U.S. EPR Spent Fuel Rack Seismic Analysis

Rockville, Maryland

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AREVA

Agenda

- Introductions – NRC / AREVA
- Background / Purpose – P. Thallapragada / J. Harrington
- Fuel Rack Seismic Analysis - P. Thallapragada / J. Harrington
- RAI 589 Path Forward - P. Thallapragada / J. Harrington
- Schedule - P. Thallapragada / J. Harrington
- Comments and Questions

Background

- **Open items pertaining to the structural analysis resulting from the June 2013 audit and review of previously submitted advanced RAIs**
  - **RAI 445 Question 3.8.4-15**
    - Additional information and clarification provided
  - **RAI 445 Question 3.8.4-21**
    - Provide clarification that the fuel grid impact allowable load covers both new and spent fuel conditions
  - **RAI 445 Question 3.8.4-20**
    - Clarification to discuss how input spectra is developed
    - Rack leg assembly evaluation clarifications
  - **New RAI 589 Question 3.8.4-31**
    - "To justify the current design for the spent fuel racks, AREVA performed analyses based on a single time history input using the new design spectra and compared the results with the analysis results based on the assumed design spectra. Because nonlinear analyses are highly uncertain, SRP acceptance criteria provide specific provisions to ensure the quality of nonlinear seismic analysis which should use multiple time histories. Nonlinear seismic analyses using a single time history cannot capture uncertainties, and therefore, this approach is unacceptable for design. Therefore, the staff requests that the applicant demonstrate the adequacy of the seismic design of the spent fuel racks for the updated design response spectra."

Purpose

- Demonstrate that the seismic analysis of the US EPR Spent Fuel Rack Design meets the requirements of SRP 3.8.4 and 3.7.1 and obtain NRC concurrence on the methodology for completing the structural analysis of the US EPR spent fuel racks

Fuel Rack Seismic Analysis

- **Requirements for structural analysis of spent fuel pool racks**
  - **RG 1.29, revision 4, defines Spent Fuel Pool Racks as a Seismic Category 1 Structure**
  - **SRP 3.8.4 , revision 3, Appendix D and NUREG/CR-5912**
    - Provides specific guidance on analysis considerations
  - **SRP 3.7.1 , revision 3, Seismic Design Parameters**
    - Scope of the SRP is to provide requirements to meet the acceptance criteria for the development of design input ground motion spectra and time histories
    - Specific requirements on developing time history input
    - Specific requirements on the use on time history input for nonlinear analysis

Fuel Rack Seismic Analysis

- **SRP 3.8.4 Appendix D and NUREG/CR-5912**
  - **Applicable guidance provided for the seismic design of spent fuel racks as Seismic Category 1 Structures**
  - **Discuss various elements of the design that can impact the results of a seismic analysis**
    - Supported or free standing rack designs
    - Friction at the rack to pool interface
    - Fuel assembly movement within the rack
    - Submergence in water, for damping, coupling and added mass effects
    - Rack-to-rack and rack-to-wall interaction
    - Single rack and multiple rack models
    - 3 dimensional analysis and combination of directions
  - **Nonlinear analysis is needed to adequately capture the above**
  - **Nonlinear analyses do not respond in a predictable manner to changes in input**

Fuel Rack Seismic Analysis

- **SRP 3.7.1 provides direction for development of time histories and additional requirements for nonlinear analysis**
  - **3 mutually orthogonal directions**
  - **Statistically independent (zero-lag cross correlations between the three components limited to 0.16)**
  - **Duration (>20 seconds) and time step (<0.010 seconds)**
  - **Spectra calculated at a minimum of 100 points per log decade (0.1 Hz – 50 Hz)**
  - **Calculated response must be within 90% and 130% of the target spectrum**

    (0.2 Hz - 25 Hz NUREG/CR-6728)
  - **A maximum of 9 consecutive values may be below the target spectra**
  - **Desired mean base fit to the target spectrum, average ratio must be greater than 1.0**
  - **Nonlinear analyses require multiple (>4) time histories**

Fuel Rack Seismic Analysis

- **Structural Analysis Approach**
  - Original design input spectra
  - Additional design input spectra
  - Development of time history input per SRP 3.7.1
  - Nonlinear whole pool analysis and sensitivity cases per guidance in SRP 3.8.4
  - Detailed stress analysis of the spent fuel rack

Fuel Rack Seismic Analysis

- **Generation of design input in structure response spectra for fuel rack design**
  - **There are 8 ground motions applicable to the U.S. EPR design certification as listed in the US EPR FSAR Tier 2 Table 3.7.1-8**
  - **In structure response spectra is generated from all 8 ground motions**
  - **In structure responses are enveloped then peak broadened**
- **Original design basis spectra used the pool floor elevation (3.7 meters)**
  - **Developed to provide spectral accelerations above 2g from 2-10 Hz**
    - Robust design
    - Cover potential changes in design certification ground motion

Fuel Rack Seismic Analysis

- RAI 445 Question 3.8.4-20 identifies that amplification in the pool walls may not be captured adequately in the design input
- A second design basis spectra has been generated for the fuel racks
  - Added new design basis spectra for the pool walls at 10.3 meters using the revised ground motion input
  - Revised spectra at 3.7 meters for new ground motion inputs
  - Design basis spectra is developed by enveloping both elevations

Fuel Rack Seismic Analysis

- **Time history development is performed to ensure the following are met per SRP 3.71 Acceptance Criteria for Design Time Histories Development [II.1.B Option 1, Approach 2]**
  - **3 mutually orthogonal directions (North-South, East-West, Vertical) [II.1.B]**
  - **Statistically independent (zero-lag cross correlations between the three components is below the limit of 0.16) [II.1.B]**
  - **Desired mean base fit to the target spectrum, average ratio is greater than 1.0 [II.1.B.ii]**
  - **Duration (>20 seconds) and time step (<0.010 seconds) [II.1.B.ii(a)]**
  - **Spectra calculated at a minimum of 100 points per log decade (0.1 Hz – 100 Hz) [II.1.B.ii(b)]**
    - extended the range for completeness with respect to target spectra
  - **Calculated response is within 90% and 130% of the target spectrum (0.2 Hz - 50 Hz) [II.1.B.ii(c)(d)]**
    - Extended the range to accommodate potential high frequency response
  - **Time histories have a maximum of 9 consecutive values below the target spectra [II.1.B.ii(c)]**

Fuel Rack Seismic Analysis

- **Development of time history input for fuel rack analysis to meet SRP 3.7.1 requirements**
  - **Multiple sets of Time Histories [II.1.B Option 2]**
    - 5 time histories developed for both of the design basis spectra (>4 used)
    - Use 5 different seed time histories
    - Soil and rock sites considered
    - Magnitudes range from 6.5 to 7.9

Fuel Rack Seismic Analysis

- **Design Basis Analysis Utilizing Both Sets of Time Histories per guidance in SRP 3.8.4**
  - **Whole Pool Seismic Analysis**
    - Simplified models for each fuel rack geometry with appropriate mass and stiffness characteristics
    - Fuel Assemblies treated as additional density for the rack elements for the first set of time histories
    - Fuel assemblies are modeled explicitly to consider contact and momentum forces for the second set of time histories (preliminarily addressed as a sensitivity run in RAI 445 Question 3.8.4-19)
    - Layout of the racks consistent with the pool design
    - Rack-to-rack and rack-to-pool wall gaps are considered
    - Fluid elements are used for hydrodynamic coupling
    - Bounding friction coefficients used for sliding and tipping considerations
  - **Sensitivity Analyses For Additional Considerations**
    - Friction coefficients are modified to consider an average of the bounding cases
    - Friction coefficients are assigned randomly to the racks
    - Rack loading is varied to consider partially loaded conditions randomly and based on engineering judgment to maximize tipping and torsion
    - Tolerances on rack installation are considered by varying the rack-to-rack gaps in the model
    - Single precision and double precision calculations are performed

Fuel Rack Seismic Analysis

- **Analysis Methodology for Detailed Rack Stress Evaluation**
  - **Governing input is selected from both sets of time history data**
  - **Critical parameters determine governing time history to be used for detailed analyses**
    - Resultant Accelerations
    - Rack-to-Rack Contact Forces
    - Vertical Uplift
    - Lateral Displacements
    - Vertical and Lateral Forces
  - **Criteria for selection for detailed stress analyses**
    - Rack with the largest resultant acceleration
    - Largest (heaviest) rack and therefore, largest inertial loading
    - Rack that experienced largest rack-to-rack impact forces
  - **Whole pool model rack stresses are used as criteria to confirm the bounding rack geometry is used in detailed rack stress evaluations**

Fuel Rack Seismic Analysis

- **Outline of analysis work to be completed**
  - **Analyses to be completed with new time history inputs to satisfy SRP 3.7.1 requirements**
    - Whole Pool Model Analyses
    - Sensitivity Analyses associated with friction, loading, tipping and tolerances
    - Region I Fuel Storage Rack Analysis
  - **Analyses to be completed for changes in methodology**
    - Evaluation of Fuel Rack Leg Assemblies for Seismic Loads (RAI 445 Question 3.8.4-20)
    - Buckling Evaluation of Racks Corner Posts (June audit input)

Fuel Rack Seismic Analysis

- **Outline of analysis work to be completed (continued)**
  - **Detailed analyses that will not be revised to include new time history runs if previous inputs remain bounding**
    - Detailed Rack Stress Analysis
      - Based on selection criteria
    - Aluminum Tube Stress Evaluation
      - Based on analysis methodology and new whole pool model results
    - Analysis for Verification of Bounding Rack Criteria
      - Based on whole pool model results
    - Fuel Assembly Grid Spring Forces
      - Based on whole pool model results
    - Fuel Storage Rack Poison Plate Analysis
      - Previous analysis will be shown as bounding

Fuel Rack Seismic Analysis

- **Summary**
  - **SRP 3.7.1 requirements for the generation of time history input are met**
  - **SRP 3.7.1 requirements for the use of multiple time histories is met through the analysis of the second set of design response spectra using all 5 time histories developed**
  - **SRP 3.8.4 requirements are met through the use of nonlinear analyses with varied critical parameters**
  - **Detailed analyses are performed based on critical input parameters from the whole pool model**
  - **All time history inputs are considered**

RAI 589 Path Forward

- **Whole Pool Model Analysis Results**
  - SRP 3.7.1 requirements for the generation of time history input are met
  - SRP 3.7.1 requirements for the use of multiple time histories are met through the analysis of the second set of design response spectra using all 5 time histories developed
  - SRP 3.8.4 requirements are considered through the use of nonlinear analyses with varied critical parameters
- **Sensitivity Analyses**
  - Relative to friction coefficients, fuel assembly loading and rack-to-rack gap tolerances will be explicitly confirmed by re-analysis with bounding time history input from the second set of design input
  - Further demonstrate compliance with SRP 3.8.4 through confirmation of design methodologies on critical parameters

RAI 589 Path Forward

- **Detailed Analysis**
  - **Verify that the time histories used are the bounding input from either set of design input response spectra**
- **Technical Report**
  - **Whole pool analyses for both sets of time histories will be included**
  - **Detailed results reported will consider the bounding time history from either set of design input response spectra**

Schedule

- A detailed schedule for this analysis effort has not been developed at this time but will be provided by August 30th