GPU Nuclear Technical Data Report	TDR No. 948 Budget Activity No. 315302	Revision No. ~~0~~ 1 Page 1 of 26
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Document Title: STATISTICAL ANALYSIS OF DRYWELL THICKNESS DATA

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*	Distribution	Abstract:
	J. D. Abramovici F. P. Barbieri G. R. Capodanno D. W. Covill D. G. Jerko M. W. Laggart L. C. Lanese S. D. Leshnoff J. A. Martin J. P. Moore M. A. Orski S. C. Tumminelli M. O. Sanford D. G. Slear R. W. Keaten	Statement of Problem The design of the carbon steel drywell includes a sand bed which is located around the outside circumference between elevations 8'-11- 1/4" and 12'-3". Leakage was observed from the sand bed drains during the 1980, 1983 and 1986 refueling outages indicating that water had intruded into the annular region between the drywell shell and the concrete shield wall. A long term monitoring program was established in 1986 to take Ultrasonic Thickness (UT) measurements at representative locations on the drywell shell to determine the corrosion rate and monitor it over time. The initial program included six locations in the sand bed region. The program was expanded in 1987 to include measurements at higher elevations. (For Additional Space Use Side 2)

* Abstract Only

A cathodic protection system is being installed in selected regions of the sand bed to minimize corrosion of the drywell. The long term monitoring program was further expanded in 1988 to monitor the effectiveness of the cathodic protection system and to monitor additional sand bed regions not covered by cathodic protection.

A critical part of the long term program is the statistical analysis of the UT measurements to determine the corrosion rate at each location. This report documents the assumptions, methods, and results of the statistical analyses of UT measurements taken through December 31, 1988.

Summary of Key Results

Bay Area	Location	Corrosion Rate**	Mean Thickness***
11A	Sand Bed	Not significant	908.6 ±5.0 mils
11C	Sand Bed	Indeterminable	916.6 ±10.4 mils
17D	Sand Bed	-27.6 ±6.1 mpy	864.8 ±6.8 mils
19A	Sand Bed	-23.7 ±4.3 mpy	837.9 ±4.8 mils
19B	Sand Bed	-29.2 ±0.5 mpy	856.5 ±0.5 mils
19C	Sand Bed	-25.9 ±4.1 mpy	860.9 ±4.0 mils
9D	Sand Bed	Indeterminable*	1021.4 ±9.7 mils
13A	Sand Bed	Not significant*	905.3 ±10.1 mils
15D	Sand Bed	Possible*	1056.0 ±9.1 mils
17A	Sand Bed	Indeterminable*	957.4 ±9.2 mils
5	51' Elev.	-4.3 ±0.03 mpy	750.0 ±0.02 mils
9	87' Elev.	Not significant	620.3 ±1.0 mils
13	87' Elev.	Not significant	635.6 ±0.7 mils
15	87' Elev.	Not significant	634.8 ±0.7 mils
17D	Trench	Not significant*	981.2 ±6.7 mils
17/19	Frame Cutout	Indeterminable*	981.7 ±4.4 mils
1D	Sand Bed	Indeterminable*	1114.7 ±30.6 mils
3D	Sand Bed	Not significant*	1177.7 ±5.6 mils
5D	Sand Bed	Not significant*	1174.0 ±2.2 mils
7D	Sand Bed	Possible*	1135.1 ±4.9 mils
9A	Sand Bed	Indeterminable*	1154.6 ±4.8 mils
13C	Sand Bed	Not significant*	1147.4 ±3.7 mils
13D	Sand Bed	Not significant*	962.1 ±22.3 mils
15A	Sand Bed	Not significant*	1120.0 ±12.6 mils

One data point in Bay 19A and one data point in Bay 5 Elev. 51' fell outside the 99% confidence interval and thus are statistically different from the mean thickness.

*Based on limited data. See text for interpretation.
**Mean corrosion rate in mils per year ± standard error of the mean
***Current mean thickness in mils ± standard error of the mean

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TITLE

STATISTICAL ANALYSIS OF DRYWELL THICKNESS DATA

REV	SUMMARY OF CHANGE	APPROVAL	DATE
1	Corrected outage numbers on pages 3 and 5 (two places). Deleted redundant discussion of Bay 15D on pages 12, 19, 25 and 26.	A Moore G. Capodanno	1-30-89 1/31/89

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1.0 INTRODUCTION

1.1 Background

The design of the carbon steel drywell includes a sand bed which is located around the outside circumference between elevations 8'-11-1/4" and 12'-3". Leakage was observed from the sand bed drains during the 1980, 1983 and 1986 refueling outages indicating that water had intruded into the annular region between the drywell shell and the concrete shield wall.

The drywell shell was inspected in 1986 during the 11R outage to determine if corrosion was occurring. The inspection methods, results and conclusions are documented in Ref. 3.1, 3.2, and 3.3. As a result of these inspections it was concluded that a long term monitoring program would be established. This program includes repetitive Ultrasonic Thickness (UT) measurements in the sand bed region at a nominal elevation of 11'-3" in bays 11A, 11C, 17D, 19A, 19B, and 19C.

The continued presence of water in the sand bed raised concerns of potential corrosion at higher elevations. Therefore, UT measurements were taken at the 51' and 87' elevations in November 1987 during the 11M outage. As a result of these inspections, repetitive measurements in Bay 5 at elevation 51' and in Bays 9, 13 and 15 at the 87' elevation were added to the long term monitoring program to confirm that corrosion is not occurring at these higher elevations.

A cathodic protection system is being installed in selected regions of the sand bed during the 12R outage to minimize corrosion of the drywell. The long term monitoring program was also expanded during the 12R outage to include measurements in the sand bed region of Bays 1D, 3D, 5D, 7D, 9A, 13A, 13C, 13D, 15A, 15D and 17A which are not covered by the cathodic protection system. It also includes measurements in the sand bed region between Bays 17 and 19 which is covered by the cathodic protection system, but does not have a reference electrode to monitor its effectiveness in this region.

Some measurements in the long term monitoring program are to be taken at each outage of opportunity, while others are taken during each refueling outage. The functional requirements for these inspections are documented in Ref. 3.4. The primary purpose of the UT measurements in the sand bed region is to determine the corrosion rate and monitor it over time. When the cathodic protection system is installed and operating, these data will be used to monitor its effectiveness. The purpose of the measurements at other locations is to confirm that corrosion is not occurring in those regions.

This report documents the assumptions, methods, and results of the statistical analyses used to evaluate the corrosion rate in each of these regions. The complete analyses are documented in Ref. 3.7.

1.2 Statistical Inferences

1.2.1 Statistical Hypotheses

The objective of these statistical analyses is to make statistical decisions or inferences about populations on the basis of sample information. In attempting to reach these decisions, it is useful to make assumptions or guesses about the populations involved. Such assumptions, which may or may not be true, are called statistical hypotheses and in general are statements about the probability distributions of the populations.

In many instances we formulate a statistical hypothesis for the sole purpose of rejecting or nullifying it. For example, in performing a t-test to test the difference between the means of two samples we first hypothesize that there is no difference between the two means. This is referred to as a null hypothesis. Any hypothesis which differs from the null hypothesis is referred to as an alternative hypothesis, eg., the means are not equal, one mean is greater than the other, etc.

1.2.2 Tests of Hypotheses and Significance

If on the supposition that a particular null hypothesis is true we find that results observed in a random sample differ markedly from those expected under the hypothesis on the basis of pure chance, we would say that the observed differences are significant and we would be inclined to reject the hypothesis (or at least not accept it on the basis of the evidence obtained). Procedures which enable us to decide whether to reject or not reject hypotheses are called tests of hypotheses.

1.2.3 Type I and Type II Errors

If we reject a hypothesis when it should not have been rejected, we say that a Type I error has been made. If, on the other hand, we fail to reject a hypothesis when it should have been rejected, we say a Type II error has been made. In either case a wrong decision or error in judgement has occurred.

1.2.4 Level of Significance

In testing a given hypothesis, the maximum probability with which we would be willing to risk a Type I error is called the level of significance of the test. This probability is usually denoted by the Greek letter alpha. In practice a level of significance of 0.05 (5%) or 0.01 (1%) is customary. If 0.05 has been selected, we say that the hypothesis is rejected (or not rejected) at a level of significance of 0.05.

2.0 METHODS

2.1 Selection of Areas to be Monitored

A program was initiated during the 11R outage to characterize the corrosion and to determine its extent. The details of this inspection program are documented in Ref. 3.3. The greatest corrosion was found via UT measurements in the sand bed region at the lowest accessible locations. Where thinning was detected, additional measurements were made in a cross pattern at the thinnest section to determine the extent in the vertical and horizontal directions. Having found the thinnest locations, measurements were made over a 6"-6" grid.

To determine the vertical profile of the thinning, a trench was excavated into the floor in Bay 17 and Bay 5. Bay 17 was selected since the extent of thinning at the floor level was greatest in that area. It was determined that the thinning below the top of the curb was no more severe than above the curb, and became less severe at the lower portions of the sand cushion. Bay 5 was excavated to determine if the thinning line was lower than the floor level in areas where no thinning was detected above the floor. There were no significant indications of thinning in Bay 5.

It was on the basis of these findings that the 6"x6" grids in Bays 11A, 11C, 17D, 19A, 19B and 19C were selected as representative locations for longer term monitoring. The initial measurements at these locations were taken in December 1986 without a template or markings to identify the location of each measurement. Subsequently, the location of the 6"x6" grids were permanently marked on the drywell shell and a template is used in conjunction with these markings to locate the UT probe for successive measurements. Analyses have shown that including the non-template data in the data base creates a significant variability in the thickness data. Therefore, to minimize the effects of probe location, only those data sets taken with the template are included in the analyses.

The presence of water in the sand bed also raised concern of potential corrosion at higher elevations. Therefore, UT measurements were taken at the 51' and 87' elevations in 1987 during the 11M outage. The measurements were taken in a band on 6-inch centers at all accessible regions at these elevations. Where these measurements indicated potential corrosion, the measurements spacing was reduced to 1-inch on centers. If these additional readings indicated potential corrosion, measurements were taken on a 6"x6" grid using the template. It was on the basis of these inspections that the 6"x6" grids in Bay 5 at elevation 51' and in bays 9, 13 and 15 at the 87' elevation were selected as representative locations for long term monitoring.

The long term monitoring program was expanded as follows during the 12R outage:

(1) Measurements on 6"x6" grids in the sand bed region of Bays 9D, 13A, 15D and 17A. The basis for selecting these locations is that they were originally considered for cathodic protection but are not included in the system being installed.

(2) Measurements on 1-inch centers along a 6-inch horizontal strip in the sand bed region of Bays 1D, 3D, 5D, 7D, 9A, 13C, and 15A. These locations were selected on the basis that they are representative of regions which have experienced nominal corrosion and are not within the scope of the cathodic protection system.

(3) A 6"x6" grid in the curb cutout between Bays 17 and 19. The purpose of these measurements is to monitor corrosion in this region which is covered by the cathodic protection system but does not have a reference electrode to monitor its performance.

2.2 UT Measurements

The UT measurements within the scope of the long term monitoring program are performed in accordance with Ref. 3.4. This involves taking UT measurements using a template with 49 holes laid out on a 6"x6" grid with 1" between centers on both axes. The center row is used in those bays where only 7 measurements are made along a 6-inch horizontal strip.

The first set of measurements were made in December 1986 without the use of a template. Ref. 3.4 specifies that for all subsequent readings, QA shall verify that locations of UT measurements performed are within $\pm 1/4"$ of the location of the 1986 UT measurements. It also specifies that all subsequent measurements are to be within $\pm 1/8"$ of the designated locations.

2.3 Data at Plug Locations

Seven core samples, each approximately two inches in diameter were removed from the drywell vessel shell. These samples were evaluated in Ref. 3.2. Five of these samples were removed within the 6"x6" grids for Bays 11A, 17D, 19A, 19C and Bay 5 at elevation 51'. These locations were repaired by welding a plug in each hole. Since these plugs are not representative of the drywell shell, UT measurements at these locations on the 6"x6" grid must be dropped from each data set

The following specific grid points have been deleted:

Bay Area	Points
11A	23, 24, 30, 31
17D	15, 16, 22, 23
19A	24, 25, 31, 32
19C	20, 26, 27, 33,
5	20, 26, 27, 28, 33, 34, 35

2.4 Bases for Statistical Analysis of 6"x6" Grid Data

2.4.1 Assumptions

The statistical evaluation of the UT measurement data to determine the corrosion rate at each location is based on the following assumptions:

(1) Characterization of the scattering of data over each 6"x6" grid is such that the thickness measurements are normally distributed.

(2) Once the distribution of data for each 6"x6" grid is found to be normal, then the mean value of the thickness is the appropriate representation of the average condition.

(3) A decrease in the mean value of the thickness with time is representative of the corrosion occurring within the 6"x6" grid.

(4) If corrosion has ceased, the mean value of the thickness will not vary with time except for random errors in the UT measurements.

(5) If corrosion is continuing at a constant rate, the mean thickness will decrease linearly with time. In this case, linear regression analysis can be used to fit the mean thickness values for a given zone to a straight line as a function of time. The corrosion rate is equal to the slope of the line.

The validity of these assumptions is assured by:

(a) Using more than 30 data points per 6"x6" grid

(b) Testing the data for normality at each 6"x6" grid location.

(c) Testing the regression equation as an appropriate model to describe the corrosion rate.

These tests are discussed in the following section. In cases where one or more of these assumptions proves to be invalid, non-parametric analytical techniques can be used to evaluate the data.

2.4.2 Statistical Approach

The following steps are performed to test and evaluate the UT measurement data for those locations where 6"x6" grid data has been taken at least three times:

(1) Edit each 49 point data set by setting all invalid points to zero. Invalid points are those which are declared invalid by the UT operator or are at a plug location. (The computer programs used in the following steps ignore all zero thickness data points.)

(2) Perform a chi-squared goodness of fit test of each 49 point data set to ensure that the assumption of normality is valid at the 95% and 99% confidence levels.

(3) Calculate the mean thickness of each 49 point data set.

(4) Using the mean thickness values for each 6"x6" grid, perform linear regression analysis over time at each location.

(a) Perform F-test for significance of regression at the 95% confidence level. The result of this test indicates whether or not the regression model is more appropriate than the mean model In other words, it tests to see if the variation of the regression model is statistically significant over that of a mean model.

(b) Calculate the co-efficient of determination (R^2) to assess how well the regression model explains the percentage of total error and thus how useful the regression line will be as a predictor.

(c) Determine if the residual values for the regression equations are normally distributed.

(d) If the regression model is found to be appropriate, calculate the y-intercept, the slope and their respective standard errors. The y-intercept represents the fitted mean thickness at time zero, the slope represents the corrosion rate, and the standard errors represent the uncertainty or random error of these two parameters.

(5) Use a z score of 2.58 and the standard deviation to establish a 99% confidence interval about the mean thickness values for each 6"x6" grid location to determine whether low thickness measurements or "outliers" are statistically significant. If the data points are greater than the 99% lower confidence limit, then the difference between the value and the mean is deemed to be due to expected random error. However, if the data point is less than the lower 99% confidence limit, this implies that the difference is statistically significant and is probably not due to chance.

2.5 Analysis of Two 6"x6" Grid Data Sets

Regression analysis is inappropriate when data is available at only two points in time. However, the t-Test can be used to determine if the means of the two data sets are statistically different.

2.5.1 Assumptions

This analysis is based upon the following assumptions:

(1) The data in each data set is normally distributed.

(2) The variances of the two data sets are equal.

2.5.2 Statistical Approach

The evaluation takes place in three steps:

(1) Perform a chi-squared test of each data set to ensure that the assumption of normality is valid at the 95% and 99% confidence levels.

(2) Perform an F-test of the two data sets being compared to ensure that the assumption of equal variances is valid at the 95% and 99% confidence levels.

(3) Perform a two-tailed t-Test for two independent samples to determine if the means of the two data sets are statistically different at the 0.05 and 0.01 levels of significance.

A conclusion that the means are not statistically different is interpreted to mean that significant corrosion did not occur over the time period represented by the data. However, if equality of the means is rejected, this implies that the difference is statistically significant and could be due to corrosion.

2.6 Analysis of Single 6"x6" Grid Data Set

In those cases where a 6"x6" data set is taken at a given location for the first time during the current outage, the only other data to which they can be compared are the UT survey measurements taken in 1986 to identify the thinnest regions of the drywell shell in the sand bed region. For the most part, these are single point measurements which were taken in the vicinity of the 49-point data set, but not at the exact location. Therefore, rigorous statistical analysis of these single data sets is impossible. However, by making certain assumptions, they can be compared with the previous data points. If more extensive data is available at the location of the 49-point data set, the t-test can be used to compare the means of the two data sets as described in paragraph 2.5.

When additional measurements are made at these exact locations during future outages, more rigorous statistical analyses can be employed.

2.6.1 Assumptions

The comparison of a single 49-point data sets with previous data from the same vicinity is based on the following assumptions:

(1) Characterization of the scattering of data over the 6"x6" grid is such that the thickness measurements are normally distributed.

(2) Once the distribution of data for the 6"x6" grid is found to be normal, then the mean value of the thickness is the appropriate representation of the average condition.

(3) The prior data is representative of the condition at this location in 1986.

2.6.2 Statistical Approach

The evaluation takes place in four steps:

(1) Perform a chi-squared test of each data set to ensure that the assumption of normality is valid at the 95% and 99% confidence levels.

(2) Calculate the mean and the standard error of the mean of the 49-point data set.

(3) Determine the two-tailed t value from a t distribution table at levels of significance of 0.05 and 0.01 for n-1 degrees of freedom.

(4) Use the t value and the standard error of the mean to calculate the 95% and 99% confidence intervals about the mean of the 49-point data set.

(5) Compare the prior data point(s) with these confidence intervals about the mean of the 49-point data sets.

If the prior data falls within the 95% confidence intervals, it provides some assurance that significant corrosion has not occurred in this region in the period of time covered by the data. If it falls within the 99% confidence limits but not within the 95% confidence limits, this implication is not as strong. In either case, the corrosion rate will be interpreted to be "Not Significant".

If the prior data falls above the upper 99% confidence limit, it could mean either of two things: (1) significant corrosion has occurred over the time period covered by the data, or (2) the prior data point was not representative of the condition of the location of the 49-point data set in 1986. There is no way to differentiate between the two. In this case, the corrosion rate will be interpreted to be "Possible".

If the prior data falls below the lower 99% confidence limit, it means that it is not representative of the condition at this location in 1986. In this case, the corrosion rate will be interpreted to be "Indeterminable".

2.7 Analysis of Single 7-Point Data Set

In those cases where a 7-point data set is taken at a given location for the first time during the current outage, the only other data to which they can be compared are the UT survey measurements taken in 1986 to identify the thinnest regions of the drywell shell in the sand bed region. For the most part, these are single point measurements which were taken in the vicinity of the 7-point data sets, but not at the exact locations. However, by making certain assumptions, they can be compared with the previous data points. If more extensive data is available at the location of the 7-point data set, the t-test can be used to compare the means of the two data sets as described in paragraph 2.5.

When additional measurements are made at these exact locations during future outages, more rigorous statistical analyses can be employed.

2.7.1 Assumptions

The comparison of a single 7-point data sets with previous data from the same vicinity is based on the following assumptions:

(1) The corrosion in the region of each 7-point data set is normally distributed.

(2) The prior data is representative of the condition at this location in 1986.

The validity of these assumptions cannot be verified.

2.7.2. Statistical Approach

The evaluation takes place in four steps:

(1) Calculate the mean and the standard error of the mean of the 7-point data set.

(2) Determine the two-tailed t value using the t distribution tables at levels of significance of 0.05 and 0.01 for n-1 degrees of freedom.

(3) Use the t value and the standard error of the mean to calculate the 95% and 99% confidence intervals about the mean of the 7-point data set.

(4) Compare the prior data point(s) with these confidence intervals about the mean of the 7-point data sets.

If the prior data falls within the 95% confidence intervals, it provides some assurance that significant corrosion has not occurred in this region in the period of time covered by the data. If it falls within the 99% confidence limits but not within the 95% confidence limits, this implication is not as strong. In either case, the corrosion rate will be interpreted to be "Not Significant".

If the prior data falls above the upper 99% confidence interval, it could mean either of two things: (1) significant corrosion has occurred over the time period covered by the data, or (2) the prior data point was not representative of the condition of the location of the 7-point data set in 1986. There is no way to differentiate between the two. In this case, the corrosion rate will be interpreted to be "Possible".

If the prior data falls below the lower 99% confidence limit, it means that it is not representative of the condition at this location in 1986. In this case, the corrosion rate will be interpreted to be "Indeterminable".

2.8 Evaluation of Drywell Mean Thickness

This section defines the methods used to evaluate the drywell thickness at each location within the scope of the long term monitoring program.

2.8.1 Evaluation of Mean Thickness Using Regression Analysis

The following procedure is used to evaluate the drywell mean thickness at those locations where regression analysis has been deemed to be more appropriate than the mean model.

(1) The best estimate of the mean thickness at these locations is the point on the regression line corresponding to the time when the most recent set of measurements was taken. In the SAS Regression Analysis output (Ref. 3.7), this is the last value in the column labeled "PREDICT VALUE".

(2) The best estimate of the standard error of the mean thickness is the standard error of the predicted value used above. In the SAS Regression Analysis output, this is the last value in the column labeled "STD ERR PREDICT".

(3) The two-sided 95% confidence interval about the mean thickness is equal to the mean thickness plus or minus t times the estimated standard error of the mean. This is the interval for which we have 95% confidence that the true mean thickness will fall within. The value of t is obtained from a t distribution table for <u>equal tails</u> at n-2 degrees of freedom and 0.05 level of significance, where n is the number of sets of measurements used in the regression analysis. The degrees of freedom is equal to n-2 because two parameters (the y-intercept and the slope) are calculated in the regression analysis with n mean thicknesses as input.

(4) The one-sided 95% lower limit of the mean thickness is equal to the estimated mean thickness minus t times the estimated standard error of the mean. This is the mean thickness for which we have 95% confidence that the true mean thickness does not fall below. In this case, the value of t is obtained from a t distribution table for <u>one tail</u> at n-2 degrees of freedom and 0.05 level of significance.

2.8.2 <u>Evaluation of Mean Thickness Using Mean Model</u>

The following procedure is used to evaluate the drywell mean thickness at those locations where the mean model is deemed to be more appropriate than the linear regression model. This method is consistent with that used to evaluate the mean thickness using the regression model.

(1) Calculate the mean of each set of UT thickness measurements.

(2) Sum the means of the sets and divide by the number of sets to calculate the grand mean. This is the best estimate of the mean thickness. In the SAS Regression Analysis output (Ref. 3.7), this is the value labelled "DEP MEAN".

(3) Using the means of the sets from (1) as input, calculate the standard error. This is the best estimate of the standard error of the mean thickness.

(4) The two-sided 95% confidence interval about the mean thickness is equal to the mean thickness plus or minus t times the estimated standard error of the mean. This is the interval for which we have 95% confidence that the true mean thickness will fall within. The value of t is obtained from a t distribution table for equal tails at n-1 degrees of freedom and 0.05 level of significance.

(5) The one-sided 95% lower limit of the mean thickness is equal to the estimated mean thickness minus t times the estimated standard error of the mean. This is the mean thickness for which we have 95% confidence that the true mean thickness does not fall below. In this case, the value of t is obtained from a t distribution table for one tail at n-1 degrees of freedom and 0.05 level of significance.

2.8.3 Evaluation of Mean Thickness Using Single Data Set

The following procedure is used to evaluate the drywell thickness at those locations where only one set of measurements is available.

(1) Calculate the mean of the set of UT thickness measurements. This is the best estimate of the mean thickness.

(2) Calculate the standard error of the mean for the set of UT measurements. This is the best estimate of the standard error of the mean thickness.

Confidence intervals about the mean thickness cannot be calculated with only one data set available.

3.0 REFERENCES

3.1 GPUN Safety Evaluation SE-000243-002, Rev. 0, "Drywell Steel Shell Plate Thickness Reduction at the Base Sand Cushion Entrenchment Region"

3.2 GPUN TDR 854, Rev. 0, "Drywell Corrosion Assessment"

3.3 GPUN TDR 851, Rev. 0, "Assessment of Oyster Creek Drywell Shell"

3.4 GPUN Installation Specification IS-328227-004, Rev. 3, "Functional Requirements for Drywell Containment Vessel Thickness Examination"

3.5 Applied Regression Analysis, 2nd Edition, N.R. Draper & H. Smith, John Wiley & Sons, 1981

3.6 Statistical Concepts and Methods G.K. Bhattacharyya & R.A. Johnson, John Wiley & sons, 1977

3.7 GPUN Calculation C-1302-187-5300-005, Statistical Analysis of Drywell Thickness Data Thru 12/31/88.

4.0 EVALUATION OF DATA THROUGH 12/31/88

4.1 Results for 6"x6" Grids in Sand Bed Region at Original Locations

4.1.1 Bay 11A: 5/1/87 to 10/8/88

Six 49-point data sets were available for this bay covering the time period from May 1, 1987 to October 8, 1988. Since a plug lies within this region, four of the points were voided in each data set. The data were analyzed as described in paragraphs 2.4 and 2.8.2.

(1) The data are normally distributed.

(2) The mean model is more appropriate than the regression model.

(3) The current mean thickness ± standard error is 908.6 ±5.0 mils.

(4) There was no significant corrosion from May 1, 1987 to October 8, 1988.

4.1.2 Bay 11C: 5/1/87 to 10/8/88

Five 49-point data sets were available for this bay covering the time period from May 1, 1987 to October 8, 1988. These data were analyzed as described in paragraphs 2.4 and 2.8.2. The initial analysis of this data indicated that the data are not normally distributed. The lack of normality was tentatively attributed to minimal corrosion in the upper half of the 6"x6" grid with more extensive corrosion in the lower half of the grid. To test this hypothesis, each data set was divided into two subsets, with one containing the top three rows and the other containing the bottom four rows.

The top subset was normally distributed but the bottom subset was not. For both subsets, the mean model is more appropriate than the regression model.

Since there is an observable decrease in the mean thickness with time, there appears to be some on-going corrosion at this location. Further analysis is required.

The current mean thickness ± standard error is 916.6 ±10.4 mils for the lower subset and 1057.6 ±16.9 mils for the upper subset.

4.1.3 Bay 17D: 2/17/87 to 10/8/88

Six 49-point data sets were available for this bay covering the time period from February 17, 1987 to October 8, 1988. Since a plug lies within this region, four of the points were voided in each data set. The data were analyzed as described in paragraphs 2.4 and 2.8.1.

(1) The data are normally distributed.

(2) The regression model is appropriate.

(3) The regression model explains 84% of the total variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 864.8 ±6.8 mils.

(6) The corrosion rate ± standard error is -27.6 ±6.1 mils per year.

(7) The measurements below 800 mils were tested and determined not to be statistically different from the mean thickness.

4.1.4 Bay 19A: 2/17/87 to 10/8/88

Six 49-point data sets were available for this bay covering the time period from February 17, 1987 to October 8, 1988. Since a plug lies within this region, four of the points were voided in each data set. The data were analyzed as described in paragraphs 2.4 and 2.8.1.

(1) The data are nearly normally distributed.

(2) The regression model is appropriate

(3) The regression model explains 88% of the total variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 837.9 ±4.8 mils.

(6) The corrosion rate ± standard error is -23.7 ±4.3 mpy.

(7) One data point that was below 800 mils at two different times was tested and determined to be statistically different from the mean thickness. The probability of this occurring is less than 1% at each specific time.

4.1.5 Bay 19B: 5/1/87 to 10/8/88

Five 49-point data sets were available for this bay covering the time period from May 1, 1987 to October 8, 1988. The data were analyzed as described in paragraphs 2.4 and 2.8.1.

(1) The data are normally distributed.

(2) The regression model is appropriate.

(3) The regression model explains 99% of the total variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 856.5 ±0.5 mils.

(6) The corrosion rate ± standard error is -29.2 ±0.5 mpy.

(7) The measurements below 800 mils were tested and determined not to be statistically different from the mean thickness.

4.1.6 Bay 19C: 5/1/87 to 10/8/88

Five 49-point data sets were available for this bay covering the time period from May 1, 1987 to October 8, 1988. Since a plug lies within this region, four of the points were voided in each data set. The data were analyzed as described in paragraphs 2.4 and 2.8.1.

(1) The data are normally distributed.

(2) The regression model is appropriate.

(3) The regression model explains 91% of the total variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 860.9 ±4.0 mils.

(6) The corrosion rate ± standard error is -25.9 ±4.1 mpy.

(7) The measurements below 800 mils were tested and determined not to be statistically different from the mean thickness.

4.2 Results for 6"x6" Grids in Sand Bed Region at New Locations

4.2.1 Bay 9D: 11/25/86 to 12/19/88

The 6"x6" grid data was taken in December 1988 during the 12R outage. This bay was considered for cathodic protection, but is not within the scope of the cathodic protection system being installed. The primary purpose of this data is to establish a base line to monitor corrosion in the future. However, previous measurements were taken in November 1986 in a 10-point 6"x6" cruciform pattern. Measurements were also taken in a 6"x6" grid in December 1986. The new data were compared with both of the previous data sets. These comparisons were made using the chi-squared test, F-test and two-tailed t-test as described in paragraph 2.5. The mean thickness was determined as described in paragraph 2.8.3.

(1) The data are normally distributed.

(2) The variances are equal in both comparisons.

(3) It is appropriate to use the two-tailed t-test in both comparisons.

(4) The difference between the means of the 1988 49-point data set and the 1986 10-point data set is not significant. However, there is a significant difference between the means of the 1988 49-point data set and the 1986 49-point data set. Therefore, significance of the corrosion rate is classified as "Indeterminable".

(5) The current mean thickness $\pm$ standard error is 1021.4 $\pm$9.7 mils.

4.2.2 Bay 13A: 11/25/86 to 12/17/88

The 6"x6" grid data was taken for the first time in December 1988 during the 12R outage. This bay was considered for cathodic protection, but is not within the scope of the cathodic protection being installed. The primary purpose of this data is to establish a base line to monitor corrosion in the future. However, previous measurements were taken in November 1986 in abutting 6"x6" cruciform patterns across the entire bay. As a best approximation, 13 of these data points are at the same location as the new 6"x6" grid data set. Therefore, the new data were first compared with these 13 data points, and then with 21 data points which include the 13 plus 8 additional points within one inch on either side. These comparisons were made using the chi-squared test, F-test and two-tailed t-test as described in paragraph 2.5. The mean thickness was determined as described in paragraph 2.8.3.

(1) The data are normally distributed.

(2) The variances are equal in both comparisons.

(3) It is appropriate to use the two-tailed t-test in both comparisons.

(4) The difference between the means of the data sets is not signficant. Therefore, the corrosion is classified as "Not Significant".

(5) The current mean thickness $\pm$ standard error is 905.3 $\pm$10.1 mils.

4.2.3 Bay 15D: 11/25/86 to 12/17/88

The 6"x6" grid data was taken for the first time in December 1988 during the 12R outage. This bay was considered for cathodic protection, but is not within the scope of the cathodic protection being installed. The primary purpose of this data is to establish a base line to monitor corrosion in the future. However, a previous 1-point measurement was taken in November 1986. The location of this point may have been somewhat removed from the location of the new 6"x6" grid data set. The previous measurement was compared with the new data set using the methods described in paragraph 2.6. The mean thickness was determined as described in paragraph 2.8.3.

(1) The new data are normally distributed.

(2) The previous measurement falls above the 99% upper bound of the new data.

(3) This implies that the corrosion may have occurred in the time period covered by this data. Therefore, the corrosion is classified as "Possible".

(4) The current mean thickness $\pm$ standard error is 1056.0 $\pm$9.1 mils.

4.2.4 Bay 17A: 11/25/86 to 12/17/88

The 6"x6" grid data was taken for the first time in December 1988 during the 12R outage. This bay was considered for cathodic protection, but is not within the scope of the cathodic protection being installed. The primary purpose of this data is to establish a base line to monitor corrosion in the future. However, a previous

1-point measurement was taken in November 1986. The location of this point may have been somewhat removed from the location of the new 6"x6" grid data set. The previous measurement was compared with the new data set using the methods described in paragraph 2.6. The mean thickness was determined as described in paragraph 2.8.3.

(1) The new data are not normally distributed. However, the top three rows and the bottom four rows are each normally distributed.

(2) The previous measurement falls below the 99% confidence interval for the top three rows, and above the 99% confidence interval for the bottom four rows.

(3) The corrosion is classified as "Indeterminable".

(4) The current mean thickness $\pm$ standard error is 1133.1 $\pm$6.9 milsfor the top three rows and 957.4 $\pm$9.2 mils for the bottom four rows.

4.3 Results for 6"x6" Grids at Upper Elevations

4.3.1 Bay 5 51' Elevation: 11/01/87 to 10/8/88

Three 49-point data sets were available for this bay covering the time period from November 1, 1987 to October 8, 1988. The data were analyzed as described in paragraphs 2.4 and 2.8.1.

(1) Except for the first data set, the data are normally distributed.

(2) The regression model is appropriate.

(3) The regression model explains 99% of the total variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness $\pm$ standard error is 750.0 $\pm$0.02 mils.

(6) The corrosion rate $\pm$ standard error is -4.3 $\pm$0.03 mpy.

(7) One data point was determined to be statistically different from the mean thickness. The probability of this occurring due to expected random error is less than 1% at each specific time.

4.3.2 Bay 9 87' Elevation: 11/6/87 to 10/8/88

Three 49-point data sets were available for this bay covering the time period from November 6, 1987 to October 8, 1988. The data were analyzed as described in paragraphs 2.4 and 2.8.2.

(1) The data are normally distributed.

(2) The mean model is appropriate than the regression model.

(3) There was no significant corrosion from November 6, 1987 to October 8, 1988.

(4) The current mean thickness ± standard error is 620.3 ±1.0 mils.

4.3.3 Bay 13 87' Elevation: 11/10/87 to 10/8/88

Three 49-point data sets were available for this bay covering the time period from November 10, 1987 to October 8, 1988. The data were analyzed as described in paragraphs 2.4 and 2.8.2.

(1) The data are normally distributed.

(2) The mean model is more appropriate than the regression model.

(3) There was no significant corrosion from November 10, 1987 to October 8, 1988.

(4) The current mean thickness ± standard error is 635.6 ±0.7 mils.

4.3.4 Bay 15 87' Elevation: 11/10/87 to 10/8/88

Three 49-point data sets were available for this bay covering the time period from November 10, 1987 to October 8, 1988. The data were analyzed as described in paragraphs 2.4 and 2.8.2.

(1) The data are normally distributed.

(2) The mean model is more appropriate than the regression model.

(3) There was no significant corrosion from November 10, 1987 to October 8, 1988.

(4) The current mean thickness ± standard error is 634.8 ±0.7 mils.

4.4 Results for Multiple 6"x6" Grids in Trench

4.4.1 Bay 17D Trench: 12/9/86 to 12/23/88

The two sets of measurements in the Bay 17D Trench were taken on December 9, 1986 and December 23, 1988. The 1986 data is a 7 column by 36 row array. The 1988 data is a 7 column by 42 row array. The 1986 data is at the same elevation as the lower 36 rows of the 1988 data, but is centered about 3-/12 inches to the left of the 1988 data. To compare these two data sets, the 1986 data set and the lower 36 rows of the 1988 data set were each subdivided into six 7 column by 6 row subsets. Each pair of subsets was compared as described in paragraphs 2.5 and 2.8.3.

Fourth Subset From The Top:

The chi-squared statistic for the fourth subset from the top from the 1986 data set slightly exceeded the critical value for level of significance of 0.05, but was within the critical value for level of significance of 0.01. Also, the F statistic exceeded the critical value for levels of significance of 0.05 and 0.01. Therefore, it is inappropriate to apply the two-tailed t-test based on equal variances. However, the approximate t-test based on unequal variances can be applied. From the results of this test, it is concluded that the difference between the mean thicknesses is not significant. This implies that corrosion at this location was not significant.

All Other Subsets:

(1) The data are normally distributed.

(2) The variances are equal.

(3) Comparison of the means using the two-tailed t-test is appropriate.

(4) The difference between the means of the subsets was not significant. This implies that there was no significant corrosion in the period from December 9, 1986 to December 23, 1988.

(5) The current mean thickness ± standard error of the top subset is 981.2 ±6.7 mils. This is the thinnest area in the trench.

4.4.2 Bays 17/19 Frame Cutout: December 1988

Two sets of 6"x6" grid measurements were taken in December 1988. The upper one is located 25" below the top of the high curb and the other below the floor. There is no previous data. The upper location has been added to the long term monitoring program. With no prior data, the only possible analysis was to check the data sets for normality using the chi-squared test.

The data at the upper location are not normally distributed. The lack of normality was tentatively attributed to minimal corrosion in the lower half of the 6"x6" grid with more extensive corrosion in the upper half of the grid. To test this hypothesis, each data set was divided into two subsets, with one containing the top three rows and the other containing the bottom four rows. These subsets proved to be normally distributed, thus confirming the hypothesis. The current mean thickness ± standard error is 981.7 ±4.4 mils for the top three rows and 1003.8 ±6.6 mils for the bottom four rows.

The data at the location below the floor is normally distributed. Also, the mean thickness is higher than at the upper location. The mean thickness ± standard error is 1034.1 ±6.8 mils.

4.5 Results for 6" Strips in Sand Bed Region

4.5.1 Bay 1D: 11/25/86 to 12/17/88

The 7-point data set was taken in December 1988 and a single point measurement was taken in November 1986. The data were compared as described in paragraph 2.7. The previous measurement falls below the 99% lower bound of the new 7-point data set. Thus, the corrosion rate is classified as indeterminable. The current mean thickness ± standard error is 1114.7 ±30.6 mils.

4.5.2 Bay 3D: 11/25/86 to 12/17/88

The 7-point data set was taken in December 1988 and a single point measurement was taken in November 1986. The data were compared as described in paragraph 2.7. The previous measurement falls within the 99% upper and lower bounds of the new 7-point data set. This implies that significant corrosion has not occurred at this location in the time period covered by the data. The current mean thickness ± standard error is 1177.7 ±5.6 mils.

4.5.3 Bay 5D: 11/25/86 to 12/17/88

The 7-point data set was taken in December 1988 and a single point measurement was taken in November 1986. The data were compared as described in paragraph 2.7. The previous measurement falls within the 95% upper and lower bounds of the new 7-point data set. This implies that significant corrosion has not occurred at this location in the time period covered by the data. The current mean thickness rate ± standard error is 1174.0 ±2.2 mils.

4.5.4 Bay 7D: 11/25/86 to 12/17/88

The 7-point data set was taken in December 1988 and a single point measurement was taken in November 1986. The data was compared as described in paragraph 2.7. The previous measurement falls just above the 99% upper bound of the new 7-point data set. This implies that corrosion has possibly occurred at this location in the time period covered by the data. The current mean thickness ± standard error is 1135.1 ±4.9 mils.

4.5.5 Bay 9A: 11/25/86 to 12/17/88

The 7-point data set was taken in December 1988 and a single point measurement was taken in November 1986. The data were compared as described in paragraph 2.7. The previous measurement falls below the 99% lower bound of the new 7-point data set. Thus, the corrosion rate is classified as indeterminable. The current mean thickness ± standard error is 1154.6 ±4.8 mils.

4.5.6 Bay 13C: 11/25/86 to 12/17/88

The 7-point data set was taken in December 1988 and a single point measurement was taken in November 1986. The data were compared as described in paragraph 2.7. The previous measurement falls within the 95% upper and lower bounds of the new 7-point data set. This implies that significant corrosion has not occurred at this location in the time period covered by the data. The current mean thickness ± standard error is 1147.4 ±3.7 mils.

4.5.7 Bay 13D: 11/25/86 to 12/17/88

The 7-point data set was taken in December 1988 and a single point measurement was taken in November 1986. The data were compared as described in paragraph 2.7. The previous measurement falls within the 95% upper and lower bounds of the new 7-point data set. This implies that significant corrosion has not occurred at this location in the time period covered by the data. The current mean thickness ± standard error is 962.1 ±22.3 mils.

4.5.8 Bay 15A: 11/25/86 to 12/19/88

The 7-point data set was taken in December 1988 and a single point measurement was taken in November 1986. Also, a 6"x6" grid data set was taken on December 2, 1986 at this location. As a best approximation, the first 5 points in the 7-point data set are at the same location as points 38 to 42 of the 6"x6" grid. These five points all fall within the 99% confidence interval of the new 7-point data set. The single measurement falls below the 99% lower bound. This implies that significant corrosion has not occurred at this location in the time period covered by the data. The current mean thickness ± standard error is 1120.0 ±12.6 mils.

4.6 Summary of Conclusions

Bay & Area	Location	Corrosion Rate**	Mean Thickness***
4.6.1 6"x6" Grids in Sand Bed Region at Original Locations			
11A	Sand Bed	Not significant	908.6 ±5.0 mils
11C	Sand Bed	Indeterminable	916.6 ±10.4 mils
17D	Sand Bed	-27.6 ±6.1 mpy	864.8 ±6.8 mils
19A	Sand Bed	-23.7 ±4.3 mpy	837.9 ±4.8 mils
19B	Sand Bed	-29.2 ±0.5 mpy	856.5 ±0.5 mils
19C	Sand Bed	-25.9 ±4.1 mpy	860.9 ±4.0 mils
4.6.2 6"x6" Grids in Sand Bed Region at New Locations			
9D	Sand Bed	Indeterminable*	1021.4 ±9.7 mils
13A	Sand Bed	Not significant*	905.3 ±10.1 mils
15D	Sand Bed	Possible*	1056.0 ±9.1 mils
17A	Sand Bed	Indeterminable*	957.4 ±9.2 mils
4.6.3 6"x6" Grids at Upper Elevations			
5	51' Elev.	-4.3 ±0.03 mpy	750.0 ±0.02 mils
9	87' Elev.	Not significant	620.3 ±1.0 mils
13	87' Elev.	Not significant	635.6 ±0.7 mils
15	87' Elev.	Not significant	634.8 ±0.7 mils
4.6.4 Multiple 6"x6" Grids in Trench			
17D	Trench	Not significant*	981.2 ±6.7 mils
17/19	Frame Cutout	Indeterminable*	981.7 ±4.4 mils

4.6.5 6" Strips in Sand Bed Region

1D	Sand Bed	Indeterminable*	1114.7 ±30.6 mils
3D	Sand Bed	Not significant*	1177.7 ±5.6 mils
5D	Sand Bed	Not significant*	1174.0 ±2.2 mils
7D	Sand Bed	Possible*	1135.1 ±4.9 mils
9A	Sand Bed	Indeterminable*	1154.6 ±4.8 mils
13C	Sand Bed	Not significant*	1147.4 ±3.7 mils
13D	Sand Bed	Not significant*	962.1 ±22.3 mils
15A	Sand Bed	Not significant*	1120.0 ±12.6 mils

4.6.6 Evaluation of Individual Measurements Below 800 Mils

One data point in Bay 19A and one data point in Bay 5 Elev. 51' fell outside the 99% confidence interval and thus are statistically different from the mean thickness.

*Based on limited data. See text for interpretation.
**Mean corrosion rate in mils per year ± standard error of the mean
***Current mean thickness in mils ± standard error of the mean