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Spent Fuel Pool Criticality Industry Meeting Opening Comments

Kent Wood
Office of Nuclear Reactor Regulation
Reactor Systems Branch
February 26, 2009

ENCLOSURE 2

Meeting Formalities

- Welcome
- Purpose
- Category 2 Public Meeting
- Logistics
- Schedule
  - 8:30 AM to 4:00 PM
  - Breaks about every 2 hours
  - Lunch about noon
- Agenda

Who is Who

- DSS/SRXB
  - Division Director: Bill Ruland
  - Deputy DD: Sher Bahudar
  - Branch Chief: Greg Cranston
  - Key Technical Reviewers
    - Diane Jackson
    - Tony Nakanishi
    - Kent Wood
    - Christian Farmer (Rotation)

Regulations

- 10CFR50 Appendix A GDC
  - 61: Fuel Storage & Handling and Radioactivity Control
  - 62: Prevention of Criticality in Fuel Storage & Handling
  - 63: Monitoring to detect abnormalities
- 10CFR50.68
  - No Boron; keff $\leq$ 0.95 at 95/95
  - Boron: keff < 1.0 w/o at 95/95; keff $\leq$ 0.95 at 95/95 w/
- 10CFR70.24
  - Monitoring
- 10CFR50.36
  - Design Features

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Guidance

- NRC, Letter dtd April 14, 1978, as amended by letter dated January 18, 1979.
- Larry Kopp Letter (ML003728001)
- SRP 9.1.1; Criticality Only
- SRP 9.1.2; everything else
- RegGuide 1.13, Spent Fuel Storage Facility Design Basis (Not Criticality)
- RIS 2001-012, 2005-005
- NUREGs (too many to list here)
- ANS Standards 57.1/57.2/57.3 and 8.XX

State of the POOL

- Criticality Analyzes are Site Specific
- Quality of Submittals
- Reduced Margins
- More Complex Analyzes
- More Complex Storage
- Material Degradation
- Fuel Handling Event Adverse Trend
- New Requirements/Challenges

Times have changed since the first SFP

- Increased SFP capacity due to re-rack
- Increased fuel enrichments
- Increased use of burnable absorbers
- New fuel assembly designs
- New fuel assembly materials
- Burnup credit
- Boron credit
- Deterioration of installed absorbers
- Increased storage configuration complexity
- ISFSI
- B.5.b
- Future Changes

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Summary

- Analysis has become more complex
- Storage has become more complex
- Margins are decreasing

Spent Fuel Pool Criticality Regulations and Guidance

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General Design Criteria

- GDC 61: Fuel Storage & Handling and Radioactivity Control
  - "The fuel storage and handling, radioactive waste, and other systems which may contain radioactivity shall be designed to assure adequate safety under normal and postulated accident conditions…."
- GDC 62: Prevention of Criticality in Fuel Storage & Handling
  - "Criticality in the fuel storage and handling system shall be prevented by physical systems or processes, preferably by use of geometrically safe configurations."
- GDC 63: Monitoring fuel and waste storage
  - "Appropriate systems shall be provided in fuel storage and radioactive waste systems and associated handling areas (1) to detect conditions that may result in loss of residual heat removal capability and excessive radiation levels and (2) to initiate appropriate safety actions."

10 CFR 50.68 (b) (4)

- If no credit for soluble boron is taken, the k-effective of the spent fuel storage racks loaded with fuel of the maximum fuel assembly reactivity must not exceed 0.95, at a 95 percent probability, 95 percent confidence level, if flooded with unborated water. If credit is taken for soluble boron, the k-effective of the spent fuel storage racks loaded with fuel of the maximum fuel assembly reactivity must not exceed 0.95, at a 95 percent probability, 95 percent confidence level, if flooded with borated water, and the k-effective must remain below 1.0 (subcritical), at a 95 percent probability, 95 percent confidence level, if flooded with unborated water
  - No Boron; keff $\leq$ 0.95 at 95/95
  - Boron: keff < 1.0.w/o at 95/95; keff $\leq$ 0.95 at 95/95 w/
  - Issued November 12, 1998!

10 CFR 70.24

- Criticality monitoring requirements
- Criticality mitigation measures
- Not consistent with NRC Strategic Goals
- Is anybody licensed to 10CFR70.24?

10 CFR 50.36 (c) (4)

- *Design features*. Design features to be included are those features of the facility such as materials of construction and geometric arrangements, which, if altered or modified, would have a significant effect on safety and are not covered in categories described in paragraphs (c) (1), (2), and (3) of this section.

NRC Guidance

- NRC, Letter to All Power Reactor Licensees from B. K. Grimes. *OT Position for Review and Acceptance of Spent Fuel Storage and Handling Applications.* April 14, 1978, as amended by letter dated January 18, 1979.
  - Vintage, predates 10CFR50.68 by 20 years.
  - What is old is what is new.

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The 'Kopp Letter'

- NRC internal Memorandum
- Basic Requirements
- Sets the Depletion Uncertainty for NRR
  - NRR is investigating
- Pre-dates 10CFR50.68

Standard Review Plan

- SRP 9.1.1; Criticality Safety of Fresh and Spent Fuel Storage and Handling
  - GDC 62 & 10CFR50.68
  - Endorses ANS 57.1/57.2/57.3
    - All THREE in combination
- SRP 9.1.2; New and Spent Fuel Storage
  - GDC 2, 4, 5, 61, & 63
  - Endorses RegGuide 1.13
  - Endorses ANS 57.2/57.3
    - But not ANS 57.1

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Regulatory Guide 1.13

- RegGuide 1.13, Spent Fuel Storage Facility Design Basis
  - Scope does include GDC 2, 4, 61 and 63
    - But not GDC 5
  - Scope does NOT include GDC 62
    - Therefore, no CRITICALITY in RegGuide 1.13
  - Endorses ANS 57.2
    - But not ANS 57.1 or 57.3

ANS Standards 57.1/57.2/57.3

- ANS Standards 57.1/57.2/57.3
  - Recommends 5% sub-critical margin, requires at least 2%
    - NRC has never accepted less than 5%
  - Require compliance with other ANS Standards to ensure fully meeting the expectations.
- Other ANS Standards
  - 8.XX
    - Really seem more appropriate for processing

Summary

- GDC 62: No Accidental/Inadvertent Criticality PERIOD
- 10CFR50.68: Sub-Critical Margin and Pedigree
- NRR looking to improve guidance

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Spent Fuel Pool Criticality Precedence and Reference

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Precedent

- There is NO generic methodology
- SFP Criticality Analysis is Site Specific
- Each acceptance is HOLISTIC in nature
- Precedents CAN be used:
  - Used in Context
  - High degree of fidelity
  - Evaluation of the similarities/differences

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References

- If you need it for the analysis we need it for the review.
- Public domain or on the docket.
- References CAN be used:
  - Used in Context
  - High degree of fidelity
  - Evaluation of the similarities/differences

Cautions

- Accessibility/Availability
- Level of NRC explicit review
- Cherry-Picking

Summary

- Use of Precedent and Reference is encouraged, but is not without limitations.

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Depletion

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First: Fuel Assembly Selection

- Why is that the limiting fuel assembly?
- What goes into that decision?
  - What is being modeled?
  - What is being omitted?
  - Why is that acceptable?
- How do other parts of the analysis affect its selection?

Fresh Fuel Characterization

- Nominal Dimensions
- Nominal Materials
- Nominal Isotopic concentrations
- Manufacturing Tolerances
  - Used to determine reactivity uncertainties

Depleted Fuel Characterization

- Depletion
  - Burnup Uncertainty
  - Axial Burnup Profile
  - Core Depletion Parameters
  - Pu241 Build up
- What happens to all of the Nominal values after depletion?

Burnup Uncertainty

- “Kopp Letter” is the current NRC NRR Guidance
  - Simple: 5% of the reactivity decrement from 0 burnup to the burnup of interest.
  - Statistical combination with other uncertainties.
- Exception is possible, but difficult to justify.
  - See ISG 8 Rev 2 for guidance to deviate from “Kopp Letter”
- To the best of my knowledge, since the Kopp Letter was published, NRR has never accepted any thing other than 5% of the reactivity decrement.

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Axial Burnup Profile

- The "End Effect" is the difference in reactivity between a uniform burnup profile and an axially distributed profile. It can be worth several Δ keff percentage points.
- "End Effect" occurs at top and bottom
- Distributed versus Uniform
- Generic versus Site-Specific
- Nodalization of the profile
- NUREG/CR-6801 is the touchstone for this review

Distributed versus Uniform

- At low burnup a uniform BU profile is conservative, at high burnup a uniform BU profile is non-conservative.
  - Transition point is UNKNOWN.
  - Effect of axial enrichment zoning is UNKNOWN.
- Reasonably/Generally
  - $\leq$ 10 GWD/MTU a uniform profile is conservative
  - $\geq$ 30 GWD/MTU a uniform profile is non-conservative
  - The middle ground is problematic

Generic versus Site-Specific

- See NUREG/CR-6801 for generic.
  - DOE/RW-0472, "Topical Report on Actinide-Only Burnup Credit for PWR Spent Fuel Packages," NOT approved by NRC
- Site-Specific requires identifying the limiting site-specific shape(s).
  - Probably less limiting than the generic
  - Maybe more than one.

Axial Burnup Profile Issues

- Using a generic profile inappropriately resulted in negative margin.
- Using a uniform profile inappropriately resulted in negative margin.
- Nodalization must be sufficient to capture the “End Effect” without adversely affecting the result.
  - Adequate nodalization maybe profile dependent.

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Axial Burnup Profile Example

- NUREG CR-6801 Group5 Profile

% of Core Ht	**Relative Burnup**	*Vol Ave*
5.560%	0.652	*0.036*
5.560%	0.967	*0.054*
5.560%	1.074	*0.060*
5.560%	1.103	*0.061*
5.560%	1.108	*0.062*
5.560%	1.106	*0.061*
5.560%	1.102	*0.061*
5.560%	1.097	*0.061*
5.560%	1.094	*0.061*
5.560%	1.094	*0.061*
5.560%	1.095	*0.061*
5.560%	1.096	*0.061*
5.560%	1.095	*0.061*
5.560%	1.086	*0.060*
5.560%	1.059	*0.059*
5.560%	0.971	*0.054*
5.560%	0.738	*0.041*
5.560%	0.462	*0.026*
100.080%		1.000744

- Actual Profile Used

Node Ht	**Node BU**	**Vol Ave**
4	0.365	0.010
4	0.490	0.014
4	0.758	0.021
4	0.873	0.024
112	1.194	0.929
4	0.988	0.027
4	0.862	0.024
4	0.555	0.015
4	0.393	0.011
144		1.075

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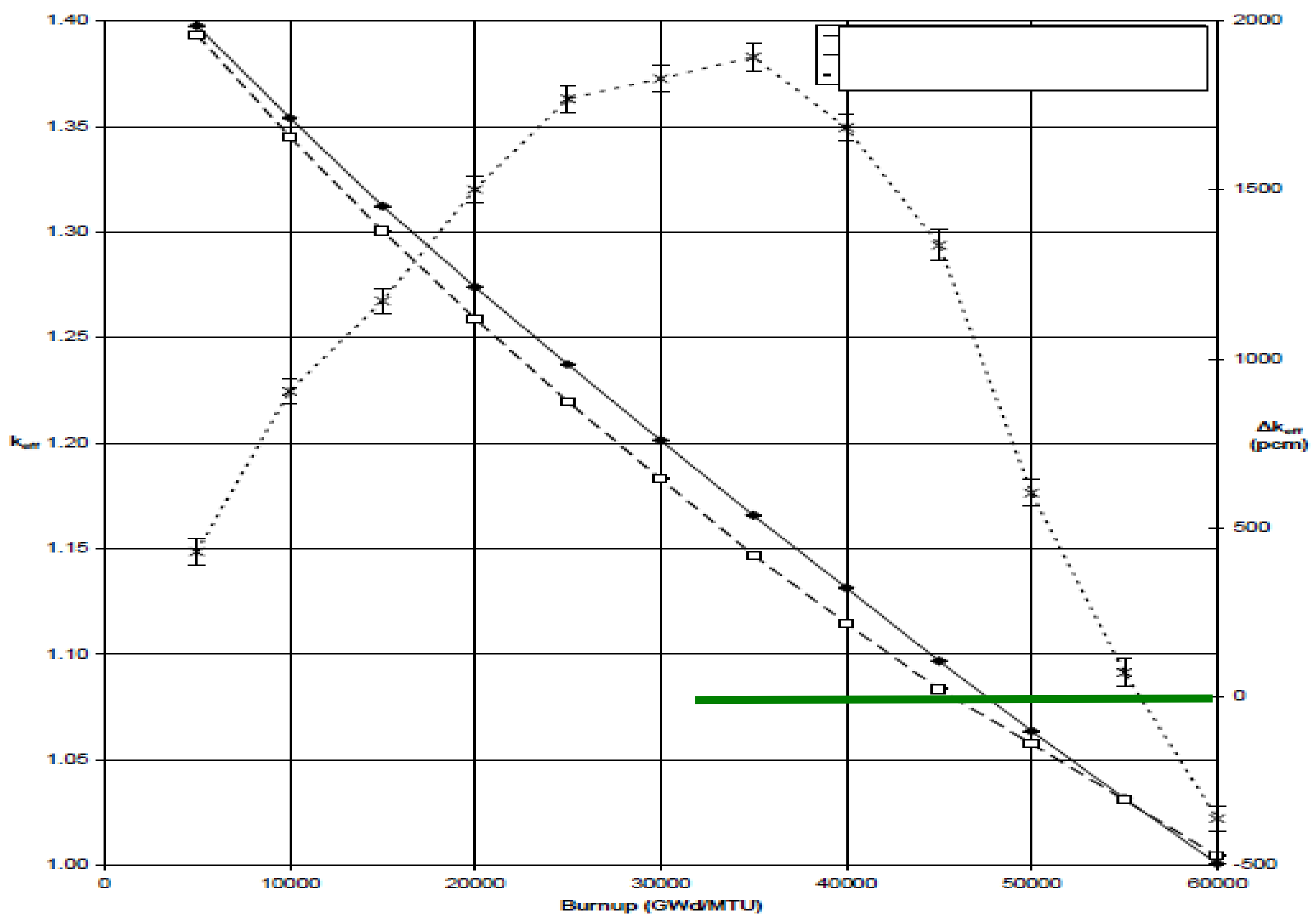
Axial Profile Examples

- Figure X shows the reactivity of what we could have done and what we did. What we did is most conservative at 35 GWd/MTU, reaching a maximum reactivity difference of about 1900 pcm Δ keff. The least conservative time of life is at 60 GWd/MTU when the reactivity difference is about 360 pcm Δ keff.

Figure X



1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
k_{eff}
2000
1500
1000
500
0
-500
Δk_{eff} (pcm)
0
10000
20000
30000
40000
50000
60000
Burnup (GWd/MTU)

Core Depletion Parameters

- NRC Guidance is for the depleted fuel to be at the highest reactivity
- Generally this means using depletion parameters which harden the neutron spectrum and increase Pu241 production.
- While core moderator temperature is probably the largest contributor, other factors can be significant.
- Recent SFP criticality LARs have not discussed the core depletion parameters used or not justified those that were used.
- Recent SFP criticality LARs have not identified fuel assemblies that do not conform to the core depletion parameters used, and why their storage is bounded by the analysis.
- NUREG/CR-6665 is the touchstone for this review.

Core Depletion Parameter Example

- LARs have been silent on core depletion parameters:
  - Specific power
  - Operating history
    - Included rodded operation
  - Fixed burnable absorbers
  - Integral burnable absorbers
  - Deviations from the TYPICAL

Core Depletion Example

- A SFP Criticality LAR stated the depletion had been performed with a moderator temperature profile based on the maximum core exit temperature.
- The licensee's UFSAR indicated the maximum core exit temperature was actually 10ºF HIGHER than what was used.
- NUREG/CR-6665 indicates this is worth about 450 pcm Δkeff.

Depletion Code

- Is the depletion code part of the licensee's list of approved methodologies?
- Are there any limitations and conditions on the depletion code?
  - Are they being met?
- What code will be used to determine the burnup for the burnup/enrichment loading curve?
  - If different than the analysis code, how does that affect the results?

What’s a BWR to do?

- What is different?
- A BWR depletes to maximum reactivity
- BWR analyzes typically focuses on a lattice rather than a whole FA
- BWR doesn’t have boron in SFP

What's a BWR to do?

- What is the same?
- The analysis FA/lattice has to be bounding.
- Depletion is Depletion
  - Uncertainty
  - Profile
  - Nodalizaton
- Overall core parameter concerns are the same

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BWR Issues

- Actual lattices more reactive than analysis lattice
  - Credit enrichment zoning
  - No proof
  - No TS control
- No depletion uncertainty

Summary

- Select a Fuel Assembly
- Deplete that Fuel Assembly
- Cover all the bases
- The Fuel Assembly that comes out of this part has to be limiting for past, present, and future actual fuel assemblies at that site!

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SFP Criticality Analysis

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Key Aspects

- References & Precedents
- Assumptions
- Geometric arrangements
- Reactivity uncertainties
- Reactivity biases
- Abnormal/Accident
- Soluble boron crediting
- TS Limits

Assumptions

- ALL Assumptions should be STATED
  - UNSTATED Assumptions lead to confusion and are fodder for LIC-109/RAI.
- ALL Assumptions should be JUSTIFIED
  - UNJUSTIFIED Assumptions lead to confusion and are fodder for LIC-109/RAI.
  - Mere previous use is NOT sufficient.
- Long Held Assumptions should be challenged.

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Geometric Arrangement

- What is the geometric arrangement?
- Is there more than one?
- What are the limitations and conditions for use?
- How are they controlled?
- 10CFR 50.36 requires this be in the TS.
- A licensee currently has 8 storage configurations and 11 categorization of FA.
  - LAR to increase that to 16 and 24 respectively

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Reactivity Uncertainties

- Manufacturing tolerances of the fuel and storage racks.
- Depletion
- Eccentric loading in the storage cells
- Code/Methodology
- Statistical Combination
  - Independence?

Uncertainty Issue Examples

- Not including all manufacturing tolerances
  - What is left out?
  - Why is that okay?
- Reactivity Uncertainties determined at one state point
  - Are they constant over the entire range of enrichment/burnup/temperature/boron?
  - Do the physical changes associated with depletion affect the uncertainties?

Uncertainty Issue Examples

- Inappropriate confidence factor with methodology uncertainty
- Not using Kopp letter depletion uncertainty
  - Not identified
  - Not justified
- Eccentric loading

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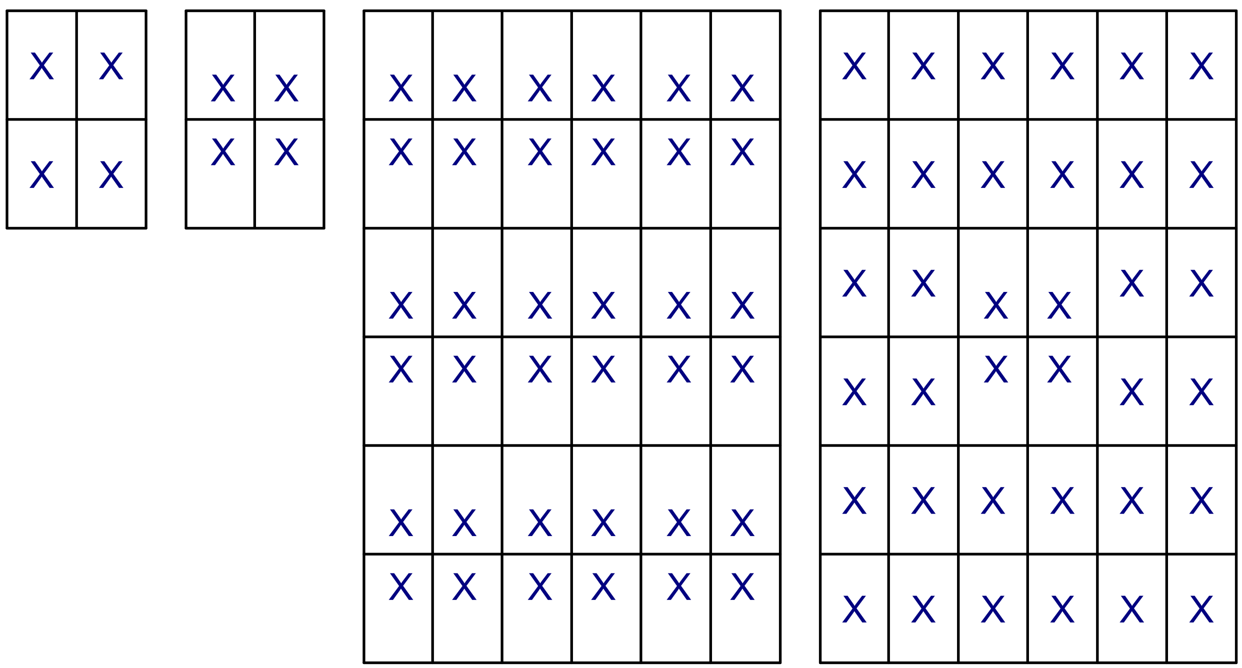
Eccentricity

Nominal

Typical

What that really looks like.

Is this more limiting?



Reactivity Biases

- Code/Methodology
- Temperature
- Other
- Reactivity Biases determined at one state point
  - Are they constant over the entire range of enrichment/burnup/temperature/boron?
  - Do the physical changes associated with depletion affect the biases?

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Keff ‘Rack-Up’

- RMSS independent Uncertainties
- Add all Biases
- Add Keff nominal
  - Fully considered full range of enrichment/burnup/temperature/boron?
  - Fully considered physical changes associated with depletion?
- Is the total less than Regulation?

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Abnormal/Accident

- What is creditable?
- What isn't creditable?
  - Why?
- How does the abnormal/accident condition change in the model affect everything that has gone before?
- Boron Dilution

Soluble Boron Crediting

- Direct simulation or boron worth?
  - What is the limiting configuration?
- How does the presence of boron affect everything that has gone before?
  - Uncertainties & Biases
  - Nominal & Abnormal/Accident level

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Summary

- Goal is demonstrating the regulatory requirement/licensing basis is met.
- Staff must be able to independently reach a reasonable assurance conclusion to that effect.
- Therefore keff must be demonstrated **in the submittal** to be below a limit (0.95 and/or 1.0) at a 95% confidence level with a 95% probability.

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SFP Criticality Code Validation

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Quotes from Kopp

- "Other computer codes and cross-section libraries may be acceptable provided they conform to the requirements of this position statement and are adequately benchmarked."
- Codes are not limited to those listed in the Kopp Letter.
- Just about any cross-section library and code can be used, provided they meet the requirements.
  - Of course unique/atypical libraries and codes will require more documentation than standard libraries and codes.

Quotes from Kopp

- "The proposed analysis methods and neutron cross-section data should be benchmarked, by the analyst or organization performing the analysis, by comparison with critical experiments. This qualifies both the ability of the analyst and the computer environment."
- Benchmarked against experiments, not other computer codes
- Qualifies both the analyst and code/methodology

Quotes from Kopp

- “The critical experiments used for benchmarking should include, to the extent possible, configurations having neutronic and geometric characteristics as nearly comparable to those of the proposed storage facility as possible.”
- Benchmark experiments need to represent the SFP being modeled.
  - Isotopics
  - Geometery

How do we do this?

- NUREG/CR-6698, Guide for Validation of Nuclear Criticality Safety Calculational Methodology, will be NRR's touchstone for this review.
- Key Elements
  - Define range of parameters to be validated
  - Select critical experiments
  - Model experiments
  - Analyze the data
  - Define Area of Applicability
  - Write the report

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Issues with Code Validation

- Analyzing the data
- Area of Applicability
- Lack of a code validation

Analyzing the Data

- Only 1 of 18 documented a trend analysis
- Only 1 of 18 considered uncertainties in the experiments themselves
- One failed a normalcy test
  - Only one was checked

Area of Applicability

- Only 1 of 18 documented an Area of Applicability analysis
  - How do we know the experiments bound the SFP?
- 0 of 17 considered that none of the critical experiments included Fission Products
  - 1 was fresh fuel only
  - This has been considered in the past, why isn't it considered now?

Lack of a Code Validation

- Occurs when different portions of the criticality analysis are performed with different codes. Only the code used to simulate Keff(nominal) is validated.
- Without the validation, how do I know anything the second code is telling me is reasonable?
- Without the validation, how do I know whether or not limitations or conditions on the second code are being applied?
- Why doesn’t the uncertainty of the second methodology have to be considered?

Summary

- Recent LARs lack key elements of a code validation.
  - Grounds for LIC-109 Non-Acceptance
- NRC hasn’t pushed this issue in the past, we will in the future.

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Spent Fuel Pool Criticality MARGIN

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Margin, Margin, Where's the Margin

- Everybody "KNOWs" there is a ton of MARGIN in the SFP. Why is the staff asking all these questions?
- Some of the reasons:
  - Increased complexity of the analyzes and storage
  - Errors in the submittals
  - Vintage assumptions unchallenged
  - Inappropriate use of precedent and reference
  - Incongruent statements

“Most fuel assemblies are well below the limiting assembly”

- Perhaps, but:
  - What is the minimum array for criticality?
  - What are the actual FA burnups?
  - What prevents ‘limiting’ fuel assemblies from being collocated?
- Hard to credit FA below the ‘limiting’ assembly unless we can answer those questions.

"We didn't model leakage"

- Okay, but how much leakage is there?
  - How much radial leakage does a FA in the center of a storage rack see?
  - How much axial leakage does a lattice see?
  - What is the most reactive reflector?
- Leakage affects the edges, not the center.

“We did/didn’t do X.”

- Okay, but there are a few questions.
  - What is X worth?
  - How do we know that?
  - What is the worth dependent upon?
- Hard to credit X if it isn’t quantified.
- Also, if X is that great, why isn’t it used in the analysis to improve storage capacity?

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We're not crediting residual poison in the racks…

- Probably but,
  - How much and where is it?
  - How fast is it leaving?
  - How do we know this?
  - What is the minimum array for criticality?
- Can't credit any residual poison unless we can answer these questions.

What do we do with Margin?

- Margin is necessary to protect from what we don’t know.
  - Some things everybody knew were conservative, aren’t
  - Material degradation
  - Accident beyond those previously identified.
  - B.5.b

Summary

- "For future licensing actions, licensees will need to submit plant-specific criticality calculations for spent fuel pool configurations that include technically supported margins."

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Spent Fuel Pool NEI Meeting Closing Remarks

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Public Comment

- Ask for public comment
- Ask to complete public meeting forms

Goal

- Goal is demonstrating the regulatory requirement/licensing basis is met.
- Staff must be able to reach a reasonable assurance conclusion to that effect.
- Therefore keff must be **demonstrated in the submittal** to be below a limit (0.95 and/or 1.0) at a 95% confidence level with a 95% probability.

LIC-101, License Amendment Review Procedures

- “The SE provides the technical, safety, and legal basis for the NRC's disposition of a license amendment request. The SE should provide sufficient information to explain the staff's rationale to someone unfamiliar with the licensee's request. The SE includes a brief description of the proposed change, the regulatory requirements related to the issue, and an evaluation that explains why the staff's disposition of the request satisfies the regulatory requirements. Given that the SE serves as the record of the staff's disposition of a license amendment request, the information relied upon in the SE must be docketed correspondence. This is not meant to hamper questions and clarifications by telephone or in meetings. However, if the information is important in the staff's decision-making process and is not otherwise in the public domain or reasonably inferred by the staff, it must be formally provided by the licensee.”