ATTACHMENT 3

CORRO-CONSULTA
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MEMORANDUM – REDACTED VERSION – JULY 19, 2007

To: Richard Webster, ESQ
Rutgers Environmental Law Clinic
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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. 2d
- 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

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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.

1; 2.a

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; 2.a; 2.d

[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).

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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.

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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.

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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.

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[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. 1; 2.a; 2.d

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. 1; 2.a

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 1; 2.a

1; 2.a

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.

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III. The Fitness for Use Criteria

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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 for which there is no physical explanation. ¶

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). ¶

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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%. ¶

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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. ¶

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<#>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]

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IV. Statistics

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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

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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 l[... [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.

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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.

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

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. ¶

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.

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

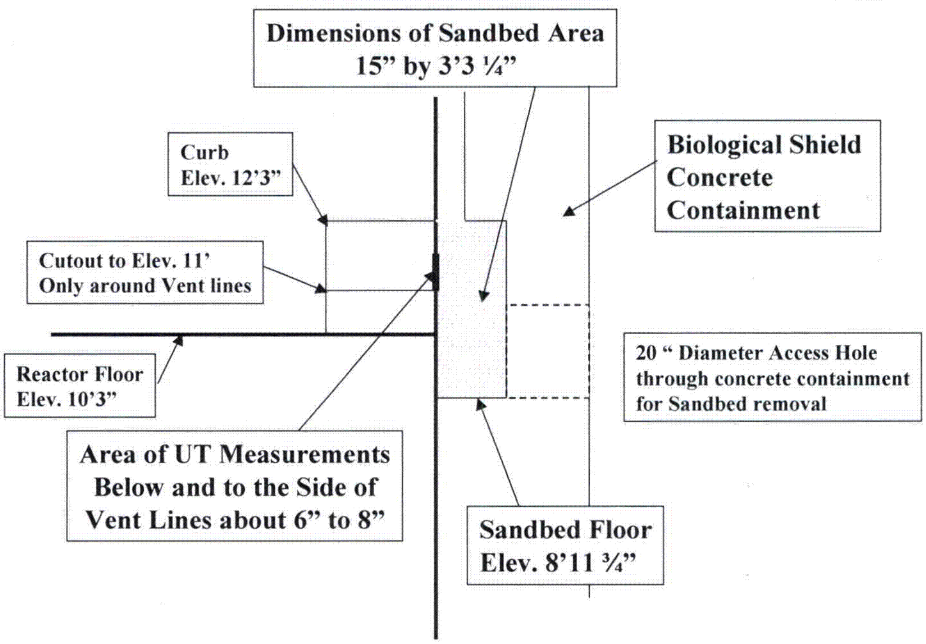
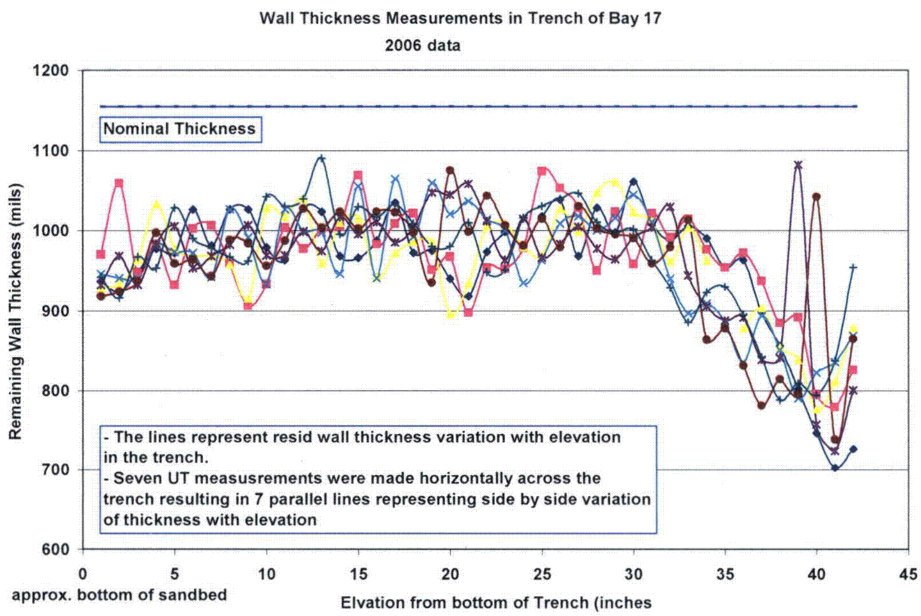
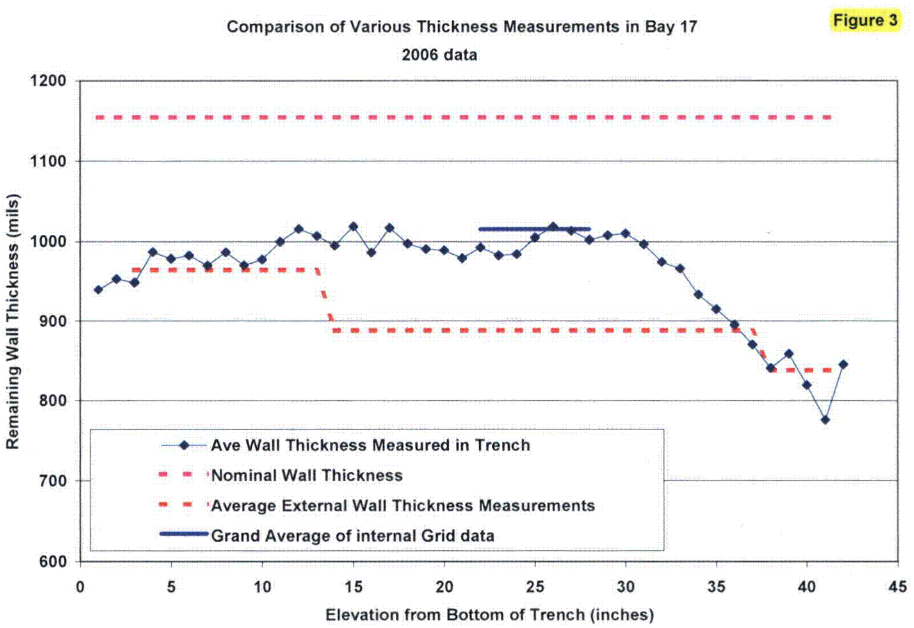


Figure 2

1; 2.a (Entire Figure)





1; 2.a (Entire Figure)

1; 2.a (Both Figures)

Figure 4

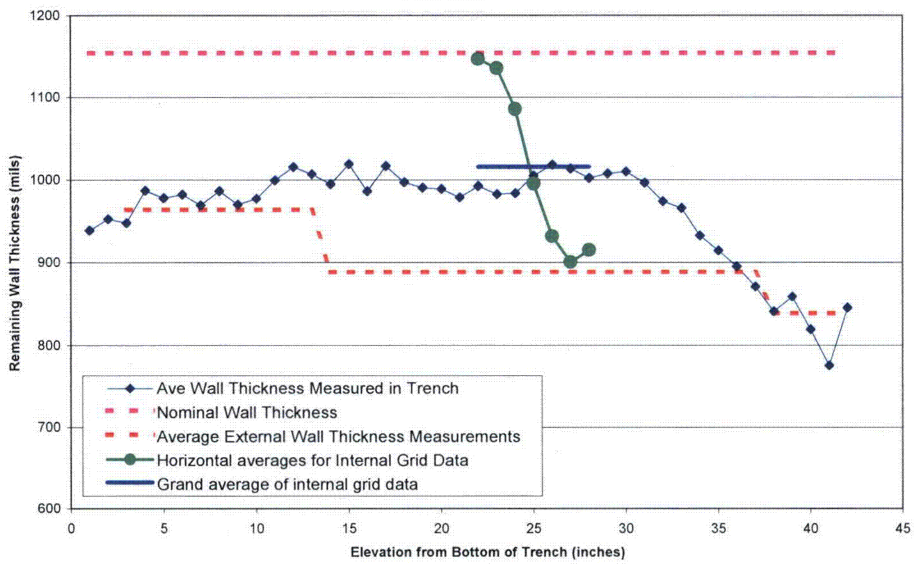
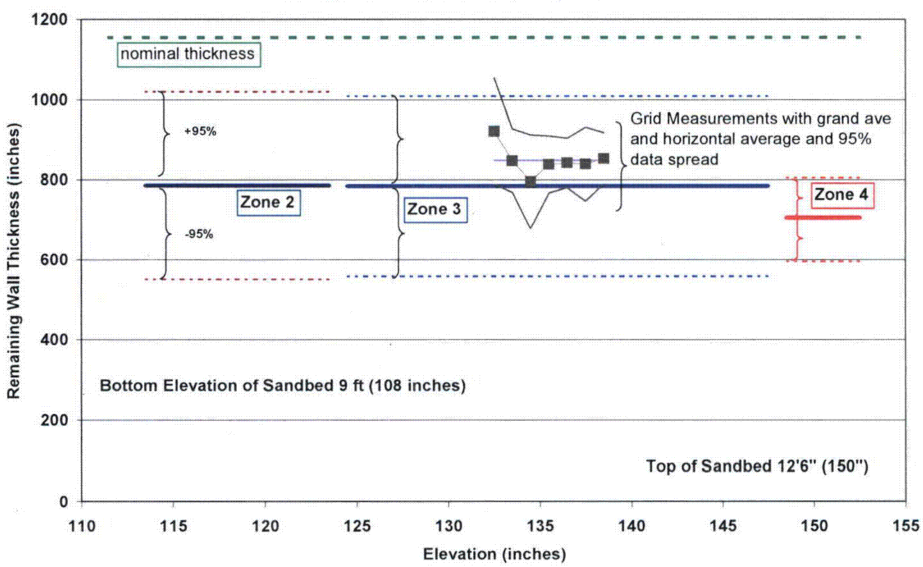


Figure 5



1; 2.a (Entire Figure)

Figure 6

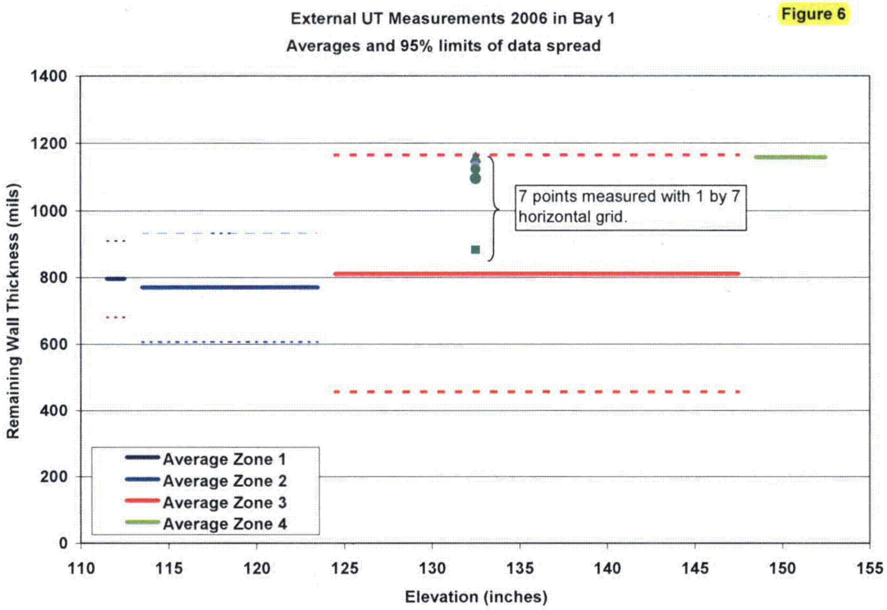


Figure 7

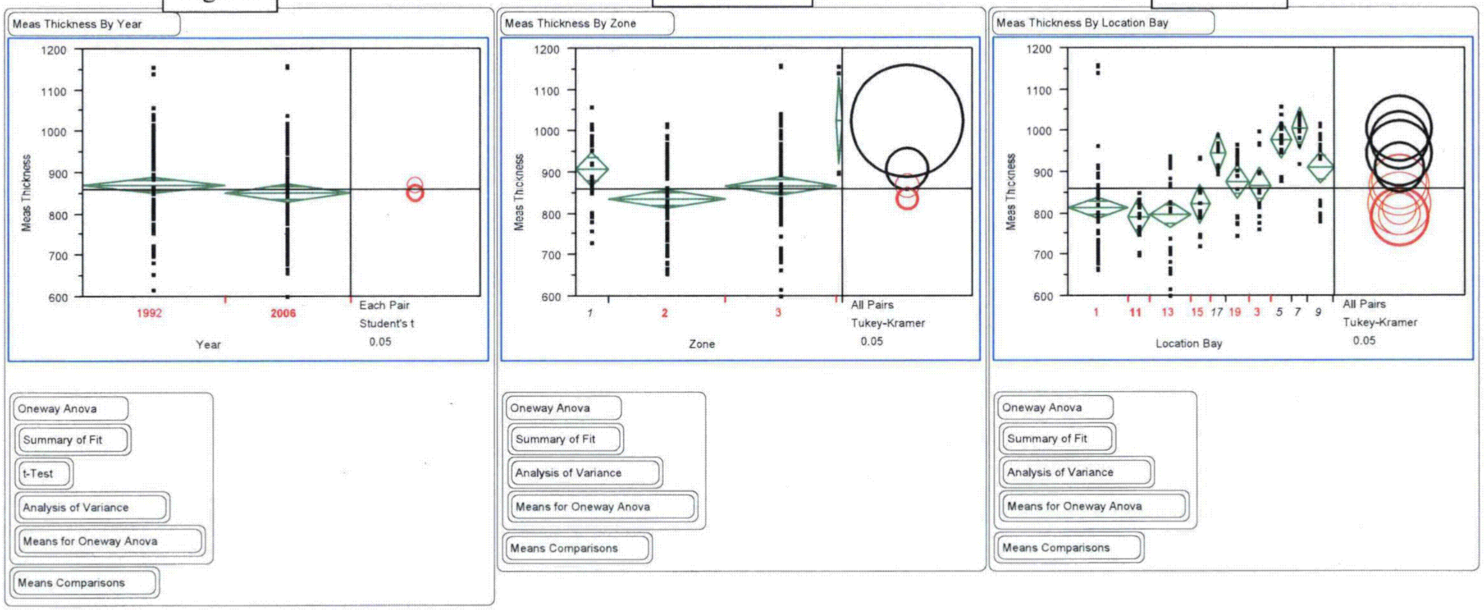
1; 2.a (Entire Figure)

Statistical Analysis of all External UT Measurements

Fig 7 a

Figure 7b

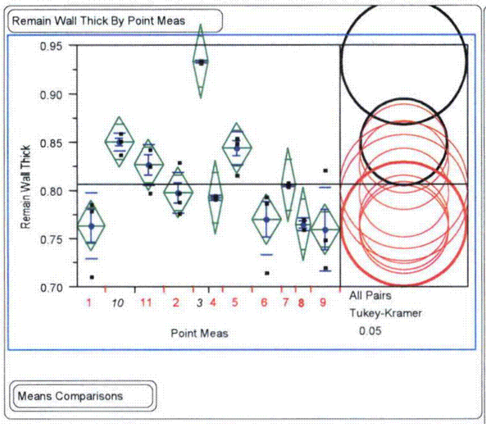
Figure 7c

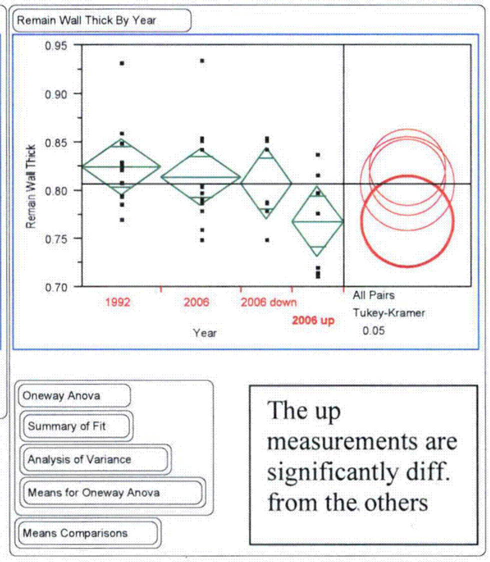


Comments: Figure 7a: Comparison between measurements I 1992 and 2006 show no significant difference. The means from 1992 and 2006 show a bias of 0.018 inches, but the bias is statistically not significant despite of the many data points. Fig. 7b: The comparison between the "zones" (elevations) is significant. 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.

1; 2.a (Both Figures)

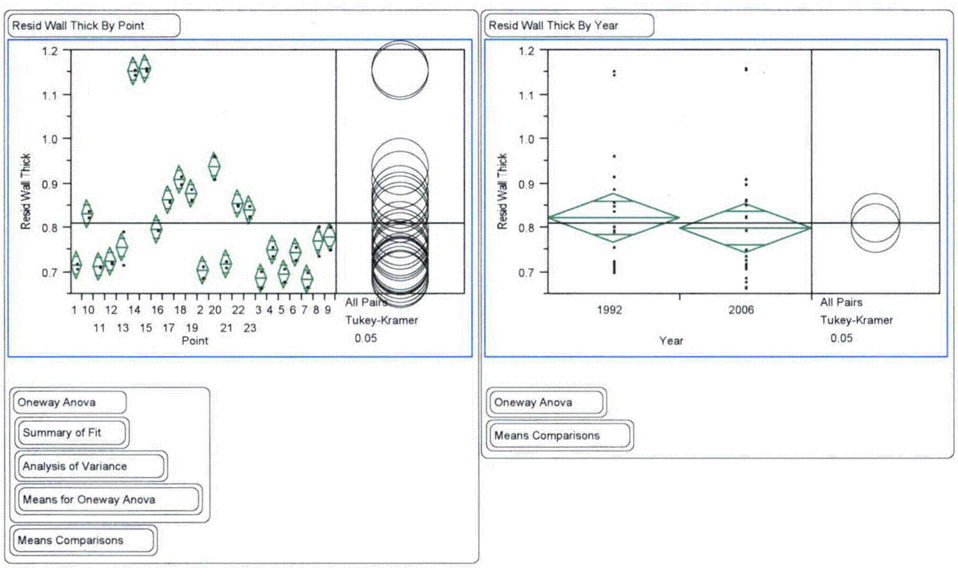
Figure 8: External UT Measurements in Bay 15





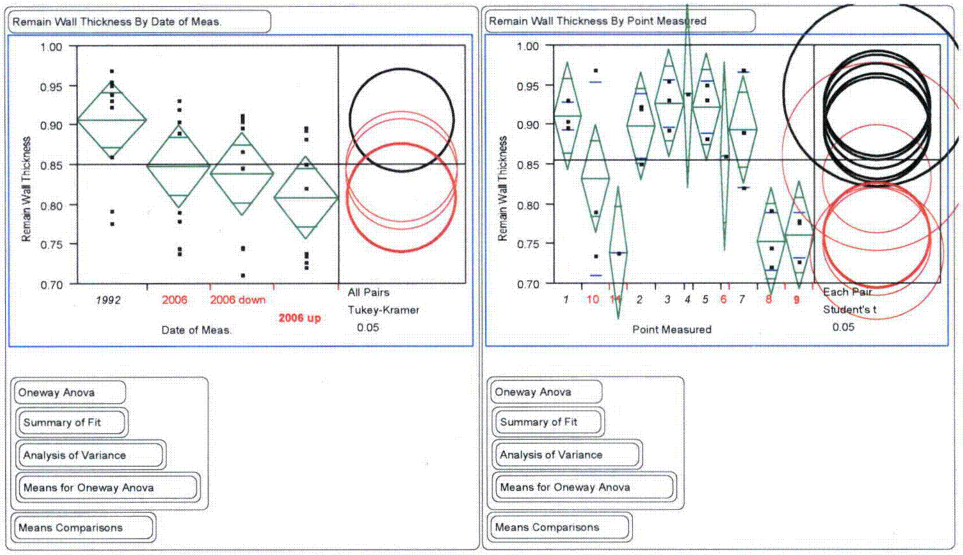
Each point has been measured multiple times. Some points (red) are significantly different from other points (black). Pitting is not uniform.

Figure 9: External UT Measurements in Bay 1.



1; 2.a (Figure 10 and Table 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**

4 n.39 (Entire Page)

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.

4 n.39 (Entire Page)

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.

4 n.39 (Entire Page)

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.

ATTACHMENT 4

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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 1; 2.a severe corrosion existed the standard deviation of the measurements is between 40 and 50 mils for 95% confidence limits of +/- 90 mils. 1; 2.a

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. 1; 2.a

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. 1; 2.a; 3

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 2.c 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

1; 2.a

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.

[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 3 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 2.d 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.

1; 2.a; 3

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 2.d 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 2.d 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.

3

1; 2.a

2.d; 3

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.

1; 2.a

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

1; 2.a; 3

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.

1; 2.a; 3

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.

1; 2.a

1; 2.a; 3

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

1; 2.a

- 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.

1; 2.a; 2.d

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 2.d 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). 2.d

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. 1; 2.a

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. 1; 2.a; 2.c

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. 1; 2.a

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%. 1; 2.a

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.

1; 2.a

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

1; 2.a

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]).

1; 2.a; 3

1; 2.a

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.

1; 2.a; 3

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

1; 2.a

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.

1; 2.a; 2.d; 3

that these areas seem to extend on the left beyond h –40 inches but no measurements are available to verify whether AmerGen did in fact manage to capture all of the most corroded areas as claimed.

1; 2.a; 3

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.

1; 2.b

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.

1; 2.b; 2.d

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.

1; 2.a; 2.d; 3

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.

1; 2.a; 2.d

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.

1; 2.a; 2.d

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. 2.c

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

2.c

- 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.

2.c

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.

2.c

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:

2.c

-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

2.c

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. 2.c

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

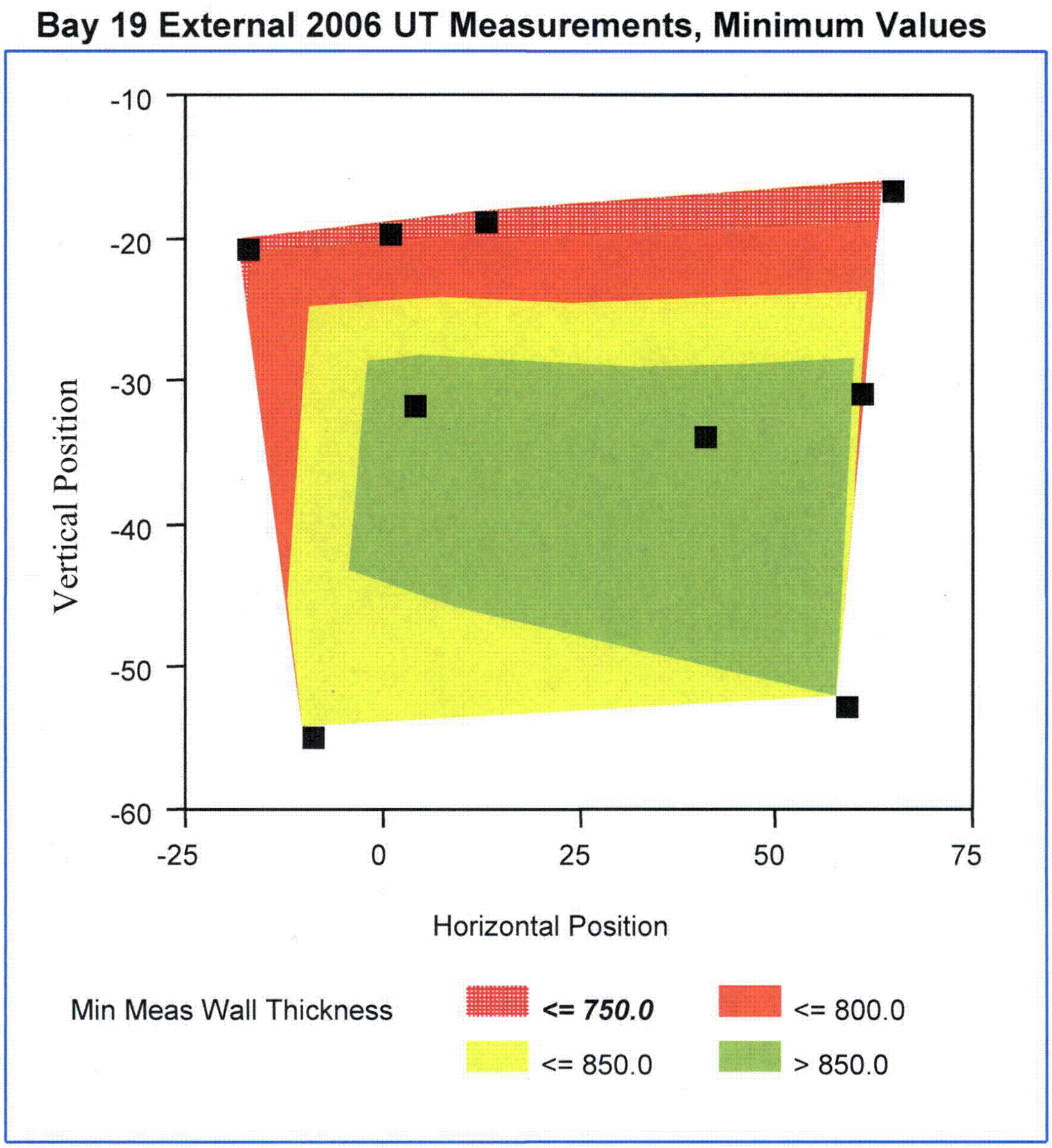
Table 2

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

1; 2.a (Entire Figure)

Figure 1



1; 2.a (Entire Figure)

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

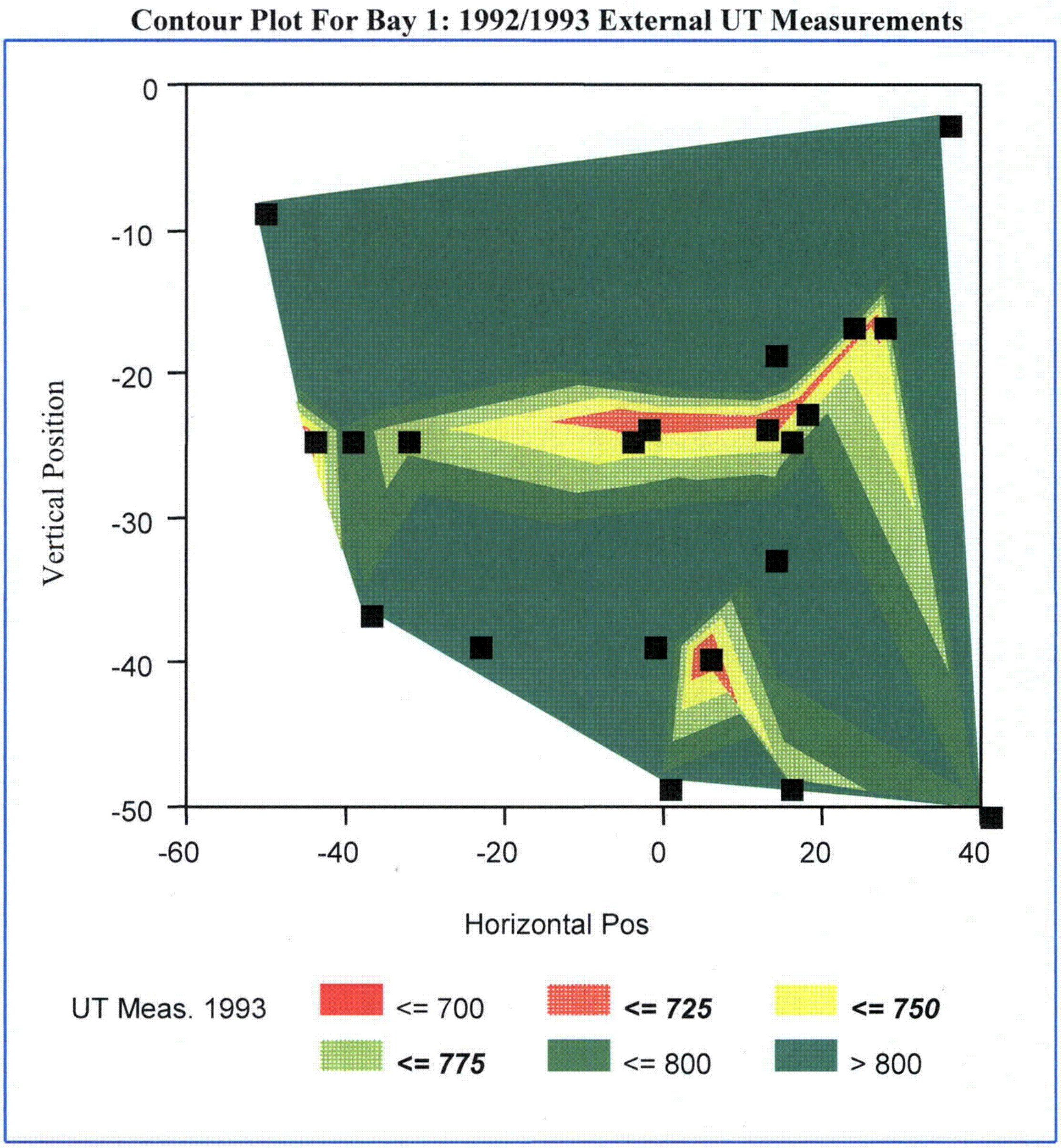
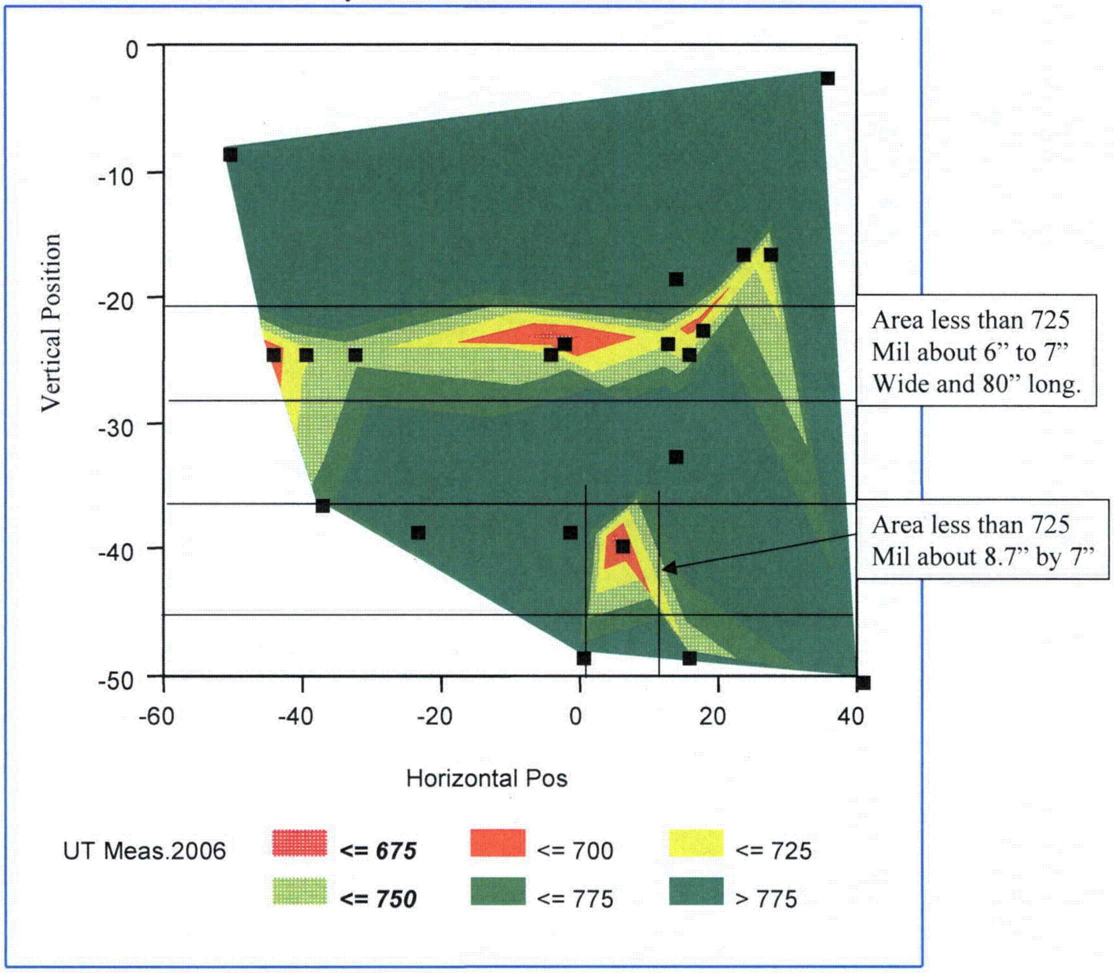


Figure 3

1; 2.a (Entire Figure)

Bay 1 Remaining Wall thickness
External UT Measurements 2006

Contour Plot for Bay 1 2006 External UT Measurements 2006



1; 2.a (Entire Figure)

Figure 4

Bay 13 Remaining Wall Thickness
External UT Measurements 1992/1993

Contour Plot for Bay 13 19921993 External UT Data

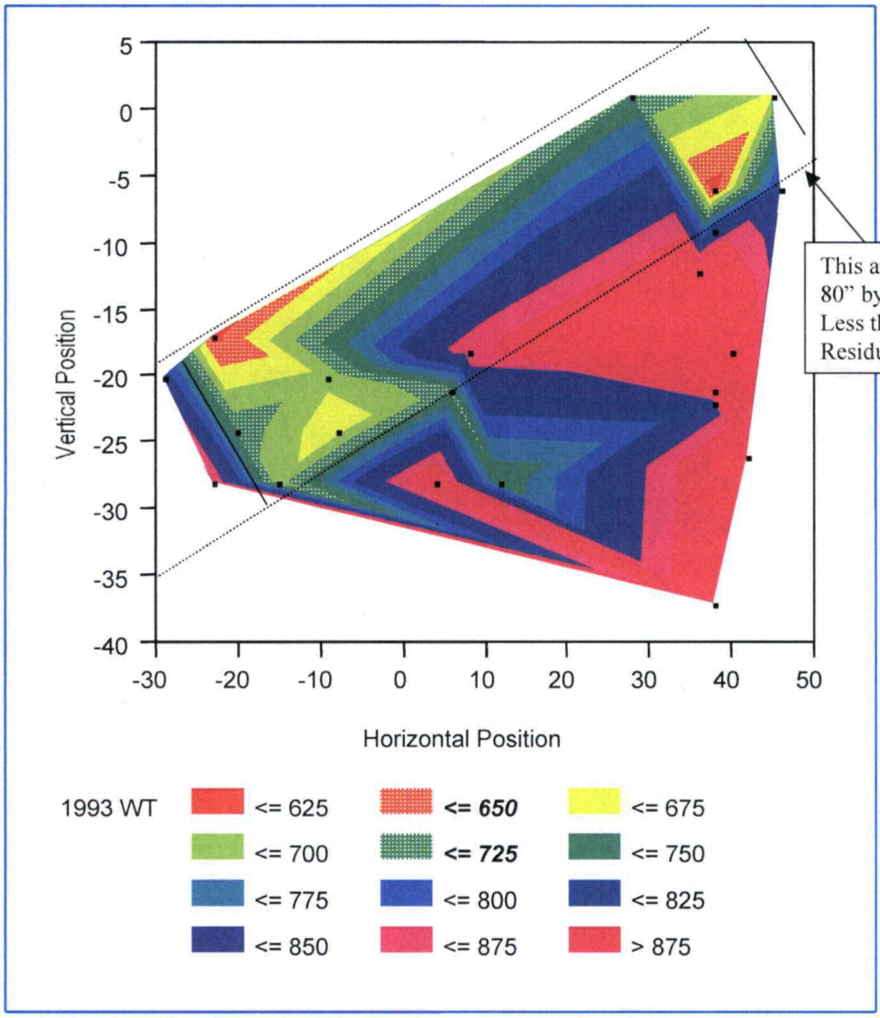
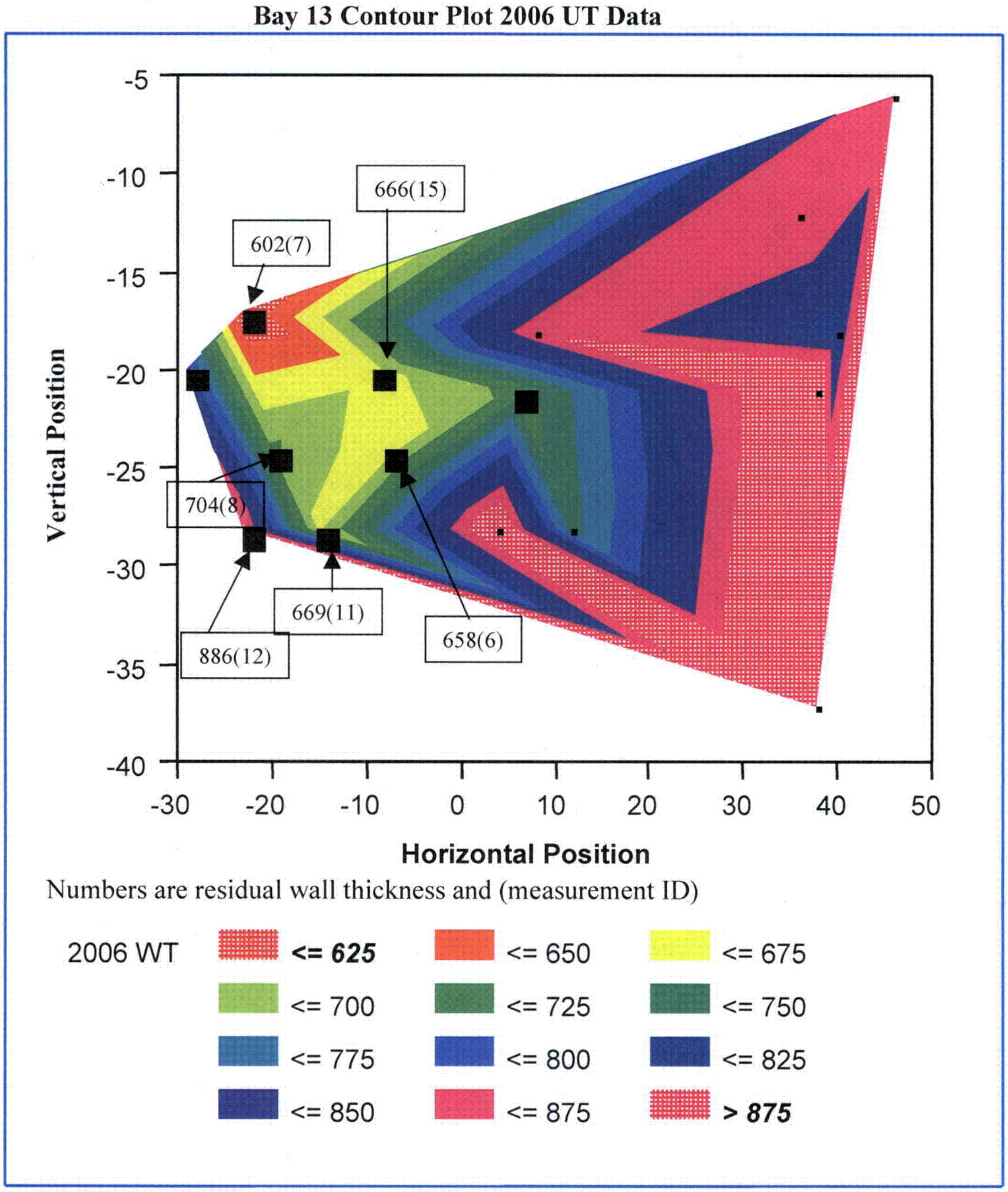


Figure 5

1; 2.a (Entire Figure)

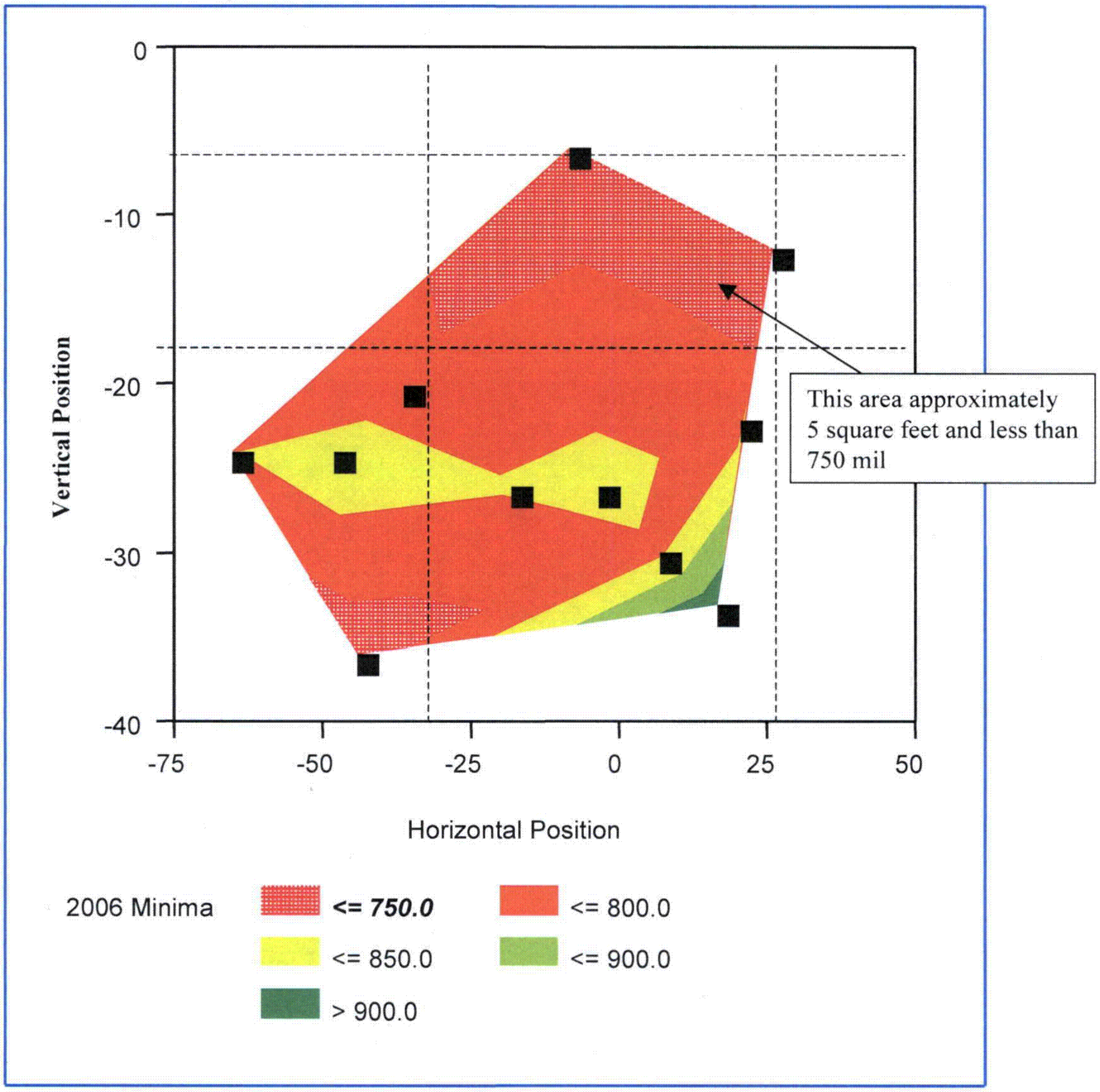
Bay 13 Remaining Wall Thickness
External UT Measurements 2006



1; 2.a (Entire Figure)

Figure 6

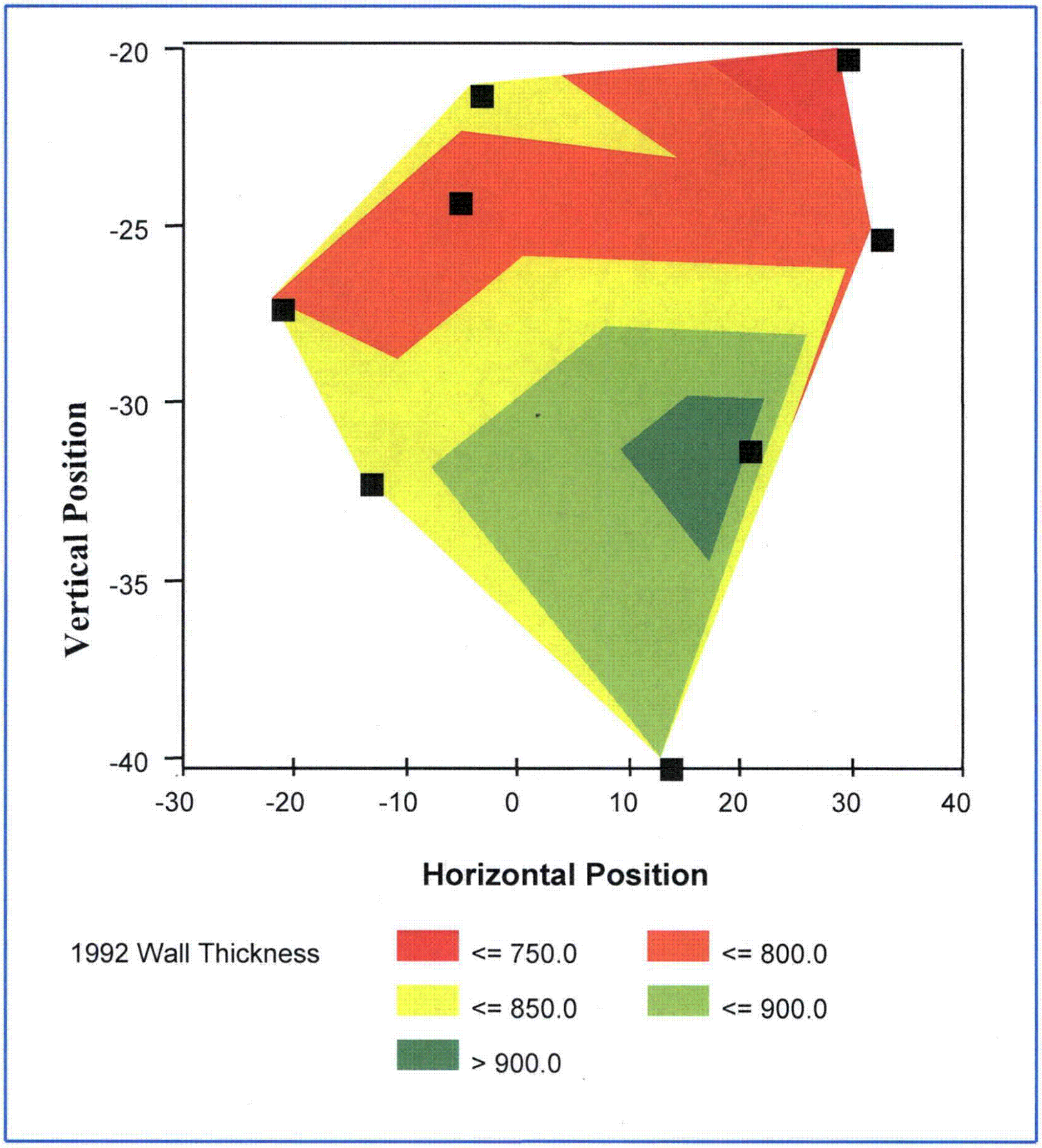
Contour Plot for Bay 15 2006 External UT Measurements



1; 2.a (Entire Figure)

Figure 7

Contour Plot for External UT 1992 Data Bay 11



Attachment 5

Legend for Attachments 1 – 4 of AmerGen's Motion in Limine to Exclude Portions of Citizens' Initial Written Submission

This chart is intended to assist the Board and the parties in reviewing the proposed redactions.

Reason for Exclusion	Section of Motion in Limine
Unqualified Expert	1
Statistical Methods	2.a
Embedded Interior	2.b
Local Buckling Acceptance Criterion	2.c
Scope of UT	2.d
Real-time Corrosion Monitoring	2.e
Speculation	3
Impermissible Attachments	4
Deleted Material	4 n.39