Oyster Creek License Renewal Presentation to ACRS Subcommittee

January 18, 2007
AmerGen Representatives

- Fred Polaski
- John O’Rourke
- Howie Ray
- Pete Tamburro
- Dr. Hardayal Mehta
- Barry Gordon
- Jon Cavallo
- Ahmed Ouaou
Agenda

• Drywell Shell Corrosion
  – Physical Overview
  – Cause and Corrective Actions
  – Drywell Shell Thickness Analysis
  – Sand Bed Region
  – Embedded Portions of the Drywell Shell
  – Upper Shell
Drywell Shell Corrosion
Cause and Corrective Actions
DRYWELL AND REACTOR CAVITY SECTION DETAIL "A"
LIP REPAIRED IN 1988 OUTAGE

DRYWELL TO REACTOR CAVITY SEAL DETAIL DETAIL "B"

PROTECTIVE SHIELDING

GUSSET

TOP PLATE

LEAKAGE PATH

STAINLESS STEEL LINER

REFUELING BELLows

DRAIN FOR STEEL TROUGH (2"

DRYWELL

GASKET

FIRE BARD INSULATION MATERIAL

BOTTOM PLATE

DRAIN FOR CONCRETE TROUGH (2"

1" GAP

OBSERVED DAMAGE AT LIP OF TROUGH CORRECTED IN 1988
LOWER DRYWELL/SANDBED REGION
DETAIL C

NOTE:
LEAKAGE PATH FROM OUTER DRYWELL TO OUTER SANDBED SHELL
Cause and Corrective Actions

• Water accumulation in the sand bed region resulted in corrosion of the exterior surface of the drywell shell

• Corrective actions were completed in 1992
  – Prevented water intrusion into the sand bed region
  – Eliminated corrosive environment by removing the sand
  – Coated the drywell shell with epoxy in the sand bed region
Verification and Monitoring

• In 2006 refueling outage
  – Leakage from the reactor cavity liner, estimated at about 1 gpm, was captured by the drainage system
  – UT measurements of the drywell at 19 monitoring locations for the sand bed region showed no change in thickness
  – 100% visual inspection of the epoxy coating showed it to be in good condition
  – There was no water in the sand bed region
Verification and Monitoring

- In 2006 refueling outage
  - 106 UT measurements at locations measured in 1992, before epoxy coating applied, showed the drywell shell exceeds design thickness requirements
  - UT measurements at 13 locations in the upper elevations of the drywell show only 1 location with minimal ongoing corrosion (meets minimum required through 2029 with margin)
# Drywell Shell Current Condition

<table>
<thead>
<tr>
<th>Drywell Region</th>
<th>Nominal Design Thickness, mils</th>
<th>Minimum Measured Thickness, mils</th>
<th>Minimum Required Thickness, mils</th>
<th>Minimum Available Thickness Margin, mils</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylindrical</td>
<td>640</td>
<td>604</td>
<td>452</td>
<td>152</td>
</tr>
<tr>
<td>Knuckle</td>
<td>2,625</td>
<td>2,530</td>
<td>2260</td>
<td>270</td>
</tr>
<tr>
<td>Upper Sphere</td>
<td>722</td>
<td>676</td>
<td>518</td>
<td>158</td>
</tr>
<tr>
<td>Middle Sphere</td>
<td>770</td>
<td>678</td>
<td>541</td>
<td>137</td>
</tr>
<tr>
<td>Lower Sphere</td>
<td>1154</td>
<td>1160</td>
<td>629</td>
<td>531</td>
</tr>
<tr>
<td>Sand Bed</td>
<td>1154</td>
<td>800</td>
<td>736</td>
<td>64</td>
</tr>
</tbody>
</table>
Drywell Thickness Analysis

Hardayal S. Mehta, Ph.D., P.E.
General Electric
Drywell Analysis

• Analysis completed in early 1990s
  – Without sand in the sand bed

• Modeling of the drywell
  – Loads and Load Combinations

• Buckling analysis
  – Controls the required drywell shell thickness in the sand bed region
  – Uniform drywell shell thickness of 736 mils over the entire sand bed region was used in the analysis

• ASME Section VIII stress analysis based on 62 psi

• Drywell pressure design basis change from 62 psi to 44 psi
  – Stress analysis of the drywell shell based on 44 psi
Modeling of the Drywell
Drywell Configuration

- Oyster Creek Drywell Geometry
  - It is 105’-6” high
  - Drywell head is 33’ in diameter
  - Spherical section has an inside diameter of 70’
  - Ten vent pipes, 6’-6” in diameter, are equally spaced around the circumference to connect the drywell to the vent header inside the pressure suppression chamber
  - Drywell interior filled with concrete to elevation 10’-3” to provide a level floor
  - Base of the drywell is supported on a concrete pedestal conforming to the curvature of the vessel
  - Shell thicknesses vary

- Drywell shell, i.e., the sphere, cylinder, dome and transitions, was constructed from SA-212, Grade B Steel ordered to SA-300 spec.
Finite Element Models Used

- Axisymmetric, Beam and Pie Slice models used
- Axisymmetric drywell model used to evaluate
  - Unflooded and flooded seismic inertia loading
  - Thermal loading during postulated accident condition
- Beam drywell model used to evaluate stresses due to seismic relative support displacement
- Pie slice drywell model used for the Code and buckling evaluations
  - Vent lines included in the model
- No sand stiffness considered in any of the models
Pie Slice Model and Load Application

- Taking advantage of symmetry of the drywell with 10 vent lines, a 36 degree section was modeled
  - The model included the drywell shell from base of the sand bed region to the top of the elliptical head and the vent and vent header
  - Drywell shell thickness in the sand bed region: 736 mils uniform
Pie Slice model
Applied Loads

- Gravity loading consists of dead weight loads, penetration loads, live loads
- Design pressure of 62 psi pressure (at 175°F)
  - Note 62 psi criterion was later changed to 44 psi per Tech. Spec. Amendment #165 (SER dated September 13, 1993)
- Seismic Loads
  - Inertia loads
  - Relative support displacement (Drywell and Reactor Building)
Seismic Load Definition

• Axisymmetric finite element model used to determine inertia loading
  – Drywell is constrained at the “reactor building/drywell/ star truss” interface at elevation 82’-6” and at its base
• Spectra at two locations: At the mat foundation and at the upper constraint
• Envelope spectrum used in ANSYS analysis
# Load Combinations and Constituent Loads

<table>
<thead>
<tr>
<th>Load Combination</th>
<th>Constituent Loads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Operating Condition</td>
<td>Gravity loads + Pressure (2 psi external) + Seismic (2 x DBE)</td>
</tr>
<tr>
<td>Refueling Condition</td>
<td>Gravity loads + Pressure (2 psi external) + Water load + Seismic (2 x DBE)</td>
</tr>
<tr>
<td>Accident Condition</td>
<td>Gravity loads + Pressure (62 psi @ 175 deg. F or 35 psi @ 281 deg. F) + Seismic (2 x DBE)</td>
</tr>
<tr>
<td>Post-Accident Condition</td>
<td>Gravity loads + Water Load to El. 74’ 6” + Seismic (2 x DBE)</td>
</tr>
</tbody>
</table>
Buckling Analysis
Buckling Analysis Conclusion

• The buckling analysis was conducted using a uniform drywell shell thickness in the sand bed region of 736 mils.
• Stress limits and safety factors are in accordance with the Code requirements.
• The analysis shows that the drywell shell meets ASME Code Case N-284 requirements considering all design basis loads and load combinations.
• A locally thinned 12”x 12” area down to 536 mils was evaluated and determined not to have significant impact on buckling.
• The drywell shell thickness will be monitored using 736 mils as acceptance criteria for the minimum required general thickness and 536 mils as the minimum required local thickness.
Buckling Analysis Details

- Basic approach used in buckling evaluation followed the methodology outlined in ASME Code Case N-284

\[
\text{Allowable Compressive Stress} = \eta_i \alpha_i \sigma_{ie} / \text{FS}
\]

- FS is factor of safety (equal to 2.0 for refueling condition and 1.67 for post accident condition)

- Boundary conditions for buckling analysis
  - Symmetric at both edges (sym-sym)
  - Symmetric at one edge and asymmetric at the other edge (sym-asym)
  - Asymmetric at both the edges (asym-asym)
  - This captures all possible buckling mode shapes

- A uniform drywell shell thickness in the sand bed region of 736 mils was used in the buckling analysis
Buckling Analysis Details

Symmetric Buckling of Drywell

Center of Drywell Sphere

Planes of Symmetry

36°

Unbuckled Shape

Buckled Shape

Vent

Radial Displacement
No Rotation
Buckling Analysis Details

Asymmetric Buckling of Drywell

Center of Drywell Sphere

Planes of Symmetry

36°

Unbuckled Shape

Buckled Shape

Rotation (No Radial Disp.)

Vent
Buckling Analysis Details

- Limiting load combination is the refueling condition
- Loads during refueling condition are
  - Gravity loads including weight of refueling water
  - External pressure of 2 psig
  - Seismic inertia and deflection loads for unflooded condition
Buckling Analysis Details

Figure 3-18  Sym-Sym Buckling Mode Shape - Refueling Case

OYSTER CREEK DRYWELL ANALYSIS - OCRFREF SYM-SYM (NO SAND, REFueling)
Buckling Analysis Details

Figure 3-19  Sym-Asym Buckling Mode Shape - Refueling Case

OYSTER CREEK DRYWELL - ASYM - SYM , NO SAND, REFUELING
### Buckling Analysis Details

#### Summary of Buckling Analysis Results – Refueling Case

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical Elastic Instability Stress, $\sigma_{ie}$ (ksi)</td>
<td>46.59</td>
</tr>
<tr>
<td>Capacity Reduction Factor, $\alpha_i$</td>
<td>0.207</td>
</tr>
<tr>
<td>Circumferential Stress, $\sigma_c$ (ksi)</td>
<td>4.51</td>
</tr>
<tr>
<td>Equivalent Pressure, $p$ (psi)</td>
<td>15.81</td>
</tr>
<tr>
<td>&quot;X&quot; Parameter</td>
<td>0.087</td>
</tr>
<tr>
<td>$\Delta C$</td>
<td>0.072</td>
</tr>
<tr>
<td>Modified Capacity Reduction Factor, $\alpha_{i,mod}$</td>
<td>0.325</td>
</tr>
<tr>
<td>Elastic Buckling Stress, $\sigma_e = \alpha_{i,mod} \sigma_{ie}$ (ksi)</td>
<td>15.18</td>
</tr>
<tr>
<td>Proportional Limit Ratio, $\Delta = \sigma_e / \sigma_y$</td>
<td>0.40</td>
</tr>
<tr>
<td>Plasticity Reduction Factor, $\eta_i$</td>
<td>1.00</td>
</tr>
<tr>
<td>Inelastic Buckling Stress, $\sigma_i = \eta_i \sigma_e$ (ksi)</td>
<td>15.18</td>
</tr>
<tr>
<td>Code Factor of Safety, $FS$</td>
<td>2.0</td>
</tr>
<tr>
<td>Allowable Compressive Stress, $\sigma_{all} = \sigma_i / FS$ (ksi)</td>
<td>7.59</td>
</tr>
<tr>
<td>Applied Compressive Meridional Stress, $\sigma_m$ (ksi)</td>
<td>7.59</td>
</tr>
</tbody>
</table>
Evaluation of Local Thinning on Buckling Analysis - Sensitivity Study

• A locally 12”x12” thin area was modeled in the sand bed region drywell shell in the highest stress area, to determine the impact of local thinning on buckling stress
  – Establish minimum required local thickness down to 536 mils

Note: UT thickness measurements taken through 2006 show that locally thinned areas of the drywell shell are not coincident with high stress areas. The locally thinned areas are typically scattered below and near the vent headers. These areas are not highly stressed because of the additional stiffness provided by the vent header.
Buckling Analysis Conclusion

- The buckling analysis was conducted using a uniform drywell shell thickness in the sand bed region of 736 mils.
- Stress limits and safety factors are in accordance with the Code requirements.
- The analysis shows that the drywell shell meets ASME Code Case N-284 requirements considering all design basis loads and load combinations.
- A locally thinned 12”x 12” area down to 536 mils was evaluated and determined not to have significant impact on buckling.
- The drywell shell thickness will be monitored using 736 mils as acceptance criteria for the minimum required general thickness and 536 mils as the minimum required local thickness.
ASME Section VIII Stress Analysis
ASME Section VIII
Stress Analysis Conclusion

• Stress analysis of the drywell shell was conducted in accordance with ASME Code and SRP 3.8.2 using reduced thicknesses due to corrosion.
• Stress limits and safety factors are in accordance with the ASME Code requirements.
• The analysis shows that the drywell shell meets ASME Code Stress requirements considering all design basis loads and load combinations.
• To regain margin, a plant specific analysis was conducted that reduced drywell design basis pressure from 62 psi to 44 psi (Tech Spec Amendment #165)
• The reduction in pressure resulted in a stress reduction of up to 5200 psi
• The minimum required general and local drywell shell thicknesses were calculated in accordance with ASME Code based on 44 psi pressure.
• The drywell shell thickness will be monitored for corrosion using the calculated minimum required general and local thicknesses as acceptance criteria.
Codes and Standards

• The Oyster Creek drywell vessel was designed, fabricated and erected in accordance with the 1962 Edition of ASME Code, Section VIII and Code Cases 1270N-5, 1271N and 1272N-5

• Original Code of record and Code Cases do not provide specific guidance in two areas

• For the size of the region of increased membrane stress, guidance sought from Subsection NE of Section III

• For the Post-accident stress limits Standard Review Plan Section 3.8.2 was used as guidance
### Drywell – Section VIII

#### Allowable Stresses

**Drywell Allowable Stresses**

<table>
<thead>
<tr>
<th>Stress Category</th>
<th>Allowable Stress Values (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All Conditions Except Post-Accident</td>
</tr>
<tr>
<td>General Primary Membrane</td>
<td>19300</td>
</tr>
<tr>
<td>General Primary Membrane Plus Bending</td>
<td>29000</td>
</tr>
<tr>
<td>Primary Plus Secondary</td>
<td>52500</td>
</tr>
</tbody>
</table>

* Allowable values based on Standard Review Plan Section 3.8.2, Steel Containment
# Code Stress Evaluation Results
(based on 62 psi, 1993)

## Primary Stress Evaluation

<table>
<thead>
<tr>
<th>Drywell Region</th>
<th>Stress Category</th>
<th>Calculated Stress Magnitude (psi)</th>
<th>Allowable Stress (psi)</th>
<th>Percent Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylinder (t=0.619 in.)</td>
<td>Primary Membrane</td>
<td>19850</td>
<td>21200*</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Primary Memb.+Bending</td>
<td>20970</td>
<td>29000</td>
<td>28</td>
</tr>
<tr>
<td>Upper Sphere (t=0.677 in.)</td>
<td>Primary Membrane</td>
<td>20360</td>
<td>21200*</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Primary Memb.+Bending</td>
<td>28100</td>
<td>29000</td>
<td>3</td>
</tr>
<tr>
<td>Middle Sphere (t=0.723 in.)</td>
<td>Primary Membrane</td>
<td>19660</td>
<td>21200*</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Primary Memb.+Bending</td>
<td>24610</td>
<td>29000</td>
<td>15</td>
</tr>
<tr>
<td>Lower Sphere (t=1.154 in.)</td>
<td>Primary Membrane</td>
<td>13940</td>
<td>21200*</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>Primary Memb.+Bending</td>
<td>17640</td>
<td>29000</td>
<td>39</td>
</tr>
<tr>
<td>Sand Bed (t=0.736 in.)</td>
<td>Primary Membrane</td>
<td>16540</td>
<td>21200*</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Primary Memb.+Bending</td>
<td>23130</td>
<td>29000</td>
<td>20</td>
</tr>
</tbody>
</table>

* This is (1.1x19300) and is the threshold for local primary membrane stress per NE-3213.10
Regain Margin through Licensing Basis Change

• The drywell pressure of 62 psi was very conservative
• Analysis was conducted in early 1990’s to establish Oyster Creek specific drywell design pressure.
  – Design pressure changed from 62 psi to 44 psi.
    • 44 psi is based on conservatively calculated peak drywell pressure of 38.1 psi plus an added 15% allowance.
  – The change was approved by NRC per Technical Specification Amendment No. 165 (SER dated September 13, 1993).
  – The reduction in pressure resulted in a pressure stress reduction of up to 5200 psi
• Recalculated the required drywell shell thicknesses based on 44 psi to regain thickness margin.
## Primary Membrane Stress Comparison 62 psi vs. 44 psi

<table>
<thead>
<tr>
<th>Drywell Region</th>
<th>Time Frame</th>
<th>As-analyzed Thickness (mils)</th>
<th>Stress Category</th>
<th>Calculated Stress (psi)</th>
<th>Allowable Stress (psi)</th>
<th>Stress Margin (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylinder</td>
<td>1993</td>
<td>619</td>
<td>Primary Membrane</td>
<td>19,850</td>
<td>21,200</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>2006</td>
<td>604</td>
<td>Primary Membrane</td>
<td>14,446</td>
<td>19,300</td>
<td>25</td>
</tr>
<tr>
<td>Upper Sphere</td>
<td>1993</td>
<td>677</td>
<td>Primary Membrane</td>
<td>20,360</td>
<td>21,200</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>2006</td>
<td>676</td>
<td>Primary Membrane</td>
<td>14,796</td>
<td>19,300</td>
<td>23</td>
</tr>
<tr>
<td>Middle Sphere</td>
<td>1993</td>
<td>723</td>
<td>Primary Membrane</td>
<td>19,660</td>
<td>21,200</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>2006</td>
<td>678</td>
<td>Primary Membrane</td>
<td>15,499</td>
<td>19,300</td>
<td>20</td>
</tr>
<tr>
<td>Lower Sphere</td>
<td>1993</td>
<td>1154</td>
<td>Primary Membrane</td>
<td>13,940</td>
<td>21,200</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>2006</td>
<td>1154</td>
<td>Primary Membrane</td>
<td>10,660</td>
<td>19,300</td>
<td>45</td>
</tr>
<tr>
<td>Sand Bed</td>
<td>1993</td>
<td>736</td>
<td>Primary Membrane</td>
<td>16,540</td>
<td>21,200</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>2006</td>
<td>736</td>
<td>Primary Membrane</td>
<td>11,404</td>
<td>19,300</td>
<td>41</td>
</tr>
</tbody>
</table>
Minimum Required Drywell Shell Thickness

• Minimum required general thickness for 44 psi
  – Calculated based on primary membrane stresses for 62 psi, adjusted for pressure reduction (62 psi to 44 psi)

• Minimum required local thickness for 44 psi
  – Calculated based on ASME Section III provisions which allow increase in allowable local primary membrane stress from 1.0 Smc to 1.5 Smc
  – Local thickness criteria is applicable to an area of 2.5” in diameter and less consistent with ASME Section III, Subsection NE-3332.1
  – Extent of Locally thinned areas is evaluated per ASME Section III, Subsection NE-3213.10, NE-3332.2, and NE-3335.1
# Minimum Required Thicknesses Based on 44 psi pressure

<table>
<thead>
<tr>
<th>Drywell Region</th>
<th>Design Nominal Thickness, mils</th>
<th>Minimum Measured General Thickness Thru 2006, mils</th>
<th>Minimum Required General Thickness, mils</th>
<th>Minimum Required Local Thickness, mils</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylinder</td>
<td>640</td>
<td>604</td>
<td>452</td>
<td>301</td>
</tr>
<tr>
<td>Upper Sphere</td>
<td>722</td>
<td>676</td>
<td>518</td>
<td>345</td>
</tr>
<tr>
<td>Middle Sphere</td>
<td>770</td>
<td>678</td>
<td>541</td>
<td>360</td>
</tr>
<tr>
<td>Lower Sphere</td>
<td>1154</td>
<td>1160</td>
<td>629</td>
<td>419</td>
</tr>
<tr>
<td>Sand Bed</td>
<td>1154</td>
<td>800</td>
<td>479(1)</td>
<td>319(2)</td>
</tr>
</tbody>
</table>

1. The minimum required general drywell shell thickness in the sand bed region is 736 mils, controlled by buckling.
2. Acceptance criteria for evaluating locally thinned areas of the drywell shell in the sand bed region is conservatively based on 490 mils instead of 319 mils.
ASME Section VIII
Stress Analysis Conclusion

• Stress analysis of the drywell shell was conducted in accordance with ASME Code and SRP 3.8.2 using reduced thicknesses due to corrosion.
• Stress limits and safety factors are in accordance with the ASME Code requirements.
• The analysis shows that the drywell shell meets ASME Code Stress requirements considering all design basis loads and load combinations.
• To regain margin, a plant specific analysis was conducted that reduced drywell design basis pressure from 62 psi to 44 psi (Tech Spec Amendment #165)
• The reduction in pressure resulted in a stress reduction of up to 5200 psi
• The minimum required general and local drywell shell thicknesses were calculated in accordance with ASME Code based on 44 psi pressure.
• The drywell shell thickness will be monitored for corrosion using the calculated minimum required general and local thicknesses as acceptance criteria.
Sand Bed Region
Sand Bed Region Conclusions

• Corrosion on the outside of the drywell shell in the sand bed region has been arrested
• The coating shows no degradation
• There is sufficient margin to the minimum thickness requirement (64 mils margin above code required average thickness of 736 mils)
Background and History
Sand Bed Internal UTs

- 1983 to 1986 corrosion data 360° at elev. 11’3”
  - When thin locations were identified, UT measurements were taken horizontally and vertically to locate the thinnest locations
  - UT grid measurements were taken at the thinnest locations
  - 19 locations were selected for corrosion monitoring based on over 500 initial data points measured
  - At least one grid is located in each of the 10 bays
NOTE:
NUMBERS IN PARENTHESES REFER TO THE ATTACHED GRAPH IDENTIFICATION NUMBERS

KEY PLAN
VIEW FROM INSIDE DRYWELL

VENT PIPE

UPPER CURB - EL. 12'-3"

TOP OF SANDBED

LOWER CURB
11'-0"

DRYWELL FLOOR - EL. 10'-3"
TOP OF SANDBED EL. 12'-3" & UPPER CURB
LOWER CURB EL. 11'-0"

FLOOR EL. 10'-3"

EL. 9'-3"

BAY 17 - TRENCH
Sand Bed Region
Background and History

- Trenches in bays 5 and 17 were excavated in 1986 to determine corrosion in sand bed at elevations below the drywell interior floor
  - Bays 5 and 17 were selected because UT measurements indicated these bays had the least and the most corrosion, respectively
  - The trenches extend to about the elevation of the bottom of the sand bed
  - UT measurements taken in the trenches confirmed that the corrosion below elev. 11’ 3” was bounded by the monitoring at elev. 11’ 3”
# 2006 Inspection Data

General Thickness (mils)

<table>
<thead>
<tr>
<th>Grid</th>
<th>Bay 5</th>
<th>Bay 17</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5D</td>
<td>17A Top</td>
</tr>
<tr>
<td>Grid Elev. 11’3” Above Lower Curb</td>
<td>1185</td>
<td>1122</td>
</tr>
<tr>
<td>Trench Lower Curb to Sand Bed Floor</td>
<td>1074</td>
<td></td>
</tr>
<tr>
<td>Trench Below Sand Bed Floor</td>
<td>1113</td>
<td></td>
</tr>
</tbody>
</table>
Sand Bed Region
Background and History

• Sand was removed in 1992 and the shell was cleaned
• External UT measurements were taken in all bays at thinned local areas (as determined by visual inspection)
• The shell was coated with epoxy coating
• UT grid measurements were taken at the 19 monitored locations at elev. 11’3” as a baseline for the new condition
Condition of the Drywell Shell in the Sand Bed Region After Sand Removal
Sand Bed Region 1992

Corrosion product on drywell vessel
Sand Bed Region 1992

As found condition of floor bed

Drywell Shell
Condition of the Drywell Shell in the Sand Bed Region After Application of Epoxy Coating
Sand Bed Region 1992

Bay 5 before shell coating
Sand Bed Region 1992

Shell and floor undergoing coating and repairs
Sand Bed Region 1992

Finished floor, vessel with two top coats – caulking material applied
Sand Bed Region
Background and History

• DEVOE Epoxy coating system (3 part)
  – Designed for application on corroded surfaces
  – One coat DEVOE 167 Rust Penetrating Sealer
    • Penetrates rusty surfaces
    • Reinforces rusty steel substrates
    • Ensures adhesion of Devran 184 epoxy coating
Sand Bed Region
Background and History

• DEVOE Epoxy coating system
  – Two coats Devran 184 epoxy coating
    • Designed for tank bottoms, including water tanks, fuel tanks, selected chemical tanks
    • Coating application was tested in a mock-up for coating thickness and absence of holidays or pinholes
    • Two coats used to minimize any chance of pinholes or holidays
    • The two coats are different colors
Use of Coatings to Prevent Corrosion

Jon R. Cavallo, PE, PCS
Vice President
Corrosion Control Consultants and Labs, Inc.
Background and History

• The OCNGS Protective Coatings Monitoring and Maintenance Program aging management program is consistent with NUREG 1801, Rev. 1 (the GALL Report), Appendix XI.S8
  – NUREG 1801, Appendix XI.S8 only covers Coating Service Level I coatings

• In addition, the OCNGS Coating Monitoring and Maintenance Program includes the Coating Service Level II coatings applied to exterior of drywell in Sand Bed region
Background and History

• Inspection and evaluation of OCNGS external coated drywell Sand Bed region surfaces (Coating Service Level II Coatings) is conducted in accordance with ASME Section XI, Subsection IWE by qualified VT inspectors.
  – Areas shall be examined (as a minimum) for flaking, blistering, peeling, discoloration and other signs of distress.
• The premise of ASME Section XI, Subsection IWE is that degradation of a steel substrate will be indicated by the presence of visual anomalies in the attendant protective coatings.
How Barrier Coating Systems Prevent Corrosion

• Barrier coating systems separate the electrolyte from the anodes, cathodes and conductors

• A barrier coating system has been applied to the steel substrate in the OCGS Sand Bed region
Technical Review of OCGS Sand Bed Region Coating System

• The OCGS Sand Bed region barrier coating system consists of:
  – Devoe Pre-Prime 167 penetrating sealer
  – Devoe Devran 184 mid- and top-coat
  – Devoe Devmat 124S caulk

and is appropriate for the intended service
Technical Review of OCGS Sand Bed Region Coating System

• With periodic condition assessment and maintenance (if required), the OCGS Sand Bed region coating system will continue to prevent corrosion of the steel substrate for the period of extended operation.

• Oyster Creek inspected 100% of the Sand Bed region coating in 2006 and will inspect at least three bays every other outage, with all 10 inspected every 10 years.

• The 10 year inspection periodicity cycle is appropriate and commensurate with the Sand Bed Region environment and industry experience.
  – EPRI 1003102, “Guideline on Nuclear Safety-Related Coatings”
UT Thickness Measurements
In the Sand Bed

Pete Tamburro
Oyster Creek Engineering
Background and History
Sand Bed Region

• UT grid measurements were taken at the 19 monitored locations at elev. 11’3” as a baseline for the new condition in 1992

• In 1992, thinnest grid average thickness 800 mils vs. criterion of 736 mils

• In 1992, thinnest local reading 618 mils vs. criterion of 490 mils
Background and History
Sand Bed Region

• 19 grids repeated in 1994 and 1996
  – Statistically, no changes in thickness were observed
  – Basis for corrosion “arrested” in the sand bed region, on outer surface of the drywell
  – Basis for NRC SER concluding that further UT measurements are not needed and visual inspection of the coating is sufficient

• The 2006 UT measurements confirmed that corrosion has been arrested
UT Measurements of 6”x6” Grid Sand Bed Region

- Measurement locations are marked on the inside of the drywell shell
- Use a stainless steel template with 49 holes to align the UT probe
- UT probe placed perpendicular to the surface to consistently obtain lowest reading
- A protective grease is applied to the 6”x6” grid during operation, and removed to take UT measurements
49 UT readings are recorded over a 6” by 6” area.

Diameter of each hole between 9/16” and 5/8”.

1/16” by 1/4” slit centered on middle row or column

A stainless steel template is used to ensure that the readings are recorded consistently and in same location (+/- 1/16”) every time.

For each location, the mean and standard error and the thinnest of the 49 readings are calculated after each inspection.
Statistical Methodology

• Because of roughness of the exterior surface of the drywell shell in the sand bed, there is uncertainty in the mean thickness calculated for each grid location.

• The major contributor to the uncertainty in the means is the variance from point to point due to the rough surface and not inaccuracy or repeatability of the UT Instrumentation.
Statistical Methodology

For each location the means and thinnest points are trended over time
Statistical Methodology

1) A curve fit based on the regression model is then developed.

2) The Corrosion “F” Test is performed to determine if the data meet the curve fit with 95% confidence.

**Diagram:**
- **Time** on the x-axis.
- **Thickness** on the y-axis.
- "F" Test of Curve to 95% Confidence.
- Curve Fit.

**Key:**
- ● - mean value
- ‹ - standard error
Projection Based on Successful Corrosion F tests

Today

Upper 95% Confidence Interval

2029

Curve Fit

Minimum Required Thickness

Lower 95% Confidence Interval

Projected Margin in 2029 with 95% Confidence

Time

Thickness

Today 2029
In the case of the 2006 sand bed inspections, there are only 4 inspections per location with most standard errors between +/- 8 and +/-16 mils.

There are not enough inspections to satisfy the Corrosion Test F test with 95% confidence.
Statistical Methodology

• We then employed a conservative statistical analysis based on a “Monte Carlo” type simulation to determine a minimum statistically observable corrosion rate for the purpose of ensuring adequate inspection frequency
Given only 4 inspections and the standard errors, simulation was required to determine the minimum observable rate with 95% confidence. This is not an actual rate!

The simulation answered the question: What is the minimum rate that passes the F Test with 95% confidence given four inspections and most standard errors between 8 and 16 mils.
The simulation used a random number generator based on the normal distribution.

An array with 49 randomly generated values. The array is normally distributed with a resulting simulated mean and a resulting simulated standard error.
Simulation – Minimum Observable Corrosion Rate

Chose a rate and performed 100 Iterations (Steps 1 through 6)

1) Simulated mean for 1992 based on 49 generated random values. Input to the generator is the grid 19A, 1992 mean and standard error.

2) Simulated mean for 1994 based on 49 random generated values. Input to the generator is: the 19A, 1992 mean minus the selected rate times 2 (1994-1992); and standard error.

3) Simulated mean for 1996 based on 49 random generated values. Input to the generator is: the 19A, 1992 mean minus the selected rate times 4 (1996-1992) and standard error.

4) Simulated mean for 2006 based on 49 random generated values. Input to the generator is: the 19A, 1992 mean minus the selected rate times 14 (2006-1992) and standard error.

5) Determine the curve fit based on the 4 simulated means and perform the Corrosion “F” Test.

6) If the curve fit passes the “F” test than this iterations counts as a successful iterations.
Simulation – Minimum Observable Corrosion Rate

The minimum rate which consistently passes the Corrosion “F” Tests 95 out of 100 times is the Minimum Observable Corrosion Rate.

Repeat each 100 iteration simulation with increasing rates.

<table>
<thead>
<tr>
<th>Rate</th>
<th>Number Successful “F” Test –19A</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 mpy</td>
<td>27</td>
</tr>
<tr>
<td>3.5 mpy</td>
<td>55</td>
</tr>
<tr>
<td>5 mpy</td>
<td>80</td>
</tr>
<tr>
<td>6 mpy</td>
<td>92</td>
</tr>
<tr>
<td>6.9 mpy</td>
<td>96.2</td>
</tr>
<tr>
<td>7 mpy</td>
<td>98</td>
</tr>
<tr>
<td>8 mpy</td>
<td>97</td>
</tr>
</tbody>
</table>

Average -100 Iterations were repeated 10 times
Next Required Inspection Based on the Minimum Observable Rate

Based on this statistical approach, the next inspection shall be performed prior to this date.

Based on this statistical approach, the most limiting locations are 19A and 17D with required inspection dates prior to 2016.

Minimum Observable Rate of 6.9 MPY

Time

Minimum Required Thickness

Thickness

1994

Results of the Statistical Simulation

- The most limiting locations are 19A and 17D, with required inspections prior to 2016
- Therefore, the next inspection scheduled for 2010 is appropriate
- Analysis after future inspections will be used to determine the appropriate inspection frequency
2006 Inspections
Sand Bed Region

• Visual inspection of coating in all 10 bays (external)
• UT measurements of 19 grids at elev. 11’3” (internal)
• UT measurements 106 locally thinned single point locations (external)
2006 Inspection Results
Sand Bed Region

• Visual inspection of External Shell Coating – no degradation
Bay 7 – Drywell shell, caulking, sand bed floor
Sand Bed Region 2006

Bay 13 Drywell shell

Reference for locating inspection points

External UT Inspection location
Sand Bed Region 2006

Drywell Shell Bay 19

Bay 19 caulking

Floor

Shell

Caulk

Drywell Shell Bay 19
2006 Inspection Results
Sand Bed Region

• UT measurements at 19 internal grid locations
  – No ongoing corrosion
# General Thickness at 19 Grid Locations

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1D</td>
<td>1115</td>
<td>1101</td>
<td>1151</td>
<td>±10.0</td>
<td>±13.6</td>
<td>1122</td>
<td>±8.4</td>
<td>365</td>
<td></td>
</tr>
<tr>
<td>3D</td>
<td>1178</td>
<td>1184</td>
<td>1175</td>
<td>±4.9</td>
<td>±7.5</td>
<td>1180</td>
<td>±5.7</td>
<td>439</td>
<td></td>
</tr>
<tr>
<td>5D</td>
<td>1174</td>
<td>1168</td>
<td>1173</td>
<td>±2.6</td>
<td>±2.2</td>
<td>1185</td>
<td>±2</td>
<td>432</td>
<td></td>
</tr>
<tr>
<td>7D</td>
<td>1135</td>
<td>1136</td>
<td>1138</td>
<td>±4.3</td>
<td>±5.9</td>
<td>1133</td>
<td>±6.5</td>
<td>397</td>
<td></td>
</tr>
<tr>
<td>9A</td>
<td>1155</td>
<td>1157</td>
<td>1155</td>
<td>±4.5</td>
<td>±4.8</td>
<td>1154</td>
<td>±4.2</td>
<td>418</td>
<td></td>
</tr>
<tr>
<td>9D</td>
<td>992</td>
<td>992</td>
<td>1004</td>
<td>±10.0</td>
<td>±10.4</td>
<td>1008</td>
<td>±10.6</td>
<td>993</td>
<td>±11.2</td>
</tr>
<tr>
<td>11A</td>
<td>833</td>
<td>820</td>
<td>830</td>
<td>±8.2</td>
<td>±7.7</td>
<td>822</td>
<td>±8.0</td>
<td>84</td>
<td></td>
</tr>
<tr>
<td>11C Bot</td>
<td>856</td>
<td>850</td>
<td>883</td>
<td>±6.4</td>
<td>±7.4</td>
<td>855</td>
<td>±4.5</td>
<td>114</td>
<td></td>
</tr>
<tr>
<td>Top</td>
<td>952</td>
<td>982</td>
<td>1042</td>
<td>±23.8</td>
<td>±23.4</td>
<td>958</td>
<td>±24.7</td>
<td>216</td>
<td></td>
</tr>
<tr>
<td>13A</td>
<td>849</td>
<td>837</td>
<td>853</td>
<td>±9.6</td>
<td>±7.8</td>
<td>846</td>
<td>±8.2</td>
<td>101</td>
<td></td>
</tr>
<tr>
<td>13D Bot</td>
<td>900</td>
<td>895</td>
<td>933</td>
<td>±9.0</td>
<td>±8.2</td>
<td>904</td>
<td>±8.9</td>
<td>159</td>
<td></td>
</tr>
<tr>
<td>Top</td>
<td>1048</td>
<td>1037</td>
<td>1059</td>
<td>±14.1</td>
<td>±13.6</td>
<td>1047</td>
<td>±13.7</td>
<td>301</td>
<td></td>
</tr>
<tr>
<td>13C</td>
<td>1149</td>
<td>1140</td>
<td>1154</td>
<td>±1.9</td>
<td>±3.2</td>
<td>1142</td>
<td>±3.1</td>
<td>404</td>
<td></td>
</tr>
<tr>
<td>15A</td>
<td>1120</td>
<td>1114</td>
<td>1127</td>
<td>±16.3</td>
<td>±10.8</td>
<td>1121</td>
<td>±16.6</td>
<td>378</td>
<td></td>
</tr>
<tr>
<td>15D</td>
<td>1042</td>
<td>1053</td>
<td>1066</td>
<td>±8.7</td>
<td>±8.5</td>
<td>1053</td>
<td>±8.9</td>
<td>306</td>
<td></td>
</tr>
<tr>
<td>17A Bot</td>
<td>933</td>
<td>934</td>
<td>997</td>
<td>±11.8</td>
<td>±10.7</td>
<td>935</td>
<td>±10.5</td>
<td>197</td>
<td></td>
</tr>
<tr>
<td>Top</td>
<td>999</td>
<td>1129</td>
<td>1144</td>
<td>±7.2</td>
<td>±6.8</td>
<td>1122</td>
<td>±7.2</td>
<td>263</td>
<td></td>
</tr>
<tr>
<td>17B</td>
<td>822</td>
<td>810</td>
<td>848</td>
<td>±9.2</td>
<td>±9.5</td>
<td>818</td>
<td>±9.5</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td>17/19 Frame Top</td>
<td>954</td>
<td>963</td>
<td>967</td>
<td>±4.8</td>
<td>±6.0</td>
<td>964</td>
<td>±4.8</td>
<td>218</td>
<td></td>
</tr>
<tr>
<td>9A</td>
<td>803</td>
<td>806</td>
<td>815</td>
<td>±8.4</td>
<td>±9.9</td>
<td>807</td>
<td>±8.9</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>9B</td>
<td>826</td>
<td>824</td>
<td>837</td>
<td>±8.7</td>
<td>±7.8</td>
<td>848</td>
<td>±8.6</td>
<td>88</td>
<td></td>
</tr>
<tr>
<td>9C</td>
<td>822</td>
<td>820</td>
<td>854</td>
<td>±11.0</td>
<td>±10.5</td>
<td>824</td>
<td>±11.3</td>
<td>83</td>
<td></td>
</tr>
</tbody>
</table>

Note: Shaded cells indicate thickness value used to conservatively calculate the margin.
## Minimum Available Thickness Margins

<table>
<thead>
<tr>
<th>Bay No.</th>
<th>1</th>
<th>3</th>
<th>5</th>
<th>7</th>
<th>9</th>
<th>11</th>
<th>13</th>
<th>15</th>
<th>17</th>
<th>19</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Available Margin, mils</td>
<td>365</td>
<td>439</td>
<td>432</td>
<td>397</td>
<td>256</td>
<td>84</td>
<td>101</td>
<td>306</td>
<td>74</td>
<td>64</td>
</tr>
</tbody>
</table>
Figure 21 Sandbed Bay # 19A

Drywell Thickness - Mils

-15 Mils/yr

+/- 8.4 mils
+/- 9.9 mils
+/- 9.6 mils
+/- 8.9 mils

Margin = 64 Mils

Figure 1. Sandbed Bay # 1D

- **Drywell Thickness - Mils**
  - **1154 Mil Nominal Shell Plate Thickness**
  - **736 Mil General Required Shell Thickness**
  - **Margin = 365 Mils**
  - **Start Sand Removal**
  - **Drain Lines Cleaned**
  - **Complete Sand Removal and apply Epoxy Coating**
  - **Strippable Coating Added to Rx Cavity**
  - **Strippable Coating Not Used**

Source: Raw Data - AmerGen Calculation C-1302-187-5300-021, C-1302-187-5300-028, C-1302-187-8610-
2006 Inspection Results
External Sand Bed UTs

• 106 individual UT measurements were taken externally in the sand bed region
• It was verified that all 106 measurements meet the local thickness requirements (both buckling and membrane stresses)
• The 2006 measurements are not directly comparable to the 1992 results because of differences in measurement techniques
Uncoated 1992
Traditional pulse echo technique

Coated 2006
Echo-echo technique

Concave Curvature Effects
1992 vs. 2006 External UT Data (106) Sand Bed Readings
## External UT Inspection Results

<table>
<thead>
<tr>
<th>Location</th>
<th>1992 UT Measurements</th>
<th>2006 UT Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of UTs</td>
<td>No. of UTs &lt;736 mils</td>
</tr>
<tr>
<td>Bay 1</td>
<td>23</td>
<td>9</td>
</tr>
<tr>
<td>Bay 3</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Bay 5</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Bay 7</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Bay 9</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Bay 11</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Bay 13</td>
<td>29</td>
<td>9</td>
</tr>
<tr>
<td>Bay 15</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>Bay 17</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>Bay 19</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>125</td>
<td>21</td>
</tr>
</tbody>
</table>

\(^1\)The locally thinned areas prepared for UT measurements in 1992 were measured in 2006. However, the inspection team was able to locate only 106 points instead of 125.
Sand Bed Region Conclusions

- Corrosion on the outside of the drywell shell in the sand bed region has been arrested
- The coating shows no degradation
- There is sufficient margin to the minimum thickness requirement (maintain 64 mils margin above code required average thickness of 736 mils)
Future Inspections in the Sand Bed Region

- Visual inspection of exterior coating in three bays every other outage, inspecting all 10 bays once every 10 years
- UT measurements at 19 grid locations at elev. 11’3” in 2010, then every 10 years thereafter
- Repeat UT at 106 locally thinned locations from the exterior in 2008 outage
  - In future outages, perform UT in 2 bays every outage
Embedded Portions of the Drywell Shell
Embedded Shell Conclusions

• Corrosion on the embedded surfaces of the drywell shell, both interior and exterior, is not significant
  – The environment of embedded steel in concrete prevents significant corrosion
• Estimated at <1 mil / year
• Drywell shell meets design basis requirements, with margin to 2029
LOWER DRYWELL-
SANDBED, TRENCH & SUMP

ELEVATION LOOKING WEST
SECTIONAL VIEW OF SAND BED AREA
AT VENT PIPE
Embedded Shell – Exterior Surface

• Any corrosion of the drywell exterior embedded surface occurred because of water leakage into the sand bed region

• Corrective actions for the sand bed region arrested corrosion of the drywell exterior embedded shell
  – Water leakage into the sand bed region was prevented
  – The joint between the drywell shell and floor of the sand bed region was sealed to prevent water from contacting the exterior shell
Embedded Shell – Interior Surface

- Water that was identified in the trenches in bays 5 and 17 inside the drywell when the foam filling was removed during the 2006 refueling outage was determined to have originated from equipment leakage inside the drywell (Not from external sources)
Embedded Shell - Interior Surface

- Investigations into the source of the water indicate that there could have been water below the drywell interior floor for an extended period.
- Additional concrete was removed from the bottom of the bay 5 trench to expose 6 inches of drywell shell that was embedded on both sides for UT thickness measurements of the drywell shell.
Embedded Shell – Interior Surface

• Corrective actions during the 2006 refueling outage included
  – Caulking the joint between the drywell interior floor and the drywell shell
  – Repairs to the collection trough in the sub-pile room
Corrosion of Steel Embedded in Concrete

Barry Gordon
Structural Integrity Associates, Inc.
Corrosion of Steel Embedded in Concrete

• Drywell shell was constructed first, followed by pouring of concrete both on the inside and the outside of the shell
• The high pH (e.g., 12.5 to 14) environment created during hydration of the cement in the concrete results in the formation of a passive, protective film \([\text{Fe(OH)}_2 + \text{Ca(OH)}_2]\) on the carbon steel surface that mitigates corrosion in the absence of an aggressive environment
Exterior Embedded Steel Environment

- The reactor cavity water that flowed into the embedded region outside the drywell was affected by the sand bed.
- However, the chemistry of the water leachate from moist sand from the sand bed region was measured in 1986 revealed high purity water:
  - pH >7, <0.045 ppm Cl⁻ <0.032 ppm SO₄²⁻
    (US Water: 59 ppm Cl⁻, 81 ppm SO₄²⁻)
  - This water is not aggressive to the embedded steel in concrete per GALL/EPRI.
Exterior Embedded Steel Environment

• The water in the embedded region would have been the same quality as in the sand bed region, except the pH would have been greater because of the interaction with high pH concrete pore water.

• Per GALL NUREG-1801 Vol. 2, Rev.1 and EPRI 1002950, no aging effects are expected since pH > 5.5, < 500 ppm Cl⁻ and < 1500 ppm SO₄²⁻ (GALL II.B1.2-2, II.B1.2-8)
Interior Embedded Steel Environment

• Chemistry of the drywell Trench #5 water (from equipment leakage) shows high pH, low Cl⁻, low SO₄²⁻ and high Ca:
  – pH 8.4 to 10.2 (despite CO₂) (> GALL/EPRI limit)
  – Cl⁻: 13.6 – 14.6 ppm (<< 500 ppm GALL/EPRI limit)
  – SO₄²⁻: 228 - 230 ppm (<<1500 ppm GALL/EPRI limit)
  – Ca: 83.5 – 96.6 ppm (No GALL/EPRI limit)
• Water is characterized as good quality “concrete pore water” that mitigates steel corrosion
• Trench #5 water complies with GALL/EPRI embedded steel guidelines
Interior Embedded Steel Environment

- Trench #5 water’s high Ca indicates that the water slowly migrated through the alkaline concrete.
- Any subsequent water ingress into the concrete floor will also become high pH concrete pore water.
Interior Embedded Steel Environment

• Corrosion of the steel shell not wetted by high pH concrete pore water is mitigated by subsequent inerting of the drywell during operation

• Any possible subsequent steel corrosion could occur only during brief outages when fresh oxygenated water can contact with the shell

• Finally, transport of any oxygenated water through the concrete to the steel is slow, will increase in pH and must displace oxygen depleted water before any possible corrosion can occur
2006 Outage Inspections
Embedded Shell

• Visual inspection of the surface in the trenches showed minor corrosion which was easily removed with no visible loss of material or degradation of the surface
2006 Outage Inspections
Embedded Shell

• UT measurements in the trenches measure total corrosion on the inside and outside between 1986 and 2006
  – Corrosion was occurring on the exterior surface that was not embedded until 1992 when sand was removed
  – Material loss was consistent with the corrosion rates on the outside of the drywell before the sand was removed
## 2006 Inspection Results

**Embedded Shell**

**UT measurements in trenches 5 and 17**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Trench 5</td>
<td>1112 mils</td>
<td>±2.59 mils</td>
<td>1074 mils</td>
<td>±2.66 mils</td>
<td>38 mils</td>
</tr>
<tr>
<td>Trench 17</td>
<td>1024 mils</td>
<td>±2.85 mils</td>
<td>986 mils</td>
<td>±4.18 mils</td>
<td>38 mils</td>
</tr>
</tbody>
</table>
2006 Inspection Results
Embedded Shell

- UT measurements of the 6 inch surface excavated in the bottom of the trench in bay 5 were performed to determine total corrosion, both interior and exterior.
- Measured thickness is 1113 mils, as compared to a nominal of 1154 mils
  - A change of 41 mils, approximately 1 mil/yr
2006 Outage Inspections
Embedded Shell

• The 106 individual UT measurements made from the exterior of the sand bed region are a baseline for monitoring corrosion of the interior embedded surface of the drywell in future outages
2006 Inspection Results
Embedded Shell

- The joint sealant between the sand bed floor and the exterior drywell shell was inspected and found to be in good condition.
- No water was identified in the sand bed region in any of the 10 bays.
Embedded Shell Conclusions

• Corrosion on the embedded surfaces of the drywell shell, both interior and exterior, is not significant
  – The environment of embedded steel in concrete prevents significant corrosion
• Estimated at <1 mil / year
• Drywell shell meets code thickness requirements, with margin to 2029
Future Inspections on the Embedded Shell

• Repeat UT measurements in both trenches, including the newly excavated 6 inches in 2008
  – If results indicate no significant changes, then fill the trenches with concrete and restore the curb to original configuration

• Repeat UT measurements at 106 external points in 2008
  – Perform external UT measurements in 2 bays every refuel outage starting in 2010
  – All bays will be inspected every 10 years
Upper Drywell Shell
Upper Drywell Shell Conclusions

• These measurements are the lead indicators of corrosion on the outside of the shell
• Corrosion of the upper shell is <1 mil / yr
• Upper Drywell shell has a minimum of 137 mils margin
• Based on current rates, will have margin through the period of extended operation
Upper Drywell Shell

- Starting in 1983, over 1,000 UT measurements were taken to locate areas of corrosion on the exterior surface of the drywell shell.

- 13 grid locations have been selected for monitoring.

- These locations are measured every other refueling outage.
## Upper Drywell UT Measurements

<table>
<thead>
<tr>
<th>Monitored Elevation</th>
<th>Location</th>
<th>Minimum Required Thickness mils</th>
<th>Average Measured Thickness 1/2 mils</th>
<th>Projected Thickness in 2029 mils</th>
</tr>
</thead>
<tbody>
<tr>
<td>50' 2&quot;</td>
<td>Bay 5-D12</td>
<td>743 755 758 760</td>
<td>747 759 762 765</td>
<td>741 748 741 743 747</td>
</tr>
<tr>
<td></td>
<td>Bay 5-5H</td>
<td>761 766 765</td>
<td>754 757 760 762</td>
<td>760</td>
</tr>
<tr>
<td></td>
<td>Bay 5-5L</td>
<td>706 703</td>
<td>702 705 706 701</td>
<td>705</td>
</tr>
<tr>
<td></td>
<td>Bay 13-31H</td>
<td>762 779</td>
<td>765 763 766 762</td>
<td>762</td>
</tr>
<tr>
<td></td>
<td>Bay 13-31L</td>
<td>687 684</td>
<td>685 688 690 682</td>
<td>678</td>
</tr>
<tr>
<td></td>
<td>Bay 15-23H</td>
<td>758 764</td>
<td>758 760 758 757</td>
<td>749 720</td>
</tr>
<tr>
<td></td>
<td>Bay 15-23L</td>
<td>726 728</td>
<td>726 724 729 727</td>
<td></td>
</tr>
</tbody>
</table>

No Observable Ongoing Corrosion
## Upper Drywell UT Measurements

<table>
<thead>
<tr>
<th>Monitored Elevation</th>
<th>Location</th>
<th>Minimum Required Thickness (mils)</th>
<th>Average Measured Thickness (1.2 mils)</th>
<th>Projected Thickness in 2029 (mils)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation 51' 10&quot;</td>
<td>Bay 13-32H</td>
<td>518</td>
<td>716 715 715 720 717 717 714 715 715 713 715</td>
<td>No Observable Ongoing Corrosion</td>
</tr>
<tr>
<td></td>
<td>Bay 13-32L</td>
<td></td>
<td>686 683 683 682 683 676 680 684 679 687 685</td>
<td>No Observable Ongoing Corrosion</td>
</tr>
<tr>
<td>Elevation 60' 10&quot;</td>
<td>Bay 1-50-22</td>
<td>518</td>
<td>693 711 693 689 693 691</td>
<td>No Observable Ongoing Corrosion</td>
</tr>
<tr>
<td>Elevation 87' 5&quot;</td>
<td>Bay 9-20</td>
<td>452</td>
<td>619 622 620 619 620 614 612 629 614 613 613 604 612 617</td>
<td>No Observable Ongoing Corrosion</td>
</tr>
<tr>
<td></td>
<td>Bay 13-28</td>
<td></td>
<td>643 641 642 645 643 635 629 641 637 640 636 635 640 642</td>
<td>No Observable Ongoing Corrosion</td>
</tr>
<tr>
<td></td>
<td>Bay 15-31</td>
<td></td>
<td>638 636 636 638 642 628 627 631 630 633 632 628 630 633</td>
<td>No Observable Ongoing Corrosion</td>
</tr>
</tbody>
</table>

**Notes:**
1. The average thickness is based on 49 Ultrasonic Testing (UT) measurements performed at each location.
3. The 1993 elevation 60' 10" Bay 5-22 inspections was performed on January 6, 1993. All other locations were inspected in December 1992.
Upper Drywell Shell  
2006 Inspection Results

• 12 of the 13 locations show no statistically observable corrosion

• The location with the minimum margin (137 mils) has no ongoing corrosion

• 1 location shows a corrosion rate of 0.66 mils/year
  – Projected thickness in 2029 is 720 mils, compared to a minimum required thickness of 541 mils
Upper Drywell Shell Conclusions

- These measurements are the lead indicators of corrosion on the outside of the shell
- Corrosion of the upper shell is <1 mil / yr
- Upper Drywell shell has a minimum of 137 mils margin
- Based on current rates, will have margin through the period of extended operation
Overall Conclusions

- The corrective actions to mitigate drywell shell corrosion have been effective.
- The drywell shell corrosion has been arrested in the sand bed region and continues to be very low in the upper drywell elevations.
- The corrosion on the embedded portion of the drywell shell is not significant.
- The drywell shell meets code safety margins.
- We have an effective aging management program to ensure continued safe operation.