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August 25, 2010

Subject: AP1000 Response to Request for Additional Information (TR44)

Westinghouse is submitting responses to the NRC request for additional information (RAI) on SRP Section TR44. These RAI responses are submitted in support of the AP1000 Design Certification Amendment Application (Docket No. 52-006). The information included in these responses are generic and is expected to apply to all COL applications referencing the AP1000 Design Certification and the AP1000 Design Certification Amendment Application.

Enclosure 1 provides the following RAI(s) which have each been superseded in their entirety by the drop accident methodology presented in RAI-TR44-01 R2 and RAI-TR44-06 R3, both dated 8/13/10.

RAI-TR44-002 R2
RAI-TR44-003 R2
RAI-TR44-04 R1
RAI-TR44-005 R2
RAI-TR44-007 R2

Questions or requests for additional information related to the content and preparation of this response should be directed to Westinghouse. Please send copies of such questions or requests to the prospective applicants for combined licenses referencing the AP1000 Design Certification. A representative for each applicant is included on the cc: list of this letter.

Very truly yours,

Robert Sisk, Manager
Licensing and Customer Interface
Regulatory Affairs and Strategy

/Enclosure

1. Response to Request for Additional Information on SRP Section TR44

D063
NRO

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ENCLOSURE 1

Response to Request for Additional Information on SRP Section TR44

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-TR44-002
Revision: 2

Question:

Section 2.8.5 states that appropriate non-linear material properties have been applied to the rack components to permit yielding and permanent deformation. Table 2-6 only provides Young's modulus, yield strength, and ultimate strength, which are not sufficient to define an engineering stress-strain curve. In addition, LYDYNA requires true stress-strain relation for its nonlinear materials. Therefore, provide the following: (1) a complete description of the material stress-strain curve and confirm that a true stress-strain curve was used in these impact analyses and (2) a description of the fuel assembly model, including the element properties and material properties for the dropped fuel assembly.

Staff Assessment: Response same as for spent fuel racks. See RAI-TR54-05.

As a result of the October 8-12, 2007 audit, **confirmatory** pending submittal of supplemental response and the application of the same resolution as noted in TR54-05, to the new fuel rack.

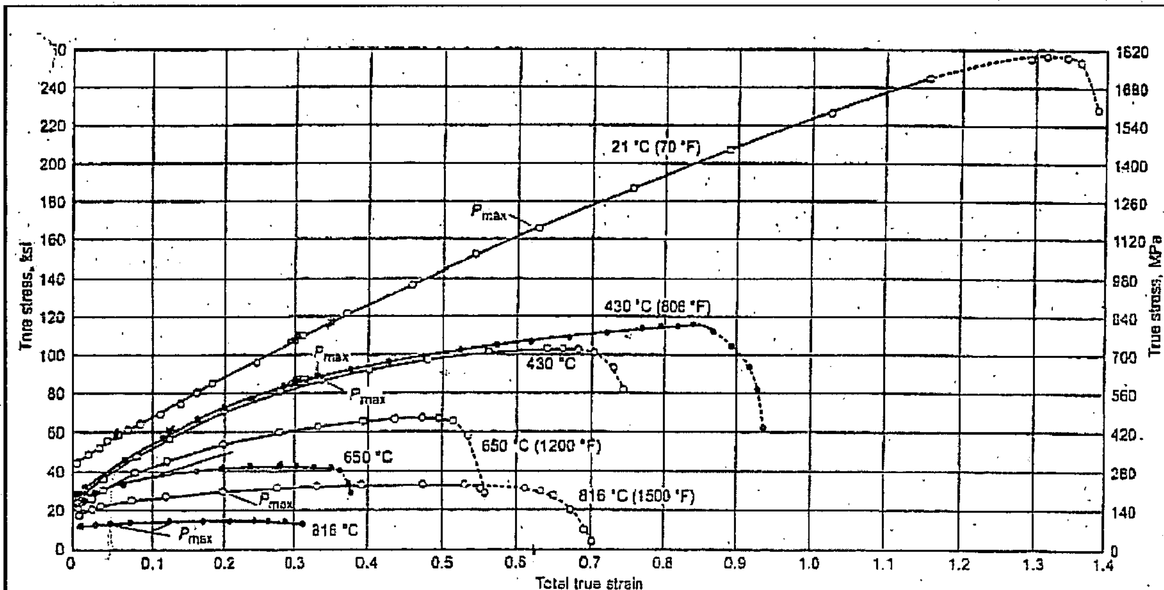
Westinghouse Response:

Revised Response: (Revision 2)

This RAI is superseded in its entirety by the drop accident methodology presented in RAI-TR44-01 R2 and RAI-TR44-06 R3, both dated 8/13/10.

Response: (Revision 0 and 1)

1) The new fuel racks are fabricated from SA240-304 and SA564-630 stainless steel. For the impact analyses, a true-stress strain curve, which is obtained from <u>Atlas of Stress Strain Curves</u> (2nd Edition, ASM International) and reproduced below as Figure TR44-2.1, is used to define the strength properties of SA240-304 stainless steel.



SS.044 304 annealed stainless steel bar, true stress-strain curves at room and elevated temperatures

Figure 44-2.1 Stress Strain Curve for SA240-304 Stainless Steel

The properties of SA564-630, which is used to fabricate the adjustable support pedestals, are input in terms of engineering stress/strain based on material data taken from the ASME Boiler and Pressure Vessel Code. Also, the welds that connect the rack components are modeled as a bi-linear elasto-plastic material having the engineering stress/strain properties of the adjoining base metal (i.e., SA240-304). The material property values, which are used to define the engineering stress-strain curves for SA564-630 stainless steel and the structural welds, are summarized in the table below.

Material Properties	Material Types	
	SA240-304 (Welds)	SA564-630
Young's Modulus ($10^6 \times$ psi)	27.87	28.77
Yield Stress (ksi)	26.7	109.2

Ultimate Stress (ksi)	73.0	140.0
Failure Strain (in/in)	0.4	0.14

2) The fuel assembly is modeled by a rigid bottom end fitting and a mass at the top (representing the weight of lifting tool) connected by an elastic beam (with a Young's modulus of 1.04×10^7 psi and a Poisson's ratio of 0.3 for typical rod material) that has an equivalent mass and total cross-sectional area of all fuel rods in an AP1000 fuel assembly. In addition, a very thin rigid shell is attached to the bottom end fitting to represent the side surfaces of the fuel assembly that might be in contact with rack cell walls in a shallow drop event. To maximize the damage in the rack, the fuel assembly is only allowed to move in the vertical direction.

Westinghouse Supplemental Response following May 21 and 22, 2008 Technical Review:

(1) The similar spent fuel rack RAI-TR54-05 was resolved during the October 8-12, 2007 audit. During the audit Westinghouse demonstrated that the true stress-strain curve for the SS material at the appropriate temperature is derived by manual interpolation of the true stress-strain curves, which are provided in Atlas of Stress Strain Curves (2nd Edition, ASM International) for Type 304 stainless. The properties were linearly interpolated to obtain the values at 150°F. Using data from the ASME Code Section II, Part D, Westinghouse demonstrated that the temperature versus yield stress and ultimate stress for stainless steel materials are not linear resulting is a slight overestimation of these values in the LS-DYNA drop analyses. Using the nonlinear curves based on the ASME Code, the overestimation was less than 4% for the ultimate strength and less than 10% for the yield. Therefore, the results would not vary significantly. The staff reviewed the two curves and agreed with Westinghouse's assessment. Westinghouse applied this same approach for the new fuel racks; therefore, Westinghouse considers this item to be resolved for the new fuel racks as well.

(2) For spent fuel rack RAI-TR54-05, Section 2.8.5 of TR54, Rev. 1 was revised to include a more complete description of the fuel assembly model. The staff reviewed Rev. 1 of TR-54 (Section 2.8.5) and found that the stiffness and mass representation is acceptable, and this item was resolved in the May 21 and 22, 2008 technical review. For the new fuel racks, Section 2.8.5 of TR44 was revised to include the equivalent information; see the Technical Report Revision section.

References:

1. APP-GW-GLR-026, Revision 0, "New Fuel Storage Rack Structural/Seismic Analysis," (Technical Report Number 44)
2. APP-FS02-Z0C-001, Revision 0, "Analysis of AP1000 Fuel Storage Racks Subjected to Fuel Drop Accidents"

Design Control Document (DCD) Revision:
None

PRA Revision:
None

Technical Report (TR) Revision:
Yes - Section 2.8.5 of TR44 was revised as follows:

Both analyses are performed using the dynamic simulation code LS-DYNA (Reference 22). A finite element model of one-quarter of the AP1000 New Fuel Storage Rack plus a single fuel assembly is modeled using appropriate shell and solid body elements available in LS-DYNA. The fuel assembly model, which is shown in Figure 2-8, consists of four parts: a rigid bottom end fitting, an elastic beam representing the fuel rods, a lumped mass at the top end of the beam representing the handling tool, and a thin rigid shell that defines the enveloping size and shape of the fuel assembly. The mass and cross-sectional area properties of the elastic beam are based on the entire array of fuel rods (cladding material only). The fuel mass is lumped with the bottom end fitting. Appropriate non-linear material properties have been assigned to the rack components to permit yielding and permanent deformation to occur. Figure 2-9 shows the details of the finite element model in the area where the impacts occur.

Figure 2-8 was added to TR44:

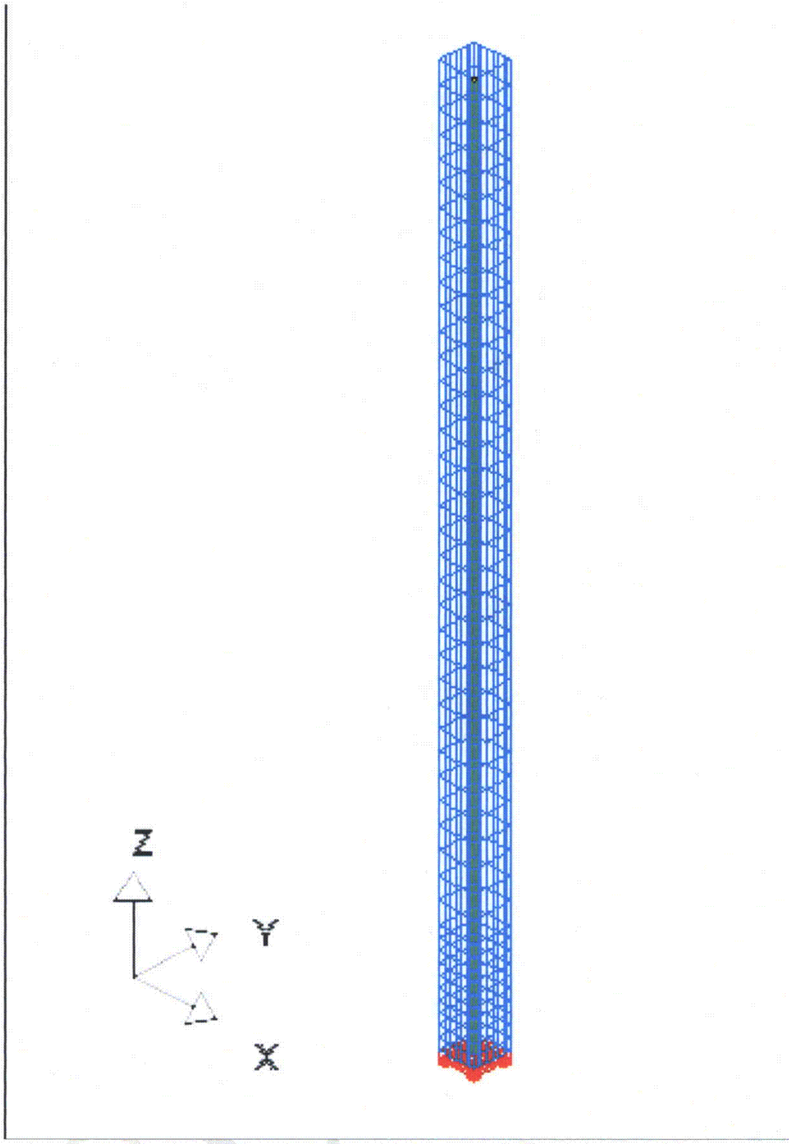


Figure 2-8 LS-DYNA Model of Dropped Fuel Assembly

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-TR44-003
Revision: 2

Question:

The baseplate in Figure 2-8 appears to have only one layer of 8 node brick element through its thickness. It is not clear if a solid or a thick shell element is used. Clarify the type of element used for the baseplate.

Staff Assessment: Response same as for spent fuel racks. See RAI-TR54-06.

As a result of the October 8-12, 2007 audit, **confirmatory** pending submittal of supplemental response and the application of the same resolution as noted in TR54-06, to the new fuel rack.

Westinghouse Response:

Revised Response: (Revision 2)

This RAI is superseded in its entirety by the drop accident methodology presented in RAI-TR44-01 R2 and RAI-TR44-06 R3, both dated 8/13/10.

Response: (Revision 0 and 1)

The baseplate is modeled using 8-noded solid elements arranged in a single layer.

Westinghouse Supplemental Response following May 21 and 22, 2008 Technical Review:

The similar spent fuel rack RAI-TR54-06 was resolved during the May 21 and 22, 2008 technical review. During the technical review, Westinghouse demonstrated that the rack baseplate model was revised to utilize thick shell elements in Revision 1 of APP-FS02-Z0C-001, "Analysis of AP1000 Fuel Storage Racks Subjected to Fuel Drop Accidents". Westinghouse also demonstrated that the model to use strain rate effects for the material properties was revised. The net effect of both improvements resulted in lower deformations. The staff found that the use of the thick shell element representation of the baseplate rather than one row of solid brick elements is acceptable and the use of strain rate effects is appropriate because it more closely simulates the true material behavior under dynamic impact loadings.

Westinghouse applied this same approach for the new fuel racks. Because the NRC staff has already reviewed and accepted Revision 1 of APP-FS02-Z0C-001, which also applies to the new fuel rack, Westinghouse considers this item to be resolved for the new fuel rack as well.

References:

1. APP-GW-GLR-026, Revision 0, "New Fuel Storage Rack Structural/Seismic Analysis," (Technical Report Number 44)
2. APP-FS02-Z0C-001, Revision 1, "Analysis of AP1000 Fuel Storage Racks Subjected to Fuel Drop Accidents"

Design Control Document (DCD) Revision:
None

PRA Revision:
None

Technical Report (TR) Revision:
None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-TR44-04
Revision: 1

Question:

Section 2.8.5 indicates that the baseplate of the rack is connected to the cells by appropriate welding. However, the cells are described in the second paragraph on page 2 of the topical report as resting on top of the baseplate. Welded connections between the cells and the baseplate would greatly increase the strength of the whole rack system. To assist the staff in its review:

(a) Confirm there is a welded connection between the baseplate and the cells.

(b) Describe the design details of this connection.

(c) Describe how this connection is modeled in LS-DYNA.

Westinghouse Response:

Revised Response: (Revision 1)

This RAI is superseded in its entirety by the drop accident methodology presented in RAI-TR44-01 R2 and RAI-TR44-06 R3, both dated 8/13/10.

Response: (Revision 0)

(a) The base of every storage cell is welded to the rack baseplate.

(b) Each cell is welded to the baseplate on four sides by 1/16" fillet welds having a minimum length of 7".

(c) The cell-to-baseplate weld connection is modeled in LS-DYNA by shell elements, which join the bottom of the cell and the baseplate top surface, with a thickness equal to the corresponding throat dimension of the weld.

References:

1. APP-GW-GLR-026, Revision 0, "New Fuel Storage Rack Structural/Seismic Analysis," (Technical Report Number 44)
2. APP-FS02-Z0C-001, Revision 0,"Analysis of AP1000 Fuel Storage Racks Subjected to Fuel Drop Accidents"

Design Control Document (DCD) Revision:
None

PRA Revision:
None

Technical Report (TR) Revision:
None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-TR44-005
Revision: 2

Question:

Section 2.8.5 does not indicate whether other fuel assemblies are in place, when a fuel assembly drops through an empty cell and impacts the baseplate at its center. Depending on how the baseplate is designed, a full load of fuel assemblies may introduce progressive deformation after a fuel assembly impacts at the center of the baseplate. The maximum downward deformation of the baseplate is about 3.8 inches, as shown in Figure 2-10. This may be significant enough to initiate a progressive deformation. Therefore, provide: (1) the assumption on the existing fuel assemblies when the impact occurs, (2) the design basis for the baseplate, and (3) a figure similar to Figure 2-10, that shows the cells together with the severely deformed baseplate.

Staff Assessment: Response similar to response for spent fuel racks. See RAI-TR54-09.

As a result of the October 8-12, 2007 audit, **confirmatory** pending submittal of supplemental response and the application of the same resolution as noted in TR54-09, to the new fuel rack.

Westinghouse Response:

Revised Response: (Revision 2)

This RAI is superseded in its entirety by the drop accident methodology presented in RAI-TR44-01 R2 and RAI-TR44-06 R3, both dated 8/13/10.

Response: (Revision 0 and 1)

1) The new fuel storage rack is assumed to be empty (i.e., no fuel assemblies in place) when a fuel assembly drops through an empty cell and impacts the baseplate at its center. This is a simplifying assumption, which is reasonable considering the degree of conservatism associated with the postulated 36" drop height. Note that the response to RAI TR44-001 indicates that it is unlikely that the drop height will ever be 36 inches, as the top of the rack is less than 6 inches below the floor elevation. Based on a realistic carry height above the floor of 12 inches, the drop height above the new fuel storage rack is not likely to exceed 18 inches.

2) The design basis for the baseplate is to provide vertical support for the stored fuel assemblies and to protect the New Fuel Storage Pit from a fuel assembly strike. In other words, a dropped fuel assembly should not pierce the baseplate and result in a direct impact with the reinforced concrete floor of the New Fuel Storage Pit.

(3) Figure TR44-005.1 below shows the cells together with the severely deformed baseplate for the same LS-DYNA solution as shown in Figure 2-10. Note that the deformation of the cells is not significant compared to the baseplate. This is because the cell-to-baseplate weld connections break as a result of the postulated fuel impact load before the cell walls are permanently deformed.

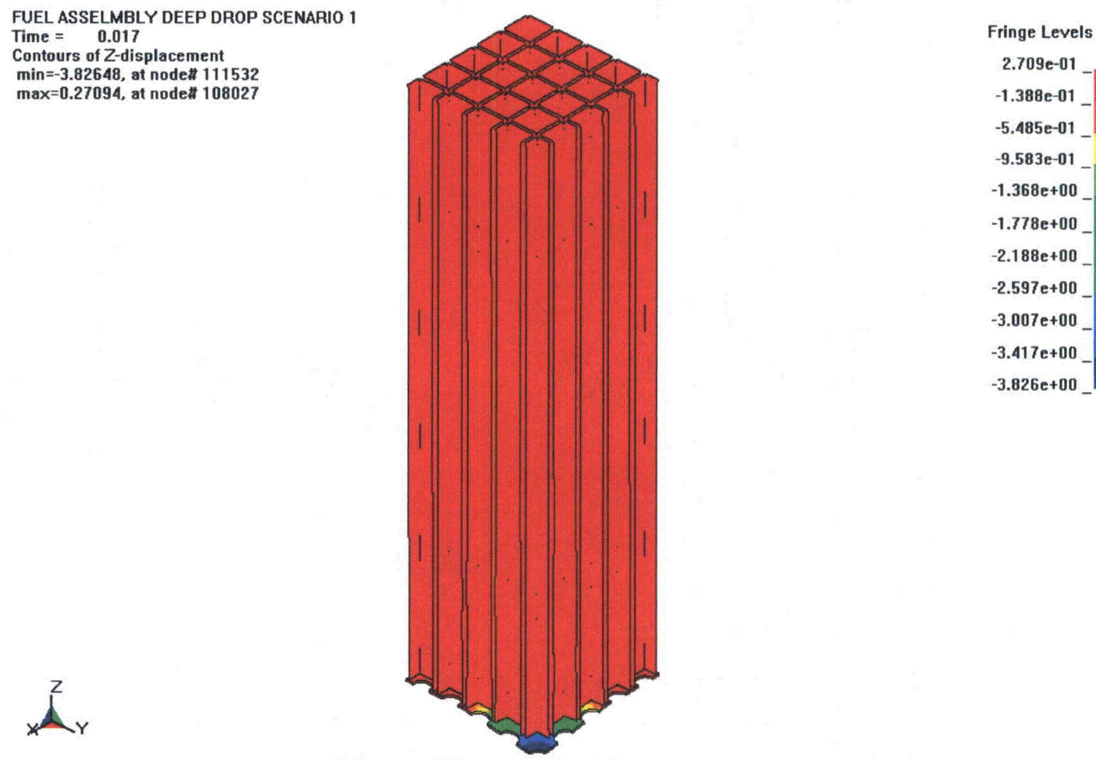


Figure TR44-05.1 Fuel Assembly Deep Drop Scenario 1 for New Fuel Rack

Westinghouse Supplemental Response following May 21 and 22, 2008 Technical Review:

Item 1: During the May 21 and 22, 2008 technical review of spent fuel rack RAI-TR54-09, Westinghouse demonstrated to the NRC staff that the model was revised to consider the effects of all of the stored fuel assemblies in the rack by modifying the density of the rack baseplate in Revision 1 of APP-FS02-Z0C-001, "Analysis of AP1000 Fuel Storage Racks Subjected to Fuel Drop Accidents". This revision to the model was made along with the use of thick shell elements for the baseplate and the inclusion of strain rate effects. The staff reviewed the calculation and confirmed that the approach utilizes the mass effect of all of the fuel assemblies by increasing the baseplate density. The staff concluded that the consideration of the rest of the fuel assemblies (excluding the single dropped fuel assembly) by increasing the mass of the baseplate is an acceptable approach to simulate the dynamic effects of the other fuel assemblies. Following the May 21 and 22, 2008 technical review this item was considered resolved. Westinghouse applied the same approach for the new fuel racks. Because the NRC staff has already reviewed and accepted Revision 1 of APP-FS02-Z0C-001, which also applies to the new fuel rack, Westinghouse considers this item to be resolved for the new fuel rack as well.

Item 2: The equivalent item for spent fuel rack RAI-TR54-09 was resolved as originally submitted. Therefore, no supplemental response is required.

Item 3: The equivalent item for spent fuel rack RAI-TR54-09 was resolved as originally submitted (in Revision 1 of RAI-TR54-09). Therefore, no supplemental response is required. Note: The concern of the large vertical deformation is being addressed under RAI-TR44-06.

References:

1. APP-GW-GLR-026, Revision 0, "New Fuel Storage Rack Structural/Seismic Analysis," (Technical Report Number 44)
2. APP-FS02-Z0C-001, Revision 1, "Analysis of AP1000 Fuel Storage Racks Subjected to Fuel Drop Accidents"

Design Control Document (DCD) Revision:
None

PRA Revision:
None

Technical Report (TR) Revision:
None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-TR44-007
Revision: 2

Question:

Figure 2-9 of this report shows the permanent deformation at the top of a cell wall. The permanent deformation is measured as 10.26 inches, which is smaller than the limit of 14 inches. However, the figure also shows indications of nontrivial hourglassing, which may significantly affect the accuracy of the analysis result. The mesh at the impact location should be locally refined, to ensure convergence with mesh size. Therefore, an additional analysis with a finer mesh at the impact region should be performed to confirm that the model is suitable.

Staff Assessment: Response similar to response for spent fuel racks. See RAI-TR54-11.

As a result of the October 8-12, 2007 audit, **confirmatory** pending submittal of supplemental response and the application of the same resolution as noted in TR54-11, to the new fuel rack.

Westinghouse Response:

Revised Response: (Revision 2)

This RAI is superseded in its entirety by the drop accident methodology presented in RAI-TR44-01 R2 and RAI-TR44-06 R3, both dated 8/13/10.

Response: (Revision 0 and 1)

The general acceptance criterion for the 36 inch fuel assembly drop onto the top of a new fuel storage rack is to maintain the stored fuel assemblies in a subcritical configuration. In measurable terms, the permanent deformation of the rack (measured downward from the top of rack) is limited to 15.27 inches, which is the distance from the top of the rack to the top of the neutron absorber panel. This limit is conservative because the active fuel region begins two inches below the top of the neutron absorber panels. Therefore, more margin exists than Technical Report APP-GW-GLR-026 indicates, and a mesh convergence study is not required.

Westinghouse Supplemental Response following May 21 and 22, 2008 Technical Review:

The 36" fuel assembly drop onto the top of the new fuel rack was re-analyzed in Revision 1 of APP-FS02-Z0C-001, "Analysis of AP1000 Fuel Storage Racks Subjected to Fuel Drop Accidents", with consideration of strain rate effects for the welds. The new analysis shows that the maximum permanent deformation of the rack cell wall is 12.75" (measured from the top of rack) versus the allowable limit of 20.83". This allowable limit is the distance from the top of the rack to the top of the poison panel, which is 2 inches above the top of the active fuel. Note the height of the new fuel rack cell was increased by 6 inches. Since the active fuel region is surrounded by an undamaged cell wall, there is no longer a need to demonstrate that the refinement of the model is adequate in the localized region of the impact zone.

For the similar RAI related to the spent fuel racks, RAI-TR54-11, the NRC staff requested Westinghouse to also confirm the adequacy of the rack model in the crushed zone region by providing curves that compare the hourglass energy to the kinetic, internal, and/or total energy. Westinghouse provided these curves which demonstrated that the hourglass energy was essentially negligible in comparison to the internal energy of the cell structure and impact bar that were being plastically deformed during these drop accident cases. For the spent fuel racks, the NRC staff found the response to be technically acceptable in view of the much larger margins in the extent of plastic deformation in the new revised model, and the comparison of the hour glass energy. Following the May 21 and 22, 2008 technical review, this item was considered resolved for the spent fuel racks. Westinghouse applied this same approach for the new fuel racks; therefore, Westinghouse considers this additional item to be resolved for the new fuel racks as well.

References:

1. APP-GW-GLR-026, Revision 0, "New Fuel Storage Rack Structural/Seismic Analysis," (Technical Report Number 44)
2. APP-FS02-Z0C-001, Revision 1, "Analysis of AP1000 Fuel Storage Racks Subjected to Fuel Drop Accidents"

Design Control Document (DCD) Revision:
None

PRA Revision:
None

Technical Report (TR) Revision:
Paragraph three, Subsection 2.8.5, Hypothetical Fuel Assembly Drop Accidents was revised as follows:

For the drop to the top of the AP1000 New fuel Storage Rack, the fuel assembly is assumed to strike the edge of an exterior cell at a speed corresponding to a 36-inch drop in air and to remain vertical as it is brought to a stop by the resisting members of the rack. The objective is to demonstrate that the extent of permanent damage to the impacted rack does not extend to the beginning of the active fuel region. For the AP1000 fuel, the top of the active fuel begins 22.83 inches below the top of the rack.

Paragraph five, Subsection 2.8.5, Hypothetical Fuel Assembly Drop Accidents was revised as follows:

The results from the analyses are shown in Figures 2-9 and 2-10. For the drop to the top of the AP1000 New Fuel Storage Rack, the extent of the permanent damage is limited to a depth of 12.75 inches. The tops of the poison panels are located 20.83 inches below the top of the rack. The poison panels overlap the active fuel by two inches at the top and bottom. The top of the active fuel begins 22.83 inches below the top of the rack, therefore, the active fuel region is surrounded by an undamaged cell wall and no further criticality analysis is required.

Figure 2-9 was replaced with the following figure:

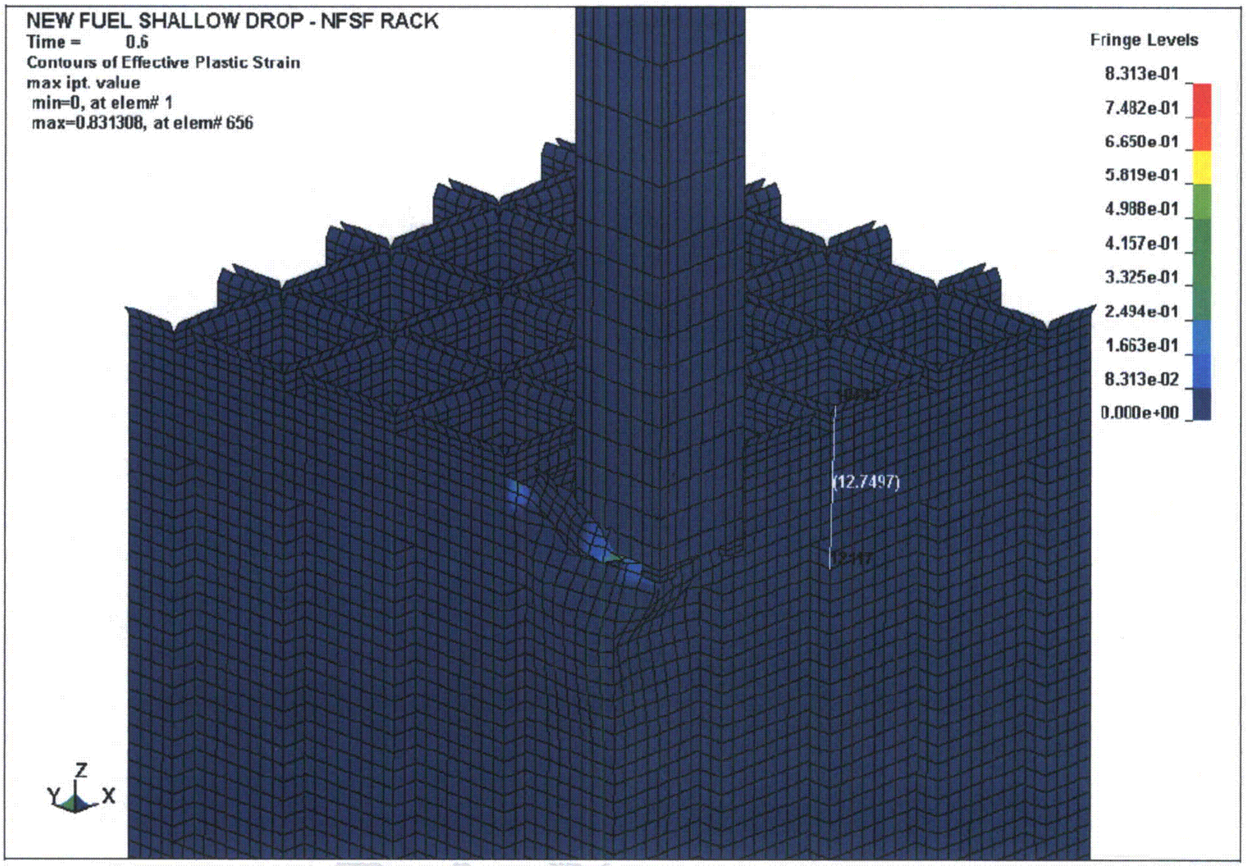


Figure 2-9 Results from Drop on AP1000 New Fuel Storage Rack