CORRO-CONSULTA

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MEMORANDUM

To: Richard Webster, Esq. July 25, 2006

From: Rudolf H. Hausler

Subject: **Oyster Creek, Drywell Liner**
Integrity Assurance and Monitoring Frequencies

I. Background

The drywell liner of GE Mark I BWR nuclear power plants, as is well known, is an important safety structure in case of a catastrophic failure of the nuclear reactor it contains. In addition, structural failure of the liner could actually cause an accident. It is therefore important that its integrity is assured prior to any relicensing of the 40-year old Oyster Creek nuclear power plant, and that subsequently its integrity is monitored throughout any extended license. The drywell liner at Oyster Creek has suffered from serious corrosion, which has brought the structure close to the limit of operability. As a consequence, the existing thin margin between acceptable and unacceptable integrity, must be maintained for another twenty years, if the reactor is to continue operating beyond the current licensed period. In an attempt to accomplish this task, AmerGen, the operator of the Oyster Creek nuclear power plant, proposed a new testing regime for the drywell liner on June 20, 2006. This memorandum attempts to discuss some of issues involved with this all-important task and finds that the June 20, 2006 proposal is a step in the right direction, but is still far from adequate.

II. The Basic Monitoring Program

In order to gauge the remaining service life of a corroding structure one needs to know the inherent corrosion (or pitting) rate. It is generally impossible to assess this rate a priori on the basis of either laboratory measurements or theoretical calculations. Hence, corrosion rates need to be established in the field under service conditions. A commonly accepted procedure is demonstrated in Figure 1. A structure such as a vessel or a pipeline has a given nominal wall thickness and is subject to corrosion. The useful service life is determined by a minimum allowable wall thickness, depending on operating conditions, the allowable “target penetration”.

In Case 1 the prevailing corrosion rate (loss of wall thickness with time) appears to be low enough such that at the end of the projected service life the remaining wall thickness is above the minimum target. In this case in service wall thickness measurements (also called direct assessment), for instance by UT technology or an intelligent pig (in case of a pipeline), would be carried out at half of the remaining service life. If the corrosion (penetration) rate can be reaffirmed, one would likely not verify the integrity of the structure by direct assessment again until the end of the service life. However, one would continue to monitor ongoing corrosion or changes of the environment, which could result in a change of the corrosion rate, by other means, such as corrosion coupons or sensors, or in the case of Oyster Creek by moisture monitors (also referred to a indirect assessment [1]).

In Case II, the known corrosion rate predicts the minimum target wall thickness to be reached at the end of the service life. In this case verification would occur at the half-life of the structure, and again half way between it and the end of the service life. Simultaneously, changes of the environment, or changes in corrosion rate would be monitored continuously. In this case the latter is all the more important.

In Case III, the corrosion rate is such that the structure would have to be abandoned prior to the expected full service life. Nevertheless, the structure would be routinely examined in order to obtain as long a service life as possible. This situation prevailed at Oyster Creek in 1992, prior to preventive measures having been applied (Ref. 2)

This general scheme is based on a number of assumptions. These are:

a) the corrosion rates are known,
b) the corrosion rates are constant, i.e. the loss of wall thickness is linear with time
c) the conditions under which the corrosion rates have been established originally remain constant with time.

In practice, none of these assumptions hold true. Various means must to be brought to bear in order to rectify the situation. First, corrosion rates must be established, usually by simpler means than direct assessment over long intervals, such as for instance corrosion coupons, which are exchanged and examined on a monthly basis. On line monitors are also used to verify the constancy of the corrosion rates with time and to observe possible changes of the corrosion rates with changes of the environment. The programmatic direct assessment schedule of the vessel or structure is then adjusted as dictated by these results.

III. The Oyster Creek Drywell Liner

[1]) The distinction between direct assessment and routine monitoring (indirect assessment) is made because direct assessment methodologies are expensive, time consuming, and often require shut down of the unit. Indirect assessment can be done routinely on line is inexpensive, and does not require shut down. However, a relationship between the two has to be established, and it cannot be assumed a priori that indirect monitoring truly reflects what is going on in the unit.

Applying these principles to Oyster Creek is not a simple task, mainly because the corrosion rates in the critical areas, i.e. the sand bed area are not known, cannot be measured by simple means, cannot be assumed to be constant with time and cannot easily be established by full examination of the vessel. These issues and others will be discussed in some detail below.

1. Assessment of the Integrity of the Drywell Liner

Review of the areas investigated

The first issue to be addressed pertains to the overall integrity of the vessel in the sandbed area in particular. The plant was built in 1968; however, water was first detected in 1980 in the area between the drywell and the concrete shield. In 1983 work began to identify the origin of the water. Only in 1986 were UT wall thickness measurement performed in order to determine if the presence of water had caused external corrosion to the drywell liner (Ref.1). The measurements in 1986 purportedly were carried out to determine the areas of most severe corrosion. Out of a total of 143 UT measurements, 60 indicated a wall loss in excess of ¼ inch. These measurements were carried out from the inside of the liner in a very narrow area above the curb (see Fig. 2) at elevation 11 ft 3 in to 12 ft 3 in (Ref. 1). However, Fig. 2 is somewhat misleading in that it creates the impression that the curb at elevation 11ft extends along the entire periphery of the inside of the vessel. This is not the case. In order clarify the physical realities inside the drywell, Figure 3 is a clearer rendering of the curb. The curb actually rises to an elevation of 12'3" and is therefore at the same height as the top of the sandbed. Only around the vent pipes is curb lowered (cut-out) to a top elevation of 11'. Hence, as shown in Fig.4 there exists an area above the curb of 6 to 8 inches below and besides the vent pipe where UT measurements can be made such that corrosion on top of the sandbed can be assessed. Below this area there are 24 inches inaccessible to UT measurements from the inside. Furthermore, the area where UT measurements were actually made is very small with respect to the circumference of the vessel, about 150 feet at this elevation.
Subsequently areas were defined in each bay were systematic UT measurements would be made using a 6 in by 6 in matrix with holes drilled at 1 in spacings to accommodate the UT probe. This was done in order to be able to repeat the 49 UT measurements at time intervals in exactly the same location in each bay. Repeat measurements over the period of 1986 through 1992 indicated that the average penetration over the 6 in by 6 in grid grew with a corrosion rate of as much as 33 mpy (Ref. 2), such that in several bays the minimum wall thickness would have been reached in 4 to 5 years (mid 1990's) if no preventive measures would have been instituted. This indicated that the drywell liner had already critically corroded in the sand bed area. These results were based on about 3% of the circumference and less than 30% of the sandbed depth. It should be noted that that the "most corroded" areas had been identified in 1986 and the locations thereof essentially fixed in order to achieve subsequent representative measurements. However, the sandbed remained in place from 1986 to 1992, the water leakage had not been arrested (continued corrosion also at the higher locations) and corrosion in the sandbed area continued. **The physical constraints meant that the most corroded areas were not rigorously**

identified in 1986. Furthermore, after the sand bed was removed, the areas identified in 1986 probably would not have remained the most corroded areas if there was continued corrosion. Thus, in view of the narrowness of the margins of safety remaining for this vessel, a much larger area should be investigated prior to extending the license in order to verify where the most corroded areas are and define the remaining safety margins. This must include all areas previously considered inaccessible because of the presence of the sandbed [2)].

<u>Review of the statistical procedures used in the interpretation of UT measurements</u>

The UT measurements, made over several years in several bays in the sandbed area with the 6 in by 6 in grid, needed to be analyzed in some manner. GPU chose to determine the average of the 49 individual measurements in order to characterize the average state of the wall thickness at that time and that location, in order to compare such averages over time and determine a corrosion rate. A further objective of this calculation was the comparison of the average UT measured wall thickness with a critical value derived from structural fitness for service calculations. This critical value was determined as 736 mils and most of the average wall thicknesses over the 6 in by 6 in grids were around 800 mils, or critically close to the critical value. It is therefore well justified to examine some of the assumptions GPUNuclear made in arriving at certain conclusions.

The first assumption inherent in this procedure pertains to the notion that corrosion in the sandbed area was uniform or nearly so. This, however, is not the case. The surface was not merely "dimpled" but in some cases severely pitted, or even grooved. GPUNuclear got around this problem by assuming that the UT measurements, i.e. local corrosion penetrations should be normally distributed, and that hence Gaussian statistics were applicable. As a consequence the 49 individual measurements (in some cases fewer where plugs had been removed in the 6 in by 6 in areas) were analyzed for "normal" distribution and data points falling outside the 3 s lower limit (wall thickness) were eliminated as atypical from determination of the average wall thickness. This approach, which tended to increase the average wall thicknesses and made the safety margins look larger than they were in reality, is unacceptable for a number of reasons.

Gaussian statistics were developed in order to deal with random variations, occurring for instance in manufacturing processes, which would allow the producer to discard manufactured items outside specified limits. The corrosion process is of an entirely different nature, and deep flaws in a corroding wall cannot simply be disregarded because their depth is outside some assumed normal distribution of all pits. There are many examples in industry, which demonstrate that the combination of

[2)] We are well aware that in some bays (Ref. 3) measurements were made from the outside, and trenches were dug into the reactor concrete floor at two locations only to verify that the "bathtub ring" type corrosion did not extend to lower depths in the sandbed. However, the interpretation of the measurements made from the outside was questionable (see my Memo of 6/22/06 (Ref. 4) and the mere fact of these measurements indicates that corrosion did extend below the "bathtub ring".

heterogeneities in metals and variations of the environment, with which they are in contact with, can lead to atypical failures, which would be considered outside the distribution of adjacent corrosion features. It is equally well established that neither pit depths nor the rate of growth of pits (pitting rate) are normally distributed because in many systems some deeper pits grow at the expense of shallower ones.

For these reasons it is important, for a critical vessel as the reactor drywell liner, to establish the depth, width and length of all the corrosion anomalies. Because it cannot be assumed that the environment in which these anomalies grew over time was uniform throughout the sandbed area, nor that it remained uniform over time, it is necessary to perform a complete UT analysis over the largest area possible in order to establish the true state of integrity of the vessel.

2. Programmatic Monitoring

The Presence of Water

Clearly water is required for corrosion to occur. Apparently water leaks continue to occur, or at least could occur, both during refueling outages as well as during normal operations. Daily monitoring of the drains during RO's and quarterly monitoring during the plant operating cycle as proposed in the June 20, 2006 letter are considered below minimum requirements for a number of reasons.

- Water leakage can occur at any time because failure of seals, welds, valves, etc. cannot be predicted.
- Water is also a necessary ingredient for degradation of polymeric resins (epoxy) and elastomers (sealing compounds).
- Even though the sandbed floor had been repaired 1992, there has never been any assurance that water accumulation has been totally prevented.

For these reasons it is considered prudent to monitor the presence of water on the outside of the drywell liner continuously. This can easily be done by installation of moisture sensors. Such devices have reportedly been installed in other Mark I power plants and are commonplace in other industries.

The problem of the Epoxy Coating and the Elastomer Seals

After the sandbed had been removed in 1992 the corroded areas in that region had been coated with a primer and an epoxy resin. Furthermore, the crevice between the floor and the drywell wall had been sealed off with an "elastomer"[3]. It is now being assumed that as long as the coating is not damaged in any way, corrosion is arrested (eradicated). While this is certainly a reasonable assumption if the coating is in good condition, and seems to have been true in the short-term according to UT measurements in 1992, 1994, and 1996, it is not appropriate to assume the coating will not deteriorate in the long term. Both the epoxy coating and the elastomer putty

[3] I believe that in view of the confined space in the sandbed area questions regarding the quality of these measures, as well as the quality control thereof, are well justified.

are subject to degradation in the presence of water, oxygen and elevated temperature. The rate and nature of such degradation are unknown. For this reason, AmerGen proposes to periodically assess the integrity of these components by visual examination every four years (Ref. 5).

We think that such "visual examination" needs to be augmented by more quantitative assessment. Holidays and pinholes in the coating cannot be assessed by "visual examination". The coatings industry has developed methodologies, which can more accurately establish the integrity of coatings (Ref. 6, 7, 8, 9) . Of particular importance is the integrity of the putty. Water leakage into the crevice will further stimulate corrosion below the sandbed area floor. We think that the coating ought to be inspected quarterly, while wet conditions prevail, and at the onset of moisture being detected.

<u>UT Measurements</u>

UT measurements (direct assessment) are considered the last defense in the sandbed area. (At the higher elevations above the sandbed region UT measurements should be made in accordance with a schedule dictated by the established corrosion rates as discussed above). If water is present, and if the coating and/or the putty have been established to be leaking water (either due to holidays or because blistering has occurred), UT measurements should be carried out. AmerGen appears to recognize that this monitoring cannot be limited to the locations that have been regularly monitored to date and that monitoring from the outside may be necessary. However, AmerGen fails to note that UT measurements cannot be taken from the outside through the epoxy coating.

Primary emphasis must be put on <u>prevention of water ingress</u> and the <u>integrity of the coating</u>. If and when both fail, the coating must be removed and the entire sandbed area must be inspected, the remaining wall thickness must be quantitatively assessed, the integrity of the vessel must be reestablished, and the coating must be reapplied and tested. AmerGen has proposed only inspecting areas affected by moisture and coating failure, but this is inadequate because once the coating starts to fail in one area, it could rapidly fail in other areas. Therefore, a complete reapplication is mandated once failure in one area is detected.

IV. Conclusions

In conclusion we find AmerGen's proposed drywell liner aging management program flawed in several respects.

- First, we contend that the integrity of the drywell liner needs to be established on a much broader basis than has been done to date. This should include detailed investigations relating to cracking in the corroded areas of the sandbed area. To date less than 3% of the entire drywell wall in the sandbed area have been examined for corrosion. Integrity predictions based on averages of such small a sample area would seem to be highly questionable.

- Second, the first priority of monitoring needs to be focused on the presence of water.
    - It needs to be established that the water does not come from below, but is in fact linked to water leakage from penetration at higher elevations
    - It needs to be established that no water puddles exist anywhere on the sandbed floor and that the drains work properly. (It does not make any sense to monitor the drains quarterly when in fact standing water prevails on the sandbed floor). Hence, quarterly monitoring of the drains from the sandbed area is not frequent enough. Rather we contend that moisture sensors ought to be installed all over the outside of the drywell shell as well as on the sandbed floor in order to definitely establish that the water originates only from the higher elevations.
- Third, the integrity of the coating and seals needs to be established with methods with can identify holidays and pinholes. Visual inspection will not be sufficient. Since the rate of deterioration of the coating and seals is not known, and since the specified useful life of such is already exceeded, these determinations must be made at least on a quarterly basis during normal cycle operation, when water is present.
- Fourth, if the continued presence of water has been observed, and if the coating has been shown to deteriorate, then UT measurements must be made throughout the sandbed region. Unless new monitoring technology is found effective, the UT measurements must be made from the outside of the drywell shell after the coating has been removed.

References

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2. GPU Nuclear Calculation Sheet No. C-1302-187-5300-019 (4/15/92)
3. GPU Nuclear Calculation Sheet No. C-1302-187-5320-024 (4/16/93)
4. Corro-Consulta Memorandum to Richard Webster, Esq., June 22, 2006; *Discussion of Monitoring Methodologies At Oyster Creek Nuclear Plant Dry Well.*
5. AmerGen Letter to US NRC April 4 2006 (2130-06-20284)
6. National Association of Corrosion Engineers, International, Standard Test Method **TM-00384**: *"Holiday Detection of Internal Tubular Coatings of 250 μm (10 mils) dry Film Thickness"*
7. National Association of Corrosion Engineers, International, Standard Recommended Practice, **RP-0188-90**, *"Discontinuity Testing of Protective Coatings"*
8. National Association of Corrosion Engineers, International, Standard Test Method **TM-0186-94**: *Holiday Detection of Internal Tubular Coatings of 250 to 760 μm (10 to 30 mils) Dry Film Thickness*
9. National Association of Corrosion Engineers, International, Test Method **TM-0183**, *"Evaluation of Internal Plastic Coating for Corrosion Control of Tubular Goods in Aqueous flowing Environment"*
10. AmerGen Letter to US NRC June 20, 2006
11. GPU Nuclear Letter to US NRC September 15, 1995
12. H. H. Uhlig, Corrosion and Corrosion Control, John Wiley and Sons, 1963, page 85.
13. M. Pourbaix, Atlas of Electrochemical Equilibria in Aqueous Solutions, NACE, 1974, pg. 307 – 321.
14. GPU Nuclear Calculation Sheet No. C-1302-187-5300-020 (49/15/92)

Figure 1

Schematic Monitoring Frequencies depending on corrosion Rate and Limiting Target Wall Thickness

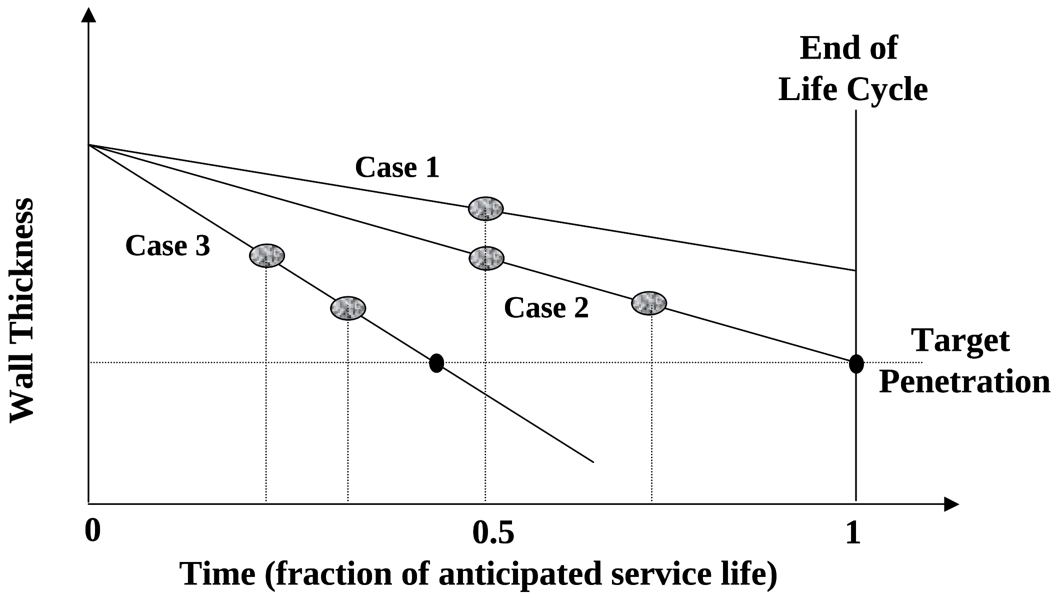


Figure 2

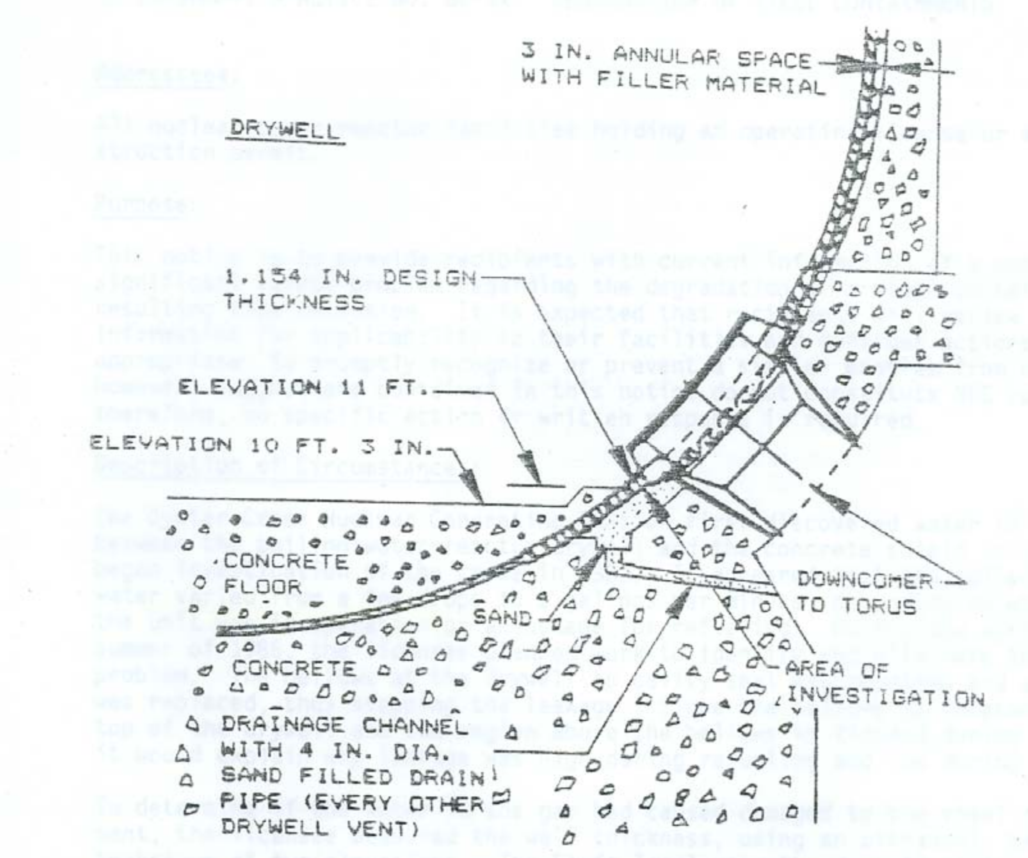
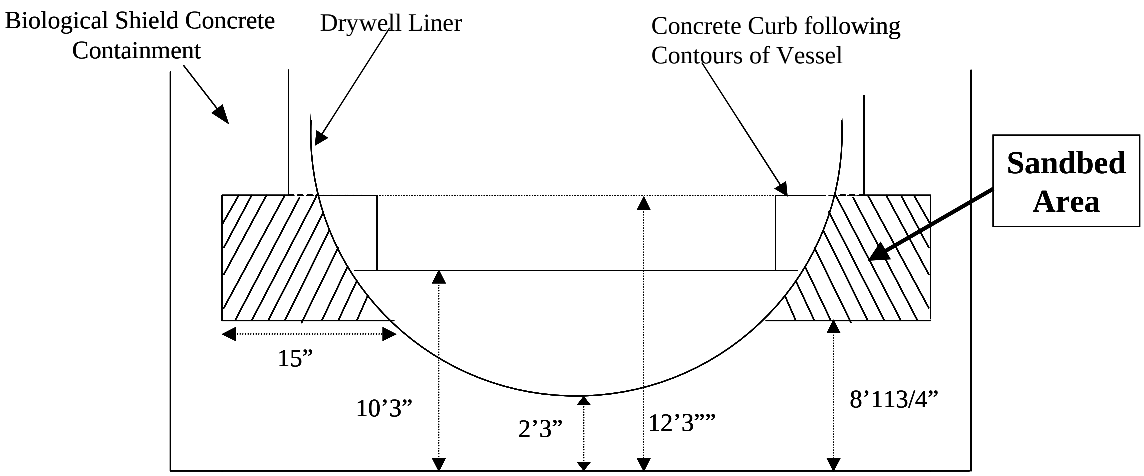

3 IN. ANNULAR SPACE WITH FILLER MATERIAL
DRYWELL
1.154 IN. DESIGN THICKNESS
ELEVATION 11 FT.
ELEVATION 10 FT. 3 IN.
CONCRETE FLOOR
SAND
DOWNCOMER TO TORUS
CONCRETE
AREA OF INVESTIGATION
DRAINAGE CHANNEL WITH 4 IN. DIA. SAND FILLED DRAIN PIPE (EVERY OTHER DRYWELL VENT)

Figure 3

Schematic Drawing of Lower Spherical Section of Drywell Liner

(not to size)



Schematic Cross Section through Sandbed Area
(not to size)

Figure 4