Citizens Exhibits 12

RAS 14322

U.S. NUCLEAR REGULATORY COMMISSION
In the Matter of AmerGen Energy Co, LLC
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OFFERED by: Applicant/Licensee Intervenor
NRC Staff Other
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Reporter/Clerk OW

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MEMORANDUM

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USNRC

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OFFICE OF SECRETARY
RULEMAKINGS AND
ADJUDICATIONS STAFF

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. [redacted]
- 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

Template= SECY-028

SECY-02

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 thc trench (right hand side). The

[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.

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.

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.

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. 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.

IV. 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.

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.

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.

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

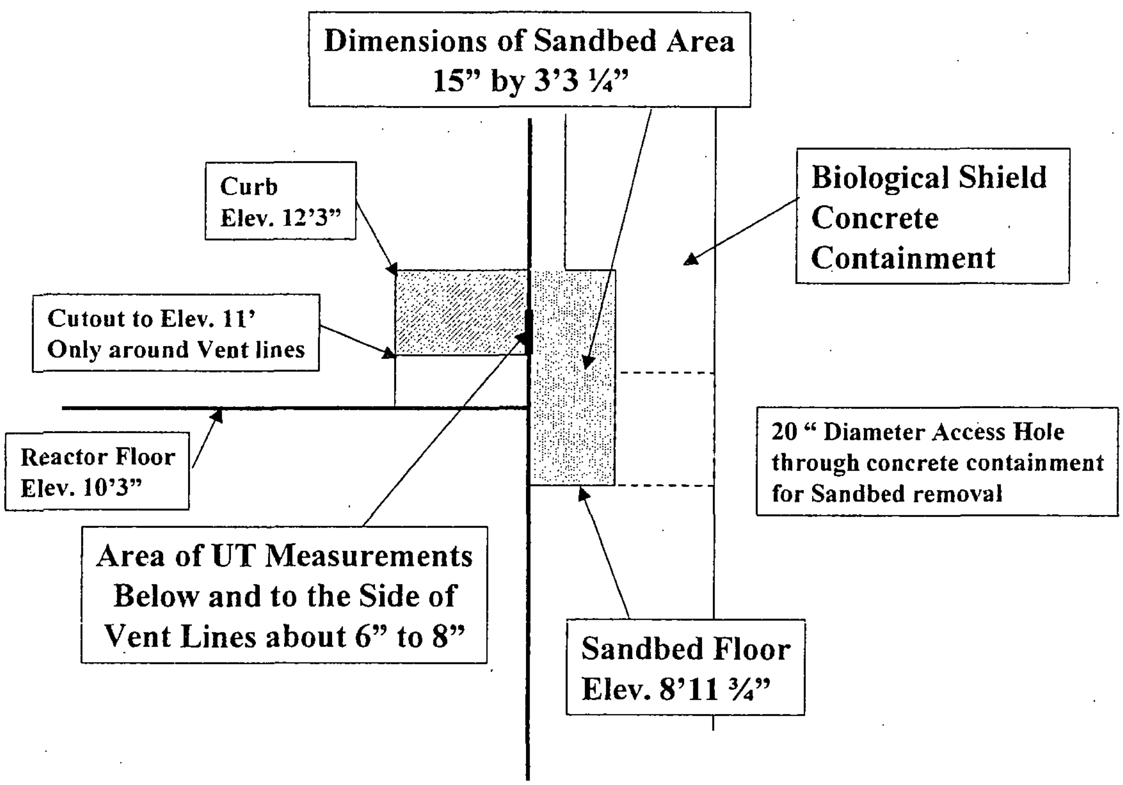
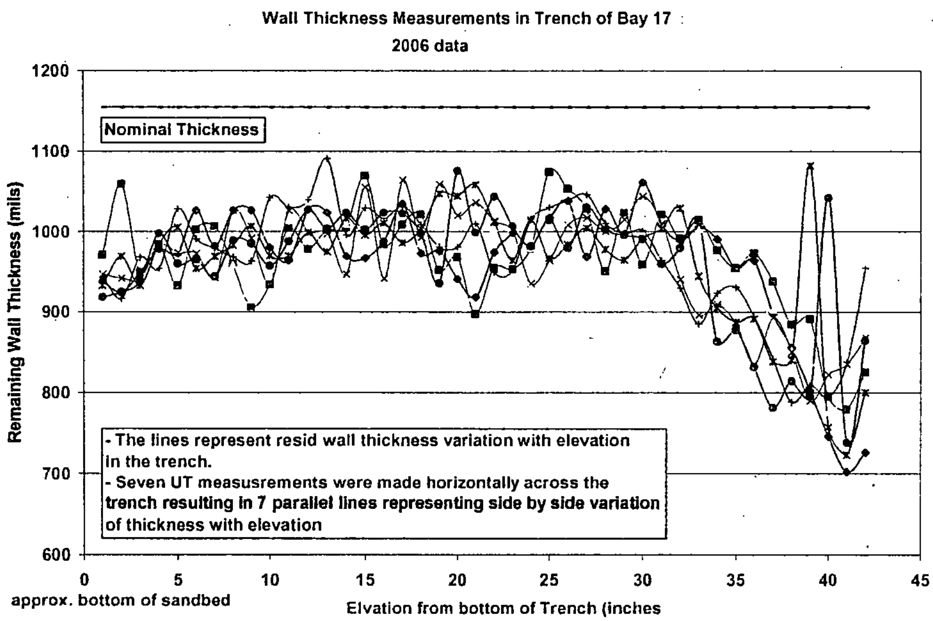


Figure 2


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

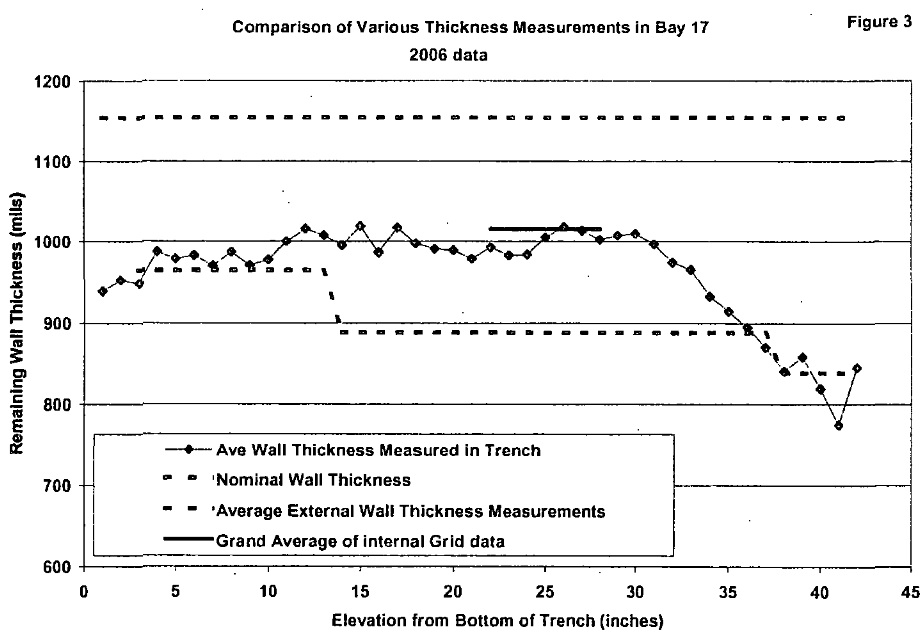

Comparison of Various Thickness Measurements in Bay 17
2006 data
Figure 3
Remaining Wall Thickness (mils)
1200
1100
1000
900
800
700
600
0
5
10
15
20
25
30
35
40
45
Elevation from Bottom of Trench (inches)
Ave Wall Thickness Measured in Trench
Nominal Wall Thickness
Average External Wall Thickness Measurements
Grand Average of internal Grid data

Figure 4

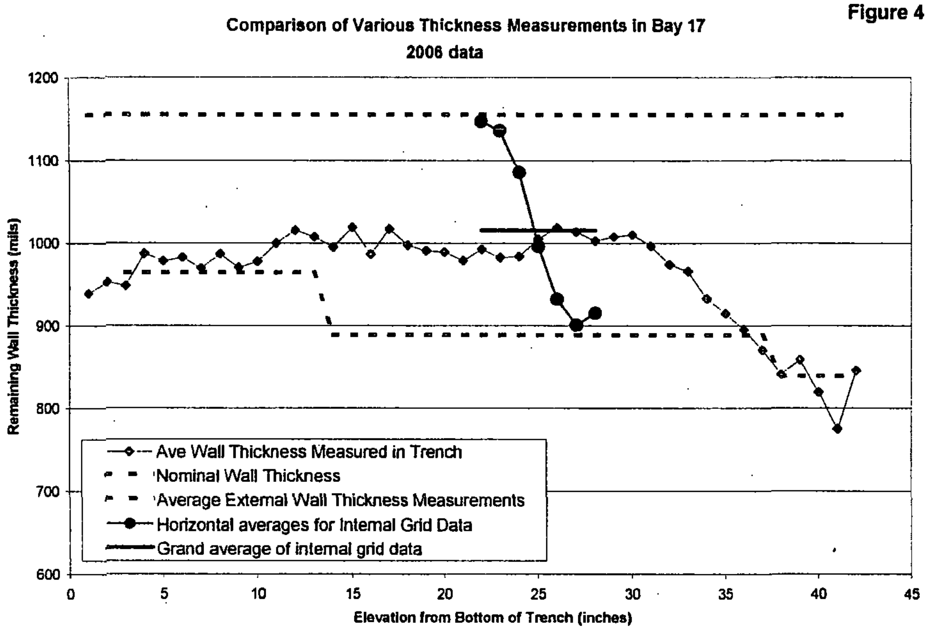


Figure 5

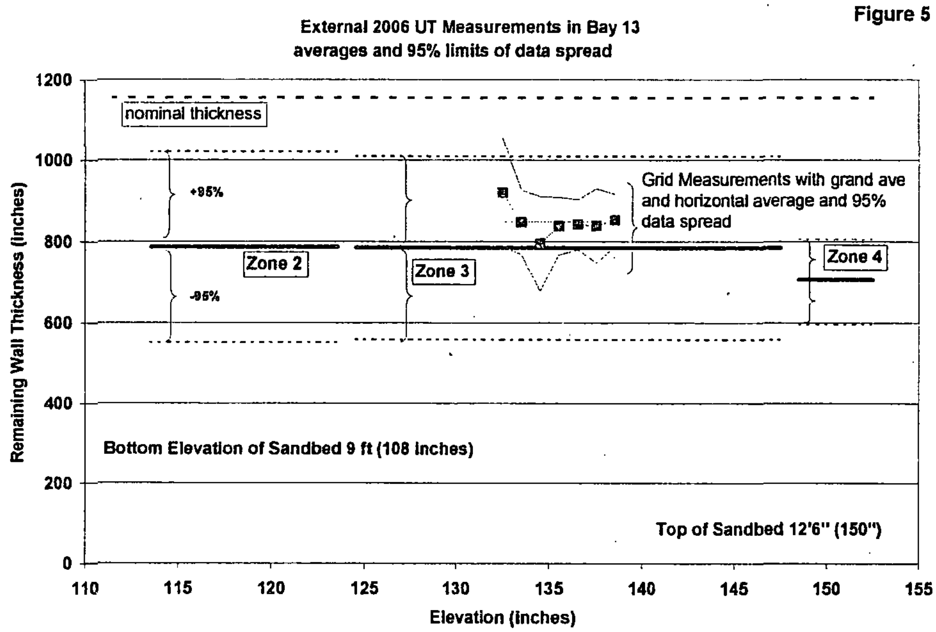


Figure 6

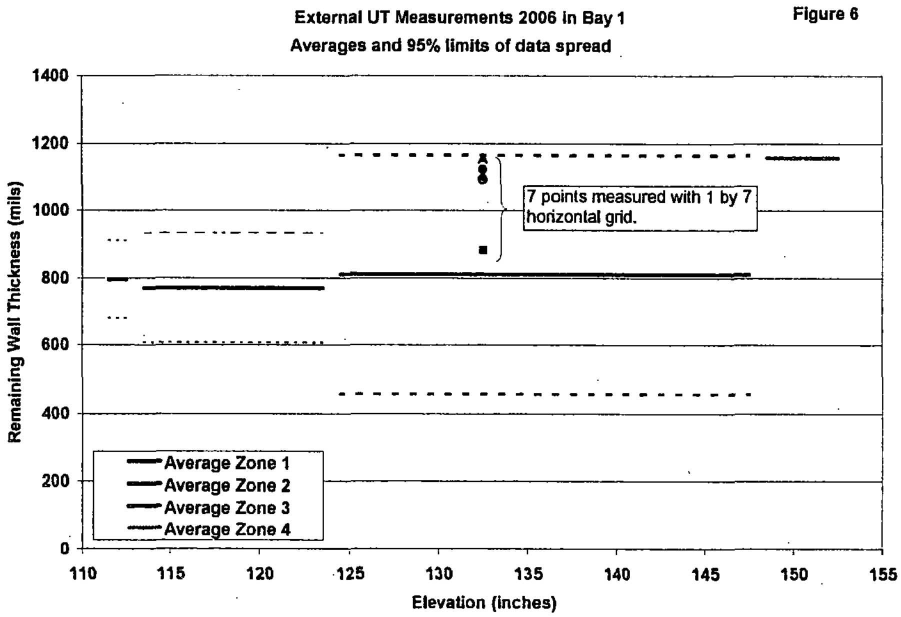
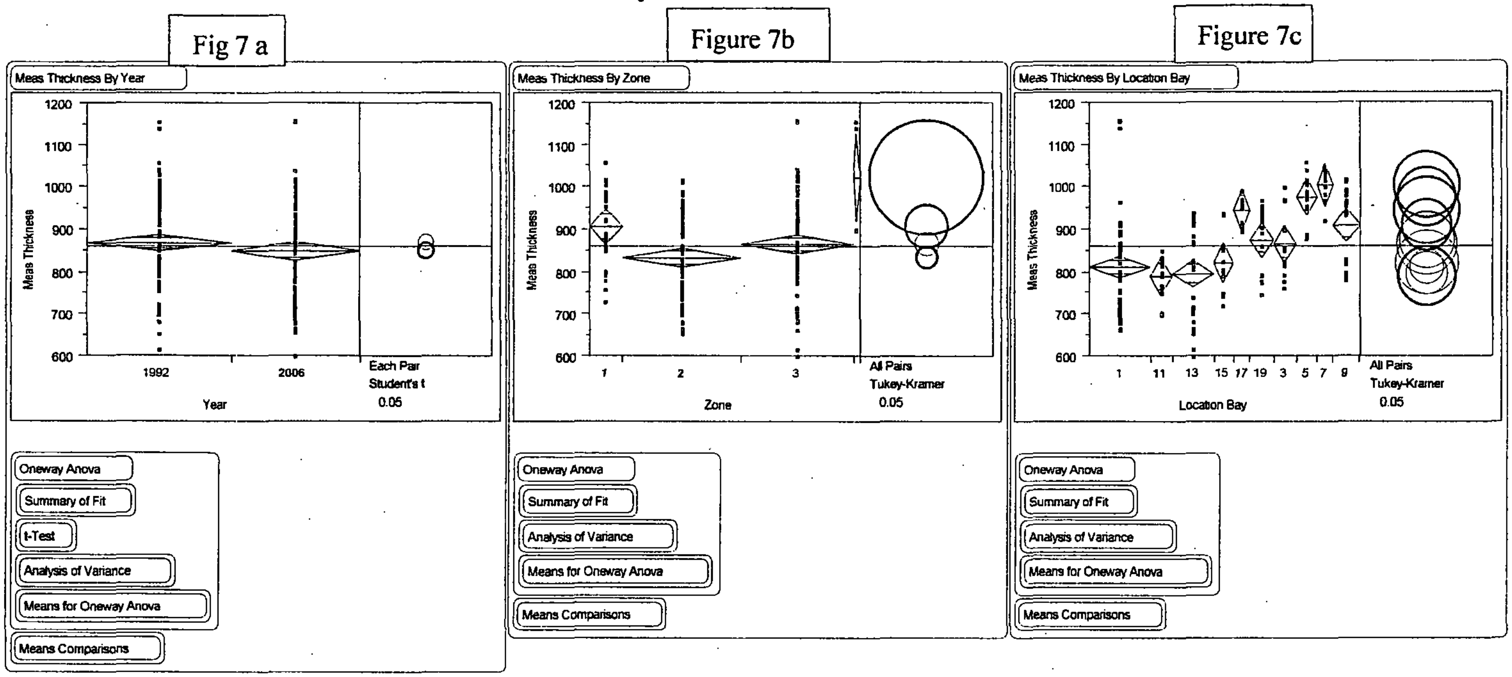

External UT Measurements 2006 in Bay 1
Averages and 95% limits of data spread
Remaining Wall Thickness (mils)
1400
1200
1000
800
600
400
200
0
7 points measured with 1 by 7 horizontal grid.
Average Zone 1
Average Zone 2
Average Zone 3
Average Zone 4
110
115
120
125
130
135
140
145
150
155
Elevation (inches)

Figure 7

Statistical Analysis of all External UT Measurements



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

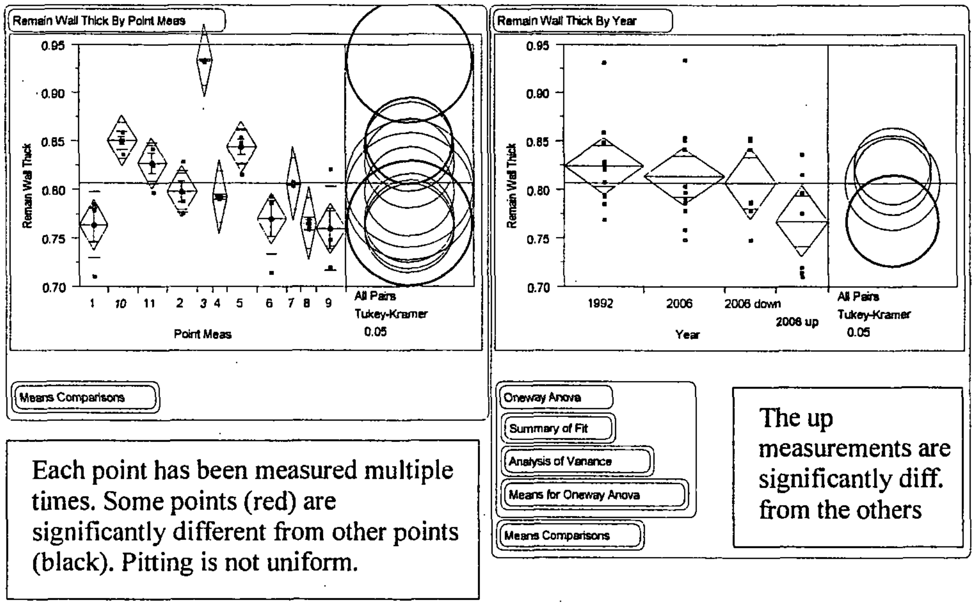


Figure 9: External UT Measurements in Bay 1.

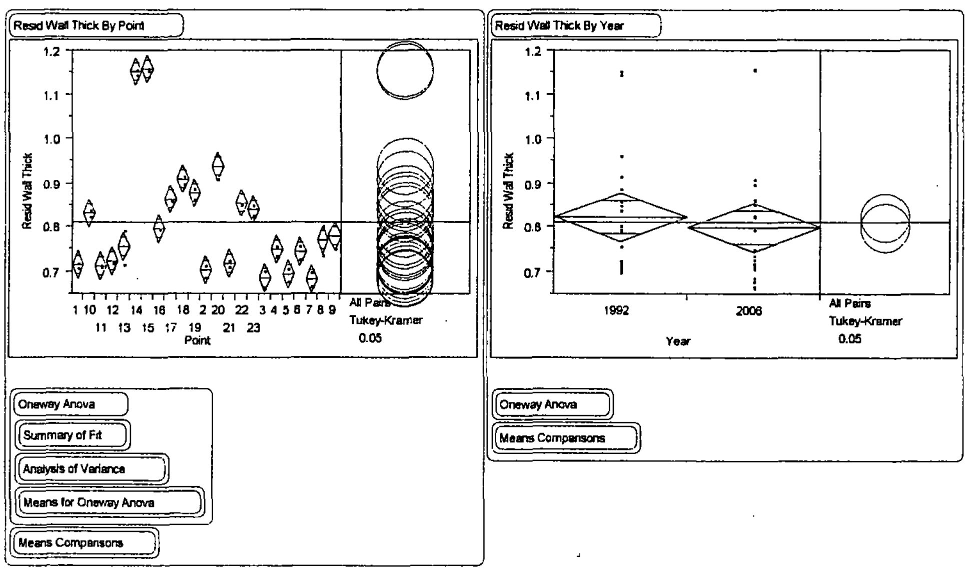
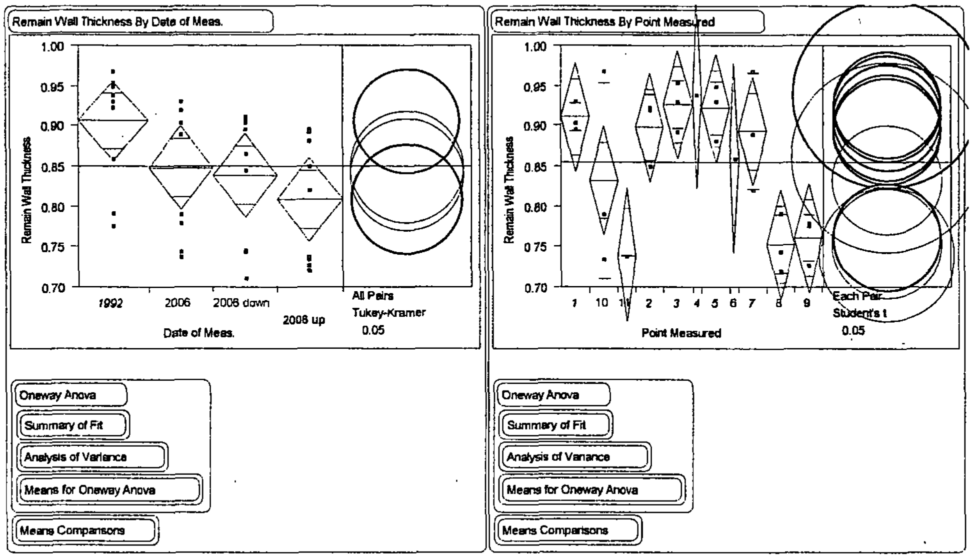


Figure 10: External UT measurements in Bay 19



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**