GPU Nuclear

Calculation Sheet

Subject	STATISTICAL ANALYSIS OF DRYWELL THICKNESS DATA THRU NOVEMBER 1991	Calc No. C-1302-187-5300-019	Rev. No. 0	Sheet No. 1 of 39
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1.0 **PROBLEM STATEMENT**

The basic purpose of this calculation is to update the thickness measurement analyses documented in References 3.7, 3.8, 3.11, 3.12, 3.13 and 3.14 by incorporating the measurements taken in November 1991. Since no measurements were taken at the 87'-5" elevation in November 1991 due to high temperatures at that elevation, the results for the May 1991 measurements at 87'-5" (Ref. 3.14) are included for completeness.

Specific objectives of this calculation are:

(1) Determine the mean thickness at each of the monitored locations.

(2) Statistically analyze the thickness measurements to determine the corrosion rate at each of the monitored locations.

2.0 **SUMMARY OF RESULTS**

The results of the calculation are summarized in the following tables. The terms used are defined below.

(1) **Best Estimate Corrosion Rate**

- With three or more data points, this is the slope of the regression line.
- For only two data points, this is the slope of the steepest line which can be drawn within the ± one-sigma tolerance interval about the mean.

(2) **95% Upper Bound Corrosion Rate**

The corrosion rate for which we have 95% confidence that it is not being exceeded. At least four data sets are required to make a meaningful estimate of this value.

(3) **Best Estimate Mean Thickness**

- When the regression is statistically significant (F-Ratio is 1.0 or greater), this is the predicted value ± standard error from the regression for the date of the last measurement.

- When the regression is not statistically significant (F-Ratio less than 1.0), this is the grand mean of all the data ± standard error.

(4) **Measured Mean Thickness**

The mean ± standard error of the valid data points from the most recent set of measurements.

(5) **F-Ratio**

- An F-Ratio less than 1.0 occurs when the amount of corrosion which has occurred since the initial measurement is less than the random variations in the measurements and/or fewer than four measurements have been taken. In these cases, the computed corrosion rate does not necessarily reflect the actual corrosion rate, and it may be zero. However, the confidence interval about the computed corrosion rate does accurately reflect the range within which the actual corrosion rate lies at the specified confidence level.

- An F-Ratio of 1.0 or greater occurs when the amount of corrosion which has occurred since the initial measurement is significant compared to the random variations, and four or more measurements have been taken. In these cases, the computed corrosion rate more accurately reflects the actual corrosion rate, and there is a very low probability that the actual corrosion rate is zero. The higher the F-Ratio, the lower the uncertainty in the corrosion rate.

- Whereas an F-Ratio of 1.0 or greater provides confidence in the historical corrosion rate, the F-Ratio should be 4 to 5 if the corrosion rate is to be used to predict the thickness in the future. To have a high degree of confidence in the predicted thickness, the ratio should be at least 8 or 9.

(6) N

The number of data sets used in the analysis.

(7) Years

The time span between the first and last of the analyzed data sets.

2.1 Sand Bed Region Using Data Thru November 1991

Bay & Area	Corrosion Rate, mpy		Mean Thickness, Mils		F-Ratio(5)	N(6)	Data Span, YRS(7)
	Best Est.(1)	95% (2)	Best Est. (3)	Measured (4)			
9D	- 11.3 ±2.2	- 15.8	894.4 ±3.8	932.4 ±10.2	4.0	7	2.8
11A	- 19.2 ±1.7	- 21.2	837.3 ±5.0	832.8 ±9.4	23.4	13	4.5
11C Top	- 24.7 ±4.7	- 33.2	859.5 ±13.0	864.3 ±24.1	6.5	12	4.5
11C Bot	- 17.9 ±2.5	- 22.4	848.8 ±6.8	856.3 ±4.5	10.3	12	4.5
13A	- 17.6 ±4.1	- 25.4	839.9 ±7.1	849.8 ±7.7	3.4	9	2.9
13D Top	+ 1.2 ±13.7	--	1063.6 ±6.2	1047.0 ±13.3	-	4	1.6
13D Bot	+ 2.8 ±6.0	-	901.6 ±2.9	893.6 ±7.8	-	4	1.6
15D	- 4.3 ±2.2	- 8.6	1054.3 ±2.4	1041.7 ±10.1	5.7	8	2.9
17A Top	- 1.8 ±1.6	- 5.0	1128.1 ±1.6	1122.6 ±3.8	0.2	8	2.9
17A Bot	- 9.0 ±2.8	- 13.1	931.5 ±4.9	952.8 ±9.7	1.9	8	2.9
17D	- 19.7 ±1.8	- 22.9	810.4 ±5.2	822.2 ±8.2	28.9	13	4.7
17/19 Top	- 11.8 ±3.4	- 18.2	861.4 ±5.8	854.2 ±4.8	2.0	8	2.8
17/19 Bot	- 14.7 ±3.3	- 21.2	874.5 ±5.7	871.1 ±5.4	3.3	8	2.8
19A	- 15.3 ±1.6	- 18.1	793.0 ±4.7	803.2 ±8.9	22.0	13	4.7
19B	- 11.5 ±2.1	- 15.4	833.5 ±5.8	848.3 ±10.0	5.8	12	4.5
19C	- 17.0 ±2.1	- 20.8	813.2 ±5.9	822.3 ±10.8	13.0	12	4.5

2.2 Elevation 50'-2" Using Data Thru November 1991

Bay & Area	Corrosion Rate, mpy		Mean Thickness, Mils		F-Ratio[5]	N[6]	Data Span, YRS[7]
	Best Est.[1]	95% [2]	Best Est. [3]	Measured [4]			
5/D-12	- 3.5 ±1.1	- 5.4	742.7 ±2.4	748.1 ±2.0	2.0	11	4.9
5/6 > Mean	- 1.7 ±2.1	- 8.5	758.9 ±1.2	760.4 ±1.8	<0.1	6	1.6
5/5 ≤Mean	- 4.5 ±5.6	- 17.7	707.6 ±3.3	737.8 ±5.3	<0.1	5	1.6
13/31 > Mean	- 4.7 ±5.1	- 16.7	787.0 ±3.1	787.4 ±1.6	<0.1	5	1.6
13/31 ≤Mean	- 4.0 ±8.0	- 22.0	693.8 ±4.5	693.1 ±8.5	<0.1	5	1.6
15/23 > Mean	+ 3.0 ±2.5	- 2.8	764.1 ±1.6	762.2 ±1.0	0.1	6	1.6
15/23 ≤Mean	+ 3.8 ±2.2	- 1.5	735.7 ±1.7	739.2 ±4.2	0.3	5	1.6

2.3 Elevation 51'-10" Using Data Thru November 1991

Bay & Area	Corrosion Rate, mpy		Mean Thickness, Mils		F-Ratio[5]	N[6]	Data Span, YRS[7]
	Best Est.[1]	95% [2]	Best Est. [3]	Measured [4]			
13/32 >705	+ 1.5 ±2.1	- 4.5	718.9 ±1.1	720.0 ±0.9	<0.1	4	1.5
13/32 ≤705	- 1.7 ±1.2	- 5.2	692.6 ±0.8	692.1 ±4.5	0.1	4	1.5

2.4 Elevation 87'-5" Using Data Thru May 1991

Bay & Area	Corrosion Rate, mpy		Mean Thickness, Mils		F-Ratio[5]	N[6]	Data Span, YRS[7]
	Best Est.[1]	95% [2]	Best Est. [3]	Measured [4]			
9/20	- 2.1 ±0.7	- 3.5	614.3 ±1.5	612.2 ±1.8	1.4	7	3.5
13/28	- 3.1 ±1.2	- 5.6	634.1 ±2.7	628.9 ±3.4	0.55	7	3.5
15/31	- 2.6 ±1.4	- 5.4	634.0 ±2.1	628.2 ±1.9	0.5	7	3.6

2.5 Evaluation of Individual Measurements Exceeding 99%/99% Tolerance Interval

The following data points fell outside the 99%/99% tolerance interval and thus are statistically different from the mean thickness.

Bay	Elev	Area	Point	Mils	Dev.	Sigmas
6	51	9-1 2	9	099	-90.9	-2.9
16	51	22	28	050	-104.3	-3.7
15	51	23	27	836	-110.3	-4.1
13	62	32	23	801	-101.8	-2.9
13	62	32	28	503	-139.0	-4.0
13	80	24	32	548	-78.8	-3.9
15	80	31	34	550	-60.3	-4.2

Evaluation of the data for each of these points indicate that none of them is corroding more rapidly than the overall grid.

NOTE: Since no data was taken at the 86′ elevation in November 1991, the results of the analyses of the May 1991 data at this elevation are listed above. (Ref. 3.14)

2.6 Mean Thickness of All Points in the Grid

The following table lists the mean thickness ± 1-sigma for all the valid points in each 6"x6" grid.

Bay	Elev	Area	Date	Mean Thk
9D	Sand Bed		11/91	887.7 ±11.1
11A	Sand Bed		11/91	832.6 ±8.4
11C	Sand Bed		11/91	832.9 ±13.0
13A	Sand Bed		11/91	849.0 ±7.7
13D	Sand Bed		11/91	869.2 ±12.9
15D	Sand Bed		11/91	1041.7 ±10.1
17A	Sand Bed		11/91	1014.1 ±14.0
17D	Sand Bed		11/91	822.2 ±9.2
17/19	Frame		11/91	830.9 ±3.8
19A	Sand Bed		11/91	803.2 ±8.0
19B	Sand Bed		11/91	848.3 ±10.0
19C	Sand Bed		11/91	822.3 ±10.9
5	51'	D-12	11/91	749.8 ±9.3
5	51'	5	11/91	742.4 ±4.3
13	51'	31	11/91	742.8 ±5.6
15	51'	23	11/91	754.0 ±4.0
13	52'	32	11/91	702.0 ±5.0

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, Rev. 0, "Statistical Analysis of Drywell Thickness Data Thru 12-31-88"

3.8 GPUN TDR 948, Rev. 1, "Statistical Analysis of Drywell Thickness Data"

3.9 Experimental Statistics, Mary Gibbons Natrella, John Wiley & Sons, 1966 Reprint. (National Bureau of Standards Handbook 91)

3.10 Fundamental Concepts in the Design of Experiments, Charles C. Hicks, Saunders College Publishing, Fort Worth, 1982

3.11 GPUN Calculation C-1302-187-5300-008, Rev. 0, "Statistical Analysis of Drywell Thickness Data thru 2-8-90"

3.12 GPUN Calculation C-1302-187-5300-011, Rev. 1, "Statistical Analysis of Drywell Thickness Data Thru 4-24-90"

3.13 GPUN Calculation C-1302-187-5300-015, Rev. 0, "Statistical Analysis of Drywell Thickness Data Thru March 1991"

3.14 GPUN Calculation C-1302-187-5300-017, Rev. 0, "Statistical Analysis of Drywell Thickness Data Thru May 1991"

4.0 ASSUMPTIONS & BASIC DATA

4.1 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 10R 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 50'-2" and 87'-5" elevations in November 1987 during the 11R outage. As a result of these inspections, repetitive measurements in Bay 5 at elevation 50'-2" and in Bays 9, 13 and 15 at the 87'-5" elevation were added to the long term monitoring program to confirm that corrosion is not occurring at these higher elevations.

A cathodic protection system was installed in selected regions of the sand bed during the 12R outage to minimize corrosion of the drywell. The cathodic protection system was placed in service on January 31, 1989. 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.

The high corrosion rate computed for Bay 13A in the sand bed region through February 1990 (Ref. 3.11) raised concerns about the corrosion rate in the sand bed region of Bay 13D. Therefore, the monitoring of this location using a 6"x6" grid was added to the long term monitoring program. In addition, a 2-inch core sample was removed in March 1990 from a location adjacent to the 6"x6" monitored grid in Bay 13A.

Measurements taken in Bay 5 Area D-12 at elevation 50'-2" through March 1990 indicated that corrosion is occurring at his location. Therefore, survey measurements were taken to determine the thinnest locations at elevation 50'-2". As a result, three new locations were added to the long term monitoring program (Bay 5 Area 5, Bay 13 Area 31, and Bay 15 Area 23).

The indication of ongoing corrosion at elevation 50'-2" raised concerns about potential corrosion of the plates immediately above which have a smaller nominal thickness. Therefore, survey measurements were taken in April 1990 at the 51'-10" elevation in all bays to determine the thinnest locations. As a result of this survey, one new location was added to the long term monitoring plan at elevation 51'-10" (Bay 13 Area 32).

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 purpose of the UT measurements is to determine the corrosion rate and monitor it over time, and to monitor the effectiveness of the cathodic protection system.

4.2 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"x6" 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 50'-2" and 87'-5" 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 50'-2" and in bays 9, 13 and 15 at the 87'-5" elevation were selected as representative locations for long term monitoring.

A cathodic protection system was installed in the sand bed region of Bays 11A, 11C, 17D, 19A, 19B, 19C, and at the frame between Bays 17 and 19 during the 12R outage. The system was placed in service on January 31, 1989.

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.

The long term monitoring program was expanded in March 1990 as follows:

(1) Measurements in the sand bed region of Bay 13D: This location was added due to the high indicated corrosion rate in the sand bed region of Bay 13A. The measurements taken in March 1990 were taken on a 1"x6" grid. All subsequent measurements are to be taken on a 6"x6" grid.

(2) Measurements on 6"x6" grids at the following locations at elevation 50'-2": Bay 5 Area 5, Bay 13 Area 31, and Bay 15 Area 2/3. These locations were added due to the indication of ongoing corrosion at elevation 50'-2", Bay 5 Area D-1.

The long term monitoring program was expanded in April 1990 by adding Bay 13 Area 32 at elevation 51'-10". This location was added due to the indication of ongoing corrosion at elevation 50'-2" and the fact that the nominal plate thickness at elevation 51'-10" is less than at elevation 50'-2".

4.3 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 ± 1/4" of the location of the 1986 UT measurements. It also specifies that all subsequent measurements are to be within ± 1/8" of the designated locations.

4.4 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 50'-2". 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 EL 50'-2"	13, 20, 25, 26, 27, 28, 33, 34, 35

The core sample removed in the sand bed region of Bay 13A was not within the monitored 6"x6" grid.

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

4.5.1 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. If the data are not normally distributed, the grid is subdivided into normally distributed subdivisions.

(2) Once the distribution of data is found to be normal, 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.

4.5.2 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 "missing." 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 "missing" thickness data points.)

(2) Perform a Univariate Analysis of each 49 point data set to ensure that the assumption of normality is valid.

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

(4) Perform an Analysis of Variance (ANOVA) F-test to determine if there is a significant difference between the means of the data sets.

(5) 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 5% level of significance. 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 due to corrosion is statistically significant compared to the random variations.

   (b) Calculate the ratio of the observed F value to the critical F value at 5% level of significance. For data sets where the Residual Degress of Freedom in ANOVA is 4 to 9, this F-Ratio should be at least 8 for the regression to be considered "reliable" as opposed to simply "significant." (See paragraph 4.10.2)

   (c) Calculate the coefficient 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.

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

(e) 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. Calculate the upper bound of the 95% one-sided confidence interval about the computed slope to provide an estimate of the maximum probable corrosion rate at 95% confidence. This is explained in greater detail in paragraph 4.10.2.

(f) When the corrosion rate is not statistically significant compared to random variations in the mean thickness, the slope and confidence interval slope computed in the regression analysis still provides an estimate of the corrosion rate which could be masked by the random variations. This is explained in greater detail in paragraph 4.10.1.

(6) Use the chi-square goodness of fit test results to determine if low thickness measurements are significant pits. If the measurement deviates from the mean thickness by three standard deviations, it is considered to be a significant pit.

4.6 Analysis of Two 6"x6" Grid Data Sets

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

4.6.1 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.

4.6.2 Statistical Approach

The evaluation takes place in three steps:

(1) Perform a univariate test of each data set to ensure that the assumption of normality is valid.

(2) Perform an F-test at 5% level of significance of the two data sets being compared to ensure that the assumption of equal variances is valid.

(3) Perform an Analysis of Variance F-test at the 5% level of significance to determine if the means of the two data sets are statistically different.

A conclusion that the means are <u>not</u> 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.

The range of potential corrosion rates is estimated by computing the slope of the steepest line which can be drawn within the ± 1 sigma confidence interval about the mean thickness for the duration between the two measurements.

4.7 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 at an earlier time. 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 Analysis of Variance F-test can be used to compare the means of the two data sets as described in paragraph 4.5.

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

4.7.1 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 at the earlier date.

4.7.2 Statistical Approach

The evaluation takes place in four steps:

(1) Perform a univariate analysis of each data set to ensure that the assumption of normality is valid.

(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 for n-1 degrees of freedom.

(4) Use the t value and the standard error of the mean to calculate the 95% confidence interval 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 the prior data falls above the upper 95% 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.

If the prior data falls below the lower 95% confidence limit, it means that it is not representative of the condition at this location at the earlier date.

4.8 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 at an earlier time 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 Analysis of Variance F-test can be used to compare the means of the two data sets as described in paragraph 4.5.

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

4.8.1 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 at the earlier date.

The validity of these assumptions cannot be verified.

4.8.2 Statistical Approach

Perform the Analysis of Variance and F-test

If the prior data falls within the 95% confidence interval, it provides some assurance that significant corrosion has not occurred in this region in the period of time covered by the data.

If the prior data falls above the upper 95% 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.

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

4.9 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.

4.9.1 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 significant (F-Ratio is 1.0 or greater).

(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 (App. 6.2), 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.

4.9.2 Evaluation of Mean Thickness Using Mean Model

The following procedure is used to evaluate the drywell mean thickness at those locations where the regression analysis is not significant (F-Ratio is less than 1.0). 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, this is the value labelled "DEP MEAN".

(3) Using the means of the sets from (1) as input, calculate the standard error about the mean. 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.

4.9.3 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.

4.10 Evaluation of Drywell Corrosion Rate

4.10.1 Regression Not Significant

If the ratio of the observed F value to the critical F value is less than 1 for the F-test for the significance of regression, it indicates that the regression is not significant at the 5% level of significance. In other words, the variation in mean thickness with time can be explained solely by the random variations in the measurements. This means that the corrosion rate is not statistically significant compared to the random variations.

The possibility does exist that the variability in the data may be masking an actual corrosion rate. Although the regression is not the result of the regression analysis can be used to estimate the potentially masked corrosion rate. We can also state with 95% confidence that the corrosion rate does exceed the upper bound of the 95% one-sided confidence interval of the slope computed in the regression analysis. The 95% upper bound is equal to the computed slope plus the one-sided t-table value times the standard error of the slope. The value of t is determined for n-2 degrees of freedom.

4.10.2 Regression Significant

If the ratio of the observed F value to the critical F value is 1 or greater, it indicates that the regression model is more appropriate than the mean model at the 5% level of significance. In other words, the variation in mean thickness with time cannot be explained solely by the random variations in the measurements. This means that the corrosion rate is significant compared to the random variations.

Although a ratio of 1 or greater indicates that regression is significant, it does not mean that the slope of the regression line is an accurate prediction of the corrosion rate. The ratio should be at least 4 or 5 to consider the slope to be a useful predictor of the corrosion rate (Ref. 3.5, pp. 93, 129-133). A ratio of 4 or 5 means that the variation from the mean due to regression is approximately twice the standard deviation of the residuals of the regression. To have a high degree of confidence in the predicted corrosion rate, the ratio should be at least 8 or 9 (Ref. 3.5, pp. 129-133).

The upper bound of the 95% one-sided confidence interval about the computed slope is an estimate of the maximum probable corrosion rate at 95% confidence. The 95% upper bound is equal to the computed slope plus the one-sided t-table value times the standard error of the slope. The value of t is determined for n-2 degrees of freedom.

5.0 CALCULATIONS

5.1 6"x6" Grids in Sand Bed Region

5.1.1 Bay 9D 12/19/88 to 11/02/91

In the analysis of data thru May 1991, these data sets did not meet the acceptance criteria for either regression or difference between means. Examination of the analysis revealed two reasons for this: (1) the mean value of the 6/26/89 data set fell about 30 mils above the regression line, and (2) there was a pit at point 15 which deviated from the mean thickness by more than 3-sigma. The data was reanalyzed without the 6/26/89 data set and without point 15. The regression of these data sets met the acceptance criteria and the regression was statistically significant.

Eight 49-point data sets were available for the period through November 1991. With the November 1991 data, the data sets meet the acceptance criteria for regression with the 6/26/89 data set and point 15. However, the regression accounts for only 61% of the variability in the data. The regression without the 6/26/89 data set accounts for 85% of the variability in the data. The regression without the 6/26/89 data and without point 15 accounts for 84% of the variability in the data. The deviation of point 15 from the mean thickness is 2.89-sigma for the November 1991 data, and thus is close to the 3-sigma value for a deep pit. The regression without the 6/26/89 data is much stronger than the regression with it, and the regressions with and without point 15 are essentially identical. Therefore, to provide continuity with the prior analyses, the reported regression results are without the 6/26/89 data and without point 15. The regression of these data sets meet the acceptance criteria and is statistically significant.

5.1.2 Bay 11A: 4/29/87 to 11/02/91

The regression of thirteen data sets for this period meets the acceptance criteria and is statistically significant.

5.1.3 Bay 11C: 5/1/87 to 11/02/91

Twelve 49-point data sets were available for this period. Prior analysis have shown that there has been minimal corrosion in the top 3 rows of the 6" x 6" grid with more extensive corrosion in the bottom 4 rows. Therefore, these subsets are analyzed separately.

Top 3 Rows

The regression of these data sets meets the acceptance criteria and is statistically significant.

Bottom 4 Rows

The regression of these data sets meets the acceptance criteria and is statistically significant.

5.1.4 Bay 13A: 12/17/88 to 11/02/91

The regression of nine data sets for this period meets the acceptance criteria and is statistically significant.

5.1.5 Bay 13D: 3/28/90 to 11/02/91

One 7-point data set and four 49-point data sets were available for this period.

Prior evaluation showed that the 7-point data set of 3/28/90 and the 49-point data set of 4/25/90 were normally distributed. However, there was a line of demarcation separating a zone of minimal corrosion at the top from a corroded zone at the bottom. Thus, it was concluded that corrosion has occurred at this location.

The 49-point data set of 2/23/91 contains an invalid measurement at point #47. Therefore, this was input as a "missing" value to exclude it from the analyses. The data sets have a line of demarcation separating the upper and lower zones. Therefore, the grid was divided into two zones consisting of the following points:

Top Zone	Bottom Zone
1 - 16	17 - 18
19 - 22	23 - 26
27 - 28	29 - 49

Top Zone

This zone consists of 22 points.

(1) The data are normally distributed.

(2) The regression is not statistically significant and has a positive slope.

(3) Analysis of variance shows no significant difference between the means. Thus, there is no indication of statistically significant corrosion during this period.

Bottom Zone

This zone consists of 27 points.

(1) The data are normally distributed except for the 4/25/90 data which is skewed to the thin side.

(2) The regression is not statistically significant and has a positive slope.

(3) Analysis of variance shows no significant difference between the means. Thus, there is no indication of statistically significant corrosion during this period.

5.1.6 **Bay 15D: 12/17/88 to 11/02/91**

Eight 49-point data sets were available for this period.

(1) The regression is not statistically significant.

(2) The data are normally distributed.

(3) The Analysis of Variance shows that there is no significant difference in the means at 95% confidence. Thus, there is no indication of statistically significant corrosion during this time period.

5.1.7 **Bay 17A: 12/17/88 to 11/02/91**

Eight 49-point data sets were available for this period.

Prior analyses have shown a lack of normality due to minimal corrosion in the top 3 rows and more extensive corrosion in the bottom 4 rows. Therefore, these subsets are analyzed separately.

Top 3 Rows

(1) the regression is not statistically significant.

(2) the data are normally distributed.

(3) The Analysis of Variance shows that there is no significant difference in the means at 95% confidence. Thus, there is no indication of statistically significant corrosion during this time period.

Bottom 4 Rows

The regression of these data sets meets the acceptance criteria and is statistically significant.

5.1.8 **Bay 17D: 2/17/87 to 11/02/91**

The regression of thirteen data sets for this period meets the acceptance criteria and is statistically significant.

5.1.9 **Bay 17/19 Frame Cutout: 12/30/88 to 11/02/91**

Eight 49-point data sets were available for this period.

Prior analyses have shown a lack of normality due to more extensive loss of thickness in the top 3 rows than in the bottom 4 rows. Therefore, these subsets are analyzed separately.

Top 3 Rows

(1) Based on the Univariate Analysis, seven of the eight subsets are normally distributed. The other one (February 1990) contains two high readings and one low reading which cause the maldistribution.

(2) The Analysis of Variance shows that there is a significant difference amongst the means at 95% confidence. This indicates that there is significant ongoing corrosion.

(3) The regression of the eight data sets meets the acceptance criteria and is statistically significant.

Bottom 4 rows

(1) Based on the Univariate Analysis, three of the subsets are normally distributed. The other two (February 1990 and April 1990) each contain a data point which deviates significantly from the mean and causes the maldistribution.

(2) The regression of the eight data sets meets the acceptance criteria and is statistically significant.

5.1.10 **Bay 19A: 2/17/87 to 11/02/91**

Thirteen 49-point data sets were available for this period. Since a plug lies within this region, four of the points were voided in each data set. The regression of these data sets meets the acceptance criteria and is statistically significant.

5.1.11 **Bay 19B: 5/1/87 to 11/02/91**

The regression of twelve data sets for this period meets the acceptance criteria and is statistically significant.

5.1.12 Bay 19C: 5/1/87 to 11/02/91

Twelve 49-point data sets were available for this period. Since a plug lies within this region, four of the points were voided in each data set. The regression of these data sets meets the acceptance criteria and is statistically significant.

5.2 6" x 6" Grids at Elevation 50'-2"

5.2.1 Bay 5 Area D-12: 11/1/87 to 11/02/91

Ten 49-point data sets were available for this period. Since a plug lies within this region, seven of the points were voided in each data set.

The initial analysis of these data sets indicated that they are not normally distributed. The following adjustments were made to the data:

(1) Point 9 is a significant pit. Therefore, it was dropped from the overall analysis and is evaluated separately.

(2) Points 13 and 25 are extremely variable and are located adjacent to the plug which removed from this grid. They were dropped from the analysis.

(3) Point 43 in the 11/01/87 data set is much less than any succeeding measurement. Therefore, this data point was dropped from the analysis.

(4) Point 29 in the 9/13/89 data is much greater than the preceding or succeeding measurements. Therefore, this data point was dropped from the analysis.

(5) Points 1 and 37 in the 4/25/90 data set are much greater than the preceding or succeeding measurements. Therefore, these two data points were dropped from the analysis.

(6) Points 3 and 36 in the 11/02/91 data set are much greater than the preceding or succeeding measurements. Therefore, these two data points were dropped from the analysis.

With these adjustments, the Univariate Analyses indicate that all of the data sets are normally distributed at the 1% level of significance.

The regression of these data sets meets the acceptance criteria and is statistically significant.

Pit at Point 9

Analyses show that the high reading of 746 mils in July 1988 for the pit at point 9 is an outlier and must be dropped to obtain a meaningful least squares fit. Dropping this point, the mean thickness of the remaining points is 694.6 ±1.9 mils, and the standard deviation of the measurements is ±6.1 mils. The best estimate of the corrosion rate is -3.6 ±1.2 mils per year with an R^2=52%. It is concluded that the corrosion rate in the pit is essentially the same as the overall grid.

5.2.2 Bay 5 Area 5: 3/31/90 to 11/02/91

Three 49-point data sets were available for this period.

The data are not normally distributed due to a large corroded patch near the center of the grid and several smaller patches on the periphery.

The data was split into two subsets consisting of points whose mean value is less than or equal to the grand mean, and those greater than the grand mean.

Points With Mean Less than Grand Mean

(1) The regression is not statistically significant.

(2) These 15-point subsets are normally distributed.

(3) Analysis of variance shows that there is not a significant difference between the means of the subsets. Thus, there is no indication of statistically significant corrosion during this period.

Points with Mean Greater than Grand Mean

(1) The regression is not statistically significant.

(2) These 34-point subsets are normally distributed.

(3) Analysis of variance shows that there is a statistically significant difference between some of the means. However, the differences do not correlate with time and are not attributed to corrosion.

(4) Thus, there is no indication of statistically significant corrosion during this period.

5.2.3 Bay 13 Area 31: 3/31/90 to 11/2/91

Five 49-point data sets were available for this period.

The data are not normally distributed. This is due to a large corroded patch at the left edge of the grid.

The data was split into two subsets consisting of those points whose mean value is less than or equal to the grand mean, and those greater than the grand mean.

Points with Mean Less than Grand Mean

(1) The regression is not statistically significant.

(2) These 14-point subsets are normally distributed.

(3) Analysis of Variance shows that there is not a significant difference between the means of the subsets. Thus, there is no indication of statistically significant corrosion during this period.

Points with Mean Greater than Grand Mean

These 35-point subsets are not normally distributed. This is due to two points with low readings in March 1990, two points with high readings in April 1990, two points with low readings in February 1991, and one point with a low reading in November 1991. When these seven points are deleted, the subsets are normally distributed.

These subsets with the outliers deleted are evaluated below.

(1) The regression is not statistically significant.
(2) Analysis of variance shows that the second data set (April 1990) is statistically different from the other four. The November 1991 subset is greater than all except the April 1990 subset. Thus, there is no indication of statistically significant corrosion during this period.

5.2.4 Bay 15 Area 23: 3/31/90 to 11/2/91

Five 49-point data sets were available for this period.

The data are not normally distributed. This is due to a large corroded patch near the center of the grid and a significant pit at point 26. There are also some random readings over 780 mils which are outliers. Also, the measurement of 638 mils at point 27 in November 1991 is 118 mils less than the lowest prior measurement. This point is adjacent to the pit at point 26 and was therefore deleted.

The data was split into two subsets:

(1) Points whose mean value is less than or equal to the grand mean. The pit at point 26 was excluded.

(2) Points whose mean value is greater than the grand mean. Readings greater than 780 mils were set to "missing."

Points with Mean Less than Grand Mean

(1) The regression is not statistically significant and has a positive slope.

(2) The 16-point subsets are normally distributed.

(3) Analysis of Variance shows that there is not a significant difference between the means of the subsets.

(4) There is no indication of statistically significant corrosion during this period.

Points with Mean Greater than Grand Mean

(1) The regression is not statistically significant and has a positive slope.

(2) The subsets are all normally distributed except for the 2/23/91 data which has two measurements (points 22 and 29) which are significantly higher than prior or subsequent measurements.

(3) Analysis of Variance indicates that there is a significant difference between some of the means. However, this is not indicative of corrosion since the later means exceed the earlier means.

(4) There is no indication of statistically significant corrosion during this period.

Pit at Point 26

The five readings are normally distributed. The best estimate of the corrosion rate is +1.2 ±3.0 mils per year. There is no indication of significant corrosion during this period.

Point 27 had a low measurement of 638 mils in November 1991. All prior measurements fell between 756 and 763 mils. Since this point is adjacent to point 26, it is concluded that the November 1991 measurement is really the pit analyzed above.

5.3 6" x 6" Grids at Elevation 51'-10"

5.3.1 Bay 13 Area 32: 4/26/90 to 11/02/91

Four 49-point data sets were available for this period.

The data are not normally distributed. This is due to a "T" shaped corrosion patch along the right edge and across the center. Examination of the Normal Probability Plot from the Univariate Analysis reveals the following distinct populations:

(1) Four pits at points 20, 23, 25 and 28.

(2) A group of 13 to 14 readings less than 705 mils.

(3) A group of 31 to 32 readings greater than 705 mils.

(4) Two outliers with values of 732 mils (Point 34 on 4/26/90) and 736 mils (point 33 on 2/23/91).

(5) The 5/23/91 value at point 11 (660 mils) was 39 to 45 mils less than the other three values. If this point were included in the analysis, it would have a major impact on the calculated mean corrosion rate.

For subsets (2) and (3) above, all points consistently fell in the same group except for points 1, 5, 7, 14, and 49. For each of these points, three measurements fell in one subset and one measurement fell in the other subset.

Subsets (2) and (3) were used to analyze the corrosion rate.

Points Less than 705 Mils

(1) The regression is not statistically significant.

(2) These subsets are normally distributed.

(3) Analysis of Variance shows that there is not a significant difference between the means of the subsets.

(4) There is no indication of statistically significant corrosion during this period.

Points Greater than 705 Mils

(1) The subsets are normally distributed except for one exceptionally high reading in February 1991.

(2) Analysis of Variance shows that there is a significant difference between the mean of the November 1991 subset

and the means of the other three subsets. However, the mean of the November 1991 subset exceeds the others and thus is not indicative of corrosion.

(3) The regression is not statistically significant.

(4) Thus, there is no indication of significant corrosion during this period.

Pits at Points 20, 23, 25 and 28

The measurement at these locations are listed below.

	20	23	25	28
4/26/90	628	594	622	558
2/23/91	626	594	621	558
5/23/91	626	592	620	555
11/2/91	630	601	626	563

The standard deviation of November 1991 data for the points less than 705 mils is 14.3 mils. With 14 data points, the 99%/99% one-sided lower bound is 682-4.5 (14.3) = 617 mils. Thus points 23 and 28 are significant pits. However, the difference between readings is minimal, so there is no indication of significant corrosion in these pits.

Low Reading at Point 11

There have been several cases where there have been significant differences between readings at a given location. It usually occurs in grids with significant pitting such that a pit is observed one time but not another time. The large difference at point 11 is attributed to this.

5.4 <u>6" x 6" Grids at 87'-5" Elevation</u>

No measurements were taken at the 87'-5" Elevation during the November 1991 due to the high temperature. Therefore, the May 1991 evaluation of corrosion rates is given below to provide complete documentation of the latest analyses.

5.4.1 Bay 9 Area 20: 11/6/87 to 5/23/91

The regression of the seven 49-point data sets for this period meets the acceptance criteria and is statistically significant.

5.4.2 Bay 13 Area 28: 11/10/87 to 5/23/91

Seven 49-point data sets were available for this period.

The data sets are not normally distributed. Examination of the data shows that this is due to the seven thinnest points: 1, 2, 22, 25, 26, 36 and 48.

Analysis of Data Without 7 Thinnest Points

(1) The data are normally distributed.

(2) The regression is not statistically significant.

(3) Analysis of variance indicate that there is a significant difference between the means of the February and May 1991 data sets and the means of the other five data sets. This could be caused by actual corrosion, random variations in the data, or a slight bias in the measurements. More data is required to determine the true cause.

5.4.3 **Bay 15 Area 31: 11/10/87 to 5/23/91**

Seven 49-point data sets were available for this period.

(1) The data sets are normally distributed at 95% confidence except for the July 1988 data which is normally distributed at 99%.

(2) The regression is not statistically significant.

(3) Analysis of variance shows that there is a significant difference between the means of the February and May 1991 data sets and the means of the prior data sets. This could be caused by actual corrosion, random variations in the data, or a slight bias in the measurements. More data is required to determine the true cause.

(4) The pit at point 34 is behaving like the rest of the grid. The current reading of 556 mils at point 34 is 9 mils below the mean for this point. The current mean reading for the grid is 8 mils below the grand mean.