NRC APR 1400 Fuel Rack Meeting Action Items - March 9, 2017

Item 1 - Verify that the final fuel report supports the fuel properties that were used.

a. Change reference for fuel properties in Section 3.4.4 away from Ref. 22/23 and verify no other uses of Ref. 22/23
b. Refer to fuel letter from KNF instead
c. Notify KNF of need to inform Doosan of any changes affecting TeR.
d. Verify that when revision issued that it is consistent with rack assumptions

KHNP/Doosan Response

Final FA properties of EOL condition were revised by KNF memo dated on March 27, 2017. This memo will be added as Reference 33 in TeR (APR1400-H-N-NR-14012-P, Rev.3) as follows:

"33. KEPCO Nuclear Fuel Company, Memo No. MFD/HS-170001M, APR1400 NRC DC(II) PLUS7 FA Material Properties, March 27, 2017"

EOL data from the FA (see Table 3-3) and the analysis results (Table 3-6 through 3-8, Table 3-11; refer to Attachment #1) based on the EOL condition will be reflected in the TeR (APR1400-H-N-NR-14012-P, Rev.3).

Table 3-3 Data for Fuel Assembly

Parameter		Data (*)
Weight of Fuel Assembly, kN (lbf)		6.27 (1,408.6)
Grid width of Fuel Assembly, mm (in)		206.45 (8.128)
Max. Fuel Rod Length between Spacer Grid, mm (in)		359.4 (14.148)
Mass of Fuel Rod, kg/m (lbm/in)		0.61 (0.034)
Outer Diameter of Fuel Rod, mm (in)		9.5 (0.374)
Inner Diameter of Fuel Rod, mm (in)		8.36 (0.329)
Clad Thickness, mm (in)		0.571 (0.0225)
Area Moment of Inertia of Fuel Rod Clad, mm^4 (in^4)		160.4 (3.853E-4)
Young's Modulus of Fuel Rod Clad, MPa (psi) at 93.3 ^oC (200 ^oF)		93,355 (13.5E+06)
Yield Strength of Fuel Rod Clad, MPa (psi) at 93.3 ^oC (200 ^oF)		540.3 (78,365)
One-sided Grid Stiffness, kN/m (lbf/in) at 93.3 ^oC (200 ^oF)	BOL	3,324 (18,982)
	EOL	4,321 (24,677)
One-sided Grid Crushing Strength, kN (lbf) at 93.3 ^oC (200 ^oF)	BOL	31.6 (7,107)
	EOL	31.3 (7,045)
Fuel Assembly Flexural Rigidity (EI), m^2-kN (in^2-lbf) at 93.3 ^oC (200 ^oF)	BOL	44.05 (1.535E+07)
	EOL	20.22 (7.047E+06)
Total Grid Number, ea		11

(*) All of the dimensions are nominal values.

NRC APR 1400 Fuel Rack Meeting Action Items - March 9, 2017

(1) The interference between the grid cell and fuel rod has a large impact on the fuel assembly flexural rigidity due to all of the 236 fuel rods (per fuel assembly) that are inserted into the grid cells. The fuel assembly grid cell supports the fuel rod at beginning of life (BOL) because the cell has an interference with a fuel rod. However, the grid cells do not support fuel rods at end of life (EOL) because the cells have gaps with the fuel rods at EOL due to irradiation. Therefore, the fuel assembly flexural rigidity at EOL is reduced more than 50 % from the fuel assembly flexural rigidity at BOL due to this gap.

(2) Reference 17 will be updated to add the revised EOL properties.

(3) The new EOL EI affects the sensitivity analysis performed for Run Number 33 as follows (Note: Rev. 2 data will be removed from Rev. 3 version of TeR):

Table 3-6 Displacement of Racks for All Simulations

TeR	Run Number	Top of Rack (in)		Reduction in Gap between Adjacent Racks (in)*				Displacement of Pedestal Relative to Pool Floor (in)		of Friction Coefficient
				Region I		Region II				
		E-W	N-S	E-W	N-S	E-W	N-S	E-W	N-S	
Rev.3	**33**	**0.292**	**0.308**	**0.165**	**0.330**	**0.176**	**0.198**	**1.236**	**0.816**	**0.8**
Rev.2	33	0.288	0.331	0.157	0.339	0.176	0.213	1.573	0.982	0.8

Table 3-7 Maximum Pedestal Loads of Each Simulation

TeR	Rack	Run No.	Load on Single Pedestal (lbf)				Coefficient of Friction
			Horizontal			Vertical	
			E-W	N-S	Combined		
Rev.3	**Region I**	**33**	**113,000**	**92,100**	**145,779**	**158,000**	**0.8**
	Region II	**33**	**103,000**	**91,700**	**137,905**	**166,000**	
Rev.2	Region I	33	92,600	90,200	129,270	156,000	0.8
	Region II	33	101,000	87,400	133,566	166,000	

Table 3-8 Maximum Impact Loads of Each Simulation

TeR	Rack	Run No.	Rack-to-Rack Baseplate Impact Load (lbf)	Fuel-to-Cell Wall Impact Load per Cell (lbf)			Combined Fuel Grid Impact Load (lbf)	Coefficient of Friction
				Horizontal		Vertical		
				E-W	N-S			
Rev.3	**Region I**	**33**	**259000**	**20,625**	**16,563**	**7,813**	**3,366**	**0.8**
	Region II	**33**	**175,000**	**20,313**	**15,281**	**9,607**	**3,248**	
Rev.2	Region I	33	295000	16,563	13,422	8,396	2,986	0.8
	Region II	33	248,000	19,375	15,938	9,750	3,089	

Used EOL Data for Fuel Assembly
(Refer to Table 3-3)

TeR	One-side Grid Stiffness @ 200^{o}F (lbf/in)	One-side Grid Crushing Strength @ 200^{o}F (lbf)	Flexural Rigidity (EI) @ 200^{o}F (in^{2}-lbf)
Rev.3	**24,677**	**7,045**	**7.047E+06**
Rev.2	17,199	5,567	4.31E+06

Item 2 - Clarify selection methodology for choosing and combining maximum design loads used in the stress evaluation (margins).

<u>KHNP/Doosan Response</u>

The maximum horizontal and vertical loads generated on the support pedestal using the applied seismic loads are summarized in Table B3 of Reference 17. These loads are used in the structural integrity evaluation of the support pedestal and rack. The dynamic simulations of the racks give results for the vertical and two horizontal forces (i.e., E-W and N-S directions) throughout the transient. From those values, the maximum axial force of the vertical direction and the maximum shear forces of the two horizontal directions per pedestal are determined at any time step.

The resultant shear force is conservatively calculated by combining the maximum horizontal loads on a single pedestal (see Table B6 of Appendix B - Reference 17) using the square root of the sum of the squares (SRSS) method.

(*) Reference 17: Doosan, “Structural and Seismic Analysis Report for New and Spent Fuel Storage Racks,” N14014-224CN-0001, Rev.2, December 2016 (Doosan Proprietary)

The maximum two horizontal forces (i.e., E-W and N-S directions) in Table B3 of Reference 17 are considered for design using the square root of the squares (SRSS) method as shown in detailed calculation (e.g. Page F41 for Region I and Page F50 for Region II of Reference 17). The shear stress on rack is conservatively calculated based on the maximum forces of each run.

Item 3 - Revise Table 4-1 to include impact velocities for both Region I and Region II for the drop oriented away from the pedestal, and revise associated text to explain why those velocities are different.

Correct typographical error in Table 4-1.

KHNP/Doosan Response

Table 4-1 of the TeR (APR1400-H-N-NR-14012-P) will be revised to include impact velocities for both Region I and Region II for the drop oriented away from the pedestal. The associated text will be revised to explain why those velocities are different.

Section 4.3.2 of the TeR will be revised to include the following paragraph.

““For deep drops over a pedestal, impact velocities are the same for both regions. For deep drops away from a pedestal, ~~different drag conditions cause the impact velocity for Region I SFSRs to be greater than that of Region II~~ the impact velocities for Region I and Region II SFSRs are calculated based on the inner dimension of the damaged fuel canister cells and that of other cells, respectively. This causes different drag conditions in the Region I and Region II SFSRs. Therefore, the impact velocity for Region I SFSRs is greater than that of Region II.”

The straight deep drop (over a pedestal) velocity was corrected in Table 4-1.

.Table 4-1 Impact Evaluation Data

Rack	Cases		Drop Weight(*), kN (lbf)	Drop Height, m (in)	Impact Velocity, m/sec (in/sec)
NFSR	Straight Deep Drop (Away from Pedestal)		10.8 (2,425)	5.18 (203.9)	10.1 (396.8)
SFSR	Straight Shallow Drop		10.8 (2,425)	0.61 (24.0)	3.14 (123.6)
			2.1 (473)	4.98 (196.0)	7.15 (281.3)
	Straight Deep Drop (Away from Pedestal)	Region I	10.8 (2,425)	5.2 (204.7)	8.22 (323.5)
		Region II			7.36 (289.6)
	Straight Deep Drop (Over a Pedestal)		10.8 (2,425)	5.2 (204.7)	3.93 (154.9)

Item 4 - Address benchmarking code comparison agreement characterization

KHNP/Doosan Response

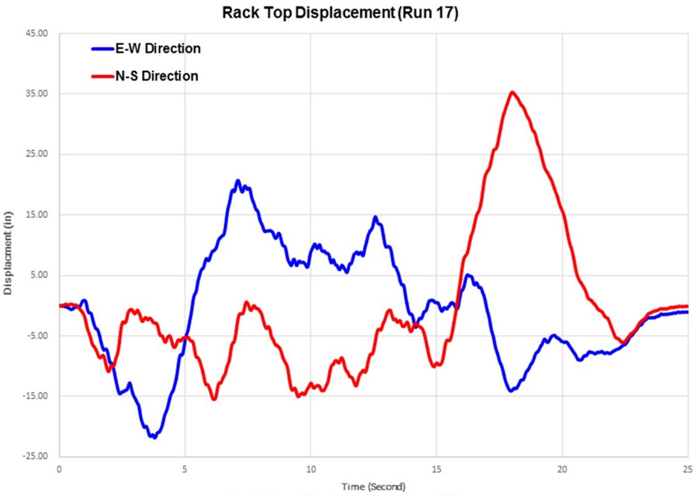
The last paragraph of section 3.5.1 of TeR (APR1400-H-N-NR-14012-P) will be revised as follows:

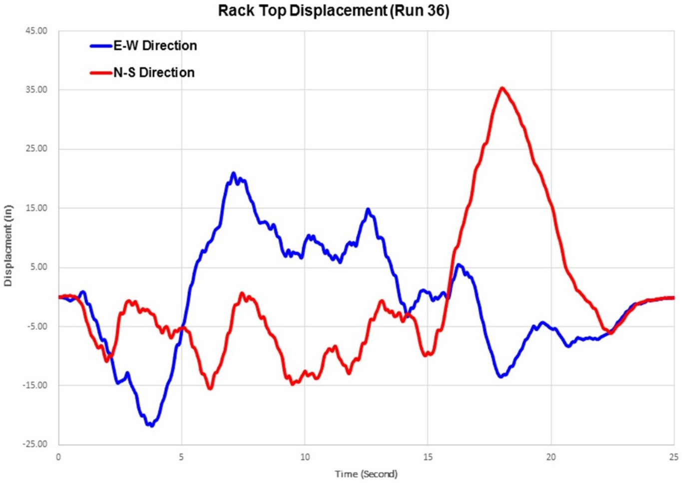
To further validate the use of ANSYS for APR1400 fuel rack seismic analysis, a single SFSR was analyzed with both ANSYS and LS-DYNA for five different sets of acceleration time histories. ANSYS is an implicit finite element code used for structural analysis with the capability to perform both static and dynamic simulations, while LS-DYNA is an explicit finite element code used for transient analysis. ~~The results showed good agreement between ANSYS and LS-DYNA, thereby providing confidence that both codes correctly solve the equations of motion and produce reasonable results.~~ The results showed reasonable agreement, considering the highly non-linear nature of the response of the free-standing racks to a seismic base excitation. Maximum forces for design purposes were comparable between the two analyses.

Item 5 - Provide displacement plots of one of the racks to compare results between time steps for the time step sensitivity

KHNP/Doosan Response

Please refer to the following figures for run #17 and #36.





a. Revise discussion of time step convergence in 3.7.4.6.

KHNP/Doosan Response

KHNP/Doosan agrees to include the above figures in Revision 3 of the report.

According to subsection III.2.B of SRP 3.9.1 Rev.3, satisfactory agreement of computer code and test solutions, usually within a +-5% error band, verifies the quality and adequacy of the computer programs for the functions for which they were designed.

Subsection 3.7.4.6 of TeR (APR1400-H-N-NR-14012-P) will be revised as follows:

Comparison of a run at one half the fixed time step used for all other runs showed small changes in calculated results comparable to the run to run variation with the different time histories.
Small differences, as opposed to identical results, are expected because the time step used affects where in each time history the acceleration is taken and how long it is applied. The 5% convergence value for dynamic simulation is applied to calculate the force and displacement quantities of interest.

Item 6 - Provide reference for acceleration used on page 41.

a. Decide whether to include acceleration value or source reference in TeR

KHNP/Doosan Response

Section 3.7.2.2 of TeR (APR1400-H-N-NR-14012-P) will be revised to include an acceleration value and source reference as follows:

$q = a \times W_{fuel}$

Where,

a = Maximum lateral acceleration in g's (= 22.8 g) per section 7.2 of Reference 17, and
W_{fuel} = Fuel assembly rod mass per unit length (0.61 kg/m)

b. Provide roadmap for calculation of the acceleration

i. Determine force at each node, use node's mass to find acceleration

KHNP/Doosan Response

b. KHNP/Doosan added numerical values of the acceleration based on force/mass on the following table.

- East-West Direction (Run 18) of Table 3-8

Node No.	Location	Time (Sec)	Fuel-to-Cell Wall Impact Load per Cell (lbf)	Grid Distribution (ea)	FA Mass Distribution on Nodes (lbf)	Grid Acceleration (g)
14	Bottom	4.01	0	1.375	176.1	0.0
15	(1/4)H		6,328	2.75	352.2	6.5
16	(1/2)H		7,641	2.75	352.2	7.9
17	(3/4)H		6,500	2.75	352.2	6.7
18	Top		3,594	1.375	176.1	**14.8**
Sum	-		**24,063**	**11**	**1408.6**	**Max. 14.8**

- North-South Direction (Run 31) of Table 3-8

Node No.	Location	Time (Sec)	Fuel-to-Cell Wall Impact Load per Cell (lbf)	Grid Distribution (ea)	FA Mass Distribution on Nodes (lbf)	Grid Acceleration (g)
14	Bottom	15.57	0	1.375	176.1	0.0
15	(1/4)H		7,291	2.75	352.2	7.5
16	(1/2)H		5,542	2.75	352.2	5.7
17	(3/4)H		4,896	2.75	352.2	5.1
18	Top		3,521	1.375	176.1	14.5
Sum	-		**21,250**	**11**	**1408.6**	**Max. 14.5**

Combined Maximum g-load = $\sqrt{14.8^2 + 14.5^2} = 20.7$g

c. How acceleration is input into cladding stress calculation to provide the results in Table 3-8

KHNP/Doosan Response

The bounding fuel-to-cell wall impact, at any level in the rack, for all run is less than the maximum fuel-to-cell wall impact load per cell (F) which is calculated by combination the maximum fuel-to-cell wall impact loads per cell of E-W and N-S direction using the SRSS method in the all run cases. The fuel mass acceleration is used conservatively to calculate a load uniformly distributed over a single fuel rod modeled as a beam simply support by the spacer grids.
The difference between “bounding” vs. “maximum” is as follows:
The bounding impact load means a combined load of the maximum fuel-to-cell wall impact loads per cell of E-W and N-S direction at the same run. The maximum fuel-to-cell wall impact load is calculated by combining the maximum fuel-to-cell wall impact loads per cell of E-W and N-S direction using the SRSS method in the all run cases at any time step for conservatism.

KHNP/Doosan added numerical values of the acceleration based on force/mass on the following table.

- East-West Direction (Run 18) of Table 3-8

Node No.	Location	Time (Sec)	Fuel-to-Cell Wall Impact Load per Cell (lbf)	Grid Distribution (ea)	FA Mass Distribution on Nodes (lbf)	Grid Acceleration (g)
14	Bottom	4.01	0	1.375	176.1	
15	(1/4)H		6,328	2.75	352.2	
16	(1/2)H		7,641	2.75	352.2	
17	(3/4)H		6,500	2.75	352.2	
18	Top		3,594	1.375	176.1	
Sum			**24,063**	**11**	**1408.6**	**17.1**

24,063/1408.6 = 17.1g

- North-South Direction (Run 31) of Table 3-8

Node No.	Location	Time (Sec)	Fuel-to-Cell Wall Impact Load per Cell (lbf)	Grid Distribution (ea)	FA Mass Distribution on Nodes (lbf)	Grid Acceleration (g)
14	Bottom	15.57	0	1.375	176.1	
15	(1/4)H		7,291	2.75	352.2	
16	(1/2)H		5,542	2.75	352.2	
17	(3/4)H		4,896	2.75	352.2	
18	Top		3,521	1.375	176.1	
Sum			**21,250**	**11**	**1408.6**	**15.1**

21,250/1408.6 = 15.1g

Combined Maximum g-load = $\sqrt{17.1^2 + 15.1^2} = 22.8$g

Item 7 - Clarify statement regarding expectations in Section 3.7.4.5 with respect to response of empty fuel racks vs. full fuel racks.

<u>KHNP/Doosan Response</u>

Subsection 3.7.4.5 of TeR (APR1400-H-N-NR-14012-P) will be revised as follows:

The free standing SFSRs do slide and different fuel loading arrangements were considered, as shown in Table 3-5. Most runs used fully loaded racks. Run 34 in Table 3-5 evaluates the all racks being empty. Run 35 in Table 3-5 evaluates the one quarter full rack/ two half full racks loaded (see Figure 3-4). ~~The results these runs were as would be expected in comparison with those done with all racks fully loaded.~~ The results showed that the displacements of empty fuel racks were less than those of fully loaded racks.

Item 8 - Provide clarification on appropriate structural frequencies and associated damping ranges.

A. Justify frequencies used for NFSR: 20-100 Hz
B. If cannot justify, perform sensitivity run with damping lower value set at 2 Hz

KHNP/Doosan Response

Structural frequencies and associated damping ranges for the NFSR will be revised in the TeR (APR1400-H-N-NR-14012-P, Rev.3). The frequency range from 2 Hz to 85 Hz is applied to the NFSR to cover the natural frequencies of the fuel assembly and the rack itself in air.

The analysis results (Tables 3-6 through 3-12, and Tables 3-14 through 3-15) for the NFSR are revised as shown in Attachment #1.

Item 9 - Explain calculations and trace origins of values used for lowest margin results:

a. Cell wall buckling

KHNP/Doosan Response

The cell wall buckling analysis is performed to evaluate the buckling capacity of the spent fuel storage rack cells at the base of the racks using the ANSYS program. The cell wall acts alone in compression for a length of about 130 mm (5.12 in) up to the point where the neutron absorbing material sheathing is attached. The sheathing provides additional strength against cell wall buckling. Therefore, the buckling analysis is considered on the lower 130 mm (5.12 in) of the cell wall.

The analysis is evaluated for Region II cells because the maximum stress factor on Region I racks is less than the maximum stress factor (i.e. FACT 2) for the region II racks as shown in Table 3-9 of the TeR.

A compressive force for cell wall buckling evaluation is calculated as follows:

$\sigma_{comp} = 1.2 \times 21400 \times FACT2 = 71.0$ MPa (10,298 psi)

Where,

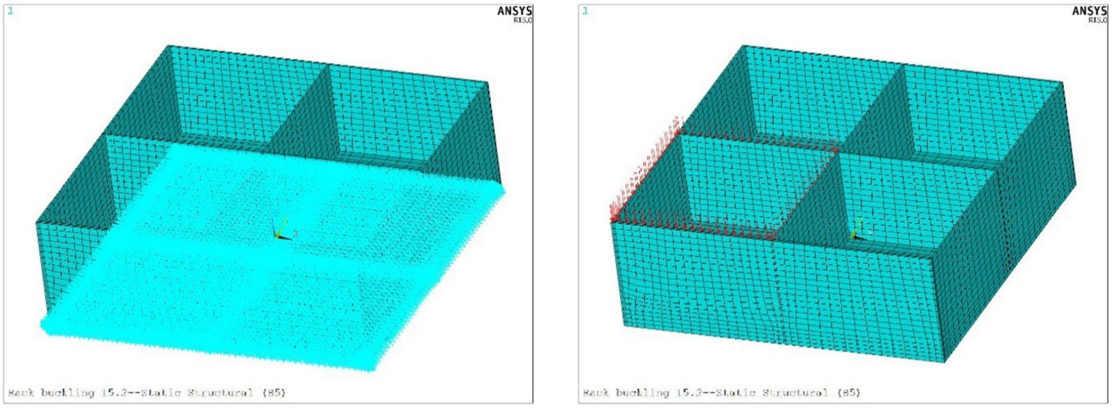
FACT2 = 0.401, the stress factor is taken from Table 3-9.

The above calculation is based on the maximum stress factor for the net vertical force on the gross cell cross-section. The vertical forces on the rack support pedestal reflect the weight of the rack plus the stored fuel assemblies during the seismic event. Since the stored fuel assemblies are supported by the rack baseplate, the actual compressive load on the rack cell structure is significantly less than the value determined by the results of dynamic simulations. It is appropriate to use a FACT2 value for cell wall buckling evaluation.

The critical elastic buckling load of cell wall is calculated by ANSYS eigenvalue analysis. Two by two cells of spent fuel storage rack are considered in the buckling analysis. The FE model reflects a reinforcement plate that is welded to outer side of the cells. The boundary condition and applied unit load (1 MPa) of FE mode is shown in Figure 1-1. A fixed boundary condition is applied on bottom surface of the FE model. Figure 1-2 depicts the results of buckling analysis.

The minimum value of load multiplier represents the critical elastic buckling pressure of fuel rack cell wall, which is 136.68 MPa (19,823 psi). Therefore, two-thirds of the critical buckling stress as the limit under Service Level D condition is calculated as 91.12 MPa (13,215 psi).

The ANSYS analysis demonstrates that the spent fuel storage rack cells remain in a stable configuration under the maximum seismic load without any gross yielding of the storage cell wall, which satisfies the ASME Code requirements for Level D conditions. Therefore, a buckling of the rack cell wall does not occur.



(a) Boundary Condition (b) Applied Load (1 MPa)

Figure 1-1. Boundary Condition and Applied Load of FE Model

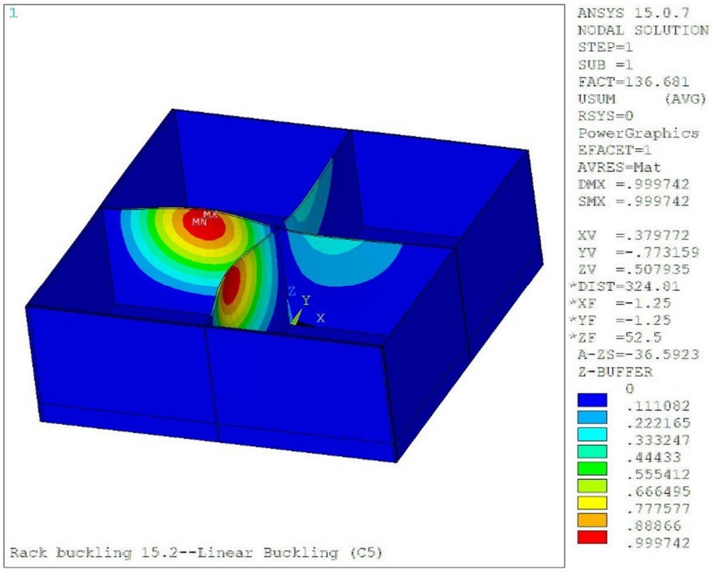
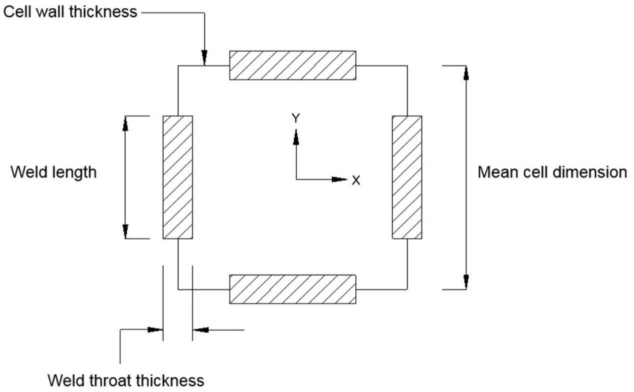


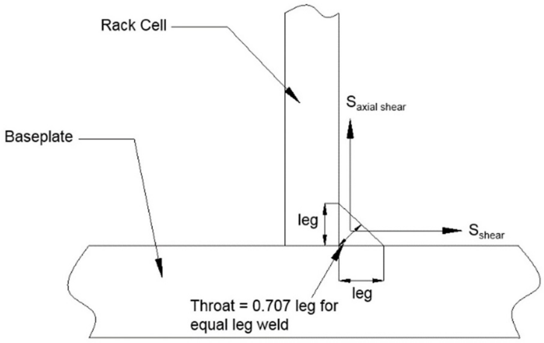
Figure 1-2. Results of Buckling Analysis

b. Base metal shear

KHNP/Doosan Response

Rack cell-to-baseplate is fillet weld with equal legs. Shear stress in a fillet weld is evaluated at the throat area that is a minimum area at the fillet weld. The throat thickness of a fillet weld having equal legs is obtained by multiplying the size of the leg by 0.707 as shown in the following figure.





The conversion factor (ratio) values are developed from consideration of the differences in material thickness and length versus weld throat dimension and length, as follows:

Ratio = [(220 + 2.5) x 2.5)] / (180 x 2.5 x 0.707) = 1.75 (for the SFSRs)

Where,

Inner cell dimension (220 mm (8.66 in)), Cell wall thickness (2.5 mm (0.098 in)),
Mean cell dimension (220 + 2.5 = 222.5 mm (8.758 in)), Weld length (180 mm (7.09 in)), and
Weld throat thickness (= 2.5 x 0.707 = 1.767 mm (0.069 in)) are used.

The highest predicted base metal shear stress is conservatively calculated based on the highest FACT2 (see Table 3-9 of TeR) for the rack cell region tension stress factor (axial shear stress on the weld) and FACT3 (see Table 3-9 of TeR) for the rack cell region shear stress factor (shear stress on the weld). The maximum stress factors used do not all occur at the same time instant and the shear stress factors are the maximum for all load conditions.

Therefore, the base metal shear stress is calculated as follows:

Sbase_axialshear = 0.707 x (FACT2) x Min.(2 x 0.6 x S_y or 0.7 x S_u) x Ratio
= 0.707 x (0.401) x Min.(2 x 0.6 x 147.5 or 0.7 x 455.7) x 1.75
= 87.8 MPa (12,734 psi)

Sbase_shear = 0.707 x (FACT3) x Min.(2 x 0.4 x S_y or 0.72 x S_y) x Ratio
= 0.707 x (0.097) x Min.(2 x 0.4 x 147.5 or 0.72 x 147.5) x 1.75
= 12.7 MPa (1,842 psi)

Sbase_metal_shear = $\sqrt{S_{axialshear}^2 + S_{shear}^2}$ = 88.7 MPa (12,865 psi)

The allowable for the Level D condition are the smaller of 2 times the corresponding allowable for the Level A condition and 0.72 x Sy, as discussed in subsection 3.2.2.3 of the TeR(APR1400-H-N-NR-14012-P). The calculated stress value of 88.7 MPa (12,865 psi) is less than the allowable base metal shear stress value of 106.2 MPa (15,408 psi).

c. Fuel spacer grid buckling

KHNP/Doosan Response

The critical buckling load of the fuel spacer grid is compared with the combined maximum fuel grid impact load of Table 3-8(see Attachment 1). Combined fuel grid impact load is calculated by SRSS method of horizontal fuel impact loads for the most highly loaded grid.

A safety factor for fuel spacer grid buckling of Table 3-11 is calculated as follows:

$$\frac{\text{One sided Grid Crushing Strength (from Table } 3-3)}{\text{Combined Maximum Fuel Grid Impact Load (from Table } 3-8)}$$

A safety factor of 1.57 is calculated based on combined maximum fuel grid impact load of BOL condition (from Run 5 of Table 3-8) and one-sided grid crushing strength of EOL condition (from Table 3-3).

Location	Category	Calculated Value	Allowable Limit	Safety Factor (-)
Fuel spacer grid	Buckling Load	19.9 kN (4,481 lbf)	31.3 kN (7,045)	1.57

KHNP/Doosan Response

(1) NFSR results in draft Rev. 3 Table 3-8 have been revised upward from Rev.2 Table 3-8 due to the decrease of applied structural damping (C). The Rayleigh damping for NFSR is revised in TeR (APR1400-H-N-NR-14012-P, Rev.3) and used to specify mass (M) and stiffness (K) proportional damping (C). The frequency range from 2 Hz to 85 Hz is newly applied to NFSR to cover natural frequencies of the fuel assembly and the rack itself in air. The structural damping decreases with the application of frequency range from 2 Hz to 85 Hz. The following table shows the Rayleigh damping coefficients, α (for mass) and β (for stiffness). The constants α and β are calculated in the range of the lowest and highest frequencies of interest in the dynamic analysis as specified on Section 5.3 (Reference 17 of TeR).

TeR	Frequency range (NFSR)	α (M)	β (K)
Rev.3	**2 ~ 85 Hz**	**0.9822**	**1.46×10^{-4}**
Rev.2	20 ~ 100 Hz	8.3766	1.06×10^{-4}

(2) The following tables summarize the details of the actual calculation, for the worst cases of NFSR and SFSR. The maximum combined fuel grid impact loads are calculated by SRSS method of horizontal (E-W and N-S) fuel impact loads on five nodes at each time. The horizontal loads calculated at five vertical nodes are not uniform, and a different number of grids share the loads. Therefore, the SRSS of the horizontal fuel-to-cell wall impact loads per cell does not yield the combined fuel grid impact load for a run.

- Maximum combined fuel grid impact load for NFSR

Run No.	Node No.	Location	Time (Sec)	Fuel Grid Impact Load per Node (lbf)		Grid Distribution (ea)	Fuel Grid Impact Load (lbf)		
				E-W	N-S		E-W[1]	N-S[1]	Combined Fuel Grid Impact Load[2]
5	14	Bottom of Rack	-	-	-	1.375	-	-	0
	15	(1/4)H	11.06	0	7,812	2.75	0	2,841	2,841
	16	(1/2)H	9.33	4,999	7,979	2.75	1,818	2,901	3,424
	17	(3/4)H	4.96	3,541	8,541	2.75	1,288	3,106	3,362
	18	Top of Rack	12.68	0	6,161	1.375	0	4,481	**4,481**

Notes: (1) Fuel Grid Impact Load per Node / Grid Distribution
(2) Combined Fuel Grid Impact Load = $\sqrt{(E\text{-}W)^2 + (N\text{-}S)^2}$

- Maximum combined fuel grid impact load for SFSR

Run No.	Node No.	Location	Time (Sec)	Fuel Grid Impact Load per Node (lbf)		Grid Distribution (ea)	Fuel Grid Impact Load (lbf)		
				E-W	N-S		E-W[(1)]	N-S[(1)]	Combined Fuel Grid Impact Load[(2)]
26	14	Bottom of Rack	-	-	-	1.375	-	-	0
	15	(1/4)H	12.04	7,288	3,743	2.75	2,650	1,361	2,979
	16	(1/2)H	6.97	7,313	4,493	2.75	2,659	1,634	3,121
	17	(3/4)H	11.62	8,670	0	2.75	3,153	0	3,153
	18	Top of Rack	9.23	3,510	3,956	1.375	2,553	2,877	**3,846**

Notes: (1) Fuel Grid Impact Load per Node / Grid Distribution

(2) Combined Fuel Grid Impact Load = $\sqrt{(E\text{-}W)^2 + (N\text{-}S)^2}$

Item 10 - Revise fuel assembly buoyancy equation

KHNP/Doosan Response

Typo on Section 3.1.2.6 on TeR (APR1400-H-N-NR-14012-P) will be corrected as follows:

Buoyant force acting on fuel assembly = $V_{FA} \times \gamma_{water}$

Where,

γ_{water} = Specific weight of fluid, 1000 kgf/m^3 (0.036 lbf/in^3)

Item 11 - Identify how vertical load impact is addressed in acceptance criteria for fuel stresses.

KHNP/Doosan Response

The vertical load impact of fuel assembly-to-baseplate is supported by fuel rod cladding and compared with the allowable stress limit (1.2 x S_y = 648.36 MPa (94,038 psi)) for the Level D condition as follows:

$$\sigma_{clad} = F_{impact} / A_{total\_clad} = 2{,}139 \text{ psi} < 94{,}038 \text{ psi ---O.K}$$

Where,

F_{impact} (Maximum fuel assembly-to-baseplate impact load in vertical direction)
= 55.7 kN (12,516 lbf) per Table 3-8, and
A_{total_clad} (Total area of fuel rod) = 0.0248 in^2 x 236 (Total fuel rod) = 5.85 in^2

Therefore, the calculated stress (σ_{clad}) by vertical impact load on FA does not exceed the allowable stress limit.

Item 12 - Characterize basis for interrelationship of results between rack regions (pg. 59)

KHNP/Doosan Response

The rack to rack baseplate impact loads between Region I and Region II.

- Values increase with increasing value of the rack weight (Region I)
- Values increase with increasing value of the rack-to-rack stiffness

Item 13 - Determine need to clarify relevance of area of leveling foot

KHNP/Doosan Response

In order to diffuse the pedestal loads, a 7” diameter of leveling foot is used for SFSR. In the straight deep drop accident over a pedestal, the resulting impact transmits a load of 471.6 kN (1.06E+05 lbf) to the concrete pool slab through the embedment plate under the pedestal of racks. The peak compressive stress due to this impact load on concrete pool slab is calculated as 11.6 MPa (1,688 psi), which is less than allowable stress limit of 16.4 MPa (2,375 psi). Therefore, the compressive stress on concrete due to dropping mass is less than the allowable stress limit.

Item 14 - Verify previous DCD changes are still applicable and submit DCD changes identified in Appendix A of TeR (to be submitted: 44, to be verified: 34, 47)

KHNP/Doosan Response

Please refer to DCD mark-up for the following RAIs (34, 36 & 44) as Attachments #2, #3 and #4. DCD mark-up for RAI No. 47 was submitted by KEPCO A/E.