UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

October 16, 2009

The Honorable Gregory B. Jaczko
Chairman
U. S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: REPORT ON THE 3-DIMENSIONAL FINITE ELEMENT ANALYSIS OF THE OYSTER CREEK NUCLEAR GENERATING STATION DRYWELL SHELL

Dear Chairman Jaczko:

During the 566th meeting of the Advisory Committee on Reactor Safeguards (ACRS), October 8 -10, 2009, we reviewed the 3-dimensional (3-D) finite element analysis (FEA) of the Oyster Creek Nuclear Generating Station (Oyster Creek) drywell shell and the associated assessment prepared by the NRC staff. Our Materials, Metallurgy, and Reactor Fuels Subcommittee also reviewed this matter during its meeting on September 23, 2009. During these reviews, we had the benefit of discussions with representatives of the NRC staff, Exelon Nuclear Generation Company (Exelon) and its contractors, and members of the public. We also had the benefit of the documents referenced.

CONCLUSION

The analysis presented by Exelon fulfills its commitment to provide a modern, realistic, 3-D FEA that better quantifies the available safety margin for the current drywell shell configuration of Oyster Creek. The analysis confirms that Oyster Creek's drywell shell complies with its current licensing basis for design basis accidents with margin. This analysis was performed using good engineering practices and judgment and used conservatively biased realistic assumptions.

BACKGROUND

During the 1980s, the licensee discovered corrosion on the outside wall of the Oyster Creek drywell shell. Although some corrosion had occurred in the upper shell region, the majority had occurred in a region near the base of the shell where it was partially supported by a sandbed. The licensee determined that water had been leaking through flaws in the refueling cavity liner during refueling operations. This water had migrated down the outside of the drywell shell and into the sandbed. As part of the corrective actions, the licensee removed the sand and applied an epoxy coating to the outside of the shell in the sandbed region. In addition, repairs were made to the refueling cavity liner and the concrete drain trough under the refueling seal. These repairs reduced the leakage and routed any leakage to a drain line rather than down the outside of the drywell shell. To further reduce leakage, the licensee applied strippable coatings to the liner during all but one of the subsequent refueling outages.

In 1992, the licensee performed ultrasonic testing to determine the as-found condition of the drywell shell and also performed a structural analysis to demonstrate acceptability of the containment in the degraded condition. The 1992 structural analysis was reviewed and approved by the NRC staff and remains the licensing basis analysis for the drywell shell. This analysis included a determination of the stresses in the thinned region under the design pressure loads and an evaluation of the potential for buckling during normal operations and postulated accident conditions.

The 1992 structural analysis was based on the assumption that the shell is uniformly thinned in the sandbed region to a thickness of 0.736 inch. The analysis showed that the shell met the allowable stress values for buckling per Section NE-3222 of the 1989 Edition of the ASME Code, Section III, Division 1, Subsection NE, Class MC Components. Since the average thickness of the shell is greater than 0.736 inch, the actual factor of safety exceeds the Code minimums. But, based on the licensing basis analysis, it is not possible to get a good estimate of the actual margins.

During our February 1, 2007 meeting regarding the license renewal application for Oyster Creek, Exelon committed to perform a 3-D FEA of the Oyster Creek drywell shell in the as-found degraded condition using more modern methods. The basic purpose of the analysis was to provide a more accurate quantification of the actual margins above the ASME Code required minimums.

In our February 8, 2007 report on the Oyster Creek license renewal application, we recommended that the staff add a license condition to ensure that the applicant fulfilled this commitment to perform a 3-D FEA of the Oyster Creek drywell shell prior to entering the period of extended operation, and requested a briefing on the results of the analysis when they became available. Consequently, this commitment was entered as a license condition in the staff's final Safety Evaluation Report. By letter dated January 22, 2009, Exelon submitted the results of the 3-D FEA of the Oyster Creek drywell shell.

DISCUSSION

The 3-D FEA submitted by Exelon to meet its commitment was performed by Structural Integrity Associates (SIA). SIA had access to proprietary design data for the drywell shell and were able to develop a very detailed structural model including all penetrations over 3 inches. Penetrations that are 3 inches or smaller are not specifically modeled. Instead, only their reinforcing plates or insert plates are modeled to account for the added stiffness of the plates. The vent pipes/header are modeled to account for the effect of their stiffness on the rest of the drywell. The base model includes approximately 406,000 shell elements ranging in size from 0.75 inch in locally thinned areas, 1.5 inches in the bulk of the sandbed region, 3.0 inches in most of the cylindrical and spherical shell, and up to 12.0 inches in the bottom spherical shell within the concrete. Mesh convergence was studied by considering meshes with up to 1,000,000 elements. Since the radius-to-thickness (R/t) ratio of the cylindrical and spherical shells ranges from 300-600, the use of shell elements, which assume a linear variation of the stress across the thickness is appropriate.

The SIA analysis has been reviewed by the staff, the ACRS and its consultants, Dr. Gery Wilkowski and Professor John Hutchinson, as well as the consultant for the State of New Jersey, Becht Nuclear Services. There is general agreement that this is a modern structural analysis performed utilizing good engineering practices and judgment. The primary sources of uncertainty are the characterization of the thickness of the sandbed region and the calculation of the capacity reduction factors, which account for the reduction in buckling loads of shells due to their sensitivity to deviations from perfect geometry.

Ultrasonic thickness measurements, which are the most accurate way to measure the remaining thickness of the shell, are available only for a small fraction of the sandbed region. Two types of measurements have been made, those based on 7 x 7 or 1 x 7 grids with 1-inch spacing between transducers, and individual ultrasonic thickness measurements at selected locations. Except for the grids in the trenches in Bays 5 and 17, all the grid measurements are made at Elevation 11' 3". The grid locations were chosen as the thinnest locations at that elevation.

The locations for the individual ultrasonic thickness measurements were selected by visual examination to be the areas of greatest local thinning over a roughly 2.5 inch diameter region. The areas selected for examination were ground to ensure flat contact of the probe with the surface. Micrometer measurements showed that this grinding further reduced the local thickness by about 0.10 inch.

The licensee used visual inspection, judgment, the results from the grids at Elevation 11' 3", supplemented by the grids in the trenches in Bays 5 and 17 to estimate the average thicknesses in each of the Bays. The licensee used the results of the individual ultrasonic thickness measurements primarily to define thinned local regions.

The selection of the locations for the grid and the locations of the individual ultrasonic thickness measurements have been inspected and reviewed by the staff. They have been found to characterize the thickness conservatively for licensing basis analyses. The staff also finds Exelon's modeling of the corroded areas in the sandbed region acceptable for a realistic analysis of the available margin to the ASME Code limits. We concur with the staff's conclusion.

In the analysis performed by the Sandia National Laboratories (SNL) to support the review of the Oyster Creek license renewal, the individual ultrasonic thickness measurements were used to estimate the average thickness of the sandbed region. Such an approach is conservatively biased, since the thinnest regions were selected, and the thicknesses were further reduced by grinding. Not surprisingly, SNL obtained average thicknesses in the bays that are typically less than those estimated by the licensee. The average difference over all the bays is -0.068 inch. For the most severely corroded Bays 1 and 19, the licensee's estimates are actually somewhat less than the SNL estimates. Based on the conservatisms inherent in using the individual ultrasonic thickness measurements to estimate remaining thickness, the SNL results support the conclusion that at least the average thickness of the sandbed region used by the licensee is appropriate for a realistic analysis of the margins in the drywell shell.

The licensee increased the size of the locally thinned zones in Bays 1, 13, 15, 17, and 19 compared to those used in the licensing basis analysis. The size and remaining thickness assigned to these local areas are conservative compared to the data, and the sizes are larger than those used by SNL.

A variety of load cases were studied by SIA. The limiting cases for buckling were the refueling case with the dead weight of the reactor cavity water and the post-accident case with seismic load and flooding. The minimum required safety factor in the refueling case for the current licensing basis is 2.0. The computed minimum value in the drywell occurs in the upper cylindrical shell and is 3.39. The minimum value in the sandbed region occurs in Bay 3 and is 3.54. The minimum required safety factor in the flooding case for the current licensing basis is 1.67. The computed minimum value is 2.02 in Bay 19.

In addition to the base case with the thicknesses selected as described above, the licensee also considered two sensitivity cases. In the first, the wall thickness of the 51-inch diameter locally thinned area in Bay 1 was reduced by an additional 0.10 inch, keeping the thickness in the un-thinned portion of Bay 1 constant. In the second, the thickness in the un-thinned portion of Bay 19 was reduced by 0.05 inch, keeping the locally thinned area in the bay constant.

In the first case, for refueling, the computed minimum safety factor occurs in the sandbed, Bay 3, rather than the upper cylinder and is 3.21 (versus 3.39). For flooding, the minimum safety factor still occurs in Bay 19 and is 1.98 (versus 2.02).

In all the solutions, although the thicknesses of the bays vary from 0.826 inch to 1.13 inches and some bays have locally thinned areas and others do not, the safety factor varies by less than +/- 8%. The safety factor associated with a bay does not correlate with the thickness of the bay. The 3-D FEA shows that loads redistribute from thinner regions to thicker regions. This suggests that the uncertainties in the thicknesses of the individual bays have relatively small effects on the safety factors, unless the average thickness of the entire sandbed region has been significantly overestimated. A comparison of the results of the licensee analysis with those of the SNL analysis of the thickness, based on the individual ultrasonic thickness measurements, reveals overestimation of the average thickness is unlikely.

The FEA performed by SIA compute buckling loads based on perfect geometries. For some structures such as beams and thick-walled cylinders, the observed buckling loads are close to those predicted based on "perfect" geometry. For thin cylindrical and spherical shells, the observed buckling load can be a small fraction (as low as 0.2) of that predicted for the perfect structure. To account for this imperfection sensitivity, capacity reduction factors, i.e., multipliers on the predicted loads, are introduced.

In the 1992 structural analysis reviewed and approved by the NRC staff, the buckling analysis used ASME Code Case N-284, Revision 1 to compute the capacity reduction factors. The staff accepted the use of this Code Case in the 1992 analysis. However, the amount of margin above the Code minimum depended on the applicability of the increase in the buckling capacity due to tensile stresses orthogonal to the applied compressive stresses computed according to the Code Case. At our February 1, 2007 meeting, Dr. C. Miller, the author of the ASME Code Case, described the technical basis for the Code Case and presented experimental results to demonstrate that the increased capacity factor was applicable. The increased capacity factor used in the 1992 analysis provided by the licensee was based on results for cylindrical shells. Dr. Miller showed results of tests conducted on spherical shells which demonstrated that the results for cylindrical shells were conservative for spherical shells. The staff reaffirmed its position that the use of the increased capacity factor was acceptable for the analysis of the Oyster Creek drywell shell. We concurred with this position.

In our assessment of the current analysis, we sought additional input on the capacity reduction factors computed from the Code Case and used by SIA. Our consultant, Professor

John Hutchinson of Harvard, is known for his analytical studies of the effect of small geometric imperfections on the buckling loads of cylindrical and spherical shells. He performed an analysis to get an independent estimate of the capacity factor for a spherical shell under biaxial loads such as those that occur in the analysis of the drywell shell. The Code Case results based on the empirical formulas developed by Dr. Miller are slightly more conservative than the results of Professor Hutchinson's analysis. Thus, we remain convinced that the use of the modified capacity factors by SIA is appropriate.

Dr. Sam Armijo did not participate in the Committee's deliberations regarding this matter.

Sincerely,

/RA/

Mario V. Bonaca

REFERENCES

1. Letter from M. P. Gallagher, Exelon Nuclear, to U.S. Nuclear Regulatory Commission, "Results of Three-Dimension Structural Analysis of the Oyster Creek Drywell Shell, Associated with AmerGen's License Renewal Application," 01/22/2009 (ML090270871, ML090270872 & ML090270873)

2. Report from W. J. Shack, Chairman, ACRS, to D. E. Klein, Chairman, NRC, "Report on the Safety Aspects of the License Renewal Application for the Oyster Creek Generating Station," 02/08/2007 (ML070390474)

3. Memorandum from M. Khanna, NRR, to R. Conte, Region I, "Assessment of the Oyster Creek 3-D Finite Element Analysis of the Drywell Shell," 05/12/2009 (ML091310413)

4. Letter from J. Lipoti, State of New Jersey, to US NRC transmitting, "New Jersey Department of Environmental Protection Oyster Creek Drywell Review," prepared by Becht Nuclear Services, 04/07/2009 (ML091040736)

5. ACRS Consultant Report from Dr. G. M. Wilkowski, to W. J. Shack, ACRS Subcommittee Chairman, "Final Report on Review of Oyster Creek Generation Station 3-D Drywell Confirmatory Analyses," 10/07/2009 (ML92870452)

6. ACRS Consultant Report from J. W. Hutchinson, "Comments on the Buckling Assessment of the Oyster Creek Drywell Shell with Emphasis on the Determination of Capacity Reduction Factors," 10/02/2009 (ML092870423)

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Letter to the Honorable Gregory B Jaczko, Chairman, NRC, from Mario V. Bonaca, Chairman, ACRS, dated October 16, 2009

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