RAS 14298

Citizens Exhibit C





**HAUSLER REBUTTAL AFFIDAVIT--CORRECTED NUMBERING. NO OTHER CHANGES TO DOCUMENT.**

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION
OFFICE OF THE SECRETARY

ATOMIC SAFETY AND LICENSING BOARD

Before Administrative Judges:
E. Roy Hawkens, Chair
Dr. Paul B. Abramson
Dr. Anthony J. Baratta

| | | |
|---|---|---|
| In the Matter of | ) | |
| | ) | |
| AMERGEN ENERGY COMPANY, LLC | ) | |
| | ) | Docket No. 50-0219-LR |
| (License Renewal for the Oyster Creek Nuclear Generating Station) | ) | |
| | ) | |

**AFFIDAVIT OF DR. RUDOLF H. HAUSLER REGARDING HIS PREFILED REBUTTAL TESTIMONY IN SUPPORT OF CITIZENS' DRYWELL CONTENTION**

I, Dr. Rudolf H. Hausler of full age, do solemnly swear, as follows:

1. Through Corro-Consulta, Inc., I am employed as a consultant to the Citizens groups in this proceeding.

2. The attached pre-filed testimony represents my current opinion on the topics it covers.

3. I believe that the currently proposed UT monitoring frequency of every four years is inadequate for the reasons stated in my pre-filed testimony.

4. As stated in my pre-filed testimony I further believe that the UT data show that it is likely that the drywell shell in the sand bed region does not currently meet the applicable acceptance criteria. At minimum, I believe AmerGen cannot show to that the drywell shell in the sand bed region currently meets the applicable acceptance criteria with 95% certainty.

5. I declare under penalty of perjury that this affidavit and the attached pre-filed testimony and attachments thereto are factually accurate to the best of my knowledge, information and belief.

Dr. Rudolf H. Hausler

Sworn to me this 16th day of August, 2007

Notary Public

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**PREFILED REBUTTAL WRITTEN TESTIMONY OF DR. RUDOLF H. HAUSLER REGARDING <u>CITIZENS' DRYWELL CONTENTION</u>**

On behalf of Citizens, Dr. Rudolph H. Hausler hereby submits the following rebuttal testimony regarding Citizens' contention.

**Q1. Have you reviewed the initial testimony of AmerGen and the NRC Staff in this case?**

**A1.** Yes I have.

**Q2. What is your overall reaction to the testimony?**

**A2.** Overall, I do not think that either AmerGen or the NRC Staff thoroughly dealt with statistical uncertainties in the data, so that the conclusions reached about margins are far more optimistic than is merited by the data. AmerGen failed to analyze numerically the only data we have for the lower two thirds of the sandbed region. Furthermore, the NRC staff took false assurance from a study by Sandia National Laboratories (the "Sandia Study"), which actually indicates that the existing margins are, at best, perilously thin. Looking at the data, I believe that the areas of corrosion probably go beyond the current local area acceptance criteria and the corrosion shapes modeled by General Electric ("GE"). In addition, based on extreme values statistics there is more than a 5% chance that the very local acceptance criterion of 0.49 inches is violated. Furthermore, AmerGen has effectively admitted that water can penetrate onto the exterior of the drywell shell during outages, and NRC Staff have admitted that corrosive conditions can occur on the interior of the drywell. I believe the corrosion rate estimated by AmerGen to be overly optimistic. Because overall corrosion rates could be approximately 0.049 inches per year and AmerGen is only claiming to have a margin of 0.064 inches, it is clear that the currently proposed UT monitoring frequency of once every four years is inadequate.

**Q3. What additional materials have you reviewed in preparation for your rebuttal testimony?**

**A3.** Among the materials I have reviewed are various AmerGen/Exelon and NRC documents and technical data, and GPU Nuclear safety evaluation data. A list of the most pertinent additional references to materials not already submitted to the Board is provided in Attachment 1 to this testimony.

**Q4. Have you reviewed all of the documents listed in Attachment 1?**

**A4.** Yes, I have used the documents in Attachment 1 to inform me of relevant facts and derive my conclusions.

**Q5. Have you prepared a memorandum to answer the Board's questions contained in the Order, dated August 9, 2007?**

**A5.** Yes. The memorandum contained in Citizens' Ex. 38 answers questions 1 to 6, question 9 in part, and question 10. I have not addressed questions 7, 8, and the rest of 9 because I believe they are best answered first by AmerGen. Question 11is a legal question, and I will answer question 12 to the best of my ability in this pre-filed testimony, even though I am not a structural engineer.

**Q6. What is your answer to Board's question 12?**

**A6.** The original GE model was based on a 36 degree pie slice of the sandbed region that was assumed to have a uniform thickness of 0.736 inches. This finite element model gave exactly the required safety factor of 2.0. To take some account of the lack of uniformity in reality, this was augmented by subsequent modeling which showed how much the buckling capacity reduced when metal was cut out of the uniformly thick shell. In this modeling the elements in the sand bed region were 3 inch by 3 inch squares. Larger elements were used above the sand bed region to model the downcomers. The tray-shaped cut out was 1.5 feet by 3 feet (6 elements by 12 elements) in total with a centre area of 0.5 feet by 1 foot (2 elements by 4 elements) which was modeled as both 0.536 inches thick and 0.636 inches thick. The cut outs reduced the buckling capacity by 9.5% and 3.9% respectively. It appears that the idea of the model was to assume a worst case within which the measured results could be placed. To ensure that the actual areas of corrosion exert less effect on buckling than the modeled shapes, I believe that, at minimum, AmerGen should only accept an area thinner than 0.736 inches if it falls within the spatial envelope of the modeled cut outs. In addition, I believe AmerGen appropriately adopted a conservative criterion that was less than the size of the full cut-outs, because the mean thickness of some of the Bays is approaching 0.736 inches, so that a reduction of 3.9% in buckling capacity is potentially significant. The contour plots show that the shapes of the corroded areas cannot be enveloped within the modeled tray shapes because they are ill-defined and in at least Bays 1 and 19 are more like long grooves than squares. Thus, the areas depicted on the contour maps cannot be accepted based on the GE modeling. Furthermore, I continue to believe that in the SER AmerGen reasonably adopted, and NRC Staff approved, a local area acceptance criterion that requires the contiguous areas that are less than 0.736 inches thick to be less than one square foot in area. This criterion is exceeded in at least Bays 1 and 13. With respect to question 12(e), I believe that is primarily a legal question. However, I observe that from a technical standpoint, if the CLB requires the pattern of corrosion to be within that modeled by GE, the licensee appears to be outside the bounds of the CLB.

**Q7. What is Citizens' Exhibit 39?**

**A7.** Citizens' Exhibit 39 is my detailed response to the testimony presented by AmerGen and the NRC Staff.

**Q8. To your knowledge, are Citizens' Exhibits 38 and 39, and this testimony, true and accurate?**

**A8.** Yes, Citizens' Exhibits 38 and 39 and this testimony provide, to the best of my knowledge, true and accurate statements of my responses to AmerGen, the NRC Staff, and the Board's questions. I should point out that in Citizens' Exhibit 38 I have refined my calculation of the sample standard deviation. Because the calculations in Citizens' Exhibit 38 are the most accurate, these should be regarded as definitive.

**Q9. Has AmerGen's and NRC Staff's initial testimony changed your opinions regarding the state of the drywell shell?**

**A9.** No.

**Q10. Has NRC Staff Required 95% confidence of the shell meeting the acceptance criteria in the past?**

**A10.** Yes. NRC Staff testimony at A.22 shows that when significant corrosion was occurring, the lower 95% confidence limit of the current and anticipated future state of the shell was used to determine the monitoring interval. Even though the corrosion observed is no longer statistically significant, it continues to be reasonable to require that the drywell will meet safety requirements with at least 95% confidence at all times. In fact, the Sandia Study shows that on initial licensing the drywell shell met the ASME code with near certainty because the lowest safety factor was 2.77 and the fabricated plate thicknesses were reasonably well known. Sandia Study at 68. Thus, I believe that NRC should not issue a new license unless AmerGen can demonstrate with near certainty that it meets the ASME code. To do otherwise would significantly reduce the assurance of safety that we had when the plant opened.

**Q11. Does the Sandia Study referenced by NRC Staff's Testimony at A.8 provide assurance that the drywell shell currently meets the safety requirements?**

**A11.** No. First, Sandia specifically noted in its report that the study was not designed to provide absolute predictions of load factors. Sandia Study (available at ML070120395) at 12. This was in part because "the thicknesses assigned in each region were based on limited measurement data since a very small percentage of the shell has been examined." *Id.* at 84. Second, the Sandia Study predicted a 7% margin if the shell remained at the same thickness as in 1992 and the only areas thinner than 0.736 inches were two areas measuring 30 inches by 18 inches, one in Bay 1 and one in Bay 13, directly below the downcomers. *Id.* at 47-49. My analysis of the data has shown that this is far from bounding for two main reasons. First the 2006 measurements showed that the shell is now approximately 2 to 3% thinner overall than measured in 1992. Second, there are probably bigger areas thinner than 0.736 than assumed in Bays 1, 13, 15, and Bay 19, those areas are not directly below the downcomers, and Bays 1 and 13 contain more than one area thinner than 0.736 inches. Thus, the Sandia Study does not demonstrate that there is any current margin. Finally, the Sandia Study does not provide reasonable assurance because it did not take account of the uncertainty in the inputs.

**Q12. AmerGen has claimed it cannot use the external results to estimate margins. Do you think this is correct?**

**A12.** No. In their modeling study, Sandia National Laboratories used the external results to generate estimated thicknesses for the drywell shell in the sandbed region. Furthermore, even AmerGen personnel have stated in writing that the internal grid results in each Bay are often not representative of that Bay. Citizens' Ex. 45 at 3; Citizens' Ex. 46 at OCLR29744-45. This was confirmed by my analysis summarized in Citizens' Ex. 12 at Figure 4. Thus, it is essential to use the external data if the margins are to be calculated in a realistic manner. Finally, if AmerGen's were correct that the external data can only demonstrate compliance with the local area acceptance criteria, but cannot determine the margin above that criterion, AmerGen could not show that its proposed monitoring regime will maintain the required thicknesses during any period of extended operation because there would be no method of predicting when the unknown margin above the local area acceptance criterion could be violated.

**Q13. Do AmerGen's analyses of the external data actually demonstrate compliance with the local area acceptance criteria?**

**A13.** No, AmerGen's latest analysis actually demonstrates non-compliance with the local area acceptance criterion. Most obviously the assessment shows 3 feet by 3 feet areas that are thinner than 0.736 inches in Bays 1 and 19. AmerGen Ex. 16 at 34, 92-93. Because these areas are highly unlikely to have vertical sides, based on AmerGen's assessment, it is likely that the areas thinner than 0.736 inches are larger than 3 feet by 3 feet in each of these Bays. Furthermore, AmerGen's assessment is based on a correction technique that is not justified. Stripping out this correction, the raw UT results show that the 3 feet by 3 feet area shown in Bay 13 is also thinner than 0.736 inches. *See Id.* at 56-57, 63-64. Finally, in Bay 1 the raw UT results go below the requirements in the transition zone between the thinnest areas and 0.736 inches.

**Q.14. Do visual observations suggest that the external UT data actually represent the thinnest points?**

**A14.** No. In fact, the best visual inspection we have shows that visually locating the thinnest parts of the shell was impossible. A memorandum dated January 28, 1993 describes a visual inspection of the shell when only Bays 17 and 19 had been fully coated. Citizens' Ex. 44. The inspection describes the surface as relatively uniform with small dimples most of which are that are approximately 0.5 inches in diameter. *Id.* at 1. In addition to the dimples, the inspection noted an area that is relatively uncorroded, below which were "two strips around the vessel" which were "slightly thinner than the general area." *Id.* In addition, the inspection noted less localized thin spots that were approximately a foot to 18 inches in diameter and covered around 20% of the corroded area. *Id.* at 2. Except for Bay 13, these thin spots were hard to detect because the variation in thickness is small. *Id.* In Bay 13, the thickness variations were more pronounced and the thin spots were at least 1 ft apart edge to edge near the downcomers and further apart toward the edges of the Bay. *Id.* The inspector noted that "I could not determine visually which of the thin spots are the thinnest." *Id.*

**Q15. Is this conclusion confirmed by the UT data?**

**A15.** Yes. The repeat exterior UT results and interior trench data taken in October 2006 prove definitively that the reported external UT measurements were not taken at the thinnest locations. First, the results for 2006 show that at some points in bays 7, 15, 17 and 19 AmerGen scanned a 0.25 inch area around the nominal location of the point. AmerGen Ex. 19 Attachment 4 at 8, 16, 18, 20. In most cases, AmerGen found a thinner point than the reported point. *Id.* Strikingly, in bay 15, the reported results were all the maximum readings obtained, while the minimum readings were as much as 0.068 inches less than the recorded value. *Id.* at 16. Similarly, in bay 19 the recorded results were up to 0.07 inches more than the minimum recorded value. *Id.* at 20. Second, as shown in Citizens' Ex. 12 Figure 4, the average of the external UT data taken at the top and bottom levels is higher than the average wall thicknesses measured in the trench in Bay

17 at the very bottom and the top. Taken together the visual inspection and the UT data show that while the external UT measurements may be somewhat biased towards the thin side, they are not taken at the thinnest points.

**Q16. Do you agree with AmerGen's argument that the external results must be the thinnest results because some of the points were overground?**

**A16.** No. As I testified to the previous question, the repeat measurements and trench data show that in general the points for which UT measurements were reported in 2006 are not the thinnest points on the shell. In addition, the idea of grinding is to create a flat area at the thickness of the thinnest point, not to make the area thinner. Furthermore, not all of the points were ground to facilitate measurement. Citizens' Ex. 43. Finally, NRC Staff have noted that AmerGen could not locate the locations measured in 1992 exactly. NRC Staff Testimony at A17. For example, in Bay 13 in 2006, AmerGen was unable to measure locations 1a, 2a, and 2, even though these points were all measured below 0.736 inches in 1992. *See* Citizens' Ex. 13 at Table 2. This indicates that they were not located at obvious low points in the surface of the shell. Moreover, AmerGen has inconsistently argued that the external UT measurements in 1992 were biased to the thick side by the curvature of the surface creating an air gap between the surface and the UT probe. Citizens' Ex. 51. Indeed, AmerGen's statistical analysis claims to show such bias. Citizens' Ex. 9 at 6-1. If this bias indeed exists, the only explanation offered assumes that the measured points were not overground. If the points were in fact overground, AmerGen has offered no plausible explanation for the observed differences in the thickness data between 1992 and 2006.

**Q.17. What is the appropriate statistical approach to finding the thinnest point on the drywell shell?**

**A17.** Because it is unlikely that the measured points are actually the thinnest points, a statistical approach must be taken to find the likely thinnest point on the shell. The 1992 external data for Bay 13 show quite definitively that they are not normally distributed. Thus, I believe the best approach is to use extreme value statistics to estimate the chance that a thinner point than the acceptance criterion (0.49 inches) would be found if more measurements were taken. Applying such an approach to Bay 13, it is likely that if 40 points had been measured, a much thinner point than 0.49 inches would have been observed. Thus, I believe that there is a significant chance that the drywell shell Bay 13 currently fails the very local area acceptance criterion in.

**Q18. To take account of the alleged bias in the external UT measurements, AmerGen has applied a correction technique to some of the measurements. Do you believe this correction technique is appropriate?**

**A18.** No, it is inappropriate for a number of reasons. First, it was derived using only measurements in Bay 13. Because the visual inspection shows that Bay 13 is atypical, even if this technique were appropriate for Bay 13, it would not be appropriate for the other Bays. Second, the technique is not even appropriate for Bay 13, because it is not based on any viable physical or statistical theory. Instead, the operator appears to have selected a correction factor that is larger than the average surface roughness.

**Q19. Since submitting your initial testimony have you refined your assumptions about the interior corrosion rate?**

**A19.** Yes. NRC Staff have confirmed that UT data taken in the trenches have show that a corrosion rate of approximately 0.002 inches per year occurred between 1986 and 2006. The interpretation of these results is very difficult. AmerGen's explanation that the thinning is caused by exterior corrosion seems unlikely, because Bays 5 and 17 are the least corroded Bays and the estimated corrosion rate in Bay 17 was not significant or was very small (no corrosion rate was even estimated for Bay 5). AmerGen Ex. 23. Indications are that corrosion on the interior could occur at outages or when water flows to the interior during operation. Thus, it is likely that the 2 mils per year average represents a situation where interior corrosion occurred in fits and starts over the years. Considerably higher short term corrosion rates have probably occurred. In the absence of any good information on this issue, I believe it would be prudent to allow for an interior corrosion rate that is a multiple of 0.002 inches per year, if new water is introduced onto the interior floor by repairs to control rod drives, use of the containment spray, or other sources.

**Q20. Has AmerGen or NRC Staff shown that water cannot be present in the exterior of the drywell shell?**

**A20.** No. At various times in the past there has been leakage onto the exterior of the drywell shell because the drywell cavity liner leaks and the trough that was provided to catch general leakage is very shallow, has only one drain, and was damaged. Citizens' Ex. 15 at 134-35; Citizens' Ex. 24 at 222-23; AmerGen Testimony Part 1 at A.20; AmerGen Testimony Part 3 at A.5. More recently, during the 1994 and 1996 refueling outages, the committed mitigation measures were not used and water leaked into the exterior sandbed region. AmerGen Testimony Part 4 at A.8-9; AmerGen Testimony Part 5 at A.14. Therefore, water could flow onto the exterior of the drywell shell in the sandbed region if a forced outage occurred that required the reactor cavity to be flooded without having the leakage mitigation measures applied. In addition, AmerGen has acknowledged that it has been unable to devise a means of stemming the leakage from the reactor cavity during refueling. Citizens' Ex. 24 at 219-21. In the 2006 outage around one gallon per minute of leakage was observed even after the required tape and strippable coating were applied to the fuel cavity liner. AmerGen Testimony Part 4 at A.9. However, the trough is still subject to high temperatures that could cause the concrete to deteriorate and the condition of the trough was seen to be far from ideal in the most recent outage. Citizens' Exs. 48-49. In addition, quite serious leaks have been observed in the past even after taping and strip coating. Citizens' Ex. 50. Furthermore, the intended function of the trough is to act as a backup for other components. Citizens' Ex. 24 at 220. Thus, if the trough degraded further, mitigating measures were not as effective as in 2006, or leakage was observed in other components, water could enter the drywell again, even without a forced outage. Finally, AmerGen acknowledges that use of the drywell chillers, which are used during refueling and other outages when access to the drywell is needed, could lead to condensation. AmerGen Testimony Part 4 at A.15. The potential for condensation is apparently confirmed by an analysis of water that had drained from the exterior of the sandbed region before March 2006, which showed no activity. Citizens' Ex. 23. This is consistent with the source being condensation.

**Q21. Is there a chance that some of the exterior of the drywell shell is not covered by a protective epoxy coat?**

**A21.** Yes. Internal documents we have received from AmerGen indicate that areas of the shell in the sandbed region were not coated with epoxy because they are inaccessible. Citizens' Exs. 40-41.

**Q22. Do you believe that AmerGen has used valid methods to evaluate the potential for external corrosion?**

**A22.** No. AmerGen makes a number of critical errors in its approach to estimating exterior corrosion. Most obviously, Mr. Gordon fails to consider the situation where the plant is forced to fill the drywell cavity in a forced outage. AmerGen Testimony Part 5 at A.13. Mr. Gordon also fails to allow for other forced outages, which could lead to condensation on the exterior of the drywell surface. In addition, Mr. Gordon has not used a reasonable approach to estimate the time in which any water on the exterior of the shell would evaporate, because he has used an equation which applies to pools or open ponds. Id. at A.19. Thus, the equation inherently assumes that the evaporation of the water does not affect the air into which it is evaporating (steady state equation). This assumption is invalid for the exterior of the sandbed region which has very limited air exchange. It is therefore likely that in the event of water leakage into the region, the air in the sandbed region would become fully saturated during the outage (transient phenomenon). It would then have very limited capacity to absorb moisture as the temperature increased with plant start up. Then, after the air becomes saturated at the operating temperature, it would not absorb more moisture unless air is being exchanged with the outside. The ability of new air to reach the sand pocket has been reduced by the placement of tubes leading to polysterene bottles in the sandbed drains. Thus, it is likely that any moisture on the exterior of the shell would evaporate slowly. I do not have access to sufficient information to provide a quantitative estimate of the rate of evaporation.

**Q23. In summary, are you convinced that the drywell will meet safety requirements during any extended period of operation?**

**A23.** No. NRC Staff and AmerGen have created a miasma of uncertainty, which makes it difficult to show what the current situation is or how it could change in the future. However, I believe that the contour plots coupled with the visual observations show that it is likely that the corrosion goes beyond the envelope of the shapes modeled by GE. Furthermore, based on my statistical analyses I believe there is a significant chance that the thinnest area of the drywell is thinner than the required amount (0.49 inches). In addition, the lower 95% confidence intervals of the external data are close to or below the criterion for mean thickness (0.736 inches). For example, based on raw UT data, I believe that Bay 15 could have a mean thickness of less than 0.736 inches at the lower 95% confidence limit and the lower 95% confidence limit of the mean thickness of Bay 13 in 1992 was 0.741 inches, a mere 0.006 inches above the requirement. There is also tremendous uncertainty in the potential corrosion rates for both interior and exterior corrosion. Thus, I believe the Board should not allow the proposed relicensing because AmerGen cannot demonstrate with any certainty that the drywell shell in the sandbed region can meet the ASME code at the start of any period of extended operation. If the Board decides to grant the license, it should ensure that AmerGen has provided an estimate of the thickness margin above each acceptance criterion that is reasonably certain. The UT monitoring frequency should be based on the smallest margin available. That frequency would be considerably less than once every four years because available margins are, at best, razor thin and such margins could be reduced to nothing in a matter of months.

**Q24. Have you now completed your rebuttal testimony?**

**A24.** Yes.

**ATTACHMENT 1**

## ATTACHMENT 1 – LIST OF MOST RELEVANT ADDITIONAL DOCUMENTS REVIEWED

| No. | Document Identification | Other Reference |
|---|---|---|
| 40. | Email from William Russell to Frederick Polaski, et al., Subject: Challenge Board #1 additional comment (Nov. 30, 2006, 9:48 EST), attached to email from John Hufnagel Jr. to Ahmed Ouaou, et al. (Nov. 30, 2006 10:41 EST). | |
| 41. | GPU Nuclear, Technical Functions Safety/Environmental Determination and 50.59 Review (Jan. 5, 1993). | |
| 42. | Email from Peter Tamburro to Ahmed Ouaou, Cc Howie Ray, et al., Subject: Surface Are (sic) of the Drywell in the sand bed (Apr. 3, 2006 3:24 PM). | |
| 43. | Email from John O'Rourke to Michael Gallagher, et al., Subject: External Inspections of DW in Sandbed Region (Oct. 10, 2006 8:08 AM), attached to email from John Hufnagel to John O'Rourke (Oct. 10, 2006 8:10 AM). | |
| 44. | Memorandum, GPU Nuclear from K. L. Whitmore, Civil/Structural Mgr. to J. C. Flynn, Manager, Special Projects, Engineering Projects, Subject: Inspection of drywell sand bed region and access holes (Jan. 28, 1993). | |
| 45. | AmerGen Technical Evaluation 330592-27-27 (Apr. 20, 2007). | |
| 46. | Email from John O'Rourke to Marcos Herrera, Cc Michael Gallagher et al., Subject: Oyster Creek Drywell Thickness to be Used for Base Case Analysis, with OYSTER CREEK DRYWELL THICKNESSES, Rev2.doc attachment (Feb. 28, 2007 7:20 PM). | |

47. Issue # 00557180, Exelon Nuclear Issue - Statement of Confirmation, Originator: Kathy Barnes (Nov. 13, 2006).

48. Email from Tom Quintenz to John O'Rourke, Subject: Notes of video inspection results of trough area with Video Inspection of Concrete Trough Notes November 1996 (Oct. 10, 2006 2:26 PM).

49. GPU Nuclear, Material Nonconformance Report (Oct. 27, 1986).

50. Memorandum, GPU Nuclear from R. Miranda, Engineer, Technical Functions to Distribution, Subject: 14R Reactor Cavity Leak Detection Effort (Feb. 1, 1993).

51. Sketches showing ultrasonic and "Echo to Echo" techniques, and explanations of sketches.

ATTACHMENT 2

**CORRO-CONSULTA**

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**Memorandum**

August 16, 2007

**Response To The Questions About Statistics**

## I. Some Background on the Origin of Statistics

- Collecting data of all sorts is a basic human and/or societal occupation. The data one collects are very simply observations put into a quantitative form. For instance, the child may separate out the red from the green pebble at the beach and then count them

- Statistics is a tool to organize and describe some innate properties of data, i.e. properties of the observations one has made.

- The most prevalent observations are measurements, and the most important property of measurements, any measurement, is the fact that they are not absolutes, as we tend to assume, but in fact estimates. Hence, the data we collect are estimates and statistics is a tool to describe certain properties of these estimates.

- What are these properties? Take an example: We have a corroded surface, which is characterized by pits. (Pitting is a most prevalent form of corrosion). We would like to know how deep the pits are. We take a micrometer, for instance, or a microscope, and start measuring the depth of pits. We measure 87 pits and acquire 87 data points each describing the depth of a pit. We now need to describe what we have done in some way that is more concise and more understandable than a collection of 87 data points. We take recourse to some statistical tools.

- The first thing we do is to calculate the **average pit depth**, also called the mean. The next day the boss comes with another piece of corroded surface, from another structure, and wants to know whether the pits are the same, or maybe were caused by a different phenomenon. So, we start all over again measuring pit depth but only take 47 pit depth measurements. We quickly calculate the average of the 47 data points and because the new average is slightly different but we then have a statistical problem – **how much confidence can we have that the two averages (means) are indeed different or come from the same universe of pit depths.**

## II. What Statistics can do and can't do

- One needs to recognize that statistics is a set of rigorous mathematical equations to answer certain very specific questions one may have about a collection of data. However, one also needs to recognize that as with all mathematical theories, they are based on assumptions, and one always needs to test whether the assumptions in a given mathematical procedure actually reflect the true nature of the phenomenon under scrutiny. Example: if the variation of the pit depths is truly normal, then Gaussian statistics will apply because they are based on the observation that measurements close to the mean are more frequent than the ones further removed. Since AmerGen and NRC have decided that Gaussian statistics are what applies to the sandbed corrosion problem, that is what we will discuss first. (An alternative will be discussed later on).

- The basic assumption underlying Gaussian statistics is the notion that the variations within the universe of data, which characterize a particular parameter, are distributed normally as defined above. The universe (also sometimes called the population) therefore can be represented by the well-known bell-curve. This simply means that the frequency of data close to the mean is higher than the frequency of data removed from the mean.

- The Gaussian or Normal Distribution curve shown in Figure 1 is rigorously described by a mathematical formula which simply says that the logarithm of the probability density p(y) (or how often a value occurs within its population) of a particular value is a quadratic function of the difference between the value and the mean of the population.

$$p(y) = const. \cdot 1/\sigma \cdot e^{-[(y-\eta)^2/2\cdot\sigma^2]}$$

where y = attribute (value to be measured)
$\sigma$ = standard error
$\eta$ = mean of the population

## III. The Error Measurement

- Since one can never measure the entire population, but only samples of the population, the average of the sample (the sample mean) and the standard deviation of the sample (standard error)[1] become **estimates** of the true population mean and the true probability density distribution, i.e. the true standard deviation. This, however, is only true if the samples have been selected randomly. The difference between a value y and the mean of the population is often called the error. However, the error is a complex function of a lot of things, some can be controlled others cannot. Therefore we would prefer to call this difference ((y-$\eta$)

[1] The variance is the square of the standard deviation

the variability in the data. The variability is composed (in the simplest case) by the "innate" reproducibility of the instrument (the accuracy of the instrument [2)]) and by the natural variation of the measured parameter (pit depth as a function of location on the surface).

- This is demonstrated in Table 1. During the 2006 refueling outage the external UT measurements from 1992 were repeated. We had already shown [3)] that even though there was a slight bias between the 1992 and 2006 data (of about 20 mil) which might have been interpreted as ongoing corrosion, this bias was not statistically significant in view of the inherent variability of the data (individual UT measurements). In 2006, additionally, duplicate and triplicate measurements were made externally in some bays. From these repeat measurements it was possible to estimate the standard deviation associated with the error of the measurement only. The results are summarized in Table 1 below.[4] In the columns headed by 'std. dev. variability' we calculated the spread of the remaining wall thicknesses between pits as a standard deviation. It is easy to understand that the wall thickness measurements will vary from pit to pit because one could not expect corrosion to be uniform over the entire surface [5)]. Hence one finds the wall thicknesses vary within certain limits as expressed by the standard deviation [6)].

  Now, it must be also understood that the variability of the data arises from two sources: a) the actual variation of the pit depths (residual wall thickness) and the measuring error. If only wall thicknesses are measured, the two effects are hopelessly confounded. In the present case, in 2006 duplicate measurements were made in some cases as shown in Table 1. It was then possible to estimate the measuring error form these repeated measurements. As Table 1 shows the measuring error (Std. Dev. from 2006 Repeat Measurements) is smaller than the variability of the wall thickness measurements themselves. This is of course anticipated since the latter contain, as mentioned above, both the error as well as the variability of the wall thicknesses. It is interesting to note that the measurement error depends on the roughness of the surface. Indeed, if the error is plotted against the variability a straight line results which extrapolates roughly to 0.01 inches at 0.01 inch (see Figure 5), i.e. the instrument error one would expect, from the manufacturers specifications, if the surface had not been corroded and were still in a pristine state.

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[2)] UT instruments are generally said to be accurate within +/- 1 to 2% of wall thickness, where newer instruments are more accurate than the older ones.

[3)] R. H. Hausler Memorandum to Richard Webster, Esq. April 25, 2007, Figure 7

[4] The standard deviations derived from repeat measurements shown in Table 1 differ slightly from those previously presented, because I have used a more rigorous calculation method than previously.

[5)] In acid for instance one could anticipate and observe that the thinning of the probe (wall) is uniform over the entire surface with no evidence of pitting. In neutral solution where the build-up of corrosion product layers can be anticipated corrosion will not be uniform over the surface and localized attack can be anticipated.

[6)] If the pit depths, or by implication the remaining wall thickness measurements, are normally distributed, characterizing the variability with a standard deviation makes sense. If the distribution is a different one (which we suspect) then the data spread should be characterized differently.

## IV. Definition of Confidence Limits and Statistical Testing

Referring back to Figure 1, it turns out that about 66% of all data belonging to the universe of data estimated by the standard deviation are within the mean m +/- 1s and 95% of the data are roughly within m +/- 2s. The exact multiple of s to be used is derived from the Student's t-distribution, which takes account of our imprecise knowledge of the true population variance. The multiples of s that encompass a certain portion of the data decrease as the number of samples increase. At the limit, when the number of samples is large, the students-t distribution becomes equivalent to the classic Gaussian distribution

Now it may arise that one asks of a particular measurement whether it belongs to this universe. If the point is more than two s removed from the mean there is a certain probability that it does not belong and vice versa. One can specify that probability with the Student's t-test, which calculates the chance that a sample would deviate that much from the population mean. The student t-test may also compare the means of two sets of measurements to calculate the chance that the difference between the means is caused by random variation.

Similarly one may ask the question whether the variabilities of two sets of data are the same. The comparisons are made on the basis of the variances ($s^2$) rather than the means and the test is called the F-test. Imagine two machines turning out bolts. The mean length of the bolts is the same for both machines, but the variance, i.e. the spread of the length measurement is different. The F-test indicates the probability that the difference in the variance is real. It might tell us that one of the machines needs to be better adjusted. Similarly, one might ask the question whether the variance of the measured residual wall thicknesses for Bay 5 in 2006 is different from that of Bay 19. If the F-test returns a probability of between 95 and 99%, this might tell us something about the corrosion mechanism or the cause of corrosion in the two Bays.

Getting back to the simple comparison of two measurements, one may for instance posit the hypothesis that the mean $m_1$ does not belong to the same universe of data as $m_2$. Based on the Student t-test one may find that there is a 75% probability that the hypothesis is true. Customarily one would not accept this as sufficiently significant. If how ever there was a 95% probability for $m_2$ to belong to a different universe, one would very likely accept the hypothesis. Happily, these statistical probabilities have been calculated and are available in tables. Even better, nowadays, computer codes have made life very easy for the experimental statistician (see for instance Fig 2 to be discussed later).

The 95% confidence limits based on the 95% probability of a specific hypothesis being accepted as true is often used in science as an indicator that it is unlikely that the observed effect is caused by random variation. However, there is no set standard in the literature or in engineering that imposes such limits. There may be certain recommended practices, which embrace this limit as practical but not as imperative. The reason for this is quite understandable. From a practical point of view 95% confidence may be too little if the consequences of drawing an erroneous conclusion are large. In such cases, the required confidence limit could as well be 99%, or in the case of GE, which advertised 5s as the a company wide standard, it is more like 99.9%. What is, however vitally important is risk assessment. To perhaps clarify the difference between probability (confidence) and risk contemplate the following situation: A blind man crossing a major thoroughfare has a one in a hundred chance of being hit by a car. The confidence level therefore is 99% that he will make it across. The risk he takes, however, is unacceptable, because he would cross thousands of roads in his lifetime and so a he would have a very high chance of being hit. Hence, assessing the confidence one may have in acquired data is only the first step, albeit an important one, in assessing risk. Generally, it is the process of risk assessment that imposes the confidence level to be used.

In the pipeline industry both internal and external corrosion damage is assessed by ILI (internal line inspection, also sometimes referred to as intelligent line inspection). Pigs equipped with sensors (either UT or magnetic flux leakage – and in earlier years mechanical calipers) are pushed through a pipeline, and the responses of the sensors recorded, to be downloaded and interpreted after the run. The API (American Petroleum Institute) has prepared a Standard for In-Line Inspection Systems Qualification [7]. The 65 page documents standardizes the entire process. We are here only interested in the statistical handling of the data. As the title indicates it is the "system" that is being standardized. The basis question is: "how accurate is the instrumentation in the pigs"? This is being demonstrated by verification of the indicated corrosion (or other) anomalies where the buried line can be accessed. The anomalies are located by means of the distance measurements (made by the pig) and verified with an alternate method or instrument. The paradigm for verification is as follows: The pig is specified (by the manufacturer) to detect anomalies with an accuracy of +/-10% of wall thickness. Verification occurs with a certain additional error, say 5%. If the anomaly is verified within the pooled accuracies it is accepted, otherwise it is rejected. The aim of this verification is to be 95% confident that the measurements of the pig have identified at least 80% of the anomalies correctly and within the set specifications. The thinking is not applicable to the Oyster Creek drywell shell problem, because no effort has been made to independently verify the corrosion anomalies. At Oyster Creek it is assumed that the UT measurements are correct. The Pipeline example however shows that a 95% confidence limit is considered adequate, albeit not imperative.

**There is power in Numbers**

There is another side to using statistics. As indicated above, by repeating measurements one can determine the standard deviation (accuracy) of the

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[7] API – 1163 Qualification of In-Line Inspection Systems, 2004

instrument and calculate a mean for the particular point that was measured. The more measurements that go into the mean the more accurate the mean becomes. Expressed in a formula:

$$s_m = \frac{s_x}{\sqrt{n}}$$

where $s_m$ = standard deviation of the mean
$s_x$ = standard deviation of a single measurement
n = number of measurements used for the mean [8)]

Applied to the problem at hand this would mean that the more wall thicknesses are determined, the greater the confidence we can have in the mean. However, this will not change the distribution (spread) of the wall thicknesses, it will only better define it and better define the average wall thickness. But structures do not fail by averages. Just likes storms do not destroy villages, but extreme storms do. Structures, like pipelines, for instance, fail where the deepest pit is located. So, how do we apply this thinking to the drywell?

## V. Margins and Extremes

Sandia recently made a new study of the integrity of the drywell. The result was that the safety factor for the undegraded shell was 3.85 while for the degraded shell is was 2.15, or 7.5 % above the minimum safety factor specified by the ASME code. The input to the calculation for the degraded shell was all the external thickness data from 1992 some of which are shown in Table 1 below. The first question we may ask is whether the 100 odd data points truly represent the state of the corroded drywelL The answer is: not likely, but that is speculation, perhaps. However, we do know that the standard deviation of the error for the individual measurement is of the order of 0.029 inches in the more heavily corroded areas, the ones of interest. This means that the 95% confidence interval for individual wall thickness measurements is of the order of 0.058 or also about 7.5% of the remaining wall thickness. The model took no account of this uncertainty. Furthermore, the Sandia model has other non-conservative features and was designed to provide accurate absolute predctions. Specifically, the model did not attempt to model the actual shapes and placement of the observed corrosion features, and it did not use the 2006 data which all agree is more accurate and shows the drywell shell is on average approximately 0.02 inches thinner than measured in 1992 data. Therefore, the Sandia model does not establish any margin with a high degree of confidence.

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[8)] This formula essentially says that the means of samples are more narrowly distributed than the samples themselves. This is a direct consequence of the "Central Limit Theorem".

In addition, we question whether the buckling models should take explicit account of other uncertainties, including variation in nominal wall thickness [9], variations in tensile strength, variation in temper properties, inclusions in the steel sheet (of which the UT tests seem to have found a relatively large number), and perhaps many more. It may be that the safety factor of 2 is designed to take account of these, but it appears that designers err on the safe side to ensure that this requirement is met with a very high degree of certainty at the outset, when the variation in wall thickness is much less than it is after 40 years of corrosion.

There are two criteria of primary interest with respect to the integrity of the Oyster Creek Dry well. First is the buckling criterion discussed above and addressed by the Sandia study. Then there is a pressure criterion, which says that a corroded area thinner than 0.536 inches shall be greater than 0.49 inches and not larger than 2.5 inches in diameter. In this case only one relatively small area corroded fairly deep could in fact lead to non-compliance with the safety requirements. The trouble is one does not know where this spot could be. One therefore tries to extract from the available data whether such a spot could exist and with what probability.

In the first attempt to answer the question one would probably examine the available data for "normalcy" (i.e. normal, or random, distribution). Figure 2 shows a histogram generated in the SAS software called JMP. While the computer program churns out a result it is up to the operator to decide whether the result justified the underlying assumption. In this case one clearly recognizes, even without any further statistical tests, that the assumption of "normalcy" is not fulfilled. (In fact statistical tests, which are not shown in the printout do confirm this). The aspect of a histogram often depends on the "bin size" (i.e. the width of the intervals chosen for the density counts). Figure 3 shows that reducing the bin size to 25 from 50 in Fig. 2, leads to the same conclusion, namely that the data are not normally distributed. It would therefore not be prudent to use the statistical data from Figure 2 and calculate the 2.5% probability for the lowest wall thickness, 790 – 2*112 = 564 mils. Of course, one could have asked for the 1% probable thinnest thickness which would have been around 790 – 3*112 = 454 mils or thin enough to violate the safety requirement. In view of the high stakes in these considerations one may then want to explore other approaches.

## VI. Extreme Value Statistics

An alternate approach is in the application of extreme value statistics, which does require the data to be normally distributed. Figure 4 shows the data from Bay 13 (external measurements made in 1992). The theory requires that when the ordered data are plotted against a double logarithmic function of the reduced or relative order of the data points (the reduced variate) in the series, a straight line is obtained. Figure 4 shows the result. The correlation would appear to be

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[9] while the nominal thickness may well have been 1.154 inches the manufacturer's tolerances vary from 10 mils to as much as 2 to 3%.

considerably better than under the assumption of normalcy (Fig. 2). The regression function of the straight line can be used to extrapolate values, which would have been obtained if more points had been measured. Thus, if 37 points had been measured, one might have observed a point of the order of 490 mils residual wall thickness. Larger number of data points might well have included even lower wall thicknesses. This is a disturbing result because it indicates that there is a significant chance that the drywell shell would not contain the gases in an accident condition.

Extreme value statistics, as I understand it, was developed in order to predict damage from extreme weather conditions. For example the 100-year flood plain is based on such predictions. These predictions only say how high water may rise if the extreme amount of rain falls. They do not predict when this may happen. Similarly, extreme value statistics applied to corrosion only says that there may be a pit deeper than all the others with a certain probability based on the number of observations, but it does not say where this pit (or damage) may be unless it has actually been measured.

## VII. Extreme Value Statistics in Industry and Risk Assessment

Extreme value statistics is beginning to be used in the pipeline industry. This writer has used the approach to calculate the corrosion rate (pitting rate) in pipelines based on successive scans and evaluation of the resulting data according to extreme value statistics. Pipelines are scanned by intelligent pigs, using either mechanical calipers (rarely used any more), UT, or Magnetic Flux Leakage (MFL) technology. This technology has been growing rapidly with advances in the respective areas. Successive MLF scans for instance rarely record the same corrosion feature twice. There are a number of reasons for this too numerous to go into here. However, because of this, extreme value statistics is the only means to compare successive scans and estimate an overall corrosion rate, It must be remembered, however, that it is individual pits that corrode, not the ensemble of pits, and one initially assumes that all the pits are subject to the postulated corrosion mechanism. If different conditions prevail along the pipeline, then the data may have to be partitioned appropriately and analyzed separately.

## VIII. Some General Remarks

I hope that these very brief remarks make it clear that the application of statistics (any statistics) in the oilfield is a difficult problem. However, in view of the fact that some recent incidences have led to the criminalization of negligence with respect to corrosion prevention of structures in the public sector, and with DOT and EPA setting rules, companies have begun to realize that failures are becoming less and less acceptable. However, while diligence has been legislated, there are currently no standards with respect to the certainty required. This means it is left to the individual companies to assess risk based on the probability predictions extracted from the data collected.

This gets us right back to risk assessment, and the probability of the "extreme corrosion damage", and the corrosion rate based upon such estimates, are only a small part of the overall input into the Monte Carlo simulations that calculate the value of the risk the company is bearing and in the end dictate corporate behavior.

In conclusion, it appears to us, that similarly to corporate behavior, where the responsibility lies squarely on the shoulders of the engineer and responsible personnel, the nuclear industry, and in particular the NRC, should take a much more sophisticated look at uncertainty and risk. Here the NRC Staff initially required the drywell shell to meet the deterministic design criteria for both pressure and buckling with a very high degree of certainty. However, the Staff seem to have drifted from this stance to approving the safety of the proposed relicensing, when compliance with those same criteria can no longer be established with any certainty. Although NRC Staff at one point required AmerGen to show margin with a nominal 97.5% confidence and the Staff appear to espouse that standard in the SER and in their testimony, they failed to apply it in practice.

Finally, I would like to point out that this writer at least recognizes the large investment in the nuclear industry, recognizes the complexity of the installations, and appreciates the accident free (or near accident free) operations up to this point. I also am of the opinion that safe nuclear power generation, safe spent fuel handling, and safe spent fuel storage, and reprocessing are in the future of the country. However, just like it has evolved in the pipeline industry, in the refining industry, and in offshore oil and gas production, the personnel involved in the nuclear industry must be held to the highest standards of technical and ethical judgment, which must trump corporate imperatives (see for instance the BP Alaska debacle). Relying on past performance when predicting future behavior of 40-year-old installations is not enough. Aging management has to be a lot more sophisticated and must require the industry to demonstrate it can meet safety-related requirements on an on-going basis with a high degree of certainty.

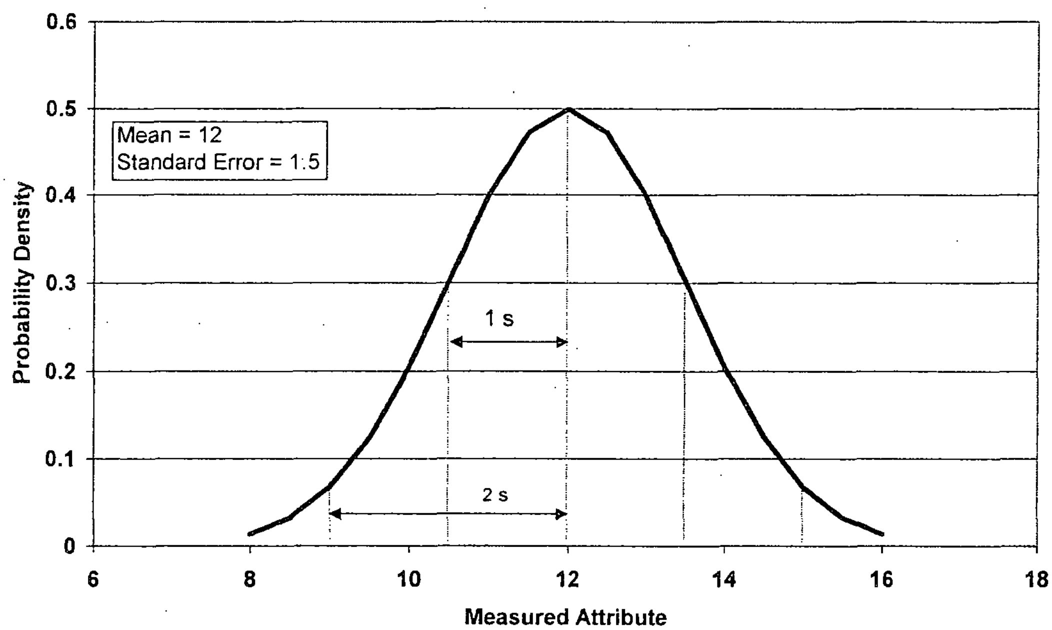
## Table 1

**Comparison of the Data Spread in the External UT Measurements with the Standard Deviation of Duplicate or Triplicate Measurements at the same Spot**

| Bay | 1992 average | | | 2006 Average | | | |
|---|---|---|---|---|---|---|---|
| | No of Data Points | Measure ments | Std. Dev. as Variability | No of Data Points | Measure ments | Std. Dev. as Variability | Std Dev. from 2006 Repeat Measurements |
| **5** | 8 | 0.994 | 0.053 | 8 | 0.96 | 0.0386 | 0.017 |
| **7** | 7 | 1.004 | 0.043 | 7 | 1.007 | 0.027 | 0.017 |
| **15** | 11 | 0.816 | 0.054 | 11 | 0.81 | 0.053 | 0.023 |
| **19** | 10 | 0.889 | 0.08 | 10 | 0.848 | 0.083 | 0.029 |

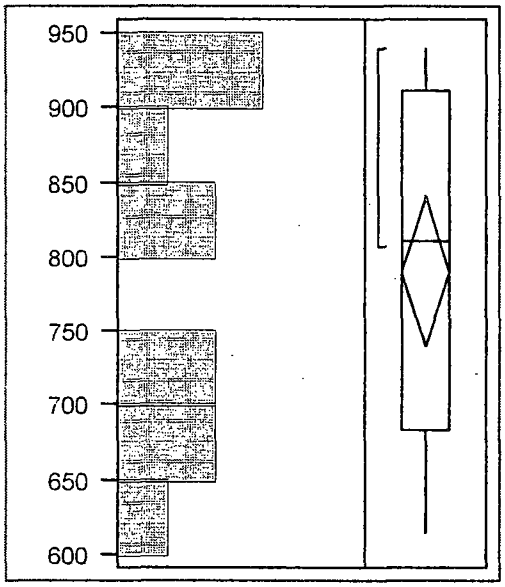
Figure 1

**Typical Gaussian Probability Density Curve**



**<u>Figure 2</u>: histogram for external wall thickness measurements in Bay 13**
***(Generated in JMP)***

1993 WT




**Quantiles**

| | | |
|---|---|---|
| maximum | 100.0% | 941.00 |
| | 99.5% | 941.00 |
| | 97.5% | 941.00 |
| | 90.0% | 933.40 |
| quartile | 75.0% | 912.50 |
| median | 50.0% | 810.50 |
| quartile | 25.0% | 684.50 |
| | 10.0% | 629.10 |
| | 2.5% | 615.00 |
| | 0.5% | 615.00 |
| minimum | 0.0% | 615.00 |

**Moments**

| | |
|---|---|
| Mean | 790.8636 |
| Std Dev | 112.1926 |
| Std Error Mean | 23.9195 |
| Upper 95% Mean | 840.6066 |
| Lower 95% Mean | 741.1206 |
| N | 22.0000 |
| Sum Weights | 22.0000 |

Figure 3

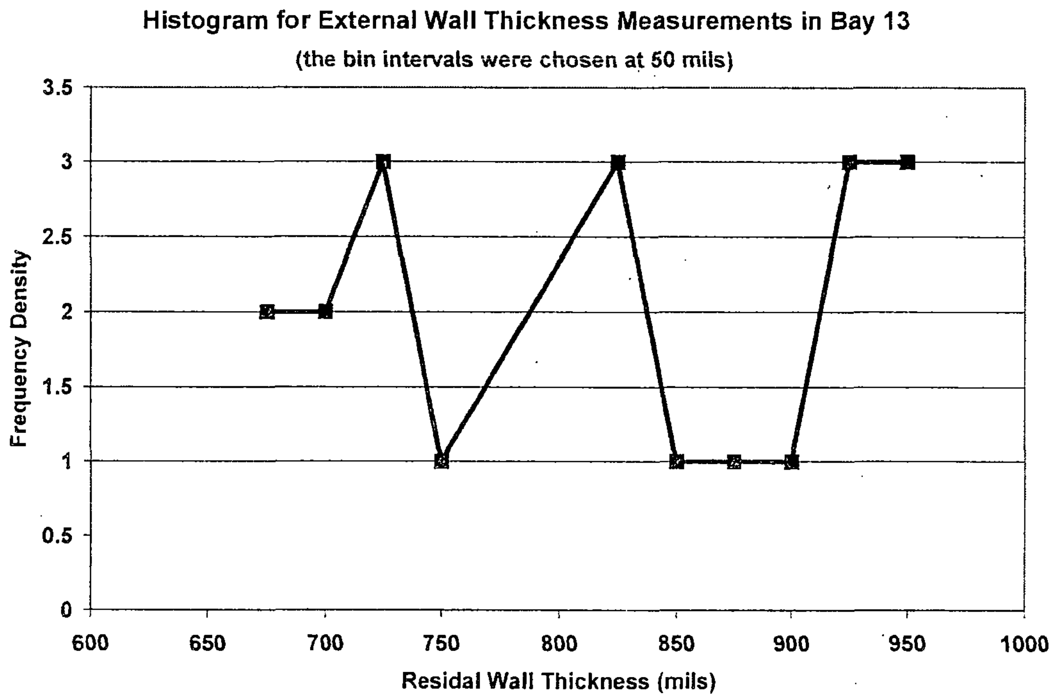
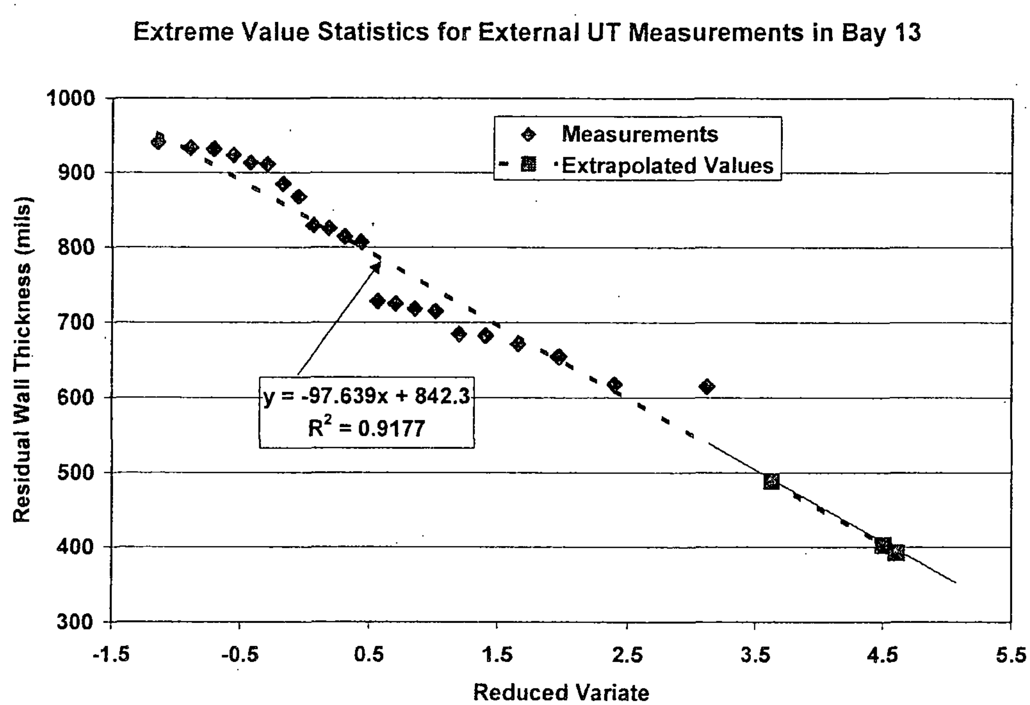
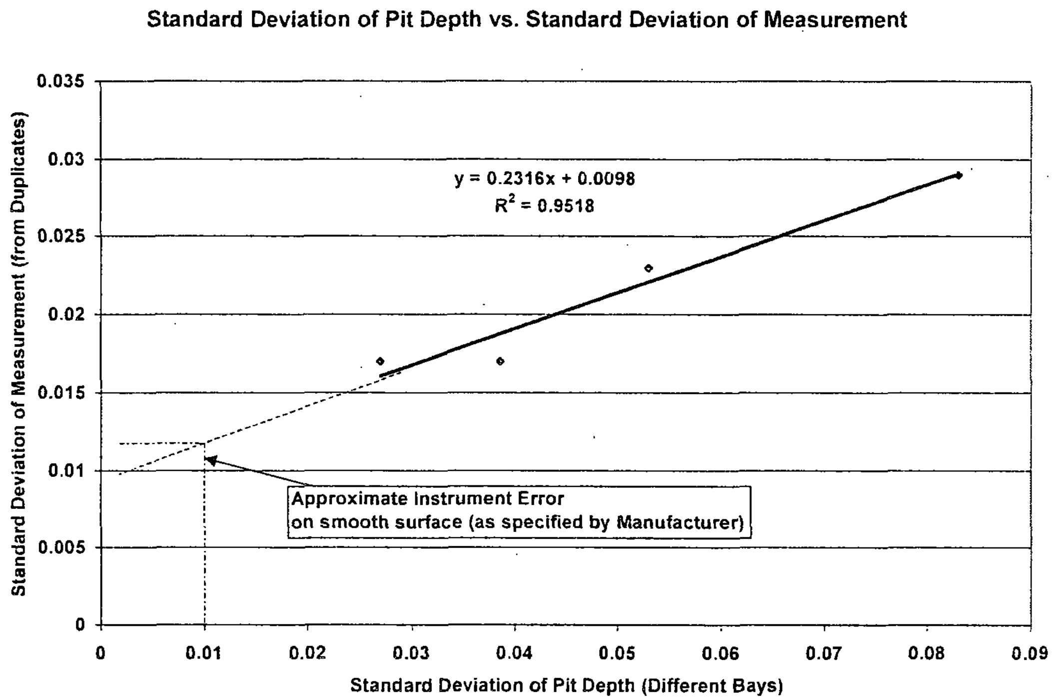



Figure 4



## Figure 5



Standard Deviation of Pit Depth vs. Standard Deviation of Measurement
y = 0.2316x + 0.0098
R² = 0.9518
Approximate Instrument Error
on smooth surface (as specified by Manufacturer)
Standard Deviation of Measurement (from Duplicates)
Standard Deviation of Pit Depth (Different Bays)
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09

**ATTACHMENT 3**

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# Memorandum

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August 16, 2007

**Subject: Further Discussion of the Nature of the Corroded Surfaces and The Residual Wall Thickness of the Oyster Creek Dry Well**

## I. Introduction

It is understood from the NRC testimony that ..."the license renewal safety review process focuses on the 'potential detrimental effects of aging that are not routinely addressed by ongoing regulatory oversight programs'" [1]. This is an extremely important statement with respect to the efforts by 'citizens' to contribute constructively to the discussion of the integrity of the Oyster Creek drywell shell. The statement in essence urges "thinking out of the box" and focuses on future potential events that are difficult to predict. NRC and AmerGen both have stated that the aging processes in question are slow and can be monitored within relatively long intervals, without risking an undesirable event. It is, however, a well-established fact and acknowledge by those skilled in the art that "rate to failure", i.e. the rate of the aging process, be it corrosion, degradation of coatings, fatigue etc., is not constant with time (often also said to be non-linear). While almost imperceptibly slow in the beginning, the processes accelerate later in the life of the structure and my lead to failure

[1] NRC Staff Initial Statement of Position on the Drywell Contention, pg. 7, July 20, 2007

exponentially with time. **It is also a well established correlation that the logarithm of the cumulative failure rate of complex aging structures is linear with time, i.e. failures accumulate exponentially as time goes on** [2]. In discussing, therefore, the processes and the monitoring of aging one has to be acutely aware that the rates of these processes are not constant with time but can and often do, after a slow initiation period, accelerate exponentially. **Monitoring intervals therefore cannot be judged by past performance.**

We also try to guard against using terminologies, which tend to create in one's mind images with conflict with the real world. It has, for instance, been said all through these proceedings that "the thinnest spots in the drywell wall in the sandbed area were identified visually (and by micrometer readings). This is utterly impossible, because just by looking at the corroded surface one cannot guess at the remaining wall thickness because one has no reference point back to the original surface. Micrometer readings can establish pit depth, but only with reference to the remaining surface, not the original one. Similarly, 2-inch plugs had been removed from the drywell wall in order to verify the UT measurement at that location. One such plug was examined by a third party [3] corrosion expert and assessed as showing *uniform corrosion.* While the assessment may have been correct for the surface of the 2-inch plug, it certainly was not representative for the drywell surface in the sandbed area in general, because here corrosion was highly non-uniform, as one would expect from the corrosion mechanism. It has also been said that the corrosion damage was caused by *galvanic corrosion.* Galvanic corrosion is defined as occurring between dissimilar metals. There were no dissimilar metals present in the sandbed area. The prevailing corrosion phenomenon is generally identified as differential aeration cell occurring under a deposit. As such, for a number of reasons, the corrosion will be highly non-uniform and characterized by pitting and trough formation, as was indicted by the term golf ball like pimpled surface (which is not what is commonly understood by uniform corrosion).

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2) This correlation was discussed by Professor Dr. Roger Staehli in a Plenary Lecture during the NACE Convention of 2004 in New Orleans with special reference to the Nuclear Industry
3) AmerGen's Pre-filed direct testimony Part 6, Future Corrosion, Barry Gordon, pg 4.

Another terminology, which causes a great deal of confusion relates to the removal of air from the reactor cavity during normal operation. Inerting, presumably with nitrogen has been said to make "the likelihood of corrosion very low" [4)]. The fact, however, is that the oxygen content in the atmosphere is reduced only from 20% to 5% [5)]. Corrosion, therefore, will continue however, at a reduced rate [6)]. In fact, it appears that several instances of carbon steel corrosion have been identified in the RBCCW system inside the containment [7)].

These examples, which are only a few of many, demonstrate that it is important not to use words, expressions, sentences, which create imagery not consistent with reality. The containments do not contain *an inert atmosphere;* rather they contain a reduced oxygen atmosphere for the purpose of preventing the formation of an explosive one.

It has been said, and this is obviously not in dispute, that the outside steel surface of the drywell in the former sandbed area had been thoroughly coated with a primer and two epoxy paint coats. Additionally, the concrete floor of the former sandbed had been built up with epoxy, etc, etc. This of course creates the image of a well-protected structure where the protective coating would have to be destroyed or damaged before corrosion could take place. **However, what had not been highlighted until recently [8)] is the fact that there are concerns about areas that were not accessible to cleaning and/or coating.**

These comments, some of which will be discussed in more detail below, bear directly on the question of "how well do we really know the condition of the drywell", i.e. the uncertainties, which surround this entire project. AmerGen has repeatedly indicated both the UT measurements using the internal grids and particularly the external

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4) NRC Staff Initial Statement of Position on the Drywell Contention, July 20, 2007 pg. 15, A12(a)
5) e-mail from T. Quintenz to K. Muggleston, 2/1/2006.
6) See also expert opinion by Dr. R. M. Latanision, letter to Mr. Ron Zak, NJDEP-Bureau of Nuclear Engineering, March 26, 2007
7) e-mail from K. Muggleson to G. Beck 1/31/07 (RAI regarding corrosion.of carbon steel mechanical components in containment atmosphere).
8) e-mail from W. T. Russell to F. Polaski, 11/30/06

measurements gave conservative results because they were obtained from areas that were most corroded. For the external measurements, the only evidence for this statement stems from visual observation of the corroded surfaces. Presenting the data AmerGen had generated in contour plots [9)] seemed to suggest that corrosion could, at least in certain cases, be more severe outside the areas that had been examined by UT. At minimum, the contour plots showed that the most severely corroded areas in the sandbed region are very poorly defined spatially. There is therefore tremendous uncertainty about the extent and the thickness of these areas. Instead of merely making optimistic or pessimistic assumptions, statistics may be used to attempt to quantify that uncertainty and illustrate the limits of our current knowledge about the corrosion of the drywell shell. At this point there are two principles one must be acutely aware of. These are: a) the larger the variability of a particular measurement, the larger will be the confidence limits within which the real value might be found. (For example: the reproducibility (s) of wall external thickness measurements is of the order 0.03 inch. The 95% confidence limits within which the wall thickness at that particular spot might be found is therefore approximately +/- 0.06 inch.); b) if it becomes necessary to estimate the thicknesses within tighter confidence limits it will be necessary to perform a larger number of measurements, because the mean will have tighter confidence limits than individual measurements. Indeed, if the null hypothesis is well demonstrated, then successive data sets may be pooled to increase certainty. Thus, a requirement for increased certainty could initially drive a higher monitoring frequency than proposed. However, in areas where there are no measurements, one is reduced to conjecture, and the question in the end is whether AmerGen can show that the drywell meets safety requirements, despite the large uncertainty associated with the proposed monitoring program.

## II. Background

The purpose of this discussion is to systematically establish the confidence levels associated with the various wall thickness measurements and the conclusions drawn from them. In reviewing the various documents dealing with these subjects it became

[9)] R. H. Hausler Memorandum to R. Webster, Esq., July 18, 2007 apparent that the methodology of measurement and interpretation was not always consistently applied and hence it is necessary to get back to the basics of what can be validly concluded from the data we have. This discussion is therefore not intended to be a critique of the methodology of UT measurements, nor the evaluation procedures of the data, but rather a further attempt to extract additional information from the existing data, and establish a reasonable perspective for the conclusions.

## III. A thought about Confidence limits

I believe everybody can agree that the *realistic assessment* of the extent of the corrosion damage on the external wall of the drywell in the former sandbed area is crucial for the establishment of the current fitness for service condition of this vessel. Additionally it will set realistic limits to the margins, which may still exist regarding further allowable corrosion.

Since fitness for service is determined on the basis of various model calculations (buckling calculation) and specific codes, such as the ASME pressure vessel code, the question boils down to the definition of "realistic" in "realistic assessment". Here is of course where experts begin to disagree because some may assess a given situation as less "severe" than others would.

For instance, NRC and AmerGen have at times practiced a statistical approach to the interpretation of measured data, and applied the 95% confidence limits to the reported results. I believe this to be prudent, since corrosion rates, for instance, determined from residual wall thicknesses as a function of time should be seen both in the as correlated form as well as in the extreme form based on the 95% confidence limits, since particularly the upper 95% confidence limit would result in more rapid deterioration or a faster elimination of still available margins [10)].

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[10)] See for instance Calc. C-1302-187-5300-20 (various revisions)

The 95% confidence limits embrace 95% of all data belonging to a specific family of data, which have been experimentally determined. The limits are defined as the mean of the data +/- approximately two (2) standard deviations (s) (depending on the degrees of freedom). Hence if a data point lies outside any of the 2 s limits it is said not to belong to the same family and is often characterized as atypical [11]. As an example, a location of corrosion damage in Bay 13 has been identified with a residual wall thickness of 0.602 inches. The standard deviation of this particular measurement has been identified from a series of duplicate measurements as being approximately 0.03 inches. Therefore, if the data are normally distributed, there is a 2.5% probability that the remaining wall thickness at this particular location could in fact be lower than 0.542 inches (the normal distribution is symmetric so the upper and lower tails beyond the 95% confidence limits each contain 2.5% of the data). If this result characterizes an area of 1 sq. ft. around it, the result should be compared to the acceptance criterion of either 0.636 inches or 0.536 inches for localized corrosion damage This comparison indicates that there could be 2.5% probability that the remaining margin is zero or less than 0.006 inches, depending on which acceptace criterion the Board decides is appropriate. It is of course within the purview of NRC or the ASLB to determine whether 2.5% probability for a certain event not to happen is or is not sufficiently conservative. (Parenthetically it may be interesting to note how over the years the statistical confidence limits have changed since in 1992 99% confidence was still considered appropriate for nuclear safety considerations and here the lower 99% confidence limit would have eliminated the remaining margin completely. [12]. To avoid this result, AmerGen's Testimony has argued that statistics should not be applied to the external measurements. Nevertheless, this residual wall thickness has been reported by AmerGen. The duplicate measurements also have been reported by AmerGen and calculating the standard deviation for a single UT wall thickness measurements on the outside of the drywell from these duplicate measurements is a simple exercise in Statistics 101 [13]. Are we therefore resigned to

[11] See for instance also Calc. 1302-187-5320-24 Rev. 0
[12] Calc. No. C-1302-187-5300-19 at page 37 for instance
[13] It should be remembered that there are actually two types of "standard deviations" in the set of measurements presented by AmerGen. The series of 49 measurements made by means of a grid on the

live with a 2.5% or 0.5% probability that in the event of a nuclear accident the drywell may not serve as a primary containment and may release radioactive emanations into the environment? Not necessarily: the well-known resolution of large uncertainties caused by large standard deviations of single measurements is to repeat the measurement a few times because the standard deviation of the mean of multiple measurements is reduced according to the well know *central value theorem.*

While the standard deviation for single measurements is quite large and tends to lead to the conclusion that at least in one area the limit for local wall thickness reduction has been reached, the spread of the measurements leads to the same conclusion as has been shown in Figure 6 of R. H. Hausler Memo of 4/25/07 [14)]. In this latter case, however, additional measurements would not reduce the spread of the data since in heavily corroded areas the pit distribution is systemic and could not be made tighter by additional measurements, only the mean would get better defined.

Since very few external wall thickness measurements have been repeated, which holds in particular for those measurements resulting in low residual wall thicknesses, one is saddled with large uncertainties in the interpretation of the UT wall thickness measurements. This is neither a criticism of AmerGen's UT measurement methodology nor of their interpretation of the data, but simply a statement of fact, which AmerGen and NRC could have arrived at themselves if they had pushed their data analysis to the same insights.

## IV. Residual Wall Thickness Measurements and the Buckling Criteria (Fitness for Service Criteria)

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inside of the vessel presents a certain spread of wall thicknesses which can be represented by a standard deviation if the distribution of the measurements is indeed Gaussian. (Similarly, the external measurements are somehow distributed). However, there is another standard deviation, which originated from repeated measurements at the same spot. This standard deviation represents the repeatability of the measurement proper. This standard deviation could actually be determined from duplicate wall thickness measurements made on the outside of the drywell in the sandbed area.

[14)] R. H. Hausler Memorandum to R. Webster, Esq., April 15, 2007 at 17.

The analyses of the UT residual wall thickness measurements in combination with the various fitness for service criteria is intended to arrive at a reliable estimate of the remaining margin, if any. The remaining margin together with an estimate of the potential corrosion rate will determine the frequency of inspection. It has been said that the remaining margin is at least 64 mils (800 mils minus 736 mils) and that the estimated corrosion rate is at most 2 mils per year (mpy). It will be shown that these statements, even if not totally grabbed out of thin air, cannot stand up to detailed scrutiny.

The remaining margin of 64 mils is based on the lowest average for the 49 point 6 inch by 6 inch internal grid measurement in one Bay (Bay 19A). It should be remembered here that the NRC had wisely requested that "the grids shall be one square foot except unless justified otherwise" [15)]. Apparently the total area of the dry well in the former sand bed is 701.5 square feet. Of this only 115.6 square feet would be accessible for UT measurements from the inside. However, the total surface area that was and will be inspected by UT is only 3.9 square feet [16)] or about 0.5% of the total area of interest. If it had been established that corrosion was spread uniformly through the sandbed area one could let the grid measurements stand as being representative. However, quite the contrary is the case. Corrosion based on UT measurements varies from bay to bay from almost nothing to 30% (on average) of wall thickness in the horizontal direction at the elevation of the grid measurements. More importantly, corrosion also varies over the approximately 3 foot height of the sandbed area in the vertical direction. This had been conclusively shown in my Memo of April 25, 2007 [17)]. ***The UT wall thickness measurements by means of and at the locations of the internal grids therefore cannot be considered representative of what may be going on in the lower parts of the sand bed region.***

A large number of UT measurements were performed in the sandbed areas after removal of the sand. It has been said that these measurements were conservative

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[15)] NRC Notice 71 FR 67923, Nov. 24, 2006

[16)] e-mail from P. Tamburro to A. Ouaou, Surface area of the Drywell in the sandbed, 4/3/06

[17)] R.H. Hausler Memorandum to Richard Webster, Esq., April 25, 2007 because they had been accomplished in areas, which were, by visual examination and micrometer measurements, identified as the thinnest areas. It should be obvious to all skilled in the art that neither visual examination of nor micrometer measurements on a corroded surface can identify or even estimate the thinnest remaining wall thickness. Visual examination will identify the corroded areas but the degree of wall thinning cannot be determined because of the absence of a reference point, i.e. the original surface was corroded away and one does not know a priori by how much. Indeed, the inspector who did the assessment of the extent of corrosion in the sandbed area stated that: *"I could not visually determine which of the thin spots are the thinnest"* [18]. Furthermore, what this inspector (not a corrosion engineer) interpreted as "thin spots" were really the corroded areas, because that was all he could see. He also stated that: *"the thin spots comprise about 20% of the total area of the corroded portion of the shell. They are spread throughout the bay, but are closer together (about 1 ft apart) in the vicinity of the vent pipe and further apart toward the frame"*. It is clear from the above that the visual inspection may have identified areas, which may have appeared more heavily corroded than others, however, the claim that these were the thinnest areas is untenable. **Moreover, the Whitmore document [(5)] makes it clear that the heavily corroded areas extended into the bays away from the vent pipes, areas, which were not examined by UT.** This was indeed suspected from the contour plots established from AmerGen's external UT measurements [19]. There is therefore great uncertainty with respect to the extent as well as the severity of corrosion in the sandbed area, and we contend that recent efforts at AmerGen to in essence downplay this state of affairs in their attempts to obtain yet another structural analysis is ill advised [20]. While previously the most corroded Bay, Bay 13, was said to have an average thickness of 0.8 +/- 0.04 (2s) inches and a margin of 0.064 inches was derived there from, this same bay is now said to have an average thickness of 0.907 inches.

[18] Memorandum from K. L. Whitmore to J. C. Flynn, January 28, 1993, re. Inspection of Drywell sandbed region and access holes.
[19] R. H. Hausler Memorandum to Richard Webster Esq., 7/18/07
[20] AmerGen Tech Eval. 330592-27-27, 4/20/07

## V. The Nature of the Corroded Surface

Much of the confusion as to which data set to use for comparison with the acceptance criteria stems from the manner in which the data have been acquired. The corroded metal surface in the sandbed region after removal of the sandbed is said to have the appearance of a "golf ball" in terms of a dimpled surface, except of course for the fact that the dimensions of the corrosion features are larger than the dimples on the surface of a golf ball. Since it was necessary to assess the remaining wall thickness in the external regions because there appeared to be corrosion more severe than reflected by the inside grid measurements, UT measurements were made only in those areas of the sand bed which were easily accessible.

It has been said time and again that these measurements were conservative and reflecting only the thinnest areas, which had been identified visually and by micrometer readings. Now, we submit that it is utterly impossible to assess the remaining wall thickness of a corroded area by looking at it or in fact by making micrometer measurements. The fundamental reason for this is a lack of knowledge regarding the extent of the total recess of the surface due to "general corrosion" rather than pitting. We have prepared a simple graph to illustrate the difficulty **(Figure 3)**. Clearly, even the highest dimple may not be at the height of the original surface. The micrometer only gives a measure of the pit depth relative to the remaining surrounding surface. Hence micrometer measurements cannot possibly reflect the remaining wall thickness at that location. As illustrated in Figure 3 the pit depth may be deceiving relative to the remaining wall thickness as a comparison between measurement 2 and measurement 3 indicates – clearly depending on the point of reference. It is of course even more difficult to identify the remaining wall thickness visually. In fact, reviewing the contour plots we have presented in Ref. 21 below [21)] one can see that a majority of the measurements had been made in areas of moderate or no corrosion.

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[21)] R. H. Hausler Memorandum to Richard Webster July 18, 2007

**We therefore submit that the statement that the areas of least remaining wall thickness were selected for external measurements and the results are therefore conservative is erroneous and misleading. The ramification of this conclusion affect the way data are treated down the line and finally the assessment or uncertainties of the remaining margins.**

Because of the rough external corroded surface it was recognized that UT measurements might be difficult. For this reason in some cases the areas around the deeper pits are said to have been ground flat to accommodate the UT probe. Does this mean that the resulting measurements are overly conservative or invalid? We think not. These measurements represent to the best of everybody's knowledge the true state of the remaining wall thickness, and the fact that maybe more metal had been ground away than corresponded to the pit depth was never demonstrated and is really irrelevant because the UT measurement of the remaining wall thickness is what it is.

However, not all areas chosen for external remaining wall thickness measurements were ground down. It was therefore felt that the roughness of the surface was falsifying the measurements and that a correction for the roughness was indicated. In order to achieve this, epoxy imprints were made of two one square foot areas in Bay 13. Twenty micrometer-readings were made on each of these imprints in order to characterize the roughness of the corroded area.

These roughness data were subsequently used to "*correct*" some UT measurements[22]. In order to better understand the procedure, we have prepared the following graphs:

- **Figure 4** shows a schematic of the epoxy imprint of the remaining corroded surface. On that epoxy surface replica 20 micrometer measurements of the "pit depth" were made in order to characterize the roughness of the surface.

[22] In fact we understand that only those measurements which indicated a remaining wall thickness of less than 0.736 inch were also assessed by micrometer and then subject to correction for roughness.

(Note that the replica was actually a negative of the surface. Therefore each depression on the replica related to a raised area on the surface. The twenty measurements were averaged and the standard deviation calculated. This was done for both replicas. It turns out that there is no statistical difference between the average micrometer readings from both replicas, hence a grand average and pooled variance could be calculated. The average "roughness" (dimple height) is 125 mils with a pooled standard deviation of 70 mils. This number reflects the average variation in height from valley to peak and in essence characterizes the roughness of the surface.

- It should be mentioned that that kind of roughness is also reflected in Fig. 2 of the April 25 Memorandum [(6)], derived from the UT grid measurement in the Trench of Bay 17.

- **Figure 5** shows how the average roughness correction is being used to correct the UT measurements. The UT measurements reflect the residual wall thickness (UT). Additionally micrometer measurements were made at each location where a UT measurement had been performed. Now the UT result and the micrometer result are added and the average roughness is subtracted from the sum in order to obtain the so called "*evaluation thickness*". It is observed that with this correction every UT measurement, except for one, which had been below 736 mil is moved to above 736 mils and therefore into the acceptable range.

- In discussing this procedure one has to remember that the correction was made because the UT measurement was said to be inaccurate because of the air gap between the probe and the metal surface caused by the inherent roughness. Now it was never established to what extent the accuracy of the UT measurement suffered because of this air gap. Did it over- or underestimate the remaining wall thickness? Similarly, the micrometer measurement is affected by the roughness of the remaining surface as well.

There is no guarantee, nor was this discussed at all, that the reference point for the UT measurement and the micrometer measurement are the same. As Figure 3 suggest, the reference can be high or low. Finally, adding the micrometer measurement to the UT measurement might have made some sense if the sum were to reflect the original wall thickness where upon the roughness could have been subtracted to indicate a possible correction. This was however not the case since in addition to pitting there was general reduction of wall thickness. (This is supported by the description of the "bathtub ring".

- This entire procedure is extremely fraught with uncertainties. There is the perceived uncertainty of the UT measurement, never established but postulated. There is the uncertainty of the micrometer measurements, and then there is the correction for which there does not seem to be a justification.

- That there really was no justification for this type of manipulation of the UT data became clear in 2006. Now the surface was coated and flat to accommodate the UT probe. The UT probe compensated for the thickness of the coating. Hence the UT measurements in 2006 should indeed reflect the true remaining wall thickness at the point of measurement. Comparing the uncorrected 1992 with the 2006 means for all measurements (200 d.f.) one finds an average small bias of 20 mils which, however, statistically is non significant ($s_{mean}$ = 11 mils). Therefore it is highly unlikely that the surface roughness had any effect in biasing the UT measurements prior to coating the surface. There was therefore no need to calculate the so-called *evaluation thickness*. Furthermore, the evaluation thickness was also calculated for other bays which were less corroded and for which the surface roughness had not been determined (i.e. using the value obtained from the Bay 13 epoxy replicas).
- It was never made clear why in the calculation of the "*evaluation thickness*" the mean micrometer depths plus 1 standard deviation was used. In fact Mr.

Tamburro realized the arbitrariness of the algorithm when he indicated a lack of established procedure [23], and the absence of a justification of why it should be justified to compare the evaluation thickness to the design basis required minimum wall thickness of 0.736 inches. Yet, even though AmerGen was aware of the lack of clarity and justification, it continued the practice in Rev. 2 [24]

- Therefore, the evaluation thickness should be disregarded (as has been done at times) in favor of the actual measurements.

## VI. Establishing the Available Margins

If for any reason corrosion in the sandbed area should continue, the question remains as to how much margin there is still available. The acceptance criteria, both for general wall thinning as well as localized corrosion have been discussed before, and their inconsistent and arbitrary application highlighted. AmerGen and NRC nonetheless have consistently maintained that there is sufficient margin remaining such that even under the worst possible circumstances a 4-year inspection cycle can assure the continued integrity of the drywell.

We shall in the following take a look at the data on the basis of which such decisions were made. We are readily prepared to stipulate that the grid UT measurements "on average" returned residual wall thickness values above 800 mils, and if representative would therefore reflect a remaining margin for general corrosion of 64 mils above the average thickness criterion (It should be noted that 800 mils is an average and no confidence limits have been reported for this number. Therefore, this could only be the margin at 50% confidence, even if the grids were representative). But we also know:

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[23] AR Report 00461639, P. Tamburro to H. Ray, Calc C-1302-187-5320-024 is not clearly documented. 3/3/2006

[24] Calc. C-1302-187-5320-024-Rev.2, 3/21/07, P. Tamburro reviewed by J. Abramovici

- That because of the location of the internal grid measurements they are not representative of the overall corrosion damage (as discussed above). This is demonstrated by way of an example in Figures 1 and 2 for Bay 13.
- That for Bay 1, where only a strip grid was used for internal UT measurements (1 inch by 7 inch for only 7 UT locations), the results returned by the internal measurements in no way reflect the overall corrosion in that Bay [25)]
- That therefore the external UT measurements have to be used for the assessment of the severity of corrosion and the residual margins.

Calc. 24 [26)] is the first manifestation of how the external UT data were to be dealt with. Here Table 1 lists all the measurements that were below 736 mils and shows that when the "evaluation thickness" was computed, as shown above, all but two of these data points were above 736 mils, but all were judged "acceptable". It is interesting to note that all points with residual wall thickness less than 736 mils were found in an area dubbed the bathtub ring. This area was said to be 18 inches wide and 30 long for a total surface area of 3.5 square feet [24)]. Without the correction, i.e. without calculating the "evaluation thickness" this area would have been out of compliance [27)]. But the evaluation thickness did not make any sense, and in 2006 it was shown that the UT measurements across the epoxy coating were essentially the same as those made before the coating had been applied. This presented a serious problem, because it essentially obviated the correction, which led to the "evaluation thickness".

A number of different approaches were taken to in effect rescue the drywell from being condemned. NRC commissioned a new buckling analysis *using advanced techniques for modeling and analyzing the complex shell structure to determine the*

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[25)] see Figure 3 R. H. Hausler Memorandum to R. Webster, Esq., July 18, 2007
[26)] Calc. No. C-1302-187-5320-024, Rev. 0 4/16/93
[27)] The GE compliance criterion stipulated that if an area was thinner than 736 mils it had to thicker than 536 mils and no larger than 1 square foot. (This formulation of the criterion for localized corrosion was subsequently modified several times in various ways).

*controlling loads* [28]. It turns out that the input data for this study were the degradation data contained in Cal. 24, Rev 0 (see 24). Sandia found a safety factor against buckling of 2.15 for the degraded shell, based on the Calc. 24 data. As discussed in my companion Memorandum on statistical procedures, the standard deviation of the UT measurements was of the order of 0.03 inch or 95% confidence limits of 0.06 inches, which corresponds to about 7.5% of residual wall thickness. This at least puts the remaining margin corresponding to 7.5 % of the safety factor in question. This, coupled with other deficiencies that I have discussed elsewhere, may well mean that there is no remaining margin left. In addition, there are equally alarming concerns, such as the fact that there may be areas, which have not been cleaned or in fact coated because of their inaccessibility.

**VII. Discussion of Future Uncertainties**

Future degradation of the drywell may occur because of a number of factors. These will be discussed below. In all of this it must be remembered that because something has not happened in the past does not mean it cannot happen in the future. And because something that happened in the past and was presumably corrected does not mean the correction will hold in the future. However, more seriously are those things, which could have (or should have) been anticipated but were not.

- Pinholes in the Coating: When the coating was qualified in extensive model tests and model applications, constant attention paid to the inclusion of dust and residual pinholes in the coating [29]. Test coatings prepared on a life-size Bay mock-up were routinely tested for dust inclusions and pinholes. Such were indeed detected on the test panels prepared in a clean environment. It is therefore all the more surprising that no such tests were ever done after the coatings had been applied to the steel surfaces of the drywell in the sandbed areas.

[28] NRC Staff initial statement of position on the drywell contention, July 20, 2007 page 15

[29] MPR Associates, Inc.: *Results of Painting Process Qualification Tests for Drywell Exterior In the Sandbed area at Oyster Creek,* 11/9/92, GPU Nuclear Document 133825.

Admittedly pinholes are rare where two coats of paint (epoxy coating) have been applied, however, tests with the wet sponge techniques as described earlier and as standardized by NACE are quite simple to carry out and it is unclear why these tests were not done.

- The Nature of Epoxy Coatings and the Question of Aging: Epoxy coatings are the reaction product of two ingredients: a) the epoxide itself, which is a phenol derivative containing two ethylene oxide groupings and b) a di-functional amine compound generally designated as the curing agent. When the two ingredients react with each other, the viscosity of the mixture increases until eventually a hard substrate is obtained. Once the coating (or cast) has hardened is it commonly assumed that the reactions have terminated. In fact, unreacted functionalities keep reacting for a long time, even when the product has become solid. Granted these solid state reactions are excruciatingly slow, but the contribute to the product's becoming brittle with time, contracting and cracking. These processes are slow and the results can be spontaneous. Visual inspection cannot discern internal stresses. Residual stresses, however, can lead to spontaneous cracking, particularly under conditions of constant vibration and fatigue and elevated temperature. Hence we think that the assurances, brought forth by Mr. John Cavallo[30], that the coating will last the life of the plant (even including the expanded operation of the plant), are overly optimistic. In view of the fact that failures of the coating can occur spontaneously and that the resulting corrosion could be as rapid as it was in the presence of the sand, we cannot rely on a coating inspection program that only reviews the coating once every four years.

- Some Properties of Epoxy Coatings: All coatings (organic substrates) exhibit a certain permeability to uncharged molecules. Oil field experience, for instance has shown that epoxy coatings are subject to spontaneous de-lamination as a consequence of abrupt pressure drops. The phenomenon

[30] Affidavit John Cavallo, at 22: 3/26/2007

clearly demonstrates that $CO_2$ for instance, but other gases as well ($CH_4$) can defuse through the coating. More detailed investigation have shown that both water and $H_2S$ can diffuse as well. Granted, these diffusion rates are slow, in fact approximately 3 orders of magnitude slower than diffusion of these same species in water. However, the slow diffusion of water and oxygen through the coating can cause formation of a thin oxide layer on the surface of the metal, which destroys the coating's adherence properties. Combined with the residual stresses in the coating de-lamination will cause cracking and of course will then provide access to water and the atmosphere. These processes are slow and will be accelerated by elevated temperature. None of this is predictable, however, one knows that it has happened, and therefore can infer that it could happen again. For these reasons we think the coating could fail in between the four year inspection cycles.

- Comments regarding Visual Observations: Essentially all epoxy coatings contain a filler. It has been said repeatedly that the coating used at Oyster Creek in the sandbed area is whiteish-grey indicating that the filler may be an oxide like possibly titanium oxide (this had never been specified). The filler functions as an agent to make the coating less brittle with aging, but it also opens up pathways for the diffusion of uncharged particles. Visual observation cannot detect what may go on underneath the coating until the coating fails. Similarly, corrosion at pinholes can proceed slowly until the pressure caused by the corrosion products leads to cracking of the coating. John Cavallo is wrong when he posits that the corrosion product occupies from 7 to 10 times the volume of iron from which it originates [30)]. A quick search in the Handbook of Chemistry and Physics teaches that iron has a density of 7.9 gm/cc (depending on the specific alloy) while iron oxide (Hematite) has a density of 5.24, and the hydrated iron oxide (rust) has a density of about 3.6. The iron oxide, which can form underneath the coatings, will therefore cause stresses, which will eventually lead to cracking. Similarly, corrosion occurring due to diffusion of water and oxygen through possible pinholes will eventually lead to cracking and blistering. While the results of these processes can be seen by visual inspection the onset cannot. Once blistering has occurred it may be too late because the margins here are, at best, tiny.

- Water, Origin and Frequency: There is universal agreement that without water no corrosion damage will occur. However, water has in the past leaked into the sandbed area, and even after the sand had been removed, water leakage was observed at times. The sandbed floors are supposed to be shaped such that water accumulations are not supposed to occur. Even if water should reach the sandbed area it is supposed to drain away, however, the drains were observed to be plugged. Finally, it is being said that even if water should for some reason accumulate in the sanded area it would evaporate quickly without being able to do a lot of harm. Specifically, Mr. Barry Gordon [31)] tries to convince us that water accumulations in the space of the former sandbed would evaporate quickly. In order to support the argument Mr. Gordon uses an engineering equation applicable to the evaporation of water from a pond or pools, in which wind velocity controls the evaporation rate. The former sandbed area, however, is a totally stagnant space where water might evaporate until the atmosphere above it is saturated with water vapor. Hence the equation used by Mr. Gordon describes a steady state, while the rate of evaporation in the confined space of the sandbed area would have to be described by a transient equation.

Where does the water come from? There clearly are many possibilities all of which point to some sort of a leak. Leaks are not predictable (otherwise they would be prevented). When possible they are repaired in the hopes that they would not occur again. However, it is impossible to rule out further leakage. The situation, however, is reminiscent of earlier incidences. "The core samples validated the UT measurements and confirmed that the corrosion of the exterior of the drywell was due to the presence of oxygenated wet sand

[31)] Barry Gordon Affidavit 3/26/2007

and exacerbated by the presence of chloride and sulfate in the sandbed region [32]. The origin of the chloride and sulfate was to our knowledge never firmly established, but was attributed to impurities dissolved into the water along the leakage path.

- Summary: Clearly a number of factors must come together in order for continued damage to occur in the former sandbed area on the exterior or the interior. The most important one is the presence of aerated aggressive water. In addition, on the exterior, the coating has to have failed in some manner at the location where water is present. And finally the corrosion has to occur at a location where the drywell has already been damaged. It has already been shown that only a very small fraction of the entire sandbed area has been surveyed with respect to corrosion damage. There is no guarantee that other areas have not experienced similar or worse corrosion damage. It has also been argued that at this advanced stage in the aging process of the coating, failure is to be expected. And finally, the presence of stagnant water cannot be ruled out. Therefore, if AmerGen can establish that it has some margin, I believe it prudent to use UT techniques to monitor the thickness of the drywell frequently. At this time, because AmerGen has not shown that there is any margin, I am unable to set forth an exact frequency. The corrosion rate from the interior could be a multiple of 0.002 mils per year and the corrosion rate from the exterior could be as high as 0.039 inches per year. Thus, even if the mean margin were 0.064 inches as AmerGen has alleged, the proposed monitoring frequency of once every four years is insufficient.

[32] AmerGen Letter to NRC 12/3/2006, 92130-06-20426, Enclosure, page 12 of 74

**Figure 1**

Iso Wall Thickness Lines for the Internal UT Measurements
in Bay Location 13A

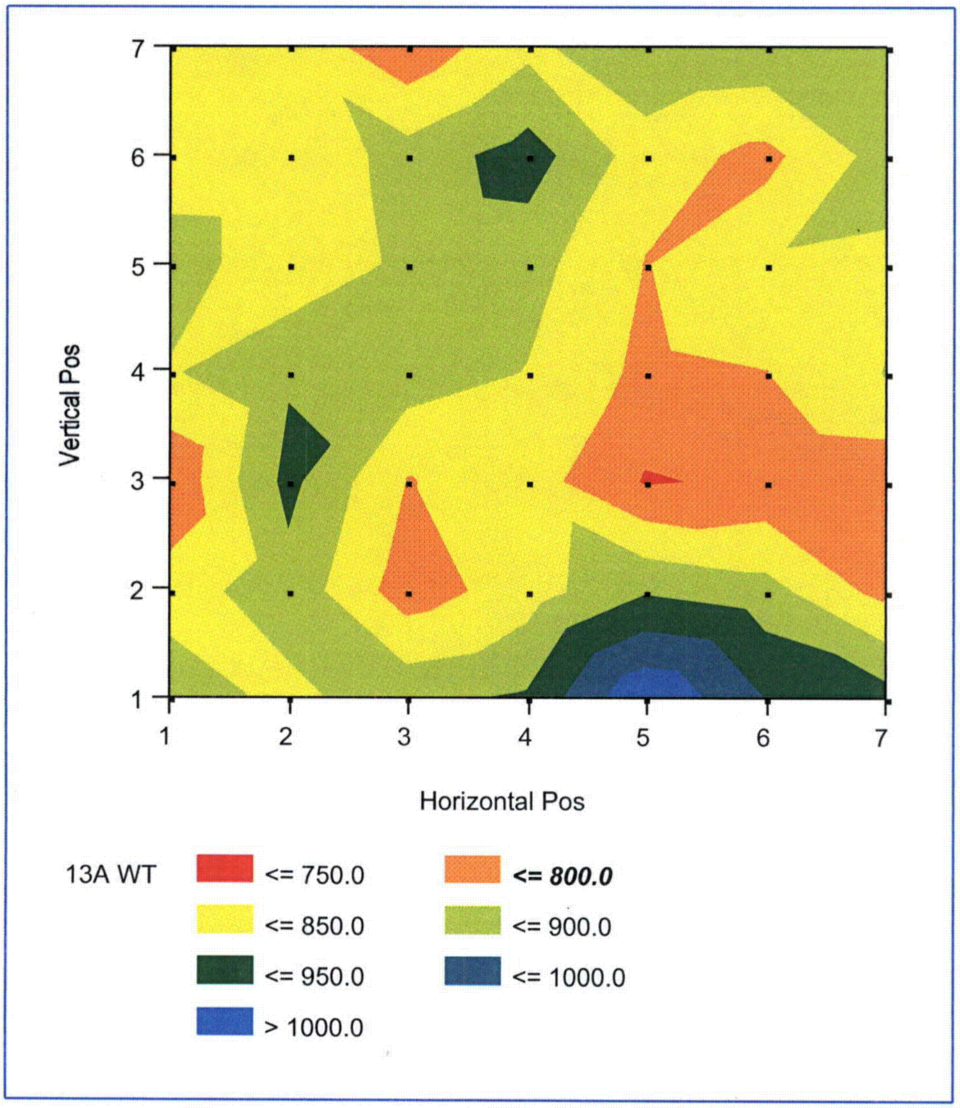
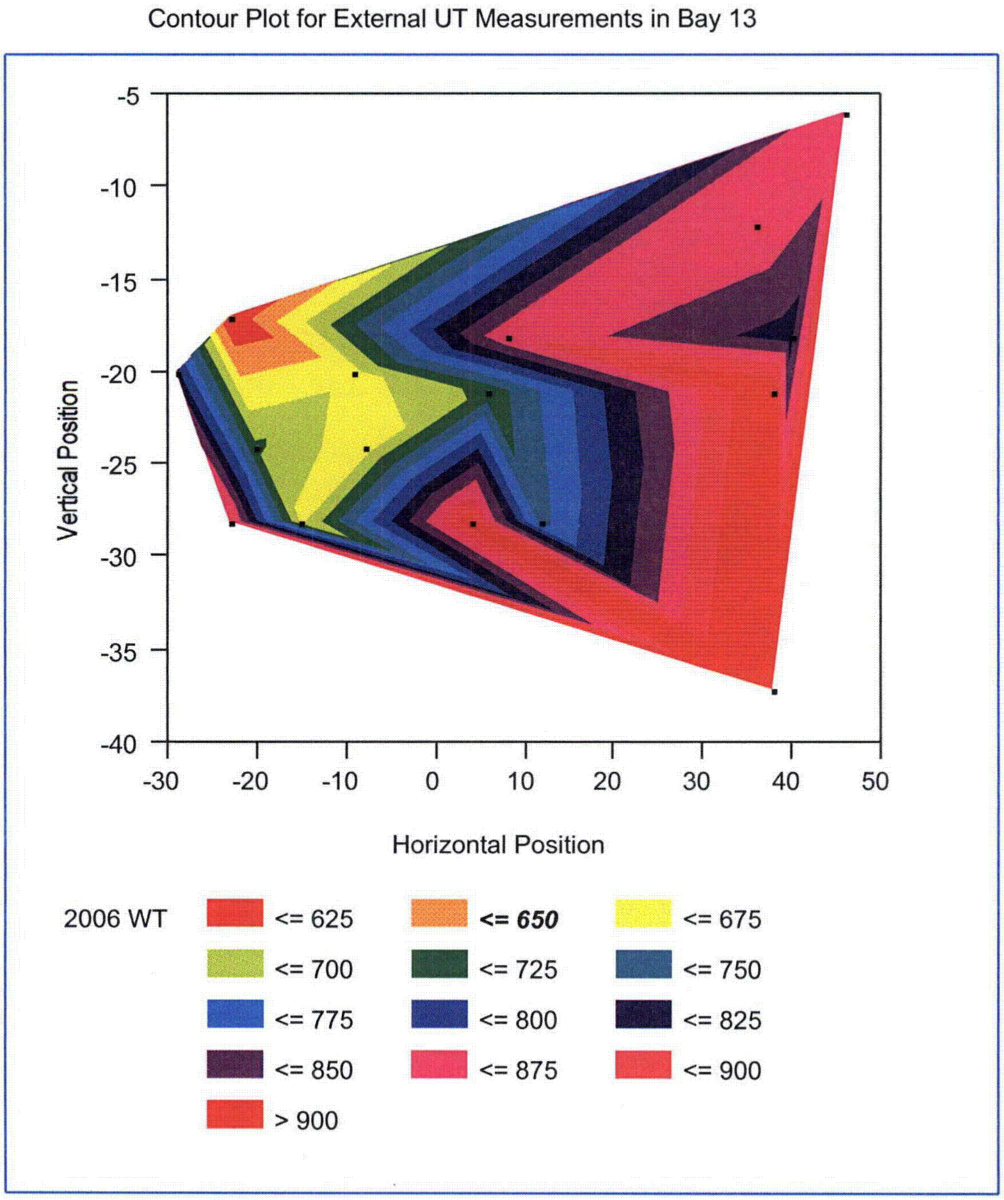
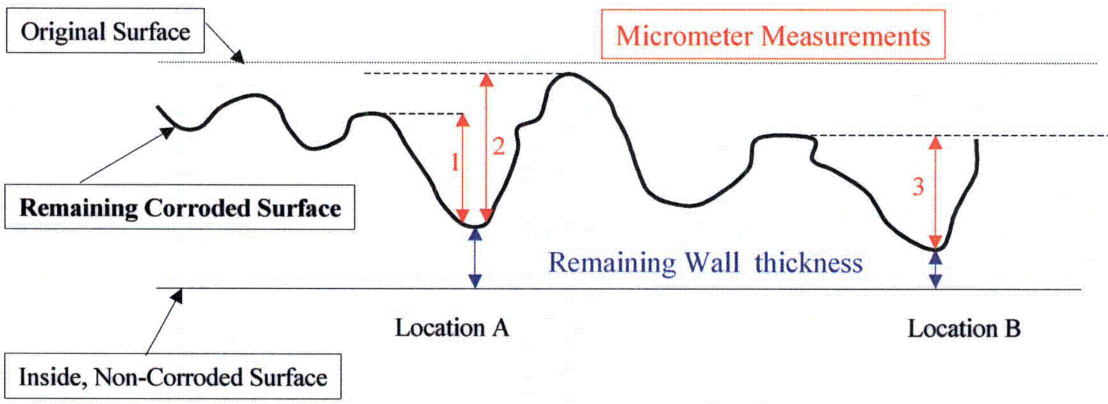


**Figure 2**


Contour Plot for External UT Measurements in Bay 13
-5
-10
-15
-20
-25
-30
-35
-40
-30
-20
-10
0
10
20
30
40
50
Vertical Position
Horizontal Position
2006 WT
<= 625
<= 650
<= 675
<= 700
<= 725
<= 750
<= 775
<= 800
<= 825
<= 850
<= 875
<= 900
> 900

## Figure 3

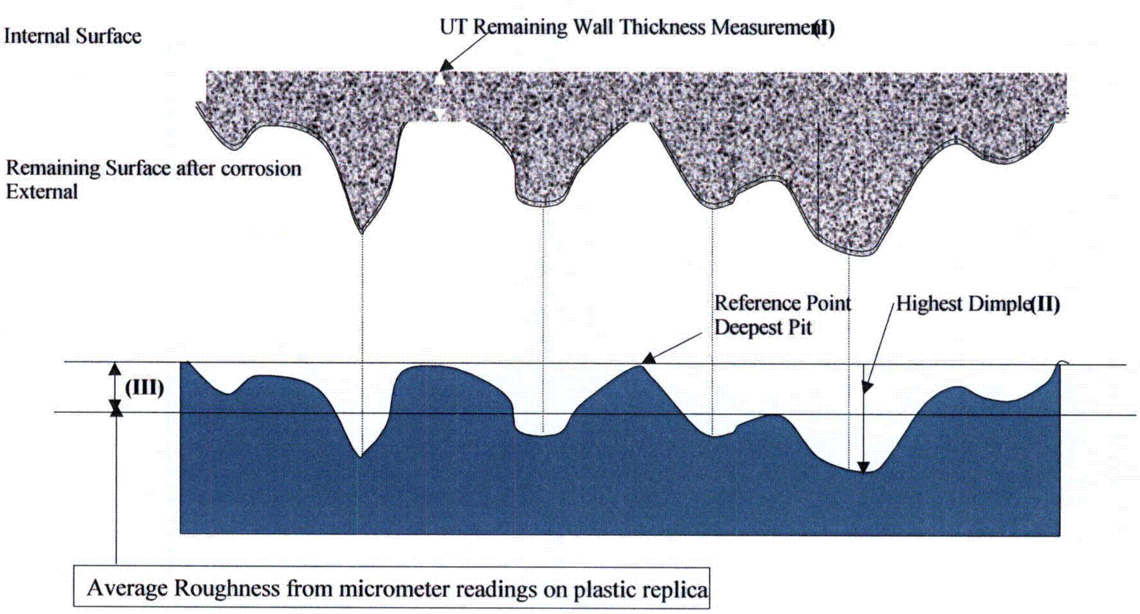
The Problem of Identifying the Thinnest Remaining Wall Thickness by ***Visual Observation*** or by ***Micrometer Measurements***.




**Location A:** Since the remaining, corroded surface is "dimpled", the *Micrometer Measurement* clearly depends on the point of reference. However, the point of reference is not, cannot be, the ***Original Surface,*** hence the *Micrometer Measurement* is in no relationship to the remaining wall thickness.

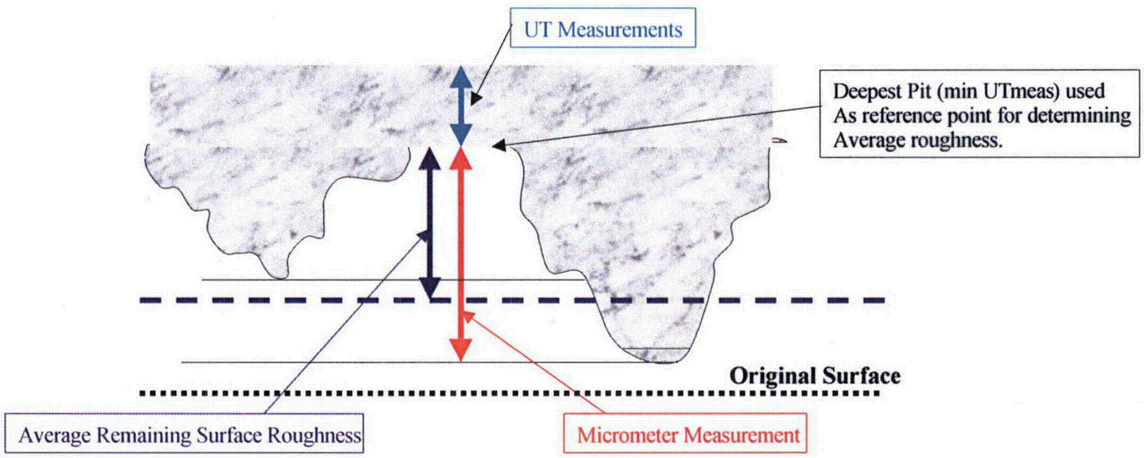
**Location B:** Here the "Pit Depth" obtained by micrometer measurement (3) is smaller than (2) in location A but the remaining wall thickness here is the least. Visual observation would identify Location B as less corroded because visually one has no reference point, in particular, one cannot refer back to the original surface area.

## Figure 4



# Figure 5

**Schematic Presentation of Drywell External Surface – State of Corrosion**




**Evaluation Thickness = UT Measurement + Micrometer Measurement – Average Surface Roughness**