Regulatory Status of Burnup Credit for Spent Fuel Dry Storage and Transport in the United States

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Status of LWR Burnup Credit in U.S.

- Storage Pools
  - PWR Burnup Credit used since early 1980s
- Casks for Dry Storage and Transport
  - PWR Burnup Credit - First applications to be submitted in August and November 2000
- Geologic Repository
  - LWR Burnup Credit under development

U.S. DOE Efforts on Burnup Credit in Casks

- DOE Topical Report on Proposed Method for Actinide-Only Burnup Credit in PWR SNF Casks
  - DOE cooperative studies with industry started in 1986.
  - Emphasized PWR over BWR fuel due to greater transportation cost benefits.
  - DOE Topical Report submitted to NRC in May 1995.
  - Topical Report revised in May 1997 and September 1998 in response to NRC comments.
  - Further efforts transferred to NRC in 1999.

U.S. NRC Efforts on Burnup Credit in Casks

- NRC Technical Review Guidance and Research
  - **NRC Burnup Credit Research Program started in May 1999.**
  - **Industry input on needs and issues provided at NRC/NEI meetings in May and December 1999.**
  - **NRC Interim Staff Guidance for Limited Burnup Credit in PWR Spent Fuel Casks:**
    - **<u>ISG-8 Rev.0</u> issued in May 1999. No applications.**
    - **<u>ISG-8 Rev.1</u> issued in July 1999, incorporated into updated NRC Standard Review Plans in March 2000. First applications expected later this year.**
  - **NRC will issue further guidance revisions to reflect new information from research and licensing experience.**

NRC Technical Review Guidance
- Recommendations in 6 Areas -

- 1. Limits for the Licensing Basis
- 2. Validation of Codes and Methods
- 3. Licensing-Basis Model Assumptions
- 4. Loading Curve
- 5. Assigned Burnup Loading Value
- 6. Estimate of Additional Reactivity Margin

1. Limits for the Licensing Basis
- Review Guidance -

- Credit from Actinides Only in UO_2 PWR Fuel
- Maximum credited burnup = 40 GWd/MTU
- Loading Offset for initial enrichments between 4 and 5 wt%
  - **Example: 4.5 wt% reduces assigned burnup by 5 GWd/MTU**
- No credit in fuels exposed to burnable absorbers
- Analyzed cooling time = 5 years, all fuels cooled $\geq$5 years

Credit for fuels and actinide compositions outside these limits requires additional isotopic assay data and/or extrapolation techniques.

1. Limits for the Licensing Basis
- Comments -

- Credit limited to actinides only:
  - **Little validation of fission product isotopics and worths.**
  - **Need margin from neglect of fission products to address uncertainties in actinide credit (see Recommendation 6).**

- Burnup Limit and Loading Offset:
  - **Lack of assay data beyond 40 GWD/MTU and 4.0 wt%.**
  - **Loading Offset reduces credited burnup to compensate for validation uncertainties in fuels enriched beyond 4.0 wt%.**

- No credit in fuels affected by burnable absorbers:
  - **Initial lack of design information and modeling studies.**
  - **Lack of chemical assay data.**

2. Validation of Codes and Methods
- Review Guidance -

- Derive isotopic bias & uncertainty from applicable fuel assay benchmarks.
- Derive k_{eff} bias & uncertainty from benchmark experiments representing major features of cask and spent fuel.
- In computing k_{eff}, use only those nuclides established in the validation process.
- Consider the bias uncertainties arising from lack of experiments that are prototypic of spent fuel in the cask.
- Apply bias and uncertainties only in ways that ensure conservatism in the licensing safety analysis.

2. Validation of Codes and Methods
- Comments -

- Nonprototypicality of fresh UO_2 and MOX criticals for cask criticality validation:
  - **Actinide isotopic mixes differ from those in spent fuel.**
  - **No axial composition gradients representing end effects.**
  - **Solid boron worth is typically much lower in benchmarks ($|\Delta k/k|<0.04$) than in casks ($|\Delta k/k|>0.20$).**

- Actual criticality bias and uncertainty may be larger than that derived from UO_2 and MOX benchmarks.
  - **Where practical, apply extra bias and uncertainty adjustments to the licensing-basis calculations.**
  - **Evaluate any remaining validation uncertainties against estimated additional margins (see Recommendation 6).**

3. Licensing-Basis Model Assumptions
- Review Guidance -

- For isotopic calculations, assume in-core conditions and parameters that maximize k_{eff} in the cask.
- Calculate k_{eff} using models and assumptions that allow adequate representation of important physics, including:
  - **Axial and horizontal burnup profiles within assemblies**
  - **The more reactive actinide compositions of fuels burned with inserted control rods or absorbers**
  - **Local neutron scattering and absorption effects around most reactive axial fuel regions.**

3. Licensing-Basis Model Assumptions
- Comments (1 of 3) -

- Effects of In-Core Operating Parameters on Fuel Isotopics:
  - **Fissile Pu production per burnup increment is bounded by maximizing: (1) in-core absorber rods, (2) dissolved boron, (3) moderator temperature, (4) fuel temperature, (5) specific power.**
  - **Isotopic calculations should assume values of in-core operating parameters that bound all spent fuel contents.**
- Effects of Cladding Creep-Down and Hydrogen Absorption:
  - **Increased moderation can be safely neglected in fuel depletion models used for actinide burnup credit.**
  - **May warrant consideration in modeling isotopic benchmarks.**
  - **Adequately approximated in cask criticality models by assuming unirradiated fuel dimensions with water in pellet-clad gap.**

3. Licensing-Basis Model Assumptions
- Comments (2 of 3) -

- Effects of Horizontal Burnup Profiles within Assemblies:
  - **Cask analysis models must consider most-reactive relative orientations of assemblies with strong burnup tilts.**
  - **Effects are especially significant in small casks.**
  - **DOE Topical (Rev.2) describes an acceptable modeling approach**.

3. Licensing-Basis Model Assumptions
- Comments (3 of 3) -

- Effects of Axial Burnup Profiles associated with In-Core Absorber Rods:
  - **Higher k_{eff} governed by two phenomena: (1) lower local burnup and (2) absorber-rod spectral hardening resulting in more fissile Pu production per burnup increment.**
    - **Most axial profile studies to-date have considered only effects of lower local burnup.**
    - **Absorber-rod effect on Pu production may be more important.**
  - **Worst-case “end effect” profiles typically result from partial insertion of control rods. Axial leakage limits increase in k_{eff}.**
  - **“Saddle effect” profiles caused by part-length absorber rods around midplane. Less widely studied, but may prove bounding.**
  - **Significant uncertainties remain. More information needed.**

4. Cask Loading Curve
- Review Guidance -

- As a function of initial enrichment, plot the Assigned Burnup Loading Value above which fuel assemblies may be loaded.
- Loading curves based on analysis for 5-year cooling.
- Load only assemblies cooled 5 years or more.

4. Cask Loading Curve
- Comments -

- Loading curves typically derived from licensing-basis k_{eff} calculations on cask loaded with identical fuel assemblies.
  - **Supplemental calculations needed for effect of mixed loadings**.

- Initial restriction to analyzed 5-year cooling based on:
  - **5-year cooling assumed in most modeling studies to-date**
  - **Little need in U.S. for cooling times less than 5 years**
  - **Questions on amplification of axial effects with cooling time (slowing net decrease in k_{eff} from ^{241}Pu decay to ^{241}Am)**
  - **Questions on multiple cooling times with added complexity in fuel loading specifications.**

5. Assigned Burnup Loading Value
- Review Guidance -

- Applicant describes administrative procedures by which cask user ensures fuel loading is within specifications.
- Pre-loading measurement to confirm reactor record value of assembly burnup.
  - **Measurement may be calibrated to reactor records for representative set of assemblies.**
  - **Confirmation: Measured and record burnup values agree within 95% confidence interval based on measurement uncertainty.**
- Reduce the confirmed record value of assembly burnup by combined uncertainties in records and measurement.

5. Assigned Burnup Loading Value
- Comments (1 of 2) -

- Reasons for requiring pre-loading measurements:
  - **Events reported at spent fuel pools suggest that errors in records, selection, and handling can be expected.**
  - **Measurements called for in ST-1(1996) and NRC RG 3.71: Criticality safety based on measured values.**
- Calibration and measurement strategy:
  - **Protection against internal inconsistencies in records.**
  - **Subtracting measurement and record uncertainties encourages high-quality measurements and records.**
  - **Sampling plan may be considered after positive experience is gained with quality of records and loading operations.**

5. Assigned Burnup Loading Value
- Comments (2 of 2) -

- Measurements based on gamma-rays or combination of gamma-rays and neutrons:
  - **Passive neutron measurements see increased production of ^{244}Cm caused by spectral hardening effects of absorber rods.**
  - **Neutron measurements may find use in addressing effects of absorber-rodded burnup histories.**

6. Estimate Additional Reactivity Margin
- Review Guidance -

- Estimate reactivity margins from actinides and fission products not included in licensing safety basis.
- Verify the analysis methods for estimating margins using:
  - **Available experimental data (e.g., FP assays, worths)**
  - **Computational benchmarks comparing against independent methods and analyses (e.g., OECD/NEA BUC).**
- Assess estimated margins against estimates of:
  - **Any uncertainties not directly accounted for in the modeling or validation process (e.g., non-prototypicality of k_{eff} benchmarks)**
  - **Potential nonconservatisms in the licensing-basis models and assumptions (e.g., neglect of outlier rodded burnup histories)**

6. Estimate Additional Reactivity Margin
- Comments -

- Goal: Show that additional margin is larger than the uncertainties remaining in actinide-only analysis.
- Note: Margin from neglect of fission products varies with cask design, enrichment, burnup, axial burnup profiles, depletion parameters, cooling times, etc.
- Validation Uncertainties
  - **Criticality benchmarks not fully representing major phenomena**
- Potentially nonconservative modeling assumptions
  - **Example: No control rods or part-length rods assumed in calculating fuel depletion. Underpredicts fissile Pu production.**

U.S. Regulatory Status of Cask Burnup Credit
What Next? (1 of 3)

- NRC and Industry Priorities on Expanded Burnup Credit:
  - Burnable Absorbers in PWR Fuel
  - Credit for Cooling Times > 5 Years
  - Credit for Burnup > 40 GWd/MTU
  - Reducing Offset for 4 to 5 wt% Enrichments
  - Fission Product Credit
  - Limited BWR Burnup Credit

U.S. Regulatory Status of Cask Burnup Credit **What Next?** (2 of 3)

- Information Needed on Fuels and Reactors:
  - Burnable Absorber Designs and Uses
  - Rodded Burnup Histories:
    - Worst-case U.S. plants, how much, how, when?
    - Needed for reducing actinide-only uncertainties and enabling future credit for fission products

U.S. Regulatory Status of Cask Burnup Credit
What Next? (3 of 3)

- **NRC Research: Ongoing Analytical Studies**
  - Modeling issues and assumptions
  - Uncertainties and sensitivities
- **NRC Research: Experimental Data**
  - Participating in international REBUS program
  - New U.S. assay data from high-burnup fuel (HB Robinson)
  - Assay data from Ariane program
  - New criticality data from DOE NERI program
  - Considering additional industry and international collaboration

U.S. Regulation of Cask Burnup Credit Conclusion

- **NRC will issue further burnup credit guidance as information and insights emerge from:**
  - Cooperative Research
  - Licensing Experience
  - Industry Data and Analysis