UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

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

PRE-FILED DIRECT TESTIMONY OF DR. RUDOLF H. HAUSLER

Richard Webster
Rutgers Environmental Law Clinic
123 Washington Street
Newark, NJ 07102-3094
Counsel for Citizens

July 20, 2007

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 (License Renewal for the Oyster Creek Nuclear Generating Station)	Docket No. 50-0219-LR

AFFIDAVIT OF DR. RUDOLF H. HAUSLER
REGARDING HIS PREFILED 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.

Rudolf H. Hausler

Dr. Rudolf H. Hausler

Sworn to me this 19th day of July, 2007

Notary Public

LORRAINE A SHELTON
Notary Public, State of Texas
My Commission Expires
May 20, 2009

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

INITIAL PREFILED WRITTEN TESTIMONY OF
DR. RUDOLF H. HAUSLER
REGARDING
CITIZENS' DRYWELL CONTENTION

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

Q1. Please state your name and address.

A1. My name is Dr. Rudolf H. Hausler and my business address is 8081 Diane Drive, Kaufman, Texas, 75142.

Q2. What is your educational and professional background?

A2. I have received the following degrees at the Swiss Federal Institute of Technology in Zurich, Switzerland: BS and MS in Chemical Process Technology and Ph.D. in Chemical Engineering. I am an expert in corrosion prevention, chemical inhibition, material selection, failure analysis, and trouble shooting. My resume is attached to this testimony as Attachment 1.

During a professional career spanning over more than 25 years, I have:

- Consulted for various organizations worldwide regarding nuclear safety, including the safety of spent fuel storage casks.
- Consulted for major oil companies and engineering companies throughout the world on selection, testing, and application of oil field chemicals, with a primary focus on corrosion inhibitors
- Developed corrosion testing facilities to meet industry-specific needs for Mobil Oil and developed custom corrosion inhibitors for Petrolite Corporation.

Q3. Can you cite specific examples of recognition by the scientific community?

A3. I received the 2003 Fellow Award, as well as the 1990 Technical Achievement Award, from the National Association of Corrosion Engineers (NACE). I am a NACE-certified Corrosion Specialist. I currently hold 17 patents, have published 58 papers, and have given more than 100 technical presentations about a variety of topics, including corrosion management, over the course of my career. I am a registered Professional Corrosion Engineer with the California Board of Professional Engineers and Land Surveyors.

Q4. Please discuss your experience as it relates to corrosion prevention.

A4. In the past 11 years as an independent corrosion consultant, I have advised several major oil companies worldwide, as well as various small US producers, on the testing of oil field chemicals, primarily corrosion inhibitors. In particular, while consulting for Teikoku Oil, Japan's National Oil Company, I advised the company on a range of corrosion subjects such as drill string corrosion, amine unit corrosion of 304 stainless steel, and the chemical prevention of corrosion of 13%-Cr in sweet production. Prior to becoming an independent consultant, I developed a $1.5M custom continuous flow-through corrosion test facility for Mobil Oil to meet industry-specific requirements. While employed at Petrolite Corp., I directed and conducted the development of novel corrosion inhibitors for extreme operating conditions. In addition, I developed the only qualified corrosion inhibitor for nuclear steam generator cleaning. The results were published in the EPRI publication, NP-2020 in June 1983. I have several years of hands-on experience with the failure analysis of coated tubulars (production tubing, pipelines), the development of unique corrosion models, and with statistical methodologies, such as Extreme Value Statistics.

Q5. What are your qualifications in the area of statistics

A5. While working in Chicago I was given the opportunity to study Statistical Design and Evaluation of Experiments under Steward Hunter and Norman Draper. I subsequently developed a 40 hour in-house course in statistics for the scientists at UOP and coached them in the use of the methodologies. At Petrolite I used Compositional Statistics to optimize complex mixtures with a minimum of tests. While at Mobil Oil Company in Dallas we always used the SAS software, specifically JMP (JUMP).

Q6. What materials have you reviewed in preparation for your testimony?

A6. 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 references is provided in Attachment 2 to this testimony.

Q7. Have you reviewed all of the documents listed in Attachment 2?

A7. Yes, I have used the documents in Attachment 2 to inform me of relevant facts and derive my conclusions.

Q8. What is your understanding of the issues presented by this proceeding?

A8. This proceeding is about the extent to which structural integrity of the steel containment system, called the drywell shell, at Oyster Creek Nuclear Generating Station has been and will be affected by corrosion. There is no doubt that the shell is severely corroded in an area called the sandbed region, an area toward the bottom of the spherical part of the shell where sand was present until around 1992. The issues in dispute are whether we can be confident that the shell will meet safety requirements when any extended period of operation begins, and, if so, whether conducting ultrasonic (UT) measurements of the shell every four years is sufficient to maintain the required safety margins.

Q9. What are Attachments 3, 4 and 5 to this testimony?

A9. Attachment 3 is an edited version of a memorandum originally prepared for the purpose of opposing summary disposition giving my analysis of the situation as I understood it in April

2007. Among other things, it contains detailed analysis of the trench results and compares the data measured externally to the data measured internally. Upon the advice of Citizens attorney, the document has been excerpted to remove certain testimony that I understand is beyond the scope of the proceeding and other testimony that is now outdated. Attachment 4 is an update to Attachment 3 and provides further detailed analysis of the areas that are currently below 0.736 inches in thickness. Attachment 5 is an overview of the relevant facts on which I have worked with Citizens' attorney in an effort to produce a factual summary that follows the logic suggested by the Board.

Q10. To your knowledge, are Attachments 3, 4, and 5, coupled with this testimony, true and accurate statements of the issues most relevant to this proceeding?

A10. Yes, Attachments 3, 4 and 5 and this testimony provide, to the best of my knowledge, true and accurate statements of the facts and my conclusions regarding the issues most relevant to this proceeding. The facts include an in-depth analysis of the 2006 data, a review of the methods used to derive the margins and project corrosion into the future, a review of past exterior corrosion including rates and sources of water to the exterior of the drywell shell, and a review of interior corrosion.

Q11. What broad conclusions have you reached concerning the current state of the drywell shell?

A11. I believe that the thickness of the drywell is very likely insufficient to meet the acceptance criterion established by AmerGen concerning the extent of contiguous areas of severe corrosion. At minimum, there is less than 95% confidence that the drywell shell currently meets the area acceptance criteria and other acceptance criteria concerning the mean thickness and the thickness of small areas that are less than two inches in diameter that were established by AmerGen and accepted by NRC.

Q12. Is 95% confidence a reasonable degree of certainty to require?

A12. I believe 95% confidence is the minimum one should require when dealing with the structural integrity of a safety-related component like the primary containment system. To put it into context, 95% confidence means that we could be wrong approximately one in forty times (on the downside) about whether the drywell shell meets safety requirements. The 95% confidence limits correspond to a spread of two (2) sigma (standard deviation) from either side of the mean to embrace all data thought to belong to the same population. Uunder Jack Welsh's leadership, General Electric instituted operating initiative whereby all parts and products manufactured by GE or its suppliers had to be within 5 sigma of the specified mean. This guaranteed a failure rate of many orders of magnitude less than one in forty. Requiring AmerGen to show that the drywell meets safety requirements with 95% confidence also accords with established past practice, when 95% confidence intervals were calculated and projected forward to derive the required monitoring frequency.

Q13. How do you reach the conclusion that the drywell shell is probably insufficient to meet safety requirements?

A13. Significant areas that are thinner than 0.736 inches exist in Bays 1, 13, and 19 of the drywell shell. A computer based interpolation package has shown that these areas in Bays 1 and 13 are probably larger than 3 square feet and 5 square feet respectively. The acceptance criterion applied to such areas has varied from requiring them to be smaller than one square foot to allowing them to be as large as nine square feet. However, the acceptance criterion established after an AmerGen employee expressed concern about the earlier approach to acceptance was tightened and requires areas that are thinner than 0.736 inches to be less than one square foot in extent and thicker than 0.636 inches. Because there are at least two areas that are probably at least three to five times larger than allowed by this criterion, I believe the drywell shell is currently deficient.

Q14. If the acceptance criterion for the areas thinner than 0.736 inches allowed them to be as large as nine square feet, would you still believe the drywell shell was deficient?

A14. Yes, because AmerGen is required to show that it has 95% confidence that it is meeting the acceptance criteria. AmerGen's own assessment places an area thinner than 0.736 inches that is nine square feet in extent in Bay 1, without taking any account of uncertainty in the measurements. This area is not well defined and could easily be larger. Similarly, in Bay 13, the five square feet area thinner than 0.736 inches shown by the contouring program is arbitrarily cut off because there is a large area on the upper left of the Bay for which there are no measurements. This area could easily be larger than nine square feet, given the uncertainty attached to each point and the lack of measurements to bound the area. Even in Bay 19, I do not believe AmerGen can show that the area thinner than 0.736 inches in smaller than nine square feet with the required degree of certainty, because a line of points that measured thinner than 0.736 inches runs along the upper part of the Bay.

Q15. Are there other reasons to believe that AmerGen lacks 95% confidence that the drywell shell is currently meeting safety requirements?

A15. Yes, there are many reasons that contribute to this lack of confidence, including the following:

1. The lower 95% confidence limit of the mean of the corrected external measurements in Bay 15 is smaller than 0.736 inches, the acceptance criterion for mean thickness.
2. The lower 95% confidence limit of the mean of the measurements in zone 3 of Bay 1 is less than 0.49 inches, the acceptance criterion for areas less than 2 inches in diameter.
3. There is at least a one square foot area whose thickness is less than 0.636 inches at the lower 95% confidence limit. The appropriate version of the acceptance criterion for areas that are larger than 2 inches in diameter but less than one square foot requires such areas to be thicker than 0.636 inches on average.
4. AmerGen's own assessment shows that in the transitions between the thinnest areas and 0.736 inches, margins are as small as 0.01 inches on individual points. Because each point is uncertain to approximately plus or minus 0.09 inches, these areas could be considerably below even the latest less stringent version of the acceptance criteria at the lower 95% confidence limit.
5. The areas thinner than 0.736 inches in Bays 1 and 13 are grooves, not squares. It is unclear how to apply acceptance criteria that assume the corroded areas are squares to such grooves, which could have more effect on buckling capacity for the same area.

Q16. If AmerGen can establish margin at the required level of confidence, is the proposed UT monitoring regime adequate to maintain safety margins?

A16. No. AmerGen is proposing to monitor once every four years. The margin AmerGen has claimed to have is 0.064 inches, but this was based on the mean of 49 point grid of measurements, not on the lower 95% confidence limit of that mean. Using AmerGen's estimate of uncertainty of the mean, this margin would be 0.034 inches at the lower 95% confidence limit and allowing for a possible 0.01 inches of systematic error. Mr. Gordon, AmerGen's expert on corrosion issues, has assumed that the corrosion rate could be around 0.039 inches per year if the exterior coating failed and water entered the sandbed region. I see no reason to disagree with this assumption. In addition, corrosion from the interior could add 0.002 inches per year onto the corrosion rate. The industry standard is to measure at half the interval in which it is possible to have lost margin. Given a total corrosion rate of 0.041 inches per year, a margin of 0.034 inches could be lost in less than a year. Thus, the monitoring interval would have to be more than once every six months.

Q17. Why do you assume that water could be present in the exterior drywell?

A17. There are a number of potential sources of water that have been identified by the reactor operator, including the refueling cavity, the equipment pool, and condensation. In addition, AmerGen has not managed to devise a method to ensure that the refueling cavity will not leak in the future, nor has AmerGen been able to definitively trace the source of the water found most recently in the drains from the drywell. Thus, it appears likely that some water will be present on the surface of the drywell shell during refueling outages, and it is not possible to rule out the potential for water from other sources to enter during operation.

Q18. Would the proposed approach to water monitoring alert AmerGen to the presence of water in the exterior sandbed?

A18. Not necessarily. AmerGen is proposing to monitor for water in the sandbed pocket by looking at the sand bed drains. However, if, for example, small droplets of condensation formed on the shell, these would likely not cause observable flow into the sandbed drains. In addition, if the defects in the floor coating recur, water could run down into those defects, rather than running to the drains. Although the cause of the deterioration of the floor coating has not been identified, it is reasonable to expect that the deterioration will continue or get worse. Furthermore, in the past the drains have clogged and it is reasonable to assume that this situation could recur. All of these effects could lead to a failure to detect corrosive conditions in the exterior sandbed using the currently proposed method.

Q19. Could AmerGen realistically achieve a monitoring interval of six months?

A19. Shutting down the plant every six months to allow measurements to be taken in the sand bed region would be possible, but expensive. A possible alternative would be to adapt real-time corrosion monitoring technology to measure corrosion of the drywell in real time. While I do not know of any nuclear power plant where this has been done, I do know of other successful applications of real-time corrosion measurement. There appears to be no technical reason why it could not be done.

Q20. Is it important to use the external measurements as well as the interior grids to check the progress of the corrosion in the sandbed region?

A20. Yes. The external measurements provide information about corrosion occurring at the lower elevations of the sandbed region below the interior floor, which cannot be gathered from the inside except in the two least corroded Bays, where the trenches are present. In addition, the exterior measurements are the only measurements that allow us to estimate the areas that are corroded beyond acceptance thresholds.

Q21. Does the epoxy coating on the exterior of the drywell shell protect the shell from further exterior corrosion?

A21. No, it is not reasonable to assume that the coating will not fail during any period of extended operation. It is also not reasonable to assume that visual inspection could detect the early stages of coating failure. The lifetime of the coating has been estimated at anything from ten to twenty years. Its exact lifespan in this application is actually unknown. We do know that the epoxy coating placed upon the concrete floor of the sandbed region deteriorated quickly after it was installed in 1992 and was eventually repaired in the 2006 outage. In addition, it is likely that there were defects in the coating when it was applied, because no electrical testing of the applied coating was performed. Over time, any water in the sandbed can penetrate the coating through defects that were present at installation or develop over time. This water would then reach steel interface beneath the coating and cause further corrosion. It is important to remember that the corrosion rate (rate of deterioration) in pitting situations as well as on coated materials, increases exponentially with time. Hence, past performance is no indication of what may happen in the future.

Q22. Do you believe that AmerGen has established valid methods to analyze the current margins and project how they may change into the future?

A22. No. In the past AmerGen used a statistical method based on regression to find the current lower 95% confidence in the margin and project that limit into the future. After the sand was removed in 1992, AmerGen has not found any statistically significant slope and so has been unable to apply the regression method. Unfortunately, AmerGen's practice since then has been inconsistent. With regard to current margins, AmerGen has asserted that it is taking account of the variance of the data and in other cases AmerGen has asserted it is comparing the lower 95% confidence limit of the data to the acceptance criteria. Unfortunately, in practice AmerGen has failed to do this. With regard to future changes in margin, AmerGen has admitted that a high corrosion rate could be experienced if water was present in the exterior drywell and the coating failed, but has not taken this into account in its latest acceptance calculations. In addition, because the interior corrosion issue was only raised in December 2006, AmerGen has not established a method to take account of future corrosion from the inside of the drywell in the sandbed region.

Q23. How has AmerGen calculated the extent of areas that were corroded below the thickness thresholds set by the local area acceptance criteria?

A23. In the first version of the calculation C-1302-187-5320-024, AmerGen made some assessments of how big these areas were based on visual observations. Unfortunately, the second version of the same calculation took an inconsistent approach to estimating the extent of the severely corroded areas and assumed, contrary to the visual observation, that all the severely areas measured were less than 2" in diameter. Most recently, in the third version of calculation C-1302-187-5320-024, AmerGen has taken the approach of drawing squares by eye on plots of the external data points. As far as I can tell there is no established valid method for estimating the extent of the severely corroded areas. Indeed, I have been unable to devise a means of doing the required estimates with the required degree of confidence.

Q24. Do you have concerns with regard to the applying the local area acceptance criteria to the identified severely corroded areas?

A.24. Yes. The local area acceptance criteria were derived for square areas. The data show that the severely corroded areas in Bays 1 and 19 are more like long grooves, and the thinnest area is Bay 13 is an irregular shape. I believe that in late 2006 AmerGen correctly took a more conservative approach to the selection of the local area acceptance criteria and required local areas thinner than 0.636 inches on average to be less than one square foot in area. However, without explanation, it has subsequently taken a less conservative approach that I believe cannot be justified.

Q25. In summary, what do you currently believe the Board should do?

A25. 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 acceptance criteria at the start of any period of extended operation. Even if the Board decides that the relicensing can proceed, the monitoring interval for UT measurements should be less than every six months.

Q26. Have you now completed your initial testimony regarding the contention?

A26. Yes.

Attachment 1

Rudolf H. Hausler
8081 Diane Drive
Kaufman, TX 75142
Tel: 972 962 8287
Fax: 972 932 3947

SUMMARY

Over 30^+ years planned, conducted, and directed advanced chemical research focused on oil production and processing additives. Acquired expertise in corrosion prevention, chemical inhibition, and materials selection, failure analysis, trouble shooting and economic analysis. Proficient in German, French, and Italian.

EXPERIENCE:

1996 - Present **CORRO-CONSULTA** (Dallas TX, and Kaufman TX)

President private Consulting Company

Consulted with major Oil Companies on selection, testing and application of Oil Field Chemicals, primarily corrosion inhibitors.

- Worked on Global Sourcing Team for Mobil Oil Company (major fulltime 6^+ months study)
- Consulted for Mobil Oil Company on production chemical usage at Mobile Bay sour gas production field and prepared for changeover to alternate chemical supplier (two year project).
- Consulted for Arco Oil company
    - on sour production in Middle East
    - reviewed North Slope corrosion data (statistical evaluation)
- Consulted for Mobil Oil Company at major CO_2 flood in Oklahoma (extensive laboratory and field testing - two major publications)
- Consulted with Teikoku Oil Company (Japanese National Oil Company) on various subjects of
    - drill string corrosion
    - amine unit corrosion of 304 stainless steel
    - corrosion of 13%-Cr in sweet production and the chemical inhibition thereof
    - identifying qualified corrosion testing laboratories in the US and the world
    - application limits for 3% Cr-steels in oil and gas production
- Consulted for Exxon Mobil on new sourcing study for combined Mobile Bay operations. (Developed novel approach for bid procedure and evaluation of bids on purely technical basis. Developed long-range approach to streamlining operations with potentially large savings.)
- Consulting for Oxy Permian Ltd. on major gas gathering system (changing from dry gas gathering to wet gas gathering)
- Prepared several major publications (see list of publications)
- Major consulting contract for ExxonMobil in Indonesia
- Consulting with various smaller Producers in the US (incl. Anadarko Petroleum Corp and Swift Energy Company)

- Consulting with various engineering companies (e.g. Stress Engineering Services Inc.)
- Consultant on call for Blade Energy Partners
- Consulted with various organization concerned with nuclear safety, including the safety of spent fuel storage casks.

1991 - 1995 **MOBIL Oil Company** (Dallas Research Center), Dallas, Texas

Senior Engineering Advisor

Developed corrosion testing facilities for basic research and to meet specific oil field requirements.

- Planned and developed H_2S corrosion test facility
- Planned safety and wrote safety manual
- Developed unique continuous flow-through corrosion test facility ($$ 1.5MM)
- Developed test protocols and supervised operations of the FTTF
- Extensive consultation with Affiliates on problem solving and chemical usage
- Established supplier relationships and consulted with Affiliates on establishing Enhanced Supplier Relationships
- Developed theory and practice of novel approach to autoclave testing

1979 - 1991 **PETROLITE CORPORATION** St. Louis, Missouri

Research Associate 1986 - 1991

Directed and conducted the development of novel corrosion inhibitors for extreme operating conditions

- New corrosion inhibitor to combat erosion corrosion of carbon steel in gas condensate wells
- Extensive studies on CO_2 corrosion aimed at establishing predictive corrosion model
- Developed the only qualified corrosion inhibitor for nuclear steam generator cleaning (EPRI publication NP-3030 June 1983)

Special Assistant to Executive Vice President 1985 - 1987

Special Assignments focused at support of International Sales

- Extensive travel to secure major accounts in Europe, Russia and East Asia
- Monitored out-sourced R&D in Germany and England

Senior Research Scientist 1979 - 1985

- Developed novel chemical composition under contract with EPRI for corrosion inhibition of cleaning fluids used in nuclear steam generators and methodology of application (only effective formulation still used today)
- Developed unique corrosion model for CO_2 corrosion in oil and gas wells
- Conducted numerous detailed field studies to establish case histories of chemical performance and applications technology

1976 - 1979 **Gordon Lab, Inc.,** Great Bend, Kansas

Technical Director

Responsible for all technical issues involving formulation, application and sales of sucker well production chemicals (corrosion, emulsion, scale, bacteria)

- Conducted failure analysis for customers and developed pertinent reports
- Supervised service laboratory
- Established technical training of sales and support personnel
- Developed technical sales literature and company brochure

1963 - 1976 **UOP (a division of SIGNAL COMPANIES)** Des Plaines, Illinois

Research Associate	1972 - 1976
Associate Research Coordinator	1967 - 1972
Research Chemist	1963 - 1967

To conduct research in electrochemistry, analytical methods development, heat exchanger fouling processes and refinery process additives

- Developed novel organic electrochemical synthesis procedure
- Developed unique (patented) test apparatus for measuring anti-foulant activity
- Introduced statistical design and evaluation of experiments to R&D department and Developed 20 hr course on statistics.
- Developed full 3 credit hour corrosion course to be taught at IIT and DeSoto Chemical Company

EDUCATION

- Ph.D. Chemical Engineering; Swiss Federal Institute of Technology, Zurich Switzerland
- BS, MS Chemical Process Technology, same as above

PROFESSIONAL ASSOCIATION

- American Chemical Society
- The Electrochemical Society
- Society of Petroleum Engineers
- NACE International (Corrosion Engineers)
- American Society fro Metals (ASM)

- Active in NACE on local, regional and national level

RECOGNITION
- NACE Technical Achievement Award (1990)
- NACE Fellow Award 2003

ACHIEVEMENTS
- 17 patents, 58 publications and more than 100 technical presentations
- Registered Professional Engineer (Corrosion Branch, California)
- NACE certified Corrosion Specialist

Attachment 2

ATTACHMENT 2 – LIST OF MOST RELEVANT DOCUMENTS REVIEWED

No.	Document Identification	Other Reference
1	GPU Nuclear, Drywell Steel Shell Plate Thickness Reduction (July 21, 1995).	Citizen's Exhibit NC 8
2	Partial Cross Section of Drywell and Torus.	Citizen's Exhibit NC 10
3	Memorandum from Peter Tamburro on the Unclear Documentation of Calculation C-1302-187-5320-024 (AR 00461639 Report) (Mar. 30, 2006).	Exhibit ANC 8
4	Exelon Nuclear, Calculation C-1302-187-5320-024 Revision 1: O.C. Drywell Ext. UT Evaluation in Sandbed (Jan. 12, 1993).	AmerGen's Exhibit 3
5	Exelon Nuclear, Calculation C-1302-187-E310-041 Revision 0: Statistical Analysis of Drywell Vessel Sandbed Thickness Data 1992, 1994, 1996, and 2006 (Dec. 12, 2006).	Exhibit SJA 1
6	Affidavit of Peter Tamburro, Mar. 26, 2007.	
7	AmerGen, NRC Information Request: Audit Question Numbers AMP-141, 210, 356 (Apr. 5, 2006).	Citizen's Exhibit NC 1
8	AmerGen, Passport 00546049 07 (AR A2152754 E09): Water Found in Drywell Trench 5 - UT Data Evaluation (Nov. 7, 2006).	Exhibit SJA 2
9	Structural Integrity Associates, Inc., Statistical Analysis of Oyster Creek Drywell Thickness Data (Jan. 4, 2007).	AmerGen's Exhibit 4

10	AmerGen, NRC Information Request: Audit Question Numbers AMP-357, 356, 210 (Jan. 24, 2006 and Feb. 16, 2006).	Citizen's Exhibit NC 2
11	Email from Peter Tamburro to Ahmed Ouaou (June 6, 2006, 14:03 EST).	OCLR00013624-13625
12	Memorandum from Dr. Rudolph Hausler, Apr. 25, 2007 (Redacted).	
13	Memorandum from Dr. Rudolph Hausler, July 19, 2007.	
14	AmerGen, Reference Material to the ACRS: Photograph of the Sand Bed Region (1992).	Exhibit SJA 3
15	Transcript of Nuclear Regulatory Commission Proceedings, Advisory Committee on Reactor Safeguards Subcommittee on Plant License Renewal Oyster Creek Generating Station (Jan. 18, 2007).	ML070240433
16	Transcript of Nuclear Regulatory Commission Proceedings, Advisory Committee on Reactor Safeguards Meeting of Plant License Renewal Subcommittee (Oct. 3, 2006).	
17	Email from Steven Hutchins to John Hufnagel Jr., with Drywell White Papers attachment (Sept. 18, 2006, 16:51 EST).	OCLR00013714 - 13734
18	Affidavit of Jon R. Cavallo, Mar. 26, 2007.	
19	AmerGen, Action Request: Determine the Proper Sealant for Drywell Sandbed Floor Voids (Oct. 23, 2006).	Exhibit ANC 5
20	Letter from Richard J. Conte, Chief Engineering Branch 1, Nuclear Regulatory Commission, to Richard Webster, Esq., Rutgers Environmental Law Clinic (Nov. 9, 2006).	Exhibit ANC 6

21	Letter from J.C. Devine, Jr., Vice President of Technical Functions, GPU Nuclear, to the Nuclear Regulatory Commission (Dec. 5, 1990) (Attachment 3; GPUN Detailed Summary Addressing Water Intrusion and Leakage Effects Related to the Oyster Creek Drywell).	OCLR00029270-29283
22	GPU Nuclear, Clearing of the Oyster Creek Drywell Sand Bed Drains (Feb. 15, 1989).	OCLR00028912-28918
23	AmerGen, Disclosed Document Relating to Drywell Leakage.	OCLR00013354
24	Transcript of Nuclear Regulatory Commission Proceedings, Advisory Committee on Reactor Safeguards 539th Meeting (Feb. 1, 2007)	
25	Letter from the Nuclear Regulatory Commission to C. Crane (Jan. 17, 2007)	ML070170396
26	Email from Steven Dunsmuir, FIN/Operations RO, Exelon Corp., to Howie Ray, et al. (Oct. 22, 2006, 04:52 EST).	OCLR00014454-14455
27	Email from Tom Quintenz to Kevin Muggleston, et al. (Feb. 1, 2006, 17:02 EST).	OCLR00013629
28	GPU Nuclear, Evaluation of February 1990 Drywell UT Examination Data (Mar. 8, 1990).	Citizen's Exhibit NC 9
29	Affidavit of Gordon, Mar. 26, 2007.	
30	Letter from Jill Lipoti, Director Division of Environmental Safety and Health, New Jersey Dept. of Environmental Protection, to Dr. Pao-Tsin Kuo, Director Division of License Renewal, U.S. Nuclear Regulatory Commission (Apr. 26, 2007).	

31	AmerGen, Calculation Sheet C-1302-187-5300-01	
32	GPU Nuclear, Calculation Sheet C-1302-187-5320-024 Revision 0: Oyster Creek Drywell Exterior Evaluation in Sandbed (1993).	Citizen's Exhibit NC 3
33	Exelon Nuclear, Calculation C-1302-187-5320-024 Revision 2: O.C. Drywell Ext. UT Evaluation in Sandbed (Mar. 18, 2007).	
34	ACRS Information Packet (Dec. 2006).	Exhibit ANC 2
35	Letter from AmerGen to the NRC (2103-06-20426) (Dec. 3, 2006)	Exhibit ANC 1
36	Email from Caroline Schlaseman, MPR Associates, Inc., to Howie Ray (Nov. 2, 2006, 12:09 EST).	OCLR00015433-15434

Attachment 3

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MEMORANDUM – REDACTED VERSION – JULY 19, 2007

To: Richard Webster, ESQ
Rutgers Environmental Law Clinic
123 Washington Street
Newark, NJ, 07102

April 25, 2007

From: Rudolf H. Hausler

Subject: **Update of Current Knowledge Regarding the State of Integrity of OCNGS Drywell Liner and Comments Pertaining to Aging Management Thereof**

Summary

- The proposed aging management plan for the Oyster Creek Drywell Liner, as proposed by AmerGen, is being discussed. It is shown that the UT monitoring locations (6 by 6 inch grids inside the drywell) as defined in 1989 are not representative of the corrosion, which had occurred in the sandbed region.
- Furthermore, since the outside of the drywell in the sandbed region had been coated in 1992, corrosion in the upper regions of the sandbed (i.e. where monitoring is being proposed) has become less relevant because water accumulations (the primary causes for corrosion) will now more likely occur towards the bottom of the former sandbed region.
- The primary cause for additional damage to the drywell by continued corrosion will be the formation of defects in the epoxy coating.
- Since there is no way to assess the **rate** of deterioration of a coating, which for all intents and purposes is already past its useful life, the frequency of inspections must be increased because the coating could fail at any time.
- Frequency of monitoring depends on the remaining safety margins. It is therefore important to gain understanding of the areal extent of the existing corrosion damage. Based on the limited understanding of the extent of locally thin areas, the drywell shell could already be in unacceptable condition. Averages from point measurements (UT measurements) are not the best measure to define average thickness of the whole sandbed region, because the mean itself has uncertainty attached. At minimum, the lower 95% confidence limit of the mean of a number of UT measurements over that area should be employed. A comparison between

Deleted: <#>These changes represent a completely new paradigm for the drywell aging management. The entire program, which had been in use since1987 or 1998, needs rethinking. The best approach would be to make use of continuous moisture monitors and possible online corrosion monitors (it is possible to monitor electrochemical potentials as indications of the onset of corrosion) to supplement the UT testing. ¶

these values with the safety criteria shows that the margins have become very thin in the areas where an assessment is possible, and that therefore frequent monitoring needs to be instituted to ensure significant further corrosion is prevented.

I. Background

Since severe corrosion had been found in the late 1980's in the "sand bed area" of the drywell liner containing the nuclear reactor at the Oyster Creek power generating station, much work has gone into assessing the degree of the damage and modeling the effects of the damage on the integrity of the vessel. Since the drywell liner is a vital safety component, and in light of the pending application for re-licensing reactor operations for another 20 years, the questions surrounding the integrity of the drywell liner have come to the front and center of the stage once again.

There is no question that deterioration of the surface of the drywell shell will continue at some rate over time. Thus, at some point in the future the liner may no longer serve its intended function. This memorandum discusses how to estimate the residual life of the liner and plan an appropriate aging management program around such an estimate.

The bases for such considerations must necessarily be:

- The current state of deterioration of the liner, i.e. the extent of corrosion and how well has it been estimated in the past.
- The criteria by means of which serviceability is ascertained and the remaining margins to condemning the vessel
- The estimated potential future corrosion rate
- And finally the combination of remaining margin and potential rate of deterioration defines the minimum frequency of inspection.

While all of the above items have been estimated and hard numbers have been proffered and written in granite, there is, as will be shown below, great uncertainty surrounding all of the assertions, which have been used by Exelon/AmerGen to support its current approach of taking UT measurements once every four years in the sandbed region.

II. Current Knowledge Regarding the True State of Deterioration.

After corrosion had been found in the sandbed area a concerted effort was made to assess the corrosion rate in order to project the life of the structure. The tools in this effort were ultrasonic measurements (UT) at well-defined locations. In order to assure repeatability of the measurements, a template was constructed containing 49 openings for placement of the UT transducer. The 49 openings were spaced 1 inch apart over a 6 by 6 inch square. This 6 by 6 inch grid was placed repetitively at the inside of the drywell liner just below the vent pipe where the inside curb was lowered from about 2 feet to just over 9 inches (see Figure 1). In this manner, every bay was monitored systematically at intervals over the past 20^{+} years.[1)] In 1992 the sand was removed from the sandbed, and all steel surfaces as well as the sandbed floor were coated with an epoxy resin. UT measurements using the 6 by 6 inch grid performed in 1992, 1994, 1996 and 2006, always at exactly the same position, indicated that within the accuracy of the test (measuring procedure) the continued corrosion was at most small. That should not be surprising because a) the outside steel surface was now coated, b) water would not accumulate against the vessel at the location were the measurements were made because of the drains in the sandbed floor, and c) if corrosion were to commence it would most likely be at imperfections in the coating near the sandbed floor where indeed, standing water could be present (see discussion below).[2]

There are however a number of additional monitoring techniques that were used. In 1986 trenches were dug in the reactor floor in bays 17 and 5 to a depth about equal to the sandbed floor on the outside. It is noted that these trenches were not dug in the bays where the most severe corrosion had been observed. These trenches enabled the operator to perform UT measurements below the sandbed surface (prior to removal) from the inside. Additionally, after the sandbed had been removed, and upon visual inspection of the corroded areas, UT and other thickness measurements were made from on the outside of the drywell in the sandbed area. It was believed at that point that the most corroded areas had been selected visually for these measurements. As a consequence of all these measurements the operator AmerGen assured the NRC that the locations where the "grid measurements" had been performed were quite representative of the corrosion that had occurred on the outside of the drywell in the sandbed area (Ref. 4).

We take issue with this statement. In support of this contention, an effort was made to show graphically the remaining wall thickness observed in all of these various locations. Thus Figure 2 shows, by way of example, the remaining wall thickness from the 2006 UT measurements made with the help of 6 by 6 inch grids as a function of elevation in the **trench of Bay 17**. It is understood, as is described in Ref. 3 that 6 such grids were placed one on top of the other in the trench in order to capture the corrosion from the bottom to the top of the sandbed. Hence, if the bottom of the trench had the elevation about 9 feet, then the top of the 6 grids would have had an elevation of about 12 feet, which according to Figure 1 corresponds to the top of the sandbed and is at least 9 inches higher than the top of the grid used for UT measurements from the inside. (Note, none of these elevations is terribly accurate, however, the top of the trench measurements were definitely lower (deeper pits) by a good margin than the inside grid measurements). Figure 2 plots all individual 2006 measurements from the trench in bay 17. The 6 traces represent the variation of the wall thickness in the horizontal direction while the traces themselves extend from the bottom of the trench (left hand side) to the top of the trench (right hand side). The

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1) 7 Bays were monitored only with 1 by 6 inch templates – probably placed in the horizontal direction – Bay 1 was among those, even though Bay 1 was one of the most corroded Bays.

2 Note that this region is above the concrete floor but just above or below the epoxy coating above the concrete and so is part of the sandbed region, not the embedded region.

undulations of the 6 traces, which are at times (at the same elevation) in synch and at other times out of phase clearly depict the nature of the "golf ball type" surface described in AmerGen literature (Ref. 1 pg. 4). Where the undulations are in synch one can estimate that the extent of the pit at that location extends over an area larger than just one inch in diameter [3)]. It should also be noted that the average amplitude of the undulations in Fig. 2 are of the order of 0.1 inch, i.e. the roughness of the surface at this point is only of that order of magnitude. AmerGen estimated the "roughness" of the surface to be rather of the order of 0.2 inches (Ref. 5 pg. 5).

The most striking observation is that the corrosion is most severe at the top, almost uniform in severity over most of the depth of the sandbed and again somewhat more severe at the very bottom.

Deleted: **In other words, one sees already in this presentation that it would be difficult to single out one small area by means of a 6 by 6 inch grid and claim it to be representative of the corrosion having occurred in the sandbed area.**

In Figure 3 an effort is being made to compare the average remaining wall thickness from trench measurements (averaged over the horizontal direction) with the average of the 6 by 6 grid measurement from the inside and the direct UT measurements from the outside. Also graphed in this figure are the averages of the outside measurements for the three zones for which data are reported (Ref. 5). What one can see is that the averages for the grid and the trench data overlap quite well at the same elevation. However, the average outside measurements are significantly lower at comparable elevations.[4)] This is probably because the choice of location for the external measurements was deliberately biased towards thin spots.

Finally in Figure 4 we see the spread of the 6 by 6 inch inside grid measurements superimposed on the averages of the other measurements.

<u>Conclusion:</u> What the superposition of the UT measurements in Bay 17 demonstrates is that wall loss ranges from zero to 33 percent, however, only the trench and outside measurements come close to represent the most severe corrosion at the highest elevations. It should also be remembered that the grid measurements at the inside curb cutout as well as those in the trench are only 6 inches wide. One does not have, therefore any indications as to how far serious corrosion may have spread laterally around the circumference of the bay.

Deleted: **The inside grid measurements give a distorted picture.**

Figure 5 shows an analysis of the available 2006 data for Bay 13. Bay 13 is probably the second worst corroded bay apart from Bay 1. The averages for the external measurements for each zone are fairly similar, as are the 95% limits for the data spread. There is a 95% percent probability for the deepest penetration to be of the order of 48% of the original wall thickness. The superposition of the internal grid data shows a higher average and a narrower distribution of the data spread. Again one recognizes that the internal 6 by 6 inch grid measurements do not represent the worst corrosion degradation.

[3)] AmerGen suggested that the "dimples" are about 0.5 inches in diameter (Ref. 1 pg. 4)

[4)] For the outside measurement averages had to be used in the graphical representations because exact elevations (or coordinates) of each point were not known. We only had the classifications into Zones as had been described in Ref. 5.

Finally in Figure 6 we show the distribution of the external measurements for Bay 1. One observes that the 95% lower limit of the data spread is around 40% of the original wall thickness, or indeed at a remaining wall thickness of 450 mils, which is 0.04 inches below the required sandbed thickness for the Design Pressure and Temperature. Because the external sampling in Bay 1 was designed to capture the thinnest points, this is a conservative estimate of the minimum wall thickness. However, given the need for a very high degree of confidence that the drywell shell is ready to withstand accident pressures and the uncertainty created by the sparse data set, I believe that a conservative approach is required in this case.

Conclusion: The deterioration of the drywell liner at Oyster Creek has been examined in various ways by UT measurements. These were in part systematic thickness measurements in predetermined locations (6 by 6 inch grids placed on the inside of the drywell at curb cut-outs –see Fig. 1, and in trenches dug below the inside floor to a depth roughly equal to the outside sandbed floor). These measurements were supplemented by residual wall thickness measurements performed on the outside of the drywell in locations where "visually" it had been determined that the deepest pits were located. (It must be interjected at this point that a pit of 600 mils cannot be distinguished visually from a pit of 500 mils). The location of these measurements is therefore rather arbitrary, but was presumed repeatable for the measurements in question.

All external UT measurements had been summarized by AmerGen (Ref. 7) for the purpose of determining the minimum safety margin still available. In order to better understand the prevailing corrosion mechanism the data had been separated in "zones" corresponding to increasing elevation above the sandbed floor (zone 1: < 9'4", zone 2: 9'4" to 10-'3", zone 3: 10'3" to 12'3", and zone 4 > 10'3"). The data obtained in 1992 and 2006 were combined and statistically analyzed for the following three effects: a) the two sets of measurements separated by time (and probably methodology or instrumentation), b) the effect of the elevation, and c) differences in the bays.

It was found that there is no significant effect of the time (Fig.7a). While there is a decrease of 19 mils between 1992 and 2006, this difference is not statistically significant within the variability of the data. The differences between the zones, however are significant. Zone 2 is by far the most corrosive zone. When the bays are compared, one finds as expected that some bays have experienced little corrosion in contrast to others. The importance of these observations is obvious: they point again to the fact that the intensity of corrosion is a clear function of elevation and bay. Hence, averaging data and generalization may lead to doubtful conclusions.

In 2006 the validity of some of the external UT measurements was explored by measuring around the nominal original locations. These data were statistically evaluated in Figures 8, 9, 10 for Bays 15, 1 and Bay 19. The additional data collected in Bays 19 and 15 had been identified as "up" or "down", hence additional data sets identified as 2006 up and 2006 down were compared with the original 2006 data. It turns out for Bay 19 for instance that the UT penetrations identified as 2006 up were significantly lower than the measurements of 1992 with a probability of better than 95%. The difference between the 1992 and 2006 up data is 0.1 inch. Similarly for Bay 15 one finds that the 2006 up data are significantly lower than the original 1992 data by about 0.06 inches, although this difference is not significant at the 5% level. For Bay 1 there is practically no difference between the 2006 and the 1992 data sets, because of the two or three measurements in the non-corroded areas. Summarizing these results in Table 1, one finds that the lower 95% confidence limits for Bays 1, 15 are marginally within the 0.736-inch limit. Since one does not know exactly how extensive the "cancer of corrosion" in the sand bed area really is, it is very difficult to put this interpretation in perspective with the assessments made by AmerGen relative to areal criteria for thinned areas (see discussion below).

Two points must be made with regards to the evaluation of these measurements. All measurements are point measurements, and even though they are closely spaced it is nevertheless difficult to estimate the area over which the measured corrosion penetration may have occurred. This is all the more so for the external measurements.

Pitting on metal surfaces may be considered random if the surrounding environment is uniform, homogenous, and clearly identifiable, because the imperfections in the metal are most likely randomly distributed. (There are of course many well-known arguments against this, such as oriented inclusions due to metalworking, however the assumptions simplify the argument without distorting it). In case of the sandbed there is no randomness because of the predictable decrease in oxygen availability with increasing depth and very likely uneven water content as well. This inhomogeneity is illustrated in Figure 2, where one can see greater corrosion attack toward the top of the sandbed. Similarly, the data show that in Bay 1 the corrosion below the ventpipe occurred more or less in a band of increased corrosion. This band appears to be about 6 to 7 feet long and perhaps a foot wide, although the lowest residual wall thickness (0.669) is found much deeper in the sandbed (Ref. 3). These data shown numerously in various discussions and appendices clearly demonstrate how difficult it is to assess the extent of the damaged areas as is necessary for comparison with the integrity criteria. For instance, the data gathered in Bay 1 in 2006 (and previous years) represent but a small fraction of the overall drywell liner surface exposed to the sandbed environment, and no amount of statistics can predict the pit distribution seen in Bay 1 (Fig. 5). Furthermore, again, the measurements which assess the corrosion in Bay 1 are all point measurements, and one has no way of assessing whether the pits are as local as the representation suggests or whether in fact the thin areas extend from one measurement to the next. I believe that when assessing the extent of severe corrosion, reviewers should assume that the measured points connect unless other measurements show this not to be the case.

III. The Fitness for Use Criteria

Deleted: Furthermore, the pit distribution has been assumed to be random or Gaussian. AmerGen chose to disregard "outliers" which were two standard deviations from the mean (of 49 points) as erroneous or atypical measurements (Ref. 6 pg 16). However, the distribution of pit depth is not necessarily normal but can be exponential, depending on the sensitivity of the measuring technique. It is therefore totally inadmissible from a statistical point of view to discard, or disregard outliers <u>for which there is no physical explanation.</u> ¶

. *It has been observed in the oil field for instance that wall penetration may occur in pipelines as single events totally unpredicted and unpredictable by statistical means; one single event within 18 miles after 6 months surrounded by practically virgin surface.*

Deleted: GE's original calculations stipulated that "if all UT wall thickness measurements in one Bay were above 736 mils, the bay would be evaluated as acceptable. In bays where measurements were below 736 mils, more detailed evaluation had to be performed" (Ref. 4, pg. 11 and Ref. 1 pg.4). ¶

¶

Subsequent calculations determined that if a 1 sq. ft. area were found with a thickness of 536 mils the theoretical load factor/eigenvalue would be reduced by 9.5%. The model stipulated that the1 sq. ft. area was surrounded by a tapering to 0.736 inches (Ref. 1 pg. 6) over a further one foot area. This additional area of reduced thickness contributed to the reduced load factor, hence also the stipulated safety factor. Similar calculations were performed for a reduction of the 1 sq. ft. area to 636 mils in which case the theoretical load factor and buckling stress would be reduced by 3.9%. ¶

¶

There are a number of questions that do arise in the context of these calculations and their application to the present situation of the OC drywell liner. We would like to make it clear from the outset that we are in no position to verify these calculations and are readily disposed to accept their veracity and results. We would, however, like to note the limitations of these results to put them in proper perspective. ¶

¶

<#>AmerGenAmerGen states that GE established these criteria as acceptance criteria for the minimum thickness for the drywell to perform its intended function. That is incorrect, GE modeled the drywell, but the operator then derived acceptance criteria. For example, GE calculated both the 536 inch local thickness and the 636 local thickn ... [1]

IV. Statistics

It has also been shown that the 6 by 6 grid measurements (let alone the 1 by 6 inch matrix measurements) do not represent the entire corroded areas. (Ref. 4: *A review of the 2006 inspection data of 106 external locations shows all the measured local thicknesses meet the established design criteria.* ***Comparison of this new data to the existing 19 locations used for corrosion monitoring leads to the conclusion that the 19 monitoring locations provide a representative sample population of drywell vessel in the sandbed.)*** This statement is patently wrong. However, it is not only wrong because the measurements in the trenches and the external measurements do not agree with the grid measurements (19 monitoring locations), it is also wrong because corrosion, if it were to accelerate significantly, would now more likely occur near the bottom of the sand bed rather than the top as was the case with the sandbed in place.

All this not withstanding, it is also recognized that safety codes exist and that safety criteria have been developed. These codes and criteria specify the minimum thickness for *areas* while the corrosion measurements (UT) are highly localized **(points)**, and are said not to capture more than about 0.5 inches in diameter. One now has to confront the problem of translating point measurements to (average) area characteristics. This has been done by making a limited number of measurements in locations, which have been chosen by accessibility and convenience (grid locations).

However, in the absence of scans it would seem prudent to maybe accept the notion that failures do not happen because of averages, but rather where there are extremes, in this case extremely thin areas. In this sense it is suggested that to use the variability of the corrosion data (spread of pit depths) and calculate the likely deepest pit or the most likely thinnest areas. Hence if an average of 10 measurements over a specific area results in a thickness of .750 inches with a variability (standard deviation) for the average of 0.03 inches, the lower 95% confidence limit for this average would be 0.69 (0.75 – 0.06).

In this sense the external measurements of Bays 1, 15, and 19 have been reexamined, and as Table 1 shows, at least in Bay 15 there is no additional margin for continued corrosion in the areas that have been monitored to this point.

V. Corrosion Underneath Coating

It is pretty well established that corrosion underneath an intact epoxy coating, especially a two-layer coating, will be immeasurably small. If it were to occur it would be of the rate of either oxygen or water diffusion through the coating, and either process is very slow. Furthermore, as we have said before, corrosion is more likely to occur near the concrete floor of the sandbed above and below the epoxy coating on the floor as we have pointed out before.

Deleted: Statistics have been used all through this discussion for different purposes. I think it is important to put the use of statistics in perspective as well. Basically there are three kinds of variabilities in the UT measurements as they have been used. First there is the variability of the instrument. The manufacturer usually specifies the "instrument error", in the case of modern UT instruments of the order of 1% of the thickness to be measured. The error usually is given as a standard deviation which means that the 95% confidence limits for the "naked" UT measurement is +/- 2% of wall thickness, in the present case about +/- 20 mils. This is the variability one would find if a calibration block was measured say 100 times. The next variability is a lot more difficult to define: It has to do with the placement of the sensor in the matrix, finding the same spot over again, holding the sensor in the same direction (vertical to the surface) each time etc. This variability (or variance) is additive to the instrumental variability. Finally the thing to be measured varies in thickness as well. This last variability is precisely the response that is desired. Because there have been no planned duplicate measurements (unless one were to assume that since 1992 no corrosion occurred) one cannot assess either the variability of the instrument nor the variability of the measuring technique. However, it is fair to say that the variability of a single measurement overall (i.e. the combination of the instrumental variance and the variance of the technique) are larger than the manufacturer's stated standard deviation, probably double. With that assumption one might expect say 100 measurements of a single location to be distributed about their mean with a 95% confidence interval of +/- 40 mils. Hence a single measurement of a true value of 800 mils might lie ... [2]

Deleted: The measured data are then translated by averaging and assuming that the average represents the entire surface even though only 1% of the total may have been measured and even though it has been shown that the assumption won't hold.

Deleted: It had for these reasons been suggested that the entire surface should be scanned in place of point measurements in selected areas.

Deleted: For this reason alone the current monitoring program could miss significant corrosion, no matter how often UT measurements are being performed. ¶

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The entire paradigm of the drywell aging management program needs to be changed, as we have also pointed out before.

What is clear is that any defects in the coating will lead to corrosion damage, provided that there is water present. Hence, the first line of defense is to make sure that there is no water present. This is easier said than done since leaks have occurred before and condensation has also been an issue. Since one still is not sure where the water may be coming from one can safely assume that water could be present at some time in the future and at least during each outage.

The second line of defense is to make sure that the coating is intact. Originally the coating life was quoted as being 10 years. Then AmerGen increased the coating life to 15 years, since the 10 years have already elapsed. However, a 15 year coating life will bring its end of service up to September of this year, hence the coating life has to be 20 years, or at least into the next twenty years of service. All of this has been documented in AmerGen literature. Now, we know that the coating on the floor has suffered damage. The most recent inspection has shown that the coating on the floor was cracked in some bays along with the concrete of the former sandbed floor (Ref. 6) [5]. The cause was attributed to the concrete "shifting and breaking up". However, the other possibility that the coating failed (it was applied too thick to begin with) whereupon water entered the cracks in the concrete, which were there dating back to construction, was not considered. Nevertheless, it has been established in the 2006 inspection that the floor had broken up and that water had entered the cracks underneath the coating. This is a dangerous situation, because now water can migrate in the concrete underneath the coating to the concrete – steel interface.

Deleted: As a consequence corrosion can occur either above or below the floor level where it had been established previously by means of measurements from the trenches that considerable corrosion had already occurred. Hence monitoring has to occur frequently in those areas. It is doubtful that UT measurements in the trenches in Bays 5 and 17 would provide enough coverage for the entire system since essentially every other bay presents worse problems.

Coatings are never 100 % perfect. There are always holidays present, albeit perhaps few. AmerGen has chosen to discount that possibility on the grounds that two layers of coatings had been applied. While extensive qualification of the coating had occurred in 1992 in a mock-up outside the system, and while test coatings were extensively tested for holidays, such tests, albeit standardized and very easy to perform, were never performed once the coating had been applied in the sandbed area. Rather AmerGen insists that relying on visual observations is sufficient. Well, visual observation did not for the past 14 years reveal the defects in the coating on the floor until 2006 and there is no telling just how much damage may have occurred as a consequence. (The coating had been found in perfect conditions in 1994, 1996, 2000 and so on until 2006 when it was found broken up).

The coating is apparently colored gray. It is said that visual inspection will reveal damage and rust if it occurs. That is true after the deterioration has become noticeable, however, the question is not whether the coating has already failed, it is how much damage might occur between inspections after the coating fails.

For that reason it is held that a four-year inspection cycle is not enough by a long shot. First, one needs to monitor for water continuously. As experience has shown on

[5] "During visual inspection of the drywell vessel's exterior coating in the sandbed region (Bays 1, 7, 9, 15) areas were observed to have voids. ... To prevent water from seeping underneath the epoxy, an expandable (?) sealer is required for the seams/voids.

the interior, water can easily percolate through the concrete, as has indeed happened and the operator still does not know where it comes from.

I don't want to go into the mechanism of corrosion once a defect has occurred other than to say the following: Once a defect (crack, pinhole, holiday etc) provides access for water to the steel surface underneath, corrosion begins slowly, hardly noticeable from the surface. However, as corrosion progresses the coating will start to crack, opening up a larger defect. (Thick coatings crack more easily than thin ones). Corrosion will progress underneath the coating and cause larger blisters, which may or may not be seen visually, but can be detected with simple test methods referenced earlier. The question of course is how rapidly will corrosion occur, and what is a reasonable time interval for inspection. I venture to say that nobody knows the answer to the first question with any certainty. It is therefore a matter of making a reasonable assumption, as I did previously. Overall, the applicant must now deal with the uncertainty is has created by taking very few UT measurements over space and time and relying on ad hoc methods for detection of moisture and coating degradation. Because we are dealing with a primary safety containment for a nuclear reactor, the uncertainties must be resolved against the applicant to ensure that a reasonable assurance of safety is maintained.

Deleted: Second, defects in the coating need to be established where subsequent damage is most likely to occur, i.e. on the former sand bed floor and in the crease between the floor and the outside of the liner. ¶

Kaufman, April 25, 2007

Rudolf H. Hausler

References

1. GPU Nuclear Calculation Sheet C-1302-187-5320-024, 1993, page 7 of 117
2. Affidavit of Peter Tamburro before the Atomic Safety and Licensing Board, Docket No 50-219, March 26, 2007
3. AmerGen Passport Document 005546049 07 (AR A2152754 E09), page 5, November 11, 2006
4. AmerGen Calculation sheet C-1302-187-E310-041, 2006, page 4 of 55
5. AmerGen Calculation Sheet C-1302-187-5300-01
6. OCLR R00014655

Schematic Cross Section through Sandbed Area
(not to size)

Figure 1

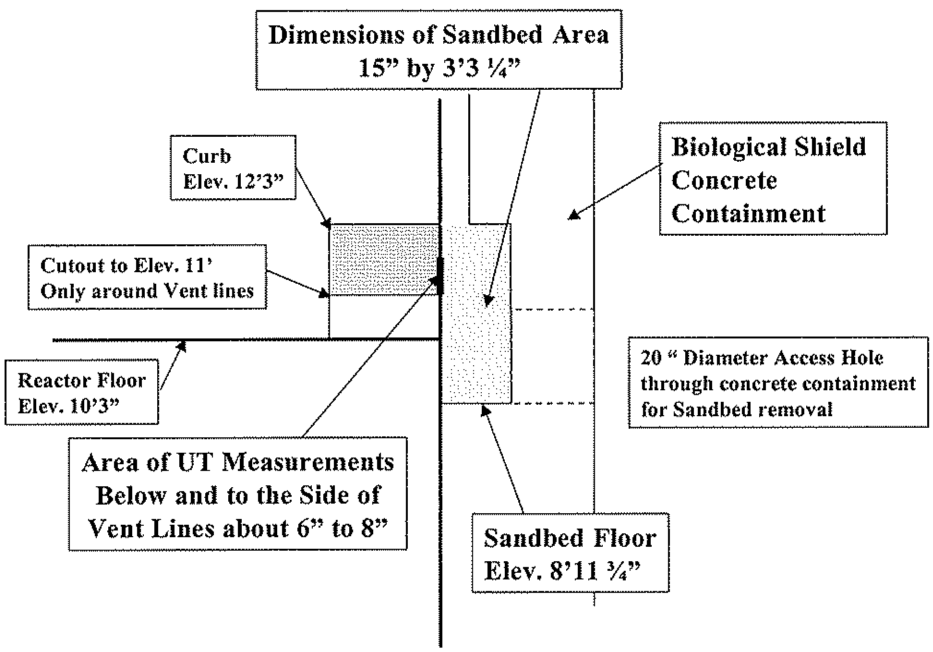
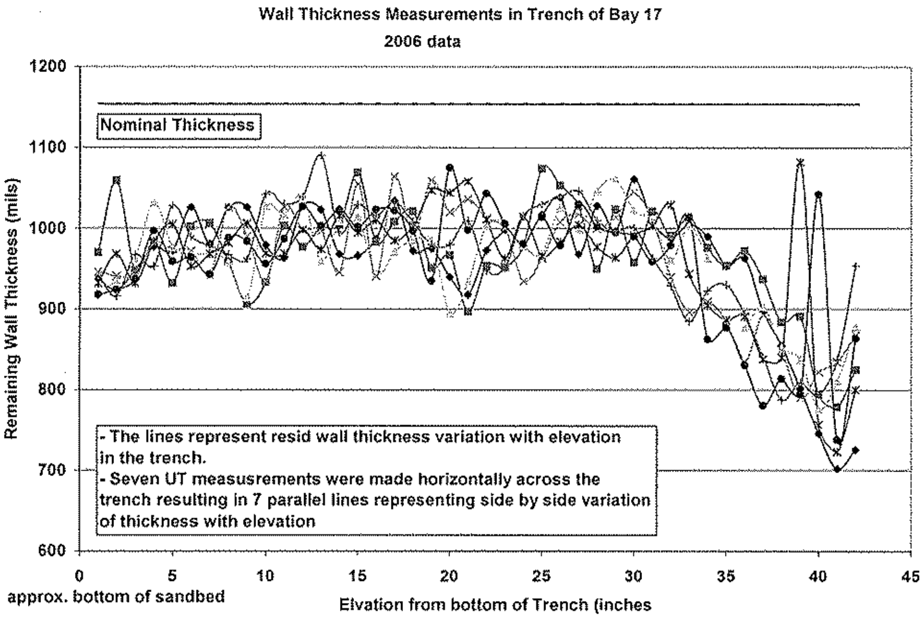
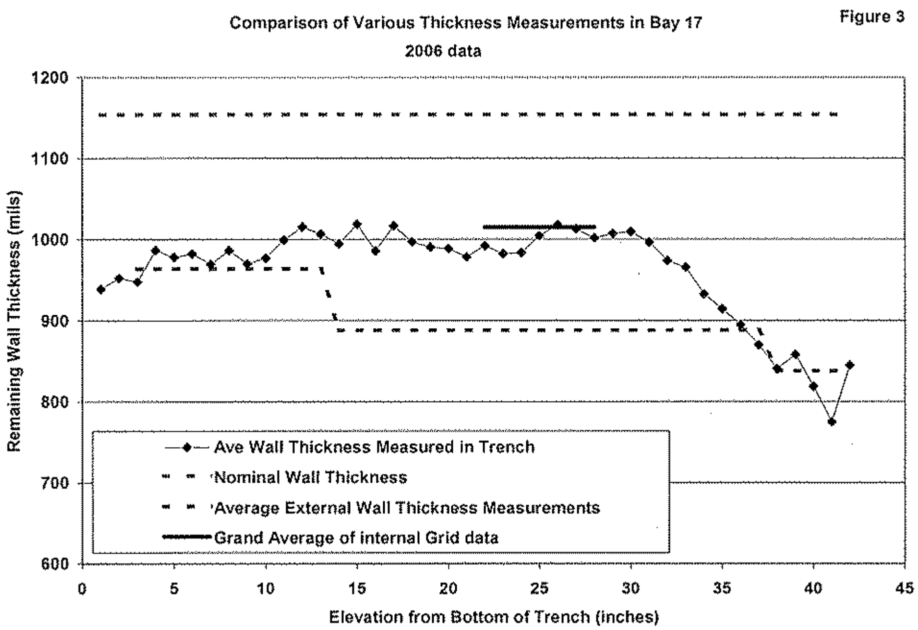


Figure 2



Wall Thickness Measurements in Trench of Bay 17
2006 data
Nominal Thickness
- The lines represent resid wall thickness variation with elevation in the trench.
- Seven UT measusrements were made horizontally across the trench resulting in 7 parallel lines representing side by side variation of thickness with elevation
Remaining Wall Thickness (mils)
1200
1100
1000
900
800
700
600
0
5
10
15
20
25
30
35
40
45
approx. bottom of sandbed
Elvation from bottom of Trench (inches

Figure 3



Comparison of Various Thickness Measurements in Bay 17
2006 data
Remaining Wall Thickness (mils)
1200
1100
1000
900
800
700
600
0
5
10
15
20
25
30
35
40
45
Elevation from Bottom of Trench (inches)
Ave Wall Thickness Measured in Trench
Nominal Wall Thickness
Average External Wall Thickness Measurements
Grand Average of internal Grid data

Figure 4

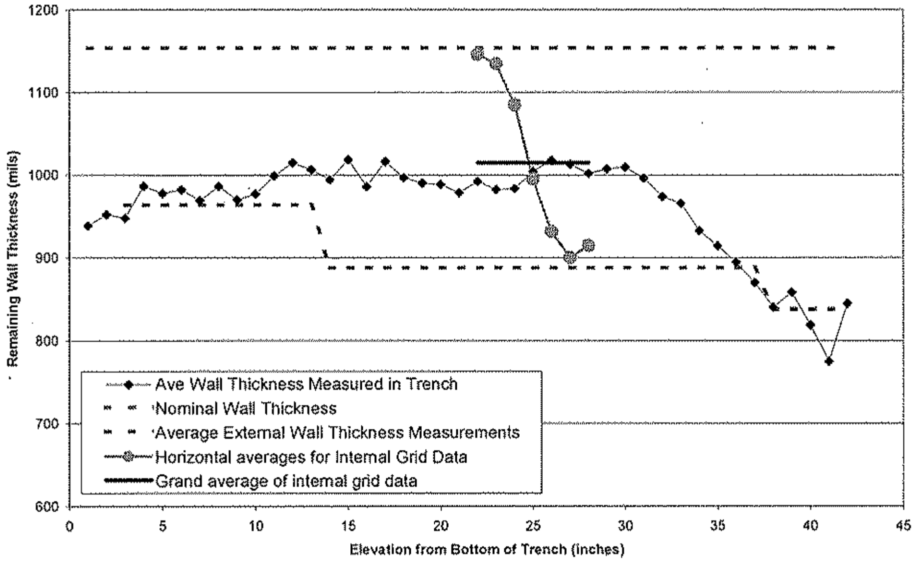


Figure 5

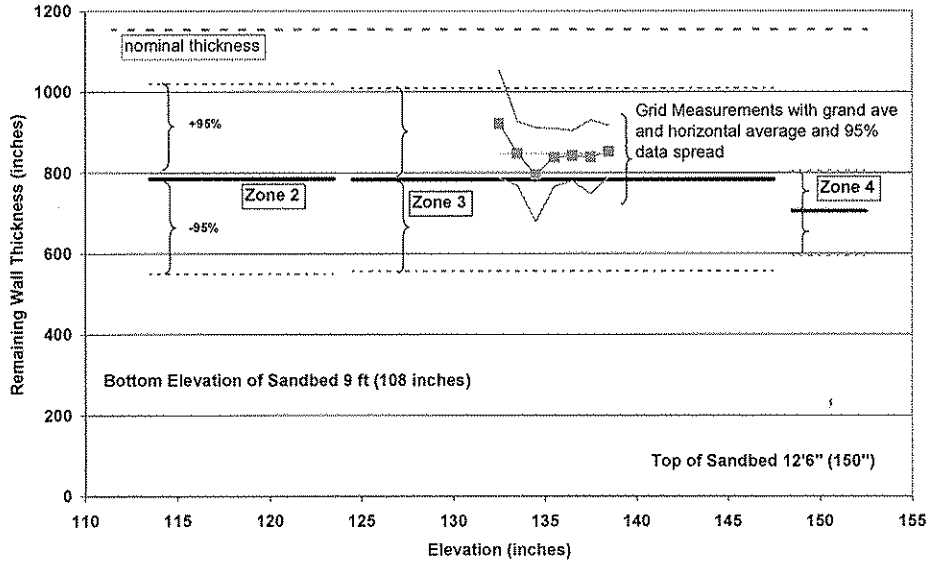
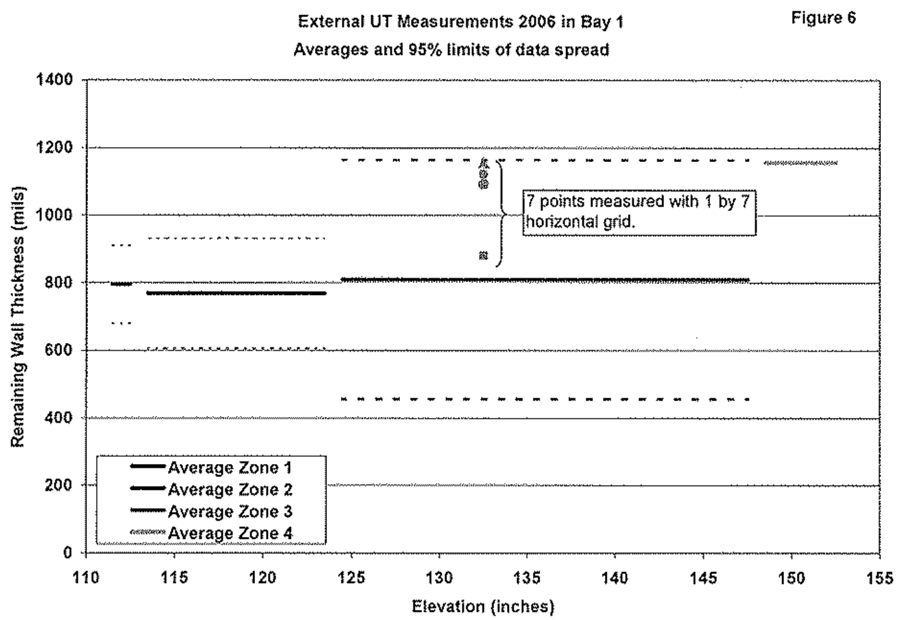


Figure 6



External UT Measurements 2006 in Bay 1
Averages and 95% limits of data spread
Remaining Wall Thickness (mils)
1400
1200
1000
800
600
400
200
0
7 points measured with 1 by 7 horizontal grid.
Average Zone 1
Average Zone 2
Average Zone 3
Average Zone 4
110
115
120
125
130
135
140
145
150
155
Elevation (inches)

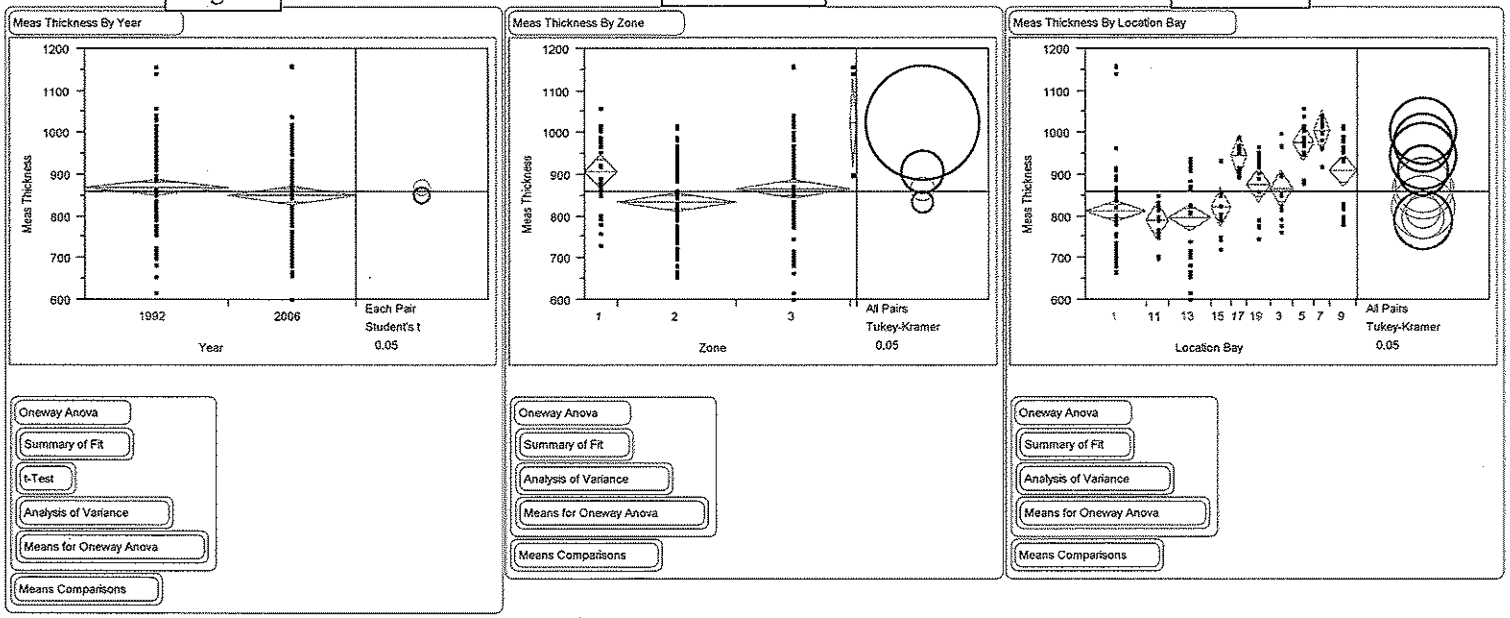
Figure 7

Statistical Analysis of all External UT Measurements

Fig 7 a

Figure 7b

Figure 7c



Comments: Figure 7a: Comparison between measurements I 1992 and 2006 show no significant difference. The means from 1992 and 2006 show a bias of 0.018 inches, but the bias is statistically not significant despite of the many data points. Fig. 7b: The comparison between the "zones" (elevations) is significant. Zones 1 is significantly different from zones 2 and 3. For zone 4 there are not enough data for statistical significance. Fig. 7c: Some bays, red ones, are significantly different from the black ones.

Figure 8: External UT Measurements in Bay 15

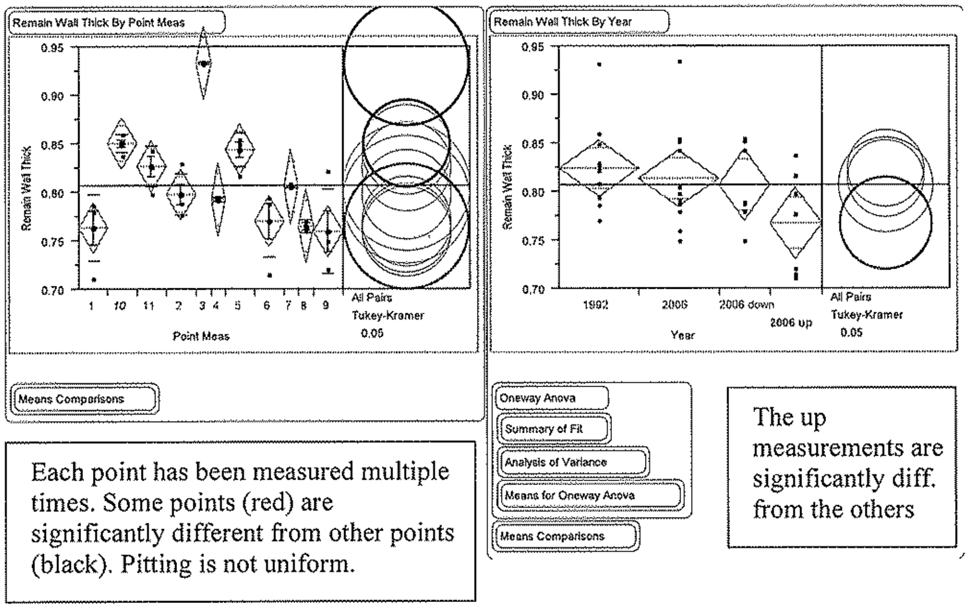


Figure 9: External UT Measurements in Bay 1.

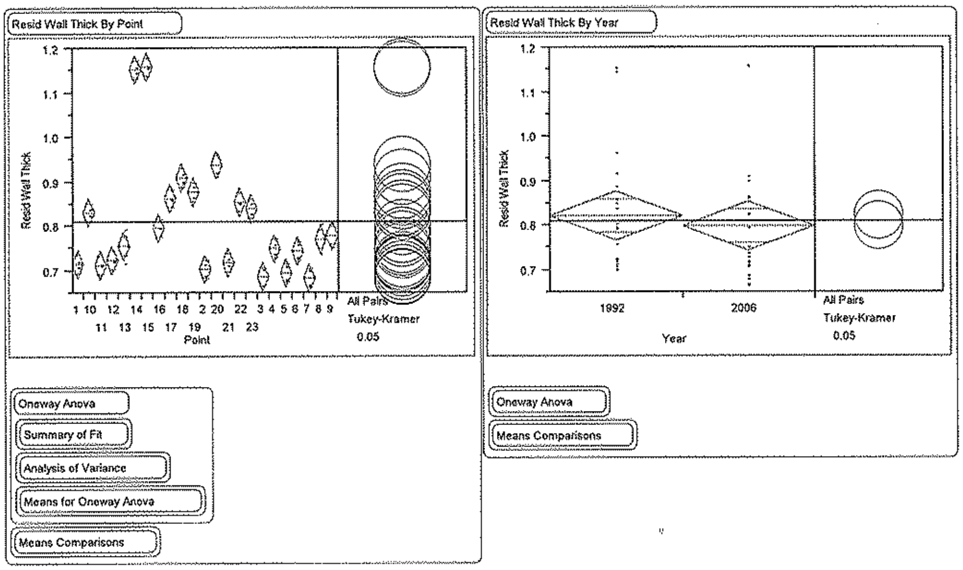
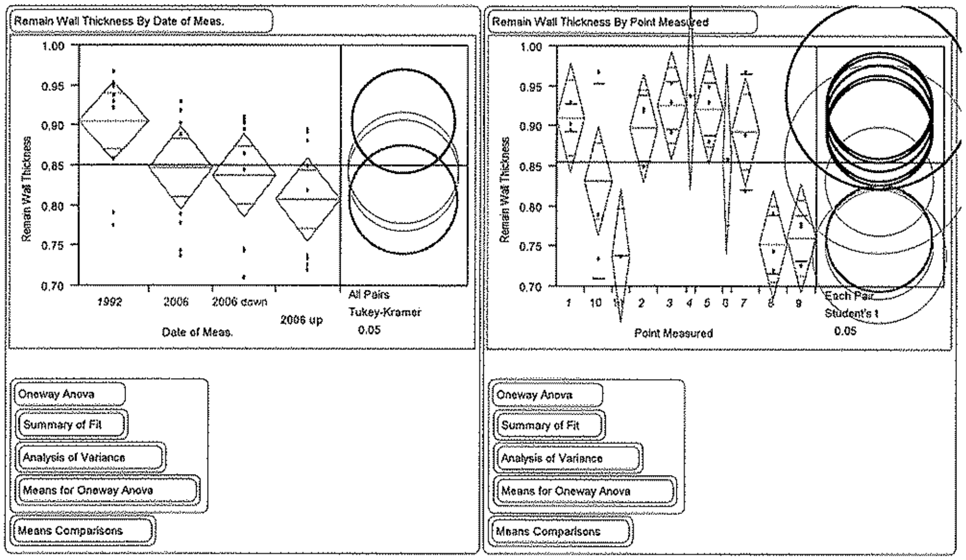


Figure 10: External UT measurements in Bay 19



Again one finds that the "up" measurements are significantly lower from the 1992 measurements.

Table 1

Average Remaining Wall Thickness Measured Externally in the Sandbed Region by UT

Bay	1992		2006		2006-up		2006 down	
	Average	Std Dev	Average	Std Dev	Average	Std Dev	Average	Std Dev
1	0.822	0.027	0.8	0.027				
15	0.825	0.014	0.814	0.014	0.808	0.018	0.768	0.0184
19	0.907	0.025	0.848	0.026	0.837	0.26	0.807	0.026

95 % Confidence Limits of lowest significant measusrements

Bay 1	0.746
Bay 15	0.731
Bay 19	0.755

GE's original calculations stipulated that "if all UT wall thickness measurements in one Bay were above 736 mils, the bay would be evaluated as acceptable. In bays where measurements were below 736 mils, more detailed evaluation had to be performed" (Ref. 4, pg. 11 and Ref. 1 pg.4).

Subsequent calculations determined that if a 1 sq. ft. area were found with a thickness of 536 mils the theoretical load factor/eigenvalue would be reduced by 9.5%. The model stipulated that the1 sq. ft. area was surrounded by a tapering to 0.736 inches (Ref. 1 pg. 6) over a further one foot area. This additional area of reduced thickness contributed to the reduced load factor, hence also the stipulated safety factor. Similar calculations were performed for a reduction of the 1 sq. ft. area to 636 mils in which case the theoretical load factor and buckling stress would be reduced by 3.9%.

There are a number of questions that do arise in the context of these calculations and their application to the present situation of the OC drywell liner. We would like to make it clear from the outset that we are in no position to verify these calculations and are readily disposed to accept their veracity and results. We would, however, like to note the limitations of these results to put them in proper perspective.

AmerGenAmerGen states that GE established these criteria as acceptance criteria for the minimum thickness for the drywell to perform its intended function. That is incorrect, GE modeled the drywell, but the operator then derived acceptance criteria. For example, GE calculated both the 536 inch local thickness and the 636 local thickness with the same assumptions and both led to a reduced load factor. AmerGen and the previous operator then interpreted these results into the current local area acceptance criteria.
It is also not clear how the criteria deal with areas that are below 736 mils thick, but are not square.

While the acceptance criteria, whatever they may be, have been developed for certain well-defined geometries, one cannot immediately relate these to other geometries as they occur in real life.

Now, a new criterion has crept in which would render all previous criteria obsolete. Ref. 4 (pg 11 of 55) states that *if an area is less than 0.736 inches then that area shall be greater than 0.693 inches thick and shall be no larger than 6 inch by 6 inch wide. C-1302-187-5320-024 has previously positioned an area of the magnitude in bay 13, and within the uncertainties of measurement, such an area also exists in Bay 1.*

It is furthermore stated if an area is less than 0.693 inches thick then that area shall be greater than 0.490 inches thick and shall be no larger than 2 inches in diameter.

At present, if we assume that the external points measured in Bay 13 represent the surface, it appears that around 2 sq. ft. clustered around points 7, 15, 6, and 11 is less than 0.693 inches in thickness. In addition, over 4 sq. ft. containing points 12, 16, 7, 8, 11, 6, 15, and 5 appears to be less than 0.736 inches in average thickness. Similarly, in Bay 1 around 4 sq ft emcompassing points 12, 5, 13, 4, 12, 3, and 11 appear to be than less than 0.736 inches in average thickness. It is unclear how AmerGen decided that these results were acceptable, given the latest statement of the local area acceptance criterion.

Page 7: [2] Deleted **The Center for Law and Justice** **7/19/2007 12:01 PM**

Statistics have been used all through this discussion for different purposes. I think it is important to put the use of statistics in perspective as well. Basically there are three kinds of variabilities in the UT measurements as they have been used. First there is the variability of the instrument. The manufacturer usually specifies the "instrument error", in the case of modern UT instruments of the order of 1% of the thickness to be measured. The error usually is given as a standard deviation which means that the 95% confidence limits for the "naked" UT measurement is +/- 2% of wall thickness, in the present case about +/- 20 mils. This is the variability one would find if a calibration block was measured say 100 times. The next variability is a lot more difficult to define: It has to do with the placement of the sensor in the matrix, finding the same spot over again, holding the sensor in the same direction (vertical to the surface) each time etc. This variability (or variance) is additive to the instrumental variability. Finally the thing to be measured varies in thickness as well. This last variability is precisely the response that is desired. Because there have been no planned duplicate measurements (unless one were to assume that since 1992 no corrosion occurred) one cannot assess either the variability of the instrument nor the variability of the measuring technique. However, it is fair to say that the variability of a single measurement overall (i.e. the combination of the instrumental variance and the variance of the technique) are larger than the manufacturer's stated standard deviation, probably double. With that assumption one might expect say 100 measurements of a single location to be distributed about their mean with a 95% confidence interval of +/- 40 mils. Hence a single measurement of a true value of 800 mils might lie anywhere between 760 and 840 mils, and this is probably an optimistic estimate.

Now, it has been assumed that the pitting phenomenon observed at the Oyster Creek drywell liner in the sandbed region was occurring in a truly random manner. It has been pointed out that this is very likely not the case. Nevertheless, lets just assume that Gaussian statistics might be applicable, simply because they are easy to calculate and are the most easily understood. If one measures with single measurements, as was done in all UT measurements, a number of locations say by means of a grid (template), one obtains a series of data reflecting the variation of metal thickness over a given area. At this point it is important to understand that these measurements are not members of a common universe which can be averaged to obtain an average measurement more truly characteristic of the universe than an individual measurement. Rather each measurement is a representative of a different universe – i.e. representing different pitting (corrosion) characteristics, or kinetics. Hence it really does not make much sense to average these measurements and say that on average "this is the corrosion rate". Rather on needs to characterize the variability of the results and superimpose onto them the instrument error. Hence if a specific measurement is, say 756 mils, it is with 95% probability somewhere between 716 and 796 mils. **Therefore, in order to be on the conservative side one would compare**

the 716 mils to the single point acceptance criteria, rather than the reported measurement.

Furthermore, using the average of the grids to represent the entire surface is problematic for many reasons. First, suppose all the sensors had been placed at the low points in the pits. In that case the estimated average would be lower than the true average surface. More importantly, if in fact the corroded surface is like a golf ball surface, how does one average the thickness over the surface area when in fact one only has point measurements within the spherical depressions?

Clearly the entire approach is problematic and perhaps the saving grace is that the design codes require large safety margins. Nevertheless, in this case, when it has been shown that in some situations thickness measurements have been observed well below 693 mils (+/- 40 mils) and below to the 490-mil boundary (with 95% certainty), more detailed measurements are needed.

<u>Attachment 4</u>

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Memorandum

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July 18, 2007

Subject: **Review of Fitness for Service Assessment of Oyster Creek Dry Well on the Basis of Extended Data Analysis**

I. Objective

One of the basic questions involved in the relicensing of the Oyster Creek nuclear power generating station aims at assessing the confidence one might have in the continued integrity of the *corroded and damaged* Dry Well Shell, the primary radiation barrier in case of an event. Specifically, should Oyster Creek continue to operate for another 20 years, and should corrosion continue, even at a low rate, one needs to define the remaining margins with a high degree of confidence in order to determine the frequency of monitoring.

It is the objective of this study to review all external wall thickness measurements from 1993 and 2006 in order to determine how well one understands the corrosion damage at this time and how much confidence one can have in the remaining margins.

II. Summary

A statistical analysis was performed of all available external corrosion data measured in various Bays in 1992/1993 and 2006.

Since there were duplicate and in some cases triplicate UT measurements available for several locations each in Bays 5, 7, 15, and 19, it was possible to establish a solid standard deviation for these UT measurements. Although these standard deviations varied somewhat with the extent and severity of corrosion from Bay to Bay, where

severe corrosion existed the standard deviation of the measurements is between 40 and 50 mils for 95% confidence limits of +/- 90 mils.

The interpretation of the data for the individual Bays was aided by "Contour Plots" which are three-dimensional plots of contours of equal wall thickness within the space of the UT measurements.

The paucity of data, particularly in the heavily corroded Bays makes definite conclusions very difficult and an assessment of the extent of the corroded areas somewhat intuitive.

Nevertheless, taking into consideration the inherent variability of the measurements and the overall paucity of the data, it is my view that the data do not allow AmerGen to show that the drywell currently meets the safety requirements at the 95% confidence level. Indeed, the extent of the corroded areas in the drywell shell is probably already larger than permitted by most versions of the acceptance criteria.

III. Background

Traditionally, corrosion of the Dry Well Liner in the sandbed area was monitored from the inside by means of UT wall thickness measurements with the help of 6 inch by 6 inch templates placed strategically such that corrosion damage could be monitored in locations corresponding to the top of the sand bed. However, a previous study **(Ref. 1)** demonstrated unequivocally on the basis of the UT data presented by AmerGen that the inside measurements obtained by means of the templates were not representative of the entire corrosion damage and severity of corrosion having occurred in the sandbed area.

The present study takes a closer look at the available UT wall thickness data obtained from the outside and below the top of the former sandbed. The locations for such measurements had been determined on the basis of "*visual observations*", since presumably it had been deemed too cumbersome and to labor intensive to examine each bay in its entirety. The results of this analysis are then discussed in the light of the general and local wall thickness criteria, which had been derived from "buckling models" and other engineering specifications **(Ref. 2)**. The confidence one may have in the current assessment of the nature, extent and severity of the corrosion damage will then:

- support the assessment of the remaining margins
- And together with estimates of future corrosion rates (pitting rates) suggest the applicable monitoring frequencies.

We do not intend to take issue with the pertinent structural questions, such as the derivation of the minimum wall thickness criteria, (even though their definitions and application have varied over the years), nor will we discuss the methodologies of obtaining the wall thickness data. We do, however, intend to make use of the available data as reported, and ask the question of how much additional information may be extracted from these data with methods, which may complement those used by AmerGen. Specifically, as we have in the past, we aim at contributing to the aging management plan by critically looking at the available data and by extending and broaden our understanding of what the data may tell us.

IV. Numbers and Numbers

It is well to remember that there are two kinds of number, absolute ones and estimates. If a number, such as the minimum acceptable wall thickness of 0.736 inches is derived from a model be means of calculation we would consider that an absolute number valid within the framework of the assumptions which had been made in the development of the model. On the other hand, numbers arrived at by measurements are really only *estimates,* afflicted with a certain probability of reflecting the true reality. It is known that UT measurements have a standard deviation defined by the manufacturer of the device of 1% of wall thickness. Hence a single wall thickness measurement of 0.750 inches reflects (estimates) a true wall thickness value of 0.750 +/- 0.015 inch with a probability of 95%[1)]. In view of the fact that it is difficult to reproducibly put the UT probe at the same location, and therefore to measure the same thickness, the confidence limits with respect to the true thickness at the location in question are larger. In Bay's 5, 15, and 19 repeat measurements were made in 2006. The standard deviation of these repeat measurements was 33, 50, and 43 mils, respectively, resulting in 95% confidence limits of about +/- 90 mils (if pooled). As a consequence of this reality it is difficult to accept AmerGen's assurances which state categorically for instance (Ref. 3, page 59) that: "the average of these three readings is 0.773 inches which is greater than 0.736". Therefore area 5 meets the 0.736 uniform criteria". Taking into consideration that the 95% confidence limit of the average of three measurements is 50 mil, there is more than a 5% probability that the average for area 5 is less than 0.736.

Similarly for areas 7, 8, and 11 in Bay 13 AmerGen states that the average of these three areas is 0.658 inches bounded by a 12" by 12" area. Therefore, this square foot area is greater than the local buckling criteria of 0.636 inches. First one should notice that the 1 square foot area has been bounded quite arbitrarily and could as well have been 24" by 24". Furthermore, the average of 658 mils for three measurements in reality is 658 +/- 52 mil such that the real value with 95% probability lies somewhere between 700 and 608 mils. We realize that this spread of the results and this uncertainty in the data is uncomfortable, however, it is based on AmerGen's data and classical statistical evaluation.

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1) Older instruments, such as were available in the late 1980's to early 1990's may have had a standard deviation more like 2% of wall thickness.

V. The Inherent Difficulties

The available models, which had been used to assess buckling (for instance), rely on uniform thinning over a large (or relatively small area as the case may be). Thus, a minimum wall thickness of 0.736 inches has been defined for the Dry Well Shell. This meant that if the Liner had been corroded down to a remaining wall thickness of 0.736 inches over an area embracing the height of the former sandbed and extending the length of one bay a real danger would exist that the Shell might "buckle". (For smaller areas the minimum wall thickness may be smaller as will be discussed below).

It is, however, well established, that corrosion did not occur in a uniform manner (see e.g. repeated references to the "golf ball like" aspects of the corroded surfaces). Additionally, the remaining wall thickness in the sandbed area was determined by ultrasonic "point measurements" at what appears to be random locations [2)] below the vent pipes in each bay but not extending far into the respective bays.

As a consequence of this situation it became necessary to convert random point measurements of the wall thickness over a highly non-uniform surface to an average wall thickness for this same surface area. In principle this can only be done properly if the surface had been scanned. However, in view of the location and accessibility of "sand bed surfaces" ultra sonic scanning may not have been possible in 1992 after the removal of the sand.

In order to escape this dilemma AmerGen presented a model **(Ref. 3),** which essentially says that if the deepest pit (thinnest remaining wall thickness) had been located all other measurements would show larger wall thicknesses, and therefore an average wall thickness could be calculated between the thinnest and surrounding locations and this average could then be compared to the criteria. Clearly this is the only approach one can take, however, it also depends on how close together the point measurements are. AmerGen indicates that the point measurements cover an area with diameter of 2.5 inches. Hence, if point measurements are not further removed than 2.5 inches (center to center) from each other, the assumption is correct. If however the point-measurements are more than say 5 inches apart, there can be no assurance that not a deeper pit may exist between the two under consideration [3)]. **The confidence one can have in AmerGen's assessment of the remaining wall thickness over the measured area depends on the density of the measurements.** We wish this "confidence" could be expressed in a number, but we think this is not

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[2)] While the inside measurements were made with the help of a 6 inch by 6 inch template which could be placed in exactly the same position each time measurements were made, the outside measurement locations needed to be described with coordinates referenced to a specific point below the vent pipe for each bay. The exact location of this reference point relative to the centerline of the vent pipe may vary from bay to bay.

[3)] AmerGen has given assurances that the inspector charged with making the measurements had selected the deepest corrosion features (thinnest wall thickness) by visual observation. We think that it would be quite difficult to discriminate between two corrosion features within +/- 0.05 inches. 0.05 inches, however, is of the order of the remaining margin in many areas.

possible. However, we can look at the situation and gain intuitive insight into this question. Figure 1, which is discussed in detail below, presents areas of equal wall thickness (contours) based on the measurements, shown as the points, performed on the outside of Bay 19 in 2006. Note the dark squares are 2.5 inch on each side (and drawn to scale with reference to the horizontal axis), hence cover the area of measurement claimed by AmerGen. It turns out that the measurements at the –20 (inch) vertical position are on average less than 0.725 inches. Since measurements had not been extended to higher elevations one has no assurance that there are no more seriously corroded areas either between those measured or further up in the sandbed.

A detailed explanation and discussion of these graphs will be offered below. At this point it must be pointed out that in general (with few exceptions) the locations chosen for UT measurements on the outside of the Dry Well Liner are few and far between, and that calculating averages between them cannot possibly lead to results with a high degree of confidence.

VI. The development of Contour Plots

Nevertheless, averages we must calculate or else we could not apply the wall thickness criteria, which have been established with considerable effort, and apply them to specified surface areas.

AmerGen went to considerable effort to attempt to demonstrate that essentially no corroded areas exceed the minimum wall thickness criteria. What AmerGen did essentially is to calculate averages from a limited set of measurements either in the y or x directions. Subsequently it estimated the surface area surrounding these points. Finally, average wall thickness and associated surface area were compared to the criteria. While AmerGen thus performed a one-dimensional analysis we propose here to perform a two dimensional analysis.

A simple statistical principle says there is "power in data" and the more data one can bring to bear on a statistical analysis, the more confidence one can have in the results. A typical example is the analysis of variance. Where experimental results have been obtained as a function of several parameters, one wants to evaluate the results using all the data over the entire parameter field, rather than studying each effect individually.

Similarly, in the present case where thickness data have been obtained as a function of horizontal and vertical distance from a reference point one wants to use all the data for an analysis rather than study variations along each axis individually, or specific arbitrarily chosen areas. Such a procedure is possible by using "triangulation" over the entire x - y field. Triangulation essentially calculates averages between all points instead of just some points. For example, take any point in Fig. 1 and connect it with any other point in its vicinity, then calculate the average between each pair and associate the coordinates to this average. Using all this data an algorithm now calculates equal response lines in the two-dimensional x/y field, in this case, lines of equal wall thickness over the area, which comprises the measurements. The areas between the lines can be shaded. In this manner, Figure 1 shows the areas where it is estimated that the residual wall thickness is between 0.800 and 0.750 inches or less than 0.750 inches, etc. Lines of equal response can be spaced closer together (each 25 mils) or farther apart. In this case, because the inherent inaccuracy of the measurements themselves and the paucity of data it was judged that spacing the lines closer together would not contribute additional insight.

The advantage of this evaluation is that one can see all the available data in a quantitative presentation. Thus, one can see in Figure 1 that an area exists at elevation –20 (20 inches below the reference point) where the remaining wall thickness is less than 750 mils, or less than the criteria for general thinning at 95% confidence. This area extends from 20 inches on the left (-20 inches) to about 60 inches on the right (+60 inches), or about 7 feet. The width of this area in Fig. 1 is maybe 4 to 5 inches, however, because measurements were not extended toward lesser elevations (from the reference point) one simply cannot estimate how much further the serious the corrosion may extend in Bay 19.

In summary, the three-dimensional presentation of the UT wall thickness measurements does two important things for us:

- It presents all data as whole over the area that has been examined and where information exists
- It also indicates where information should have been gathered but wasn't. We therefore get a much better picture with respect to the confidence one may have in the results of the monitoring data.

VII. AmerGen's Treatment of the Raw UT Measurements

AmerGen perceived a difficulty with the UT measurements as far back as 1992 (Ref. 4) in that UT measurements on a "rough" corroded surface were judged inaccurate. In order to improve the accuracy, or, as the case may be, verify the UT measurements, the pit depths in the locations (areas) where UT measurements had been performed were measured by means of micrometers. However, the pit depths could not be referenced to the original surface because the surface from which the pit depth was measured was itself corroded. It was apparently felt that the micrometer measurements would need to be corrected themselves because of the corroded nature of the surface ("golf ball like pimples"). Therefore an imprint was made of the surface and the roughness assessed on the imprint by means of micrometers again. These measurements, about 40 randomly chosen over an area of 40" by 40" were averaged and the average plus one (1) standard deviation was used as a "conservative estimate of the roughness of the surface. Now raw UT measurements were corrected to account for the surface roughness and to yield a value called the "Evaluation Thickness" as follows:

$$T_{evaluation}=UT_{measurement}+(\text{AVG Micrometer readings})-T_{roughness}$$

This algorithm appears to correct for the fact that due to the roughness the UT probe may not have "coupled" well with the metal surface and therefore detect less metal (thinner wall) than was actually there. This explanation had not been given in so much detail in the original calculation of 1993 and is in part our interpretation. It turned out that almost all UT measurements were reduced by this correction. However, when the average roughness plus two (2) standard deviations was used, the opposite was the case. Furthermore, we understand that the 2006 measurements were made with the epoxy coating in place. In this case the correction would not apply because the sensor would necessarily have coupled better with the smooth epoxy surface, and the instrument would have compensated for the thickness of the epoxy coat.

We can therefore not accept the evaluations done by AmerGen using the "evaluation thickness). Indeed, Mr. Tamburro himself commented in early 2006 that:

> *The calculation develops a term called "evaluation thickness" based on actual measured thicknesses. This value is then compared to the design basis minimum required uniform thickness for the sandbed region of 0.736 inches. The method in which "evaluation thickness" is developed is poorly explained. In addition the justification as to why it is acceptable to compare the evaluation thickness to the design basis required minimum uniform thickness of 0.736 inches is not documented in the calculation, nor is there a reference to an industry standard. (Ref.5)*

As it turns out, the procedure is used again in Ref. 3, page 23 without any further explanation or justification, other than that the evaluation thicknesses better fulfill the design basis criteria.

Another comment should be made at this point regarding the quality of the data used for the evaluation of fitness for purpose of the Dry Well Shell. Repeated reference is made to the fact that: *in 1992 inspections began with visual inspections to identify the thinnest areas in each bay. UT measurements were then performed on the thinnest points within each area (e.g. Ref.3, page 4 of 183).* One keeps wondering how it is possible to discern "the thinnest points" by visual inspection. No doubt the Dry Well Liner is not corroded uniformly in the former sand bed area. And certainly there are areas that are pitted more severely than others, which is totally consistent with the nature of this type of corrosion and the underlying corrosion mechanism. However, in view of the fact that the margins (difference between design basis thickness and actual UT measurements) are already very thin, one has to wonder how visual inspection can differentiate between areas that might differ by 50 to 75 mils in residual wall thickness. Case in point is repeat measurements in 2006. In Bay 15 for instance, area 1 was first measured as 0.779" residual thickness while repeat measurements are shown to vary from 0.711" to 0.779 inches. Similar variations were found for a large number of the areas in Bay 15 as well as other Bays (Ref. 6).

The difference between the average of the first set of 2006 measurements in Bay 15 and the average of subsequent sets is statistically not significant. The standard deviation for repeat measurements, however, is of the order of 45 mils and the 95% confidence limits are of the order of +/- 90 mils.

AmerGen discusses the bathtub ring in Bay 1 (See also Figure 2) as one single area using 1992 and 2006 data for which the *evaluation thicknesses* had been determined (See discussion of evaluation thicknesses above). AmerGen finds that in this area the average of 11 data points, which is around 4 square feet in area, is 0.766 inches and 0.765 inches for the 1992 and 2006 measurements, respectively. Considering the uncertainty of the measurements, +/- 27 mils, there is at least a 5% probability that the remaining margin is of the order of 2 to 3 mils, assuming that areas larger than one square foot in extent must average 0.736 inches or more.

Even more seriously, if the original data as measured in 2006 had been used for this assessment, the average thickness from the 11 measurements would be 0.735. There would therefore be no margin left for corrosion for this particular area, not even taking into consideration that the 95% confidence limits are +/- 27 mils for the average of 735 mils.

At this point we should make a comment concerning the use of statistics. The statistical parameters for a set of data said to belong to the same population, such as the mean, the standard deviation, the 95% confidence limits, etc., are mathematically derived entities based on broadly accepted theory. The central limit theorem says that the standard deviation of the mean is smaller as more data is gathered. Thus, if a mean of 5 measurements is say 745 mils with a standard deviation for the individual measurements of 40 mils, then the 95% confidence limits are +/- (40/((5)^2))*2, or +/- 36 mils, ranging from 781 mils to 709 mils. The probability that this area does not meet design criteria then is of the order of 35 – 40 % (not rigorously determined), while the probability that it does meet it is of course the complement 60 to 65%.

One finds often in the practice of statistics a tendency to disregard statistical assessments in favor of intuitive approaches. For example, one way out of the dilemma is to use 1 sigma, but that would reduce the level of confidence, which is unacceptable here. Large variabilities are often in the nature of the phenomenon to be measured (corroded surfaces being a good example) or in the method of measuring. Only large data sets can overcome these difficulties. The table below may illustrate this situation.

Means, Variability, and Standard Deviation of UT Measurements on Corroded External Surfaces.

Bay	1993 Mean of all Measurements	1993 Variability 1 sigma	2006 Mean of all Measurements	2006 Variability 1 sigma	2006 Standard Deviation
5	0.993	0.053	0.960	0.039	0.033
7	1.005	0.043	1.007	0.028	0.023
15	0.816	0.054	0.810	0.053	0.050
19	0.889	0.077	0.848	0.083	0.043

The variability for the individual measurements reflects the irregularity of corrosion. One would not really expect the remaining wall thicknesses to be uniform over the corroded area. In that sense the spread of the data does not really reflect a standard deviation in the purest sense of the word. However, since a large number of repeat measurements had been carried out at the identical coordinates in Bays 5, 7, 15, and 19, it was possible to calculate a true standard deviation for these measurements. It turns out that this standard deviation is also a function of the degree of corrosion found on the varying surfaces.

VIII. Discussion of Contour Plots

The data used for the analysis are contained in Tables 1 and 2 for Bays 1 and 13 as extracted from AmerGen documents. Presumably, these were the most corroded Bays. Figure 2 shows a contour plot for Bay 1 obtained with the data from 1992. The dimensions of the points in the plot are 2.5 by 2.5 inches. Again, one needs to remember that the specific shape of the contours depends not only on the residual wall thickness measured at the locations indicated, but on the density of measurements as well. (For instance, an additional measurement at coordinates h (-20) v (-25) could completely alter the contours and in all likelihood extend the area of wall thickness below ~750 mils [4)].

Nevertheless, it appears in Figure 2 that in the so called "bathtub ring" an extensive area exists with wall thicknesses between 700 and 750 mils (0.75 inches). This area extends well over 52 inches (4^+ feet) and is about 5 inches wide. In view of the fact that UT measurements are at best accurate with a standard deviation of about 45 mils, (95% confidence limits +/-90 mils), this area could well be more extensive.

Figure 3 shows the contours for Bay 1 obtained with the data from the 2006 inspection. The general shapes are the same as in Figure 2 except that here we have sizeable areas with residual wall thicknesses below 725 mils. The unexpected thing is

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4) The spacing of the contours is chosen arbitrarily and lightly different results could be expected for alternate contours. In this case 25 to 50 mils was chosen because, as discussed above, there is essentially no difference, statistically significant, between the "criterion" or 736 mils and a measurement of 750 mil residual wall thickness.

that these areas seem to extend off the left beyond -40 inches but no measurements [illegible]

corroded areas as claimed.

Based on Figure 3, together with and assessment of the accuracy (reliability) of the data one must conclude that there is a good likelihood that the entire bathtub ring area extending from 40 to –40 inches on the horizontal axis and from about –30 to perhaps -20 inches on the vertical axis is below the 0.736 inch criteria for general thinning and is, much larger than the one square foot acceptance criterion. (Of course, since this area is the most corroded, it will taper off to higher wall thickness on both sides of the vertical axis). The corroded area is indeed shaped quite irregular, but one could venture a guess that the contoured areas below 750 mils are of the order of 4 to 7 square feet all together. This estimated area does not include the area to the left of -40, which probably contains additional area below 0.750 inches.

Figures 4 and 5 show the contours for Bay 13, 1992 and 2006 data, respectively. Here large areas exist with wall thicknesses below 700 mils and at least two seemingly unconnected areas where the residual wall thickness is less than 650 mils. It could be argued that those heavily corroded areas are less than 1 square foot and therefore are still acceptable according to the 636 mil criterion. However, the heavily corroded area on the left hand side (-20, -20) has not been further explored. One therefore does not know whether it might extend further. Similarly, the area on the right ((40, -7), clearly showing a fairly deep pit, was not further explored and was not even measured in 2006. While in Bay 1 the bathtub ring was at elevation –20 to –25 (from the reference point) in Bay 13 there is no clearly prominent bathtub ring. This may be because it was not there, but it may also be because the measurements were not extended toward elevation –15 and –10. We are therefore left with a great uncertainty as to the true extension of the damage in this Bay.

Figure 6 shows the contours for Bay 15. There is a heavily corroded area at elevation –10 with an extension of 1 ft by about 4.5 feet. However, this area was explored only with 2 measurements and was not extended beyond about 2 feet either side of the centerline. It appears that the majority of the measurements occurred in the non-corroded zones. Interestingly there appears some serious corrosion near the sandbed bottom, but the occurrence was not further explored either.

Figure 1 mentioned previously shows a heavily corroded area in Bay 19 at elevation –20. The extent of this area is highly uncertain because it was not further defined by additional UT measurements toward higher elevations (>-20). Indeed, one could find here an extended bathtub ring area.

Figure 7 shows the contours for Bay 11. Again there is a suggestion of severe corrosion at elevation –20 and no further exploration into the bathtub ring area. Once again, the extent of this area is highly uncertain because it was not further defined by additional UT measurements.

In summary, the contours for these various bays show a consistent but equally disturbing pattern. While AmerGen has consistently assured us that visual observation led to the selection of the locations to be evaluated by UT measurements we also find that assertion was not verified, once severe corrosion had been measured, by further exploring the surroundings. This omission greatly contributes to the uncertainty one must have regarding the integrity of the Dry Well Shell.

IX. Discussion of the Minimum Wall Thickness Criteria

Several minimum wall thickness criteria have been developed by means of a General Electric Company computational model. Of interest was the relationship between the degree of wall thinning and the area over which such thinning occurred. It stands to reason that the greater the thinning the smaller the thin area one could tolerate would have to be.

The first criterion so derived states that the limiting wall thickness in one bay was 736 mils in the case that the entire Dry Well Surface formerly in contact with the sandbed were uniformly corroded to that depth. This has been interpreted by AmerGen to apply to the mean of the measured thicknesses.

However, individual measurements less than 736 mil residual wall thickness have been observed. For this reason GE conducted a sensitivity analysis in order to determine the extent of corroded surface area still acceptable when the residual wall thickness was below 736 mils.

The analysis technique embedded in the GE Model the case of a local area of 12 inch by 12 inch having a residual wall thickness of 0.536 or 0.636 inches tapering back to 0.736 inches over a further foot. The theoretical load factor for this case was reduced by 9.5% for the 0.536 inches case and 3.9% for the 0.636 inches case. The safety factor in the first case of general wall thinning is 2 (as required by the ASME code). Therefore, allowable reductions in load factor should get less as the average thickness of the sand bed approaches the general wall criterion.

The following wall thickness acceptance criteria were derived from this model:

- If an area is less than 0.736 inches thick then that area shall be greater than 0.693 inches thick, and shall be no larger than 6 inches by 6 inches. C-1302-187-5320-024 has previously placed an area of this magnitude in Bay 13 **(Ref.2)** [5)] Actually, as can be seen from Figure 4, there are two such areas in Bay 13.

- Most recently, the limiting wall thickness criterion was formulated as follows: *An evaluated area for local buckling shall not be greater than 36 inches by 36 inches wide. The center of the area shall be no larger than 12*

[5)] please note that this reference is dated 12/15/06. This date is important, because it follows a detailed critique of the GE Model results by the same author dated 6/30/06.

inch by 12 inch and shall be on average 0.636 inch thick or thicker. The surrounding 36" by 36" area centered on the 12" by 12" area shall be on average thicker than the transition from 0.636" to 0.736".

This definition, most recently formulated (3/21/07) appears to be saying that the allowable area thinner than 0.736 inches is 9 square feet, but that no 12 inch by 12 inch area of 0.636 inch or less wall thickness should be present. However, it seems to us that this definition is in stark contrast to earlier more conservative interpretations, which limited the area thinner than 0.736 inches to one square foot or less.

An additional criterion relates to the pressure effect and essentially states that an area of 2.5 inch by 2.5 inch must have a wall thickness larger than 0.490 inches.

The real question then is this: If for general thinning of the wall in one bay the residual acceptable wall thickness is close to 0.736 inches how much additional reduction in load factor (or safety factor) can one tolerate if there are local areas with thinner, or much thinner wall thicknesses. We have not found an answer to this question.

X. General Questions and Reservations

For local areas corroded beyond the thickness of 0.736 inches the most stringent criterion derived from the GE calculations states that:

-if an area is less than 0.736 inches thick, then that area shall be greater than 0.693 inches and shall be no larger than 6 inch by 6 inch wide.

Such areas definitely exist in Bays 1 and 13. However, while apparently the criterion was derived for square areas, such areas do not exist in reality. Rather, the major area in Bay 1 which has wall thicknesses below 0.736 inches (and somewhere between 650 and 720 mils) is of the order of 80 inches by 5 inches. If total area rather than linear dimensions are important then the area in Bay 1 which is below 736 mils is 10 times larger than specified by the criteria (400 square inches vs. 36 square inches). There is another area in Bay 1 clearly below 725 mils about 10 inch by 10 in dimensions.

Finally, the acceptance criteria have been based on modeling of square areas of corrosion less than 0.736 inches. However, in Bays 1, 15 and 19 the most corroded areas are actually long grooves. It is likely that such grooves have more effect on the stability of the drywell shell than square areas because the stresses cannot easily distribute around such areas. In the absence of further modeling of the effect of these shapes on stability, it is prudent to use conservative acceptance criteria to review these grooves, based on the modeling conducted to date, especially in Bays 1 and 15 where the average thickness is, at best, very close to 0.736 inches. Thus, the area below 0.736 inches should at least be smaller than one square foot, and thicker than 0.636 inches on average as it appears AmerGen also decided in 2006, after careful consideration.

References:

1. **Affidavit of Dr. Rudolf H. Hausler, April 25, 2007** (Memorandum to Richard Webster, Esq., *Update of Current knowledge regarding the state of integrity of OCNGS Drywell Liner and comments pertaining to the aging management thereof*)
2. **Sandbed Corrosion Rate Assessment,** Attachment 1, Calculation Sheet C-1302-187-E310-041, Preparer Pete Tamburro , 12/15/06, page 11 of 55, (also OCLR 00019286)
3. **CC-AA-309-1001 Rev.2** Calculation Sheet C-1302-187-5320-024, 3/28/07, page 7 of 183
4. **Calculation Sheet C-1302-187-5320-024, Rev. 0,** 04/16/93, page 5 of 54
5. **AR 00461639 Report:** Peter Tamburro, (*Calc C-1302-187-5320-024 is not clearly documented,)* 06/30/06, page 2 of 5, item 3
6. **AR A2152754 E09,** Passport 00546049 07 (Also OCLR 00018401 through 00018494)

Table 1

Bay 1 UT Measurements for External Corrosion.

Measurement ID	Vertical Position inches	Horizontal Position inches	Remaining Wall Thickness 1992 inches	Remaining Wall Thickness 2006 inches
1	-16	30	720	710
2	-22	17	716	690
3	-23	-3	705	665
4	-24	-33	760	738
5	-24	-45	710	680
6	-48	16	760	731
7	-39	5	700	669
8	-48	0	805	783
9	-36	-38	805	754
10	-16	23	839	824
11	-23	12	714	711
12	-24	-5	724	722
13	-24	-40	792	719
14	-2	35	1147	1151
15	-8	-51	1156	1160
16	-50	40	796	795
17	-48	16	860	846
18	-38	-2	917	899
19	-38	-24	890	856
20	-18	13	965	912
21	-24	15	726	712
22	-32	13	852	854
23	-48	15	850	828

Table 2

Bay 13 UT Measurements for External Corrosion.

Measurement ID	Vertical Position inches	Horizontal Position inches	Remaining Wall Thickness 1992 inches	Remaining Wall Thickness 2006 inches
1a	1	45	672	.
2a	1	38	725	.
3a	-21	48	941	932
1	-6	46	814	873
2	-6	38	615	.
3	-26	42	934	.
4	-12	36	914	873
5	-21	6	715	708
6	-24	-8	655	658
7	-17	-23	618	602
8	-24	-20	718	704
9	-28	4	924	915
10	-28	12	728	741
11	-28	-15	685	669
12	-28	-23	885	886
13	-18	40	932	814
14	-18	8	868	870
15	-20	-9	683	666
16	-20	-29	829	814
17	-9	38	807	.
18	-22	38	825	.
19	-37	38	912	960

Figure 1

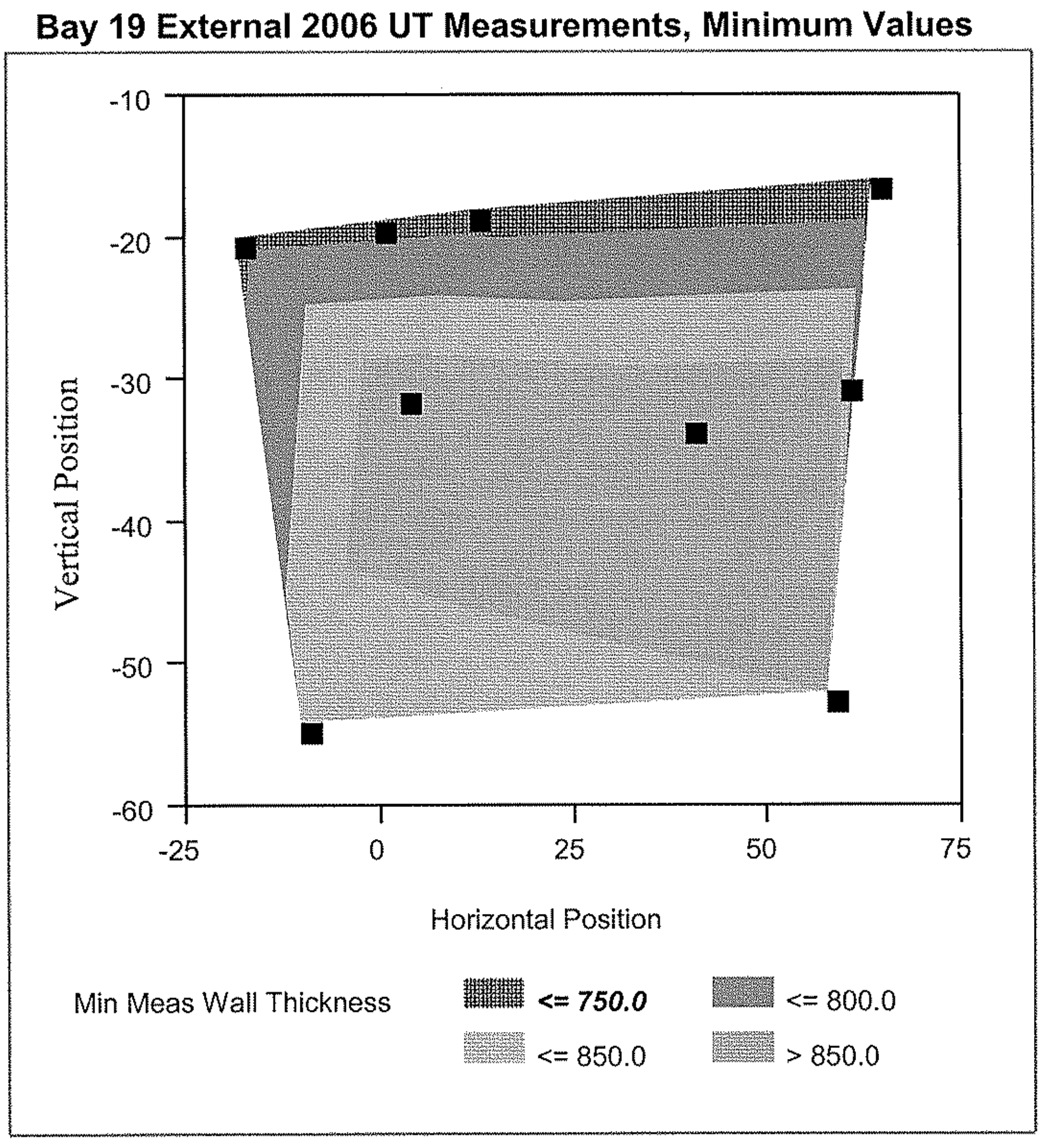

Bay 19 External 2006 UT Measurements, Minimum Values
-10
-20
-30
-40
-50
-60
Vertical Position
-25
0
25
50
75
Horizontal Position
Min Meas Wall Thickness
<= 750.0
<= 800.0
<= 850.0
> 850.0

Figure 2
Bay 1 Remaining Wall thickness
External UT Measurements 1992/1993

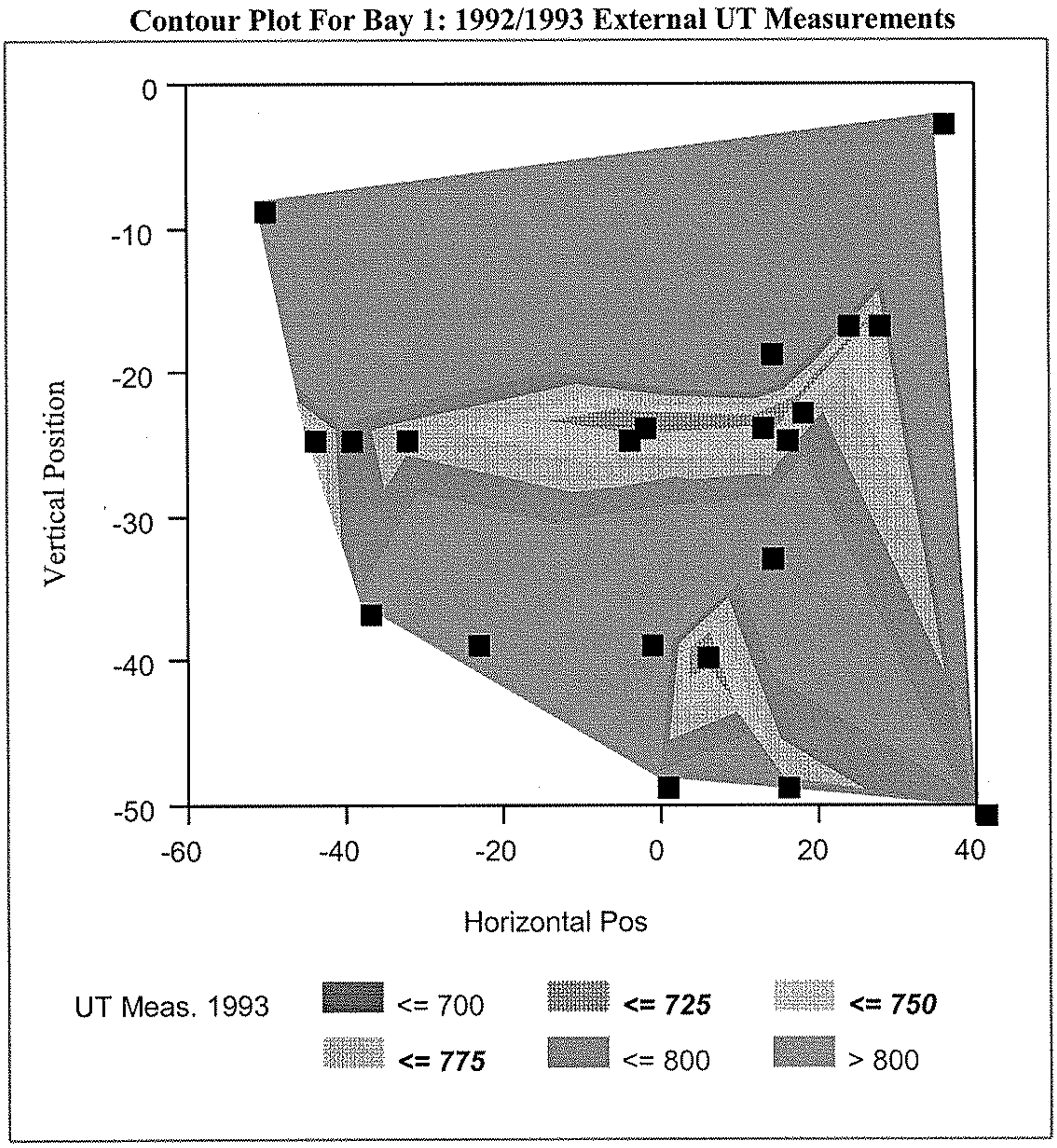


Figure 3

Bay 1 Remaining Wall thickness
External UT Measurements 2006

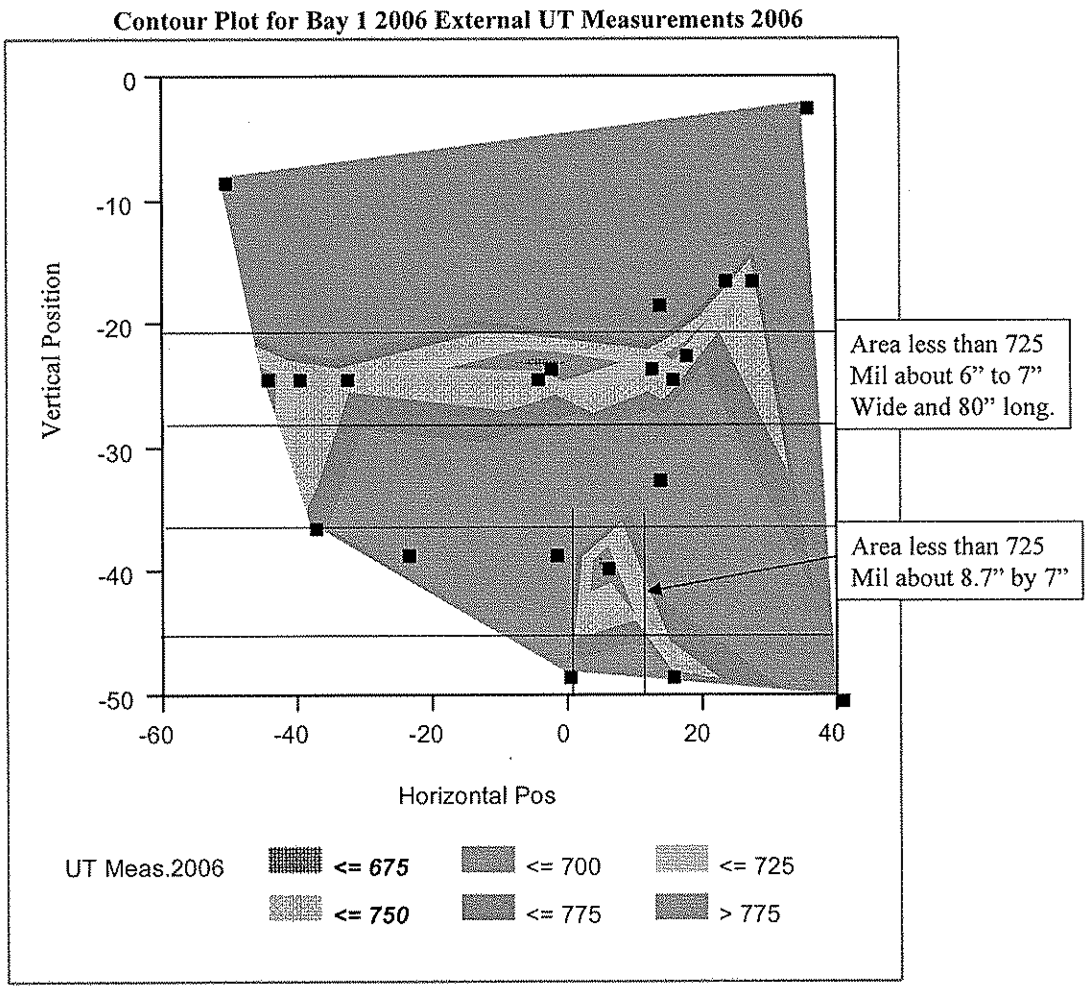


Figure 4

Bay 13 Remaining Wall Thickness
External UT Measurements 1992/1993

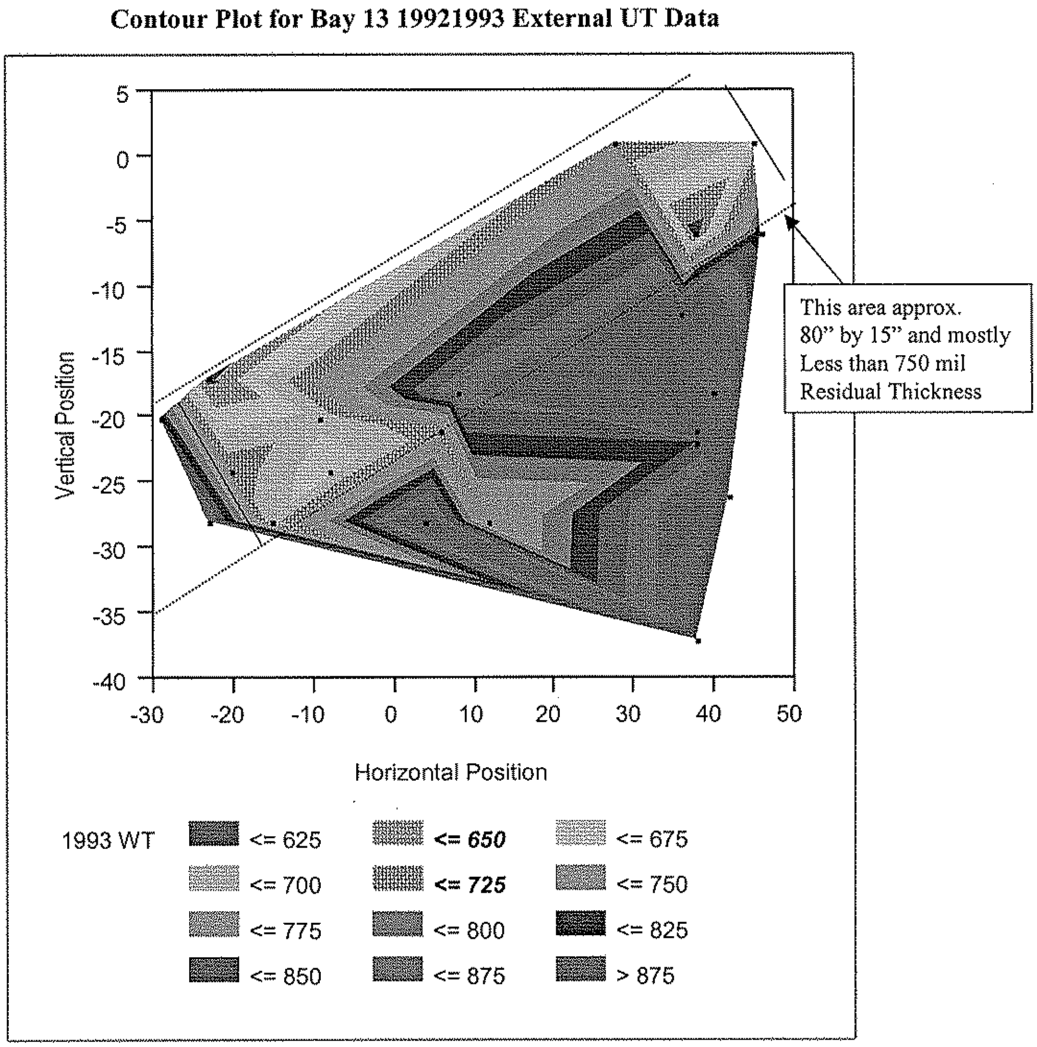


Figure 5

Bay 13 Remaining Wall Thickness
External UT Measurements 2006

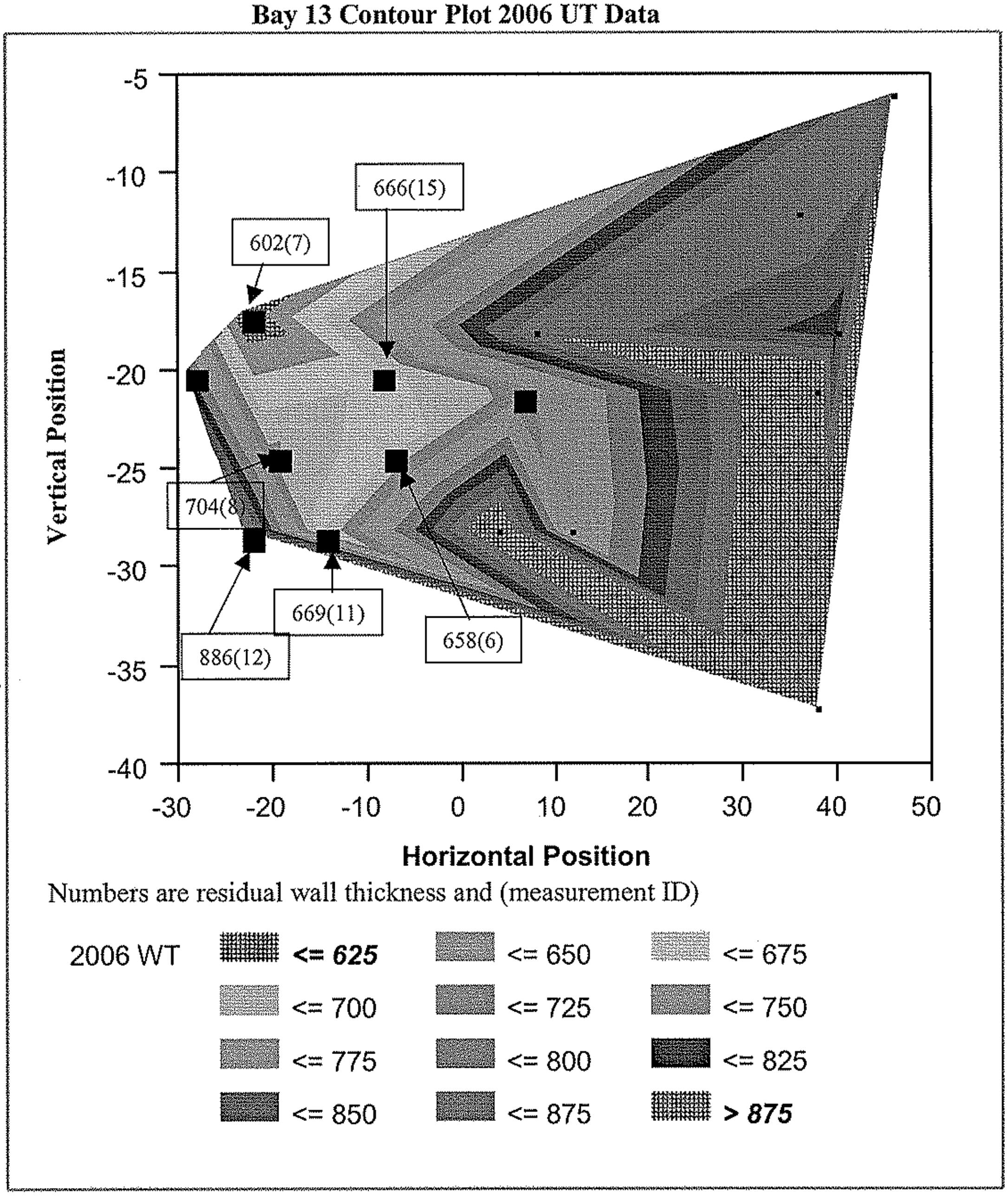


Figure 6

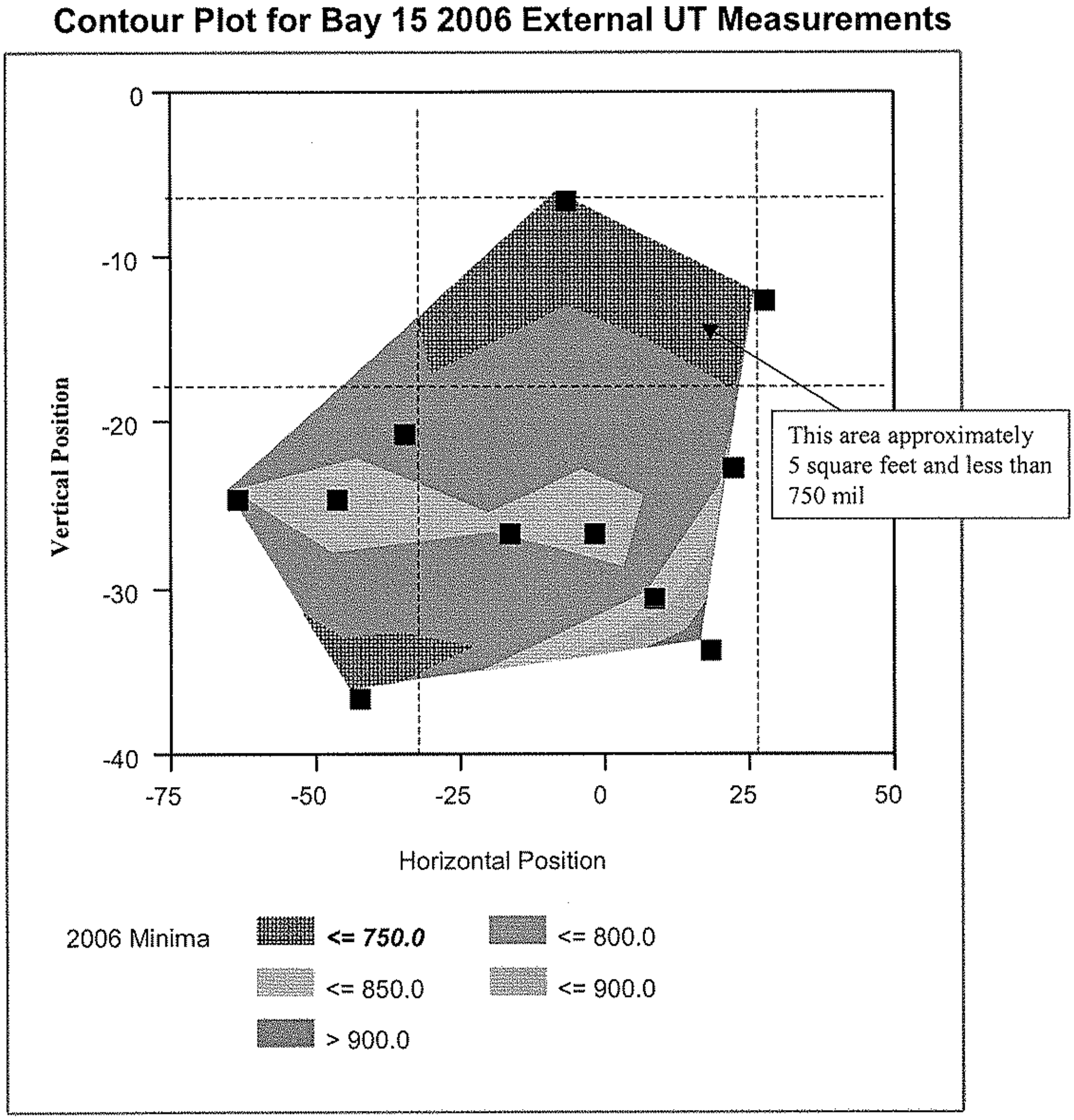
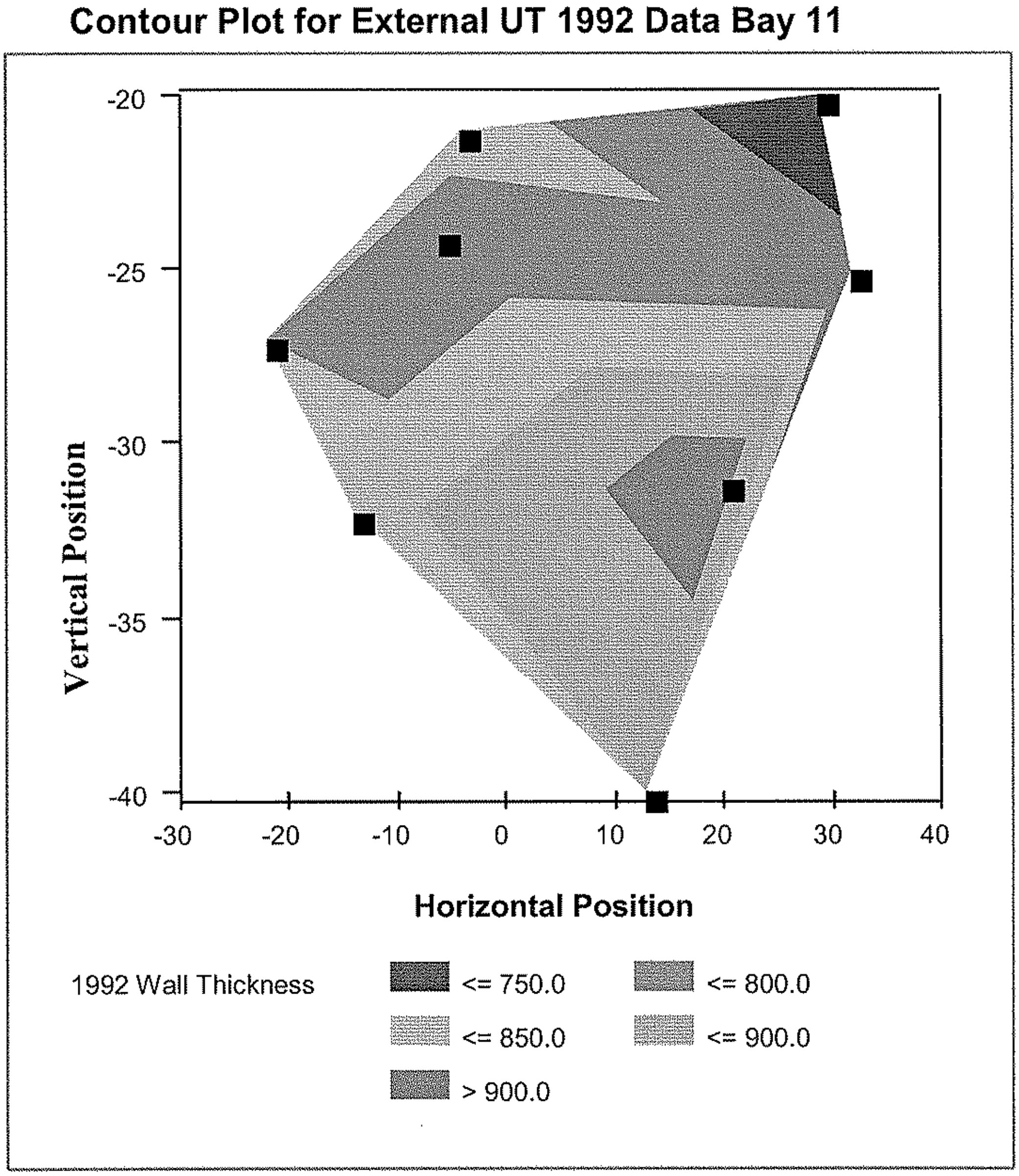

Contour Plot for Bay 15 2006 External UT Measurements
0
-10
-20
-30
-40
Vertical Position
-75
-50
-25
0
25
50
Horizontal Position
This area approximately 5 square feet and less than 750 mil
2006 Minima
<= 750.0
<= 800.0
<= 850.0
<= 900.0
> 900.0

Figure 7



Contour Plot for External UT 1992 Data Bay 11
-20
-25
-30
-35
-40
Vertical Position
-30
-20
-10
0
10
20
30
40
Horizontal Position
1992 Wall Thickness
<= 750.0
<= 800.0
<= 850.0
<= 900.0
> 900.0

Attachment 5

ATTACHMENT 5 – OVERVIEW OF THE RELEVANT FACTS REGARDING CORROSION OF THE DRYWELL SHELL AT THE OYSTER CREEK NUCLEAR GENERATING STATION

BACKGROUND

The drywell shell is a vital part of the safety equipment at Oyster Creek. The shell provides containment in the event of an accident and structural support to many pipes that penetrate the shell. The lower portion of the shell is spherical with an inside diameter of 70 feet. Ex. 1 at 47.[1] It is free standing from an elevation of 8 feet 11.75 inches from the bottom. *Id.* at 40. For around 3 feet 4 inches above that level to elevation 12 feet 3 inches, the exterior of the steel shell used to be supported by sand, but the sand was removed 1992 in an effort to prevent further corrosion. *Id.* at 47-48. This portion of the drywell shell is termed the sand bed region. An interior floor is at elevation 10 feet 3 inches, *id.* at 47, and concrete curbs around the edge of the floor go up to the 11 foot elevation below the downcomers and to 12 feet 3 inches elevation elsewhere. *See* Ex. 2. In the sand bed region, the thickness of the shell wall was 1.154 inches in its uncorroded state. Ex. 1 at 40.

STATEMENT OF FACTS

I. Current Margins

A. Established Acceptance Criteria

AmerGen has established that, on average, each Bay must be thicker than 0.736 inches and that no area should be thinner than 0.49 inches. In addition, AmerGen has recognized the need for a local acceptance criterion to control the extent of contiguous areas that are less than

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1 Citizens' trial exhibits are referred to throughout as "Ex. __," where the blank is the exhibit number. Similarly, AmerGen trial exhibits are referred to as "AmerGen Ex. __." Citizens understand that NRC Staff will attach relevant sections of the Safety Evaluation Report for Oyster Creek ("SER") as an exhibit. These sections are merely referred to as "SER" in this statement.

0.736 inches. However, AmerGen's practice regarding this criterion has been inconsistent so that the Board must determine which is the most appropriate local area acceptance criterion.

B. The Local Area Acceptance Criterion

Until recently, the reactor operator consistently used the local area acceptance criterion to accept areas that were thinner than 0.736 inches, larger than 2 inches in diameter, but less than one square foot in extent. For example, in March of 2006, Mr. Tamburro, AmerGen's employee who has authored many of the reports accepting the measurements, wrote that calculation C-1302-187-5320-024 "uses a Local Wall Acceptance Criteria . . . [which] can be applied to a small area (less than *12 by 12*), which are less than 0.736 inches thick so long as the small area is at least 0.536 inches thick." Ex. 3 at 2 (emphasis added).

Ultimately, the NRC Staff also adopted this approach in the SER by quoting AmerGen's Request for Additional Information ("RAI") response of April 7, 2006 stating that:

> UT measurements identified isolated, localized areas where the drywell shell thickness is less than 0.736 inches. Acceptance for these areas was based on engineering calculation C-1302-187-5320-024. The calculation uses a "Local Wall Acceptance Criteria." This criterion can be applied to small areas (less than *12" by 12"*) which are less than 0.736" thick so long as the small *12" by 12"* area is at least 0.536 inches thick.

SER at 4-56 (emphasis added). After discussion of buckling issues, the quoted document applied that criterion, stating that the total area thinner than 0.736 inches was 0.68 sq. ft, and thus less than one square foot. *Id.* at 4-58. AmerGen continued "these local areas [that are less than 0.736 inches] could be continuous, provided their total area did not exceed one square foot *and* their average thickness was greater than . . . [0.536 inches or 0.636 inches]." *Id.* (emphasis added). Thus, prior to April, 2006 AmerGen documents state that the local acceptance criterion can only be applied to small areas that are less than one square foot in area and NRC Staff adopted this approach in the SER.

Mr. Tamburro's memorandum of March 2006, expressed concerns that calculation C-1302-187-5320-024 was deficient, even though it was the only safety related calculation demonstrating that the drywell shell in the sandbed region met safety requirements. Ex. 3 at 1. Mr. Tamburro himself noted that when a nine square foot area thinner than 0.736 inches was modeled by General Electric, the buckling capacity of the shell decreased by 9.5%. *Id.* at 2. Thus, Mr. Tamburro recommended that calculation C-1302-187-5320-024 be revised to ensure that "a 9.5% reduction in buckling load still meets code allowables." *Id.* at 4. He also noted numerous other deficiencies, the most glaring of which was that four engineers with at least 15 years experience had reviewed the calculation and none could understand how the calculation method and acceptance criteria demonstrated the conclusions of the calculations. *Id.* at 1.

Revision 1 of calculation C-1302-187-5320-024, dated September 21, 2006, did not take the path recommended by Mr. Tamburro. Instead, the authors adopted a more stringent local area acceptance criterion. In a summary table on page 2, the revised calculation applied a local thickness criterion of 0.636 inches to areas that are less than 12 inches square. Ex. 4 (AmerGen Ex. 17) at 5. The calculation also applies this criterion in the text. *E.g. Id.* at 17, 36. However, while it never clearly states the origin of the criterion employed, it does state that modeling done by General Electric ("GE") used tapered shapes with minimum thickness 0.536 inches and 0.636 inches. *Id.* at 10-11. Thus, although the document authors were aware of the approach previously taken, which was to compare the measurements over a 12 by 12 inch area to 0.536 inches, they took a more conservative approach by using 0.636 inches as the allowable thickness over a one square foot area.

In December 2006, AmerGen applied the following local area acceptance criterion: "if an area is thinner than 0.736" thick, then that area shall be greater than 0.693 inches thick and shall be no larger than 6" by 6" wide." Calculation C-1302-187-E310-041, Ex. 5 (AmerGen Ex. 20) at 11. This is yet more stringent than the criterion previously put forward by AmerGen. More recently, for the purpose of summary disposition, AmerGen alleged that the "local area average thickness" criterion is 0.536 inches for a 1 square foot area, but the total area that can be thinner than 0.736 inches is *nine square feet*. Affidavit of Peter Tamburro, dated March 26, 2007, Ex. 6 at ¶¶ 20-23 (emphasis added). This 2007 criterion is considerably less stringent than that used in December 2006. Furthermore, Mr. Tamburro failed to provide justification of why a 9.5% reduction in bucking capacity would be acceptable, contrary to his March 2006 recommendations.

Most recently, revision 2 of calculation C-1302-187-5320-024, dated May 18, 2007, authored by Mr. Tamburro, discusses yet another less stringent criterion. The report requires the UT results to either meet the requirements for general wall thickness given in Section 6.1, or the requirements for local areas that are less than 36 inches by 36 inches in extent given in Section 6.2. C-1302-187-5320-024 rev. 2, Ex. 33 (AmerGen Ex. 16) at 10. The acceptance criterion for general wall thickness requires the average thickness of a 36 inch by 36 inch area to be greater than 0.736 inches. *Id.* If an area fails Section 6.1, it must meet Section 6.2 regarding local wall thickness. In turn, the local wall thickness criterion requires areas that "an evaluated area for local buckling shall not be larger than 36" by 36" wide." *Id.* at 10, Figure 6.2-1. In addition, the 12 inch by 12 inch center of the evaluated area must be thicker than 0.636 inches on average, and the one foot long transition area surrounding the thinnest central area must be "on average thicker than the transition from 0.636 inches to 0.736 inches." *Id.*

In summary, the SER and AmerGen documents show that AmerGen first established an acceptance criterion that required contiguous areas thinner than 0.736 inches to be smaller than one square foot in extent and thicker than 0.536 inches on average. This was accepted by NRC Staff in the SER. Thereafter, in response to internal concerns, AmerGen made the criterion more stringent requiring areas thinner than 0.736 inches to be smaller than one square foot and thicker than 0.636 inches. In December 2006, AmerGen then used a still more stringent criterion: "if an area is thinner than 0.736" thick, then that area shall be greater than 0.693 inches thick and shall be no larger than 6" by 6" wide." Calculation C-1302-187-E310-041, Ex. 5 (AmerGen Ex. 20), at 11. In 2007, AmerGen then deviated from past practice by allowing contiguous areas of up to nine square feet in extent to be thinner than 0.736 inches on average.

Another major issue with the local area acceptance criterion is that it assumes that the corroded areas are squares. The NRC Staff did not consider this issue in the SER because they erroneously believed AmerGen's representation that the total area thinner than 0.736 inches was around 0.68 inches. SER at 3-128, 4-58. As shown below, in some Bays, the areas thinner than 0.736 inches are long, thin grooves running almost horizontally along the drywell shell. These grooves could undermine the stability of the drywell more than square areas of corrosion of the same size. Therefore, great care must be exercised in applying acceptance criteria based on modeling of square areas to such grooves. As such, Dr. Hausler believes that at minimum, local areas thinner than 0.736 inches should be smaller than one square foot and thicker than 0.636 inches on average, as AmerGen required in September 2006.

C. Methods Employed For Measuring Drywell Thickness

The available UT data fall into three categories, 6 inch by 6 inch grids of data taken above the interior concrete floor of the drywell, additional grids of data taken in two trenches that were created on the inside of the drywell before the sand in the sandbed region was removed, and data taken from the exterior of the sandbed region. The grid and trench data consists of 49 points taken at one inch spacing over various 6 inch by 6 inch areas. In each trench six such areas were measured. The drywell shell in the sandbed region is divided into odd numbered bays numbered from 1 to 19. The locations of the grids taken above the interior concrete floor were selected by a horizontal scan in accessible areas below the downcomers at elevation 11'3." SER at 3-137. Grids were taken at the worst 12 of these locations in Bays 9, 11 (two areas), 13 (two areas), 15, 17 (two areas), 19 (three areas), and the frame between bays 17 and 19. Ex. 7 at 16. At 7 other locations a single horizontal line of 7 points was taken in Bays 1, 3, 5, 7, 9, 13, and 15. *Id.* at 16. Measurements were taken at the 12 grids at various times between 1986 and 1992, and then in 1992, 1994, 1996, and 2006. *Id.* at 18; Ex. 5 (AmerGen Ex. 20) at 6.

AmerGen only measured the thicknesses in two trenches below the drywell interior floor thrice, in 1986, 1992, and in 2006. Ex. 8 (AmerGen Ex. 19) at 4. The reactor operator created the two trenches in Bay 5 and 17 to a depth about equal to the sandbed floor on the outside. *Id.* at 1. These trenches enabled the operator to perform UT measurements below the interior concrete floor prior to removal of the sand from the outside. Finally, measurements have been taken from the exterior in 1992 and 2006 at various locations that were visually identified as the thinnest points before the 1992 measurements. Calculation C-1302-187-E310-041, Rev. 0, Ex. 5 (AmerGen Ex. 20) at 48. However, in 2006 it emerged that these results were not actually measured at the thinnest points. Because the locations of the points measured in 1992 were not marked on the coating, the exact locations could not be repeated. *Id.*; *see also* Ex. 8 (AmerGen Ex. 19) Attachment 4 at 14 (some locations not found). However, 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. *Id.* at 8, 16, 18, 20. Strikingly, in Bay 15, the reported results were actually the *maximum* readings obtained. In this Bay, 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 measured value. *Id.* at 20.

D. Margins Based On Mean Thickness

1. Interior Data Taken Above The Curb

The latest grid data show that the mean thickness of the normally distributed data taken in the grids at 11'3" varied from 0.807 inches in Bay 19 to 1.122 inches in Bay 17. Ex. 5 (AmerGen Ex. 20) at 6. Where corrosion was occurring, AmerGen compared the current and projected lower 95% confidence limit of the means to the acceptance criteria for the uniform thickness. SER at 4-60. AmerGen has previously estimated that the uncertainty in the mean of the 49 measurements in a grid is around 0.021 inches, consisting of the standard deviation of the mean, 0.011 inches, plus 0.01 inches allowance for "instrument accuracy." Ex. 10 at 2; SER at 3-121. Confirming that AmerGen really was referring to the standard deviation, the standard deviation of the data set from the interior grid at location 19A is around 0.06 inches, Ex. 5 (AmerGen Ex. 20) at 28, 50, giving rise to a standard deviation in the mean of around 0.01 inches, because 49 points were used to calculate the mean. However, AmerGen appears to have mistakenly only applied one standard deviation to derive the uncertainty. Using normal statistics one should use 1.96 standard deviations as the 95% confidence interval. Thus, using AmerGen's own approach, the uncertainty in the means of the interior grids at 95% confidence is around 0.02 inches of random error plus a possible 0.01 inches of systematic error, giving an uncertainty of plus or minus 0.03 inches.

Moreover, AmerGen has admitted that it must determine the variance of the means of these data and compare the "mean and the variance" to the acceptance criterion. SER at 4-55. Indeed, in 2006, AmerGen mistakenly stated that it had used the 95 percentile of the measured means to calculate the margin. Ex. 35 at 13. In fact, to date AmerGen has largely failed to take account of the variance of the means or the uncertainty regarding systematic error when comparing them to the acceptance criteria, except prior to 1992, when corrosion was clearly ongoing.

Confirming the importance of considering both random and systematic errors, Citizens highlighted systematic errors in the 1996 UT data. After Citizens pointed out that the 1996 means were consistently higher than the 1992 means, NRC Staff also "pointed out a definite bias in the 1996 readings because the average thicknesses . . . increased at almost all locations." SER at 3-127. The Staff also noted that "UT measurements taken from inside the drywell after 1992 show a general increase in metal thickness." SER at 4-53. The Staff further expressed doubt about the validity of the 1994 and 1996 results stating "it appears that the UT measurements taken after 1992 require proper calibration." *Id.* After discussing a response by AmerGen, Staff concluded that the 1994 and 1996 readings were "anomalous." SER at 4-55. Providing the magnitude of the systematic error, AmerGen calculated that the 1996 values were on average 0.015 inches thicker than those taken in 1992. Ex. 11 at 1. Thus, an allowance of at least 0.01 inches to control for systematic error is justified.

2. Interior Data Taken In The Trenches

Unfortunately, the trenches were dug in Bays 5 and 17, which are the least corroded bays. The trench data are therefore of little assistance in deriving margins. However the data are helpful to examine how representative the grid data are and to see how the external measurements compare. Dr. Hausler's analysis shows that the interior grids may overestimate the overall thickness of the drywell shell and that the external results may more accurately represent the thickness of certain areas of the drywell shell.

Figure 2, attached to Ex. 12, plots all individual 2006 measurements from the trench in Bay 17. The 6 traces represent the variation of the wall thickness in the horizontal direction while the traces themselves extend from the bottom of the trench (left hand side) to the top of the trench (right hand side). The undulations of the 6 traces, which are at times (at the same elevation) in synch and at other times out of phase show the nature of the "golf ball type" surface described in AmerGen literature. Where the undulations are in synch, the pit at that location extends over an area larger than just one inch in diameter. The average amplitude of the undulations in Figure 2 are of the order of 0.1 inch.

Figure 2 further shows that the corrosion is most severe at the top, almost uniform in severity over most of the depth of the sandbed and again somewhat more severe at the very bottom. To shed light on these issues, Figure 4, also attached to Ex. 12, compares the average remaining wall thickness from trench measurements (averaged over the horizontal direction) with the average of the 6 by 6 grid measurement from the inside and the direct UT measurements from the outside. Also graphed in this figure are the averages of the external measurements for the three zones for which data are reported.[2] The averages for the grid and the trench data overlap quite well at the same elevation, but the floor and above curb zones are significantly thinner than the curb zone in which the grids are located. Figure 4 actually shows that the external data better represent the floor and above curb zones.

Finally, confirming that the uncertainty in the trench data is similar to the interior grids, in taking account of the variability of the mean of the measured data in the trenches, AmerGen subtracted 0.02 inches before it compared the mean to the acceptance criterion. *See e.g.* Ex. 8 (AmerGen Ex. 19) at 8.

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[2] The zones are: Zone 1 < 9'4" wetted surface; Zone 2 9'4" to 10'3" floor; Zone 3 10'3" to 12'3" curb; Zone 4 >12'4" above curb. Ex. 9 at Figure 4-6

3. Data Taken From The Exterior

Turning to the measurements taken from the exterior, the results taken in Bay 11 show that the measured average thickness was 0.783 inches. Calculation C-1302-187-5320-024 Rev. 2, Ex. 33 (AmerGen Ex. 16) at 52. For Bay 1, the mean of the points is 0.801 inches. *Id.* at 21, and the mean of the minimum data measured at each point in Bay 15 is 0.768 inches. *See* Ex. 12 at Table 1.

AmerGen has argued that applying uncertainty to these results is unnecessary because they are already biased toward the thin side. However, this qualitative reasoning is undercut by Ex. 4, Figure 4, which compares all the data available for Bay 17. It shows that while the external data are indeed biased low for the middle elevations, they overestimate the mean thickness compared to the trench data for the most extreme upper and lower elevations. Thus, it is necessary to take account of the uncertainty in the external data to derive statistical estimates of parameters of interest, such as the mean thickness of the shell in the sandbed region.

For example, looking first at the random errors, in Bay 11, the standard deviation of the data set is 0.048 inches (this includes the random error of the instrument and the variability of the surface itself). Because eight points were measured, the standard deviation of the mean is 0.017 inches. Therefore, the lower 95% confidence limit for the mean thickness is 0.750 inches. Similarly, in Bay 15, the lower 95th percentile of the mean of the corrected data is 0.731 inches, and in Bay 1, it is 0.747 inches. Ex. 12 at Table 1.

In addition to the random error, it is also important to take account of the possibility of systematic error. Indeed, AmerGen has claimed that the 1992 measurements were biased high by 12 to 20 mils. Ex. 9 at 5-2. Although AmerGen has reasonably claimed that the 2006 technique was an improvement over the previous method, *id*, it is prudent to allow for the possibility of systematic bias. Citizens believe that the best approach to this problem is to regard the external readings as representative, even though they might actually be biased to the thin side by their method of selection. This approach ensures that the required degree of conservatism is maintained.

4. Margins Derived From Mean Values

The acceptance criterion for the mean values is 0.736 inches. The lowest estimated mean from the 2006 interior grids is 0.807 in Bay 19 plus or minus 0.03 inches at 95% confidence. Thus, the estimated lowest mean margin derived from the interior grids is 0.071 inches and the lower 95% confidence limit is 0.041 inches. However, the trench data suggest that the means of the external data more accurately represent the true state of the drywell, at least at the extreme upper elevations and below the level of the interior floor. The means of the exterior measurements are 0.783 inches in Bay 11 and 0.768 inches in Bay 15 (using the corrected data). Thus, the mean margins in these Bays are 0.047 inches and 0.032 inches respectively. At the lower 95% confidence limit the means derived from the external data in Bays 11 and 15 are 0.750 inches and 0.731 inches. Thus, these data indicate that there is currently no reasonable assurance that AmerGen can meet its acceptance criterion for the means in Bay 15 and the margin in Bay 11 is a miniscule 0.014 inches at the lower 95% confidence limit.

E. Margins For Very Small Areas

The lowest single point measurement is 0.602 inches taken from the exterior in Bay 13. The 95% confidence limits on single point measurements are around plus or minus 0.09 inches. Ex. 13 at 8. Adding in a possible 0.01 inches of systematic error means that this measurement could represent a thickness of 0.502 inches at the lower 95% confidence limit. Based on an acceptance criterion of 0.49 inches, this means the lower 95% confidence limit of the margin is 0.012 inches.

The lack of certainty on single point values comes in part from the inconsistent search for the thinnest points at each location and the failure to take account of the repeat values where such a search was conducted. In addition, high uncertainty may well be inherent in the measurement methodology. The lack of certainty is illustrated by the scans around the nominal points in Bay 15, where the minimum readings were as much as 0.068 inches less than the recorded value, Ex. 8 (AmerGen Ex. 19), Attachment 4 at 16, even though the nominal point was visually chosen as the thinnest point.

Another way of approaching this issue is to look at the statistics for the external data, divided into zones, which correspond to the interior wetted surface, the elevations beneath the interior floor, the elevations above the floor but below the curb, and the elevations above the interior curb. Ex. 9 at Figure 4-6. In zone 3 of Bay 1, above the interior floor, but below the curb, the lower 95% confidence limit is around 0.456 inches. Ex. 12 at Figure 6. The uncertainty in estimating the minimum thickness of this area stems from large measured differences in a few data points. Because the lower 95% confidence limit is below the acceptance criterion of 0.49 inches, AmerGen has failed to establish that it has any margin above the very small area criterion.

F. Margins For Local Areas Larger Than Two Inches In Diameter

1. Existing Local Areas Thinner Than 0.736 Inches

AmerGen evaluated the 2006 external results in revision 2 of Calculation C-1302-187-5320-024. The new revision shows that AmerGen now estimates that over 20 square feet of the drywell shell in the sandbed region is thinner than 0.736 inches. Calculation C-1302-187-5320-024, Rev. 2, Ex. 33 (Amergen Ex. 16) at 29, 64, 79, 89. This contrasts with the estimate contained in the previous version of the calculation that only 0.68 square feet of the drywell shell was thinner than 0.736 inches. Calculation C-1302-187-5320-024, Rev. 1, Ex. 4 (AmerGen Ex. 17) at 13. The expansion of the critically thin areas is caused in part by the reduction in measured thickness in 2006 and in part by a change of estimation technique.

The latest revision to Calculation C-1302-187-5320-024 also shows a 9 square foot area in Bay 1 that is 0.696 inches thick. Calculation C-1302-187-5320-024, Rev. 2, Ex. 33 (AmerGen Ex. 16) at 26, 34. Looking at Figure 1-2 on page 29, there is no data just outside the boundaries of the 36 inch by 36 inch box used for the assessment. *Id.* at 29. In fact, this box could have been drawn considerably larger without including any more measurement points. Furthermore, the "bathtub ring" shown on Figure 1-2 appears to be even more extensive than estimated by AmerGen. Thus, based on AmerGen's own estimates, it is possible that an area exists in Bay 1 that is thinner than 0.736 inches but thicker than 0.636 inches and is larger than nine square feet in extent.

To take a more systematic approach than merely drawing shapes around data points, Citizens applied a contouring program to produce unbiased interpolations of the data. This approach estimated that Bay 1 has two areas thinner than 0.736 inches. Ex. 13 at Figure 3. The first is a long thin groove that is around 3 square feet in extent and the second is a smaller area that is around 0.4 square feet in extent. The actual extent of the first area could be considerably larger because it is not bounded by the data on the left hand side.

Similarly, on the top left of Bay 13, there could be a rectangular area which is 28 inches high by 84 inches wide (16.3 square feet) that has an average thickness of 0.692 inches. *See* Calculation C-1302-187-5320-024, Rev. 2, Ex. 33 (AmerGen Ex. 16) at 64. The contouring program confirmed these findings. The best fit for the data show an area thinner than 0.736 inches that is around 5 square feet in extent, but is not bounded by the data. Ex. 13 at Figures 4 and 5 (the thin area on the upper right of Bay 13 is not shown on the 2006 plot because AmerGen failed to repeat the measurement at point 2, which was 0.615 thick in 1992). Indeed, the thinnest point is at the edge of the predicted area.

Finally, Bay 19 has an elongated area that is thinner than 0.736 inches, but is very poorly defined spatially. Calculation C-1302-187-5320-024, Rev. 2, Ex. 33 (AmerGen Ex. 16) at 95; Ex. 13 at Figure 1. The extent of this area could range from around 3 square feet to more than 9 square feet.

Turning to the thickness of areas that are greater than 2 inches in diameter, but less than one square foot in extent, in 1992 the thinnest local area measured was 0.618 inches thick at point 7 in Bay 13, which AmerGen stated could extend over a 6 inch by 6 inch area. Calculation C-1302-187-5320-024, Rev. 1, Ex. 4 (AmerGen Ex. 17) at 36. In 2006, the thickness at the same location was measured at 0.602 inches. Ex. 8 (AmerGen Ex. 19), Attachment 4 at 14. The data show that this point is adjacent to point 15, which has measured thickness of 0.666 inches. Calculation C-1302-187-5320-024 Rev 2, Ex. 33 (AmerGen Ex. 16) at 58, 63-64. Thus, that data show that an area of over one square feet at thickness 0.636 inches could exist in Bay 13. AmerGen appears to have omitted consideration of the reading at point 15 from its calculations, but based on readings at points 7, 8, and 11, it has concluded that the thinnest one square foot area in Bay 13 is 0.658 inches. *Id.* at 59. Notwithstanding the omission of point 15, because the 95% uncertainty limits of a mean based on three points are at around plus or minus 0.05 inches, AmerGen's own calculation shows an area of one square foot in extent could be less than 0.608 inches thick, at the lower 95% confidence limit.

The area estimates are highly uncertain because large areas of the sandbed have not been measured at all. This means that the areas thinner than certain thresholds cannot be accurately estimated numerically because those areas are often not bounded by the data points. The estimates of area given by the contouring program should therefore be regarded as a floor rather than a ceiling.

2. Margins Based on Local Area Criteria

The various formulations of the local area acceptance criteria restrict the area of the drywell that can be below certain thicknesses. Citizens have shown that the mid-range estimate of the largest contiguous area thinner than 0.736 inches in Bay 1 is probably larger than 3 square feet and the area thinner than 0.736 inches in Bay 13 is probably larger than 5 square feet. Upper bound estimates put the largest contiguous areas in Bays 1 and 13 thinner than 0.736 inches at over nine square feet. Most versions of the acceptance criteria for local areas requires contiguous areas thinner than 0.736 inches to be smaller than one square foot. It is therefore highly likely that Bays 1 and 13 violate these criteria. Even the most expansive version of the local area acceptance criterion only allows a contiguous area of 9 square feet to be thinner than 0.736 inches. Because the thin areas in Bays 1, 13, and 19 are not bounded, it is not possible to demonstrate that these areas meet even that minimum requirement with 95% certainty.

Figure 1-5 of Calculation C-1302-187-5320-024, Rev. 2 (Ex. 33 or AmerGen Ex. 16) applies the latest version of the local area acceptance criterion to the thickness measurements taken in the transition zone from the thinnest area and shows that, according to AmerGen, the margin at locations 1 and 5 in Bay 1 is around 0.01 inches. At the lower 95% confidence limit either of these readings could be 0.09 inches lower. Thus, AmerGen cannot show that Bay 1 even meets the latest applied version of the local area acceptance criterion with anything like 95% confidence. This means that there is no reasonable assurance that Bay 1 meets AmerGen's current required acceptance criteria for local areas thinner than 0.736 inches. Figure 19-4 of

Calculation C-1302-187-5320-024, Rev. 2 (Ex. 33 or AmerGen Ex. 16) shows a similar problem in Bay 19.

Turning to areas of around one square feet in extent, it is likely that an area of thickness 0.636 inches that is larger than one square foot exists in Bay 13. Most versions of the local area acceptance criteria require thin areas of one square feet in extent to be thicker than 0.636 inches. It is likely that Bay 13 violates these versions of the local area acceptance criterion for areas of around one square feet in extent.

II. Potential For A Corrosive Environment To Exist

A. Exterior Corrosion

Epoxy was applied to the shell in the sandbed region in two different ways. For most of the shell, a two-layer epoxy coating with a primer was painted onto the metal of the drywell. However, for a small potion of the shell just above the uneven concrete floor of the sandbed region, it was covered by epoxy poured upon the floor to direct any water reaching the sandbed region away from the drywell shell and into the drains. The epoxy coating on the floor was poured before the epoxy was painted on the rest of the drywell shell. *See* Photograph of "Bay 5 before shell coating" provided by AmerGen as reference material to the ACRS, Ex. 14. Thus, portions of the shell above the sandbed concrete floor, but below the level of the epoxy coating applied to the floor, are protected only by the epoxy coating on the floor.

Corrosion on the exterior of the drywell shell will occur if the epoxy coating is not intact and water is present. Looking first at the integrity of the coating, there are always holidays or pinholes present when coatings are installed that can provide sites for corrosion to develop. Here, the reactor operator did electrical testing of the coating in a mock-up outside the system, Transcript of ACRS Meeting on January 18, 2007, Ex. 15 at 135:15-17; Ex. 17 at OCLR13720, but failed to monitor the actual coating in a similar way relying instead on visual inspection.

Transcript of ACRS meeting on October 3, 2006, Ex 16 at 60:20-61:2; Ex. 17 at OCLR13720. Because AmerGen's expert, Mr. Cavallo, acknowledged that "usually holidays are not visible," Transcript of ACRS Meeting on January 18, 2007, Ex. 15 at 144:21-22, it is likely that there were at least some pinholes in the coating from the start.

The next question is whether the coating could deteriorate over time. Mr. Cavallo in his affidavit for summary disposition did not dispute that deterioration of the coating could occur, indeed he admitted that it was possible that repair of the coating might be necessary at some point. Affidavit of Jon R. Cavallo, dated March 26, 2007, Ex. 18 at ¶ 22. Furthermore, AmerGen has admitted that the epoxy coating has a limited life of between 10 and 20 years. Transcript of ACRS meeting on October 3, 2006, Ex. 16 at 61:12-22. The coating was applied in 1992 and is now around 15 years old. Thus, it is reasonable to assume that the coating could fail at any time during any extended period of operation.

Showing that the potential for the epoxy coating to deteriorate is not mere speculation, since 1996, inspections have found that the epoxy coating on the floor was separating from the concrete underneath. Ex. 19 at 1. The latest inspections showed separated seams and voids in Bays 1, 7, 9, 15. *Id.* These defects meant that water could have penetrated the epoxy coating on the floor prior to its repair. *Id.* at 2. This means that any water in the sand pocket would not necessarily have been directed to the drains.

With regard to the potential for water to be present, operating experience shows that much water entered the sandbed region in the past. For example, AmerGen found water in the sandbed drains as recently as March 2006. Ex. 20, Letter from Conte to Webster, dated November 9, 2006 *available at* ML063130465. The source of this water was not determined. *Id.* Furthermore, it has not been established that the only source of water is the reactor fueling cavity. Indeed, documents indicate that the equipment pool has also leaked. Ex. 21 at OCLR 29277. Other documents indicate that fuel pool water that did not originate from the reactor cavity has been found in the sandbed region. Ex. 22 at OCLR 28915. In addition, some water will result from condensation during outages. *See* Ex. 23 (water found in bottles capturing drainage from the sandbed region in April 2006 had no activity). Moreover, AmerGen has admitted that it has not yet devised a means of preventing the reactor fueling cavity from leaking. Transcript from ACRS Meeting on Feb. 1, 2007, Ex. 24 at 217-222. Thus, it is entirely reasonable for all parties to assume that water may enter the exterior of the sandbed region during any extended period of licensed operation.

B. Interior Corrosion

In the October 2006 inspection, AmerGen unexpectedly found water in the trenches. Ex. 25, Letter from NRC to C. Crane, dated January 17, 2007 enclosing summary of results of in-service inspection from October 16 to December 6, 2006 ("Inspection Report") *available as* ML070170396 ("water was discovered in the drywell trenches . . . . The presence of water was not expected by AmerGen. . . . AmerGen determined that an environment/material/aging effect combination exists that had not been previously included in the Oyster Creek license renewal application. AmerGen's letter to the NRC (2103-06-20426), dated December 3, 2006 addresses this issue. . . ."); *see also* Ex. 35 at 2 ("as a result of performing planned inspections [in October 2006] of the internal surface of the drywell shell trenches excavated in the concrete floor in 1986, AmerGen identified an environment/material/aging effect combination that was not included in the LRA.")

Comments by AmerGen presenters at the meeting of the ACRS on January 18, 2007 confirmed that the finding of the wet interior condition was unexpected. Mr. Gordon described it as "surprise water." Transcript of ACRS meeting on January 18, 2007, Ex. 15 at 209:17-19. Mr. Polaski stated "we believe that the whole inside of the drywell below the floor has water in there," *id.* at 216:2-3, and then confirmed that AmerGen believes that "there's water in this lower part of the sphere . . .between the concrete and the shell." *Id.* at 216:4-9. In fact, the Inspection Report 05000219/2006013 revealed that contrary to AmerGen's assertions, this condition had been previously identified in 1992 and 1994, but not addressed:

> The inspectors noted that the presence of water in the bay 5 and bay 17 trenches inside the drywell had been reported in Structural Inspection Reports in 1992 and 1994. The Structural Inspection Report from 1994 (dated January 3, 1995) indicates that the rectification of the situation will require prevention of water from reaching the trenches with proven material(s). However, this condition and the evaluation were not addressed by the corrective action process in effect at the time.

Ex. 25 at 9.

NRC Staff have stated that corrosion has occurred at other reactors in containment steel plates where wet concrete abuts the steel liner and there were voids or foreign objects in the concrete. SER at 4-51. Indeed, it was partly the possibility of "some insignificant corrosion" on the interior that led AmerGen to commit to further external UT monitoring in 2008. AmerGen Letter of Dec 3, 2007, Ex. 35 at 14. Finally, AmerGen has tried to suggest that inerting of the atmosphere inside the containment during reactor operation would prevent a corrosive environment on the interior of the drywell. That is incorrect, because other BWRs have experienced corrosion *inside* their drywells. SER at 4-67 (emphasis added). Even at Oyster Creek, some rust was observed when the trenches were opened in October 2006. Transcript of ACRS meeting on January 18, 2007, Ex. 15 at 222:8-10. In fact, the precise description was that the "surface had traces of red primer and gray sealant layer. Bare metal had a light oxide layer and areas of light to moderate pitting. . . . In areas of pitting no attempt was made to clean out or 'chase the pits.'" Ex. 26 at OCLR 14454. Furthermore, Oyster Creek has experienced corrosion inside the drywell in the reactor building closed cooling water system. Ex. 27 at OCLR13629. The observed corrosion can probably be explained because the specifications only require oxygen to be below 5% during operation, they do not require the drywell to be completely inerted. *Id.*

In summary, it is substantially certain that a potentially corrosive environment exists on the interior of the drywell liner in the sandbed region. The critical issue whether the corrosion rate could be significant.

III. Future Corrosion Rate

A. Exterior Corrosion

For the grid data taken from the inside of the drywell liner AmerGen established a statistical method to project the past corrosion rate to the future in situations where the corrosion rate was linear and significant. SER at 4-60. It did this by trending the mean of the grid data and then projecting the lower 95% confidence limit of the projected thickness into the future. *Id.* This method worked well before the sand was removed from the drywell because the corrosion rates were quite large. For example, the mid-range estimates of the corrosion rate from mid-1989 to early 1990 were up to 0.069 inches per year. Ex. 28 at 7. Long term corrosion rates were lower, at up to 0.035 inches per year. *Id.* The estimates of the corrosion rate were quite uncertain, depending on how many results were used to generate the estimate. However, after 1992, where no trend was visually identifiable, AmerGen tried to use the established statistical method, but found it inapplicable because there was no significant slope. It then assumed the corrosion rate to be zero and failed to analyze the uncertainty in the data. Ex. 7 at 19-30.

In Calculation C-1302-187-E310-041 AmerGen took a different approach when considering the external data. It compared the points measured in 1992 with those measured in

2006 and found that the largest apparent corrosion rate was 0.034 inches per year. Ex. 5 (AmerGen Ex. 20 at 49). It then calculated that at this rate the thinnest measured point would be 0.515 inches thick in 2008. *Id.* It therefore decided to take another round of external measurements in 2008.[3] *Id.*

To illustrate the potential for corrosion from the outside, using a set of assumptions that included a corrosion rate of 0.039 inches per year, Mr. Gordon estimated that if the coating failed and moisture got to the metal surface, metal loss could be up to 0.042 inches in the 56 weeks following an outage. Ex. 29, Affidavit of Barry Gordon, dated March 26 2007 at ¶ 18. Thus, Mr. Gordon appears to believe that additional corrosion at an appreciable rate could occur if the coating fails and wet conditions are present. This supports Citizens' position. The difference is that because Citizens believe that that the margins are, at best, less than 0.04 inches, Citizens conclude that a monitoring frequency of every 4 years is too long. Indeed, even if Mr. Tamburro were correct that the minimum margin is 0.064 inches, the possibility that 0.042 inches could be lost each outage if coating decay commences would still indicate that monitoring should be undertaken every outage.

B. Interior Corrosion

Although AmerGen believes the rate of interior corrosion will generally be small, New Jersey has recently written to NRC providing cautionary expert comments. Ex. 30, Letter from Lipoti to Kuo, dated April 26, 2007 attaching letter from R.M. Latanision, dated March 26, 2006.

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3 In fact, inspection of the results shows that the thinnest measurement at the location used to calculate the corrosion rate (point 2 in Bay 17) was 0.663 inches, not the 0.681 inches reported. Using the thinnest point measured at this location, as was apparently done in 1992, would therefore yield a corrosion rate of 0.04 inches per year. Applying this rate and a single point uncertainty of 0.09 inches to the thinnest measured result in Bay 13 of 0.602 inches would mean that the acceptance criterion for areas of less than 2 inches in diameter could be violated in 6 months. Citizens provide this analysis to illustrate the consequences of applying AmerGen's latest approach to any extended period of operation.

Mr. Latanision, an expert retained by New Jersey, warned that interior corrosion could be appreciable if voids are present in the concrete adjacent to the steel shell. In addition, he warned that if the water chemistry changed, corrosion could accelerate in the future. He therefore suggested that real time monitoring of the thickness of the drywell at the thinnest spots should be considered. *Id.*

Even the members of the ACRS recognized the dangers of interior corrosion. For example, Dr. Shack commented at the January 18, 2007 meeting:

> Well, the surprise for me today was the notion that we have water in the imbedded region. That concerns me a little bit. I mean, I fully agree with the argument that it's a fairly benign environment and the corrosion rates are low, and in a containment that didn't have the already substantial corrosion that this one does, I would sort of agree that its probably not a problem. But this is a containment where there isn't a whole lot of margin, and you know, the estimate was you had 41 mils lost and that was less than one mil per year. Well, I do the arithmetic and I get more like two mils per year.

Ex. 15 at 356:4-17.

The 41 mils Dr. Shack is referring to came from an effort to measure corrosion in Bay 5 below both the exterior sandbed floor and the interior floor. The UT measurements at this location showed 41 mils of wall loss. Ex. 35 at 20. In this region the interior was wet from at least 1994 onwards. However, it is unclear whether the exterior was wet. Bay 5 was the bay with the least corrosion. Therefore, assuming negligible exterior corrosion, and that the wall loss occurred between 1994 and 2006, the average interior corrosion rate would be around 2 mils per year. This corrosion rate will also apply to the interior of the sand bed region below the 10 feet 3 inches level, which is the height of the interior floor. At minimum, this should be added to estimates of corrosion rate from the exterior to derive a combined corrosion rate.

In addition, it is possible that water chemistry could change in the future and accelerate the interior corrosion rate. Indeed AmerGen's own consultant has stated that AmerGen's assessment of negligible corrosion on the interior relies in part on the high pH of the concrete pore water in contact with the drywell shell, but at times the pH of that water drops significantly due to control rod drive maintenance. Ex. 36, E-mail from Schlaseman to Ray, dated November 2, 2006. Indeed, the consultant stated "the protective pH cannot be assumed to exist during outages anywhere below the 10'3" level in the DW [drywell]." *Id.* at 2. Another potential source of water to the interior of the drywell shell is the containment spray. Recently, on July 17, 2007, Citizens understand that the containment spray was used during an unplanned outage. It is currently unclear what quantities of water were released or whether that water contained impurities that could accelerate interior corrosion. To date, AmerGen's assessment of corrosion from the interior has failed to take account of the pH variation on the interior and the potential for the core spray to add significant amounts of water. Thus, there is inadequate assurance that the past low rate will be maintained in the future.