Citizens Exhibits 9

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Statistical Analysis of Oyster Creek Drywell Thickness Data

Prepared for:

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1.0 INTRODUCTION

In 1986, Oyster Creek experienced a problem with corrosion of the exterior of their drywell at the "sand cushion". The problem that was determined at that time was that the sand cushion had become wet from leakage that dripped along the outside of the drywell, the sand remained wet, and the exterior of the carbon steel drywell began to corrode.

The plant performed extensive analysis to demonstrate that loading of the drywell would remain within acceptable limits even without the sand cushion to disperse the loads from the drywell to the ground. The plant then removed all of the sand and sealed off the steel-concrete interface on the exterior of the drywell to make sure it remained dry. In addition, several trenches were jack-hammered into the concrete inside the drywell to permit UT thickness measurements of the steel to be performed from inside the drywell. In the 1986 time frame, thickness measurements from the ID and from the OD all confirmed that the minimum thickness of the drywell exceeded minimum required thickness at all locations.

Now that the plant has applied for license renewal, the issue of the condition of the drywell steel has been reopened. During the most recent refueling outage (October 2006), the concrete in the trenches was found to be wet (one trench had 5" of standing water) so the question of the condition of the steel in the (former) sand bed region, above the sand bed, and embedded in the concrete was raised again.

2.0 BACKGROUND

The drywell (see Figure 2-1) is a huge (30' diameter or more where it intersects the concrete) but thin steel structure. The portion that is embedded in concrete (much of it has concrete on its interior as well) is basically a hemisphere. The drywell structure itself is shaped like a light bulb (upside down) with the reactor vessel, pumps, piping, etc. inside. The drywell is a secondary containment structure for radionuclides (fuel cladding, then the reactor vessel, then the containment). Because the containment and drywell are key safety features, the condition of the containment and drywell receives significant regulatory scrutiny and attention from the public.

2.1 Objective

Plant and corporate personnel from Exelon have indicated that a thorough and statistically based review of drywell thickness data is required. For example, the UT thickness methods applied in 1986, 1992, and 2006 are all different; the prior examinations (1986 and 1992) were done on bare steel while the 2006 examination was done with a different technique and was done through the coating. Questions associated with repeat UT thickness determinations always have some uncertainty regarding whether the exact locations were examined at the different points in time. Further, the limited data from Zone 4 (above the 12'4" elevation; an area that should never have been wet) appears to exhibit a thinning between the 1992 and 2006 inspections. That observation, as well as the use of the different UT techniques, suggests that a bias may exist between the 1992 and 2006 measurements. A key objective of this evaluation was to determine whether there was indeed a bias between those two different time points, to quantify the magnitude of the bias, and to determine how best to compare the thickness measurements between 2006 and 1992. For example, is it reasonable to simply subtract the bias from all of the apparent deltas to account for the technique differences?

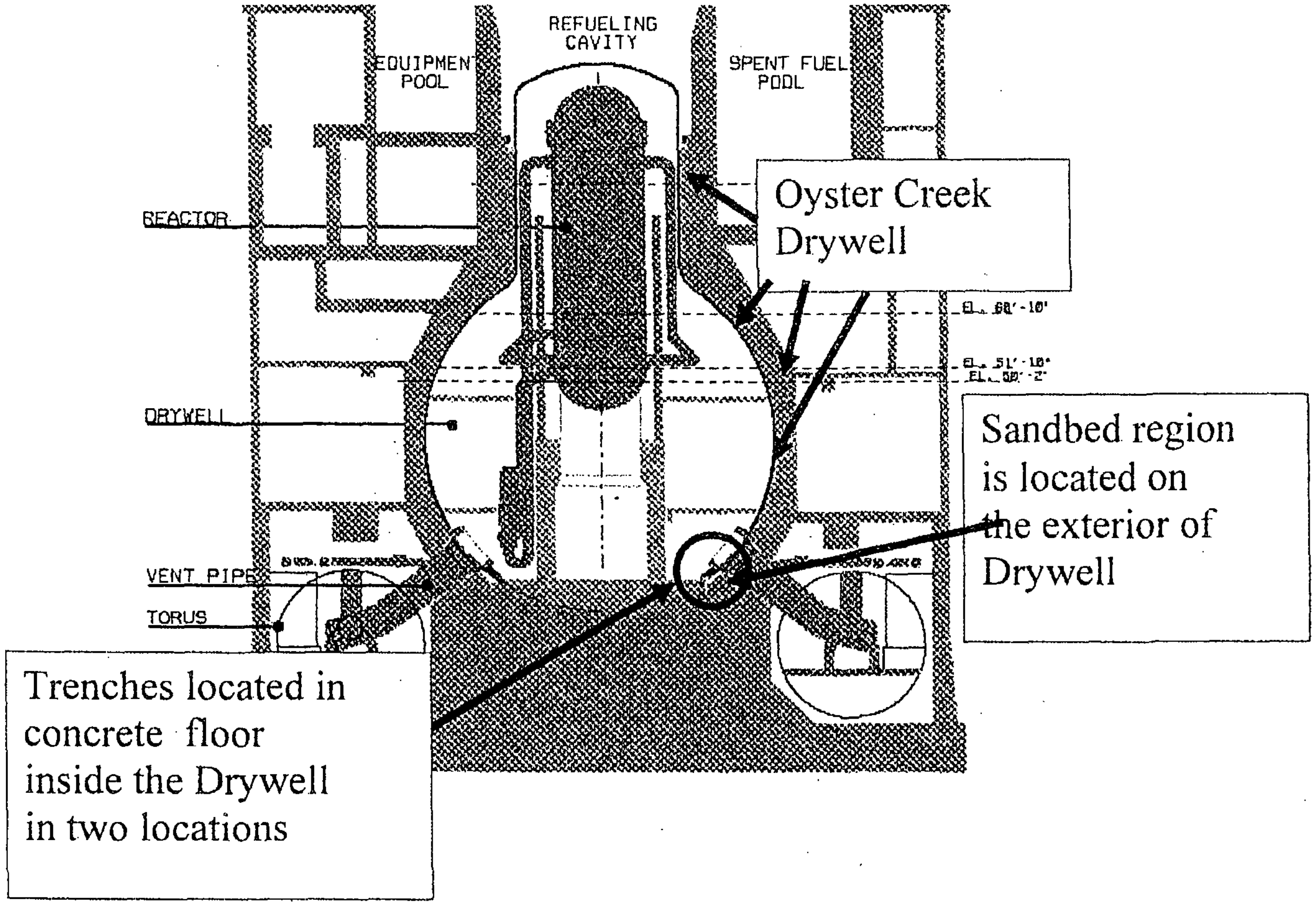

Figure 2-1. Schematic of Oyster Creek Drywell

3.0 APPROACH

A data set including UT thickness measurements from 106 points, measured from the outside of the drywell in 1992, then repeated in 2006, was received from Wayne Choromanski [1].

A Tech Eval prepared by Oyster Creek [2] was also received. The Tech Eval includes data in various forms from 1986, 1992, and 2006. It focuses on present thickness with a lesser emphasis on the trends. Most of the evaluation is for data collected for Bays 5 and 17, where the trenches are. The Tech Eval concludes that "the Drywell Vessel in the region below the concrete floor at elevation 10'3" may have been corroding at a rate of .002 to .003 inches per year between 1986 and 2006. UT readings below the concrete floor at Elevation 10'3" confirm that all locations meet the required thickness criteria."

The data were reviewed from numerous perspectives to ascertain systematic conditions (e.g., any bias) between measurements, differences among zones, among bays, and any oddities or obvious outliers. Fits of the data were also developed to test for the most appropriate distribution to use and to determine coefficients that would enable quantitative analysis of the statistics.

Those evaluations of deltas and thicknesses included graphical and numerical checks for the proper distribution to describe the variations in the data and included comparisons and evaluations of means and standard deviations of all values (thicknesses in 1992 and 2006 and the difference between those two thickness measurements), and creation of cumulative distribution functions to check for fit to normal or other distributions.

4.0 RESULTS

All 106 data points were included in the spreadsheet assembled and checked by Wayne Choromanski and denoted in this report as Reference 1. This analysis processed those data in an Excel spreadsheet graphically and numerically with results described below.

4.1 Apparent Deltas

The original focus in the evaluation was on the deltas (2006 thickness minus 1992 thickness). Those deltas were evaluated as a function of "original" (1992) plate thickness, and the distribution of delta by zone and by bay (Figures 4-1 through 4-4). Figure 4- 2 clearly shows that the mean delta varied by bay and by zone and that the distribution of deltas (Figures 4-3 and 4-4) looked very much like a normal distribution centered at a small negative value, implying a small metal loss. There was no apparent effect of original (1992) plate thickness (Figure 4-1). The variation of delta among bays was significantly larger than the variation among zones, despite the fact that the time of wetness among the different zones would be very dramatic. The lowest zone would be wet the longest, Zone 2 would be wet for a shorter time (as any water rolled down the drywell), and the upper two zones (Zones 3 and 4) would be expected to be wet for the least amount of time. Key data are summarized in Table 4-1.

A cumulative distribution of the deltas was created by ordering the deltas from smallest to largest and applying a look-up table from standard statistical texts to assign a parameter PHI. PHI is related to where in a normal distribution the point lies, based on the point's rank. For example, the point that is in the exact middle of the distribution (F = 0.50000) is at the mean (i.e., PHI = 0; which means 0 standard deviations from the mean). The first (lowest value) point defines the extreme of the data that is available and will be in the lower tail of the distribution (PHI will be a relatively large negative number). Similarly, the largest value will correspond to a relatively large positive PHI. When the data are plotted as PHI vs. delta, the data generate a reasonably straight line. The better the straight line, the better the fit to the normal distribution. The mean of the distribution is where PHI = 0 and the breadth of the distribution (i.e., how large the standard deviation is) can be determined by how small the slope of the curve is (i.e., a horizontal line would have a very large standard deviation). For example, if all of the values were at exactly the same value, that value would obviously be the mean and the standard deviation would be zero (no variation in the data).

The CDF plot for the deltas (Figure 4-5) produced a very nice straight line over much of the population, however, the larger negative deltas were the values that destroyed the quality of the linear fit. The best fit line had an R^2 value of 0.83 (a perfect fit has $R^2 = 1.000$); not a bad fit but not a great one. Figure 4-5 also includes an eyeball best fit to the well behaved data.

Physical observations of the coating condition at the 2006 examination indicated that the coating was still in excellent condition. The expected corrosion rate for an intact coating would be zero. That is, the coating provides a barrier between the electrolyte and the metal so that the anodic and cathodic half-reactions that are critical to any corrosion process would be totally eliminated. Actual metal losses of a mil or more are not consistent with a coating that is still in good condition; the condition that was found in 2006. Apparent deltas of 70 mils or more (six such deltas were reported) are totally unreasonable in view of the physical condition of the coating as well as examination of the drywell from the inside. Those large negative deltas, like the positive values of delta (i.e., the drywell was thicker in 2006 than in 1992) indicate that the deltas determined from the difference between the 1992 thickness (t_{1992}) and the 2006 thickness (t_{2006}) were subject to significant uncertainty and the use of delta only would be misleading.

4.2 Thickness Evaluations

Using the difference between separate measurements as discussed in Section 4.1 clearly magnifies the potential error. The 1992 and 2006 thickness measurements were each evaluated as separate populations to determine the appropriate distribution and to assess any systematic differences between the two measurements such that bias and any corrosion effects could be separated. As shown in Figures 4-6 and 4-7, the primary attribute that the thickness analyses determined was that thickness was a strong function of the bay and much less a function of zone.

The cumulative distribution functions for the 1992 and 2006 thickness populations were created as described below.

As was done for the deltas (Figure 4-5), the individual thickness measurements from 1992 and from 2006 were ordered, from smallest to largest. A look-up table was applied to assign a parameter PHI, where PHI is related to where in a normal distribution the point lies, based on the point's rank. For example, the point that is in the exact middle of the distribution (F = 0.50000) is at the mean (i.e., PHI = 0; which means 0 standard deviations from the mean). The first (lowest value) point defines the extreme of the available data and will be in the lower tail of the distribution (PHI will be a relatively large negative number). Similarly, the largest value will correspond to a relatively large positive PHI. When the data are plotted as PHI vs. thickness, the data should generate a straight line. The better the straight line, the better the fit to the normal distribution. The mean of the distribution is where PHI = 0 and the breadth of the distribution (i.e., how large the standard deviation is) can be determined by how horizontal the curve is. For example, if all of the values were at exactly the same value, that value would obviously be the mean and the standard deviation would be zero (no variation in the data).

Figure 4-8 shows that the 2006 thickness data are described well by a normal distribution, with an excellent straight line fit to the data ($R^2 = 0.98$). Figure 4-8 also shows that the 1992 plate thickness data were also described by a normal distribution (linear; $R^2 = 0.98$). The cumulative distribution of the 1992 thickness data also showed that the 1992 measurements were thicker at all values of PHI than those from 2006 (i.e., the drywell apparently lost thickness between 1992 and 2006 as might be expected). At the mean (PHI = 0), that difference was about 20 mils of thinning. At PHI = -3 (3 standard deviations below the mean, approximately the 99th percentile), the thickness difference was about 29 mils (29 mils of thinning). At PHI = 3, approximately the 1st percentile, the difference was about 12 mils. Those observations suggest that the measurements made in 2006 were systematically lower than the those in 1992 by 12 to 20 mils. It can be argued that the ***actual*** thickness differences based upon subtracting the 2006 thickness from the 1992 thickness (and ignoring the error associated with performing the measurements at exactly the same locations in both 1992 and 2006) are actually 12 to 20 mils less than the delta values that are reported.

Table 4-2 summarizes the comparison between the 1992 and 2006 measurements, including the means and standard deviations determined graphically and those same parameters determined for the two populations using the appropriate functions in Excel. The agreement between the graphical analysis and the computational analysis using Excel is excellent.

Note that this analysis does not say whether the 1992 measurements are better than the 2006 measurements or vice versa; only that the difference between the two has a bias in it.

Table 4-1

Mean Deltas by Bay

	Deltas				
Bay	Mean	S.D.	n[1]	n'[2]	
1	-19	21.8	23	23	
3	-3	6.8	9	9	
5	-34	31.1	8	8	
7	-13	13.7	5	7	
9	-10	9.6	10	10	
11	-14	14.7	8	8	
13	-17	30.9	15	19	
15	-1	15.2	11	11	
17	-13	32.0	9	11	
19	-24	27.8	8	10	
Population	-15	23	106	116	
Total Population			t_{1992}	t_{2006}	Delta
	Mean		865	849	-15
	Std. Dev		114	112	23
	Max		1156	1160	27
	Min		618	602	-118

[1] Thickness measurements in 1992 and 2006
[2] Thickness measurements in 1992 or 2006

Table 4-2

Comparison of Cumulative Distributions of Thickness (1992 and 2006)

Best fits to CDFs for 1992 and 2006 thicknesses									
2006:	PHI_{2006} =	0.0086	t	-7.2708					
1992:	PHI_{1992} =	0.0084	t	-7.2742				Per Excel (RawData2)	
OR					implying	Mean	Std. Dev.	Mean	Std. Dev.
2006:	t_{2006} =	116.2791	PHI_{2006}	845.4419		845	116	849	112
1992:	t_{1992} =	119.0476	PHI_{1992}	865.9762		866	119	865	114
PHI	Delta, mils[3]								
-3	28.8								
-2.5	27.5								
-2	26.1								
-1.5	24.7								
-1	23.3								
-0.5	21.9								
0	20.5								
0.5	19.2								
1	17.8								
1.5	16.4								
2	15.0								
2.5	13.6								
3	12.2								

[3]Determined from the difference between best fits for thickness distributions from 2006 and 1992. Note that sign is opposite that for Table 4-1 and Figures 4-1 through 4-4.

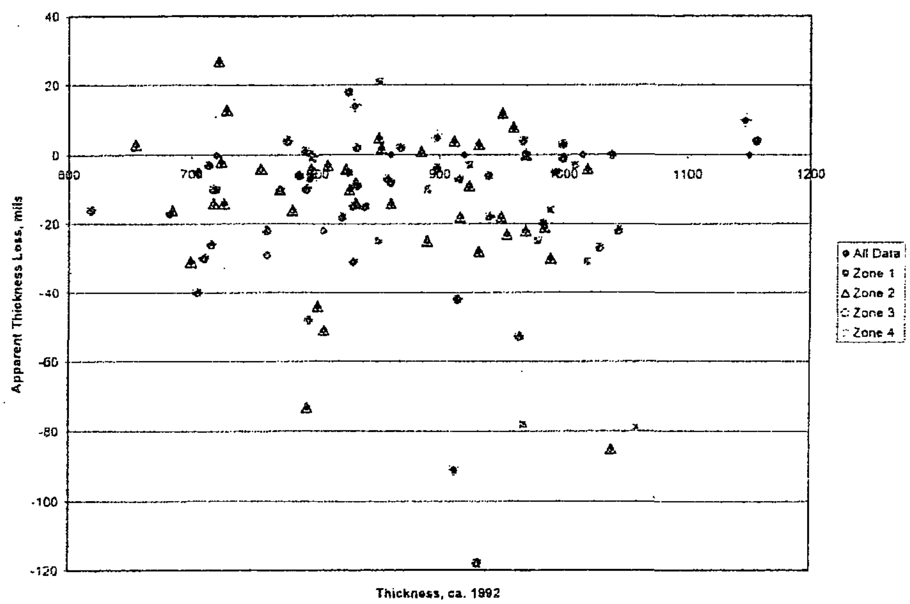

Figure 4-1. Apparent Thickness Change as a Function of Thickness Determined in 1992

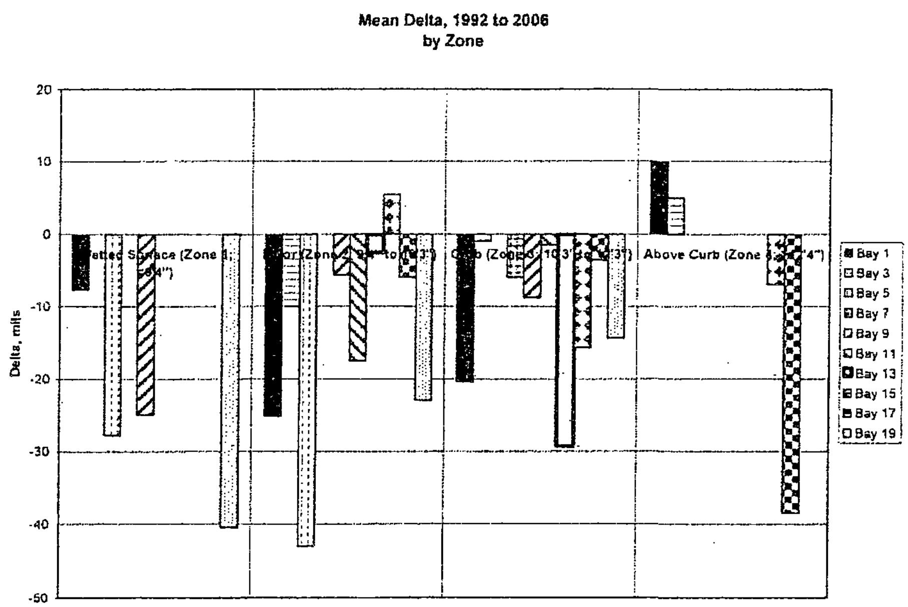

Figure 4-2. Delta by Zone and by Bay

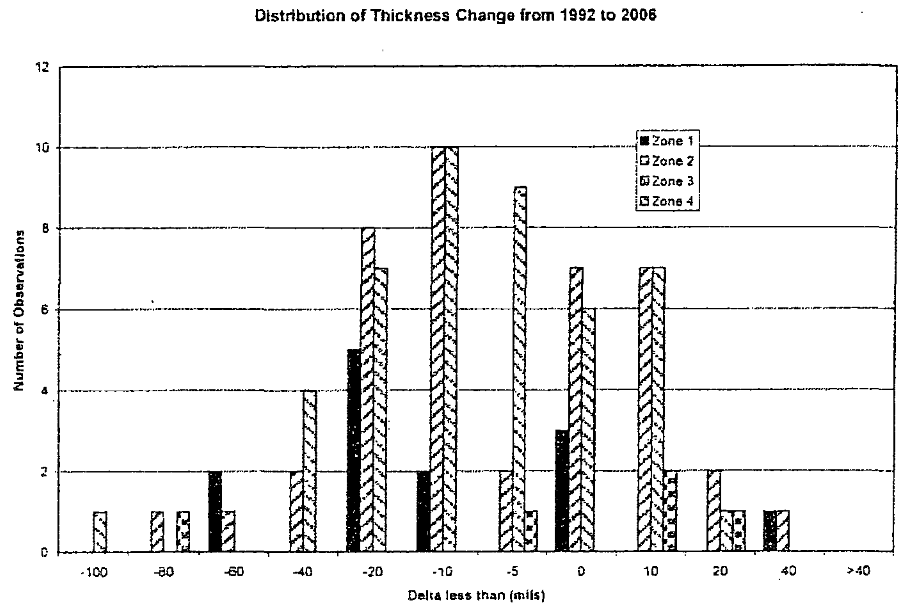

Figure 4-3. Distribution of Delta by Zone

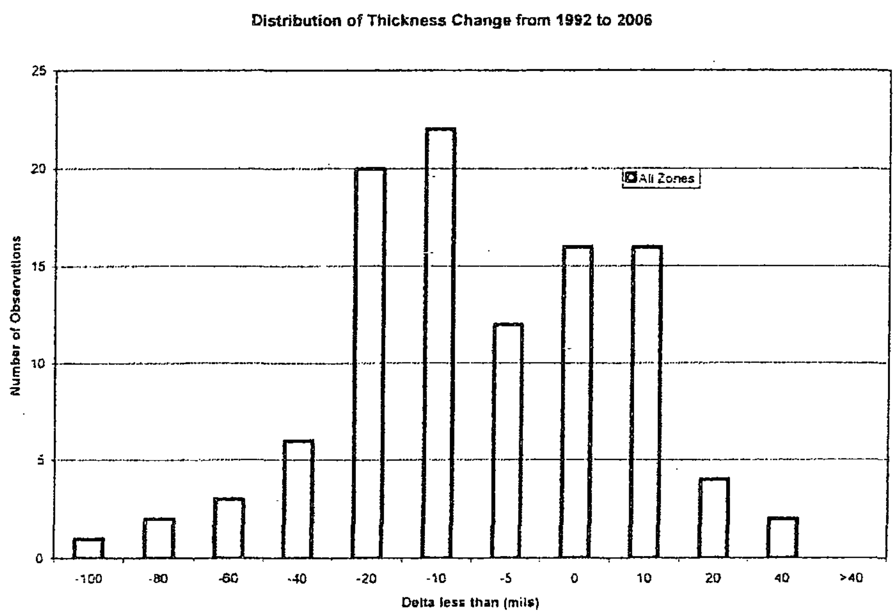

Figure 4-4. Distribution of Delta – All Zones

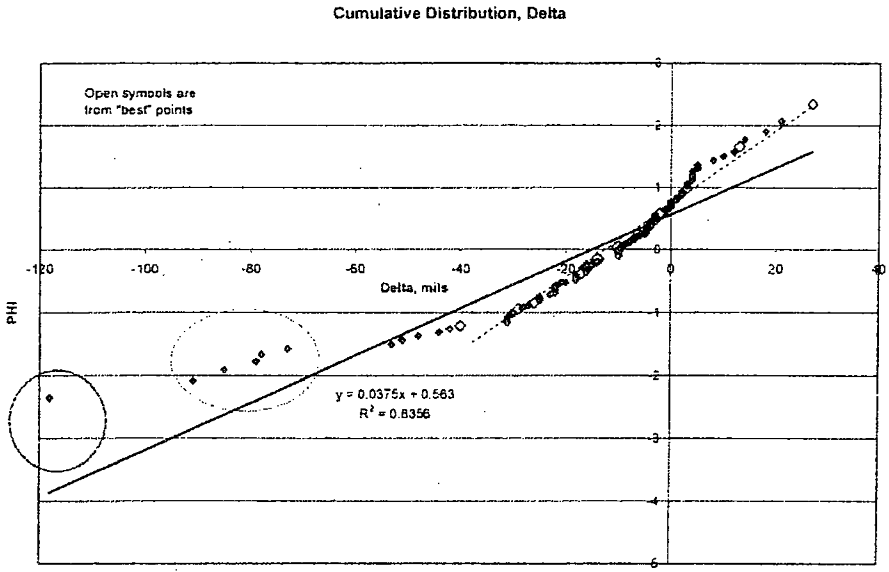

Figure 4-5. Cumulative Distribution, Delta

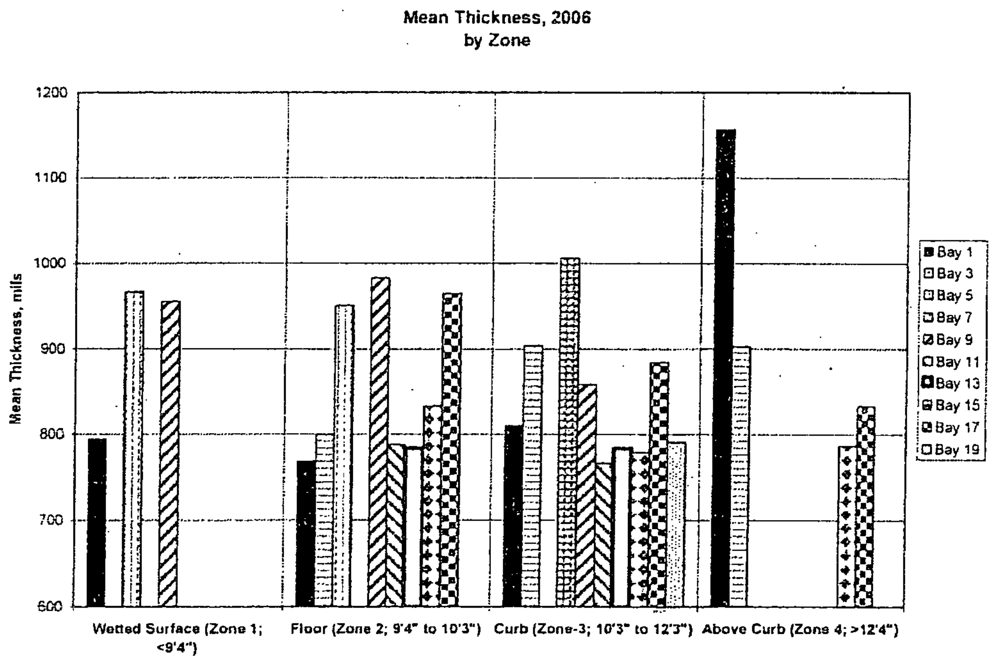

Figure 4-6. Mean Thickness (2006) by Zone and by Bay

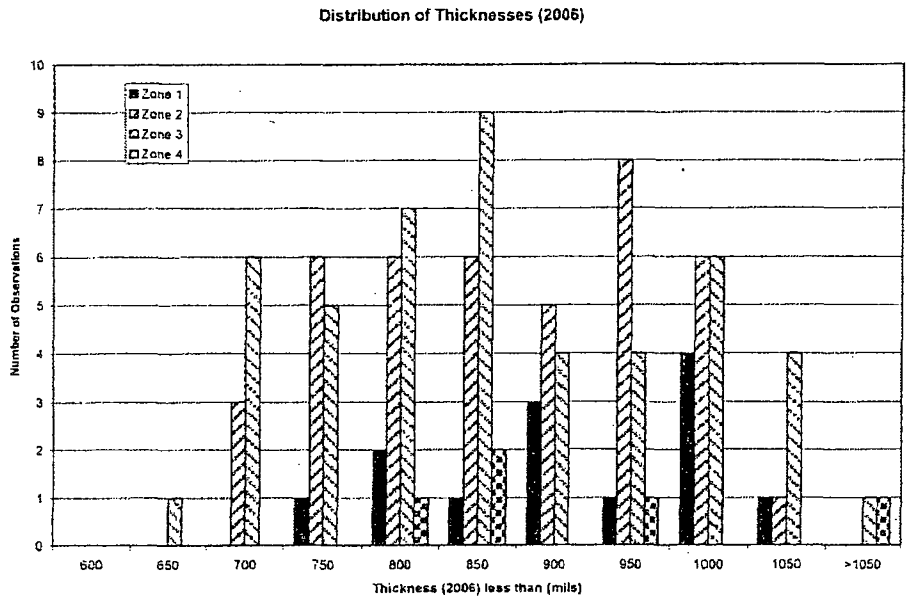

Figure 4-7. Distribution of Thickness (2006) by Zone

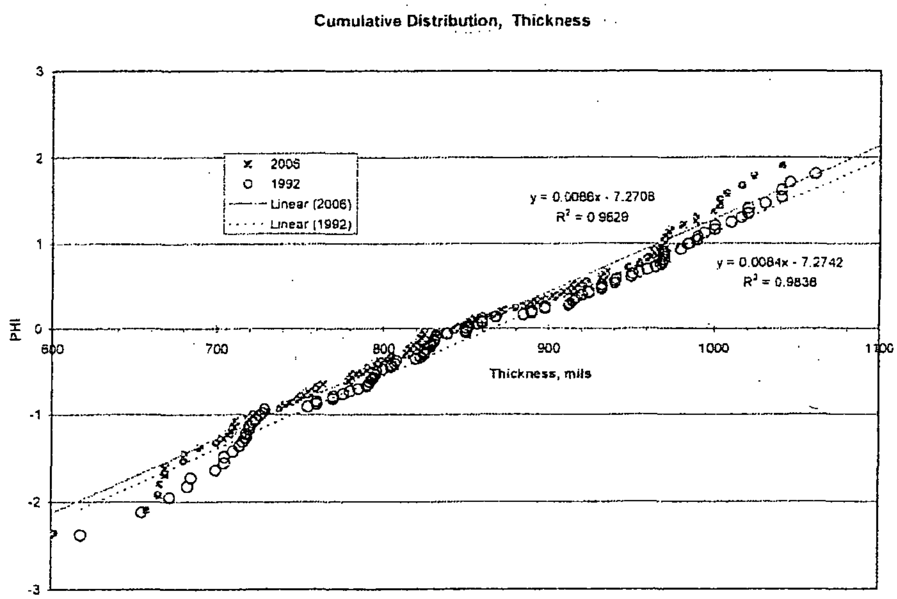

Figure 4-8. Cumulative Distributions, t_{2006} and t_{1992}

5.0 DISCUSSION

The delta, determined by the difference between separate UT thickness measurements taken at the same locations in 1992 and 2006, will be the sum of several terms as shown below:

Delta = Any Corrosion + bias (technique and operator) ± random error in measurements (both 1992 and 2006).

Random errors in the separate measurements will result from the inherent uncertainty in each UT thickness measurement plus the uncertainty associated with placing the transducer on exactly the same location at both points in time. Standardizing the procedure (e.g., scanning each location over a small, pre-determined area, and always reporting the minimum or average reading) can minimize the latter contribution to error. The site reported that different techniques were used in 1992 (done prior to coating; only a single point reported for each location) and 2006. The 2006 measurements were done through the coating, with software corrections to account for the coating and to adjust for the "air gap" resulting from placement of a flat transducer on a slightly curved (dimpled to provide a smooth and readily discernible location for repeat measurements) surface. Perhaps most significantly, the 2006 measurements scanned the defined areas and reported the minimum thickness. The differences in technique between 2006 would be expected to introduce some amount of bias (e.g., reporting minimum values vs. a single value) and could increase or decrease the random error.

Those separate thickness measurements will magnify the error, especially when two separate measurements at different points in time are intended to define a delta, where the expected delta is actually very near zero. The result is that some fraction, 21% in this case, of the locations appear to become thicker while others become thinner. The use of the difference between the 2006 and 1992 thickness measurements suggests that some locations appear to have become much thinner; clearly in stark contrast to the physical observation of the condition of the coating. In all cases, the delta is the difference between two thickness values that are very close in value. The error in individual measurements is clearly greater than the actual difference between drywell thickness in 1992 vs. that in 2006.

The statistical evaluation discussed in Section 4.1.2 clearly demonstrates that there is a bias in the thickness measurements, where the magnitude of that bias is at least 12 mils and is probably more like 20 mils. Clearly, that bias should be added to all of the 1992 readings, which defines the 2006 thickness data as the reference point (i.e., improved technique vs. 1992). Still, random errors can produce differences between individual measurements that do not correspond to the physical observation of coating condition.

Combining the statistical analysis with the physical observation of coating condition and the maximum corrosion rate that could occur beneath an intact coating provides clear evidence that the actual mean value of the difference between the 2006 and 1992 thickness measurements is zero or a value very near zero and that the six points (possibly twelve points) that indicate large negative deltas are actually outliers that should be ignored. That is, the actual differences in thickness between the 2006 and 1992 measurements have a mean that is essentially zero and a maximum of four mils or less. Those mean and maximum differences are far less than the bias introduced by the different techniques.

The most effective use of these data is to define the 2006 thickness measurements as the baseline as of 2006. Corrosion rate, as defined by physical observation of coating condition and a thorough analysis of the 106 thickness measurements done in both 1992 and 2006 confirms that the apparent corrosion over that 14 year period is essentially nil. The latter determination (i.e., corrosion or corrosion rate defined by the difference in the thickness measurements at each of the 106 locations) is subject to systematic and random errors that make the use of the differences less useful. Those latter measurements should be used with caution. Future determinations of corrosion of the drywell must be sure to combine physical observation of coating condition and supplement (but not replace) those observations with the thickness differences.

6.0 CONCLUSIONS

A statistically based review was performed on Oyster Creek drywell thickness data from 1992 and 2006. That review showed that the variation in individual thickness values varied significantly by bay and to a lesser extent by zone (i.e., height above or below the drywell floor).

Differences between the 1992 and 2006 UT thickness measurements, taken at the same 106 locations at both times showed that the vast majority of the difference data (deltas) were distributed around zero. More than 20% of the difference measurements indicated that the drywell became thicker over time; a few measurements suggested that there were large decreases in thickness over the 14 year period.

The several differences that suggested that there were very large thickness losses were in sharp contrast to the physical observation of the coating, which was in good condition. Metal losses beneath an intact coating would be non-existent or extremely small; clearly not losses of 70 mils or more.

Evaluation of the thicknesses in 1992 and 2006 showed that the thickness populations at both times were described well by a normal distribution. The statistical evaluation clearly demonstrates that there is a bias in the thickness measurements, where the magnitude of that bias is at least 12 mils and is probably more like 20 mils. Clearly, that bias should be added to all of the 1992 readings, which defines the 2006 thickness data as the reference point (i.e., improved technique vs. 1992). Still, random errors can produce differences between individual measurements that do not correspond to the physical observation of coating condition.

Combining the statistical analysis with the physical observation of coating condition and the maximum corrosion rate that could occur beneath an intact coating provides clear evidence that the actual mean value of the difference between the 2006 and 1992 thickness measurements is zero or a value very near zero and that the six points (possibly twelve points) that indicate large negative deltas are actually outliers that should be ignored. That is, the actual differences in thickness between the 2006 and 1992 measurements has a mean that is essentially zero and a maximum of four mils or less. Those mean and maximum differences are far less than the bias introduced by the different techniques.

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7.0 REFERENCES

1. "Data submittal 2006 vs. 92.xls", e-mail from Wayne Choromanski (Exelon) to George Licina, 11-3-2006.

2. Tech Eval A2152754 E09 (transmitted to SI by Wayne Choromanski. 11-1-2006).