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MFN 09-773, Revision 2

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Subject: **Revised Response (Revision 2) to Portion of NRC Request for Additional Information Letter No. 398 Related to ESBWR Design Certification Application – Fuel Racks – RAI Numbers 9.1-149 and 9.1-150**

The purpose of this letter is to submit the GE Hitachi Nuclear Energy (GEH) revised responses (Revision 2) to the U.S. Nuclear Regulatory Commission (NRC) Requests for Additional Information (RAIs) 9.1-149 and 9.1-150 sent by NRC Letter No. 398, Reference 1.

The GEH revised responses (Revision 2) to RAIs 9.1-149 and 9.1-150 are provided in Enclosure 1. Enclosure 2 contains the LTR markups associated with these revised responses. The purpose of this revision is solely to remove proprietary information markings from the markups provided in Enclosure 2. Since the submittal of the first revision of this response, as provided by Reference 2, GEH has determined that the markups contain no proprietary information.

If you have any questions or require additional information, please contact me.

Sincerely,

Peter M Yandow FOR

Richard E. Kingston
Vice President, ESBWR Licensing

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NRO

References:

1. MFN 09-768, Letter from U.S. Nuclear Regulatory Commission to Jerald G. Head, Request for Additional Information Letter No. 398 Related to ESBWR Design Certification Application, December 2, 2009

2. MFN 09-773 Revision 1, Revised Response (Revision 1) to Portion of NRC Request for Additional Information Letter No. 398 Related to ESBWR Design Certification Application – Fuel Racks – RAI Numbers 9.1-149 and 9.1-150, January 26, 2010

Enclosures:

1. Revised Response (Revision 2) to Portion of NRC Request for Additional Information Letter No. 398 Related to ESBWR Design Certification Application – Fuel Racks – RAI Numbers 9.1-149 and 9.1-150

2. Revised Response (Revision 2) to Portion of NRC Request for Additional Information Letter No. 398 Related to ESBWR Design Certification Application – Fuel Racks – RAI Numbers 9.1-149 and 9.1-150 – LTR Markups

cc:	AE Cubbage	USNRC (with enclosures)
	JG Head	GEH/Wilmington (with enclosures)
	DH Hinds	GEH/Wilmington (with enclosures)
	TL Enfinger	GEH/Wilmington (with enclosures)
	eDRF Section	0000-0110-4462 (response)
		0000-0114-9034 (markups)

Enclosure 1

MFN 09-773, Revision 2

Revised Response (Revision 2) to Portion of NRC Request for Additional Information Letter No. 398 Related to ESBWR Design Certification Application

Fuel Racks

RAI Numbers 9.1-149 and 9.1-150

NRC RAI 9.1-149

When the stress limits based on F-1332 of Appendix F to ASME B&PV Code, Section III, Division I are used for plate type supports, sizeable contribution from bending stress should be present in the plate in addition to the membrane stresses. Therefore, the stress limits per F-1332.2 for membrane plus bending are characterized as peak stresses (recognizing the effect of bending on stress distribution across the plate section) and are much higher than the membrane stress limits provided per F-1332.1.

While the applicant stated in Sections 1, 2 and 3 related to plate stress results that bending plate stresses are negligible, the allowable stresses for Service Level D were chosen from F-1332.2. The staff believes that if bending effect is negligible, then the plate stress state is controlled by the membrane stresses. Therefore, the stress allowable per F-1332.1 should apply. The staff requests that the applicant make appropriate corrections to the allowable stresses based on F-1332.1 if bending stress is determined insignificant.

GEH Response (Original)

In reviewing this issue, it was found that the information shown in NEDC-33373P was not fully explained with respect to the bending stresses. The statement "bending plate stresses are negligible," which applies only to specific locations (10 mm enveloping plates, 7 mm upper plates, and 20 mm base plate stiffeners), refers to local stress variations across the plate thickness, which are classified as secondary stresses and are not subject to Subsection NF or Appendix F ASME Code limits, i.e., for the service level D category only primary stresses need to be calculated per the criteria specified by the ASME Code. As defined in paragraph NF-3121.3, stresses located at local structural discontinuities are classified as secondary stresses, and high stresses resulting from local structural discontinuities redistribute as necessary to maintain the structural integrity of the fuel storage rack. An example of a secondary stress is bending stress at a gross structural discontinuity.

At these specific locations, the maximum calculated stresses at the middle of the plates represent the maximum primary local membrane plus bending stresses. For example, the stress at the middle of the rack lateral plates represents the primary bending stress across the rack section as a result of the bending moment at the rack body-to-base plate junction. Therefore, since primary bending stresses are included in the analysis results, it is appropriate to compare the results to the $P_m + P_b$ code allowable stress limit.

To clarify NEDC-33373P, the locations that contain the statement that bending plate stresses are negligible will be changed to the following:

"Bending stresses across the plate thickness are negligible and are classified as secondary stresses; however, other directions of the plate contain primary bending stresses that are included in the stress analysis results."

GEH Response (Revision 1 and Revision 2)

The original response is unchanged. The LTR markup pages are replaced in their entirety by this revised response.

DCD/LTR Impact (Revision 2)

No DCD changes will be made in response to this RAI.

LTR NEDO-33373 (formerly NEDC-33373P), Sections 1.5.4.3.1, 1.5.4.3.2, 1.5.4.3.3, 2.5.2.1, 2.5.2.2, 2.5.2.3, 3.5.2.1, 3.5.2.2, 3.5.2.3, 3.5.2.4 and 3.5.2.5 will be revised in response to this RAI as shown in the attached markup.

NRC RAI 9.1-150

Sections 2.5.4 and 3.5.4 provided analyses of fuels impacting the rack cells. These analyses first utilized simplified beam mass models to develop impact forces on the rack cells, and then applied these forces to detailed finite element models for the racks and performed plastic analyses to determine the stresses in the cell plates. The applicant referred to NF-1342.2 which the staff cannot locate in the Subsection NF. The staff requests that the applicant clarify the apparent incorrect reference. Further, the staff requests that the applicant identify applicable and specific ASME code requirements which were based for these plastic analyses.

GEH Response (Original)

In NEDC-33373P, Sections 2.5.4 and 3.5.4, there are references to NF-1341.2 of the ASME Boiler and Pressure Vessel Code. It appears it is these references that this RAI is referring to rather than references to NF-1342.2, as stated in the text of the RAI. In reviewing these references, it was found that these references were typographical errors and should have been to Appendix F, F-1341.2.

With regard to the applicable and specific ASME code requirements associated with the plastic analysis, ASME Section III, Subsection NF is applicable, and the non-mandatory Appendix F is applicable for Level D Service Limits; however, the fuel storage racks are not safety-related, and there is no regulatory requirement to meet these standards. In using Appendix F, several analytical methods are permitted, including plastic analysis. As stated above, the plastic analysis was performed in accordance with F-1341.2. This code paragraph is sub to F-1340, which is also applicable. Paragraph F-1340 states that the criteria is subject to the restrictions on methods of evaluation stated in F-1322. Paragraph F-1332 has several requirements that pertain to plastic analysis methods. For example, the most significant requirement is shown in F-1322.3, which contains material behavior requirements.

In Sections 2.5.4 and 3.5.4 of NEDC-33373P, it is explained that the appropriate plastic stress-strain material curves as specified in NUREG/CR-0841 have been used. Therefore, this ASME code requirement has been met. In the performance of the analysis, it was determined that the conservative temperature conditions imposed, which are not expected during actual plant operation, led to the need to do a plastic analysis. The stress results (206.8 and 180 N/mm^2 vs. the 436 N/mm^2 allowable) demonstrate that under these design conditions, the plastic deformation is local and very minimal. Considering that the stresses are local, the elastic stress limit of 292.8 N/mm has also been met. In conclusion, ASME code requirements have been met, and the use of plastic analysis methods is considered conservative for these applications.

GEH Response (Revision 1 and Revision 2)

In NEDC-33373P, Sections 2.5.4 and 3.5.4, there are references to NF-1341.2 of the ASME Boiler and Pressure Vessel Code. It appears it is these references that this RAI is referring to rather than references to NF-1342.2, as stated in the text of the RAI. In reviewing these references, it was found that these references were typographical errors and should have been to Appendix F, F-1341.2.

With regard to the applicable and specific ASME code requirements associated with the plastic analysis, ASME Section III, Subsection NF is applicable, and the non-mandatory Appendix F is applicable for Level D Service Limits. In using Appendix F, several analytical methods are permitted, including plastic analysis. As stated above, the plastic analysis was performed in accordance with F-1341.2. This code paragraph is sub to F-1340, which is also applicable. Paragraph F-1340 states that the criteria is subject to the restrictions on methods of evaluation stated in F-1322. Paragraph F-1332 has several requirements that pertain to plastic analysis methods. For example, the most significant requirement is shown in F-1322.3, which contains material behavior requirements.

In Sections 2.5.4 and 3.5.4 of NEDC-33373P, it is explained that the appropriate plastic stress-strain material curves as specified in NUREG/CR-0841 have been used.

Therefore, this ASME code requirement has been met. In the performance of the non-linear analysis of fuel rack loads, as discussed in NEDC-33373P, it was determined that the conservative temperature conditions imposed, which are not expected during actual plant operation, led to the need to do a plastic analysis. The stress results (206.8 and 180 N/mm^2 vs. the 436 N/mm^2 allowable) demonstrate that under these design conditions, the plastic deformation is local and doesn't lead to any global plastic deformation that would impact the function or performance of the fuel storage racks. Considering that the stresses are local, the elastic stress limit of 292.8 N/mm^2 has also been met. In conclusion, ASME code requirements have been met, and the use of plastic analysis methods is considered conservative for these applications.

The LTR markup pages are replaced in their entirety by this revised response.

DCD/LTR Impact (Revision 2)

No DCD changes will be made in response to this RAI.

LTR NEDO-33373 (formerly NEDC-33373P), Sections 2.5.4 and 3.5.4, will be revised in response to this RAI as shown in the attached markup.

Enclosure 2

MFN 09-773, Revision 2

Revised Response (Revision 2) to Portion of NRC Request for Additional Information Letter No. 398 Related to ESBWR Design Certification Application

Fuel Racks

RAI Numbers 9.1-149 and 9.1-150

LTR Markups

Table 1-8

Combined Effective Masses

Event	X direction		Y direction		Z direction	
	Mass (kg)	(%)	Mass (kg)	(%)	Mass (kg)	(%)
SSE	74837 (98.7%)		73356 (96.8%)		53388 (98.0%)	
LOCA	74838 (98.7%)		74174 (97.9%)		53413 (98.1%)	
SRVD	73818 (97.4%)		73047 (96.4%)		53429 (98.1%)	

1.5.4.2 Deformation Results

The maximum deformation obtained at the top of the FSR for the most unfavorable load combination (level D) is 2.0 mm for horizontal X-direction, 3.2 mm for horizontal Y-direction, and 0.9 mm for the vertical Z-direction (see Figures A-27, A-28 and A-29, respectively).

1.5.4.3 Plate Stress Results

The stress results obtained for the different load combinations are checked in the most critical sections of the different plates of the FSR.

1.5.4.3.1 10 mm Thick Enveloping Plate

The maximum stresses obtained for the 10 mm thick enveloping plate compared with the corresponding allowable stresses are presented in Table 1-9, where:

$S_Z \equiv$ Vertical direction (Z) membrane stress

$S_H \equiv$ Horizontal direction (X or Y) membrane stress

$S_{HZ} \equiv$ Shear stresses on the plane of the plate

Bending stresses across the plate thickness are negligible and are classified as secondary stresses; however, other directions of the plate contain primary bending stresses that are included in the stress analysis results.

1.5.4.3.2 7 mm Thick Upper Level Plates

The maximum stresses obtained for the 7 mm thick upper level plates compared with the corresponding allowable stresses are presented in table 1-11, where:

$S_Z \equiv$ Vertical direction (Z) membrane stress

$S_H \equiv$ Horizontal direction (X or Y) membrane stress

$S_{HZ} \equiv$ Shear stresses on the plane of the plate

Bending stresses across the plate thickness are negligible and are classified as secondary stresses; however, other directions of the plate contain primary bending stresses that are included in the stress analysis results.

Table 1-11

7 mm Thick Upper Level Plates Maximum Stress Results

Service Level	Calculated Stress (MPa)	Allowable Stress (MPa)
Level A Conditions	S_Z = 7.9 (Figure A-31)	201.1
	S_H = 3.6	201.1
	S_{HZ} = 1.1	80.4
Level D Conditions	S_Z = 17	292.8
	S_H = 42 (Figure A-32)	292.8
	S_{HZ} = 6.0	198.6

The 7 mm thick plates are welded with a 3 mm fillet weld 30 mm in length, in each corner connection between perpendicular plates.

The maximum stress on these welds due to the pull-up force of 17.79 kN (section 1.4.6.2) is obtained assuming that this force is transmitted through the four fillet welds of one cell. That is, S_{max} = 17790/(4x30x3) = 49.4 MPa <65.1 MPa.

The maximum vertical force in a corner between perpendicular plates for level D conditions is 9292 N. Therefore, the maximum stress on the fillet weld is:

$$S_{max} = 6223 \text{ x } 1.4142/(30\text{x}3) = 97.8 \text{ MPa} <198.6 \text{ MPa}.$$

1.5.4.3.3 20 mm Thick Base Plate Stiffener Plates

The maximum stresses obtained for the 20 mm thick base plate stiffener plates and welds compared with the corresponding allowable stresses are presented in Table 1-12, where:

$S_Z \equiv$ Vertical direction (Z) membrane stress

$S_H \equiv$ Horizontal direction (X or Y) membrane stress

$S_{HZ} \equiv$ Shear stresses on the plane of the plate

Bending stresses across the plate thickness are negligible and are classified as secondary stresses; however, other directions of the plate contain primary bending stresses that are included in the stress analysis results.

Table 1-12

20 mm Thick Base Plate Stiffener Plates Maximum Stress Results

Service Level and Weld Location	Calculated Stress (MPa)	Allowable Stress (MPa)
Level A Conditions	S_Z=13.9	201.1
	S_H=15.5	201.1
	S_{HZ}=5.6	80.4
Level D Conditions	(1) S_Z=69 (Figure A-33)	292.8
	S_H=46	292.8
	S_{HZ}=48	198.6
Welds (2) to base support plate. Near the corners (3 cells) 2x6 mm fillet weld (160–168)	S_{max}=57×(20/12)×(168/160) =100	198.6
Welds (2) to base support plate. Mid-plate, 2x6 mm fillet welds (100–336) 'maximum'	S_{max}=15.1×(20/12)×(336/100)=85	198.6

Notes:

2.5.1 Displacement Results

The maximum horizontal displacement obtained at the top of the FSR for the most unfavorable load combinations are 2.8 mm for the X-direction, and 3.8 mm for the Y-direction (see Figures C24 and C25, respectively, in Appendix C).

One half of the expansion due to thermal expansion (Section 2.4.6.3) is applied to each rack in opposing horizontal directions. If the abnormal pool temperature were to occur simultaneously with a seismic event, the resulting total displacement is calculated as:

$$3.8 \text{ mm} + 3.7 \text{ mm}/2 = 5.7 \text{ mm}$$

The minimum distance between adjacent FSR at the top level or between FSR and pool wall is 100 mm (ID 6). Therefore, no contact occurs between the FSR or between the FSR and the pool walls.

2.5.2 Plate Stress Results

The stress results obtained for the different load combinations are checked in the most critical sections of the different plates of the FSR. Figures C26 to C31 in Appendix C show the results.

2.5.2.1 10 mm Thick Enveloping Plate

The maximum stresses obtained on the 10mm thickness enveloping plate compared with the corresponding allowable stresses are given in Table 2-8, where:

- S_Z ≡ Vertical direction (Z) membrane stress
- S_H ≡ Horizontal direction (X or Y) membrane stress
- S_{HZ} ≡ Shear membrane stresses on the plane of the plate.
- Bending stresses across the plate thickness are negligible and are classified as secondary stresses; however, other directions of the plate contain primary bending stresses that are included in the stress analysis results. ~~Bending plate stresses are negligible~~

Table 2-8

10mm Thickness Enveloping Plate Stress Results

Stress Category	Calculated Stress (MPa)	Allowable Stress (MPa)
Level A Conditions Maximum Membrane Stresses	$S_Z = 7.0$	134.1
	$S_H = 2.1\times2 = 4.2$	134.1
	$S_{HZ} = 2.2$	80.4
Level D Conditions Maximum Membrane Stresses	$S_Z = 131$ (Figure C26)	292.8
	$S_H = 35\times2 = 70$	292.8

2.5.2.2 7 mm Thick Upper Level Plates

The maximum stress obtained for the 7 mm thick upper level plates compared with the corresponding allowable stresses are given in Table 2-10, where:

- S_Z ≡ Vertical direction (Z) membrane stress
- S_H ≡ Horizontal direction (X or Y) membrane stress
- S_{HZ} ≡ Shear membrane stresses on the plane of the plate.
- Bending stresses across the plate thickness are negligible and are classified as secondary stresses; however, other directions of the plate contain primary bending stresses that are included in the stress analysis results. ~~Bending plate stresses are negligible~~

Table 2-10

7 mm Thickness Upper Level Plates Stress Results

Stress Category	Calculated Stress (MPa)	Allowable Stress (MPa)
Level A Conditions Maximum Membrane Stresses	S_Z = 7.8 (Figure C27)	134.1
	S_H = 3.2	134.1
	S_{HZ} = 1.1	80.4
Level D Conditions Maximum Membrane Stresses	S_Z = 21.0	292.8
	S_H = 55.8 (Figure C28)	292.8
	S_{HZ} = 7.3	198.6

The 7 mm thickness plates are welded with a 3 mm fillet weld, 30 mm in length, in each corner connection between perpendicular plates.

The maximum stress on these welds due to the pull-up force of 17.79 kN (Section 2.4.6.2) is obtained assuming that this force is transmitted through the four fillet welds of one cell. That is,

$$S_{max} = 17790/(4x30x3) = 49.4 \text{ MPa} < 65.1 \text{ MPa}$$

The maximum vertical force in a corner between perpendicular plates for level D conditions is 9117 N. Therefore, the maximum stress on the fillet weld is

$$Smax = 9117 \text{ x } 1.4142/(30x3) = 143.2 \text{ MPa} < 198.6 \text{ MPa}$$

2.5.2.3 20 mm Thick Base Plate Stiffener Plates

The maximum stress obtained for the 20 mm thickness base plate stiffener plates and welds compared with the corresponding allowable stresses are given in Table 2-11, where:

- $S_Z \equiv$ Vertical direction (Z) membrane stress
- $S_H \equiv$ Horizontal direction (X or Y) membrane stress
- $S_{HZ} \equiv$ Shear membrane stresses on the plane of the plate
- Bending stresses across the plate thickness are negligible and are classified as secondary stresses; however, other directions of the plate contain primary bending stresses that are included in the stress analysis results. ~~Bending plate stresses are negligible~~

Table 2-11

20mm Thickness Base Plate Stiffener Plates Stress Results

Stress Category	Calculated Stress (MPa)	Allowable Stress (MPa)
Level A Conditions Maximum Membrane Stresses	S_Z=8.4	134.1
	S_H=6.4	134.1
	S_{HZ}=5.3	80.4
Level D Conditions Maximum Membrane Stresses	S_Z =142 (Figure C29)	2092.8
	S_H =116	292.8
	S_{HZ} =83.6	198.6
Welds to base support plate. On corners (3 cells) 2x6mm fillet weld (100–168)	S_{max} =55.4×(20/12)×(168/100) =155.1	198.6
Welds to base support plate. Out of corners, 2x6mm fillet welds (2x100–504) 'maximum'	S_{max} =24.3×(20/12)×(504/200)=102.1	198.6

Note The stress used to check the fillet weld is the maximum shear stress for the weld localization, given by $(S_Z^2+S_{HZ}^2)^{1/2}$

2.5.2.4 20 mm Thick Base Plate and 60 mm Thick Bolted Support Plates

The maximum stress obtained for the 20 mm thick base plate and in 60 mm thick bolted support plates compared with the corresponding allowable stresses are indicated in Table 2-12.

Maximum bottom fuel horizontal force $\Rightarrow$ FHB $\approx$9.6 E+4 /77= 1247 N

Maximum bottom fuel vertical force $\Rightarrow$ FHT $\approx$ 315 E+4 /77= 40909 N

The stresses produced by these impact forces are analyzed using the detailed FSR model defined in Section 2.4.5. The analysis is only focused on the stress produced for the FSR fuel base plate, since the top fuel impact forces obtained show low values and therefore judged non-significant.

The impact forces are applied in the three directions by nodal forces on the circular holes of the fuel support base plate.

The vertical fuel impact forces have high values. For this reason a plastic material analysis is considered for the FSR fuel base plate. The plastic stress-strain material curve is obtained from (Reference 11).

The stress distribution on the base plate is show in figure C33. The maximum stress is S_{max}= 208 MPa.

This maximum stress is lower than the maximum membrane plus bending admissible stress per Appendix F, ~~N~~F-1341.2 (Reference 4), considering support plastic analysis, $S_{adm}=0.9\times S_U$= 436 MPa.

Change to Section 2.5.4

2.6 CONCLUSIONS

The analyses performed for the FSR with the geometry of drawings ID 1, 2 and 3 demonstrate the integrity of these structures when subjected to the applicable loads and load combinations as described in the report.

Table 2-2 summarizes results obtained from the analysis of the FSR components: plate thickness, welds, and anchor bolts. Included in the table are the ratios of the actual results with their allowable values.

The analyses presented herein demonstrate that the FSR satisfy the structural requirements of ASME B&PV Code, Section III, Subsection NF (Reference 3) for all proposed loading condition specified in FSR Design Specification (ID 4).

Note on Section 2.4.8:

The response of the racks is mainly due to the first frequencies under the SSE loads. For racks in the buffer pool, the minimum mass percentage combined in the SSE modal response is 92.7%, indicating 7.3% missing mass. The most critical stress ratio is 0.93.

The global response of the rack from the response spectrum analysis developed can be expressed as:

$$R = (\sum R^2 ij)^{1/2} \quad ; i = SSE, LOCA, SRVD; \ j = x, y, z$$

where Rij is linearly dependant of $(\sum(M_k \cdot a_k)^2)^{1/2}$, where M_k and a_k are, respectively, the effective mass and acceleration for the mode k. Including the missing mass for each event and each

Table 3-7b indicates the acceleration considered to account for the high-frequency modes, with the corresponding percentage of missing mass.

Table 3-7b

Acceleration for Missing Masses

Event	X direction		Y direction		Z direction	
	Acceleration (g)	(%)	Acceleration (g)	(%)	Acceleration (g)	(%)
SSE	1.27	27.7	1.25	25.2	1.74	100
LOCA	0.05	31.2	0.029	19.3	0.225	100
SRVD	0.067	31.2	0.067	25.2	0.143	100

3.5.1 Displacements Results

The maximum horizontal displacement obtained at the top of the FSR for the most unfavorable load combination is 18.0 mm and occurs in the X-direction (see Figure A-24, in Appendix A).

One half of the expansion due to thermal expansion (Section 3.4.6.3) is applied to each rack in opposing horizontal directions. If the abnormal pool temperature were to occur simultaneously with a seismic event, the resulting total displacement is calculated as:

$$18.0 \text{ mm} + 5.9 \text{ mm}/2 = 21.0 \text{ mm}$$

The minimum distance between adjacent FSR at the top level or between FSR and pool wall is 100 mm (ID 6). Therefore, no contact occurs between adjacent FSR or between the FSR and the pool walls.

3.5.2 Plate Stress results

The stress results obtained for the different load combinations are checked in the most critical sections of the different plates of the FSR. Figures E-25 to E-28 in Appendix E show the results.

3.5.2.1 8 mm Thick Channel Plate

The maximum stresses obtained for the 8mm thick channel plate compared with the corresponding allowable stresses are given in Table 3-8, where:

- $S_Z \equiv$ Vertical direction (Z) membrane stress
- $S_H \equiv$ Horizontal direction (X or Y) membrane stress
- $S_{HZ} \equiv$ Shear membrane stresses on the plane of the plate.

- Bending stresses across the plate thickness are negligible and are classified as secondary stresses; however, other directions of the plate contain primary bending stresses that are included in the stress analysis results. ~~Bending plate stresses are negligible~~

Table 3-8

8mm Thick Channel Plate Stress Results

Stress Category	Calculated Stress (MPa)	Allowable Stress (MPa)
Level A Conditions Maximum Membrane Stresses	$S_Z = 35.8$ (Figure E-25)	134.1
	$S_H = 6.7$	134.1
	$S_{HZ} = 3.9$	80.4
Level D Conditions Maximum Membrane Stresses	$S_Z = 267$ (Figure E-26)	292.8
	$S_H = 57.4$	292.8
	$S_{HZ} = 41.5$	198.6

The maximum stresses obtained for the channel to support-base, compared with the corresponding allowable stresses are given in Table 3-9.

Table 3-9

Channel to Support-Base Weld Stress Results

Stress Category	Calculated Stress (MPa)	Allowable Stress (MPa)
6 mm double fillet welds (end channels)	(267)×(8/12) =178.0	198.6
6 mm fillet welds (all channels)	(137)×(8/6) =182.6	198.6

3.5.2.2 12 mm Thick Door Plates

The maximum stress obtained for ~~the~~ the 12 mm thick door plates compared with the corresponding allowable stresses are given in Table 3-10, where:

- $S_Z \equiv$ Vertical direction (Z) membrane stress

- $S_H \equiv$ Horizontal direction (X or Y) membrane stress
- $S_{HZ} \equiv$ Shear membrane stresses on the plane of the plate.
- Bending stresses across the plate thickness are negligible and are classified as secondary stresses; however, other directions of the plate contain primary bending stresses that are included in the stress analysis results. ~~Bending plate stresses are negligible~~

Table 3-10

12 mm Thick Door Plates Stress Results

Stress Category	Calculated Stress (MPa)	Allowable Stress (MPa)
Level A Conditions Maximum Membrane Stresses	$S_Z = 0.1$	134.1
	$S_H = 0.08$	134.1
	$S_{HZ} = 0.2$	80.4
Level D Conditions Maximum Membrane Stresses	SZ = 40.3	195.2
	S_H = 123 (Figure E-27)	195.2
	$S_{HZ} = 44.2$	198.6

3.5.2.3 10 mm and (10+8) mm Assembly Grid Plates

The maximum stress obtained for the assembly grid plates compared with the corresponding allowable stresses are given in Table 3-11, where:

- $S_Z \equiv$ Vertical direction (Z) membrane stress
- $S_H \equiv$ Horizontal direction (X or Y) membrane stress
- $S_{HZ} \equiv$ Shear membrane stresses on the plane of the plate.
- Bending stresses across the plate thickness are negligible and are classified as secondary stresses; however, other directions of the plate contain primary bending stresses that are included in the stress analysis results. ~~Bending plate stresses are negligible~~

Table 3-11

10 mm and (10+8) mm Thickness Assembly Grid Stress Results

Stress Category	Calculated Stress (MPa)	Allowable Stress (MPa)
Level A Conditions Maximum Membrane Stresses	$S_Z = 11$	134.1
	$S_H = 14$	134.1
	$S_{HZ} = 3$	80.4
Lifting Load	$S_HZ = 47$ (Figure E-29)	80.4
Level D Conditions Maximum Membrane Stresses	$S_Z = 37.4$	195.2
	$S_H = 52.5$ (Figure E-28)	195.2
	$S_HZ = 7$	198.6

Welds in these plates are judged to have enough margin in view of the low stress results in plates.

3.5.2.4 Axis and Hinge Plates

The maximum stress obtained for the axis and hinges compared with the corresponding allowable stresses are given in Table 3-12, where:

- $S_Z \equiv$ Vertical direction (Z) membrane stress
- $S_H \equiv$ Horizontal direction (X or Y) membrane stress
- $S_{HZ} \equiv$ Shear membrane stresses on the plane of the plate.
- Bending stresses across the plate thickness are negligible and are classified as secondary stresses; however, other directions of the plate contain primary bending stresses that are included in the stress analysis results. ~~Bending plate stresses are negligible~~

Table 3-12

Axis and Hinge Stress Results

Stress Category	Calculated Stress (MPa)	Allowable Stress (MPa)
Level A Conditions Maximum Membrane Stresses	$S_Z = 3.8$	134.1
	$S_H = 1.6$	134.1
	$S_{HZ} = 1.1$	80.4
Level D Conditions Maximum Membrane Stresses	$S_Z = 106$	195.2
	$S_H = 130$	195.2
	$S_{HZ} = 31.3$	198.6

3.5.2.5 15 mm Thick Support-Base Stiffener Plates

The maximum stress obtained for the 15 mm thick stiffener plates and welds compared with the corresponding allowable stresses are given in Table 3-13, where:

- $S_Z \equiv$ Vertical direction (Z) membrane stress
- $S_H \equiv$ Horizontal direction (X or Y) membrane stress
- $S_{HZ} \equiv$ Shear membrane stresses on the plane of the plate
- Bending stresses across the plate thickness are negligible and are classified as secondary stresses; however, other directions of the plate contain primary bending stresses that are included in the stress analysis results. ~~Bending plate stresses are negligible~~

Table 3-13

15mm Thick Stiffener Plates Stress Results

Stress Category	Calculated Stress (MPa)	Allowable Stress (MPa)
Level A Conditions Maximum Membrane Stresses	$S_Z = 2.6$	134.1
	$S_H = 8.9$	134.1
	$S_{HZ} = 3.2$	80.4
Level D Conditions Maximum Membrane Stresses	$S_Z = 127$	195.2
	$S_H = 138$	195.2
	$S_{HZ} = 54$	198.6

The coupling between FSR cell and fuel beam immersed in water, are modeled through MATRIX27 elements applied by node pairs (see Reference 10 for details).

Mass elements reproducing the mass of internal water are considered on the connection nodes of the beam elements simulating the FSR cells.

The fuel beam is coupled in the horizontal direction with the FSR beam at the bottom node. One vertical contact element is located at this same location to evaluate whether the fuel uplifts then impacts with a vertical load when it falls and strikes the base plate.

Between the FSR beam top node and fuel beam top node, two horizontal contact elements (one for each direction of movement) are located to evaluate any potential lateral impacts that may be produced against the FSR cells. The stiffness of these contacts has been estimated by a local analysis made with the detail analysis model, applying local loads at the top cell level.

Based on the acceleration time-histories corresponding to the SSE (ID 8), double integration is used to generate the displacement histories to be applied at the node of the model that represent the pool. Intervals of 0.005 s were used, which means 3200 load steps for a 16-s transient.

The dead weight and the buoyancy effects are considered during the process by application of a constant vertical downward acceleration value of 8.6 g (reduced gravity acceleration, see Section 3.4.6.1).

The maximum impact loads obtained from the this local analysis are:

Maximum top fuel horizontal force $\Rightarrow$ FHT $\approx$ 1.2 E+4 /28 = 429 N

Maximum bottom fuel horizontal force $\Rightarrow$ FHB $\approx$ 5.3 E+4 /28= 1893 N

Maximum bottom fuel vertical force $\Rightarrow$ FHT $\approx$ 150 E+4 /28= 53571 N

The stresses produced by these impact forces are analyzed using the detailed FSR model defined in Section 3.4.5. The analysis is only focused on the stress produced for the FSR fuel base plate, since the top fuel impact forces obtained are low and therefore judged to be insignificant.

The impact forces are applied in the three directions by nodal forces on the circular holes of the fuel support base plate.

The vertical fuel impact forces have high values. For this reason a plastic material analysis is considered for the FSR fuel base plate. The plastic stress-strain material curve is obtained from Reference 11.

The stress distribution on the base plate is show in Figure E-30. The maximum stress is S_{max}= 180 MPa.

This maximum stress is lower than the maximum membrane plus bending admissible stress from Appendix F, ~~N~~F-1341.2 Reference 4, $S_{adm}=0.9\times S_U$= 436 MPa.

Change to Section 3.5.4