March 29, 2007

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SUBJECT: WESTINGHOUSE AP1000 COMBINED LICENSE (COL) PRE-APPLICATION TECHNICAL REPORTS 54 - REQUEST FOR ADDITIONAL INFORMATION (TAC NOS. MD2551)

Dear Ms. Sterdis:

By letter dated July 7, 2006, (DCP/NRC1760), you submitted AP1000 Technical Report 54, “Spent Fuel Storage Racks Structure/Seismic Analysis,” which provided information related to the structural and seismic analysis of the AP1000 Spent Fuel Storage Racks. The Nuclear Regulatory Commission’s staff has reviewed the report, and has determined that additional information is required. Our questions are provided in the Enclosure. We discussed these issues with your staff on March 5, 2007. Your staff indicated that you would attempt to provide your response by April 13, 2007.

Please contact me at (301) 415-1313, if you have any other questions on these issues.

Sincerely,

/RA/

Steven D. Bloom, Senior Project Manager
AP1000 Projects Branch
Division of New Reactor Licensing
Office of New Reactors

Project No. 740

Enclosure:
Request for Additional Information

cc w/encl: See next page

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REQUEST FOR ADDITIONAL INFORMATION

WESTINGHOUSE AP1000 DOCUMENT NO. APP-GW-GLR-033, Revision 0

SPENT FUEL STORAGE RACKS STRUCTURAL/SEISMIC ANALYSIS

PROJECT NUMBER 740

LSDYNA Analysis of Accidental Fuel Assembly Drops

TR54-1 Section 2.8.5 indicates that all 3 drop scenarios are from 36 in. above the top of the AP1000 Spent Fuel Storage Rack. Describe the fuel handling operation that leads to this drop height.

TR54-2 As described in Section 2.8.5, the objective of the LSDYNA impact analyses is to assess the extent of the permanent damage to the rack and the structural integrity of the spent fuel pool liner. In light of the second "bullet" in Section 2.9 - Conclusions, please clarify whether the analyses are also intended to address the structural condition of the dropped fuel assemblies, which may be more vulnerable than the rack. If intended to address damage to the fuel assemblies, the staff needs additional fuel assembly design details and LSDYNA analysis details. If not, identify where this is addressed in the design control document (DCD) or other topical report.

TR54-3 Section 2.8.5 indicates the impact velocity was calculated considering the resistance of the water and the confinement effect of the rack cell. Explain how these effects were considered with more details and the calculated impact velocities.

TR54-4 Section 2.8.5 indicates that a quarter of the spent fuel rack and a single fuel assembly were modeled appropriately using LSDYNA's shell and solid elements. Since the rack is submerged under the water when an impact occurs, the water-structure interaction might need to be considered. Confirm whether the water-structure interaction has been accounted for or provide an explanation why this effect is not important.

TR54-5 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, LSYDYNA 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.

TR54-6 The baseplate in Figures 2-7 and 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.

TR54-7 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 Sections 2.1.1.1 and 2.1.1.2 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 LSYDYNA.

TR54-8 For the drop case in which the impact occurs directly above a rack pedestal, Section 2.8.5 provides the concrete strength of the pool floor and the thickness of the stainless steel liner, but does not provide the thickness of the pool floor. There is a possibility that the impact could also cause damage to the concrete floor, and pose a more severe consequence than yield of the liner. The maximum Von Mises stress in the spent fuel pool liner is reported as 23.4 ksi, which is much larger than the concrete strength of 4 ksi; the concrete may crush and crack locally at this level of stress. Therefore, provide additional details on the modeling of the concrete floor (including a figure of the concrete model, element type, boundary conditions, material properties, etc.) and the analysis results for the concrete floor (in addition to Figure 2-11).

TR54-9 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 4.3", 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.

TR54-10 A vertical movement of 2 in. of a fuel assembly is defined as the criticality limit in Section 2.8.5, and the impact analysis shows that quite a number of fuel assemblies will have more than 2 in. displacement. It appears that a rack design with only a 2 in. space between the bottom of the baseplate and the top of the floor would eliminate this risk. Please explain why the design has a space larger than 2 in.

TR54 -11 Figure 2-9 of this report shows the permanent deformation at the top of a cell wall at Region 2. The permanent deformation is measured as 20 in., which is just slightly smaller than the limit of 20.5 in. Since the deformation at the impact location is so close to the limit (i.e., very little margin exists), the mesh 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.

TR54-12 Section 2.8.5 indicates that the maximum baseplate deformation occurs in the Region 1 rack for the case of drop to the center of the baseplate. The Region 1 rack is very similar to the new fuel rack, described in report APP-GW-GLR-026, except it is 6.25" taller. The difference in initial potential energy due to gravity is only (199.5-193.25)/(193.25+36) = 2.7%. The water in the spent fuel pool, coupled with the confinement of the cell, will provide a drag force on the dropping fuel assembly. However, the maximum deformation shown in Figure 2-10 is 4.264", compared to 3.795" for the new fuel rack case. The difference is (4.264 - 3.795)/3.795=12.4%. Therefore, please explain how an increase in potential energy of 2.7% causes an increase in deformation of 12.4%. Also describe how drag forces on the fuel assembly were considered in the analysis.

TR54-13 There are a total of six (6) impact analyses for the Region 1 and Region 2 racks (3 drop cases for each rack region). The report only presents the results for three (3) analyses, on the basis that these are the bounding conditions. Please explain the technical basis for concluding that these are the bounding conditions, or provide the results for the three (3) analyses not presented in the report.

<u>Spent Fuel Racks</u> - Structural/Seismic Analysis

TR54-14 In accordance with Standard Review Plan (SRP) 3.8.4, App. D, and as indicated in Table 2-5 of the report and the markup for DCD Table 9.1-1, one of the fuel handling accident loads that need to be considered is uplift force on the rack caused by a postulated stuck fuel assembly. Section 2.8.3 of the report states: "An evaluation of a stuck fuel assembly, leading to an upward load of 2,000 lb has been performed. The results from the evaluation show that this is not a bounding condition because the local stresses do not exceed 2,500 psi." The information provided is not sufficient for the staff to reach a conclusion that this load has been adequately considered. Please provide a detailed description of the assumptions, the analyses conducted, the results obtained, and the basis for the conclusion that this is not a bounding condition.

TR54-15 Insufficient descriptive information has been included in the spent fuel report to permit an adequate review of the structural/seismic analysis of the spent fuel racks. As indicated in SRP 3.8.4, App. D, provide descriptive information including plans and sections showing the spent fuel racks and pool walls, liner, and concrete walls. All of the major features of the racks including the cell walls, baseplate, pedestals, bearing pads, neutron absorber sheathing, any impact bars, welds connecting these parts, and any other elements in the load path of the racks should be shown on one or several drawings. These drawings should also indicate related information which includes key: cutouts, dimensions, material thicknesses, and gaps (fuel to cell, rack to rack, rack to walls, and rack to equipment area). In addition to the above, for review of postulated fuel handling drop accident and quantification of the drop parameters, drawings with sufficient details for the fuel handling system should be provided to facilitate the review as indicated in SRP 3.8.4, App. D.

TR54-16 The Westinghouse Report APP-GW-GLR-033, Rev. 0, appears to be a summary type report. However, to adequately perform a technical review of the analysis and design of the spent fuel racks, a more detailed report should have been submitted, similar to those provided in past technical reviews of spent fuel racks for specific nuclear power plants. Therefore, provide the detailed spent fuel storage rack report/calculation for review prior to the planned audit. This type of report has been provided in past reviews; its submittal prior to scheduling the on-site audit may resolve many of the RAIs, and would make the audit much more productive.

TR54-17 Insufficient data is provided regarding the input loads used for the seismic analysis of the spent fuel racks. The following information is requested:

a. Floor response spectra (X, Y, and Z - vertical directions) at or the near the elevation of the top of the fuel racks and near the bottom of the fuel rack or pool floor corresponding to the damping value used for the analysis.

b. Explain why the envelope of these two sets of spectra was not used.

c. The current DCD is applicable for the hard rock site. Therefore, provide further explanation for the range of soil and rock properties used in enveloping the seismic floor spectra. Where are these range of soil/rock properties specified for confirmation by future combined license applicant?

d. For the synthetic time histories, provide plots of the three time histories, the cross correlation coefficients, the comparisons of the spectra from the synthetic time histories to the enveloped target response spectra, and the comparisons of the power spectral density plots to the target power spectral density function associated with the target response spectra.

e. Which time history was used (displacement, velocity, or acceleration)? Were all three directions input simultaneously? Was gravity included in the time history analysis?

TR54-18 The seismic analyses only considered the bounding values for the coefficient of friction at 0.2 and 0.8 between the pedestal and the pool liner. Provide the technical basis for only considering these two bounding values and not other intermediate values. Also, what is assumed to slide: the pedestal to bearing plate or bearing plate to pool liner, and the basis for this? If it is the surface between the bearing plate and pool liner, how is damage to the pool liner due to horizontal forces avoided. Are there any physical provisions to prevent the bearing plate and pedestal to slide excessively to the point that the pedestal centerline would be at or beyond the edge of the bearing plate?

TR54-19 Section 2.2.1, first paragraph indicates that the response of the freestanding rack involves a complex combination of motions (sliding, rocking, twisting, and turning). Explain the difference between twisting and turning.

TR54-20 Explain the reason for the different type racks (i.e., Region I and Region II). If it is because of different fuel assembly types, then explain how the analysis considers the various types and combinations of fuel assemblies (e.g., mass, sizes, gaps, fluid coupling, etc.).

TR54-21 How are the different impact stiffness values determined for the fuel to cell wall, rack to rack, rack to wall, and pedestal to floor? Since the impact forces can be greatly affected by the impact spring constant, what is the sensitivity of the impact forces and rack responses to variation in these spring constants? Are impact forces imparted directly onto the cell walls or are there impact bars?

TR54-22 A number of sections in the report refer to analytical methods in other references, rather than providing sufficient information to explain the approaches used. Therefore, to understand the modeling and analysis approach, provide references 10, 11, 16 and 18.

TR54-23 Section 2.2.2.2 of the report describes some modeling information for a single rack. It indicates that the rack cellular structure elasticity is modeled by a 3-D beam having 3 translational and 3 rotational degrees-of-freedom (DOFs) at each end so that two-plane bending, tension/compression, and twist of the rack are accommodated. Explain why shear stiffness/deformation is not also included. Provide more detailed information about how the beam model of the rack was developed, considering that it is an assembly of many square-celled structures welded at discrete locations.

TR54-24 Section 2.2.2.2 refers to Figure 2-2 for the dynamic beam model of a single rack. The text and figure do not adequately describe the model. Therefore, explain the following:

a. Define what each series of nodal DOFs correspond to (i.e., nodes 1,2; P1, P2, ...; q4, q5, ..., 1*, 2*, ...). While some of these may be deduced by judgement, the report should clearly define all of these.

b. Explain whether there are 5 nodes and 4 beams along the rack beam model to coincide with the 5 nodes and 4 elements of the fuel assemblies?

TR54-25 Explain whether only full fuel racks are included in the two simulations, or if several scenarios are considered; i. e., different fill ratios, from partially full to full within a given rack; varying fuel locations within the partially filled rack; varying fill and locations in adjacent racks. Provide the technical justification if only full racks are considered. Also, would it ever be possible to have less than all fuel racks (eight) in the pool. If so, then additional simulations would be needed. If not, is there a requirement in the DCD that specifies all fuel racks must always be in place whenever fuel is stored in any of the racks?

TR54-26 What are the gaps and tolerances for each of the gaps between the fuel to cell wall, rack to rack, and rack to wall? What are the assumed initial locations of the various components (fuel assemblies and each rack) and what is the technical basis for this assumption. Were any studies done for different initial conditions (considering tolerances); if not, explain why. What requirements are in the DCD to ensure that the assumed gaps (considering tolerances) will always be maintained throughout the licensing period?

TR54-27 Provide more detailed information about how the fluid coupling was calculated and implemented in the AP1000 simulations. Describe the approaches used for fluid coupling of fuel assemblies to fuel cell walls, rack to rack, and rack to pool wall because there would be some differences among these. For the rack to rack and rack to wall fluid coupling, explain how fluid flow was considered horizontally as well as vertically over the top of the racks and flow to the bottom of the rack. Describe and justify any assumptions made in the approach. For example, small vibratory deflections relative to the gaps are probably assumed and the fluid gaps are not updated according to the rack displacements (see Section 2.4 of the report).

TR54-28 Even though a time history analysis was performed, good engineering practice is to also perform a modal analysis for a fixed base single rack to understand its dynamic characteristics. Was this done and what are the natural frequencies and corresponding mode shapes?

TR54-29 The load combinations specified in Table 2-5 of the subject report and Table 9.1-1 (markup version of the DCD provided with the subject report) do not match SRP 3.8.4, App. D criteria. Therefore, explain or modify the tables to address the following:

a. No load combinations are specified for the spent fuel racks corresponding to service Level A.

b. Temperature conditions T_o and T_a are not included in Table 2-5; however, they are included in the markup DCD Table 9.1-1. A footnote in the markup of DCD Table 9.1-1 states that “For the faulted load combination, thermal loads will be neglected when they are secondary and self limiting in nature and the material is ductile. In freestanding spent fuel racks, thermal effects mainly affect the temperature that is used in specifying the allowable stress and Young’s Modulus.” Based on this statement:

(i) Regarding the first quoted sentence above, Table 2-5, Load Combination corresponding to service levels A and B (which are not the faulted condition) should include $T_{o.}$

(ii) regarding the last quoted sentence above, SRP 3.8.4, App. D indicates that thermal loads due to temperature effects and temperature gradients across the rack structure need to be considered. Temperature gradients can occur due to differential heating effects between one or more filled cell(s) and one or more adjacent empty cell(s). The stresses from these types of thermal loads should be considered because they can still lead to localized failure of the structure. When responding to this, consider temperature loads due to normal and accident conditions, as noted in your Table 9.1-1 and SRP 3.8.4, App. D.

c. Table 2-5 in the report and DCD Table 9.1-1 indicate that the load term P_f is the uplift force on the rack caused by a postulated stuck fuel assembly accident condition or the force developed on the rack from the drop of a fuel assembly during handling to the top of the rack or the baseplate through an empty cell. SRP 3.8.4, App. D separates these two accident events into P_f for the uplift force event and P_d for the drop load event. This is necessary because SRP 3.8.4, App. D specifies that the acceptance limits for these two events (in combination with deadweight + live load + thermal) are different.

d. Table 2-5, last load combination with E', does not provide the Service Limit. If the same Service Limit, D(1), as indicated in the load combination above the last load combination was intended, then explain whether the functionality capability requirement in footnote (1) (which is applicable to only the new racks) is in addition to or in-place of Level D limits.

TR54-30 When utilizing ASME Code, Section III, Subsection NF, are all of the applicable provisions in NRC Regulatory Guide, 1.124, Rev. 1 also satisfied? This should be clearly stated in the report and the DCD.

TR54-31 The subject report does not discuss any analysis for seismic sloshing effects. Provide a description of the sloshing calculation approach and results for both horizontal directions.

TR54-32 Section 2.3.4.3, first paragraph, refers to 304L stainless steel material and uses 70 ksi for ultimate and 25 ksi for yield. Explain why these values are higher than the ultimate and yield given in Table 2-6 for type 304L stainless.

TR54-33 Section 2.3.4.3, 4th bullet, develops the faulted allowable maximum weld stress for the weld material. Why isn't an allowable maximum weld stress based on the base metal also developed? Normally welds are checked for both weld material and base metal, as was done for Levels A and B in Section 2.3.4.1.

TR54-34 Section 2.3.5 of the report discusses dimensionless stress factors. It states that "R_1 is the ratio of direct tensile or compressive stress on a net section to its allowable value (note pedestals only resist compression)." Explain why this indicates that pedestals only resist compression, since horizontal forces are also generated due to friction during a seismic event? These forces could be quite high and also would introduce shear and moments into the pedestal and rack structure.

TR54-35 Section 2.8.1.4 of the report, which describes the impact loads, indicates that these loads do not result in damage to the racks that would prevent retrievability. Confirm that the acceptance criteria for these impacts include both retrievability and the stress limits for Level D in accordance with the ASME Code, Section III, Subsection NF. Provide the stress ratios for the most critical cells adjacent to the worst case impact.

TR54-36 Some of the information provided in Section 2.8.2 (Rack Structural Evaluation) and Tables 2-9 through 2-15 (stress results) is not clear. Therefore, describe/explain the following:

a. Section 2.8.2.1, 2nd paragraph, indicates that the tables also report the stress factors for the AP1000 Spent Fuel Storage Racks cellular cross section just above and below the baseplate. This implies that the fuel cells continue below the baseplate. Please explain.

b. The same paragraph refers to “pedestal five in the first sheet of the summary tables for each simulation (that is, 9.M.0 where M stands for run number).” Please explain what this means since the tables do not reflect this terminology.

c. The same paragraph refers to “ensures that the overall structural criteria set forth in subsection 2.2.3 are met.” Structural criteria are not presented in subsection 2.2.3.

d. Section 2.8.2.2 a., refers to a stress factor of 2.1516 which it states is given in the tables. However, no such stress factor is given, please explain. Also, are all cells welded to the baseplate on all four sides?

e. Section 2.8.2.2 a.., first bullet, calculates the stress in the weld, connecting the cell walls to the baseplate, equal to 25,047 psi; however, Table 2-12 shows a smaller (maximum) weld stress of 22,647. Please explain.

f. Section 2.8.2.2 b., indicates that a separate finite element model is used to check the baseplate to pedestal welds. Provide a short description of the model, computer code, loading, and location of the maximum tabulated stress in the weld referred to in Table 2-14.

g. Section 2.8.2.2 c., indicates that for calculation of cell welds, the fuel assemblies in adjacent cells are conservatively calculated by assuming that the fuel assemblies in adjacent cells are moving out of phase with one another. It then states that cell to cell weld calculations are based on the maximum stress factor from all runs. However, elsewhere in the report, it was stated that all of the fuel assemblies in the simulation are assumed to vibrate in phase. Provide more information to explain this.

Also, this paragraph indicates that both the weld and the base metal shear results (for cell to cell) are reported in Table 2-14; however, Table 2-14 is labeled baseplate to pedestal welds. If reference was intended to Table 2-15, then note that Table 2-15 provides the shear stress only for the base metal.

h. Section 2.8.2.3 refers to Tables 2-9 through 2-14 for limiting pedestal thread shear stresses for every pedestal. These tables do not seem to apply to pedestal thread shear stress. Therefore, clarify or correct this information.

i. Table 2-9, Summary, identify what rack component/element applies to each of the column headings (i.e., Max Stress Factor, Max. Shear Load, Max Fuel to Cell Wall Impact). Similarly, for the other tables, identify what rack component/element the table applies to (e.g., Tables 2-13 and 2-15 are missing this information).

j. Table 2-10, provides maximum rack to rack displacements relative to the floor. Also provide maximum & minimum relative displacements to the walls.

k. Why are results for “Run 1 and 2" given for some tables and not others? Both should be provided or an explanation should be given why they are included for some tables and not for others.

l. Table 2-15, why is this table labeled “Allowable Shear Stress ...” versus the labeling of other tables and why is it labeled Level D, versus other tables where there is no indication of Levels? All tables should identify which load level they apply to.

TR54-37 Section 2.8.4 indicates that this subsection presents evaluations for potential cell wall buckling and the secondary stresses produced by temperature effects. The description of secondary stresses produced by temperature effects is not included in this section. Add this information to the report. Regarding the evaluation presented for compressive stress in the cell wall for buckling, confirm whether the R5 stress factor used for this calculation includes the worst impact forces generated, including the impacts at the top of the racks.

TR54-38 A number of figures in the markup of the DCD, provided with this report, were eliminated. Even if the new configuration is different, basic outline drawings and key dimensions need to be provided in the DCD.

TR54-39 The computer code MR216 (a.k.a. DYNARACK) as well as the other computer analysis codes should have complete validation documentation and should be made available for review of selected package(s) during the audit. If any of the computer codes have been previously reviewed and approved by the staff on other licensing applications, for the same version of the code, these should be identified.

TR54-40 Explain what provisions are provided for performance of inservice examination of the rack, as indicated in 10 CFR 50.55a(g)(3) for ASME Class 3 component supports.

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