Meeting Copy

Modified Closure Plan U.S. EPR Fuel Assembly Design Topical Report

May 2, 2012

EPR™ by AREVA

AREVA

Introduction

Jerry Holm

May 2, 2012

Agenda

- Non-proprietary portion of presentation
  - Meeting Objectives
  - Modified Closure Plan Summary
- Proprietary portion presentation
  - Modifications
  - Impact of Modifications
  - Key Issues Remaining
  - Technical Report
  - RAI Responses
  - NRC Interactions
  - Schedule

Objectives

- ▶ Modified Closure Plan (letter NRC:12:016, March 30, 2012)
  - Confirm Acceptability of Closure Plan
- ▶ Discuss Future Interactions

Modified Closure Plan Summary

- **Modify the U.S. EPR fuel assembly design to incorporate stronger HTP spacer grids.**
- **Limit the selection of soil cases to a subset of the cases in FSAR Section 3.7 to reduce the load on the spacer grid.**
  - **These two changes are made to eliminate issues related to:**
    - Coolability
    - Control rod insertability
    - Modeling of plastic deformation
    - Regulatory requirements for SSE+AOO
  - **And to minimize the importance of issues related to:**
    - Lack of measured fuel assembly characteristics for irradiated conditions
    - Linear versus non-linear model
- **Submit a Technical Report that provides a detailed description of the fuel seismic methodology and application for U.S. EPR.**
  - **Provide a clear definition of the methodology and its application**

Regulatory Acceptance Criteria

- *"Operating basis earthquake ground motion (OBE)* is the vibratory ground motion for which those features of the nuclear power plant necessary for continued operation without undue risk to the health and safety of the public will remain functional.
- Safe-Shutdown Earthquake (SSE)
  - "Two criteria apply to the SSE—(1) fuel rod fragmentation must not occur as a result of the seismic loads and (2) control rod insertability must be assured."
- Loss-of-Coolant Accident (LOCA)
  - "Two principal criteria apply for the LOCA—(1) fuel rod fragmentation must not occur as a direct result of the blowdown loads and (2) the 10 CFR 50.46 temperature and oxidation limits must not be exceeded."

AREVA Proposed Acceptance Criteria

- ***OBE, SSE, SSE+LOCA***
  - ***Use OBE criteria for all conditions to define allowable grid strength***
  - ***Fuel assembly will remain functional***
    - *No impact on DNBR*
    - *No impact on LOCA*
    - *No impact on control rod insertability*

Modified Closure Plan Schedules

Date	Activity	Subject
July 16, 2012	RAI 64, 65, 66	Submit interim responses
Week of July 30, 2012	Audit	RAI 64, 65, 66
October 31, 2012	RAI 68 and 70	Submit draft responses
Week November 12, 2012	Audit	RAI 68 and 70
February 28, 2013	Technical Report	Submit interim technical report
Week March 11, 2013	Audit	Interim technical report
May 31, 2013	RAI 64, 65, 66, 67, 68, 69, 70 and 71	Submit final RAI responses
May 31, 2013	Technical Report	Submit final
May 31, 2013	Letter	Final updates to ANP-10285 and FSAR

Modified Closure Plan Details

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Richard Harne
Victor Hatman

May 2, 2012

Agenda

- Review of Key Issues Prior to Modified Closure Plan
- Modifications
- Impact of Modifications
- Key Issues Remaining After Modifications
- Technical Report
- RAI Responses
- NRC Interactions
- Schedule

Key Issues To Be Addressed Prior to Modified Closure Plan

- Forced vibration versus pluck test
- Empirical fuel assembly frequency response at high amplitudes
- Fuel assembly characteristics in the irradiated condition
- Linear versus non-linear bundle modeling
- Definition of grid strength and testing protocol
- CASAC acceptability
- Modeling of grid post-buckling behavior
- Evaluation of coolability under grid buckling
- Evaluation of control rod insertion under grid buckling
- SSE plus AOO Criteria

Modifications to Closure Plan

Increase seismic margin

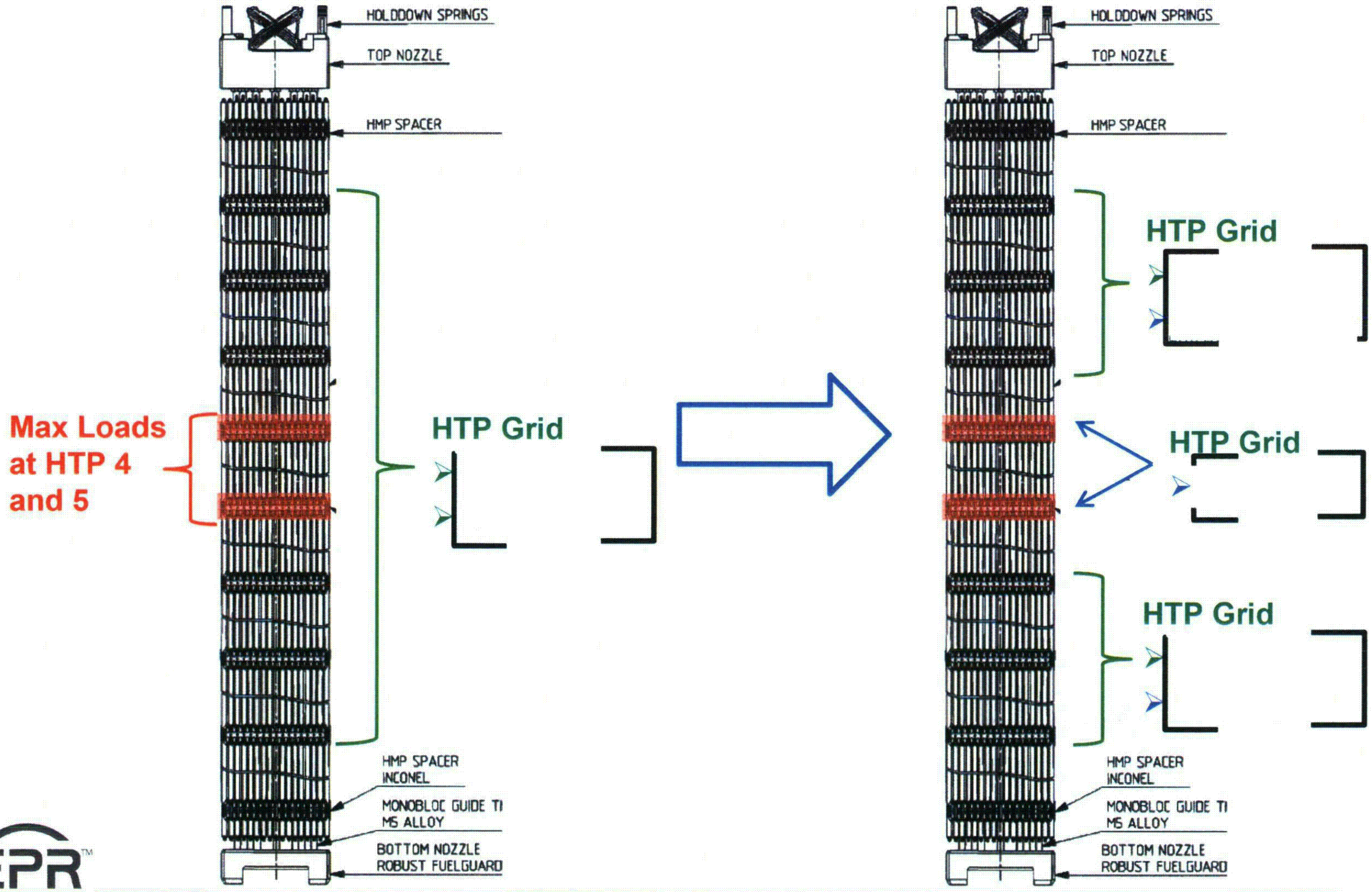
- Modify the U.S. EPR fuel assembly design to incorporate stronger HTP spacer grids at the critical elevations.
- Limit the selection of soil cases to a subset of the cases in FSAR Section 3.7 to reduce the load on the spacer grid.

Clarify fuel seismic work

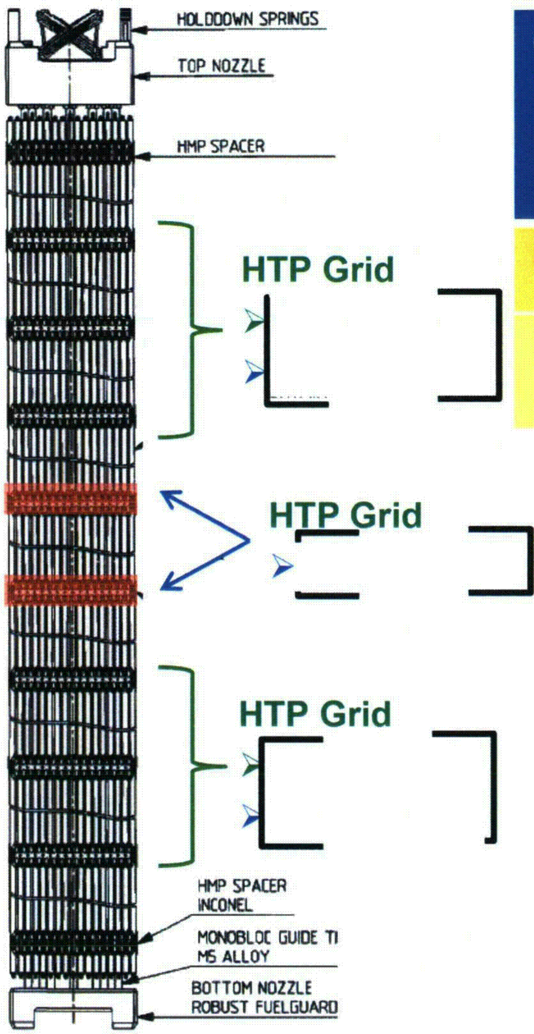
- Submit a Technical Report that provides a detailed description of the fuel seismic methodology and application for U.S. EPR.

The first two modifications eliminate post-buckling in spacer grids and subsequent evaluations of coolability and control rod insertion

Fuel Assembly Design Change



Fuel Assembly Design Change



Grid Location	Grid Description	Irradiated Grid Strength (lbs)	EOL Max Load on Grid (lbs)
HTP 4 & 5	HTP [ ]	4585	3220
HTP 3 & 6	HTP [ ]	3210	2850

Note: Strength of HTP with [ ] (current design) is 2740 Lbs

- 17x17 HTP with [ ] already used at Harris and being implemented at Sequoyah
- Change increases seismic margin with minimal effect elsewhere on design

Impact of Fuel Assembly Design Change

▶ Mechanical

◆ No significant impact on bundle characteristics

- Lateral stiffness impact is minimal since the stronger grids are close to the middle of the bundle, where the rotation due to bending is minimal
- Natural frequency impact is minimal as well, since stiffness does not change
- Mid-span stiffer grids could affect 2^{nd} mode, but the participation factor for this mode is zero for lateral acceleration loading.

◆ Some impact on spacer grid stiffness

- Can be addressed analytically, based on grid testing

◆ Grid Stiffness effect on Impact Loads

- Stiffer spacer grids generally result in higher impact loads.
- However, no significant effect is expected, since the preliminary models are based on high stiffness grid models (based on the Cold simulated EOL test)

Impact of Modifications: Fuel Assembly Design Change

- **T-H, ACH-2 CHF Correlation Applicability and Performance Impact for a[ ]Change**
  - **EPR Fuel Design**
    - HTP Grid, 0.496 inch Fuel Rod Pitch, 0.374 inch Fuel Rod OD,[ ]
    - CHF Tested at AREVA's KATHY Facility in Karlstein, Germany
  - **AREVA has earlier HTP Grid CHF Test results from Columbia University where the CHF performance impact was measured for a Strip Thickness change**
    - HTP Fuel Design: HTP Grid, 0.500 inch Fuel Rod Pitch, 0.374 in Fuel Rod OD
    - CHF Test 59:[ ]
    - CHF Test 60:[ ] [ ]
    - Both tests used a uniform axial power shape and represented the guide tube subchannel
    - The differences in Measured Results between Tests 59 and 60 were insignificant (within test repeatability).
  - **Conclusion:**
    - The ACH-2 CHF correlation is applicable for EPR HTP grids with a[ ]increase from[ ]

Impact of Modifications: Fuel Assembly Design Change

- **T-H, ACH-2 CHF Correlation Applicability and Performance Impact to Weld Nugget Size Change**
  - **EPR Fuel Design**
    - HTP Grid, 0.496 inch Fuel Rod Pitch, 0.374 inch Fuel Rod OD, [ ]
  - **The 6 HTP grids with the original [ ] to improve the grid strength.**

Impact of Modifications: Fuel Assembly Design Change

▶ T-H, ACH-2 CHF Correlation Applicability and Performance Impact to Weld Nugget Size Change

[ ]

◆ **Conclusions:**

- The ACH-2 CHF correlation is applicable for EPR HTP grids with a [ ]

Impact of Modifications: Fuel Assembly Design Change

▶ **T-H, Pressure Drop Impact to Strip Thickness Change and Weld Nugget Size Change**

[ ]

◆ **Conclusions:**

- The HTP grid modifications will increase the fuel assembly and core pressure drops.
- Since the modifications will be present on all fuel assemblies in the core, the impact of the pressure drop increase is expected to produce no impact on the radial core flow redistribution during isothermal conditions and a negligible impact at power operation.

Impact of Modifications: Fuel Assembly Design Change

- **T-H, Fuel Assembly Hydraulic Lift Impact to Strip Thickness Change and Weld Nugget Size Change**

[ ]

- **Conclusion:**
  - The net hydraulic lift force calculations for the EPR fuel design will be revised to reflect the increased hydraulic lift force to assure there is adequate hold down for lower core plate contact by the fuel assembly during operation and core plate pin engagement during the turbine overspeed event.

Impact of Modifications: Fuel Assembly Design Change

- **T-H, Core Bypass Flow Fraction Impact to Strip Thickness Change and Weld Nugget Size Change**

[ ]

  - **Conclusion:**
    - The core bypass flow fraction calculation will be revisited and revised to reflect the change in core pressure drop.
    - The RCS flow rate basis used for the existing DNB analyses will not change as a result of these grid modifications because a conservatively low RCS flow rate has been used that provides ample margin to cover the impact of the RCS flow measurement uncertainty and the impact of the grid modifications noted above.

Impact of Fuel Assembly Design Change

- **Thermal-Mechanics**
  - Evaluate rod stress with new grids
- **Non-LOCA**
  - No impact
- **LOCA**
  - Evaluation of design change will be performed
  - Preliminary assessments indicate no impact to previously reported PCT values

Limit the Selection of Soil Cases

- **Limit the Selection of Soil Cases**
  - ***2sn4um will be eliminated from fuel design certification***
    - *No current U.S. EPR customers affected*
  - ***4um becomes the next most limiting case based on preliminary assessments***
  - ***All remaining soil cases will be evaluated***
    - *1us, 1n2us, 2n3um, 2us, 2um, 3r3um, 3um,4um, 4uh, 5uh, 5ah*

[ ]

Benefit of Modifications

Grid Location	HTP 4&5	HTP 3&6
Grid Description		
Irradiated Grid Strength (lbs)	4585	3210
EOL Max Load - Limited Soil Case Selection (lbs)**	3220	2850
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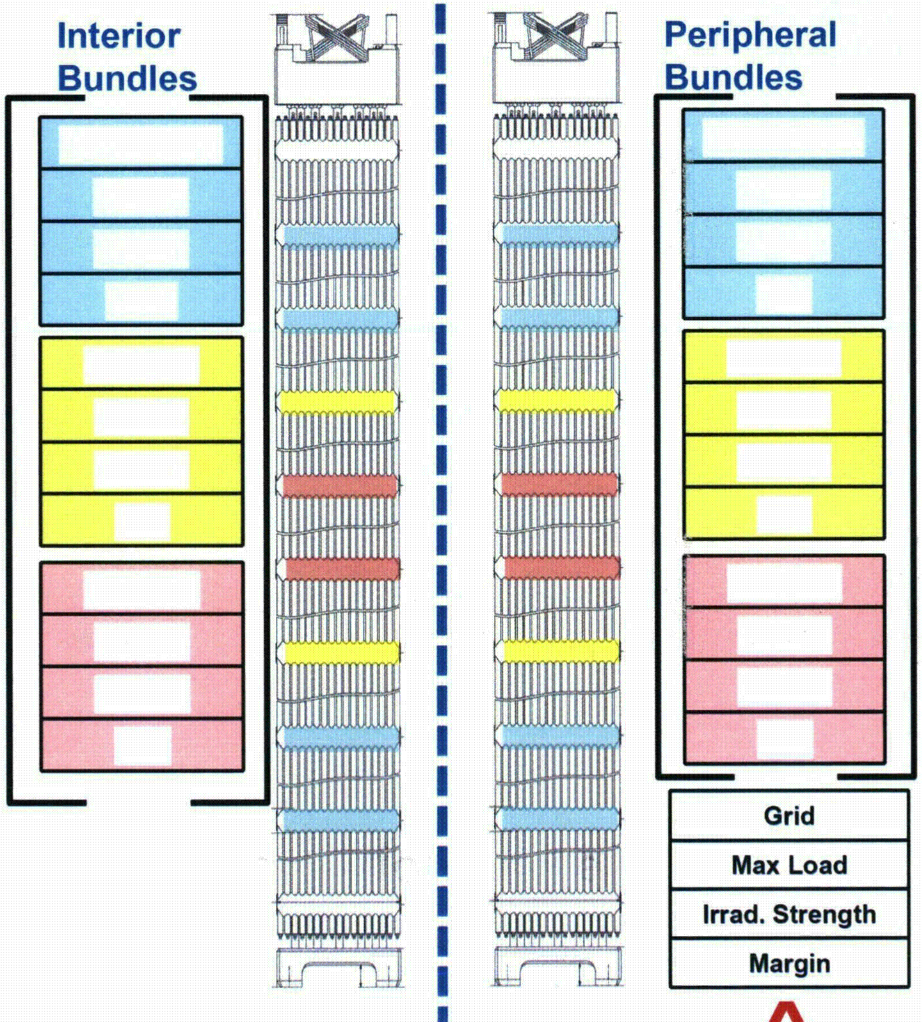

Key Issues To Be Addressed
After Modifications

- Forced vibration versus pluck test
- Empirical fuel assembly frequency response at high amplitudes
- Fuel assembly characteristics in the irradiated condition
- Linear versus non-linear bundle modeling
- Definition of grid strength and testing protocol
- CASAC acceptability
- ~~Modeling of grid post-buckling behavior~~
- ~~Evaluation of coolability under grid buckling~~
- ~~Evaluation of control rod insertion under grid buckling~~
- ~~SSE plus AOO Criteria~~

Key Issues Remaining: Forced Vibration versus Pluck Test

- AREVA will perform comparative testing on a 14 ft HTP bundle representative of the U.S. EPR fuel design
  - Bundle will be in a simulated irradiated condition
  - Both forced vibration (up to ~0.3 inches) and pluck test (up to ~1.0 inches) will be performed
- Objective is to demonstrate equivalency in the two approaches
- Thereby validate the existing test basis for the U.S. EPR which is largely based on forced vibration testing

Key Issues Remaining: Frequency Response at High Amplitudes

- AREVA will perform testing on a 14 ft HTP bundle representative of the U.S. EPR fuel design
  - Bundle will be in a simulated irradiated condition
  - Pluck test (up to ~1.0 inches) will be performed
- This empirical information can be used to validate and reassess the range used for the frequency sweep

Key Issues Remaining: FA Characteristics in Irradiated Condition

▶ Irradiated Bundle Frequency

- **AREVA will perform testing on a 14 ft bundle representative of the U.S. EPR fuel design**
  - Bundle will be in a simulated irradiated condition
  - Pluck test (up to ~1.0 inches) will be performed
- **This empirical information can be used to validate and reassess the range used for the frequency sweep**

▶ Irradiated Condition Damping

- **Un-irradiated damping is defined in Addendum 2 of BAW-10133PA, and consists predominantly of the reactor coolant flow damping effect**
  - The mechanism of energy dissipation is due to a hydrofoil effect, whereby the lateral deflection of the bundle, imposes a slope on all sub-channels, which in turn, produces fluid reaction forces on the bundle, opposing the lateral motion of the bundle.
- **This damping mechanism is <u>independent of the lateral stiffness</u> of the bundle, hence, it is the same at BOL and EOL**
  - Coolant flow damping is a function of the coolant density, and velocity, and the bundle relative velocity with respect to the containment (next page ➔)

Key Issues Remaining: FA Characteristics in Irradiated Condition

- **Irradiated Condition Damping (cont'd)**
  - **The implementation of this damping mechanism for the U.S.EPR core models will be performed on a consistent basis (BOL vs. EOL) by means of the Rayleigh damping technique (this also addresses RAI 67)**

    [ ]

  - **This approach has been validated through extensive tests performed on 14ft BOL and EOL bundles, under full reactor flow conditions, demonstrating that 50% is a lower bound on the measured damping ratio**

Key Issues Remaining: Linear versus Non-linear Bundle Modeling

- AREVA has provided information to show that the linear modeling (frequency versus amplitude) of the U.S. EPR is appropriate
- Sensitivity to non-linear effects is reduced in absence of grid buckling
  - For grid impacts below buckling, the second order non-linear effects of the bundle stiffness vs. amplitude become even less significant.
  - With the grid operating on the stable side of the loading curve, the ability to capture the overall strain energy stored in the fuel assembly in a displaced configuration is the primary focus.
  - The importance of axial load re-distribution between grids is less in the case of stable grid operation.
- Margin to buckling load further reduces the importance of second order effects (non-linear frequency versus amplitude)

Key Issues Remaining: HTP Grid Strength and Testing Protocol

- P(crit) definition consistent with SRP and NUREG
- Standard Review Plan. Chapter 4.2, Appendix A, III, 1. Grids
  - "the crushing load P(crit) has been suitably selected from the load-versus-deflection curves"
  - "Therefore, average values are appropriate, and the allowable crushing load P(crit) should be the 95-percent confidence level on the true mean as taken from the distribution of measurements on unirradiated production grids at (or corrected to) operating temperature."
- Standard Review Plan. Chapter 4.2, Appendix A, IV, 1. Loss-of-Coolant Accident
  - "If combined loads on the grids remain below P(crit), as defined above, then no significant distortion of the fuel assembly would occur and the usual ECCS analysis is sufficient."

Key Issues Remaining: HTP Grid Strength and Testing Protocol

- P(crit) definition consistent with SRP and NUREG
- NUREG/CR-1018, IV Acceptance Criteria, 2.2 No Permanent Deformation
  - "Initial coolable geometry calculations are performed on the un-deformed fuel assembly and must demonstrate that the design is coolable. If spacer grid loading causes no permanent deformation of the spacer grid then rod to rod spacing and coolant channel flow area is undisturbed and a coolable geometry would be maintained."
  - "A sufficient condition to demonstrate that no permanent deformation has occurred appears to be that the spacer grid remain within manufacturing tolerances. This condition should be sufficient although possible not necessary because the only meaningful definition of departure from a no-deformed condition would be that deformation which causes a measurable perturbation in the ECCS peak cladding temperature calculation. A manufacturing tolerance criteria should fall within this deformation definition."

Key Issues Remaining: HTP Grid Strength and Testing Protocol

- EMF-93-074PA, "Generic Mechanical Licensing Report for Advanced 17x17 Fuel Design", approved April 1994
  - This is the first mechanical design report for an assembly which used the HTP grid
  - Response to NRC Question 6 addresses grid strength definition
- Test Protocol
  - Room temperature test
  - Room temperature measured strength defined as buckling point
  - Hot strength defined as room temperature multiplied by ratio hot to cold modulus
  - Dynamic compression load
- Report compares various strength definitions
  - Room temperature modified by ratio of hot to cold modulus
  - Hot buckling
  - Hot yield point

Key Issues Remaining: HTP Grid Strength and Testing Protocol

- P(crit) – unirradiated test protocol

[ ]

- Grid behavior approximated as elastic up to P(crit) load
  - Consequences of deformation within manufacturing tolerance are negligible
    - Industry standard approach

Key Issues Remaining: HTP Grid Strength and Testing Protocol

- P(crit) – irradiated test protocol

[ ]

- Grid behavior approximated as elastic up to P(crit) load

Key Issues Remaining:
HTP Grid Strength and Testing Protocol

Key Issues Remaining: HTP Grid Strength and Testing Protocol

- Yield Strength - Irradiation vs. Temperature Effects

Key Issues Remaining: HTP Grid Strength and Testing Protocol

- **Irradiation Hardening vs. Irradiation Stress Relaxation**

[ ]

Key Issues Remaining: HTP Grid Strength and Testing Protocol

Key Issues Remaining: CASAC Acceptability

- **Information previously provided:**
  - CASAC code has been verified with sample problems with known answers, including problems that are directly representative of fuel assembly modeling
  - CASAC code and underlying modeling technique has been validated through full-scale testing with a row of six fuel assemblies for both in-air and in-water conditions.
  - Comparison of CASAC-generated load vs. deflection curves with actual test data is presented
- **Additional information to be provided:**
  - Benchmark CASAC to NRC sample problem defined in NUREG/CR-1019
  - This is a commonly accepted method of seismic code validation

Technical Report: Table of Contents (Part 1)

Technical Report: Table of Contents (Part 2)

- **Application to U.S. EPR**
  - **Acceptance Criteria**
  - **Inputs**
    - Time Histories
    - Fuel Characteristics
      - Fuel assembly testing
      - Spacer grid testing
  - **Horizontal Analysis**
    - Fuel Assembly Modeling
    - Row Modeling
    - Analysis Method (Grid Impact Analysis)
  - **Vertical Analysis**
    - Fuel Assembly Modeling
    - Analysis Method
  - **Post-processing Horizontal and Vertical Loads**
    - Combination of Loads
    - Stress Analysis

Technical Report

- Information from round 6 RAIs will be included in the technical report
  - Round 6 RAI-53 – Plots of acceleration, velocity and displacement time histories for SSE
  - Round 6 RAI-54 – Peak deflection information
  - Round 6 RAI-55 – Load versus frequency information
  - Round 6 RAI-56 – Damping and stiffness sensitivities
  - Round 6 RAI-57 – Representative fuel assembly used in test
  - Round 6 RAI-58 – Input sensitivity study
  - Round 6 RAI-59 – Upper and lower core plate loading histories
  - Round 6 RAI 60, 61, 62, and 63 – Not related to fuel assembly seismic

Technical Report

- Information from round 7 RAIs will be included in the technical report
  - Round 7 RAI 64 – Justification of linear analysis approach
  - Round 7 RAI 65 – CASAC verification and validation
  - Round 7 RAI 66 – BOL and EOL frequency characteristics
  - Round 7 RAI 67 – Definition of seismic methodology and relationship to BAW-10133PA and Addendum
  - Round 7 RAI 68 – EOL simulation, fuel assembly characteristics and grid strength
  - Round 7 RAI 69 – Not applicable
  - Round 7 RAI 70 – Pcrit definition
  - Round 7 RAI 71 – Not applicable

Technical Report – Mechanical Tests

Test	Use in Developing Analytical Model
1. Shaker Tests (Forced Vibration Tests)	- Obtain the natural frequencies of the first five modes of vibration. - Determine higher order mode frequencies scaling ratio. Obtain best effective fuel assembly beam properties to benchmark analytical model.
2. Static Stiffness Tests	Obtain fuel assembly static stiffness and compare with analytical value.
3. Lateral Impact Tests	Derive one-sided spacer grid stiffness value by comparing analytical results with test impact forces and then derive the spacer grid in-grid stiffness.
4. Dynamic Grid Impact Tests	Obtain spacer grid through grid stiffness, damping and allowable elastic limit force.
5. Axial Stiffness Tests and Fuel Assembly Drop Tests	- Obtain the fuel assembly axial stiffness and drop impact loads for various drop heights. - Adjust lower end fitting stiffness and damping.

Technical Report – Mechanical Tests

- **Additional testing**
  - **Assembly pluck (~ 1 inch) and forced vibration tests**
    - 14 ft HTP bundle representative of the U.S. EPR Fuel Assembly in simulated irradiated condition
    - Purpose:
      - Justify forced vibration testing
      - Reinforce understanding of irradiated properties and large amplitude behavior; Confirm frequency sweep approach and reassess sweep range

Summary

Jerry Holm

May 2, 2012

Summary Meeting Objectives

- Objective
  - Modified Closure Plan (letter NRC:12:016, March 30, 2012)
    - Confirm Acceptability of Closure Plan
  - Discuss Future Interactions

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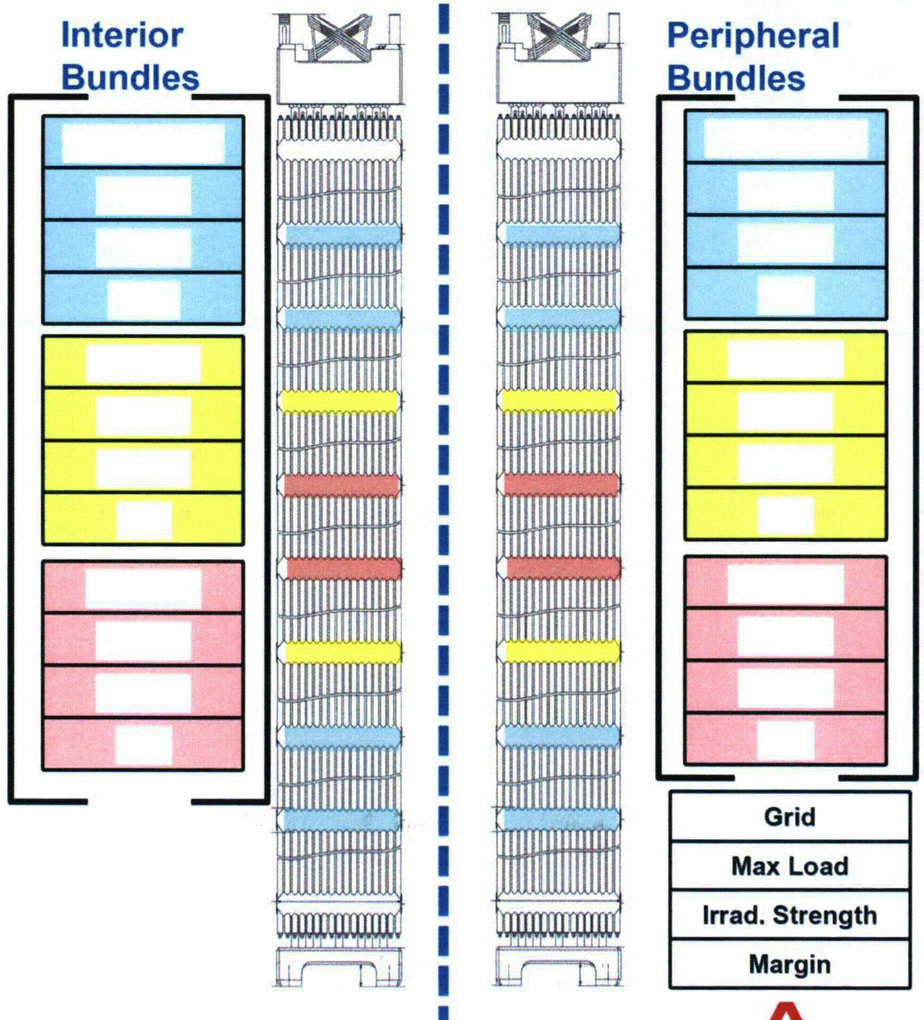

NRC Interactions

- RAI responses
- Feedback on RAI responses
- Public meetings
- Audits

Modified Closure Plan Schedules

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