AREVA

July 12, 2013
NRC: 13:054

U.S. Nuclear Regulatory Commission
Document Control Desk
11555 Rockville Pike
Rockville, MD 20852

Response to U.S. EPR Design Certification Application RAI 445, FSAR Ch. 3, Supplement 16

In Reference 1, the NRC provided a request for additional information (RAI) regarding the U.S. EPR design certification application. Reference 2 provided a schedule for a complete response to RAI No. 445. References 3, 4 and 5 were submitted to the NRC to revise the schedule. Reference 6 provided complete responses to 3 of the 13 remaining questions and a revised schedule for Question 03.08.04-20. Reference 7 was submitted to revise the schedule for 9 of the 10 questions. Reference 8 was submitted to revise the schedule for 10 of the 10 questions. Reference 9 provided complete final responses to five Questions (03.08.04-16, 03.08.04-17, 03.08.04-18, 03.08.04-22, and 03.08.04-26), and interim responses to five questions (03.08.04-15, 03.08.04-19, 03.08.04-20, 03.08.04-21, and 03.08.04-27). Reference 10 was submitted to provide complete final responses to three Questions (03.08.04-18, 03.08.04-25 and 03.08.04-26), and revise interim responses to three questions (03.08.04-19, 03.08.04-21, and 03.08.04-27). References 11, 12, and 13 were submitted to the NRC to revise the schedule. Reference 14 provided a complete final response to two questions (03.08.04-26 and 03.08.04-27). Reference 15 provided a complete final response to one question (03.08.04-17). Reference 16 provided a revised schedule for a final response for two questions (03.08.04-15 and 03.08.04-21). Reference 17 provided a revised schedule for a final response for two questions (03.08.04-19 and 03.08.04-20).

The enclosure to this letter provides a complete final response to one question (03.08.04-19). Appended to the enclosure are affected pages of the U.S. EPR Technical Report TN-Rack.01 01 in red line-strikeout format which support the final response to Question 03.08.04-19.

AREVA TransNuclear considers some of the material contained in the enclosure to be proprietary. As required by 10 CFR 2.390(b), an affidavit is included to support the withholding of the information from public disclosure. Proprietary and non-proprietary versions of the enclosure to this letter are provided.

The following table indicates the respective pages in the enclosure that contain the response provided by AREVA NP Inc. (AREVA NP) to the subject question.

Question #	Start Page	End Page
RAI 445 — 03.08.04-19	2	23

AREVA NP INC.

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NRO

The schedule for a complete response to the remaining three questions is unchanged as provided below:

Question #	Response Date
RAI 445 — 03.08.04-15	July 23, 2013
RAI 445 — 03.08.04-20	August 9, 2013
RAI 445 — 03.08.04-21	July 23, 2013

If you have any questions related to this information, please contact Len Gucwa by telephone at (434) 832-3466, or by e-mail at Len.Gucwa.ext@areva.com.

Sincerely,

Pedro Salas, Director
Regulatory Affairs
AREVA NP Inc.

Enclosures:
1. Proprietary Response to U.S. EPR Design Certification Application RAI 445, Supplement 16
2. Non-Proprietary Response to U.S. EPR Design Certification Application RAI 445, Supplement 16
3. Notarized Affidavit

cc: A. M. Snyder
Docket 52-020

References

Ref. 1: E-mail, Getachew Tesfaye (NRC) to Martin C. Bryan (AREVA NP Inc.), "U.S. EPR Design Certification Application RAI No. 445 (5083), FSAR Ch. 3," October 1, 2010.

Ref. 2: E-mail, Martin C. Bryan (AREVA NP Inc.) to Getachew Tesfaye (NRC), "Response to U.S. EPR Design Certification Application RAI No. 445 (5083), FSAR Ch. 3," October 29, 2010.

Ref. 3: E-mail, Martin C. Bryan (AREVA NP Inc.) to Getachew Tesfaye (NRC), "Response to U.S. EPR Design Certification Application RAI No. 445 (5083), FSAR Ch. 3, Supplement 1," January 27, 2011.

Ref.4: E-mail, Russ Wells (AREVA NP Inc.) to Getachew Tesfaye (NRC), "Response to U.S. EPR Design Certification Application RAI No. 445 (5083), FSAR Ch. 3, Supplement 2," February 25, 2011.

Ref. 5: E-mail, Russ Wells (AREVA NP Inc.) to Getachew Tesfaye (NRC), "Response to U.S. EPR Design Certification Application RAI No. 445 (5083), FSAR Ch. 3, Supplement 3," March 23, 2011.

Ref. 6: E-mail, Russ Wells (AREVA NP Inc.) to Getachew Tesfaye (NRC), "Response to U.S. EPR Design Certification Application RAI No. 445 (5083), FSAR Ch. 3, Supplement 4," April14, 2011.

Ref. 7: E-mail, Russ Wells (AREVA NP Inc.) to Getachew Tesfaye (NRC), "Response to U.S. EPR Design Certification Application RAI No. 445 (5083), FSAR Ch. 3, Supplement 5," April 22, 2011.

Ref. 8: E-mail, Dennis Williford (AREVA NP Inc.) to Getachew Tesfaye (NRC), "Response to U.S. EPR Design Certification Application RAI No. 445 (5083), FSAR Ch. 3, Supplement 6," May 31,2011.

Ref. 9: Letter, Sandra Sloan (AREVA NP Inc.) to U.S. NRC Document Control Desk, "Response to U.S. EPR Design Certification Application RAI No. 445 (5083), FSAR Ch. 3, Supplement 7," July 8, 2011.

Ref. 10: Letter, Sandra Sloan (AREVA NP Inc.) to U.S. NRC Document Control Desk, "Response to U.S. EPR Design Certification Application RAI No. 445, FSAR Ch. 3, Supplement 8," August 15, 2011.

Ref. 11: E-mail, Dennis Williford (AREVA NP Inc.) to Getachew Tesfaye (NRC), "Response to U.S. EPR Design Certification Application RAI No. 445, FSAR Ch. 3, Supplement 9," November 17, 2011.

Ref. 12: E-mail, Dennis Williford (AREVA NP Inc.) to Getachew Tesfaye (NRC), "Response to U.S. EPR Design Certification Application RAI No. 445, FSAR Ch. 3, Supplement 10," March 16, 2012.

Ref. 13: E-mail, Dennis Williford (AREVA NP Inc.) to Getachew Tesfaye (NRC), "Response to U.S. EPR Design Certification Application RAI No. 445, FSAR Ch. 3, Supplement 11," April 26, 2013.

Ref. 14: Letter, Pedro Salas (AREVA NP Inc.) to U.S. NRC Document Control Desk, "Response to U.S. EPR Design Certification Application RAI 445, FSAR Ch. 3, Supplement 12," June 13, 2013.

Ref. 15: Letter, Pedro Salas (AREVA NP Inc.) to U.S. NRC Document Control Desk, "Response to U.S. EPR Design Certification Application RAI 445, FSAR Ch. 3, Supplement 13," June 27, 2013.

Ref. 16: E-mail, Dennis Williford (AREVA NP Inc.) to Amy Snyder, (NRC), "Response to U.S. EPR Design Certification Application RAI No. 445, FSAR Ch. 3, Supplement 14," June 28, 2013.

Ref. 17: E-mail, Dennis Williford (AREVA NP Inc.) to Amy Snyder, (NRC), "Response to U.S. EPR Design Certification Application RAI No. 445, FSAR Ch. 3, Supplement 15," July 9, 2013.

AFFIDAVIT PURSUANT
TO 10 CFR 2.390

Transnuclear, Inc.)
State of Maryland) SS.
County of Howard)

I, Paul Triska, depose and say that I am a Vice President of Transnuclear, Inc., duly authorized to execute this affidavit, and have reviewed or caused to have reviewed the information which is identified as proprietary and referenced in the paragraph immediately below. I am submitting this affidavit in conformance with the provisions of 10 CFR 2.390 of the Commission's regulations for withholding this information.

The information for which proprietary treatment is sought is listed below:

- Portions of Transnuclear, Inc. document TN-Rack.0101, "U.S. EPR New and Spent Fuel Storage Rack Technical Report," Revision 1.
- Portions of response to RAIs 03.08.04-19.

These documents have been appropriately designated as proprietary.

I have personal knowledge of the criteria and procedures utilized by Transnuclear, Inc. in designating information as a trade secret, privileged or as confidential commercial or financial information.

Pursuant to the provisions of paragraph (b) (4) of Section 2.390 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure, included in the above referenced document, should be withheld.

1) The information sought to be withheld from public disclosure involves details and analyses related to Transnuclear, Inc.'s design for new and spent fuel storage racks, which are owned and have been held in confidence by Transnuclear, Inc.

2) The information is of a type customarily held in confidence by Transnuclear, Inc. and not customarily disclosed to the public. Transnuclear, Inc. has a rational basis for determining the types of information customarily held in confidence by it.

3) Public disclosure of the information is likely to cause substantial harm to the competitive position of Transnuclear, Inc. because the information consists of details and analyses related to Transnuclear, Inc.'s design for new and spent fuel storage racks, the application of which provide a competitive economic advantage. The availability of such information to competitors would enable them to modify their product to better compete with Transnuclear, Inc., take marketing or other actions to improve their product's position or impair the position of Transnuclear, Inc.'s product, and avoid developing similar data and analyses in support of their processes, methods or apparatus.

Further the deponent sayeth not.

Paul Triska
Vice President, Transnuclear, Inc.

Subscribed and sworn to me before this 11th day of July, 2013.

Notary Public

My Commission Expires ____/____

Lauren McKee
NOTARY PUBLIC
Anne Arundel County, Maryland
My Commission Expires 2/12/2015

LAUREN MCKEE
NOTARY PUBLIC
ANNE ARUNDEL COUNTY, MD

Response to

Request for Additional Information No 445, Supplement 16

10/01/2010

U.S. EPR Standard Design Certification
AREVA NP Inc.
Docket No. 52-020
SRP Section: 03.08.04 - Other Seismic Category I Structures
Application Section: 3.8.4

QUESTIONS for Structural Engineering Branch 2 (ESBWR/ABWR Projects) (SEB2)

Question 03.08.04-19:

Appendix 3C of the Technical Report addresses the seismic analysis of the spent fuel racks. To ensure compliance with 10 CFR 50, Appendix A, GDC 2, as it relates to the design of safety-related structures being able to withstand the most several natural phenomena such as earthquakes, the following additional information on seismic modeling is needed:

a. Provide more detailed descriptions of the Arbitrary-Lagrangian-Eulerian (ALE) analysis algorithms; for example, explain how the important parameters were obtained and how ALE analysis algorithms compare with traditional potential theory-based added mass/damping method. Clarify whether water in the aluminum tube cells and water below the racks were also modeled with fluid elements, and whether hydrodynamic coupling was taken into account in the stress analysis using the detailed single rack model. If not, provide the technical basis for not doing so.

b. Subsection 3C.3.4 of the Technical Report does not mention how grid assemblies were modeled. Provide an explanation of how these assemblies were modeled.

c. Subsection 3C.3.5.1 of the Technical Report describes contact force definitions. Clarify whether those contact definitions consider impact stiffness. If yes, provide the impact stiffness values for rack to rack, fuel to fuel cell, rack to wall and rack to floor. Explain how those values were determined, including the value of effective stiffness given in Section 3C.3.6 of the Technical Report for spacer grids between fuel cells and fuel assemblies. Also clarify whether any sensitivity analysis for impact stiffness was performed.

d. Provide the technical basis for the use for the friction coefficient value and the coefficient of restitution value, and values for other important parameters in the models used.

e. As indicated in Section I.3 of SRP 3.8.4, Appendix D, loads generated by the impact of fuel assemblies during a postulated seismic excitation should be considered for local as well as overall effect. Section 3C.3.6 of the Technical Report discusses the modeling of the fuel rattling inside the tube of cells for the detailed single rack model. Clarify whether assumptions were made on fuel motions. In addition, clarify whether fuel assembly rattling was also considered in the seismic analysis for the whole pool analysis. If yes, provide detailed descriptive information on the modeling. If not, provide the technical basis.

f. Provide information on the modeling of support legs, for example, the vertical stiffness of the tube (screw jack) in a support leg and the element type of the tube. Confirm that the design check on support legs has been done.

g. Section 2.2.1, Item 1, of the Technical Report mentions that underwater fuel storage rack modules may be interconnected to provide additional seismic restraint. However, the Technical Report does not present any analysis that includes these interconnections. Explain why not.

h. As indicated in Section I.5 of SRP 3.8.4, Appendix D, details of the methods used to account for the effect of sloshing water on the pool walls should be provided. Provide the detailed information.

i. Explain how the dead weight mass was treated for submerged rack structures and how the effective damping of the fuel assemblies and water damping were considered.

j. The friction coefficient between the bearing pads and the pool liner is an important factor affecting the seismic response of the racks. Provide the technical basis for only considering the two bounding values and not other intermediate values for the fully loaded configuration. For the cases of partially loaded configuration, several runs may be needed in order to adequately consider the randomness of the friction coefficient and the configuration of loaded cells. Therefore, provide the number of runs for each of the two cases of partially loaded configuration and the technical basis for the determination of the number.

Supplemental NRC Comments, Letter Dated 7-02-13:

The staff reviewed the advanced RAI response dated June 3, 2013, and requests that the applicant address the remaining items listed below.

(a) The mark-up for the AREVA TR TN-Rack.0101 report (TN) Section 3C.3.10 references TN Figures 3C-57 through 3C-60; however, the mark-up for these figures was not provided. The staff requests that the applicant provide the mark-up for TN Figures 3C-57 through 3C-60.

(e) The RAI response referenced TN Section 3C.3.8; however, the corresponding TN mark-up was not provided. The staff requests that the applicant provide the mark-up for TN Section 3C.3.8.

Response to Question 03.08.04-19:

a) The multi-rack whole pool analysis model uses a combination of Lagrangian, Eulerian, and Arbitrary-Lagrangian-Eulerian (ALE) methodologies to model the fluid-structure interactions between the racks (rack-to-rack interaction) and between the racks and the pool structure (rack-to-pool walls/floor interaction). The discussion in this response illustrates how these three approaches are implemented in the analysis of the whole pool multi-rack model in order to adequately capture these interactions.

In the whole pool model, the rack structures are modeled using Lagrangian finite element meshes. Lagrangian solution algorithms are most common in structural mechanics applications. In the Lagrangian formulation, the finite element mesh is deformable (i.e., each individual node of the mesh follows the deformation of the structure as the structure deforms in space and time under the applied external loads). The deformed state of the structure is tracked explicitly and is known at any point in time. Although this represents an advantage of the Lagrangian approach, its weakness is its inability to follow large distortions of the computational domain, such as those associated with modeling fluid continuum and structure/fluid boundary interfaces. For such situations, Eulerian algorithms are most suitable and are most commonly used in fluid dynamics applications.

In the Eulerian approach, the computational mesh is a fixed and non-deformable mesh. The mesh allows the continuum (the fluid) to flow through the mesh grid. The Eulerian approach does not track the path of the individual particles of the fluid. Instead, it measures flux or flow through the mesh grid. This method yields information about the flow in terms of what happens at fixed points in space (the fixed mesh) as the fluid flows past those points. In the Eulerian approach, large deformations of the fluid continuum are handled with relative ease;

but the deformation of each particle of the continuum is not explicitly tracked in space and time.

The ALE is a method that combines the positive features of both, the purely Lagrangian and the purely Eulerian approaches. ALE is a finite element formulation that utilizes a two-step approach to solve the fluid flow or large distortion/deformation problems in the presence of moving and deformable boundaries. First, a Lagrangian step that allows the mesh to deform under applied loads, with material staying within their mesh. Second, as the mesh becomes overly distorted when subjected to the applied loads; it is reorganized in a process called "mapping/advection," which maps the deformed shape into an updated and fixed Eulerian mesh that accounts for material flow across the mesh.

In the LS DYNA implementation of the ALE approach to the whole pool analysis model, each rack module is modeled using Lagrangian finite element meshes. LS DYNA *SECTION_SHELL, command with ELFORM 16 option for fully integrated shell elements are used for the Lagrangian rack structures. The fluid is modeled using an Eulerian mesh using *SECTION_SOLID, with ELFORM 12 option; consisting of solid elements with one point integration element formulation, are used for the water and void elements. The Eulerian mesh is a fixed mesh that consists of a water part and a void part. The ALE formulation is used to verify compatibility of potentially deformable rack-to-fluid boundary interface. As the Lagrangian structure displaces/deforms and pulls away from (or pushes into) the fluid-structure boundary due to inertial seismic loads or fluid pressures, the fluid present at the original boundary interface flows into the void mesh that becomes exposed due to displacements/deformations of the Lagrangian structures. This process results in the proper accounting of the continuous coupling interactions between the body of fluid and the corresponding surrounding structures. The *CONSTRAINED_LAGRANGE_IN_SOLID command defines the coupling mechanism between the Lagrangian structures (racks and concrete pool) and the Eulerian fluids. The meshes for the Eulerian void part are continuously connected with the water part and spatially overlap each rack. Interaction occurs when the Lagrangian meshes intersect with the Eulerian meshes.

In the ALE approach, the nodes of the computational mesh may be moved with the continuum (i.e., the ALE mesh can be referenced to a moving Lagrangian mesh, which allows the non-deformable fluid mesh to track the motion of the Lagrangian concrete pool). The *ALE_REFERENCE_SYSTEM command is used to allow the ALE Eulerian mesh (consisting of a water part and a void part) to follow the motions of the concrete pool structure. The outer boundary nodes of both ALE parts are merged with the concrete pool inner nodes.

In the whole pool model, the domain outside of each rack, including the volume above the racks, the volume below the rack's baseplate, and the volume in the gaps between racks and between racks and the pool walls, was specified as WATER (modeled with fluid elements), and the domain occupied by each rack was defined as VOID (water can flow into it once the rack displaces or deforms). Rack-to-rack and rack-to-pool structure hydrodynamic coupling is explicitly considered. The water inside the tube cells is not explicitly modeled with fluid elements, but its mass (and the mass of the fuel assemblies) is accounted for as added mass to the tubes.

The domain above the water surface level consists of a VOID mesh and is extended above the top surface water level to capture the effect of sloshing of the water as the water moves into this void mesh once the analysis proceeds.

As described above the fluid is modeled using Eulerian finite element meshes which consist of a WATER part and a VOID part. At the beginning of the analysis, the part of the Eulerian mesh outside each of the racks, including the volume below the rack's baseplate, the volume of the gaps in between racks and between the racks and the pool walls, and the volume above the racks is specified as WATER material; and the volume occupied by the racks is modeled as a VOID mesh part. As the analysis proceeds, the water may flow and occupy the volume of the VOID parts of the mesh as a result of the horizontal and vertical displacements of the racks due to the dynamic input motions. Thus, the model permits the water to flow below the racks, as well as through the space between the racks and in the spaces between the racks and the pool walls. The water in between tubes (for Region 1 racks only) or inside the tube cells is not explicitly modeled with fluid finite elements. This water is considered as an added mass to the fuel beam or to the tube cells, as appropriate.

Hydrodynamic coupling is considered in the stress analysis using the detailed single rack model by the application of the displacement field resulting from the whole pool model fluid structure interaction analysis. The mapped displacement field contains the hydrodynamic coupling effects from the multi-rack whole pool analysis. Additionally, hydrodynamic coupling of the fuel assembly and the fluid inside the tube cell was considered by including the water mass of the net water volume inside the tube cell (total water volume less volume displaced by the fuel assembly) as added mass of the fuel assembly. This is a conservative coupling approach because only the inertial effect of the water is considered, with no credit taken for water resistance forces and damping effects that take place inside the cells. Also, it results in net unbalanced hydrodynamic pressures being applied to the outside surfaces of the perimeter tube walls because the water inside the tubes is not explicitly modeled with fluid elements. This approach translates in higher inertial loads on the tube walls and the fuel assembly.

The water fluid is modeled using the LS DYNA *MAT_NULL hydrodynamic material law, where the fluid is fully defined by two properties: its density, equal to 0.001kg/cm^3; and elastic bulk modulus, equal to 1.5E7kg/cm sec^2. Therefore, the modeling of the water is consistent with that of an ideal fluid (i.e., fluid is inviscid (frictionless) and essentially incompressible, which is consistent with potential theory principles).

To validate the analysis methodology, a number of sample problems have been executed in LS DYNA using the ALE approach and the results compared with those based on potential theory. These sample problems are documented as part of TN's Validation and Verification (V&V) package for LS DYNA, and include comparisons of the LS DYNA ALE results against those obtained using other computer codes (i.e. ANSYS), closed form solutions (Ref. 2) and experimental tests (Ref. 3).

Also, an additional sample problem consisting of a small rectangular tank filled with water fluid and subjected to dynamic motions is analyzed. The objective of this problem is to evaluate the response of the tank obtained using the LS DYNA ALE approach against other industry wide accepted formulation method, such as that in the ASCE 4-98 Standard (Ref. 4).

A finite element model of the rectangular tank filled with water is developed using LS DYNA. The rectangular tank is modeled with shell elements and the water inside of the tank is modeled with solid fluid elements. The LS DYNA solution is implemented using the ALE approach. The input consists of a triangular shape acceleration pulse applied in the lateral direction. The force resulting from the dynamic pressures on the tank walls along with the fluid oscillation period and the maximum sloshing height are determined based on the LS DYNA analysis.

The same problem is analyzed using the solution procedure for a rectangular tank described in Ref. 5 that is referenced in the ASCE 4-98 Standard. The impulsive and convective components of the hydrodynamic forces on the tank walls, the fluid oscillation period, and the sloshing height are determined and the results are compared with the results from the LS DYNA analysis

The results are shown in the table below and confirm the adequacy of the ALE LS DYNA methodology.

Quantity Measured	ASCE 4-98 Method	LS-DYNA ALE Method
Max Lateral Reaction Force (lbs)	3.55	3.88
Sloshing Period (sec)	1.34	1.43
Sloshing Height (in)	3.25	3.06

In the whole pool analysis, the fuel assemblies are not explicitly modeled inside the tube cells. Instead, the fuel assembly mass, including the entire mass corresponding to the net water volume inside the tube cells, is included as added density to the tubes containing the fuel assemblies.

The basis for this approach is that the mass of the fuel assembly is dominant relative to the mass of the tube; therefore, the approach conservatively accounts for the total inertia loading from the fuel assemblies on each individual rack. This approach is conservative because of the following reasons:

1) It conservatively ignores the retarding/damping effect of the fluid inside the tube cells on the motions of the fuel assembly.
2) It conservatively ignores the stiffness contribution of the fuel assembly.
3) It conservatively ignores any friction forces that develop between the fluid assembly bottom nozzles and the rack's baseplate.

To address concerns with not including the "rattling" of the fuel assemblies and water within the rack cells (tubes), the whole pool multi-rack model is modified to incorporate a simplified representation of the fuel assembly inside all the tube cells. This analysis assesses the effect of the fuel assembly "rattling" inside the tube compartment cells on the overall motions of the racks. The appropriateness of including the entire mass of the net water volume inside each of the tube cells as added density to the fuel assemblies is confirmed by calculating the hydrodynamic added mass based on formulae in the literature (Ref 6). The analysis is performed using the bounding time history set 1. The whole pool model run results (e.g., relative rack sliding and uplifts, legs lateral friction and vertical impact forces, and rack-to-rack and rack-to-pool wall forces (if any) as well as rack stresses) is evaluated and compared with the same run case where the fuel assemblies were modeled as added density to the tubes. These analyses are documented in Section 3C.3.10 of Technical Report TN-Rack.0101.

b) The objective of the simplified rack model is to adequately capture the overall fluid-structure interaction response of the racks configured in the whole pool analysis model. For this purpose, each simplified rack structure is modeled as a grid of interconnected plates that represent the geometric configuration of the detailed rack. The simplified model consists of a grid or assemblage of interconnected plates that mimic the geometry of the [ ] tube assembly in the actual rack structure. The [ ] tube thickness is [ ]; thus, the grid plates have an equivalent thickness of [ ] as it represents the combined thickness of two adjacent [ ] tubes. The plates that make up the grid assemblage are connected at the intersections. There are no contact definitions in the simplified rack model. The grid is modeled using the same fully integrated shell elements and same hourglass controls as those used for the detailed rack model. The density of the grid plates is increased to include the weight of the poison plates, the weight of the fuel assemblies, and all other parts of the rack not explicitly modeled. Therefore, the overall mass of the actual rack is maintained.

The modeling simplifications described in this response result in a simplified model that is stiffer than the detailed model or the actual rack structure. Therefore, the elastic modulus (E) of the grid material is iteratively adjusted to approximately match the main frequencies of the detailed model. This approach achieves a simplified but dynamically equivalent representation of the rack structure that is adequate for the purposes of capturing the overall fluid structure interaction coupling response of the racks from the whole pool analysis.

c) The contact at the rack-to-rack, rack-to-wall, and rack legs-to-floor interfaces are defined via the standard contact definitions in LS-DYNA. These contact definitions consider the impact stiffness of the nodes/surfaces in contact. These impact stiffnesses are calculated internally by LS-DYNA, based on the material properties of the contacting components (i.e., the modulus of elasticity (E) and poison's ratio). These are local stiffnesses that are calculated for pairs of contacting nodes or segments and are akin to placing normal interface springs between penetrating nodes at the contact surfaces. For shell elements, the contact stiffness is proportional to KA/L; where K is the bulk modulus, A is the surface area, and L is the diagonal length dimension.

The contact surfaces for the rack legs-to-floor interface consist of shell elements, which model the bearing pad of the rack leg (on the rack side) and the floor surface (on the pool floor side).

The body of each rack's leg is modeled as a rigid body with the proper height to correctly model the kinematic behavior of the rack. This modeling approach yields conservative forces on the rack legs because it does not credit the flexibility of the rack's leg body.

The effective stiffness for the spacer grids between fuel cells and the fuel assemblies is determined as follows:

- Because the fuel assembly is not explicitly modeled in the whole pool analysis, the displacements of the tube cells that are mapped into the detailed model do not fully capture the local interaction between fuel assemblies and the tube cell at the interface points with the spacer grids. Therefore, additional analyses are performed to adequately account for these local interactions and the associated effects on the tube stresses. These additional analyses are summarized in this response.

- First, an equivalent stiffness is determined by performing two separate analyses. The first analysis (baseline analysis) is performed using a submodel consisting of a single tube and fuel assembly components (i.e., [ ] tube, fuel assembly, and compression-only springs). This analysis uses a spring stiffness of [ ] (this stiffness value corresponds to the fuel assembly's "through grid stiffness" and is taken from previous work associated with the experimental characterization of the fuel assembly). An acceleration is input to the top and bottom of the [ ] tube submodel and the forces and nodal displacements in the springs are calculated. These results are considered as the baseline conditions to be matched by a second analysis described in this response.

- The second analysis is performed in two steps to mimic the procedure used in the overall seismic analysis. In the first step, a model of only the [ ] tube is used. The fuel assembly is not included, but its mass is accounted for by increasing the density of the [ ] tube. The [ ] tube is excited in the same manner as in the baseline analysis. In the second step, the analysis (similar to the detailed analysis) is performed using the model with all of the components included (i.e., [ ] tube, fuel assembly, and springs). The displacement profile from the first step is applied as boundary conditions to the second step model. The stiffness constant of the springs is iteratively determined such that the maximum force and nodal displacement in the springs match those of the baseline analysis. The resulting impact stiffness of [ ] matched the maximum force and nodal displacement in the springs from the first analysis (baseline case). This effective impact stiffness is then used in the analysis of the detailed rack model.

- A sensitivity analysis is performed where the impact stiffness is increased by 20 percent [ ], and the maximum impact force decreased from [ ].

d) The coefficient of friction values of 0.2 and 0.8 were used because they are considered bounding values for fuel rack design based on the recommendation from the results of extensive tests by Rabinowicsz (see Section 6.3, NUREG/CR-5912, "Review of the Technical Basis and Verification of Current Analysis Methods Used to Predict Seismic Response of Spent Fuel Storage Racks," Ref. 7).

As part of the Response to RAI 445, Question 03.08.04-19, Item j, an additional whole pool analysis case was performed with a coefficient of friction of 0.5. The analysis was run for the fully loaded rack layout configuration using Input Time History Set 1, which has been determined to be the bounding input time history in the Response to RAI 445, Question 03.08.04-20, Item a. Similarly for the partially loaded cases, two additional analyses were performed, corresponding to each of the two partially loaded rack layout configurations, using a uniform coefficient of friction of 0.5.

The results show that the 0.2 and 0.8 cases provide bounding responses; and, hence, are generally the controlling cases. Similarly, the results with the 0.5 coefficient of friction for the partially loaded cases are shown to be generally bounded by the original runs with random friction coefficients.

A coefficient of friction of 0.25 was used for the surfaces of the rack structure that may come in contact with each other. This applies to the rack's external contact surfaces (e.g., rack-to-rack, rack-to-pool liner, or internal surfaces such as tube-to-tube and tube-to-frame). These are generally vertical contacting surfaces.

A coefficient of friction of 0.25 is selected as a representative lower bound value for contact between metallic surfaces. The analysis model is not expected to be sensitive to the coefficient of friction for these vertical contact surfaces because of the following:

1) There is minimal to no relative sliding between contacting surfaces of the rack's internal parts. This is because relative vertical movement of the aluminum tubes is restrained by stop bars welded to the top steel grid. Thus, no friction forces develop along the internal contact surfaces.
2) The whole pool analysis demonstrates that there is no contact between the racks and the pool floor. Because there is no contact, no friction forces are developed along these external contact surfaces. Technical Report TN-Rack.0101, Section 3C.3.5.3.4 will be revised for consistency.
3) The whole pool analysis also shows that there is very limited rack-to-rack contact. Rack-to-rack contact is not long because it starts late in the time history (at about 35 seconds of the 40 seconds duration) and is also limited to only two racks (out of 17 racks in the pool) contacting their neighboring racks. The normal (perpendicular contact) forces on these vertical surfaces are instantaneous, not sustained forces. Therefore, no significant friction forces are developed and no appreciable sliding takes place along the contacting surfaces.

An effective coefficient of restitution (COR) of 0.52 is used as a conservative value for the rack's feet impacting on the concrete pool floor. The COR is a measure of energy loss that occurs with the impact of two masses; and is a function of the material of the impacting bodies and their impact velocity, among other factors. A COR value of zero represents a perfectly plastic impact with complete energy dissipation (no bounce), and a value of one represents a perfectly elastic impact with no energy loss.

The COR value of 0.52 is, in part, based on the test results reported in Ref. 1. Ref. 1 provides results of tests performed to determine the COR of various impacting materials in vacuum conditions and as a function of impact velocity. The tests show a COR of approximately 0.63 for a steel ball impacting on a steel plate at an impact velocity of about 33 in/sec (Ref. 1, Figure 3(a)). One of the test findings was that the COR decreases with increasing of the impact velocity. Considering a drop height of about two inches, the impact velocities for the racks is in the range of 40 in/sec. The 0.52 value is obtained by adjusting for the calculated impact velocities. A COR value of 0.52 is a very conservative and bounding value because the racks are under immersed conditions and the stress levels of the rack foot assembly are consistent with the Level D service accident conditions.

e) No assumptions are made regarding the motions of the fuel assemblies, as they are allowed to freely respond (rattle) inside the tube cells. A model of the fuel assembly is incorporated into each cell of the detailed rack model. The fuel cladding rods portion of the assembly is modeled using beam elements with stiffness and mass properties that represent the actual assembly. The top and bottom nozzles are modeled with shell elements. The fuel assembly rests vertically inside the tube cell with the bottom nozzle in contact with the rack's baseplate. At each spacer grid location, a contact (compression-only) spring is connected to the walls of the vertical tube. The motions of the simplified rack obtained from the whole pool analysis are applied to the corresponding nodes of the detailed model. These motions get transmitted to the fuel assembly through the motions of the baseplate, the spacer grids springs, and the top and bottom nozzle contacts with the tubes. "Rattling" of the fuel assemblies inside each of the tube cells of the racks is considered and captured in the detailed rack analysis.

A subsequent analysis has been performed to further address the "rattling" effects of the fuel assemblies on the whole pool response analysis. This additional analysis was performed, in part, in the Response to RAI 402, Question 09.01.01-41, regarding the adequacy of the Region 1 rack flux trap gap geometry under normal and credible accident conditions. This additional analysis is discussed in AREVA Technical Report TN-Rack.0101, Section 3C.3.8, and is briefly summarized in this response. While Section 3C.3.8 is not being revised by this response, a copy of this section is included with the Technical Report TN-Rack.0101 Markups for the NRC's convenience.

A detailed model of the Region 1 rack is developed using a similar modeling approach as that used for the detailed rack model as described in AREVA Technical Report TN-Rack.0101, with the exception that all six feet of the rack are incorporated versus the four feet conservatively modeled in the previous analyses. The water in the flux trap gap and inside the tube cells is conservatively modeled as added density to the surrounding parts of the rack and the fuel assembly, respectively. The fuel assemblies are modeled using the same beam stiffness and mass properties as in the previous detailed analysis model. However, for computational efficiency, the contact springs and dashpots at the discrete spacer grid locations are not modeled. Instead, continuous contact of the fuel assembly with the [ ] tubes along the length of the assembly is specified. For contact purposes, the fuel assembly contacting surface consists of a circular beam having an effective diameter that is benchmarked to produce tube cell stresses that are approximately the same as those produced with the spring and dashpot fuel assembly model.

To evaluate the hydrodynamic coupling effects on the response of the rack with the fuel assemblies rattling inside the tube cells, the detailed Region 1 rack model, described above, is used to perform a single rack pool model analysis. The rack model is set up in the pool in such a way as to model the rack to wall gaps on two sides of the rack and the rack-to-rack gaps on the remaining two sides (simulating a corner rack). The modeling parameters and analysis procedures are the same as those used for the multi-rack whole pool model analysis. The results of the seismic fluid structure interaction analysis consist of maximum stresses for the various rack frame components and [ ] tubes that are evaluated for global and local effects to Subsection NF ASME Code stress criteria. This analysis shows that the stresses in the racks components are generally of the same order of magnitude as those from the previous analysis in Technical Report TN-Rack.0101. The [ ] tubes stresses are also consistent with previous results. There are limited areas of localized stresses in the [ ] tubes that are shown to be acceptable.

In addition, to further address the "rattling" effects, a whole pool multi-rack analysis with the fuel assemblies explicitly modeled inside each of the rack cells is performed, as described in response to Item (a).

f) The primary purpose in including the support legs in the whole pool model is to adequately account for the discrete interface locations with the pool floor and to provide the correct height of the rack to properly account for stability effects. In the whole pool model analyses, the support legs are modeled as rigid body parts.

The whole pool analysis results provide interface sliding forces and vertical forces for the rack feet and pool concrete floor/liner. These forces are used for detailed rack design evaluation of the leg support components.

The rack legs design evaluation for the seismic load combination will be summarized in AREVA Technical Report TN-Rack.0101, Appendix 3C, Section 3C.3.6.5. Also refer to the Response to RAI 445, Question 03.08.04-20, Item b.

g) The seismic analysis has demonstrated that the independent racks perform their design function without any interconnection. Therefore, the statement in AREVA Technical Report TN-Rack.0101, Section 2.2.1, regarding the racks being interconnected to provide additional seismic restraint will be deleted.

h) The effect of sloshing is explicitly considered in the ALE analysis methodology as described in the Response to Item a). Sloshing is modeled by prescribing a void mesh part directly above and connected to the water surface level. This volume of void material, similar to open air above a body of water, represents a "numerical reservoir" that is initially absent of water material where water can flow in and out as necessary during the analysis, capturing the sloshing of the fluid. As stated in the response to Item a, the effect of sloshing using the ALE method has been verified by comparing the sloshing response obtained using the ALE methodology and that from an industry wide accepted method, such as that described in ASCE 4-98.

i) The dead weight mass is applied to the model as body forces with 1g gravity acceleration to the parts that make up the whole pool model, including the individual rack structures and the fluid parts representing the water below, in between, and above the racks. This modeling approach accurately accounts for gravity, hydrostatic pressure, and buoyancy effects.

The fuel assemblies in the detailed rack model have discrete dashpots at each spacer grid elevation. The spacer grid dashpot equal to [ ] is applied as discrete damping elements in series with the spacer grid compression-only spring stiffness. The corresponding equivalent damping value expressed as a percentage of critical at each of the spacer grid locations ranges from 6.3 percent to 7.1 percent with an average value of 6.9

percent. This value compares favorably to SSE damping values for bolted structures in RG 1.61.

No explicit damping mechanism is applied to the fluid elements modeling the water. The water is defined by two basic properties, density and bulk modulus.

j) An additional analysis of the fully loaded whole pool model has been performed using an intermediate value of coefficient of friction of 0.5. The results show that the use of the bounding coefficients of friction of 0.2 and 0.8 generally bound the results of the intermediate 0.5 case. Figure 03.08.04-19-1 through Figure 03.08.04-19-5 compare each rack of the response parameters previously evaluated in AREVA Technical Report TN-Rack.0101. These include the following:

- Figure 03.08.04-19-1 Maximum resultant accelerations.
- Figure 03.08.04-19-2 Maximum sliding displacements.
- Figure 03.08.04-19-3 Maximum vertical.
- Figure 03.08.04-19-4 Maximum resultant friction forces of the rack feet.
- Figure 03.08.04-19-5 Maximum vertical impact forces.

These figures show that on an individual rack basis, the 0.2 and 0.8 cases are generally the controlling cases; and, in all instances, the maximum controlling values are from either from the 0.2 or the 0.8 coefficients of friction cases.

Two additional analyses have been performed for the partially loaded cases, one for each of the two partially loaded configurations. The two additional cases are performed using a uniform coefficient of friction of 0.5.

The results are shown in Figure 03.08.04-19-6 to Figure 03.08.04-19-10 for the same response parameters as for the fully loaded cases. The results show that on an individual rack basis, there are not significant differences between the four cases analyzed. For the cases where the responses are not close to each other, the results for the random coefficient of friction are the controlling cases.

From these additional analyses, it can be concluded that the cases analyzed and presented in AREVA Technical Report TN-Rack.0101 represent the bounding configurations.

In addition to the responses to the NRC question, the maximum fuel assembly grid force values reported in Sections 3C.3.6.2 and 3C.6.3.B are being updated.

References:

1. Radill, K. C., Palazzolo, A. B., "Influence of Temperature and Impact Velocity on the Coefficient of Restitution", NASA Technical Memorandum 106485, Army Research Laboratory Memorandum Report ARL-MR-135, July 1994.
2. Fritz, R.J., "The Effect of Liquids on the Dynamic Motions of Immersed Solids," Journal of Engineering for Industry, Trans. ASME (Feb. 1972).
3. Fritz, R.J. and Kiss, E., "The Vibration Response of a Cantilevered Cylinder Surrounded by An Annular Fluid, KAPL-M-6539, General Electric Co., Schenectady, N.Y. (February, 1966).
4. ASCE Standard, "Seismic Analysis of Safety Related Nuclear Structures," ASCE 4-98.
5. "Nuclear Reactors and Earthquakes," TID-7024, United States Atomic Energy Commission, August 1963.
6. Dong, R.G., "Effective Mass and Damping of Submerged Structures," UCRL-52342, April 1, 1978.
7. NUREG/CR-5912, "Review of the Technical Basis and Verification of Current Analysis Methods Used to Predict Seismic Response of Spent Fuel Storage Racks," October 1992.

FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Technical Report TN-Rack.0101 Impact:

AREVA Technical Report TN-Rack.0101, Section 2.2.1, Item 1 will be revised as described in the response and indicated on the enclosed markups.

AREVA Technical Report TN-Rack.0101, Sections 3.C.3 and 3.C.4, Tables 3C-18 through 20, and Figures 3C-57 through 61 will be revised as described in the response and indicated on the enclosed markup. In addition, a new Section 3C.3.10 will be added to document the whole pool multi-rack analysis with fuel assemblies explicitly modeled.

While Section 3C.3.8 is not being revised by this response, a copy of this section is included with the Technical Report TN-Rack.0101 Markups for the NRC's convenience.

Figure 03.08.04-19-1—Rack Resultant Acceleration: Fully Loaded Configuration

[

]

Figure 03.08.04-19-2—Rack Leg Maximum Resultant Sliding Displacement: Fully Loaded Configuration

Figure 03.08.04-19-3—Rack Leg Plate Maximum Uplift: Fully Loaded Configuration

Figure 03.08.04-19-4—Rack Leg Resultant Maximum Lateral Force: Fully Loaded Configuration

Figure 03.08.04-19-5—Rack Leg Maximum Vertical Force: Fully Loaded Configuration

[ ]

Figure 03.08.04-19-6—Rack Resultant Acceleration: Partially Loaded Configuration

Figure 03.08.04-19-7—Rack Leg Resultant Maximum Lateral Displacement: Partially Loaded Configuration

Figure 03.08.04-19-8—Rack Leg Plate Maximum Uplift: Partially Loaded Configuration

[

]

Figure 03.08.04-19-9—Rack Leg Resultant Maximum Lateral Force: Partially Loaded Configuration

Figure 03.08.04-19-10—Rack Leg Maximum Vertical Force: Partially Loaded Configuration

[

]

Technical Report TN-Rack.0101 Markups

2.2.1 Fuel Storage Rack Modules

1. The underwater fuel storage rack modules are free standing structures. The rack modules are not mechanically connected to the fuel pool floor or walls in the spent fuel pool.
2. *Deleted.*
3. The storage capacity of the underwater fuel storage racks provides a minimum of 382 accessible fuel storage spaces in Region 1 and 865 accessible fuel storage spaces in Region 2 of the spent fuel pool as shown in Figure 1-2 of Chapter 1.
4. The fuel storage rack modules will maintain the capability to remove and insert fuel assemblies for the design lifetime of the rack modules.
5. The fuel storage rack modules are designed to prevent physical damage to the stored fuel assemblies.
6. The fuel storage rack modules are capable of maintaining the stored fuel assemblies in a subcritical configuration.
7. The Region 1 and 2 rack modules have been designed so that they can be disassembled and removed from the new fuel storage vault area or spent fuel pool for servicing and replacement, if necessary, so that maintenance time and dose to personnel is ALARA.
8. Modules have been designed and fabricated so that periodic inspections of the rack components are not required.
9. The affect of fuel handling tools or other foreign objects that are vulnerable to being dropped into the pool were evaluated to ensure they cannot degrade the performance of the fuel storage racks.
10. The neutron absorber material used in the construction of the fuel storage rack modules provides a minimum *design* life of **[ ]**
11. Fuel storage rack modules have been designed to minimize pockets which could trap air bubbles.
12. Each fuel storage rack module includes **[ ]** support pads (feet) on the bottom. The support feet are vertically adjustable and sized so that each foot does not exert more than 2,175 psi (15 MPa) pressure on the fuel pool bottom liner for normal operating loads. Bearing pressures for the postulated free drop of a fuel assembly meet the requirements of ACI 349-97 [1] **[ ]** compressive strength concrete. The feet are circular with the edges rounded to avoid sharp edge loads that could jeopardize the fuel pool floor liner from any rack rotation during a seismic event.
13. The empty weight of the fuel storage rack modules is limited to 22 ton (20 tonne) including the lifting rig to meet the available crane capacity.

The vertical load applied to the pool liner by the leg plates is determined from the associated contact-forces. The maximum vertical force for the fully loaded configuration applied to the pool liner of **[ ]** occurred in Run1 (Friction=0.2 Set 1) for the **[ ]**. The maximum vertical force for the partial loading cases is **[ ]**.

3C.3.5.3.4 Rack-to-Rack and Rack-to-Pool Wall Contact Forces

RAI 03.08.04-19d

The results of the whole pool analyses show that the racks adjacent to the pool walls do not generate impact loads on the perimeter pool walls. Thus, there are no contact forces generated between the fuel racks and the concrete pool walls.

Similarly, (with the exception of time history set 1), rack-to-rack relative displacements are generally smaller than the gap separating them such that racks do not contact each other and, thus, do not generate rack-to-rack impact forces. The exception is for analysis case with input time history Set 1. (Analysis runs cases 1 and 2 with friction coefficients of 0.2 and 0.8, respectively). In Run1 (Friction=0.2 Set 1) and Run2 (Friction=0.8 Set 1) the 7x10 group 120 rack and adjacent 7x8 Group 130 rack contact the adjacent 9x10 group 20 rack and 9x8 Group 80 racks. The maximum rack-to-rack contact force of 208,250 lbs (9.264×10^7 kg·cm/sec^2 or 9.264×10^5 N) occurred between the group 20 (9x10) and group 120 (7x10) racks during Run1. Similar behavior is obtained for the partial pool cases; where the 7x10 group 120 and the 7x8 rack group 130 contact the adjacent 9x10 group 20 and the 9x8 group 80 racks, respectively. However, the maximum contact force of 205,840 lbs (9.156×10^7 kg·cm/sec^2 or 9.156×10^5 N) is smaller than in the full loaded case.

3C.3.5.3.5 Minimum Factor of Safety Against Rack Tipping-Over

The seismic stability response of the racks documented in this report is based on dynamic time history analyses with multiple time histories. These multiple analyses include fully loaded pool and partially loaded pool cases with full/partial/empty racks have shown no tendency to tipping of the racks and, therefore, there is a reasonable confidence of an adequate margin of safety against tipping. Nevertheless, in order to demonstrate a minimum factor of safety of **[ ]** against tipping in the SRP [6], an additional whole pool analysis is performed. The input acceleration time histories for each of the three orthogonal directions are increased by a factor of **[ ]**. In addition, based on observations from the production analyses the direction of the time history in the Z-direction (North-South) is reversed in order to maximize the tipping response of those racks that experienced the largest tipping in the fully loaded rack configuration analysis.

The results show that the racks remain stable and do not tip for the increased accelerations. The maximum tipping angle is estimated at **[ ]** degrees for the **[ ]**. This is significantly below the angle of **[ ]** degrees required to cause overturning of the rack. Thus, a minimum factor of safety of **[ ]** against tip-over has been demonstrated.

3C.3.6.2 Fuel Assembly Grid Forces

The maximum force for each compression only spring element representing the contact stiffness between the grid spacer and [ ] tube is retrieved from the LS-DYNA DEFORCE file for the bounding analysis case. The maximum resultant force is [ ]

RAI 03.08.04-19c

3C.3.6.3 [ ]

[

]

B. Tube Stresses due to Fuel Assembly Localized Impact Force

RAI 03.08.04-19c

The maximum force exerted by the fuel assemblies' on the [ ] tube is [ ] Conservatively, [ ] is applied to the [ ] tube at all the fuel grid spacers using the ANSYS finite element model described above. The maximum membrane and membrane plus bending stresses in the [ ] tube are calculated to be [ ] and [ ] respectively.

C Tube Stresses due to Tube Overall Bending

The maximum overall bending of the [ ] tube during a seismic event is taken from the detail seismic stress run. The maximum stress in the [ ] tube is calculated due to these deflections superimposed on to the tube. The maximum membrane and membrane plus bending stresses in the [ ] tube due to overall tube bending are calculated to be [ ] and [ ] respectively.

D. Maximum Stress at [ ] Tube

The maximum local impact and overall bending stresses do not occur at the same time or location; therefore only the membrane plus bending stress are added at each nodal location to get the total tube stress. The maximum membrane and membrane plus bending stresses are [ ] and [ ] respectively. These stresses are less than the Level D code allowable for membrane stress of $0.7S_u$ (19,460 psi) and S_u for membrane plus bending stress (27,800 psi).

No change, this page included for NRC information only.

3C.3.8 Seismic Analysis of Region 1 [ ] Rack

This section describes the analysis performed for the Region 1 [ ] rack. A detailed model of the Region 1 [ ] rack, as shown in Figure 3C-41, was developed using a similar approach to that described in Section 3C.3.3.1 for the representative rack with the exception that all six feet are included instead of the bounding four feet configuration used for the rack model described in Section 3C.3.3.1. In addition to the rack design features described in Section 3C.3.3.1, the Region 1 rack model includes [

]

The modeling parameters and analysis procedures used are the same as those described for the whole pool model analysis in Section 3C.3.5. However, for purposes of evaluating the hydrodynamic coupling effects of the fuel assemblies rattling inside the tube cells, a detailed model of the rack with the fuel assemblies explicitly incorporated into each [ ] tube cell is used in the fluid structure interaction analysis using a single rack pool model, as shown in Figure 3C-42. The fuel assemblies are modeled using the same beam stiffness and mass properties as in the previous detailed stress analysis model. However, for computational efficiency, the contact springs and dashpots at the discrete spacer grid locations are not modeled. Instead continuous contact of the fuel assembly with the [ ] tubes along the length of the assembly is specified. For contact purposes the fuel assembly contacting surface consists of a circular beam having an effective diameter that is benchmarked to produce tube cell stresses that are approximately the same as those produced with the spring and dashpot fuel assembly model. The water in the flux trap gap and inside the tube cells is conservatively modeled as added density to the surrounding parts of the rack and the fuel assembly, respectively. The rack model is set up in the pool in such a way as to model the rack to wall gaps on two sides of the rack and the rack-to-rack gaps on the remaining two sides (simulating a corner rack). The analysis is performed for the bounding case based on the analysis in Section 3C.3.5.3 using the bounding acceleration time history and coefficient of friction case (Set 1 and 0.8).

The results of the seismic fluid structure interaction analysis consist of maximum accelerations and stresses for the various rack frame components and [ ] tubes. Maximum accelerations in the horizontal directions are very similar to the multi-rack analysis results in Section 3C.3.5.3 [ ] for single rack model versus [ ] for multi-rack model along short rack direction and [ ] for single rack versus [ ] for multi-rack model along long rack direction). As expected the vertical rack accelerations are lower due to the incorporation of all six feet in the analysis model [ ] for the single rack model versus [ ] for the multi rack model). Tube stresses are evaluated for global and local effects to Subsection NF stress criteria. Maximum stresses of the stainless steel rack frame structural components and the comparison with ASME Level D allowable stress intensities are shown in Table 3C-14. As shown, rack frame stresses meet ASME Level D stress limits. Maximum primary stresses on the [ ] tubes are on the order of [ ] which is below the primary maximum stress intensity allowable of

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[ ] The [ ] tubes show localized stresses due to impacts from the fuel assemblies. These stresses are self-limiting (due to instantaneous load reversals) and incremental to the global inertial stresses and are satisfied by localized yielding of the tube in the area of the impacts. Per Subsection NF these localized stresses are not required to be evaluated against the Code primary stress limits. These stresses are below the ultimate strength of the material and, as such, the localized yielding will not lead to failure.

The results of the seismic fluid structure interaction analysis consist of the maximum stresses for the various rack frame components and [ ] tubes that are evaluated for global and local effects to Subsection NF ASME Code stress criteria. Maximum stresses of the stainless steel rack frame structural components and the comparison with ASME Level D allowable stress intensities are shown in Table 3C-14. As shown, rack frame stresses meet ASME Level D stress limits. The [ ] tubes show localized stresses due to impacts from the fuel assemblies. However, the maximum primary stresses are on the order of [ ] which is below the primary maximum stress intensity allowable of [ ]

In addition maximum lateral deformations of the [ ] tubes are obtained in order to assess the flux trap gap configuration during and after the seismic accident event. These evaluations show that the [ ] tubes geometry does not significantly vary from its initial undeformed geometry as the flux trap gap maximum opening is on the order of [ ] and gap closing is on the order of [ ]

3C.3.9 Effect of Erection Tolerances Evaluation

As described in Section 3C.3.1, the racks are placed contiguous to each other, and separated by a nominal ½-inch gap at the rack's baseplate level. The rack layout assumes rack-to-rack erection gap tolerances of plus or minus (±0.25 inch). This section documents the results of the study performed to evaluate the effect of the gap erection tolerances on the seismic analyses results.

For purposes of this study, the whole pool model is modified to represent a bounding layout configuration of the racks assuming worst-case gaps among the 17 racks in the whole pool model. The modified rack configuration is shown in Figure 3C-43. Figure 3C-43 shows rack-to-rack gaps at the baseplate level ranging from [ ] The gap configuration shown in Figure 3C-43 bounds the ±0.25-inch gap erection tolerance. The gaps between the perimeter racks and the pool walls are also adjusted to cover the ±0.25-inch gap erection tolerance.

The analysis is performed using the bounding time history set 1 and a coefficient of friction between the fuel racks and fuel pool floor of 0.2. Time history set 1 is the bounding time history because it has the largest energy content of the five sets of time histories and is the only time history that produces rack-to rack impacts. Using the lower bound friction coefficient of 0.2 is conservative because a lower friction coefficient would maximize sliding of the racks.

RAI 03.08.04-19

3C.3.10 Effect of Modeling the Fuel Assemblies in the Whole Pool Model (WPM)

As described in Section 3C.3.4 the fuel assemblies in the WPM are modeled as added density to the rack plates representing the tubes containing the fuel assemblies. In this approach, the fuel assembly mass is included in the added density calculation. The responses of the racks from the WPM are then input to the detailed rack model(s) wherein the fuel assemblies are modeled explicitly (see Section 3C.3.6).

This section describes the additional analysis performed to explicitly include the rattling effects of the fuel assemblies and water inside the rack cell in the WPM. The fuel assembly mass includes the entire mass corresponding to the net water volume inside the tube cells. This net water mass closely corresponds to the hydrodynamic added mass calculated for the fuel assembly using formulae in the literature [11]. This analysis is performed using the bounding time history run [ ] and the results are evaluated and compared to the same case where the fuel assemblies were modeled as added density to the rack parts modeling the rack tubes. The additional analysis is performed using [ ] is the bounding time history because it has the largest energy content of the five sets of time histories and is the only time history that produced rack-to-rack impacts. The selected case corresponds to the friction coefficient of 0.8 which produced the bounding rack stresses.

The fuel assemblies are explicitly incorporated into each and every cell of all the racks modeled in the whole pool multi-rack model. The fuel assemblies are modeled as two concentric but integral beams. The first beam is modeled with beam elements with mass and stiffness properties representative of the fuel assembly. The second beam is modeled with null beam elements and is used solely to set up the contact definitions required to properly represent the gap between the fuel assembly and the compartment cell. This gap, which is on the order of [ ], is modeled by specifying the contact thickness of both the contact null beam elements and the tube wall shell elements in the contact definition. The top and bottom nozzles are modeled with shell elements and both are tied to the fuel assembly beam elements. This modeling approach captures the rattling of the fuel assemblies inside the cells and the associated momentum imparted by the fuel assemblies onto the supporting racks. In addition, the individual racks in this whole pool multi-rack model are modified to incorporate their 6 support legs, in accordance with the actual rack design, instead of 4 legs used in the original whole pool analysis model.

The results are evaluated in terms of maximum accelerations, maximum sliding lateral displacements and vertical uplifts, maximum lateral and vertical leg forces, maximum rack-to-rack forces, and maximum rack stresses for the bounding rack.

***Maximum Accelerations:** Figure 3C-57 shows the comparison of maximum resultant accelerations. Maximum acceleration is [ ], compared with [ ] for the corresponding original case [ ]. These maximum resultant accelerations remain bounded by the maximums from previous analysis cases, as reported in Section 3C.3.5.3.1.*

RAI 03.08.04-19

***Maximum Lateral and Vertical Displacements**: Figure 3C-58 shows the comparison of maximum lateral displacements. The maximum value is [ ], compared with [ ] for the corresponding same original case. These maximums are lower than the original bounding value of [ ], as discussed in Section 3C.3.5.3.2. Figure 3C-59 shows the comparison of maximum vertical uplifts. The maximum vertical uplift value is [ ], compared with the corresponding original value of [ ] and also higher than the original bounding uplift of [ ], also discussed in Section 3C.3.5.3.2. As can be observed, although the maximum values are higher, when seen in the context of their absolute values the differences are relatively small [ ] for the lateral displacement and the vertical uplift, respectively) when compared to the corresponding original case, and less than [ ] when compared to the original bounding value.*

***Maximum Lateral and Vertical Leg Forces:** Figure 3C-60 shows the comparison of the lateral leg forces. The maximum lateral force is [ ] which is lower than the corresponding original same case of [ ]. Furthermore, these values are also lower than the bounding maximum of [ ] from the previous seismic analyses runs, as reported in Section 3C.3.5.3.3. Figure 3C-61 shows the comparison of the vertical leg forces. The maximum vertical force is [ ] which is higher than the corresponding original same case of [ ] and also higher than the original bounding load of [ ], as reported in Section 3C.3.5.3.3. Therefore, additional evaluations of the rack legs are performed for the increased seismic load and documented in Section 3C.3.6.4.*

***Rack-to-Rack and Rack-to-Pool Wall Contact Forces:** As discussed above, the maximum resultant lateral sliding displacement is [ ]. This is less than the smallest nominal rack-to-wall gap of [ ] (See Chapter 1 Figure 1-2). Therefore, there are no rack-to-pool wall contacts and hence, no rack-to-pool wall contact forces are generated. Contacts forces are generated due to rack 7x10 G120 contacting rack 9x10 G20 and adjacent rack 7x8 G130 contacting rack 9x8 G80. These rack-to-rack contacts are similar to those in the original case, as discussed in Section 3C.3.5.3.4. Three additional rack-to-rack contacts were observed in this additional analysis: rack 9x10 G20 contacts rack 10x8 G50; the adjacent rack 9x8 G80 contacts rack 10x8 G60; and rack 7x8 G140 contacts rack 9x8 G90. The largest contact forces are on the order of [ ]. These maximum contact forces are larger than the maximum of [ ], reported in Section 3C.3.5.3.4. The impacts generating these contact forces are dynamic and instantaneous in nature and do not impose sustained loads onto the racks. Nevertheless, to ensure that any effect of the increased contact forces is evaluated, a detailed stress analysis of the bounding rack [ ] is performed, as described next.*

***Maximum Rack Stresses:** A detailed stress analysis of the bounding [ ] is performed to evaluate rack stresses using the same methodology as in the original detailed rack stress analyses (i.e., the nodal displacement time histories from the [ ] in the whole pool multi-rack model are input into the detailed model to calculate rack stresses. This [ ] rack was selected because this rack was shown to be the controlling rack based on the following set of criteria: (1) rack with high resultant acceleration; (2) rack with largest mass,* *and hence, the largest inertial loading [ ]; and (3) rack that experienced rack-to-rack impacts [ ]. As seen from Figure 3C-57, rack [ ] is the rack that experienced the highest acceleration [ ]. Rack 9x10 has the largest mass (see Table 3C-8), and rack [ ] is one of the racks with the highest rack-to-rack impact forces. Therefore, rack [ ] meets the above stated criteria.*

Table 3C-18 summarizes the stress results of the structural components of the 9x10 G20 rack. The results in Table 3C-18 show that the rack stresses are within the allowable maximum stress intensity with a minimum margin of safety of [ ].

Table 3C-19 shows a comparison of the resulting rack stresses from this analysis to the maximums from the original evaluations, as summarized in Section 3C.3.6.1. Table 3C-19 shows that the rack structural components stresses are within [ ] of the previous results and only exceeds the previous results by a maximum of [ ] for the baseplate component. The minimum margin of safety of [ ] shown in Table 3C-18 incorporates this stress increase.

Similarly, the relative change in maximum aluminum tube stresses for the controlling [ ] between the case where the fuel assemblies are explicitly modeled in the whole pool analysis and the case where the fuel assemblies are modeled as added density to the rack cells is found to be about [ ]. The controlling maximum stress intensity for the aluminum tubes reported in Section 3C.3.6.3 is [ ] and the corresponding stress intensity allowable is [ ]. The scaled up stress is [ ]. Therefore, the existing margin is sufficient to accommodate this small stress increase.

Assessment of Conservatism in the Reported WPM Analysis Results

The reported whole pool model results are based on maximum values of each response parameter (accelerations, lateral displacements, vertical uplifts, lateral and vertical forces, rack-to-rack forces, and rack stresses) taken from 10 baseline time history analysis cases (5 TH sets times 2 coefficients of friction). The conservatism of this approach can be easily quantified since the original baseline results were performed using multiple time history analyses. Per the Standard Review Plan, Section 3.7.2 Section 2-C, the average responses generated from the multiple time history analyses may be used for design. Table 3C-20 below summarizes the margins available based on the multiple time history analyses (Baseline run cases 1 to 10).

From Table 3C-20, it can be seen that there is substantial margin in the results reported in Section 3C.3.5.3. The average-to-maximum ratios shown in Table 3C-20 can be applied to demonstrate that the original baseline results remain bounding. For example, as reported above, the maximum vertical force in the rack legs is [ ] in the corresponding original baseline case. A [ ] credited, resulting in a revised force of [ ] to demonstrate that the original force of [ ] remains bounding.

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