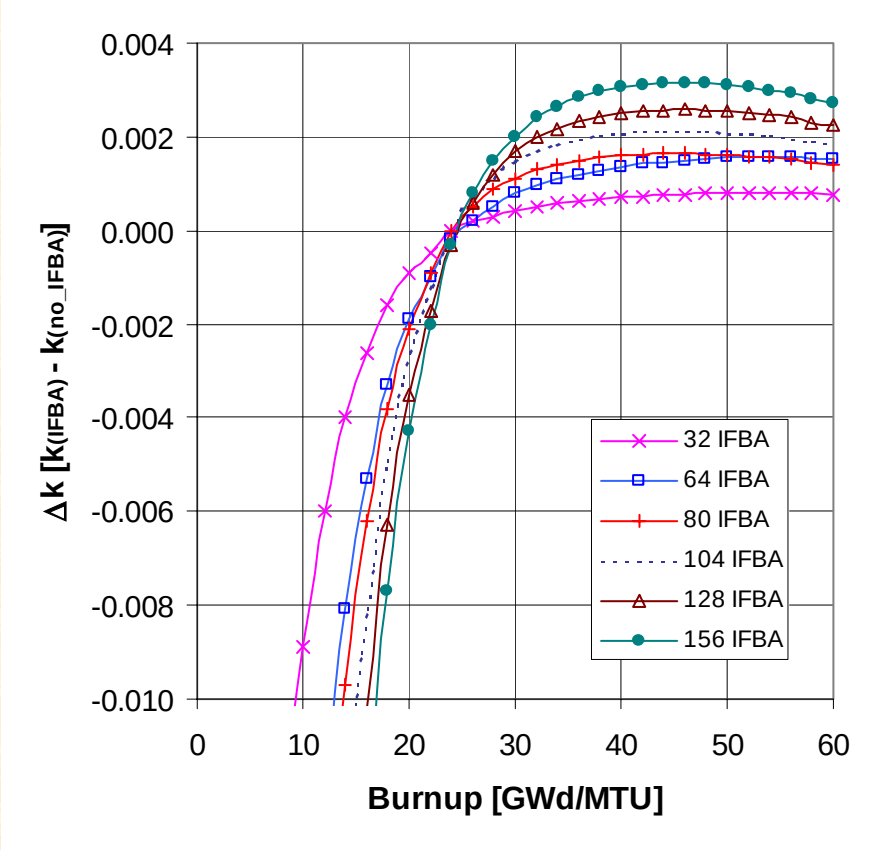
OPERATIONAL PRACTICES

- **Burnable Poison Rods (BPRs):**
  - are typically inserted into a PWR fuel assembly during its first cycle in the reactor core
  - number of BPRs and/or poison loading is variable
  - typically discarded after one-cycle residence in core
- **Integral burnable absorbers (IBAs) are non-removable and remain with the assembly**
- **In the U.S., CRs are used intermittently**
  - Typically not inserted in active fuel during full power operation
  - Full insertion only for short periods
  - Potential regulatory concern about effect of small insertion into upper end region during long burnup periods
- **Axial power shaping rods (APSRs) can be inserted over portion of core for long burnup period**

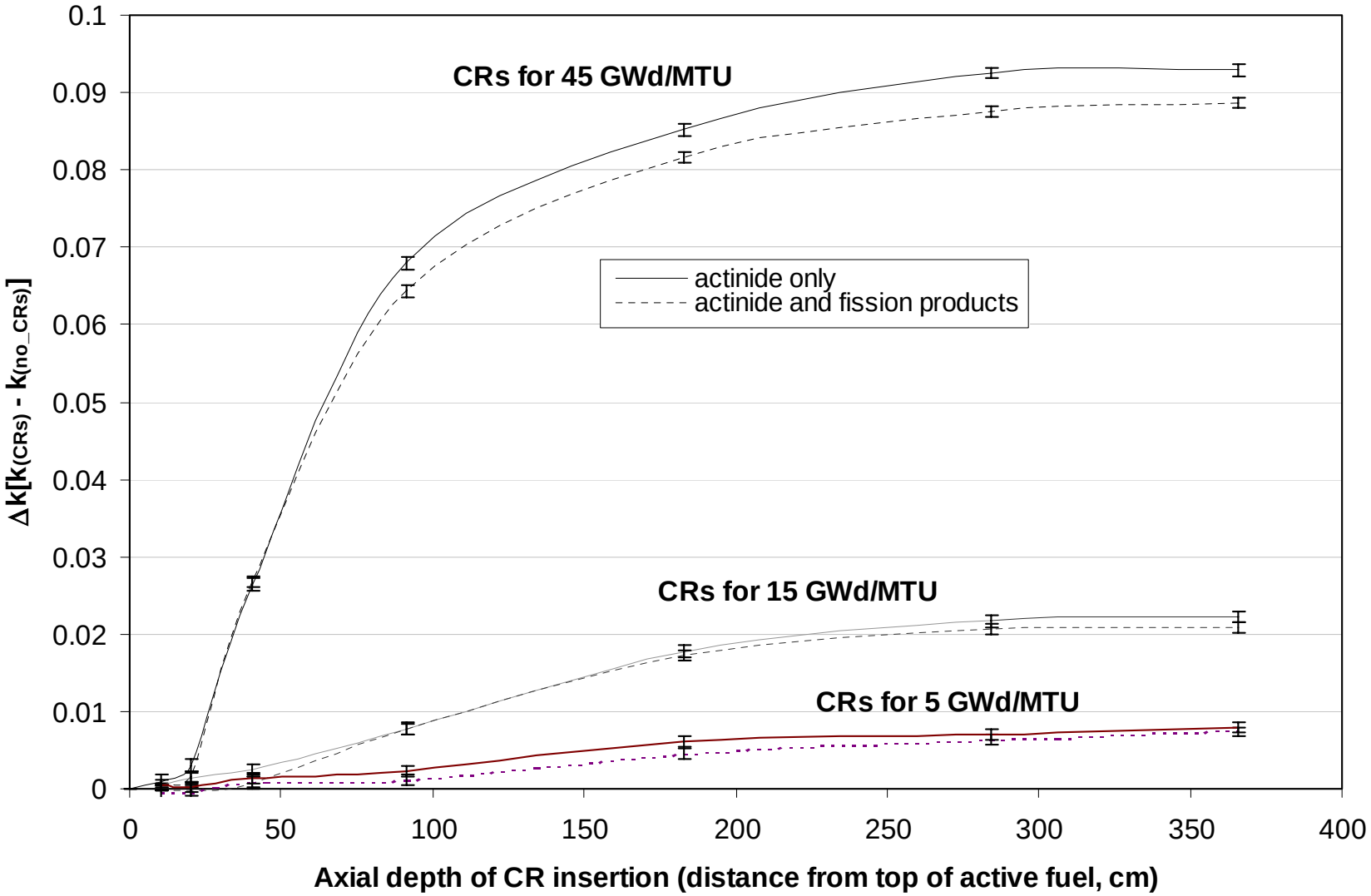
REACTIVITY EFFECT OF WABAs – Actinide-Only




1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
k inf
0
10
20
30
40
50
60
Burnup [GWd/MTU]
no IFBA
32 IFBA
64 IFBA
80 IFBA
104 IFBA
128 IFBA
156 IFBA


0.004
0.002
0.000
-0.002
-0.004
-0.006
-0.008
-0.010
Δk [k(IFBA) - k(no_IFBA)]
0
10
20
30
40
50
60
Burnup [GWd/MTU]
32 IFBA
64 IFBA
80 IFBA
104 IFBA
128 IFBA
156 IFBA

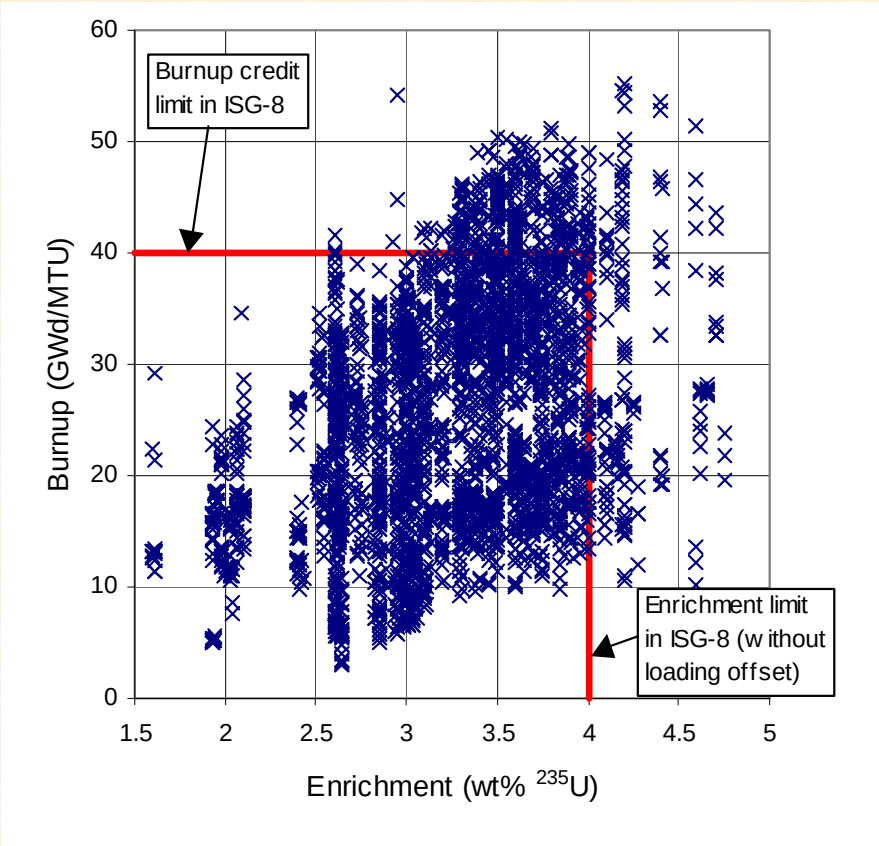
Control Rod Effects

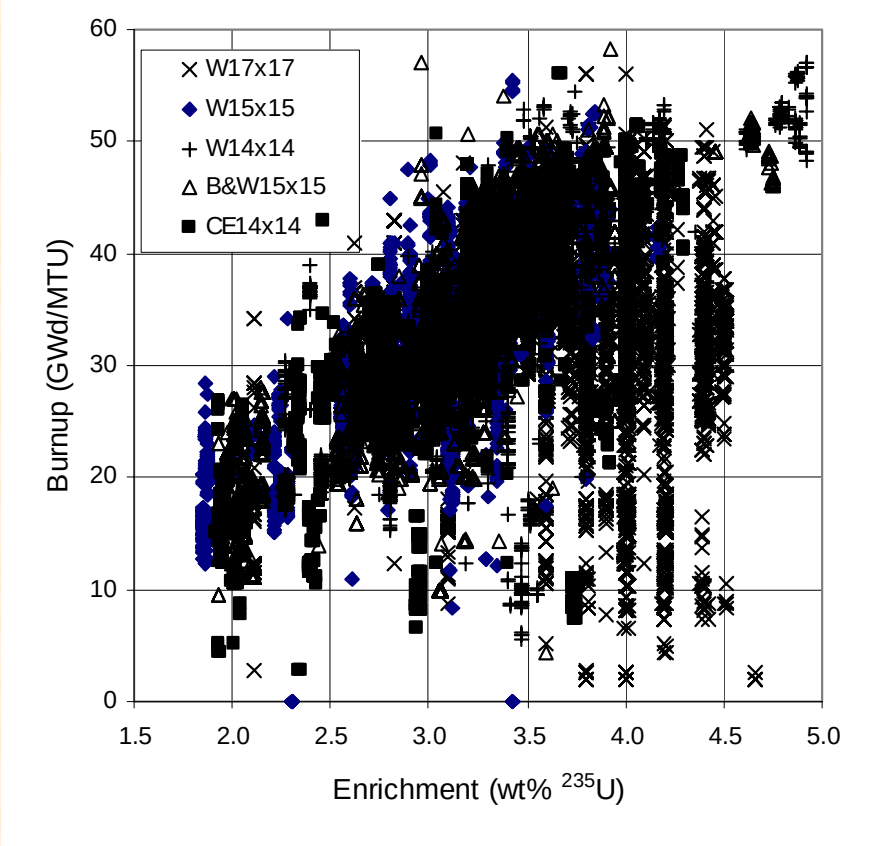


Burnable Absorbers: Summary and Recommendations

- **Demonstrated behavior on SNF using wide variety of designs, poison loadings, and operating histories.**
- **BPRs: 1-3% Δk increase with maximum loading and exposure (1-cycle, max loading typically <1% Δk)**
- **IBAs: Insignificant increase or decrease in k_{eff}**
- **CRs: Impact of 2% Δk found for bounding typical conditions**
- **Recommendation: Allow loading of assemblies exposed to BAs into BUC casks.**
  - **Include effect of BPRs in safety analysis**
  - **Justify assumptions if less than maximum exposure**
  - **Establish restriction on license**

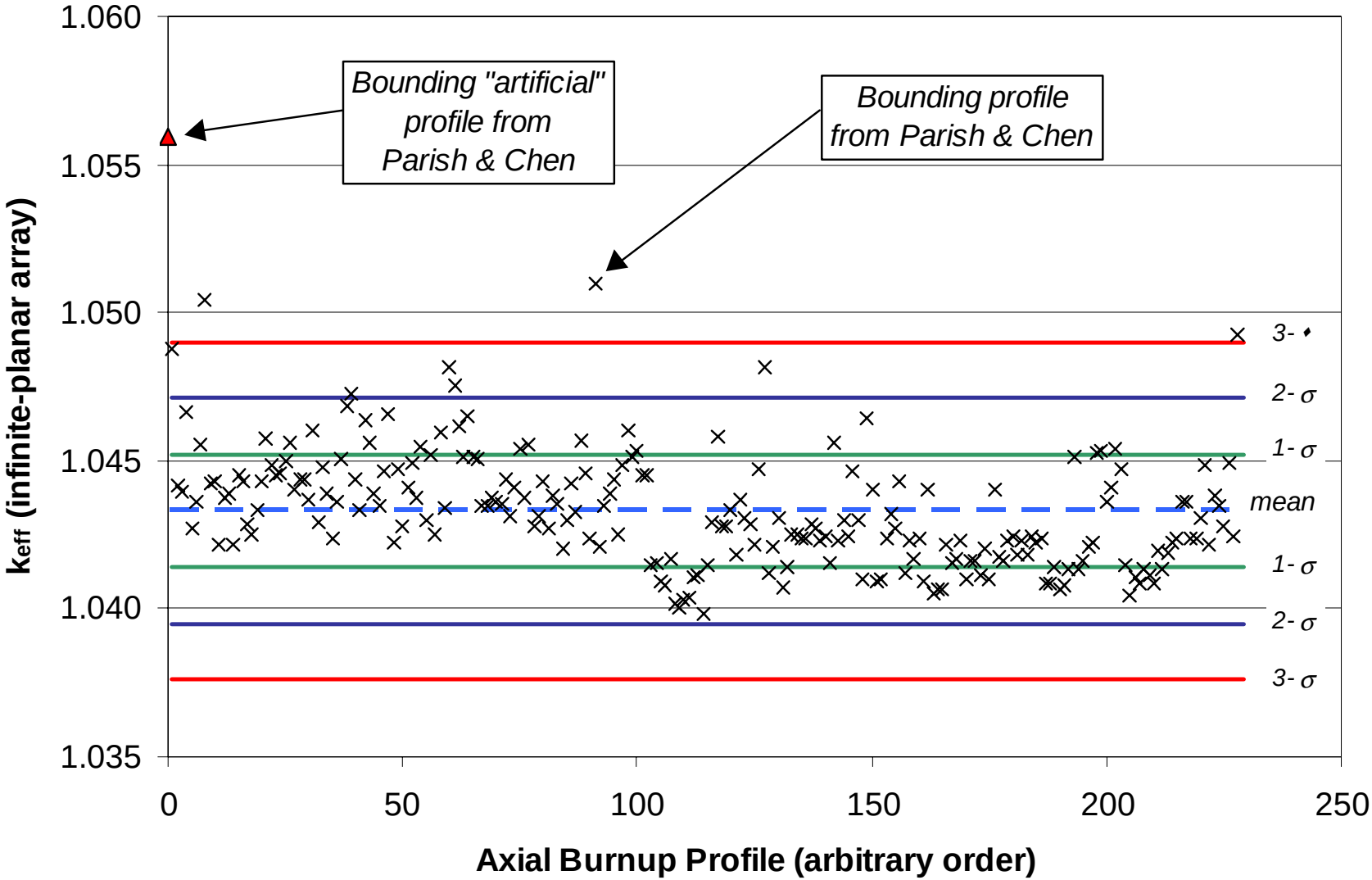
Axial Profiles





(a) **(b)**

Burnup and enrichment combinations: (a) YAEC-1937 database and (b) discharge data through 1998.



k_{eff} values based on the YAEC-1937 database profiles for 38-42 GWd/MTU

Guidance for Selecting Axial Burnup Profiles

- **Publicly available US data base of over 3000 profiles investigated for:**
  - **Representation of PWR assembly designs and reactor types**
  - **Representation of operating cycle histories**
  - **Confirmation of bounding profiles**
  - **Adequate probabilistic range for bounding profiles**
- **Recommendation: Existing finite data base acceptable for use in licensing analyses with actinide-only BUC**
  - **Work needed to add profiles for higher burnups and/or demonstrate adequacy of current database in this regime (> 40 GWd/MTU)**

Loading Offset

Loading Offset Recommendation

- **Recommendation: Remove requirement for loading offset for fuel with enrichments above 4.0 wt %.**
  - NRC requested additional justification for recommendation
  - Offset "penalty" has minimal impact with other current restriction on burnup (40 GWd/MTU)
- **Rationale:**
  - Sensitivity studies suggest existing data may be highly applicable to extended enrichment regime.
  - Published results of French indicate no significant trends in bias or uncertainty for higher enrichment fuel.
  - With actinide-only BUC, negative reactivity margin from FPs will more than offset any additional uncertainties associated with increase in enrichment.
- **Note: Recently obtained higher enrichment assay data from Japan support rationale and addresses NRC request for added justification**

Summary and Conclusions

- NRC implementation and guidance for BUC varies with application area (cask vs. pools vs. disposal).
- NRC guidance on BUC for casks does have areas where clear, concise guidance is not provided - evidence of evolutionary stage of the experience in these areas.
- Cask vendors indicate they are working on applications for use of burnup credit in transportation, but none submitted to NRC.
- Recommendations from NRC research program are currently being used to revise ISG-8.
- Extension of burnup limit beyond 40 GWd/MTU also being considered.