UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

DRYWELL STRUCTURAL INTEGRITY

OYSTER CREEK NUCLEAR GENERATING STATION

GPU NUCLEAR CORPORATION

DOCKET NO. 50-219

I. INTRODUCTION

In 1986 the steel drywell at Oyster Creek Nuclear Generating Station (OCNGS) was found to be extensively corroded in the area of the shell which is in contact with the sand cushion around the bottom of the drywell. Since then GPU Nuclear Corporation, (GPUN, the licensee of OCNGS), has instituted a program of periodic inspection of the drywell shell sand cushion area through ultrasonic testing (UT) thickness measurements. The inspection has been extended to other areas of the drywell and some areas above the sand cushion have been found to be corroded also. From the UT thickness measurements, one can conclude that corrosion of the drywell shell in the sand cushion area is continuing. In an attempt to eliminate corrosion or reduce the corrosion rate, the licensee tried cathodic protection and found it to be of no avail. An examination of the results of consecutive UT measurements, confirmed that the corrosion is continuing. There is concern that the structural integrity of the drywell cannot be assured. Since the root cause of the corrosion in the sand cushion area is the presence of water in the sand, the licensee has considered sand removal to be an important element in its program to eliminate the corrosion threat to the drywell integrity.

In the program, the licensee first established the analysis criteria and then performed the analyses of the drywell for its structural adequacy with and without the presence of the sand. The licensee performed stress analyses and stability analyses for both with and without the sand cases and concluded the drywell with or without the sand to be in compliance with the criteria established for the reevaluation. It is to be noted that the original purpose of the sand cushion is to provide a smooth transition of stresses from the fixed portion to the free-standing portion of the steel drywell.

II. EVALUATION

The staff with the assistance of consultants from Brookhaven National Laboratory (BNL) has reviewed and evaluated the information (Refs. 1,2,3,4,5) provided by the licensee.

1. Re-Analysis Criteria

The drywell was originally designed and constructed to the requirements of ASME Section VIII code and applicable code cases, with a contract date of July 1, 1964. The Section VIII Code requirements for nuclear containment vessels at that time were less detailed than at any subsequent date. The evolution of the ASME Section III Code for metal containments and its relation with ASME Section VIII Code were reviewed and evaluated by Teledyne Engineering Services (TES). The evaluation criteria used are based on ASME Section III Subsection NE Code through the 1977 summer addenda. The reason for the use of the Code of this vintage is that it was used in the Mark I containment program to evaluate the steel torus for hydrodynamic loads and that the current ASME Section III Subsection NE Code is closely related to that version. The following are TES's findings relevant to Oyster Creek application:

a) The steel material for the drywell is A-212, grade B, Firebox Quality (Section VIII), but it is redesignated as SA-516 grade in Section III.

b) The relation between the allowable stress (S) in Section VIII and the stress intensity (Smc) in Section III for metal containment is 1.1S = Smc.

c) Categorization of stresses into general primary membrane, general bending and local primary membrane stresses and membrane plus bending stresses is adopted as in Subsection NE.

d) The effect of a locally stressed region on the containment shell is considered in accordance with NE-3213.10.

In addition to ASME Section III Subsection NE Code, the licensee has also invoked ASME Section XI IWE Code to demonstrate the adequacy of the Oyster Creek drywell. IWE-3519.3 and IWE-3122.4 state that it is acceptable if either the thickness of the base metal is reduced by no more than 10% of the normal plate thickness or the reduced thickness can be shown by analysis to satisfy the requirements of the design specification.

The staff has reviewed the licensee's adoption of ASME Section III Subsection NE and Section XI Subsection IWE in its evaluation of the structural adequacy of the corroded Oyster Creek drywell, and has found it to be generally reasonable and acceptable.

By adopting the Subsection NE criteria, the licensee has treated the corroded areas as discontinuities per NE-3213.10, which was originally meant for change in thicknesses, supports, and penetrations. These discontinuities are highly localized and should be designed so that their presence will have no effect on the overall behavior of the containment shell. NE-3213.10 defines clearly the level of stress intensity and the extent of the discontinuity to be considered localized. A stress intensity limit of 1.1 Smc is specified at the boundary of the region within which the membrane stress can be higher than 1.1 Smc. The region where the stress intensity varies from 1.1 Smc to 1.0 Smc is not defined in the Code because of the fact that it varies with the loading. In view of this, the licensee rationalized that the 1.1 Smc can be applied beyond the region defined by NE-3213.10 for localized discontinuity without any restriction throughout the drywell. The staff disagreed with the licensee's interpretation of the Code. The staff pointed out that for Oyster Creek drywell, stresses due to internal pressure should be used as the criterion to establish such a region. The interpretation of Section XI Subsections IWE-3519.3 and IWE-3122.4 can be made only in the same context. It is staff's position that the primary membrane stress limit of 1.1 Smc not be used indiscriminately throughout the drywell.

In order to use NE-3213.10 to consider the corroded area as a localized discontinuity, the extent of the reduction in thickness due to corrosion should be reasonably known. UT thickness measurements are highly localized; however, from the numerous measurements so far made on the Oyster Creek drywell, one can have a general idea of the overall corroded condition of the drywell shell and it is possible to judiciously apply the established re-analysis criteria.

2. Re-analyses

The re-analyses were made by General Electric Company for the licensee, one reanalysis considered the sand present and the other considered the drywell without the sand. Each re-analysis comprises a stress analysis and stability analysis. Two finite element models, one axisymmetric and another a 36° pie slice model were used for the stress analysis. The ANSYS computer program was used to perform the analyses. The axisymmetric model was used to determine the stresses for the seismic and the thermal gradient loads. The pie slice model was used for dead weight and pressure loads. The pie slice model includes the vent pipe and the reinforcing ring, and was also used for buckling analysis. The same models were used for the cases with and without sand, except that in the former, the stiffness of sand in contact with the steel shell was considered. The shell thickness in the sand region was assumed to be 0.700" for the with-sand case and to be 0.736" for the without-sand case. The 0.70" was, as claimed by the licensee, used for conservatism and the 0.736" is the projected thickness at the start of fuel cycle 14R. The same thicknesses of the shell above the sand region were used for both cases. For the with-sand case, an analysis of the drywell with the original nominal wall thicknesses was made to check the shell stresses with the allowable values established for the re-analyses.

The licensee used the same load combinations as specified in Oyster Creek's final design safety analysis report (FDSAR) for the re-analyses. The licensee made a comparison of the load combinations and corresponding allowable stress limits using the Standard Review Plan (SRP) section 3.8.2 and concluded they are comparable.

The results of the re-analyses indicated that the governing thicknesses are in the upper sphere and the cylinder where the calculated primary membrane stresses are respectively 20,360 psi and 19,850 psi vs. the allowable stress value of 19,300 psi. There is basically no difference, in the calculated stresses at these levels, between the with and without sand cases. This should be expected, because in a steel shell structure the local effect or the edge effect is damped in a very short distance. The stresses calculated exceed the allowable by 3% to 6%, and such exceedance is actually limited to the corroded area as obtained from UT measurements. However, in order to perform the axisymmetric analysis and analysis of the pie slice model, uniform thicknesses were assumed for each section of the drywell. Therefore, the calculated over-stresses may represent only stresses at the corroded areas and the stresses for areas beyond the corroded areas are less and would most likely be within the allowable as indicated in results of the analyses for nominal thicknesses. The diagram in Ref. 6 indicated such a condition. It is to be noted that the stresses for the corroded areas were obtained by multiplying the stresses for nominal thicknesses by the ratios between the corroded and nominal thicknesses.

The buckling analyses of the drywell were performed in accordance with ASME Code Case N-284. The analyses were done on the 36° pie slice model for both with-sand and without-sand cases. Except in the sand cushion area where a shell thickness of 0.7" for the with-sand case and a shell thickness of 0.736" for the without-sand case were used, nominal shell thicknesses were considered for other sections. The load combinations which are critical to buckling were identified as those involving refueling and post accident conditions. By applying a factor of safety of 2 and 1.67 for the load combinations involving refueling and the post-accident conditions respectively, the licensee established for both cases the allowable buckling stresses which are obtained after being modified by capacity and plasticity reduction factors. It is found that the without-sand, case for the post-accident condition is most limiting in terms of buckling with a margin of 14%. The staff and its Brookhaven National Laboratory (BNL) consultants concur with the licensee's conclusion that the Oyster Creek drywell has adequate margin against buckling with no sand support for an assumed sandbed region shell thickness of 0.736 inch.

A copy of BNL's technical evaluation report is attached to this safety evaluation.

III. <u>CONCLUSION</u>

With the assistance of consultants from BNL, the staff has reviewed and evaluated the responses to the staff's concerns and the detailed re-analyses of the drywell for the with-sand and without-sand cases. The reanalyses by the licensee indicated that the corroded drywell meets the requirements for containment vessels as contained in ASME Section III Sub ection NE through summer 1977 addenda. This Code was adopted in the Mark I containment program. The staff agrees with the licensee's justification of using the above mentioned Code requirements with one exception, the use of 1.1 Smc throughout the drywell shell in the criteria for stress analyses. It is the staff's position that the primary membrane stress limit of 1.1 Smc not be used indiscriminately throughout the drywell. The staff accepted the licensee's reanalyses on the assumption that the corroded areas are highly localized as indicated by the licensee's UT measurements. The stresses obtained for the case of reduced thickness can only be interpreted to represent those in the corroded areas and their adjacent regions of the drywell shell. In view of these observations, it is essential that the licensee perform UT thickness measurements at refueling outages and at outages of opportunity for the life of the plant. The measurements should cover not only areas previously inspected but also accessible areas which have never been inspected so as to confirm that the thicknesses of the corroded areas are as projected and the corroded areas are localized. Both of these assumptions are the bases of the reanalyses and the staff acceptance of the reanalysis results.

References:

1. "An ASME Section VIII Evaluation of the Oyster Creek Drywell Part 1, Stress Analysis" GE Report No. 9-1 DRF #00664 November 1990, prepared for GPUN (with sand).

2. "Justification for use of Section III, Subsection NE, Guidance in Evaluating the Oyster Creek Drywell" TR-7377-1, Teledyne Engineering Services, November 1990 (Appendix A to Reference 1).

3. "An ASME Section VIII evaluation of the Oyster Creek Drywell, Part 2 Stability Analysis" GE Report No. 9-2 DRF #00664, Rev. 0, & Rev. 1. November 1990, prepared for GPUN (with sand).

4. "An ASME Section VIII Evaluation of Oyster Creek Drywell for without sand case, Part I, stress analysis" GE Report No. 9-3 DRF #00664, Rev. 0, February 1991. Prepared for GPUN.

5. "An ASME Section VIII Evaluation of Oyster Creek Drywell, for without sand case, Part 2 Stability Analysis" GE Report No. 9-4, DRF #00664 Rev. 0, Rev. 1 November 1990, prepared for GPUN.

6. Diagram attached to a letter from J. C. Devine Jr. of GPUN to NRC dated January 17, 1992 (C321-92-2020, 5000-92-2094).

Principal Contributor: C.P. Tan

Date: April 24, 1992

Attachment:
BNL Technical Evaluation
Report

BROOKHAVEN NATIONAL LABORATORY

TECHNICAL EVALUATION REPORT

ON

STRUCTURAL ANALYSES OF THE CORRODED OYSTER CREEK STEEL DRYWELL

1. Introduction

An inspection of the steel drywell at the Oyster Creek Nuclear Generating Station in November 1986 revealed that some degradation due to corrosion had occurred in the sandbed region of the shell. Subsequent inspections also identified thickness degradations in the upper spherical and cylindrical sections of the drywell. The licensee, GPU Nuclear Corporation, has performed structural analyses to demonstrate the integrity of the drywell for projected corroded conditions that may exist at the start of the fourteenth refueling outage (14R). This outage is expected to start in October 1992. In an attempt to arrest the corrosion, the licensee plans to remove the sand from the sandbed region. Consequently, they have submitted structural analyses of the drywell both with and without sand for drywell wall thicknesses projected to exist at the start of 14R outage.

2. Summary of Licensee's Analyses

The analyses performed by the licensee utilized the drywell wall thicknesses summarized in Table 1.

Table 1
Drywell Wall Thicknesses

Drywell Region	As-Designed Thicknesses (in.)	Projected 95% Confidence 14R Thicknesses (in.)
Cylindrical Region	0.640	0.619
Knuckle	2.5625*	2.5625*
Upper Spherical Region	0.722	0.677
Middle Spherical Region	0.770	0.723
Lower Spherical Region Except Sand Bed Area	1.154	1.154
Sand Bed Region	1.154	0.736

*NOTE: Table 2-1 of both References 1 and 3 indicates that the knuckle thickness is 2.625". This appears to be a mistake since the knuckle thickness is shown to be 2-9/16" in Figure 1-1 of the same report.

The stress analysis for the "with sand" case is described in Reference 1. For this analysis the licensee utilized the as-designed thicknesses, except for the sandbed region where a thickness of 0.70" was used. The stress results were obtained from a finite element analysis which utilized axisymmetric solid elements and the ANSYS computer program. Later, the stress results were scaled to address the local thinning in areas other than the sandbed region (the projected 95% confidence 14R thicknesses in Table 1). The loads and load combinations considered in the analysis are based on the FSAR Primary Containment Design Report and the 1964 Technical Specification for the Containment. Appendix E of Reference 1 compares the load combinations considered in the analysis with those given in Section 3.8.2 of the NRC Standard Review Plan, Rev. 1, July 1981.

The stress analysis for the "without sand" case is described in Reference 3. For this analysis the licensee also utilized the as-designed thicknesses, except for the sandbed region where a thickness of 0.736" was used. In this case, two finite element models, an axisymmetric and a 36° pie slice model, were used. The axisymmetric model is essentially the same as that used in Reference 1; however, the elements representing the sand stiffness were removed. This model was used to determine the seismic and thermal stresses. The pie slice model was used to determine the dead weight and pressure stresses, as well as the stresses for load combinations. The pie slice model included the effects of the vent pipes and the reinforcing ring in the drywell shell in the vicinity of each vent pipe. The drywell and vent shell were modeled using 3-dimensional elastic-plastic quadrilateral shell elements. At a distance of 76 inches from the drywell shell, beam elements were used to model the remainder of the ventline. The loads and load combinations are the same as those considered in Reference 1.

The code of record for the Oyster Creek drywell is the 1962 Edition of the ASME Code, Section VIII with Addenda to Winter 1963, and Code Cases 1270N-5, 1271N and 1272N-5. The licensee utilized these criteria in evaluating the stresses in the drywell, but also utilized guidance from the NRC Standard Review Plan with regard to allowable stresses for service level C and the post-accident condition. The licensee also used guidance from Subsection NE of Section III of the ASME Code in order to justify the use of a limit of $1.1S_{mc}$ in evaluating the general membrane stresses in areas of the drywell where reduced thicknesses are specified. Based on these criteria the licensee has concluded that the stresses in the drywell shell are within code allowable limits for both the "with sand" and "without sand" cases.

The licensee also performed stability analyses of the drywell for both the "with sand" case (Reference 2) and the "without sand" case (Reference 4). For the "with sand" case the licensee utilized the as-designed thicknesses shown in Table 1, except in the sandbed region where a thickness of 0.700 inch was used. For the "without sand" case the same thicknesses were used , except in the sandbed region where a thickness of 0.736 inch was used. The buckling capability of the drywell for both the "with sand" and "without sand" cases was evaluated by using the 36° pie slice finite element model discussed above. For the "with sand" case spring elements were used in the sandbed region to model the sand support. For the "without sand" case these spring elements were removed. The most limiting load combinations which result in the highest compressive stresses in the sandbed region were considered for the buckling analysis. These are the refueling condition (Dead Weight + Live Load + Refueling Water Weight + External Pressure + Seismic) and the post-accident condition (Dead Weight + Live Load + Hydrostatic Pressure for Flooded Drywell + External Pressure + Seismic).

The buckling evaluations performed by the licensee follow the methodology described in ASME Code Case N-284, "Metal Containment Shell Buckling Design Methods, Section III, Class MC", Approved August 25, 1980. The theoretical elastic buckling stress is calculated by analyzing the three dimensional finite element model discussed above. Then the theoretical buckling stress is modified by capacity and plasticity reduction factors. The allowable compressive stress is obtained by dividing the calculated buckling stress by a factor of safety. In accordance with Code Case N-284 the licensee used a factor of safety of 2.0 for the refueling condition and 1.67 for the post-accident condition. The capacity reduction factors were also modified to take into account the effects of hoop stress. Originally the licensee based the hoop stress modification on data related to the axial compressive strength of cylinders (References 2 and 4). Later the licensee revised the approach based on a review of spherical shell buckling data and recalculated the drywell buckling capacities for both the "with sand" and "without sand" cases (Reference 8). For the "with sand" case, the licensee reports a margin above the allowable compressive stress of 47% for the refueling condition and 40% for the post-accident condition. For the "without sand" case, the licensee reports margins of 24.5% for the refueling condition and 14% for the post-accident condition.

3. Evaluation of Licensee's Approach

The analyses performed by the licensee as summarized in Section 2 and discussed more fully in References 1 through 4 have been reviewed and found to provide an acceptable approach for demonstrating the structural integrity of the corroded Oyster Creek drywell. The finite element analyses performed for both the stress and stability evaluations are consistent with industry practice. Except for the use of a limit of $1.1S_{mc}$ in evaluating the general membrane stress in areas of reduced drywell thickness, the loads, load combinations and acceptance criteria used by the licensee are consistent with the guidance given in Section 3.8.2 of the NRC Standard Review Plan, Rev. 1, July 1981. To further support their position, the licensee has provided two appendices to Reference 1.

Appendix A provides a detailed justification for the use of Section III, Subsection NE as guidance in evaluating the Oyster Creek drywell. Appendix E compares the load combinations given in the Final Design Safety Analysis Report (FDSAR) with the load combinations given in SRP 3.8.2 and demonstrates that the load combinations used in the analysis envelop those given in the SRP.

In the areas of the drywell where reduced thicknesses are specified, the licensee has used a limit of $1.1S_{mc}$ to evaluate the general membrane stresses. In support of this position the licensee has cited the provisions of NE-3213.1 of the ASME Code concerning local primary membrane stresses. In effect, the licensee's criteria would treat corroded or degraded areas as discontinuities. For such considerations the code places no limit on the extent of the region in which the membrane stress exceeds $1.0S_{mc}$ but is less than $1.1S_{mc}$. In support of this position the licensee has provided the opinion of Dr. W.E. Cooper, a well known expert on the development of the ASME Code. Dr. Cooper concluded that "given a design which satisfies the general Code intent, as the Oyster Creek drywell does as originally constructed, it is not a violation of Subsection NE requirements for the membrane stress to be between $1.0S_{mc}$ and $1.1S_{mc}$ over significant distances". The licensee has also cited the provisions of IWE-3519.3 which accepts up to a 10% reduction in the thickness of the original base metal.

The licensee's position has merit, but great caution must be exercised to assure that such a position is not applied indiscriminately. In the case of the Oyster Creek drywell the licensee has concluded that "there are very few locations where the calculated stress intensities for design basis conditions, would exceed $1.0S_{mc}$, and in these cases only slightly" (Reference 7). The licensee has provided additional information in Reference 9 to support this conclusion. Based on the information provided by the licensee which demonstrates that the use of the $1.1S_{mc}$ criteria is limited to localized areas, it is concluded that the Oyster Creek drywell meets the intent of the ASME Code.

As discussed in Section 2, the capacity reduction factors used in the buckling analysis are modified to take into account the beneficial effects of tensile hoop stress. As a result of a question raised during the review regarding this matter, the licensee submitted additional information in Reference 5 to support the approach. This information included a report prepared by C.D. Miller entitled "Effects of Internal Pressure on Axial Compression Strength of Cylinders" (CBI Technical Report No. 022891, February 1991). The report presented a design equation which was the lower bound of the test data included in the report. It also demonstrated that the equation used in References 2 and 4 was conservative relative to the proposed design equation. The report presented further arguments that the rules determined for axially compressed cylinders subjected to internal pressure can be applied to spheres. Subsequently the licensee has submitted Reference 8, which indicates that the original approach was not conservative with regard to its application to spherical shapes and recommends a new equation. However, the documentation supporting the use of this equation is not included in Reference 8, but apparently is contained in a referenced report prepared by C.D. Miller entitled "Evaluation of Stability Analysis Methods Used for the Oyster Creek Drywell" (CBI Technical Report Prepared for GPU Nuclear Corporation, September 1991). This report was subsequently submitted and reviewed by the NRC staff. As discussed in Section 2, the use of the revised equation still results in calculated capacities in compliance with the ASME Code provisions; however, the margins beyond those capacities are reduced from those reported by References 2 and 4.

It is noted that the licensee may have "double-counted" the effects of hoop tension, since the theoretical elastic instability stress was calculated from the finite element model using the ANSYS Code. The elastic instability stress calculated by the ANSYS Code may have already taken into account the effects of hoop tensile stress. However, by comparing the theoretical elastic instability stress and the corresponding circumferential stress predicted by the licensee for the refueling and post-accident cases, it appears that the effect of hoop tension in the ANSYS calculations is small and there is sufficient margin in the results to compensate for the potential "double-counting". Furthermore, it is judged that there is sufficient capacity in the drywell to preclude a significant buckling failure under the postulated loading conditions since the licensee's calculations: (a) incorporate factors of safety of 1.67 to 2.0, depending upon the load condition, and (b) utilize a conservative assumption by considering the shell wall thickness to be severely reduced for the full circumference of the drywell throughout the sandbed region.

During the course of the review of the licensee's submittals, a number of other issues were raised regarding the approach. These included: (a) the basis and method of calculating the projected drywell thicknesses, (b) the scaling of the calculated stresses for the nominal thickness case by the thickness ratio, (c) the effect of stress concentrations due to the change of thickness, (d) monitoring of the drywell temperature, (e) sensitivity of stresses due to variations in the sand spring stiffness, (f) sensitivity of the plasticity reduction factor in the buckling analysis, (g) use of the 2 psi design basis external pressure in the buckling analysis, (h) effect of the large displacement method, (i) the treatment of the large concentrated loads considered in the analysis, and (j) the method of applying the seismic loads to the pie slice model. These issues were adequately addressed by the additional information provided by the licensee in References 5 and 6.

4. Conclusions

The licensee has demonstrated that the calculated stresses in the Oyster Creek drywell (both with and without the sandbed), as a result of the postulated loading conditions, meet the intent of the ASME Code for projected corroded conditions that may exist at the start of the fourteenth refueling outage. However, if the actual thickness in the sandbed region at 14R is close to the projected thickness of 0.736", there may not be adequate margin left for further corrosion through continued operation unless it is demonstrated that removal of sand will completely stop further thickness reductions. The licensee has also demonstrated that there is sufficient margin in the drywell design (both with and without the sandbed) to preclude a buckling failure under the postulated loading conditions.

It should be recognized that the conclusions reached by the licensee have been accepted for this particular application with due regard to all the assumptions made in the analysis and the available margins. The use of the $1.1S_{mc}$ criteria for evaluating general membrane stress in corroded or degraded areas should be investigated further by the NRC staff and the ASME Code Committee and appropriate bounds established before it is accepted for general use. The licensee's buckling criteria regarding the modification of capacity reduction factors for tensile hoop stress and the determination of plasticity reduction factors should also be investigated in a similar manner.

5. References

1. GE Report Index No. 9-1, "An ASME Section VIII Evaluation of the Oyster Creek Drywell - Part 1 - Stress Analysis", November 1990.

2. GE Report Index No. 9-2, "An ASME Section VIII Evaluation of the Oyster Creek Drywell - Part 2 - Stability Analysis," November 1990.

3. GE Report Index No. 9-3, "An ASME Section VIII Evaluation of the Oyster Creek Drywell for Without Sand Case - Part 1 - Stress Analysis," February 1991.

4. GE Report Index No. 9-4, "An ASME Section VIII Evaluation of the Oyster Creek Drywell for Without Sand Case - Part 2 - Stability Analysis," February 1991.

5. GPU Nuclear letter dated March 20, 1991, "Oyster Creek Drywell Containment."

6. GPU Nuclear letter dated June 20, 1991, "Oyster Creek Drywell Containment".

7. GPU Nuclear letter dated October 9, 1991, "Oyster Creek Drywell Containment"

8. GPU Nuclear letter dated January 16, 1992, "Oyster Creek Drywell Containment".

9. GPU Nuclear letter dated January 17, 1992, "Oyster Creek Drywell Containment".