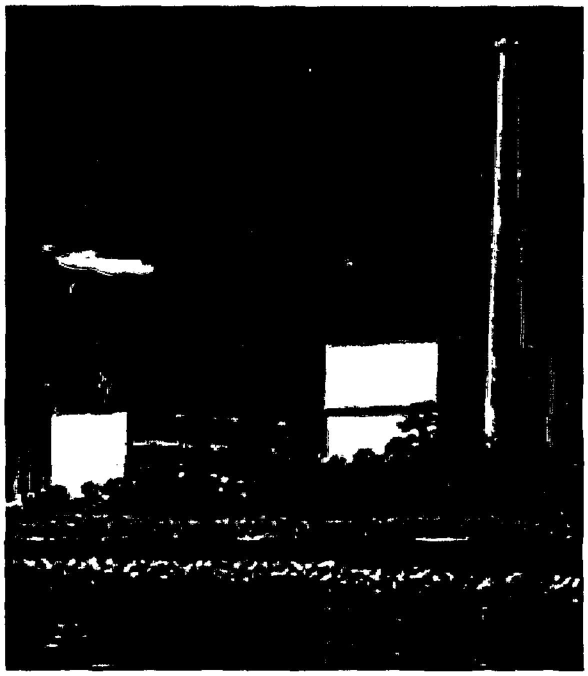
Oyster Creek
License Renewal Project
Drywell Monitoring Program



Information for ACRS Subcommittee

Reference Material

Volume 1

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Nuclear

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December 18, 1986
5000-86-1116

Mr. John A. Zwolinski, Director
BWR Licensing Directorate #1
Division of BWR Licensing
U.S Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. Zwolinski:

Oyster Creek Nuclear Generating Station
Docket No. 50-219
Licensing No. DPR-16
Oyster Creek Drywell Containment

On December 1 and December 10, 1986, the GPU Nuclear staff met with NRR to review certain facts, data and assessments related to measurements showing localized thinning of the Oyster Creek drywell. These measurements were initiated by GPUN during the current refueling outage to confirm the condition of the drywell containment vessel. This letter is a follow-up to the referenced two meetings and briefly summarizes the investigations to date, the data obtained, our assessment of that data including a safety evaluation and future planned work.

Background Data:

Initial surveillance measurements, utilizing a UT probe, were made of the Oyster Creek drywell in the April/May time frame. The initial measurements indicated containment plate condition and thickness consistent with the original design except for areas at the approximate elevation of the interior drywell floor directly opposite the exterior sand cushion and extending over several bays. These early readings indicated apparent thinning due to loss of material on the exterior of the drywell down to thicknesses of about 0.95" compared to the as-fabricated thickness of 1.154". These early measurements led to an attempt to qualify the technique for painted surfaces and then to a much more extensive series of measurements. The more extensive UT surveys confirmed the general corrosion wastage mentioned above and further indicated potentially highly localized pitting with indicated shell thicknesses as small as .383". In order to confirm the adequacy and accuracy of the UT measurements, to understand further the source of the highly localized UT readings, and to assess drywell containment below the level of the interior concrete floor, it was decided to take containment core samples in seven locations. These samples were obtained early in December. Based both on the UT measurements and on the examination of the containment shell samples, we have concluded:

A. The ultrasonic thickness probing of the drywell containment has been confirmed to give accurate results with physical measurement of the plug thicknesses being consistent with UT but, in general, about 2% greater. Therefore, the UT measurements have been a conservative assessment of thickness.

B. The highly localized UT measurements characterized as pitting are now believed to be inclusions or laminations in the original plate. This is based upon destructive metallurgical examination of a containment core.

C. The general areas characterized as exterior corrosion wastage have been verified.

D. These broad areas of exterior corrosion seem to be localized at an elevation corresponding to the exterior sand cushion. Measurements of drywell thickness below the level of the interior concrete floor (which were made by removal of the interior concrete at two locations down to a depth of about two feet, bay 5 and 17) show that wastage below the floor level is no greater than measured just above floor level. In fact, measurements at the location where general wastage was indicated above the floor show the drywell below the floor to be about 50 mils thicker than the immediately adjacent above floor area.

As a result of removing core samples from the steel drywell, certain other observations can be made. Where there was general corrosion, the sand cushion was wet. While metallurgical work on the corrosion films is still ongoing, the films have a characteristic of being magnetic, dark in color and exhibit chlorides throughout the oxide film and at the oxide to base metal interface. The interface between the base metal and the oxide appears to be very sharply defined. In addition to the metallurgical work on the core samples and corrosion films, we have also removed samples of the backing sand and are subjecting those to chemical and other analyses. Results to date show high nitrates, chlorides and sulfates. The source of the chemical species detected in the sand may be the insulating materials applied to the exterior of the drywell during construction, with contaminants carried by moisture to and in some manner concentrated in the sand bed or may be original sand contamination. We have also attempted to culture samples of the sand and corrosion films to ascertain the possibility of microbiological activity. Initial culturing shows an active presence of microbiological species. These species have not been further defined and work is ongoing. We have concluded that the observed damage is not indicative of common forms of microbiologically induced corrosion.

Details of the UT measurements, metallurgical results, and chemical analyses are more fully summarized in the attached GPU Nuclear Safety Evaluation. Detailed backup is available.

Assessment:

Our ongoing assessment has concentrated on verifying the existing structural adequacy of the drywell, the source and form of the corrosive attack on the drywell, and source or sources of water in the sand cushion.

With regard to the corrosion mechanism, our efforts have focused on either attack by aqueous films containing high levels of impurities or potential microbiological attack. We had separately made ground potential measurements which proved to be negative. Drywell metallurgical samples from areas in which the underlying sand cushion was dry did not show unusual corrosive attack.

With regard to the water source, we believe that the insulation materials and the gap between the drywell and concrete were wet during the construction of the plant, and we have confirmed that, in the time frame from 1980 to the present, we have seen periodically some moisture from the sand cushion drain pipes. This moisture was seen during times coincident with the refueling cavity being flooded. During the time frame from 1980 to the present, attempts were made to identify and repair potential leak paths. It is believed repairs to the connecting area between the upper drywell flange and the refueling cavity in 1986 were successful. It is possible water leakage could have been experienced during refuelings before 1980, but we have no record or any observations that would confirm or refute that postulate.

Based upon the observed wastage and experimental corrosion data, the corrosion rate that could be inferred would be 15 mils per year with an upper limit corrosion rate of 50 mils per year. While our understanding of the corrosion mechanism is still not complete, our assessment of microbiological and concentrated chemical attack would not be inconsistent with the preceding inferences. For safety review purposes, we have utilized what we believe is a conservative upper bound of 50 mils per year as future wastage allowance for the next operating cycle.

Structural analysis of the capability of the Oyster Creek drywell containment was reviewed by Chicago Bridge and Iron, the original designer and installer of the vessel, with supplementary work performed by GPUN. This assessment shows that a shell thickness of 0.7" (actual minimum averaged thickness equals 0.87"), averaged over an area which could structurally respond to accident loads, results in stresses meeting the original plant design bases, is consistent with the additional review conducted under the SEP program, and is consistent with applicable Section NE of the ASME Section III code. This assessment was conducted assuming both the presence of the sand cushion as well as no residual structural support provided to the shell by the exterior sand cushion which is conservative. To the 0.70" thickness would have to be added the appropriate corrosion allowance to ensure the structural analysis covers the future operational time frame of interest. It is our conclusion the drywell meets the licensed structural integrity requirements and that operation of the plant for the next cycle is consistent with License requirements. The underlying Safety Evaluation again summarizes in more detail the basis for the above conclusions.

While the Safety Evaluation concludes that licensed safety margins are maintained for the plant during the next cycle, we intend to maintain an intensive effort to:

A. Eliminate the source of any future water incursions into the sand bed.

B. Dry the moisture from the sand cushion and/or otherwise render corrosive ''ack minimal.

C. Continue the metallurgical and chemical investigations to determine, if possible, the exact cause of the attack.

D. Further assess longer term corrective actions that may be appropriate.

E. Continue the UT shell thickness test program at future outages of opportunity including forced outages otherwise requiring drywell entry during the next cycle.

If you should have any questions, please contact Mr. M. W. Laggart at (201) 263-6205.

Very truly yours,

R. F. Wilson
Vice President
Technical Functions

/amm

GPU Nuclear

Technical Functions
Safety/Environmental Determination and 50.59 Review

UNIT Oyster Creek Nuclear Generating Station — PAGE 1 OF 1~

DOCUMENT NO. ______ (if applicable) — SE No. 000243-002

ACTIVITY TITLE Drywell Steel Shell Plate Thickness Reduction at the Base Sand Cushion Entrenchment Region — Rev. No. 0

Type of Activity Evaluation of Reduced Plate Thickness of the Drywell Steel Liner
(Modification, procedure, test, experiment, or document)

1. Is this activity/document listed in Section I or II of the matrices in Corporate Procedure 1000-ADM-1291.01? ☒ Yes ☐ No

   If the answer to question 1 is "no" stop here. (Section IV activities/documents should be reviewed on a case-by-case basis to determine if this procedure is applicable.) This procedure is not applicable and no documentation is required. If the answer is "yes" proceed to question 2.

2. Is this a new activity/document or a substantive revision to an activity/document? (See Exhibit 3, paragraph 3, this procedure for examples of non-substantive changes) ☒ Yes ☐ No

   If the answer to question 2 is "no" stop here. This procedure is not applicable and no documentation is required. If the answer is "yes" proceed to answer all remaining questions. These answers become the Safety/Environmental Determination and 50.59 Review.

3. Does this activity/document have the potential to adversely affect nuclear safety or safe plant operations? ☒ Yes ☐ No

4. Does the activity/document require revision of the system/component description in the FSAR or otherwise require revision of the Technical Specifications or any other Licensing Basis Document? ☒ Yes ☐ No

5. Does the activity/document require revision of any procedural or operating description in the FSAR or otherwise require revision of the Technical Specifications or any other Licensing Basis Document? ☐ Yes ☒ No

6. Are tests or experiments conducted which are not described in the FSAR, the Technical Specifications or any other Licensing Basis Document? ☐ Yes ☒ No

7. Does this document involve any potential Non-Nuclear environmental impact? ☐ Yes ☒ No

8. Does the activity/document require a review of criteria as outlined in SDD-T1-000, TMI-1 Division I Plant Level Criteria? ☐ Yes ☒ No

   If yes, identify TR/TFWR. ______

   If any of the answers to questions 3, 4, 5, or 6 are yes, proceed to EXHIBIT 6 and prepare a written safety evaluation. If the answers to 3, 4, 5, or 6 are no, this precludes the occurrence of an Unreviewed Safety Question or Technical Specifications change. If the answer to question 7 is yes, either redesign or provide supporting documentation which will permit Environmental Licensing to determine if an adverse environmental impact exists and if regulatory approval is required (Ref. LP-010). If in doubt, consult the Radiological and Environmental Controls Division or Environmental Licensing for assistance in completing the evaluation.

Signatures - See attached sign-off sheet	Date
Engineer/Originator	
Section Manager	
Responsible Technical Reviewer	
Other Reviewer(s)	

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8612220289 861218
PDR ADOCK 05000219
P PDR

GPU Nuclear

Technical Functions Safety Evaluation

UNIT Oyster Creek Nuclear Generating Station

SE No. 000243-002

Rev. No. 0

ACTIVITY/DOCUMENT TITLE Drywell Steel Shell Plate Thickness Reduction at the Base Sand Cushion Entrenchment Region

Document No. ______ (if applicable)

Type of Activity/Document Evaluation of Reduced Thickness of the Drywell Steel Liner.
(Modification, procedure, test, experiment, or document)

This Safety Evaluation provides the basis for determining whether this activity/document involves an Unreviewed Safety Question or impacts on nuclear safety.

Answer the following questions and provide reason(s) for each answer per Exhibit 7. A simple statement of conclusion in itself is not sufficient. The scope and depth of each reason should be commensurate with the safety significance and complexity of the proposed change.

1. Is the margin of safety as defined in Licensing Basis Documents other than the Technical Specifications reduced? ☐ Yes ☒ No
2. Will implementation of the activity/document adversely affect nuclear safety or safe plant operations? ☐ Yes ☒ No

   The following questions comprise the 50.59 considerations and evaluation to determine if an Unreviewed Safety Question exists:

3. Is the probability of occurrence or the consequences of an accident or malfunction of equipment important to safety previously evaluated in the Safety Analysis Report increased? ☐ Yes ☒ No
4. Is the possibility for an accident or malfunction of a different type than any evaluated previously in the Safety Analysis Report created? ☐ Yes ☒ No
5. Is the margin of safety as defined in the basis for any Technical Specification reduced? ☐ Yes ☒ No

   If any answer above is "yes" an impact on nuclear safety or an Unreviewed Safety Question exists. If an adverse impact on nuclear safety exists revise or redesign. If an unreviewed safety question with no adverse impact on nuclear safety exists forward to Licensing with any additional documentation to support a request for NRC approval prior to implementing approval.

6. Specify whether or not any of the following are required, and if "yes" indicate how it was resolved

	Yes	TR/TFWR/Other	No
a. Does the activity/document require an update of the FSAR?			

   Explain: Yes: an analysis to support the new drywell shell thickness must be included in the Final Safety Analysis Report Section 3.8.

   b. Does the activity/document require a Technical Specification Amendment?

   Explain: No, the minimum shell thickness found during the inspection meets the design criteria specified in the OCNGS Technical Specifications

SAFETY EVALUATION NO. 000243-002

Preparers:	Signature	Date
M. Laqqart	[signature]	12-18-86
D. Jerko	[signature]	12-18-86
P. Huebsch	[signature]	12/18/86
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Responsible Technical Reviewers:		
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Independent Safety Reviewer J. R. Thorpe	J R Thorpe	12/18/86

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TABLE OF CONTENTS

1.0 PURPOSE

The purpose of this safety evaluation is to assess the structural integrity of the Drywell steel pressure vessel in light of a recent (Inspection) finding that sections of the drywell shell near the base sand entrenchment region have a thickness which is below the thickness utilized in the original stress report prepared by Chicago Bridge & Iron Company ("Structural Design of the Pressure Suppression Containment Vessels", for JCPL/Burns & Roe, Inc., Contract No. 9-0971, by CB&I Co., 1965). In addition, this evaluation provides a justification for operation up to the end of the 11th operating cycle (18 months) for the Oyster Creek Nuclear Generating Station (OCNGS).

2.0 SYSTEMS AFFECTED

2.1 System No. 243, Drywell and Suppression System, particularly the drywell shell structure. This structure is directly affected by the localized thinning.

2.2 Drawings showing original thickness - Chicago Bridge and Iron Co., Contract Drawings 9-0971, Drawings #1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11.

2.3 Documents that Describe the Drywell Structure are listed below.

2.3.1 Amendment #15 to OCNGS FDSAR, Primary Containment Design Report.

2.3.2 Updated FSAR, Paragraph 3.8.2.

2.3.3 OCNGS Technical Specification Section 5.2.

2.3.4 CB&I Stress Report, "Structural Design of the Pressure Suppression Containment Vessels" for JCPL/Burns & Roe, Inc., CB&I Company Contract No. 9-0971, 1965.

3.0 EFFECTS ON SAFETY

3.1 Identification of Documents

3.1.1 OCNGS Unit 1 Facility Description and Safety Analysis Report.

- Licensing Application, Amendment 3, Section V.
- Licensing Application, Amendment 11, Question III-18
- Licensing Application, Amendment 15
- Licensing Application, Amendment 68

3.1.2 Technical Specification Documents

3.1.2.1 Technical Specification and Bases - OCNGS Unit, Appendix A to Facility License DRP-16, JCP&L Docket No. 50-219, Sections 3.5, 4.5, 5.2

3.1.3 Regulatory Documents

3.1.3.1 10CFR50, Appendix A, General Design Criteria for Nuclear Power Plants

- Criterion 2 - Design Bases for Protection Against Natural Phenomena
- Criterion 4 - Environmental and Missile Design Bases
- Criterion 16 - Containment Design
- Criterion 50 - Containment Design Basis

3.1.4 Industry Codes and Standards

3.1.4.1 ASME Boiler and Pressure Vessel Code, Section VIII, 1962 with Code cases 1270N-5, 1271N, and 1272N-5 Code cases, Section III, Div. 1, Subsection NE

3.1.4.2 See Attachment 1 for additional codes and standards.

3.2 Drywell Containment Structure

3.2.1 Attachment 1 provides a description of the Oyster Creek Drywell Geometry, Design Bases, Materials, Shop and Field Fabrication and Testing, and Concrete Interfaces.

3.2.2 Extent of Drywell Thinning

Background information on the source of the sand cushion wetting, UT techniques, drywell thickness measurements, and core sample locations are included in Attachment 2. Based on information contained in Attachment 2, the following conclusions can be stated:

A. The ultrasonic thickness probing of the drywell containment has been confirmed to give accurate but conservative results. The physical measurements of the thicknesses of the plugs were approximately 0-4% greater than that determined by UT results.

B. Destructive metallurgical examination of one of the containment plugs verified that the highly localized UT indication was an inclusion and that pitting did not exist.

C. The general areas characterized as broad exterior corrosion have been verified to be general wastage.

D. These broad areas of exterior corrosion are localized at an elevation corresponding to the exterior sand cushion. Measurements of drywell thickness below the level of the interior concrete floor (which were made by removal of the interior concrete at two locations) show that wastage below the floor level is no greater than that measured just above the floor level. Measurements at the two locations show the drywell below floor level to be slightly thicker than the immediately adjacent area above the floor area.

E. The drain line gasket was found to be leaking and was replaced. Leak tests were performed on the bellows, and no leaks were detected. Observations of the areas where leakage had previously been found indicated that the leakage had been arrested.

F. Based on the conservative methodology utilized in Attachment 2, the effective drywell thickness at the sand entrenchment region has a mean value of 0.87. This value exceeds the minimum required shell thickness calculated for structural stability and integrity. (See Attachment 4)

3.2.3 Drywell Corrosion Mechanism and Rate

A review of the potential causes of corrosion and a conservative prediction of a future corrosion rate is included in Attachment 3. Based on information contained in Attachment 3 the following conclusions can be stated:

A. In all cases where general corrosion was present, the sand cushion appeared to be wet.

B. No deep pitting was observed and no sulfide or substantial concentration of manganese was detected in the corrosion product. This indicates that microbiological influenced corrosion is minimum..

C. The corrosion observed can be explained by an aqueous corrosion mechanism assuming chloride contamination and oxygen depletion.

D. A conservative corrosion allowance rate of 48 mils per year will account for any uncertainties in the assumptions of the corrosion mechanism.

3.2.4 Structural

Attachment 4 provides an assessment of the Drywell structural capability assuming a reduced shell thickness of .7 inches within the sand entrenchment area for two critical load combinations.

Conclusions which can be made from this assessment are:

A. The original allowable stress criteria of ASME Boiler and Pressure Vessel Code, Section VIII, 1962 with appropriate Code cases is met when credit is taken for the radially inward reaction due to the sand. Without the sand, (a beyond design basis condition) code allowable stresses are exceeded by 2.7% with a reduced shell thickness of 0.7 inches at the sand entrenchment region. However, ASME Sect. III, Div. 1, Subsection NE allowable stress criteria are met without exception using stress intensities. While peak local membrane stresses are less than the allowable, the meridional extent of these is more than allowed by Section III (but 2X). The original Code placed no bounds on the extent of a local stress. It is reasonable to neglect this departure from present Code guidance because the present situation is an in-service condition and not a design condition, and because the departure from present Code guidance is small.

B. The load combinations selected for this analysis represent the design basis accident condition.

3.3 <u>Effects of Thickness Reduction on the Safety Function of Drywell Containment Structure (DCS)</u>

3.3.1 <u>Structural Performance</u>

The reduction in thickness of the drywell shell at the sand entrenchment region does not prevent the structure from performing its intended safety function.

3.3.2 Quality Standards

Repair of the core samples taken were made in accordance with the quality standards of the plant.

3.3.3 Natural Phenomena Protection

Since the DCS is protected from the outside elements by a safety class structure capable of withstanding a tornado or hurricane, and since the plant elevation prevents natural flooding, these loadings do not contribute to the concerns posed by this activity. However, in the evaluation of structural performance, seismic loads were included and found that this event does not affect the integrity of the DCS when the event occurs singly or in combination with other design loads.

3.3.4 Fire Protection

The thinning of the drywell shell does not affect the fire protection program for the plant, since the drywell was not considered as one of the fire protection measures.

3.3.5 Environmental Qualifications

The assumptions utilized in complying with 10CFR50.49 "Environmental Qualification of Electrical Equipment Important to Safety for Nuclear Power Plants" have not been altered, therefore there is no effect on Environmental Qualification.

3.3.6 Missile Protection

The affected area is protected by a concrete shield wall as described in Section 3.2.1 and by the Reactor Building which provides protection from external missiles.

3.3.7 High Energy Line Break; Internal Flooding

The maximum pressure inside the DCS after a high energy line break has been conservatively assumed to be 62 psig. Subsequent evaluation of the affected area considering this pressure increase together with SSE and deadloac shows that DCS structural integrity is still maintained.

3.3.8 Electrical Separation

The reduction in thickness of the affected area does not impact any electrical components.

3.3.9 Electrical Isolation

The reduction in thickness of the affected area does not impact any electrical components.

3.3.10 Electrical Loading Impact on Emergency Diesel Generators and Safety Buses.

No effects per explanation 3.3.9.

3.3.11 Single Failure Criteria

No effects on single failure criteria since the structural integrity and stability of DCS is assured.

3.4 Licensing Basis Documents Margin of Safety

Review of the FDSAR requirements as to the structural integrity of the DCS during all modes of plant operation reveal that the minimum thickness of the affected regions still have ample margin of safety to satisfy Technical Specification 5.2 and the intended design as stated in the FDSAR. This was ascertained after reanalysis (see Attachment 4) of the structural response to the most severe load combinations considering the minimum thickness of the affected area.

3.5 Nuclear Safety/Safe Plant Operation

Since the structural integrity and stability of the DCS have not been affected by the thinning of the affected regions of the shell, and the corrosion rate determined will not degrade the structural integrity and stability of the DCS during cycle 11, nuclear safety and safe plant operation will not be affected. The thinning is limited to the area described in this evaluation; no evidence of damage to other drywell areas or other safety related equipment was found.

3.6 Probability of Occurrence or Consequences of an Accident

Since the structural integrity and stability of the DCS is still maintained, the minimum thickness of the affected shell region of the DCS will not affect the probability of occurrence of any accident when the plant is in any mode of operation or plant condition. Furthermore, since the containment isolation function of the DCS is intact, the consequences of any postulated accident at O.C.N.G.S. will not be affected.

3.7 Probability of Occurrence or Consequence of Malfunction of Safety Equipment

The fact that the structural integrity and stability of the DCS has not been affected by the condition, the probability of occurrence or consequence of a malfunction of safety equipment in the plant will not be affected.

3.8 Possibility for an Accident or Malfunction of a Different Type Than Any Previously Identified in FDSAR.

Since the DCS still meets design requirements no accident or malfunctions are different from what have been previously identified.

3.9 Margin of Safety on Basis of Technical Specification

The thickness of the affected region of the shell has been ascertained to satisfy the original allowable stress criteria of ASME Boiler and Pressure Vessel Code, Section VIII, 1962 with appropriate Code cases when credit is taken for the radially inward reaction due to the sand. Without the sand, (a beyond design basis condition) Code allowable stresses are exceeded by 2.7%. However, ASME Sect. III, Div. 1, Subsection NE allowable stress criteria are met without exception. While peak local membrane stresses are less than the allowable, the meridional extent of these is more than allowed by Section III (but 2X). The original Code placed no bounds on the extent of a local stress. It is reasonable to neglect this departure from present Code guidance because the present situation is an in-service condition and not a design condition, and because the departure from present Code guidance is small.

3.10 Violation of Plant Technical Specification

The minimum thickness at the affected regions does not violate any section of the OCNGS Technical Specification. As stated in Section 3.9, the allowable stress criteria is satisfied.

3.11 Violation of Any Licensing Requirements or Regulations

Review of OCNGS Licensing requirements and commitments reveal that the thinning of the drywell shell does not violate any of Licensing requirements or regulations. This is primarily due to the fact that containment isolation function and the structural integrity of the DCS have not been affected.

3.12 Radiological Safety Concerns

The reduction in thickness of the drywell shell will not affect any radiological safety concerns because the containment isolation safety function of the DCS is still intact. The drywell shell in the area of concern is within the biological shield, and adequate shielding of occupied plant areas will be maintained.

3.13 Change to FSAR

This condition will require a change to the FSAR to reflect the change in the plate thickness, and the results of the analysis which support this evaluation.

3.14 Change to Established Practice or Procedure

This condition will not require any change to an established practice or procedure.

4.0 EFFECTS ON THE ENVIRONMENT

4.1 Changes to Plant Environmental Interface

The reduction in thickness of the affected shell area will impose no changes to the OCNGS plant environmental interfaces, because the structural integrity and stability of the DCS is still intact.

4.2 Potential Environmental Impact

Since the activity does not affect the environment, it does not have any potential impact to the following:

A. Environmental Technical Specification

B. Applicable Environmental Permit Requirements

C. Final Environmental Statement

D. Environmental Impact Statement

Consequently, no additional evaluation is required.

5.0 CONCLUSION

Recent findings revealed that sections of the drywell shell near the base sand entrenchment region have a mean thickness of 0.87 inch. This is less than the original thickness that was utilized

In the evaluation of structural stability and integrity in support of Licensing the OCNGS. Extensive review of the original calculations, load combinations and different plant conditions, and new calculations generated to evaluate the structural stability and integrity of DCS show that:

1. The structural performance of the DCS during the most severe plant condition (DBA) will not be affected. The margins of safety found are more than enough to assure structural stability and integrity of the DCS.
2. The containment isolation safety function of DCS is still intact. Consequently, no environmental or radiological concerns exist due to the reduced thickness.
3. FSAR and Technical Specification Commitments have not been violated.
4. Plant Procedures and Safe Practices are not affected.
5. The corrosion rate determined for will not degrade the structural integrity and stability of the drywell during cycle 11.
6. Based on Sections 3.6, 3.7, 3.8, and 3.9, there does not exist an unreviewed safety question as defined in 10CFR50.59.

Attachment 1

DESCRIPTION OF DRYWELL DESIGN

Primary Containment Geometry

The primary containment consists of a pressure suppression system with two large chambers as shown in Figure 1. The drywell houses the reactor vessel, the reactor coolant recirculating loops, and other components associated with the reactor system. It is a 70 ft. diameter spherical steel shell with a 33 ft diameter by 23 ft high cylindrical steel shell extending from the top.

The pressure absorption chamber is a steel shell in the shape of a torus located below and around the base of the drywell.

The two chambers are interconnected through 10 vent pipes 6 ft. 6 in. in diameter equally spaced around the circumference of the pressure absorption chamber. The two chambers are structurally isolated by expansion bellows in the interconnecting piping and analysis for each unit may be considered independently.

The drywell interior is filled with concrete to elevation 10 ft. 3 in. to provide a level floor. Concrete curbs follow the contour of the vessel up to elevation 12 ft. 3 in. with cutouts around the vent lines.

On the exterior, the drywell is encapsulated in concrete of varying thickness from the base elevation up to the elevation of the top head. From there, the concrete continues vertically to the level of the top of the spent fuel pool.

The proximity of the concrete surface to the steel shell varies with elevation. The concrete is in full contact with the shell over the bottom of the sphere at its invert elevation 2 ft. 3 in. up to elevation 8 ft. 11 1/4 in. At that point, the concrete is stepped back 15 inches radially to form a pocket which continues up to elevation 12 ft. 3 in. That pocket is filled with sand which forms a cushion to smooth the transition of the shell plate from a condition of fully clamped between two concrete masses to a free standing condition. The sand pocket is connected to drains provided to allow drainage of any water which might enter the sand.

Above elevation 12 ft. 3 in. the concrete is stepped back 3" measured radially from the steel shell. This gap was created during the construction by applying a compressible, inelastic material to the outside of the shell prior to concrete placement. The material was later permanently compressed by controlled vessel expansion in order to create a gap between the vessel and the concrete.

Drywell Design Bases

Design codes used for the original design are as follows with the effective dates at the time of design:

- ASME Boiler and Pressure Vessel Code, Sections VIII and IX with all applicable addenda in effect at the time of design.

- Nuclear case interpretations 1270 N-5, 1271 N and 1272 N-5.

- ASME Boiler and Pressure Vessel Code, Section II with all applicable addenda for the following material

SA-212	High Tensile Strength Carbon - Silicon Steel Plates for Boilers and Other Pressure Vessels
SA-300	Steel Plates for Pressure Vessels for Service at Low Temperatures
SA-333	Seamless and Welded Steel Pipe for Low Temperature Service
SA-350	Forged or Rolled Carbon and Alloy Steel Flanges, Forged Fittings, and Valves and Parts for Low Temperature Service

- ASTM A-36 Structural Steel

- AISC Specification for the Design, Fabrication and Erection of Structural Steel for Buildings

Pressure and temperature parameters in the original drywell design include:

- Drywell and connecting vent system tubes are designed for 62 psig internal pressure at 175°F and/or 35 psig at 281°F, and an external pressure of 2 psig at 205°F.

- In addition, the drywell is designed to withstand a local hotspot temperature of 300°F with a surrounding shell temperature of 150°F concurrent with the design pressure of 62 psig.

- The lowest temperature to which the primary containment vessel pressure containing parts are subject to while the plant is in service is 50°F. To provide an additional factor of safety, 30°F was actually used for the design basis.

- During reactor operation, the vessel will be subjected to average temperatures up to 150°F at approximately atmospheric pressure.

Loadings considered in the design of the drywell include

- Loads caused by temperature and internal or external pressure conditions.
- Gravity loads from the vessels, appurtenances and equipment supports.
- Horizontal and vertical seismic loads acting on the structures
- Live loads
- Vent thrusts
- Jet forces on the downcomers
- Water loadings under normal and flooded conditions
- Weight of the contained gas in the vessels
- The effect of unrelieved deflection under .emporary concrete loads during construction.
- Restraint due to compressible material
- Wind loads on the structures during erection

Load combinations used the design of the drywell and vent system for accident conditions include:

- Gravity load of vessel and appurtenances
- Gravity load from equipment supports
- Gravity load of compressible material
- Gravity load on welding pads
- Seismic loads
- Design pressure: maximum positive pressure of 62 psig at 175°F decaying to 35 psig at maximum temperature of 281°F, to maximum negative pressure of 2 psig at 205°F.
- Restraint due to compressible material
- Vent thrusts
- Jet forces

Allowable stress levels used in the design of the drywell are based on Code Case 1272 N-5

- General membrane (does not include thermal) = 19250 psi
- Local membrane (does not include thermal) = 28875 psi
- Surface stress = 52500 psi

Drywell Materials of Construction

Steel plates are A-212-61T, Grade "B", made to ASTM A-300 requirements. Minimum charpy vee notch impact test values of 20 ft.-lbs. at 0°F were used instead of 13 ft.-lbs. at 0°F as permitted by Code Case 1317. Test specimens were taken both parallel to and transverse to the direction of final rolling of the plate.

Forgings are A-350 Grade LF1. Minimum charpy vee notch impact test values were 13 ft.-lbs. at 0°F in addition to charpy keyhole impact test values required by the Burns and Roe specifications.

Pipe is A-333, Grade "O" seamless. Minimum charpy vee notch impact test values were 13 ft.-lbs. at 0°F on full size test specimens in addition to charpy keyhole impact test values required by the Burns and Roe specifications.

Miscellaneous plate and structural steel (not within the scope of ASTM A-36): All permanent structural attachments and lugs, welded to the shells, were made of impact tested material for a distance of not less than 16 times the plate thickness. The erection skirt supporting the drywell was also made of impact tested material.

Drywell Shop Fabrication and Testing

Components were shop welded, where possible, into large size shipping pieces, utilizing either submerged or metallic coated arc techniques. In either case, low hydrogen electrodes were used, thus assuring the notch toughness requirements to meet the ASME Code Impact Tests.

All seam welds in the shell of the containment were of the double bevel butt type. All butt welds in any accessories subject to the ASME Code were also of the double welded type or equivalent, and all the joints were full penetration welds. All welds subject to the Code were radiographed or otherwise examined in accordance with Code Case 1272 N-5. All mandatory provisions of this code were followed and all recommended provisions were also followed where practical.

Heavy weldments and penetration weldments were furnace stress relieved as follows:

a. Any plate segment wholly containing a penetration, nozzle, or column connection was furnace stress relieved at the shop after insertion of the penetration.

b. All large penetrations intersecting more than one shell plate were stress relieved as follows. Any portion of a penetration containing ·· ms joining metal over 1 1/2 in. thick at the joint was furnace stress relieved as a unit before welding into a penetration assembly or into the shell.

In keeping with the above, the vent line penetrations were shop assembled to the reinforcing collar and the completed assemblies were stress relieved. The weld between the collar and the shell plate was made in the field and was not stress relieved.

All shop welds were radiographed in the shop. All welds in those parts of the work subject to the ASME Code were radiographed by methods complying with Paragraph UW-51 of the code.

Prior to shipment, all materials were cleaned and painted. Surface preparation and painting was in accordance with the paint manufacturer's recommendations. The interior of the drywell above the concrete floor, including jet deflectors and the exterior of the drywell above the water seal support bracket received one coat of Carboline Carbo-Zinc 11. The interior of the drywell below elevation 8 ft. 11 1/4 in. and the exterior surface of the drywell adjacent to concrete surfaces at completion of construction were not coated. All other surfaces of the drywell were given one coat of Carboline primer.

After erection and testing, all field welds and abraded places on the shop paint were cleaned by sandblasting and painted as noted above.

Drywell Field Fabrication and Testing

During field fabrication the drywell steel was supported on a steel skirt of approximately 39 ft. diameter with its base plate at elevation-0 ft. 1 in. and invert of the sphere at elevation 2 ft. 3 in.

The 70 foot diameter spherical drywell and upper cylinder were field assembled and welded. The transition knuckle and top head flanges were field stress relieved in accordance with the ASME Code.

The heavy plate flanges for the 33 foot diameter cover and neck flanges of the drywell were subassembled in segments, welded, x-rayed and stress relieved as complete units.

All completed shell plate assemblies, with penetrations installed, were stress relieved after fabrication. All butt welds were 100% x-rayed. Other welds which could not be 100% x-rayed were magnafluxed before and after stress relieving.

Upon completion of fabrication of the drywell and pressure absorption chamber, acceptance testing was initiated. This included soapsuds testing at 5 psig, a holding period at 40.25 psig and a second soapsuds test at the design pressure of 35 psig. This was followed by the overload test at a pressure of 71.3 psig which corresponds to a 115 percent overload. The procedures for the overload test fulfilled the requirements of Section VIII of the ASME Code and Code Case 1272 N-5.

At the time of the tests, the downcomers, designed to pass the released steam and gases from the drywell into the suppression chamber were capped in order that a separate test could be conducted on each vessel. The drywell was tested with no pressure in the suppression chamber. The suppression chamber, however, was tested with a balancing pressure in the drywell to avoid an excessive external pressure on the vent lines and header inside the suppression chamber.

Drywell/Concrete Interfaces

The drywell shell is designed as a free standing structure and, with the exception of concentrated jet forces, will resist all required loads without interaction with the surrounding concrete. The function of the concrete is to act as a radiation shield, provide a "back-up" to limit deformation due to concentrated jet forces and to form a support at the base of the sphere.

At the base of the sphere, subsequent to completion of pneumatic testing, the volume inside the skirt was filled with concrete while simultaneously pouring the concrete floor inside the bottom of the shell. The concrete pour outside the vessel proceeded in full contact with the vessel up to elevation 8 ft. 11 1/4 in. where the concrete line was stepped back radially 15 inches. This gap continues up to elevation 12 ft. 3 in. At points on the perimeter of the vessel where the vent lines penetrate the concrete, the forms were set back around the vent lines to provide clearance which would prevent contact between the vent lines and the concrete surface during any design condition. The 15 inch radial gap was filled with sand to provide a cushion for the shell plate during the transition from clamped between two concrete surfaces to free standing.

At all elevations above the sand layer, the external concrete mass is set back from the surface of the stee' vessel an amount calculated to allow unimpeded expansion of the steel shell during any design condition. The gap was created by applying a compressible, inelastic material to the exterior surface of the vessel prior to pouring concrete. The material properties were chosen to provide resistance to crushing by the pressure induced by the head of concrete, but of low compressive strength to allow collapsing by induced vessel expansion.

The criteria for maximum gap was established to limit the deflection of the vessel wall due to local impact of jet forces. The criteria used was that the space between the steel drywell vessel and the concrete shield outside must be sufficiently small that, although local yielding of the steel vessel may occur under concentrated forces, yielding to the extent causing rupture would be prevented. Using this criteria, the formed gap was 2 inches from elevation 12 ft. 3 in. to elevation 23 ft. 6 in. Above 23 ft. 6 in. the formed gap was increased to 3 inches. This dimension allowed for inelastic compression due to concrete pressure during the pour and residual thickness of gap material after compression by controlled vessel expansion.

The criteria used for selection of the gap material was as follows:

- It must adhere tightly to a curved, painted steel plate surface in flat, vertical and overhead positions.
- Could have relatively insignificant deformation under fluid pressure of wet concrete estimated at 3 psi.
- Would be reduced in thickness inelastically by about one inch from an initial thickness of 2 to 3 inches under a pressure of not more than 10 psi.

* Would remain dimensionally stable at the reduced thickness without significant flaking or powdering
* Would be unaffected by long term exposure to radiation and heat
* Should be susceptible to minimum damage which exposed on the vessel before concrete placement.

The 2 inch gap was formed using Owens-Corning Fiberglass SF Vapor Seal Duct Insulation. The material was supplied with a factory applied laminated asphalt kraft paper waterproof exterior face, and was attached to the vessel with mastic and insulation pins. Joints between the boards, and edges and penetrations were sealed with glass fabric reinforced mastic.

The gap material used above elevation 23 ft. 6 in. was Firebar-D, a proprietary asbestos fiber - magnesite cement product applied as a spray coat. The solid materials, asbestos fibers, magnesite and magnesium sulphate (roughly 75% asbestos), were premixed and combined in a mortar mixing machine with water and, to control density, with foam to form a slurry suitable for spray application. After application and curing, the material surface was faced with polyethylene sheets with all edges sealed by tape and held in place by insulation pins. The polyethylene sheets formed the bond-breaker for the concrete pour.

Gap Formation and Results

At the most critical location, drywell expansion at 281°F and 35 psig was expected to be approximately 0.7 inches. Considering an allowance for material rebound, it was calculated that the required vessel expansion could be achieved by raising its temperature 140°F above ambient. Concurrent with induced thermal loading, an internal pressure was created to balance the shell external compressive forces induced by the crushing of the gap material. An internal pressure of 40 psig was calculated as appropriate for this function, and considering the expansion induced by internal pressure, the temperature differential was reduced from 140°F to 130°F.

After placement of the gap material on the drywell shell, concrete placement continued in a staged schedule to complete encasement of the drywell. The vessel was then expanded to create the required air gap required for thermal and pressure expansion.

Expansion of the vessel was monitored via use of pairs of extensometers at 7 points around the exterior of the vessel at locations of penetrations. The extensometers were read and recorded hourly and the readings compared with calculated theoretical values. While the horizontal movements were in good agreement with calculated values, the upward accumulation of expansion expected due to the embedment of the lower region was at all points less than predicted. Therefore, vessel discontinuity stresses at the embedment would have been less than calculated and the load on the concrete wall would have been more uniformly distributed and with a lower maximum.

During the expansion, it was noted that the gap material had entrapped moisture due to incomplete curing and introduction of water from external sources. This was evidenced by appearance of water at sleeves around several penetrations. This was deemed to be of no practical significance since the moisture's effect on material compression characteristics would be a moderate improvement through a slight reduction in strength and a lesser rebound.

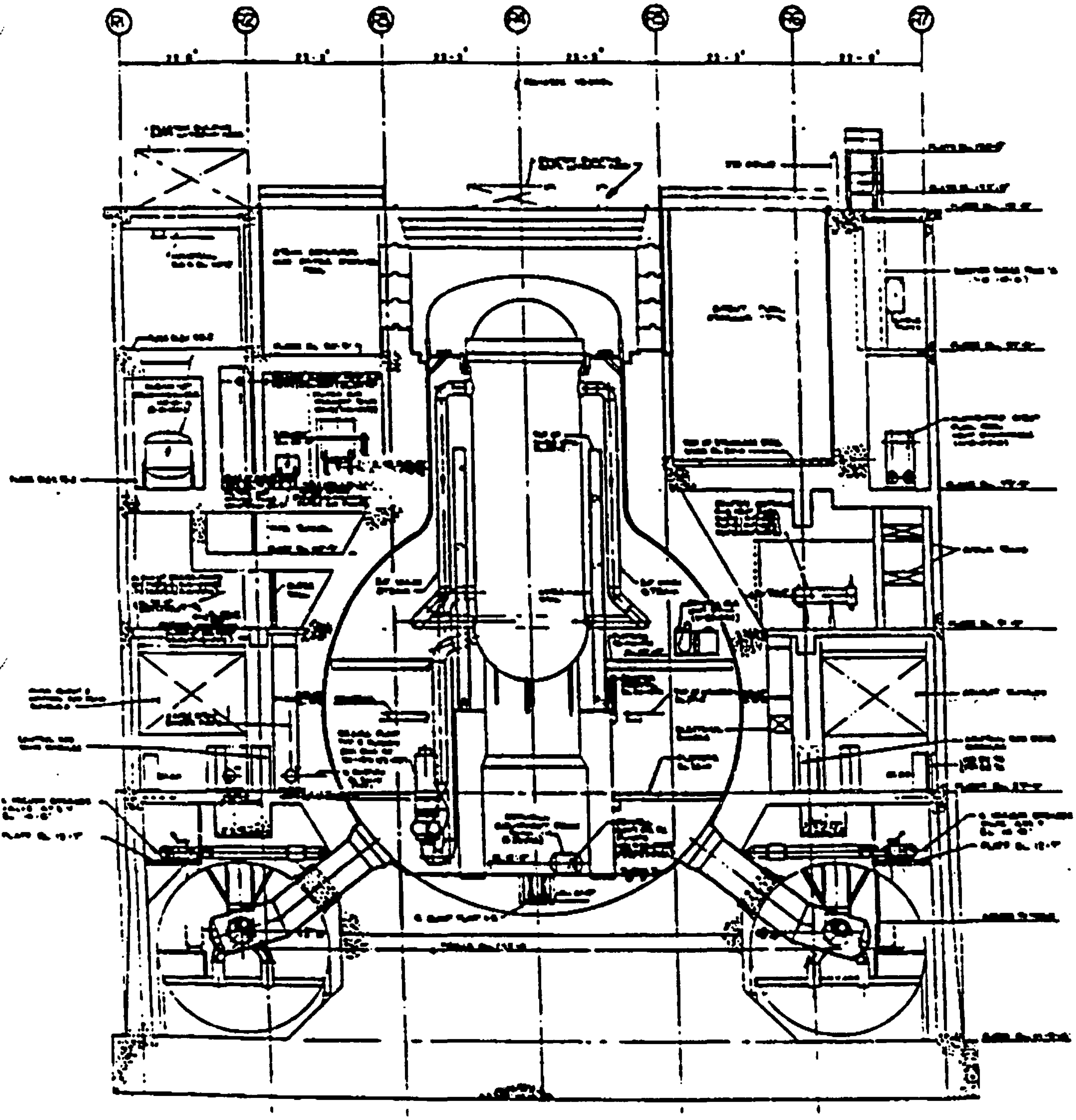
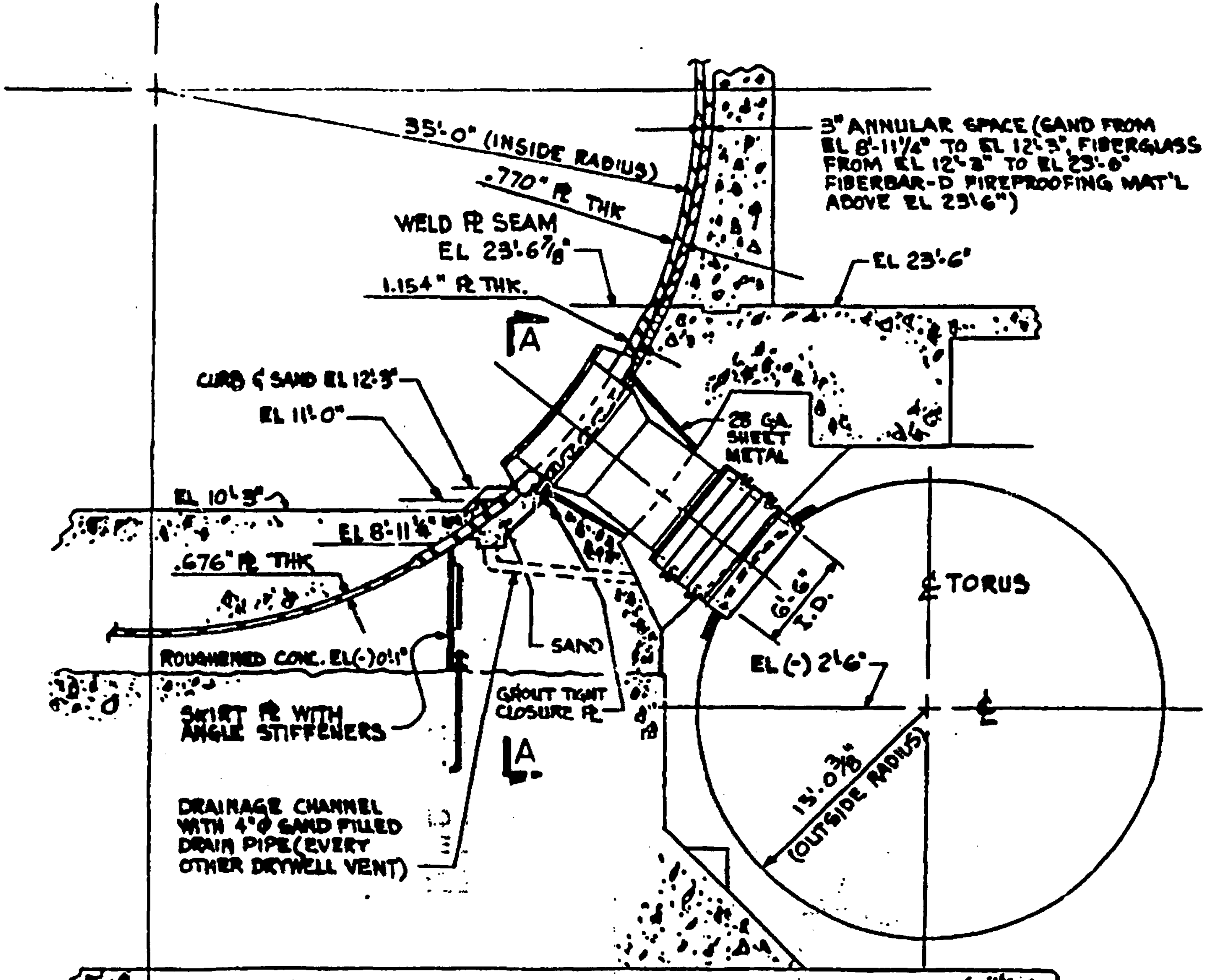


Figure 1 Drywell Containment Structure

Figure 2 Cross Section of Drywell & Torus



PARTIAL CROSS SECTION OF DRYWELL & TORUS

Attachment 2

Extent of Damage

EXPECTED SOURCE OF SAND CUSHION WETTING

During the 1980 Oyster Creek plant outage, water was found leaking from various locations from the concrete surrounding the drywell. Containment penetration X-46 (Elev. 86'-0") on the south west, and penetration X-50 (Elev. 47'-0") on the north east were reported to have water leaking from within the concrete biological shield. These identified areas correspond to Bays 7 and Bays 17 & 19, respectively. In addition it was reported that water was coming from the sand cushion drain lines in Bays 3, 11, and 15 into the torus room.

Efforts were made to identify the source of the water and its leak path. The leakage was found to have the same range of radioactivity as that within the reactor. The leak path for the water was believed to have been from the reactor cavity located immediately above the drywell. This cavity is filled with water during refueling operations. It was believed that a leak from this cavity through the bellows seal at the bottom drained to the space between the drywell and the surrounding concrete (i.e., the space filled with insulation). The volume below the bellows was pressurized with service air and the bellows checked for bubbles. Another leak test was performed by injecting helium behind the bellows and the bellows sniffed. The results of these tests were negative. The 2 inch reactor cavity drain line that includes a flexible pipe section was also tested with no significant leakage detected. Plans were made during the following operating cycle to locate and seal any potential leak path from the reactor refueling cavity.

During the 1983 outage the welds of the refueling cavity were leak tested. Some minor leaks were detected and repaired. The bellows area between the containment and the refueling cavity was cleaned to remove contaminants. The area was then inspected and attempts were made to apply various pressure tests to the bellows, however, no leaks were detected. Also, during the 1983 outage the water level was dropped to the lowest reactor cavity shield plug step. At this time it was observed that leakage from penetrations X-46 and X-50 stopped. Furthermore, leakage into the torus room had diminished. Three of the four shield plug steps were inspected via liquid penetrant for the full circumference; no indications were detected. The single drain line used to detect leakage from the refueling cavity was suspected of being restricted. A restriction in this line would cause any leakage to be directed into the area between the containment and biological shield. This drain line was purged with air and did not appear to have any flow restrictions. When the refueling cavity was filled, similar leakage was found as previously described, however, it had been reduced appreciably.

During the cycle 11 outage outage the drain line from the refueling cavity was inspected. Drain line gasket (30"x7") was found to have leaks, and it was replaced. Leak tests were performed on the bellows, and no leaks were detected. Observations of the areas where leakage had previously been found indicated that the leakage had been arrested.

DRYWELL THICKNESS MEASUREMENTS

Because of these wetting conditions, there was concern that repeated exposure of the drywell steel to water could result in degradation of the drywell.

Measurements of the drywell portion of the containment shell were made to verify its thickness during the 11R outage. These measurements were made using UT, a Non Destructive Examination (NDE) method, that is able to accurately determine the thickness of material or presence of abnormalities, i.e., nonmetallic inclusions.

UT plate thickness measurements were made on the Oyster Creek drywell. Approximately 1,000 UT readings were eventually taken utilizing an ultrasonic thickness gauge device (D-meter). Measurements were obtained by transmitting ultrasound through the plate and measuring the time it takes for the longitudinal wave mode to travel to a reflector (front wall interface or mid-wall reflector or backwall) and back. Since the electronic measurement of time results in the digital thickness measurement of the first significant sound reflector, the probability of a mid-wall reflector being measured verses the backwall is dependent on the size of the reflector related to the surface area of the ultrasound transducer. The larger the mid-wall reflector, the more likely the digital thickness reading will be the mid-wall number, and not the backwall value.

To further characterize the drywell and "A-Scan" UT technique was also employed. "A-Scan" is important for the expanded analysis of the character, location and amplitude of various ultrasound reflectors. The "A" scan is the ultrasonic indication displayed on a cathode ray tube (CRT). The front surface pip or amplitude appears first, and the back surface pip or amplitude appears sometime later in the CRT sweep display. The space between the pips is a measure of the distance between the surfaces. Pips in between the front and back surfaces may be mid-wall reflectors such as laminations, inclusions or isolated holes and/or pits.

Other characteristics of the reflector can be observed by a qualified technician when using an "A" scan that are not available with a D-Meter. Profile of the amplitude, break pattern at the baseline, number of doublets following the amplitude pip, multiples of original reflectors, and amplitude height on the screen and other characteristics all give information that may be useful in analyzing origins of ultrasound reflectors.

MEASUREMENT LOCATION

Initial UT measurements were made from the inside of the drywell containment at elevations 51 feet and 10 feet. A digital UT system was used. The measurements opposite the sand cushion at the 10 ft. elevation in the Bays corresponding to where water leaks were observed, indicated that the containment wall was thinner than expected. Measurements above these areas in the same plate indicated thicknesses within the original plate thickness variability. Additional UT readings in the same Bay quadrants at elevation 51 indicated no abnormal thickness variations. Although there are no specific requirements for surveillance of the containment wall thickness, it was considered prudent to make these measurements due to the wetted conditions that had occurred.

The initial measurements were made through the protective coatings on the inside of the containment. Since the effect of the protective coating on the UT measurements was questioned, special test blocks were made that included the coating material to quantify the effects of the coating on the UT readings. The accuracy of the UT system was established for the coating thickness of the upper portions of the drywell. The effects of Carboline Carbo-Zinc 11 coating on the accuracy of UT measurements was verified through an experiment conducted by GPUN. Two carbon steel plates approximately 1.15-inch thick and six by six-inch square were coated with carbon zinc. One plate had five mils coating and the other plate had 10 mils coating. Both plates had a half inch wide strip on one edge left uncoated. Both plates were laid out in a half inch grid pattern across the entire partially coated side including the uncoated strip. Similar equipment (D-meter of same make and model) transducers, and couplant as used in the field was utilized and measurements taken. Approximately 149 readings of thickness were taken for each plate. Additionally each grid (excluding the uncoated strip) was measured by Dry Film Technique (DFT) gauge to determine the coating thickness. The uncoated strip for each was measured by micrometer. The three readings: 1) ultrasonic (coated and uncoated); 2) dry film technique; and 3) micrometer (uncoated strip) were compiled, averaged and final factors developed. The uncoated micrometer reading, plus the DFT reading was treated as the true reading of combined thickness. The UT reading was found to overcall 0.3% for 5 mil coatings and 1.5% for 10 mil coatings after subtracting the DFT reading from the combined UT reading of steel and coating thickness. It should be noted that the coating application on the test plates and the upper portion of the drywell were consistently uniform. The coating along the basement wall, however, was found to be considerably thicker at places effecting the UT readings. For this reason the coating was removed and a new set of UT measurements were made. The new readings indicated that the containment wall was thinner than expected in several areas along the basement floor. The areas of indicated thinning was adjacent to the sand cushion.

EXTENDED UT MEASUREMENTS

As a result of the initial UT readings adjacent to the sand cushion being considerably thinner than expected, a program was initiated to obtain detailed measurements to determine the extent and characterization of the thinning. UT measurements were made in each Bay at the lowest accessible locations. Where thinning was detected, additional measurements were made in a cross pattern at the thinnest section to determine the extent and direction. Measurements over a six by six inch grid were then made, moving over the thinnest area to further quantify the wastage area.

To determine the vertical profile of the thinning, a trench was excavated into the floor in Bay 17 and Bay 5. The concrete floor and rebar was removed to expose a portion of the drywell wall about 18 inches wide and sufficiently deep to allow measurement to the bottom of the sand cushion area. Bay 17 was selected since the extent of thinning at the floor level was greatest in that area. It was measured that the thinning below the initial measurements were no more severe and became less severe at the lower portions of the sand cushion. Bay 5 was excavated to determine if the thinning line was lower than the floor level in areas where no thinning was detected although several inclusions were found, there were no significant indications of thinning. The Safety Evaluation (SE No. 328227-001) for the excavation and its treatment for continued plant operation is separate from this evaluation.

Heat Affected Zones & Reinforcement Structure

Other areas of concern requiring additional UT investigation were the plate to plate welds under the torus vents and the vent opening reinforcement plates. These areas were given extra consideration on the basis that material sensitized by welding may have been attacked by a corrosion mechanism with greater damage or cracking occurring at those locations. The extra UT investigation was conducted at three spots equal distance along side each toe of the vertical plate to plate weld and on either side of the bottom center gusset of the vent opening reinforcement plate.

D-meter thickness measurements were taken at all eight spots for Bay 5, 7 and 19. At these three Bay sites the six spot locations on each side of the plate to plate weld under the torus vent openings were also 45° shear tested to interrogate the weld Heat Affected Zone (HAZ). The 45° shear wave test was especially done to detect HAZ cracking. The top two spots were also the sites from which the plate to torus vent reinforcement plate weld was examined for

HAZ cracking. No crack indications were found and no wastage of the torus vent reinforcement plate was found. The plate to plate weld HAZ as well as the weld when tested as part of a B or C location grid (6"x6") indicated wastage similar to the surrounding plate wastage.

Alternate UT Techniques and Verifications

EPRI NDE Center UT personnel were invited to independently analyze the containment vessel plate. Their objective was to independently analyze the condition of the drywell liner. They scanned two areas using a "Zero Degree Longitudinal Wave Method". One area compared was just above the curb that we indicated had general wastage. Another area was where we had indications of mid-wall deflections or laminar inclusions. Their observation and measurements independently verified GPUN's results.

Mapping of the wall profile indicated a corrosion transition at seven to eight inches up from the concrete curb in Bay 19. This detailed map was corroborated by the GE Ultra Image III "C" Scan topigraphical mapping system that will be used to obtain a baseline profile to track continued wastage.

GPUN experimentally utilized the I.D. Creeper or "30-70-70" technique (a UT integration method) to detect minor changes in back wall surface conditions. This technique compared "A" scan presentations from one inch thick corroded samples the results from Bay 13 locations "A" and "E". Reference standards were utilized representing light, moderate and heavy corrosion conditions. This 30-70-70 technique defined surface roughness conditions by matching "A" Scan presentations from materials that have light, medium and heavy corrosion on their back surfaces. It was able to verify the roughness condition of wastage and the light corrosion areas of the containment wall.

The "A" scan displays from the vessel plate were categorized by comparing them to the reference "A" scan displays. Location A of Bay 13 (0"-6" up from concrete curb) showed typical "A" scan display of moderate corrosion on average and local sites of heavy corrosion. Bay 13 locations "A" and "E" indicated heavy corrosion between 0 to 6 inches above the curb, moderate corrosion 6 to 14 1/2 inches above the curb, and very low or no corrosion 14 1/2 to 17 inches above the curb.

LOGIC OF CORE SAMPLE LOCATION

The selection of areas to obtain the core samples was made to evaluate if the UT measurements represented indicated material wastage or if there was localized "pitting". Those measurement areas that indicated thickness readings of less than half of the thickness expected, i.e., .4 to .7 inches, and had adjacent measurements of the expected thicknesses (nominally 1.154"), were designated as "pitted" areas. Areas that had indicated thinning at adjacent measurements were designed as wastage areas. A third area, above the wastage area, and within the sand cushion that appeared to have no thinning or "pits", was also selected as a sample site. The core sampling sequence and logic were to first obtain a sample of a suspected "pitted" area and two samples of a wastage areas but in different bays. Should the "pitted" sample turn out to be an inclusion as suspected from the UT evaluation and the adjacent areas were actually the thickness as measured by UT, additional samples of areas that were suspected as being "pitted" would not be required.

Core Samples

Core samples of the Drywell wall were taken at seven locations. The samples were 2 inches in diameter. This was considered the minimum diameter to produce an adequate sample of the wastage area and provide an opening large enough to remove sand samples. The opening size also permitted insertion of a miniature video camera. Larger openings would have required a more complex plug design to restore the structure to its original condition.

The "pitted" sample #2 from bay 15 location "A" (GPUN 3E-SK-S-85) was found to be an inclusion in the plate with little to no indication of corrosion on the outside of the sample.

Samples #1 and #3 were from bays 19 location "C" and bay 17 "D", respectively. Both showed significant wastage with good correlation of actual micrometer measurement with the UT measurement (See Table 1).

The wastage samples (plug 1 & 3) were measured for thickness by ultrasonic (D-meter) and dimensional (micrometer) in a four-point cross pattern and a center location. The micrometer readings were taken with a ball micrometer to minimize the error observed when a flat bottom micrometer measures a locally irregular surface. The micrometer measurements through the oxidized surface indicated the UT measurements to be between 0% and 4% less than the micrometer measurements.

Two additional wastage locations were selected below the severely thinned locations (Samples 4&5) and two locations above the wastage areas (Samples 6&7) were selected to bound the conditions. The wastage samples 4&5 were similar to samples 1&3 confirming the UT measurement accuracy. Samples 6&7 did not have wastage and the sand behind them was found to be dry, also confirming UT measurement accuracy.

TABLE 1

CORE SAMPLE THICKNESS EVALUATION

Sample No.	Location	Type of Sample	Pre-removal Thick.	Post-Removal Thick. (Ave.)
1	19C - 11'3 5/8"	Wastage	.815" (avg.)	.825"
2	15A - 11' 5 1/4"	Pitting	.490" (min.) 1.17 (avg.)	1.170" center only
3	17D - 11' 3 3/4"	Wastage	.840" (avg.)	.860"
4	19A - 11' 3 3/8"	Wastage	.830" (avg.)	.847"
5	11A - 11 3	Wastage	.860" (avg.)	.885"
6	11A - 12' 2 3/4"	Above Wastage	1.170" (avg)	1.19" center only
7	19A - 12' 1"	Above Wastage	1.140" (avg.)	1.181" center only

The openings in the Drywell wall were repaired and sealed with a special designed and fabricated steel plug. The final repair was accepted by the Authorized Nuclear Inspection (ANI) after successfully completing a magnetic partical examination of the welds on each plug. A final acceptance test for each plug was performed using a vacuum box bubble test. In addition a local leak rate test was conducted on each plug and met the integrated leak rate requirements of the Code of Federal Regulations 10CFR50 Appendix J. Actual leak rate measurement at each plug was 0.000 standard liters per minute at 35 psi. The repair left the interior surface flush with the inside of the drywell wall. A separate Safety Evaluation (SE No. 328227-001) for the removal of the samples and for the repair of the Drywell openings has been conducted.

DATA SUMMARY

The thickness measurements obtained adjacent to the sand cushion are tabulated on GPUN drawing number 3E-SK-S-85. Initial measurements were taken at four locations near the lower curb at each torus vent. These locations, A-B-C-D, were selected to provide two thickness measurements of the left and right drywell plates that make up each Bay section. Each tabulation heading defines the location of the tabulated matrix of measurements with respect to the top of the curb and to the weld between the two plates at the center of the vent line. The matrix of measurements are at one inch increments both vertical and horizontal. Those measurements around heat affected zones and on the vent line reinforcement were taken one inch on each side of the weld. No degradation or wastage was indicated on the reinforcement plate or around the reinforcement plate to the containment plate weld. Wall thinning indications on the containment plate on each side of the containment plate weld was the same magnitude as surrounding areas indicating that the weld heat effected zone did not cause or accelerate wastage.

Data Reduction

UT drywell thickness data was collected in each of the ten bays. The UT data is presented on GPUN Drawing No. 3E-SK-S-85 Rev. 1. The primary concentration of data was within a 6 inch wide circumferential banu above the drywell floor curb since data above this band indicated minimal wastage of the drywell wall material.

A new nominal wall thickness was sought for the affected lower portion, 6' wide band, of the drywell shell. Two approaches were taken. The first, was to establish the mean and standard deviation values of all the UT data in the affected region of the drywell. The second approach was to establish the mean and standard deviation values of the UT data in the affected region which is contained within a 60 inch circumferential extent of the drywell. The second approach using six measurement locations in each bay yielded nine (9) 60 inch combinations of mean and standard deviation values for each of the ten (10) drywell bays. The significance of the 60 inch spans is that it represents a physical property of the shell.

This property is the deflection half wave length which defines the shell boundary relative to the location of applied primary and secondary loads beyond which the applied load does not cause shell deflection. This property was calculated by Professor A. Kalnis of Lehigh University.

Although some of the low value UT indications were identified as inclusions in some of the areas measured, they were used as thickness measurements for the statistical reduction of data.

The first approach yielded a mean and standard deviation value of 0.96 inches for all of the UT data in the affected region.

The second approach yielded a value of 0.87 in. for the minimum mean wall thickness within the 60 inch arc length criteria. This segment included 50 data points within a 26 x 6 inch segment of the drywell shell in Bay #19. A wall combination in the same bay within the 60 inch criteria included 148 data points with the data points extending over an area 57 x 6 inch and including the data within the former 26 inch segment. This latter segment also yielded a value of 0.87 in. for the mean wall thickness.
For purposes of the engineering calculations regarding the structural integrity of the shell, based on the above minimum mean values, a nominal wall thickness of 0.87 in. should be utilized.

Attachment 3

BACKGROUND

Water Intrusion Detection

The first documented evidence of the intrusion of water into the annular space between the drywell shell and concrete shield wall came to light during the 1980 refueling outage when water was visible around penetrations X-46 at elevation 86' 0" and running down the wall to floor elevation 75' 3". Water was also observed at penetration X-50 at elevation 47' 0' and running down the wall to floor elevation 23' 6". Water collection was also observed on the torus room floor coming from the leak drains in bays 3, 11, and 15. Informal, undocumented communications, however, also indicate water was observed on the torus room floor following construction.

Construction

The primary containment pressure vessel is contained within a concrete shield with a 3" annular space between the two structures. The annulus is filled with sand specified as ASTM: C33 from elevation 8' 11 1/4" to elevation 12' 3" and from the bottom of this sand bed are 5 drain lines. The sand appears to be a natural sand compcsed of silica with some alumina. An Owens-Corning Fiberglass SF vapor seal duct insulation was applied to the vessel shell from elevation 12' 3" to 23' 6". The insulation was supplied as individual boards 2" thick with a factory applied laminated asphalt kraft paper waterproof exterior face. These boards were attached to the vessel shell with mastic and insulation pins. The joints between the boards and edges and penetrations were then sealed with fabric reinforced mastic. The remaining annular region above elevation 23' 6" is filled with a Firebar-D material. It was applied as a spray coat (approximately 2.75" thick) over the vessel shell. The material is composed of asbestos fiber (approximately 75%), magnesite, magnesium sulphate and a foaming agent (Aerosol PK) to control density. Over the top of the Firebar-D was placed a 4 mil thick polyethylene sheet.

The primary vessel is fabricated from ASTM-A 212 Grade B which is equivalent to SA-516 Grade 70. The vessel was coated on the I.D. with Carbo-zinc 11 and on the O.D. with "Red Lead" primer identified as TT-P-86C Type I. Coating on the exterior of the vessel extends from elevation 8'-11 1/4".

POTENTIAL SOURCES OF WATER INTRUSION

Probable Sources

Observations of leakage from the sand bed drains during the 1980 and 1983 refueling outages indicated that water had intruded into the annular region between the drywell shell and the concrete shield wall. In addition, water samples withdrawn from the drains in 1980 were radiologically analyzed and showed activity similar to primary water. From this information it was concluded that the probable sources of water were (1) the equipment storage pool, (2) the reactor cavity, or (3) the fuel pool. It was further concluded that the leakage only occurred during refueling when the reactor cavity, the equipment storage pool, and the fuel pool are flooded. During the 1986 refueling outage, water samples were again taken from a drain line and analyzed. In addition to tritium, these samples were also analyzed for contaminants. The results of these analyses are shown in Table 1-M.

TABLE 1-M

Drywell Drain Line Water Analysis

Parameter	Sample I (ppm)	Sample II (ppm)
Na	145	96
K	142	85
Ca	7.5	6.4
Mg	30	11
Al	.33	.02
Ni	< .01	< .02
Fe	< .01	.74
Cr	< .01	< .02
Mn	< .01	.02
Pb	.06	< .02
NH_3(N)	3.6	-
Cl	32.5	25
NO_3	8.7	6
SO_4	153	60
PO_4	5	N.D.
F	< 1	
TOC	51	23.3
Organic Acid	< .1	
Total Sulfur	153	
Conductivity	1100 us/cm	814 us/cm
pH	8.9	8.7
Alkalinity (HCO_3)		130

Samples taken 12/86

UT Data Interpretation

Prior to core sample removal possible causes of the low UT thickness readings were attributed to external corrosion, laminations or a field of inclusions within the plate. Because the very low readings were localized it was expected that they would be a result of laminations. The general wastage, however, extended from plate to plate and the affected areas of the shell were within the sand bed only. Thus it was concluded that the plate thinning was most likely due to corrosion. In addition, a qualitative assessment of the plate condition was made using an "A" scan presentation with a 5 mghz transducer. This data was also indicative of corrosion on the outside.

Numerous ultrasonic thickness readings were taken in the drywell particularly at the elevation of 11' 3". Review of this ultrasonic test data showed that potential corrosion damage appeared to be confined to regions in Bays 11, 13, 17 and 19. Furthermore, the thinned parts of the drywell were limited to those areas which were in contact with the sand bed from elevation 10' to 11' 9". Numerical analysis of this data determined the minimum mean remaining wall thickness was .87".

UT thickness readings below the concrete floor elevation showed the thickness to be greater than .87" and at the bottom of the sand bed to be nearly nominal design thickness.

Sampling

After the completion of the ultrasonic testing (UT) of each of the drywell bays above the concrete floor, the data was assembled and reviewed. This data indicated that there were at least three regions which showed different characteristics. One set of data showed regions of overall general wall reduction which we characterized as wastage. Another set showed regions with little or no general wall reduction but localized areas with large wall reduction which we characterized as pitting/inclusions. The last set of data showed regions of little or no wall reduction and no random large reductions, which we characterized as minor wastage. The characterization of each bay is summarized in Table 2-M.

TABLE 2-M

Bay No.	UT Characterization
1	Minor wastage
3	Minor wastage
5	Pitting/inclusion
7	Minor wastage
9	Pitting/inclusions
11	Wastage
13	Wastage
15	Pitting/inclusions
17	Wastage
19	Wastage

In addition to the above general characterizations, it was also observed from the UT readings that above an elevation of approximately 11'9" the wall thickness would return to the nominal value. This occurred even though the readings were still within the sand bed and there was wastage below this elevation. Likewise, there were regions of the sand bed below the concrete which heretofore had not been ultrasonic tested and hence no characterization could be made.

It was decided, therefore, that core samples should be removed from the drywell in each of these different regions in order to achieve the following goals:

a) Verify UT thickness reading

b) Characterize the form of corrosion

c) Obtain sand samples and samples of other annulus materials

d) If corrosion existed, characterize corrosion products and environment

e) Provide access for visual examination of the outside surface of the drywell

f) Allow for sampling of sand and/or corrosion products for bacteria

With these goals in mind, a first cut was made at selecting regions for sampling of the drywell steel. Twelve regions were selected: four from wastage regions, four from "pitted" regions, two from above the wastage region and two from below the concrete level. These initial selections were, however, modified slightly as the program progressed and additional information became available from ultrasonic testing and initial core sample examinations.

Table 3-M identifies each of the seven core sample locations ultimately chosen and the types of samples obtained.

TABLE 3-M

Core Samples

Sample No.	Bay/ Location	Type	Elevation	Samples Obtained
1	19C	Wastage	11'-3 5/8"	Core, sand, bacteriological
2	15A	Pitting/ Inclusion	11'-5 1/4"	Core, sand, bacteriological
3	17D	Wastage	11'-3 3/4"	Core, sand
4	19A	Wastage	11'-3 3/8"	Core, sand, bacteriological
5	11A	Wastage	11'-3"	Core, sand, bacteriological
6	11A	Minor wastage	12'-2 3/4"	Core, sand
7	19A	Minor wastage	12'-1"	Core, sand

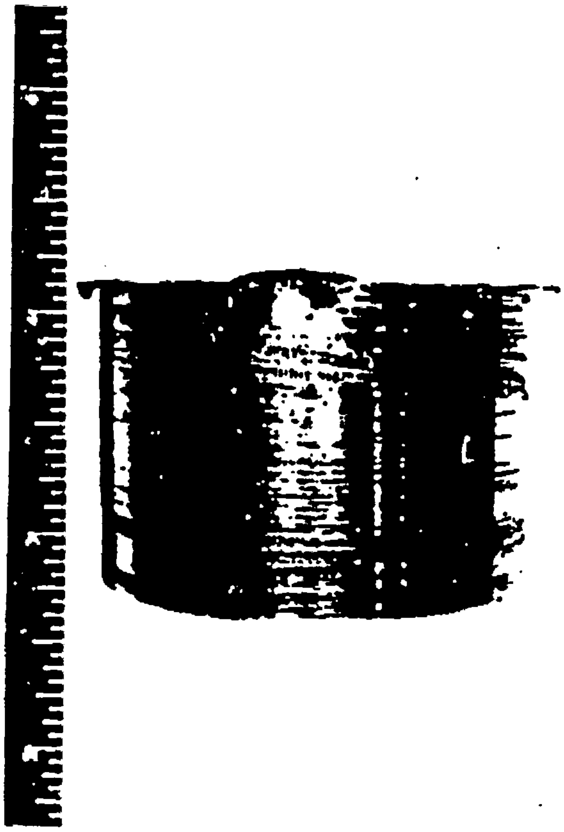
Evaluation of Pitting/Inclusion Sample

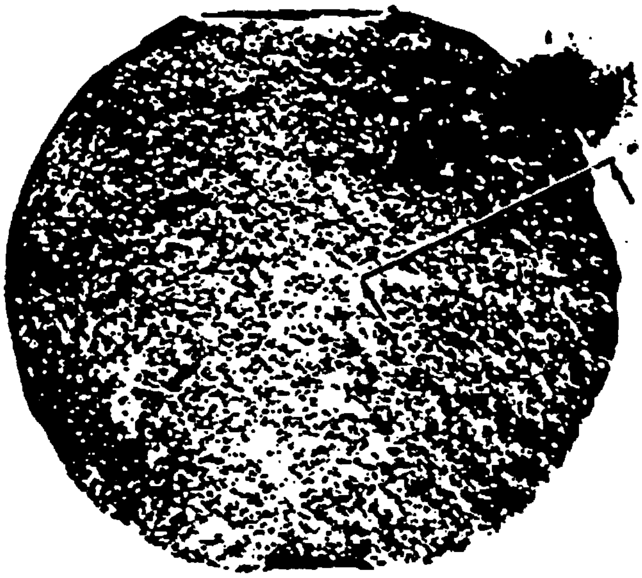
Core sample #2 which was removed from bay 15 was taken to assess whether pitting or inclusions were responsible for the low ultrasonic thickness readings observed in random locations. In region C where the sample was removed, the general area had thickness readings on the average of about 1.17" with random low readings of .48". This particular plug had a region approximately 1/2" in diameter where the low readings resided.

Upon removal of this plug it was immediately evident visually that no serious corrosion or pitting had occurred. The outside surface of the plug was covered with a reddish brown oxide and the actual measured thickness of the plug was 1.17" (avg.), Figure 1M. Elemental analysis of this oxide by EDAX indicated iron as the major constituent although in random location very high levels of lead were observed. This lead is from remnants of the red lead primer originally applied to the shell. Other elements observed at trace levels were Al, Si, Mn, Ca, K, Cl, S.

Metallographic specimen, were prepared from the core plug both parallel to the rolling direction and perpendicular to it. Examining the micro specimen at the outside surface of the core revealed some minor pitting. These pits were filled with oxide which appeared normal for carbon steel corrosion. At the mid-plane of the specimen, however, a band of aluminide stringers was found in the region where the low UT readings existed, Figures 2M - 3M. These stringers were sufficiently dense as to form a lamination which could easily reflect ultrasound. This observation validates the conclusion drawn by the GPUN NDE people via their "A" scan UT analysis of this region that the low "D" meter readings were a result of laminations. In addition, the examination of this plug also validated the accuracy of the thickness measurements. It was concluded that UT could adequately define this type of condition and additional samples from pitting/inclusion regions were not required.

SE No. C00243-002
Att. 3-12

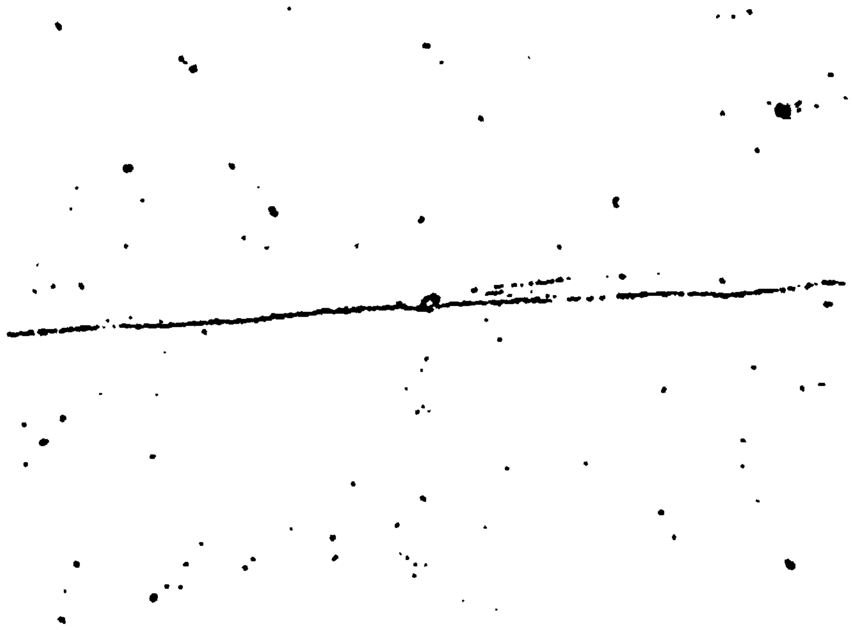




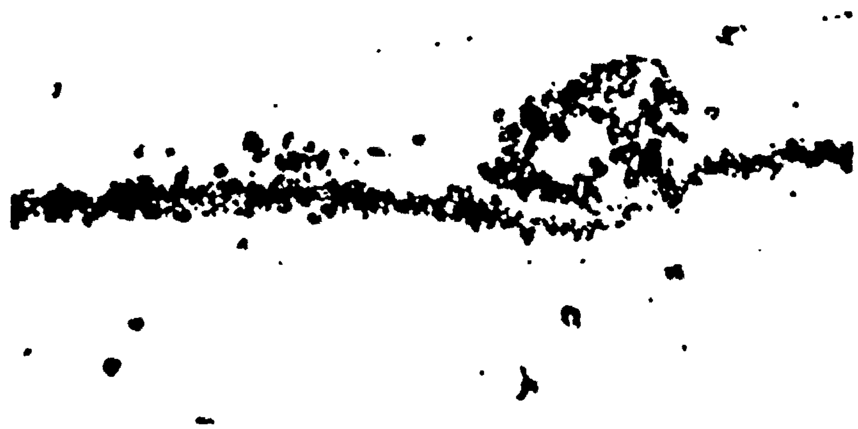
2X

<u>Figure 1-M</u>

Plug #2 outside surface of drywell.
Uniform red brown corrosion product.



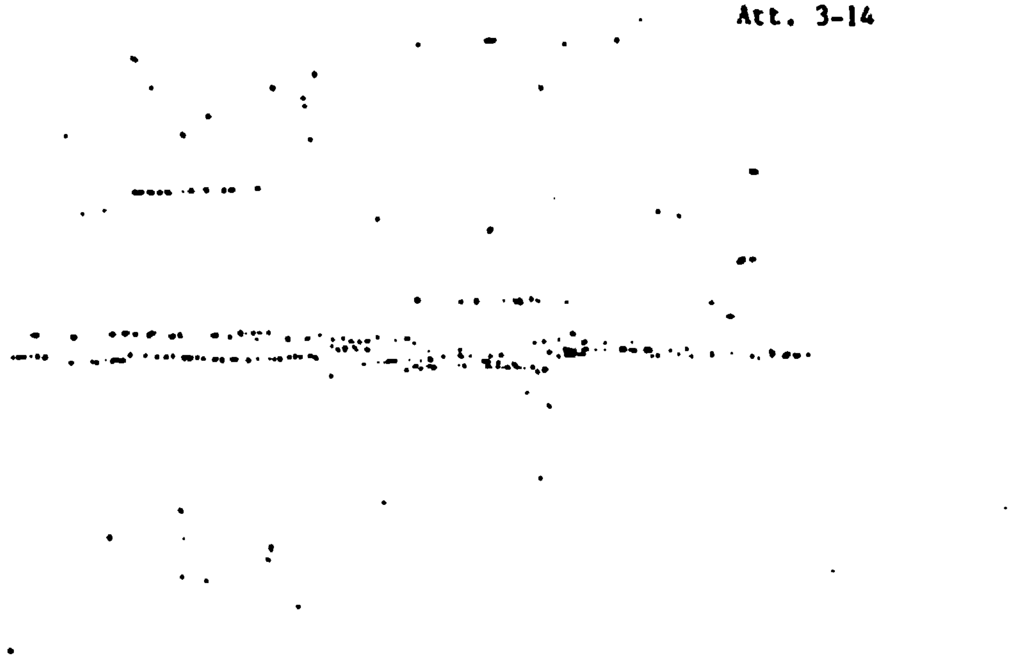
50X



500X

Figure 2-M

Plug #2 Aluminide stringer at mid-wall.
Plane parallel to rolling direction.



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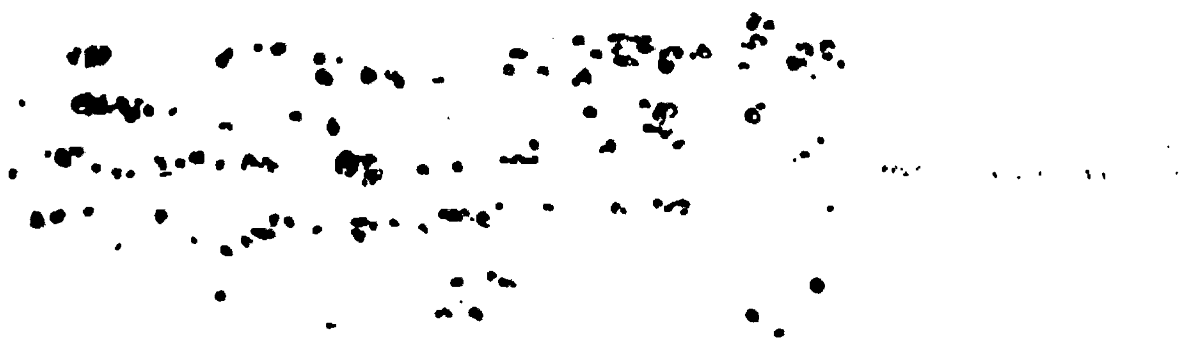


500X

Figure 3-M

Plug #2 Aluminide Stringer at mid-wall.
Plane perpendicular to rolling direction.

Examination of Wastage Samples

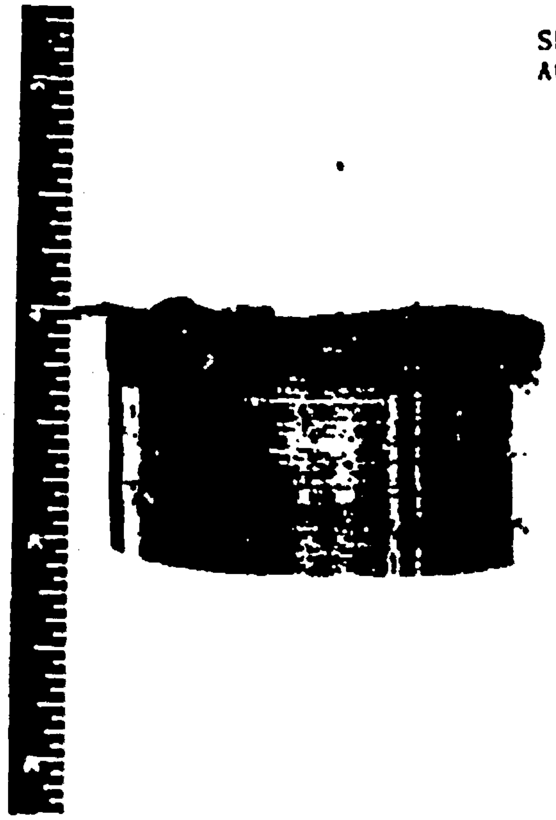
As discussed previously, four samples were removed from wastage regions. Three of these samples were sent to General Electric (Sample Nos. 3, 4 & 6) for analysis and one was analyzed by GPUN (Sample No. 1).

When core samples (numbers 1, 3, 4 and 5) were cut, it was noted that a hard black crust remained in the hole on top of the sand. This crust was approximately 1/2" thick. It was quickly realized that this crust was the corrosion product from the iron and as such was collected along with the sand beneath it for later analysis.

In general, all the wastage samples looked similar showing a relatively uniformly corroded surface with some hills and valleys (Figure 4-M). Overall, the surfaces were covered with a thin black adherant type deposit with some regions having a thicker more dense buildup of deposit (approx. .030" thick). Elemental analysis of this deposit showed iron to be the major constituent with varying levels of chloride contamination. Minor traces of manganese, aluminum and silica were also noted and on occasion a trace of sulfur (Figure 5-M). On sample #1 a cross section was prepared through one of the valleys on the corroded surface (Figure 6-M). This valley had a layer of corrosion product on it approximately 30 mils thick. EDAX analysis of this deposit revealed a high chloride concentration in a 2 mil thick layer of deposit adjacent to the steel, while further into the oxide but adjacent to this region the chloride levels were very low (Figure 7-M). Although other samples did not show this dramatic variation in chloride, all did show that chlorine was a major contaminant.

In addition to EDAX analysis, x-ray diffraction was performed by GE on the black deposit. The results showed the material to be primarily Fe_3O_4 (magnetite). This confirmed an initial observation that the deposit was magnetic; no other compounds were identified.

Metallography on the core samples showed that there was no deep pitting and no signs of any type of cracking or intergranular attack. Manganese sulfides were observed within the microstructure which were typical for this type material (Figure 8-M).



Plug #1

Figure 4-M

Plug #2 outer wall surface microplane is located

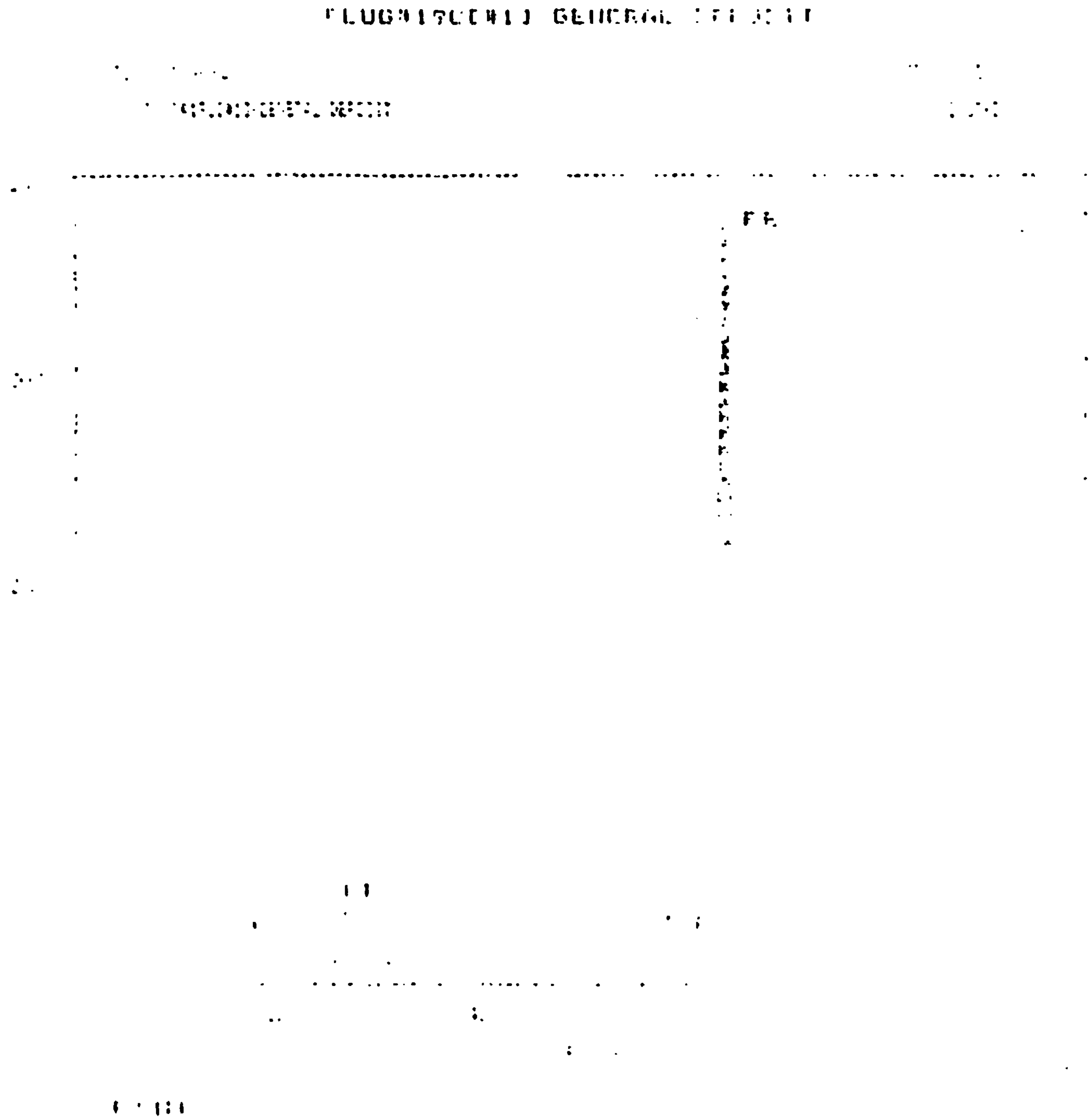


Figure 5-M

Typical elemental analysis of sample #1 corrosion product.

56X

Figure 6-M

Thin layer of corrosion product remaining on sample #1 showing different layers and the presence of voids.

Att. 3-20

PLUG 1 SCALE

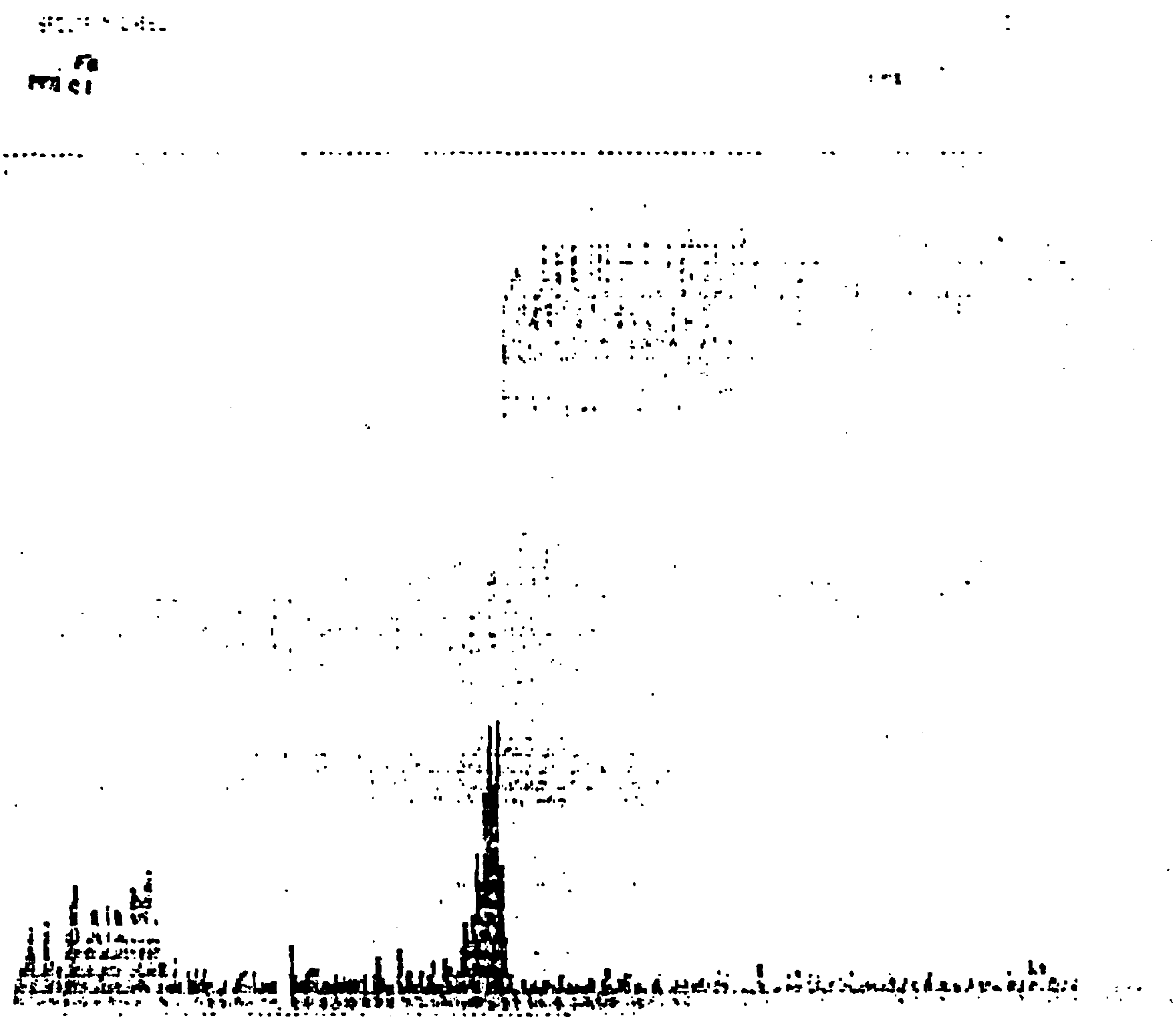


Figure 7-M

EDAX scan through deposit shown in Figure 6M.
Deposit runs from 0% - 49% full screen.
Chloride peak is at steel/oxide interface.

[redacted]

100X

O.D. surface; Plug #1

200X

MnS inclusions below surface.

Figure 8-M

Analysis of Sand and Firebar-D

As was shown in Table 3-M sand samples were removed from behind each core plug. In addition, sand was removed from the Bay 11 drain line. EDAX analysis as well as leachate analysis was performed on representative samples of the sand. The results are shown in Figures 9-M and Table 4-M. The sand appears to be a natural sand composed of silica with some alumina present. As noted on the EDAX spectrum, some chloride is present and this was confirmed by the leachate analysis which showed chloride in the range of 6.5 - 93 ug/gm. Also noted in the leachage analysis was magnesium and sulfate which most probably came from the Firebar-D. Some organic carbon was also detected. These analysis indicate that a source of the chloride found in the corrosion product existed in the sand which was probably leached from the Firebar-D and that organic material as well as a source of sulfur exist which could provide nutrients for bacterial growth.

A sample of the Firebar-D was obtained through one of the drywell penetrations and subjected to a leachate analysis. As might be expected, this material was high in Na, K, Ca, Mg and SO_4 as well as chlorine. The results of these analyses are also shown in Table 4-M.

TABLE 4-M

Sand Leachate Analysis

Analytical Parameters	Firebar-D* Leachate 1 Hr, 60° C (ug/g)	Sand Leachate Bay 11 Drain 24 Hrs, Room Temp (ug/g)	Sand Leachate Bay 11 Drain 1 Hr, 90° C (ug/g)	Sand Leachate Plug #1 (19C) 1 Hr, 60° C (ug/g)	Sand Leachate Plug #2 (15A) 1 Hr, 60° C (ug/g)
Na	777	25	25	37	47
K	784	25	20	37	23
Ca	176	30	25	47	< 23
Mg	1936	30	10	10	< 23
Al	< 0.3	< 0.5	1.5	39	2.3
Ni	< 0.3	< 0.5	0.5	< .33	< 2.3
Fe	< 0.3	5.0	1.0	82	8.4
Cr	< 0.3	< 0.5	< 0.5	< .33	< 2.3
Mn	< 0.3	0.5	< 0.5	3.[illegible]	< 2.3
Pb	0.6	1.5	< 0.5	< .33	< 2.3
NH_3 (N)	-	-	-	-	-
Cl	573	10.5	6.5	45	93
NO_3	132	2.5	1.5	< 17	6
SO_4	2850	< 25	32	28	79
PO_4	N.D.	N.D.	N.D.	N.D.	N.D.
F	14	N.D.	N.D.	N.D.	N.D.
TOC	1056	39	37	46.6	N.D.
Organic Acids	< 20	< 5	< 5	-	-
Total Sulfur	~ 50	-	-	-	-
B	-	-	-	-	-
Conductivity	588	-	-	-	-
pH	8.46	7.43	7.58	7.02	5.99

* Firebar-D is a composite of foam, fibers and concrete

SAND/GROUP OF SMALL [illegible]

Figure 9-M

Photo shows distribution and type of sand particles.
Spectra shows basic elemental composition.

Microbiological Assessment

In order to assure a complete assessment of the corrosion damage it was decided early on that a microbiological analysis needed to be performed. Because of limited in-house expertise in this area, an outside consultant, Dr. Carolyn Mathur from York College, was contracted to perform this analysis. It was decided that four samples of material from the sand bed would be analyzed from the regions indicated in Table 3-M. Two samples would be sand and two would be corrosion product. These samples were secured immediately upon removal of the core plugs to assure minimal environmental effect on the bacteria. Samples were treated for microscopic evaluation as well as for future culturing. During core removal close attention was also paid to metal temperatures to assure temperatures did not exceed 150° which would kill the bacteria.

Results of the cultures are not yet available; however, preliminary indications are that there is no strong presence of sulfate reducing bacteria (SRB). The microscopic evaluation results are shown in Table 5-M. Cell counts appear typical for levels of bacteria found in natural environments. In addition, it was reported that the bacteria appear filamentous and in some cases bacteria was observed to be attached to the corrosion product.

Currently cultures are being grown aerobically and anaerobically to establish the type of bacteria present including the presence of sulfate reducing bacteria.

Ground Potential Measurements

The possibility of stray currents influencing the corrosion rate was also considered. In order to provide an assessment of this, external potential measurements were conducted to check for the presence of stray currents. Potential measurements were taken between the ground and each of the five sand bed drain lines using a copper-copper sulfate reference cell. The measurements revealed no evidence of stray currents while the reactor is shut down, however, these measurements will need to be repeated during power operation.

TABLE 5-M

Bacteriological Studies
Preliminary Results

Sample No.	Type	Cell Count *	SRB
2-15A	Sand (dry) Adjacent to Drywell	1×10^7 cells/gm 71% viable	negative
1-19C	Corrosion Product Adjacent to Drywell	5×10^6 cells/gm 50% viable	weak pos.
6-11A	Sand (moist) Away from Drywell	4×10^7 cells/gm 74% viable	weak pos.
4-19A	Corrosion Product Adjacent to Sand	6×10^6 cells/gm 40% viable	negative

* Stained with fluorescein isothiocyanate

Corrosion Assessment

As discussed in the background section, wetting of the sand bed may have occurred as early as initial construction. The only other documented evidence of leakage was during the 1980, 1983 and 1986 outages. Although the exact source of leakage during construction is unknown, it was reported that during the application of the Firebar-D material that copious quantities of water were observed coming from the Firebar and running down the drywell presumably into the sand bed. During outages water was most likely coming from a leaking gasket in the seal plate region. This gasket was replaced during the 1986 refueling outage and the leakage appears to be stopped. On the above basis and in view of the fact that there would not be other sources of water to enter the annular region behind the drywell during operation, it has been concluded that the introduction of water was an intermittent occurrence (i.e. during outages) which may have occurred during construction but definitely occurred in 1980, 1983 and 1986. Also, it can be concluded that the sand as a result of this water introduction is contaminated with chloride and sulfate along with numerous metal ions.

Sand is generally ascribed with good drainage properties which would allow for the bulk of the water which entered the sand bed to flow out of the drain lines; however, because this region is fairly enclosed with little air circulation, high humidity is believed to exist in the annular space which could result in the sand remaining moist for indefinite periods of time. This is partially substantiated by the fact that high humidity and sweating is generally observed in the torus room where the sand bed drains exit. Above the sand bed, however, fiberglass boards and above that Firebar are applied to the exterior drywell steel which would help prevent moisture from coming directly in contact with it. In addition, during operation the average drywell air temperature is approximately 140° F which again would prevent condensation from forming on any exposed steel surfaces. The overall environment within the annular region can therefore best be described in the following manner: Water was introduced into the sand bed possibly as early as in the late sixties and probably contained magnesite and magnesium sulfate from the Firebar. The bulk of this water would have drained off leaving moist sand behind. We know that the exterior of the drywell was coated with red lead primer over which Firebar and fiberglass boards were applied which would afford general protection to these steel surfaces from corrosion. Coating damaged areas and with time all areas within the sand bed would be expected to experience general corrosion as long as the sand remained moist or until a protective oxide film built up on the steel surface as a result of the corrosion process. It appears, however, that a completely protective film did not result most probably because of the presence of chloride. The actual metal loss which may have occurred during the time frame from initial startup until the next time water was reintroduced as a result of leakage into the cavity is unknown. The first documented incident of water intrusion following startup which would definitely initiate corrosion was in 1980. Water samples collected and analyzed at this time for radioactivity measurement, indicated that it was refueling water and hence adds credence to the assessment that the source of the water was the leaking bellows gasket. Corrosion rates would therefore be properly based on the assumption that the corrodent was refueling quality water contaminated with chloride from the Firebar and that the corrosion process was aqueous general corrosion. Some shallow pitting is also occurring but it is considered only in view of its contribution to overall thinning.

The possibility of stress corrosion cracking and hydrogen embrittlement were also considered. However, these forms of corrosion are generally associated with high strength steels or high temperatures and not considered a damage mechanism for the environment or material associated with the drywell. Ultrasonic examination of the welds and heat-affected zone in the wastage regions also showed no indication of cracking.

An upper bound general corrosion rate for carbon steel would be expected to be in the range of 10-20 mpy depending on the drywell plate temperature. These corrosion rates, however, if applied generally to the drywell re.. on in contact with the sand bed are consistent with the average wall loss of .288" only if the corrosion is assumed to have occurred since 1969 which was the first possible time water could enter the sand bed drains.

In fact, however, close scrutiny of the UT thickness data indicates that corrosion was extremely non-uniform as defined above in the section on UT measurements. First, the region above the 11' 9" elevation shows little or no wall loss. Then the region from 10' 3" to 11' 9" shows the greatest wall loss followed by the region below 10' 3" which shows substantially less wall loss. Lastly, only two regions of the drywell encompassing four bays show any significant wall loss. A possible explanation for this is that due to channeling only these regions became wetted. This assumption is potentially confirmed by the observation that the sand in the minor wastage regions was dry. Also, the intimacy of the contact between the sand and the plate is a factor. If the sand had been pushed away from the drywell in certain regions due to the preoperation pressure test causing the drywell to expand; this also can result in variations in corrosion rate. The protectiveness of the red lead primer will be a function of its integrity in the various regions and again may be leading to variable corrosion rates. Lastly, differential aeration may be playing a role in where corrosion is occurring. Clearly the presence of magnetite, an oxygen defficient oxide, in some regions and hematite in other regions suggests this is occurring.

Conclusion

Aqueous corrosion of the carbon steel drywell is estimated to have initiated in 1969 resulting from the first intrusion of water into the sand bed region. This inventory of water may have been added to during subsequent outages but was definitely added during the 1980, 1983 and 1986 refueling outages. This latter water is expected to flow down over the insulation material in the annular space and pass through the sand and out through the drains. Depending on flow rates, an inventory of water may be accumulated in the sand bed or channeling of the water may also occur leading to wetting in specific locations. Irrespective of the water flow rate some sand will become wetted with oxygen saturated water and corrosion will result.

This corrosion was most likely influenced by the presence of chloride, leached from the Firebar-D, as it was found to be incorporated within the Fe_3O_4 corrosion product. Bacteria are not believed to have been a major influence on the corrosion. This latter conclusion is based on the facts that no deep pitting was observed and no sulfide or substantial concentration of manganese was detected in the corrosion product, all of which are typical evidence of microbiological influenced corrosion. In addition, the corrosion observed can be explained solely on the basis of chemical attack. However, because there is viable bacteria present, any plans for inhibiting future corrosion may also require destroying or rendering this bacteria harmless.

Review of the literature suggests corrosion rates can vary widely for carbon steel in aqueous environments. Rates can be as low as 1-2 mpy in high pH aqueous environments or greater than 50 mpy in acid solutions. Dr. Uhlig in his "Corrosion Handbook" lists corrosion rates for ambient temperature, seawater at approximately 1-7 mpy which at 140°F would conservatively equate to approximately 17 mpy. Uhlig further states that with the formation of corrosion products the rate of corrosion will be less than it would be if the steel were in direct contact with seawater and that the rate will stabilize and not change with time. In addition, he observed that, "specimens of steel have been exposed to seawater where sulfate reducing bacteria were known to be prese[illegible] and in fact were found in the corrosion products which contained appreciable percentages of iron sulfide. The observed rates of corrosion and pitting of such steel fell within the normal range previously defined."

If we then take the 17 mpy corrosion rate and project this over the 17 year life of the plant it correlates closely with the average corrosion loss of 288 mils. However, in order to insure conservatism in the structural analysis a factor of safety should be applied to this rate. To arrive at a defendable factor it has been assumed that all corrosion occurred over the past six years as a result of the water intrusion in 1980. This would equate to a corrosion rate of 48 mpy and give a factor of safety of 2.8.

<u>Conclusion Summary</u>

1. Wastage of the drywell plate is the result of an aqueous general corrosion process influenced by localized oxygen depletion, the degree to which moisture is present, temperature and chloride contamination.

2. Although viable bacteria were identified in the sand and corrosion product, no substantive evidence exists as to its involvement in the corrosion process, at least in terms of currently publicized mechanisms. However, because of the variable nature of microbial induced corrosion any attempts at mitigating corrosion should consider this mechanism.

3. D-Meter thickness readings, which initially were thought to be either pitting and later characterized by "A" scan UT as inclusions, were confirmed by metallography to be aluminide inclusions in the carbon steel.

4. The combination of using a D-Meter for ultrasonic thickness measurements and an "A" scan for qualitative assessment of the plate condition are adequate for engineering evaluations.

5. Corrosion is limited to the steel in contact with the sand bed and is present to a significant amount (i.e., .25" - .35") only in bays 11, 13, 17 and 19 and only within elevations 10' 3" to 11' 9".

6. The areas of observed corrosion appear to be those areas in which the sand has remained significantly wetted. This wetting most likely occurred during initial construction and then periodically during refueling outages as a result of leakage from the drywell bellows. Documented evidence of such leakage exists since 1980.

7. Corrosion rates have been conservatively set at 48 mpy although more typically, through review of industry experience and corrosion literature, would be expected to be approximately 17 mpy.

Structural Analysis Bases

A reevaluation of the drywell containment structure has been performed to insure structural integrity for the combined effects of local shell thinning, operating basis earthquake, pressure and temperature due to a postulated Design Basis Accident (DBA) and the mechanical loads. In performing this analysis the following design bases were used.

Applicable Codes Establishing Allowable Stress Criteria

(1) ASME Boiler and Pressure Vessel Code, Section VIII, 1962 Edition.

(2) Nuclear Code Case 1270N-5, 1271N and 1272N-5

(3) ASME Boiler and Pressure Vessel Code, Section III, Division 1, applicable portions of Subsection NE-3000, namely, NE-3213.10, NE-3221-2, NE-3221.4 and Table NE 3217-1.

Materials of Construction

According to the Chicago Bridge and Iron drawing No. 9-0971 sheet No. 1, Rev. 2, the material used in the fabrication of the drywell shell is ASTM SA-212 grade B Firebox. The examination of the original mill certificates reveals that all 1.154" plates used in fabrication of the drywell shell have a yield strength of about 5 to 33% greater than the minimum specified in the ASTM.

Design Condition

The drywell shell is analyzed for the maximum positive pressure 35 psig at 281°F and 62 psig at 175°F. The former condition represents the double end breaks of a recirculation loop. This is the design basis accident.

Other Loads

All other loads considered concomitant with accident conditions were taken from the Chicago Bridge and Iron original analysis.

Load Combination

The load combination representing a DBA during normal operation, as specified in the original Chicago Bridge and Iron original report, was chosen for analysis. This load combination includes the gravity load of vessel and appurtenances, gravity load from equipment supports, seismic loads (OBE), as well as accident conditions for temperature and pressure.

Structural Model

The mathematical model used to evaluate effects of the reduced shell thickness within the sand entrenchment area consists of a lower region of the spherical shell between elevations 23'-6 7/8" and the point of complete fixity against translational movement and rotation at the foundation level at elevation 8'-11 1/4". This model is developed to calculate the membrane and bending stresses at the point of fixity due to the accident internal pressure and thermal loads as well as loads associated with normal operation. The results of the structural analysis will allow the determination of the minimum allowable pressure boundary thickness using ASME Code allowable stress criteria.

Except for the sand pocket zone, all other shell thicknesses used in the analyses were those shown in the Chicago Bridge and Iron Drawing No. 9-0971 Sheet No. 4 Rev. 1.

The function of the sand pocket is to provide a proportional reaction so that the discontinuity stresses due to the embedment will be gradual and lower rather than abrupt and high.

In order to evaluate the sensitivity of the sand pocket, two separate structural models were considered. In the first model, the sand is assumed to provide an inward reaction linear in proportion to shell displacement. The second model assumes the sand to offer no resistance against the drywell shell movement.

The thermal gradient in the sand entrenchment zone is assumed to be linear. The attenuation of the thermal gradient in the meridional direction is assumed to be complete within the sand pocket, that is, the temperature distribution is 175°F/281°F at elevation 12'-3" and 60°F (ambient temperature) at elevation 8'-11 1/4".

The drywell shell membrane loads from the original Chicago Bridge and Iron analysis are introduced at the top boundary of the structural models to simulate shell continuity.

The structural model and the loading are assumed to be symmetrical; the penetration and their effects are not considered. This is reasonable since the reinforcement at the penetrations restores the shell to its original condition.

ne fiberglass insulation material within the annulus between the drywell and the concrete shield wall is assumed to have no structural stiffness.

Stress Analysis

The drywell containment structure model described above is analyzed by the Chicago Bridge & Iron Corporation utilizing the Kalnins KSHEL Program for axisymmetric shells of revolution to evaluate the adequacy of the lower shell region within the sand entrenchment area.

Each of the two models, with and without sand entrenchment, is subjected to the mechanical loads, operating basis earthquake and the accident pressure and temperature conditions of 35 psig at 281°F and 62 psig at 175°F.

This analysis identifies meridional and circumferential membrane and meridional and circumferential bending stresses for the dead weight, earthquake, pressure, and thermal loads.

The acceptance criteria used to establish structural adequacy of the drywell are taken from Section VIII, ASME Boiler and Pressure Vessel Code, 1962 Edition, Nuclear Code Case 1272N-5, and Section III, ASME Boiler and Pressure Vessel Code 1986 Edition, Division I, Subsection NE, paragraphs NE-3213-10, NE-3221-2, NE-3221-4 and Table NE 3217-1.

For purposes of analysis, the shell thickness in the sand entrenchment zone is taken to be equal to 0.700".

Mean of thickness readings as representing structural response

Structural loads will follow paths through the affected region having the largest stiffness (thickness). Less stiff (thinner) sections will follow the strain of the stiffer sections such that there will be a compatibility of strain through-out, as governed by the stiffer sections. The condition of strain compatibility means that the stress in the thinner sections will be equal to the stress in the adjacent thicker sections. It is reasonable to use the mean thickness, as opposed to the minimum thickness, because the mean represents the actual load reacting action of the shell.

Potential for Buckling

In addition, another analysis has been performed by Professor A. Kalnins of Lehigh University using the Kalnins shell of revolution computer program to evaluate the potential of buckling of the drywell shell in the sand entrenchment zone.

The mathematical model used to perform buckling analysis is basically similar to the model used for the stress analysis, except that credit was taken for the structural effect of the concrete that extends upward from the foundation around the inside of the drywell and for the sand which provides an inward reaction in direct proportion to shell expansion.

For purposes of analysis the shell thickness in the sand entrenchment zone is taken to be equal to 0.700".

STRESS ANALYSIS RESULTS FOR SHELL THICKNESS TAKEN TO BE EQUAL TO 0.700"

The allowable stress criteria are:

1) Local primary membrane stress (not including thermal) = P_L = 1.5.Smc = 28,875 psi (No change since 1962).

2) Surface stresses (local membrane and secondary stresses, both thermal and mechanical axial and bending) = Q = 3 Sm = 52,500. (Q=3 S_{mc}=57,900 from Sect. III, Div. 1, Subsect NE)

Table 1 shows the results of the stress analysis at the point of embedment taking credit for the radially inward reaction because of the resistance of the sand and also for analytically removing it. Using stress intensity, the stresses satisfy the former Code allowable stress criteria except for the condition of full sand removal when allowable stresses are exceeded by 2.7%. This load combination considered the accident condition of 62 psig and 175°F, which is not the same as the design basis accident (DBA) representing a double ended break of a recirculation line. Present Code Allowable stress criteria are satisfied in all cases.

Except as mentioned above the stresses shown satisfy the allowable stress criteria of ASME Sect. VIII, 1962, with Nuclear Code Cases 1270 N-5, 1271 N and 1272 N-5, as well as those of ASME Sect. III, Div. 1, Subsection NE, 1986, using stress intensities as directed in the latter code. Meridional extent, but not the peak value, of local primary membrane stress slightly exceeds (but < 2X) the guidance given in Sect. III. It is reasonable to neglect this small departure from present code guidance because the present situation is an in-service condition and not a design condition, and because the departure is small.

Results of the analysis for buckling potential

Stability margin is identified in Table 2. Margin is defined as the ratio of the calculated buckling load to the actual applied load. The reference is the point of the embedment. Normal and accident load combinations are considered with and without the radially inward resistance of the sand. The stiffness of the concrete on the inside of the shell is included in both cases. The shell is considered to be imperfect. The minimum margin to safety is 3.80.

Conclusion

Structural integrity of the primary pressure boundary is maintained with a local shell thickness reduction limited to the sand entrenchment region. Code allowable stress criteria are met using a thickness equal to 0.700".

A large margin to buckling exists such that buckling of a locally thinned shell is not a technical issue.

TABLE 1

LOAD COMBINATIONS	STRESS INTENSITIES ALONG MERIDIAN (PSI) Shell Thickness t=0.7 in.							
	With Sand Pocket				Without Sand Pocket			
	MEMBRANE		MEMBRANE & BENDING		MEMBRANE		MEMBRANE & BENDING	
	Calculated	Allowable	Calculated	Allowable	Calculated	Allowable	Calculated	Allowable
P = [illegible] psig T = 281° F	[illegible]	1.5 S_{mc} 28,875	32,147	3 S_m 52,500	8821	1.5 S_{mc} 28,875	43,722	3 S_m 52,500
P = 62 psig T = 175° F	[illegible]		24,935	3 S_{mc} 57,900	16,944		53,897	3 S_{mc} 57,900

TABLE 2

Load Combinations	MARGIN AGAINST INSTABILITY Shell thickness = 0.7"					
	With Sand Pocket			Without Sand Pocket		
	S_ϕ #/in.	S_θ #/in.	Margin of Safety	S_ϕ #/in.	S_θ #/in.	Margin of Safety
Normal Operation	-4031	+3312	6.12	-4031	+3312	6.12
DBA P-35 psig T 281° F	+7259	-10209	3.8	tension	tension	N/A
P=[illegible] psig, T, 175°F	tension	tension	N/A	tension	tension	N/A

DRYWELL ANALYSIS

SAND TRANSITION ZONE

OYSTER CREEK CONTAINMENT VESSEL

GPU NUCLEAR CORPORATION

PARSIPPANY, NEW JERSEY

Also called
'the Restart Report'.

CBI Services, Inc.
December 1[illegible], 1986
Contract 861172
Revision 1
December 30, 1986
Revision 2
February 9, 1987

Table of Contents

SUBJECT	MADE BY	CHKD BY	REV			CHARGE NO.
Oyster Creek Restart	TJA			BY	TJA	NG1147
Analysis Report	DATE 12/16/86	DATE		CHKD	PM	SHT i-1 OF
				DATE	3/25/87	

Introduction

The Oyster Creek Nuclear Power Plant Mark 1 Steel Containment Vessel was designed, fabricated and erected by Chicago Bridge and Iron Company in 1965. The configuration of the drywell portion is shown on page 1A1 of the attached Appendix B. The lower spherical portion of the drywell is embedded in concrete at elevation 8'-11 1/4. A sand pocket extends from the point of complete embedment upward 3'-3 3/4 to an elevation of 12'-3. This sand pocket performs two major functions:

a) Provides a transition from the completely embedded portion of the spherical shell to an unconfined portion. The sand "springs" help to ease this transition.

b) Provides a suitable means to dissipate the thermal gradient in the meridional direction.

A recent inspection of the steel shell in the sand pocket region revealed that some degradation of the steel shell had taken place at some time during the twenty plus years since completion of construction. Preliminary information indicates that the steel shell may have been reduced from the original 1.154" to as little as .80-.90" in thickness.

This report is an assessment of the stress levels which will exist if the shell is assumed to be reduced to .70 inches around the entire periphery in the sand pocket region. The analysis is performed for the following two cases:

a) Pressure = 35psig   Temperature = 281°F

b) Pressure = 62psig   Temperature = 175°F

Other normal dead loads and earthquake loads for the operating basis accident are included.

SUBJECT	OFFICE	REVISION		REFERENCE NO.
Oyster Creek Embedment Analysis - Reduced Thickness	CBI Oak Brook			NG1147
	MADE BY: TJA / CHKD BY: JSE	MADE BY	CHKD BY	SHT 1.0 OF ___
	DATE: 12/16/86 / DATE: 12/86	DATE	DATE	

Printed in USA   GO 84 REV SEP 84

Applicable Codes

The Oyster Creek Nuclear Plant Mark 1 Containment vessel was designed, fabricated and erected in accordance with the 1962 Edition of ASME Code, Section VIII and Code Cases 1270N-5, 1271N and 1272N-5. The allowable stresses used in this reduced thickness analysis are consistent with the original code of record. Some symbols and clarification have been extracted from the 1986 ASME Section III, Subsection NE Code. The use of these references in no way changes the allowable stress levels intended for the original design. The references used merely reflect the current day interpretations of the stress state and tend to be more consistent with todays analytical tools.

Specific references to ASME III, 1986 Edition are:

1. NE - 3221.2
2. Table NE - 3217-1
3. NE 3213.10
4. NE 3221.4

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Oyster Creek Embedment Analysis - Reduced Thickness	CBI Oak Brook				NC1147
	MADE BY	CHKD BY	MADE BY	CHKD BY	SHT 11 OF
	TJA	JSE			
	DATE	DATE	DATE	DATE	
	12/16/86	12/86			

Allowable Stresses*

Primary Stresses (does not include thermal effects)

	Allowable Stresses	Ref.
General Membrane	1.1 x 17500 = 19250 psi	1272N-5 5(g)(1)
Local Membrane**	1.5 x 1.1 x 17500 = 28875 psi	NE-3221.2
Local Membrane + bending	1.5 x 1.1 x 17500 = 28875 psi	1272N-5 5(g)(2)
Surface Stress***	3.0 x 17500 = 52500	Table NE-3217-1

Secondary Stresses (includes thermal effects)

Surface Stresses	(P_1+P_b+Q) = 3.0x17500 =52500psi	1272N-5 5.(f) and NE-3212.4

* all actual stresses are either stress intensities per NE 3000 or unidirectional stresses per ASME VIII, and Code Case 1272N-5, whichever is greater

** a local primary membrane stress is defined as one which does not exceed 1.1.x1.1x17500 = 21175 psi for a distance greater than 1.0 $\sqrt{rt}$ Ref. NE 3213.10

*** if bending moment at the edge is required to maintain the bending stress in the middle to acceptable limits, the edge moment is classified as P_b. Otherwise it is classified as Q.

Note: For primary stress evaluation - loads include

(1) Internal pressure (2) Dead weight of Steel (3) Dead weight of appurtenances (4) 11% Horizontal Earthquake - OBE equivalent (5) 5% Vertical Earthquake - OBE Equivalent essentially service Level A in 1983 ASME Code

For Secondary Stress Evaluation - loads include all of above plus meridional thermal gradient.

SUBJECT	OFFICE	REVISION		REFERENCE NO.
Oyster Creek Embedment Analysis - Reduced Thickness	CBI Oak Brook			NG1147
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	DATE: 12/12/86 / DATE: 12/8/86	DATE	DATE	

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Input Loading Information

The spherical portion of the containment vessel is assumed to be completely embedded at elevation 8'-11 1/4 (point G as shown on sheet 1A1 of Appendix B). This analysis of the sand pocket zone includes a segment of the spherical shell extending up to elevation 23'-6 7/8 (point F as shown on sheet 1A1 in Appendix B)

The boundary conditions at point F are taken from the tables shown on sheet 1B1 thru 1B4 as shown in Appendix B. This consists of the S_2 values as described below: (S_2 is the resultant load in the meridianal direction in pounds per inch)

The table on the following page is a compilation of these input loads.

> Note: The earthquake stresses shown on pages 1B1 through 1B4 were originally calculated for a 22% horizontal earthquake and a 10% vertical earthquake. This has been assumed to be the equivalent of today's description of a Safe Shutdown Earthquake. Since the 1986 Code would permit higher allowable stresses for the SSE included earthquake, the SSE earthquake loads shown have been divided by 2; i.e. 11% horizontal and 5% vertical earthquake to simulate an equivalent Operating Basis Earthquake. These levels are compatible with todays description of the Operating Basis Earthquake. The allowable stresses for the loads in which the OBE is included are lower than those which include the SSE. An assessment of both earthquakes with their respective allowables indicates that the more critical is the OBE case.

SUBJECT	OFFICE		REVISION		REFERENCE NO.
Oyster Creek Embedment Analysis - Reduced Thickness	CBI Oak Brook				NC1147
	MADE BY	CHKD BY	MADE BY	CHKD BY	SHT L3 OF
	TJA	VJE			
	DATE	DATE	DATE	DATE	
	12/16/86	12/56			

N_ϕ LOADS AT POINT F

Load Description	Case 1 P = 35 psig T = 281 °F N_ϕ #/in	Case 2 P = 62 psig T = 175 °F N_ϕ #/in
Internal Pressure	+ 7350	+ 13020
Steel Shell Dead Weight	- 271	- 271
11% Horiz. Earthquake on steel wt.	+ 77	+ 77
5% Vert. Earthquake on steel wt.	+ 14	+ 14
Appurtenances D.L.	- 86	- 86
Appurt. Horiz. E.Q.	+ 12	+ 12
Appurt. Vert. E.Q.	+ 5	+ 5
Floor beams D.L.	- 495	- 495
Floor beam E.Q.	+ 84	+ 84
Access Live Load	- 35	- 35
Total Load	+ 6655 #/in	+ 12325 #/in

SUBJECT	OFFICE	REVISION	REFERENCE NO.
Oyster Creek Embedment Analysis - Reduced Thickness	CBI Oak Brook		NG1147
	MADE BY TJA / CHKD BY [illegible]	MADE BY / CHKD BY	SHT L4 OF ___
	DATE 12/5/86 / DATE 12/8/86	DATE / DATE	

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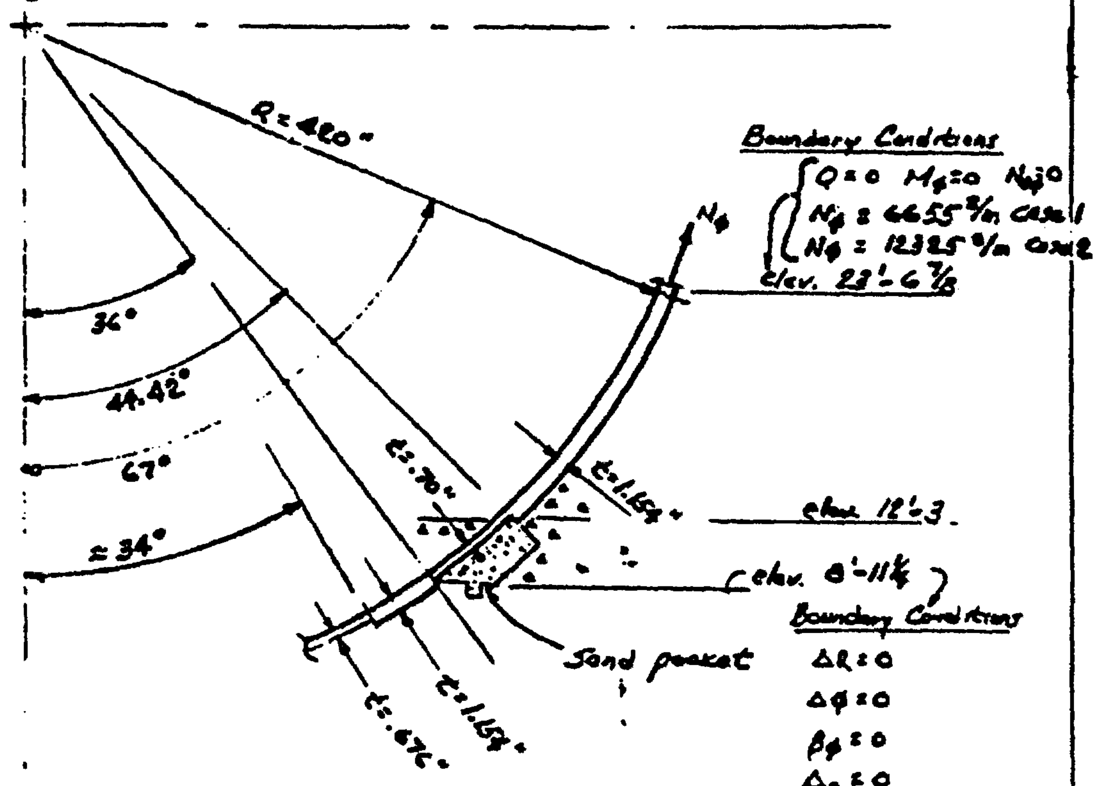
The CBI Model used in the analysis of the reduced thickness Oyster Creek embedment zone is described in the figure shown below. Complete fixity is assumed at elevation 8'-11 1/4.

Sand springs are modeled as inward radial forces, the magnitude of which are dependent upon the magnitude of the shell displacements. The sand spring constant is 274.3 psi/inch of radial displacement.

The attenuation of the thermal gradient in the meridional direction is assumed to be completed within the sand embedment zone, that is, the temperature distribution is 175°/281°F at elev. 12'3 and 60°F at elev. 8'-11 1/4.

The embedment zone is analyzed by use of the Kalnins Shell of Revolution Computer Code. Complete fixity begins at 36° from vertical axis. The model continues to 67°. See Appendix A for the program description.

Boundary loads at elev. 23'-6 7/8 are taken from the original design. *



* Loads include 1) Internal pressure 2) dead load 3) 11% Horiz E.Q. 4) 5% vert E.Q. See pg 181-185 of original design

SUBJECT	OFFICE	REVISION		REFERENCE NO.
Oyster Creek Embedment Analysis - Reduced Thickness	CBI Oak Brook			N61147
	MADE BY: TJR / CHKD BY: JSE	MADE BY	CHKD BY	SHT L5 OF
	DATE: 11/09/86 / DATE: 12/86	DATE	DATE	

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GO 84 REV SEP 84

Description of Kolnins Computer Output

Meridional Stress — Circumferential Stress — $\tau_{\phi\theta} = 0$

OYSTER CREEK EMBEDMENT, CASE 1: P=35 TEMAX=281 THICK=0.70

PART 1

FACES=-1. 1. 2.

Location of point angle measured from downward vert. axis

COORD	S PHI	S THETA	S SHEAR	S1-S2	S1-S3	S2-S3
36.0	2.503E+04	7.508E+03	0.000E+00	1.752E+04	7.508E+03	2.503E+04
36.0	1.370E+04	4.111E+03	0.000E+00	9.592E+03	4.111E+03	1.370E+04
36.0	2.381E+03	7.142E+02	0.000E+00	1.666E+03	7.142E+02	2.381E+03
37.1	1.602E+04	1.510E+03	0.000E+00	1.451E+04	1.510E+03	1.602E+04
37.1	1.342E+04	5.848E+02	0.000E+00	1.283E+04	5.848E+02	1.342E+04
37.1	1.082E+04	-3.398E+02	0.000E+00	1.116E+04	-3.398E+02	1.082E+04
38.1	1.143E+04	-2.207E+03	0.000E+00	1.364E+04	-2.207E+03	1.143E+04
38.1	1.309E+04	-1.851E+03	0.000E+00	1.494E+04	-1.851E+03	1.309E+04
38.1	1.474E+04	-1.495E+03	0.000E+00	1.623E+04	-1.495E+03	1.474E+04
39.2	1.033E+04	-5.435E+03	0.000E+00	1.576E+04	-5.435E+03	1.033E+04
39.2	1.271E+04	-4.806E+03	0.000E+00	1.752E+04	-4.806E+03	1.271E+04
39.2	1.510E+04	-4.177E+03	0.000E+00	1.928E+04	-4.177E+03	1.510E+04
40.2	1.201E+04	-8.578E+03	0.000E+00	2.059E+04	-8.578E+03	1.201E+04
40.2	1.229E+04	-8.547E+03	0.000E+00	2.084E+04	-8.547E+03	1.229E+04
40.2	1.257E+04	-8.516E+03	0.000E+00	2.108E+04	-8.516E+03	1.257E+04
40.2	1.204E+04	-8.491E+03	0.000E+00	2.053E+04	-8.491E+03	1.204E+04
40.2	1.229E+04	-8.471E+03	0.000E+00	2.076E+04	-8.471E+03	1.229E+04
40.2	1.254E+04	-8.451E+03	0.000E+00	2.099E+04	-8.451E+03	1.254E+04
41.3	1.613E+04	-1.078E+04	0.000E+00	2.690E+04	-1.078E+04	1.613E+04
41.3	1.182E+04	-1.216E+04	0.000E+00	2.398E+04	-1.216E+04	1.182E+04
41.3	7.505E+03	-1.354E+04	0.000E+00	2.105E+04	-1.354E+04	7.505E+03

outside surface stress

membrane (midthickness) stress

inside surface stress

S_z = through thickness stress, neglected ≈ 0

Stress Intensity | S PHI − S Theta

Stress Intensity | S Theta − S_z

Stress Intensity | S PHI − S_z

SUBJECT: Oyster Creek Embedment Analysis - Reduced Thickness

OFFICE: CBI Oak Brook

REVISION

REFERENCE NO. NG1147

MADE BY	CHKD BY	MADE BY	CHKD BY
TJA	JSE		
DATE 12/10/86	DATE 12/86	DATE	DATE

SHT 46 OF ___

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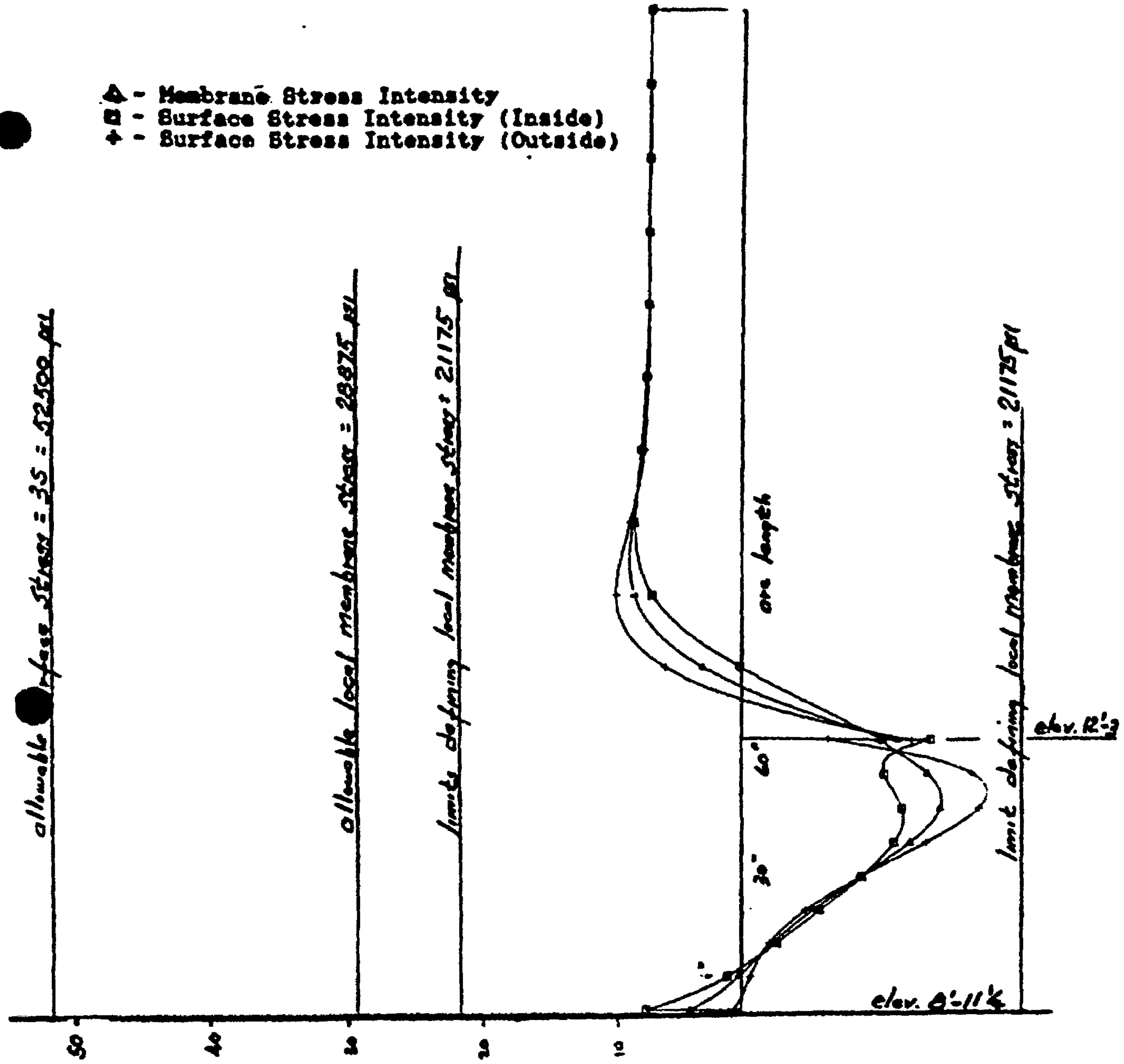
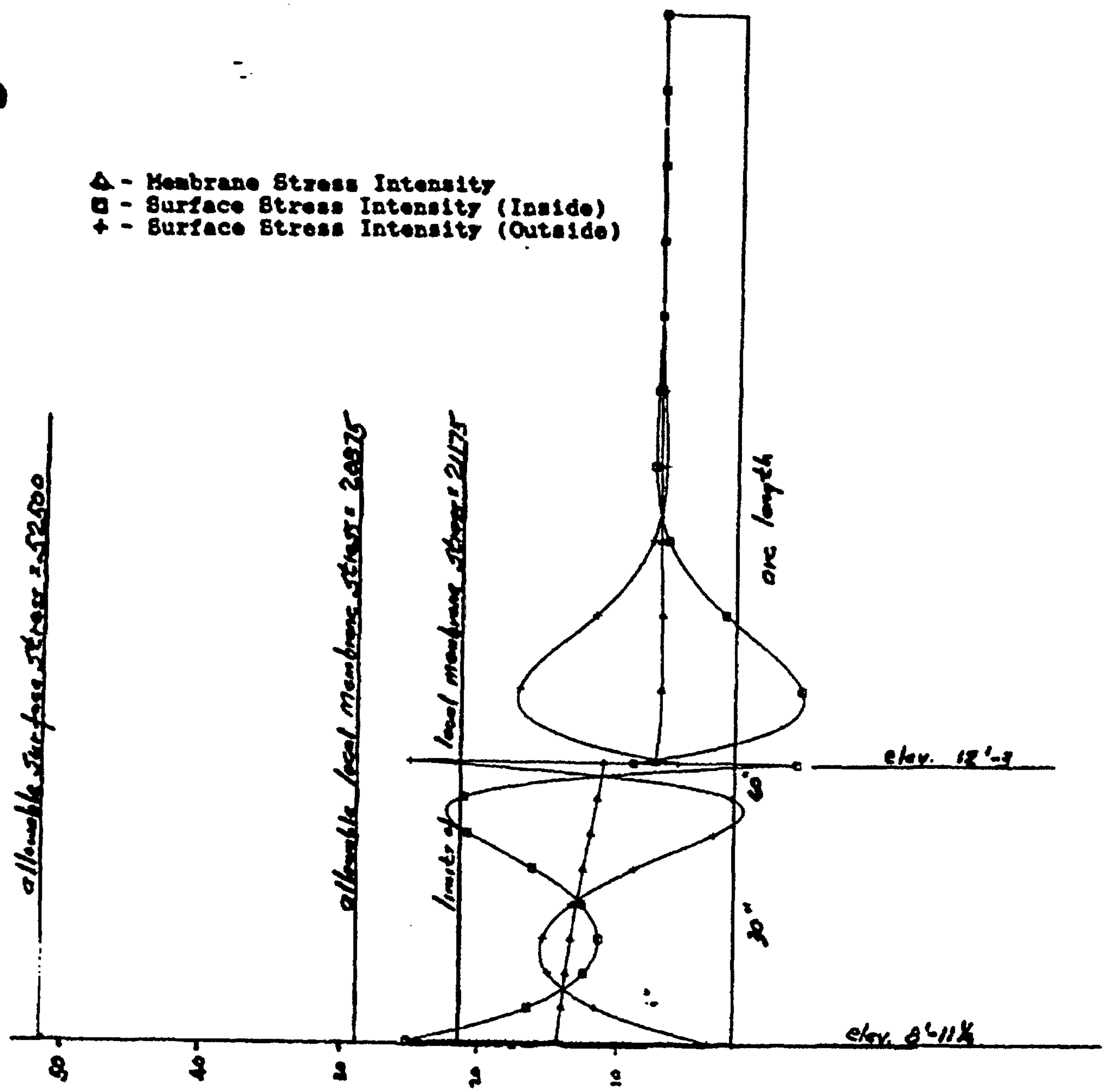


Scale 1" = 10 KSI
1" = 30" arc length

CIRCUMFERENTIAL STRESS ALONG MERIDIAN
OYSTER CREEK EMBEDMENT, CASE 1: P=35 T(MAX)=281 THICK=0.70
MAXIMA 14102. 14951. 18321.

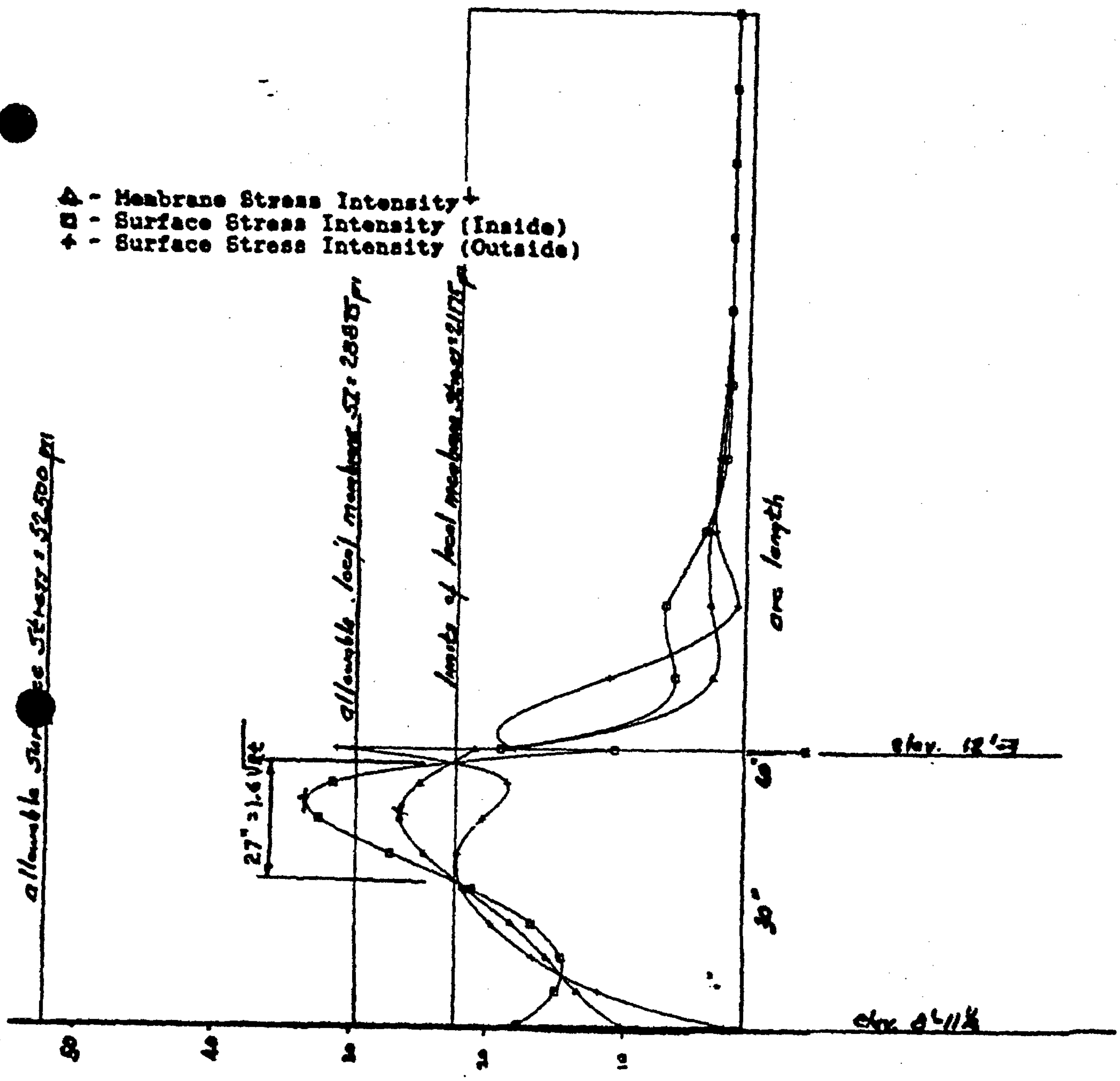
SUBJECT	MADE BY	CHKD BY	REV			CHARGE NO.
Oyster Creek Embedment	JSE	TJA		BY		N61147
Analysis - Reduced Thickness	DATE 12/16/86	DATE 12/16/86		CHKD / DATE		SHT 1.7 OF



Scale 1" = 10 KSI
1" = 30" arc length

MERIDIANAL STRESS ALONG MERIDIAN
OYSTER CREEK EMBEDMENT, CASE 1: P=35 T(MAX)=281 THICK=0.70
MAXIMA 23615. 12719. 23475.

SUBJECT	MADE BY	CHKD BY	REV			CHARGE NO.
Oyster Creek Embedment	JSE	TJA		BY		NG1147
Analysis ~ Reduced Thickness	DATE 12/16/86	DATE 12/16/86		CHKD / DATE		SHT 1.8 OF

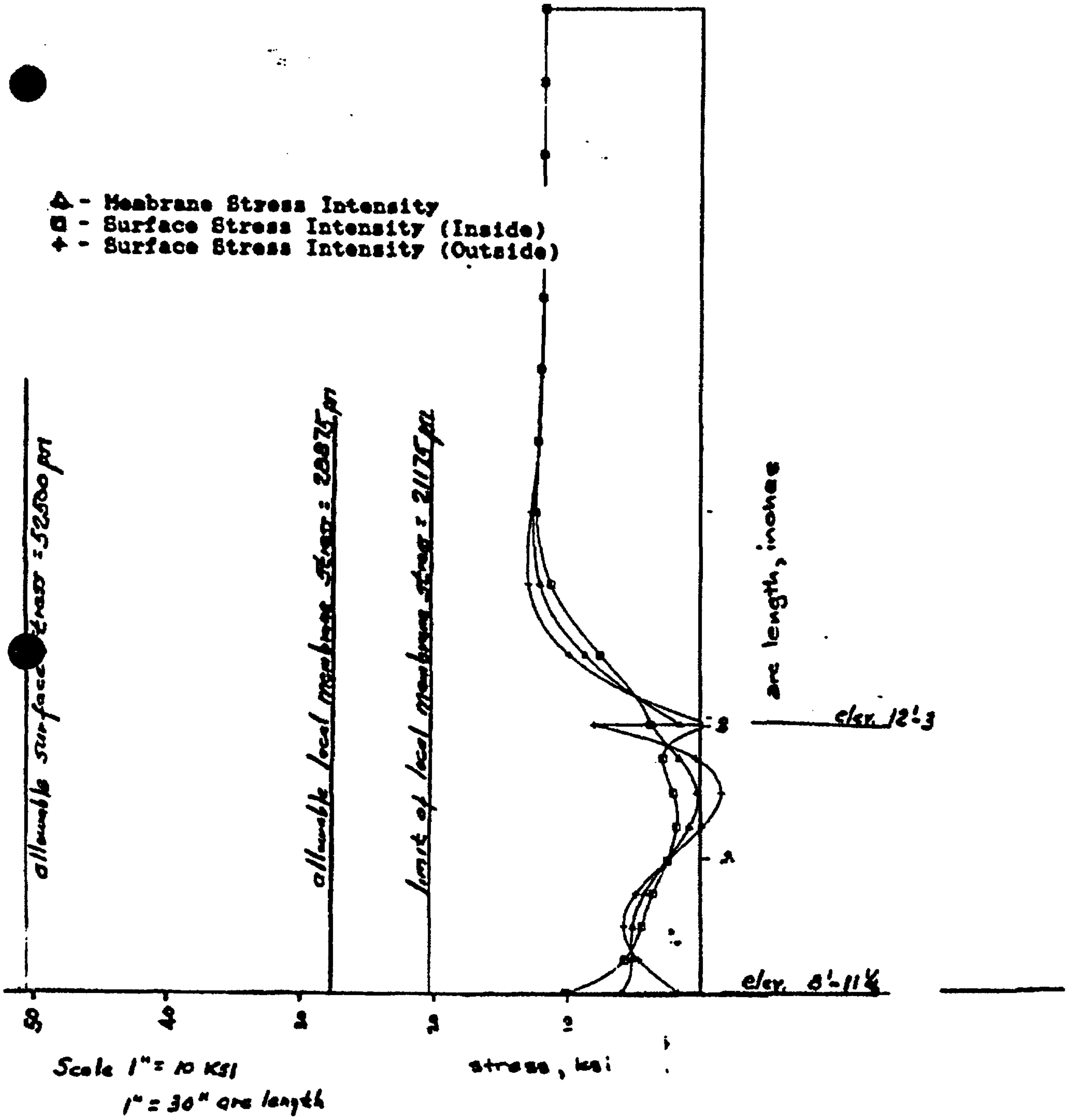


Scale 1" = 10 KSI

1" = 36" arc length

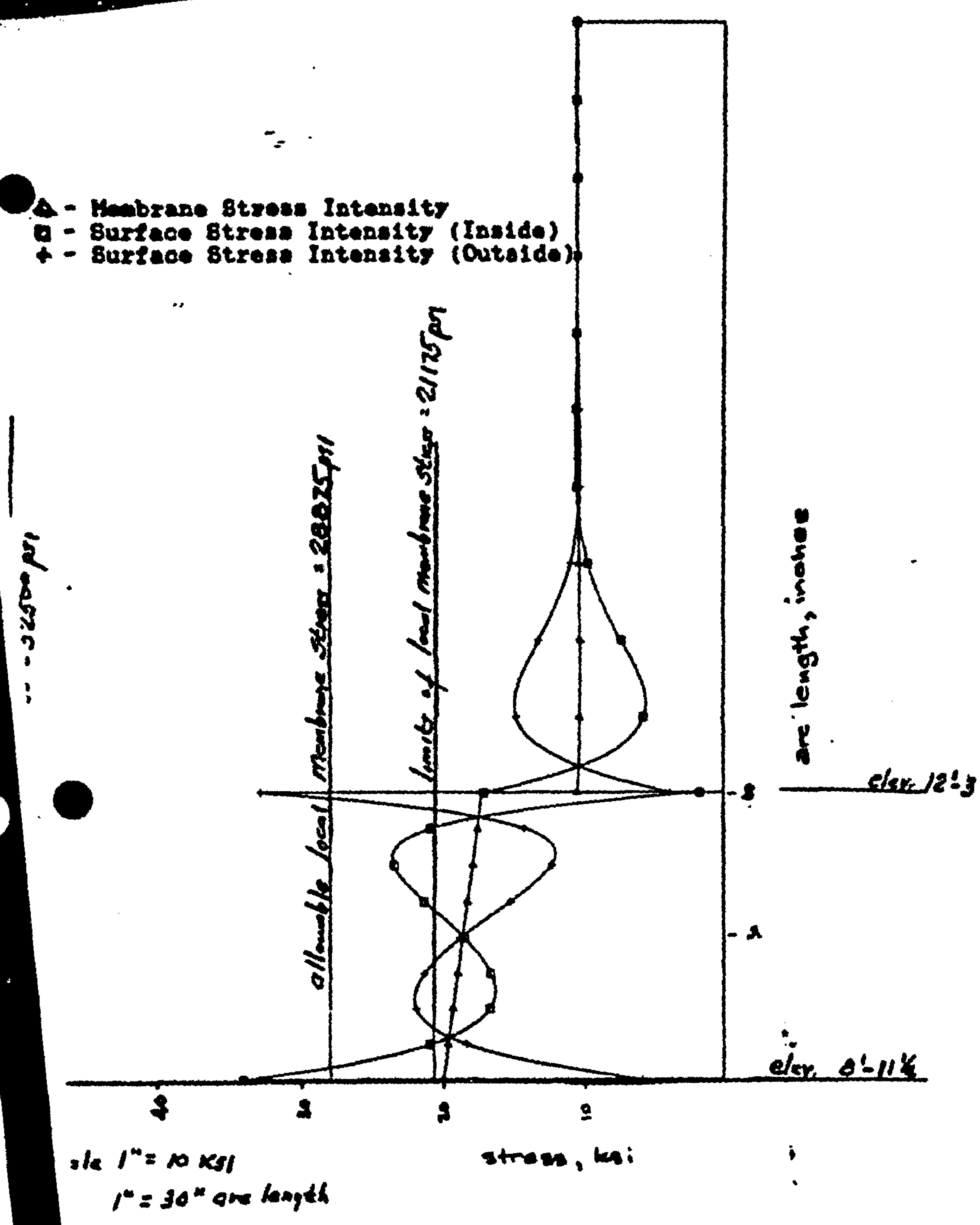
STRESS INTENSITIES ALONG MERIDIAN
OYSTER CREEK EMBEDMENT, CASE 1: P=35 T(MAX)=281 THICK=0.70
MAXIMA 32147. 25251. 29914.

SUBJECT	MADE BY	CHKD BY	REV			CHARGE NO.
Oyster Creek Embedment	JSE	TJA		BY		NG1147
Analysis – Reduced Thickness	DATE 12/16/86	DATE 12/16/86		CHKD		SHT 1.9 OF
				DATE		



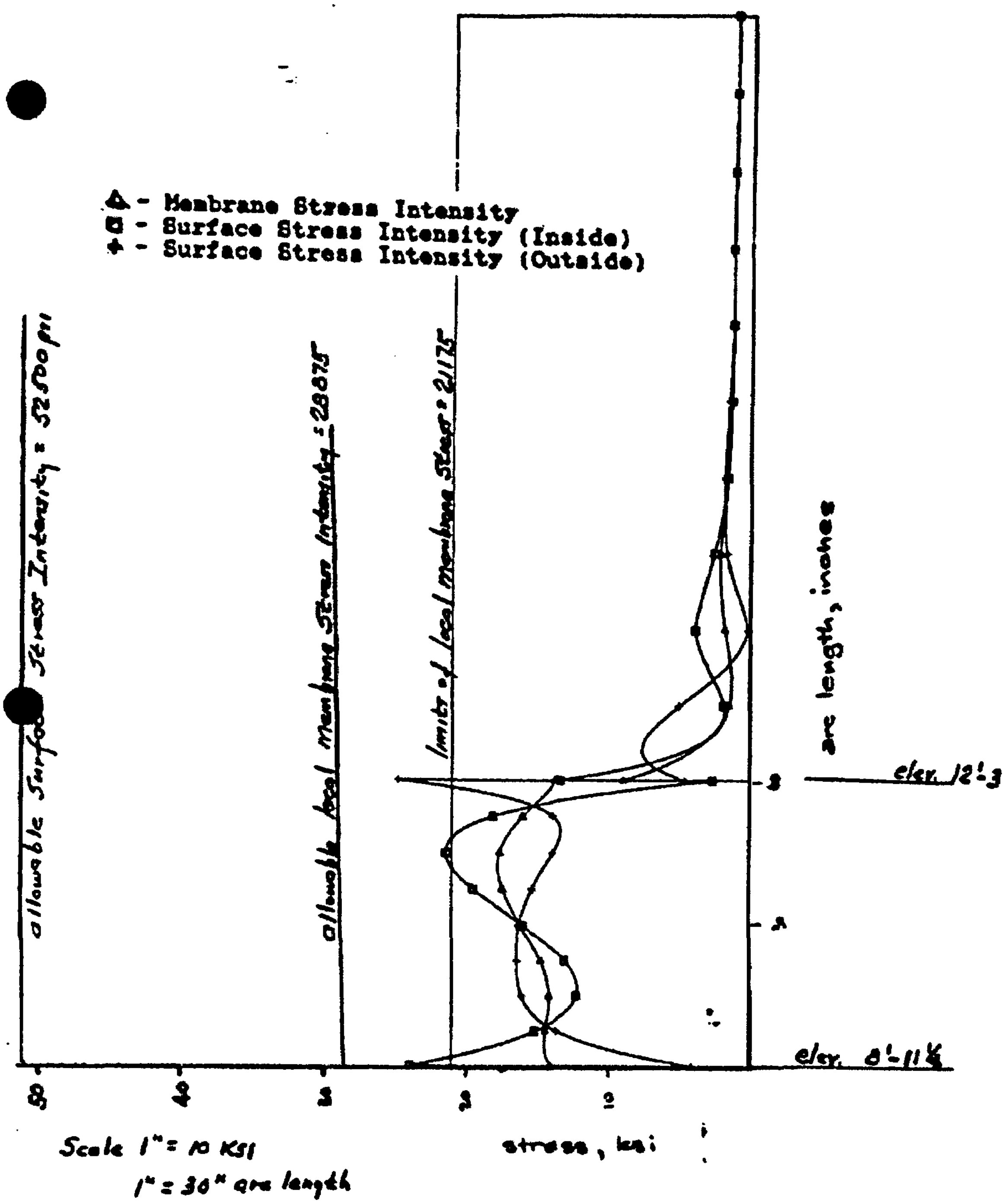
CIRCUMFERENTIAL STRESS ALONG MERIDIAN
OYSTER CREEK EMBEDMENT, CASE 2: P=62 T(MAX)=175 THICK=0.70
MAXIMA 12445. 12655. 13124.

SUBJECT	MADE BY	CHKD BY	REV	BY		CHARGE NO.
Oyster Creek Embedment	JSE	T/C		CHKD		NG1147
Analysis - Reduced Thickness	DATE 12/16/86	DATE 12/16/86		DATE		SHT 1.10 OF



MERIDIANAL STRESS ALONG MERIDIAN
OYSTER CREEK EMBEDMENT, CASE 2: P=62 T(MAX)=175 THICK=0.70
MAXIMA 34324. 20108. 33060.

SUBJECT	MADE BY	CHKD BY	REV	BY		CHARGE NO.
Oyster Creek Embedment	JSE	TJA				NG1147
Analysis – Reduced Thickness	DATE 12/16/86	DATE 12/16/86		CHKD / DATE		SHT 1 of 1 OF



STRESS INTENSITIES ALONG MERIDIAN
OYSTER CREEK EMBEDMENT. CASE 2: P=62 T(MAX)=175 THICK=0.70
MAXIMA 24027. 17889. 24935.

SUBJECT	MADE BY	CHKD BY	REV			CHARGE NO.
Oyster Creek Embedment	JSE	TJA		BY		NG1147
Analysis – Reduced Thickness	DATE 12/16/86	DATE 12/16/86		CHKD		
				DATE		SHT 1.12 OF

Analysis of embedment zone
with sand considered to be ineffective

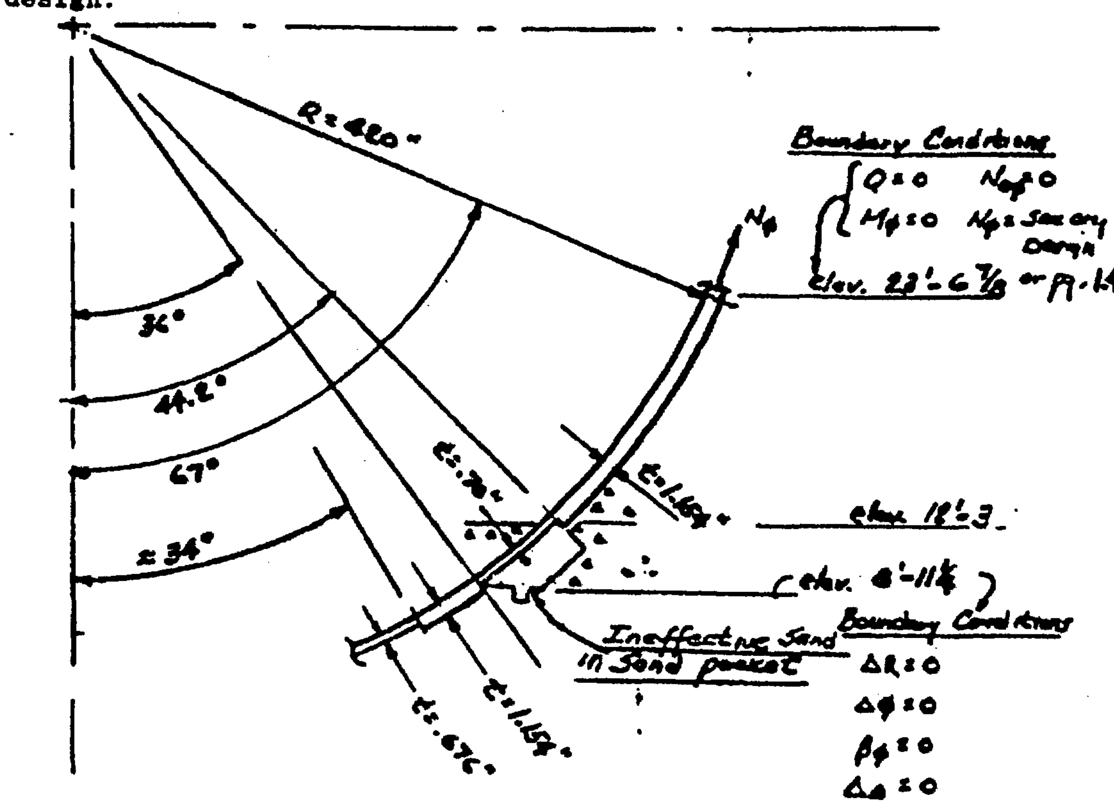
The CBI Model used in the analysis of the reduced thickness Oyster Creek embedment zone is described in the figure shown below. Complete fixity is assumed at elevation 8'-11 1/4.

Sand springs are assumed to be ineffective.

The attenuation of the thermal gradient in the meridional direction is assumed to be completed within the empty embedment zone, that is, the temperature distribution is 175°/281°F at elev. 12'3 and 60°F at elev. 8'-11 1/4.

The embedment zone is analyzed by use of the Kalnins Shell of Revolution Computer Code. Complete fixity begins at 36° from vertical axis. The model continues to 67°.

Boundary loads at elev. 23'-6 7/8 are taken from the original design.



SUBJECT	OFFICE	REVISION	REFERENCE NO.
Oyster Creek Embedment Analysis - Reduced Thickness Ineffective Sand in Sand Pocket	CBI Oak Brook		N61147
	MADE BY: TJA; CHKD BY: JSE	MADE BY; CHKD BY	SHT 20 OF
	DATE: 11/19/86; DATE: 12/86	DATE; DATE	

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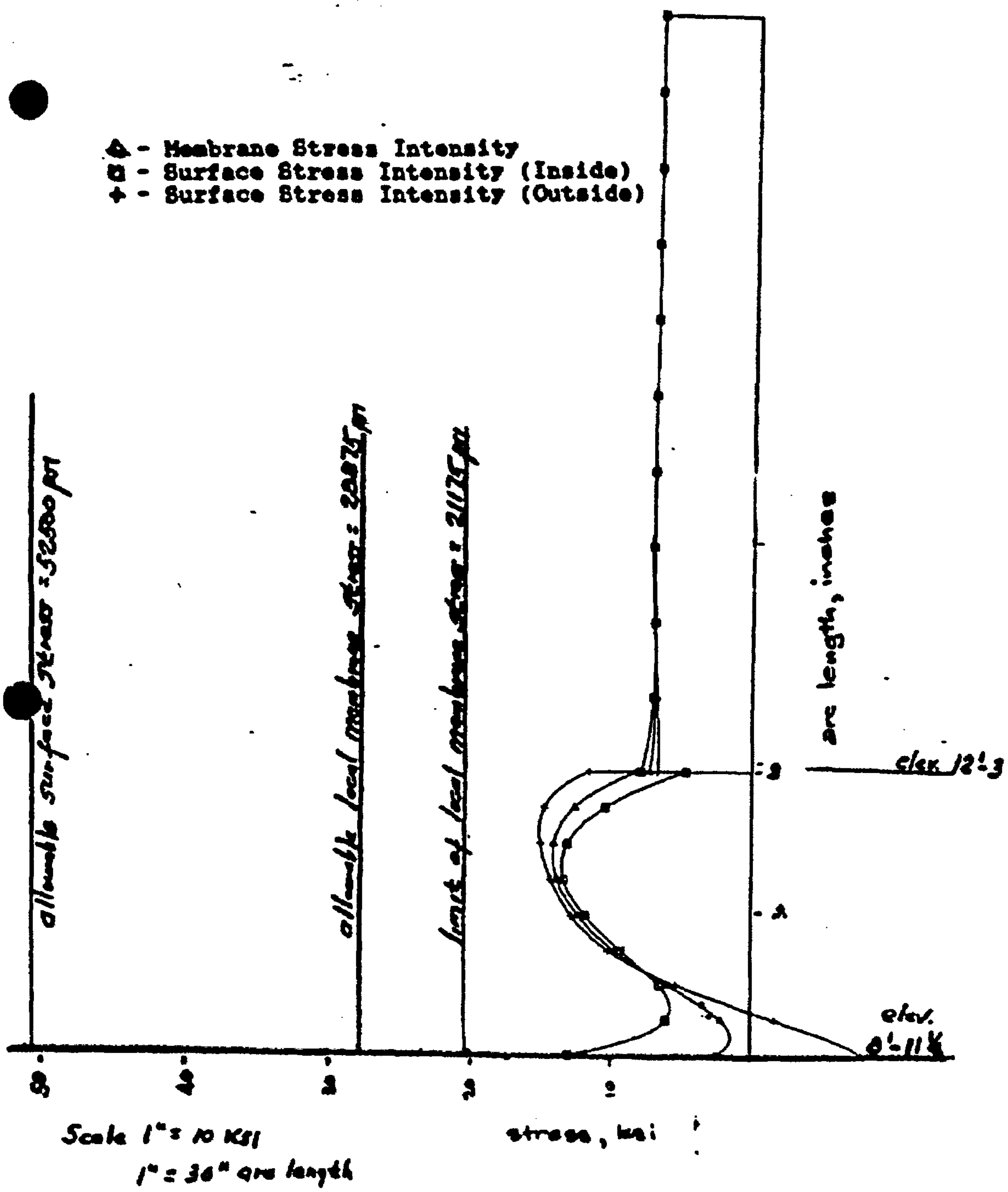

CIRCUMFERENTIAL STRESS ALONG MERIDIAN
OYSTER CREEK EMBEDMENT, CASE 1: P=35 T(MAX)=281 THICK=0.70 W/O SAND
MAXIMA 13620. 14265. 15245.

SUBJECT	MADE BY	CHKD BY		BY		CHARGE NO.
Oyster Creek Embedment	JSE	TJA		CHKD		NG1147
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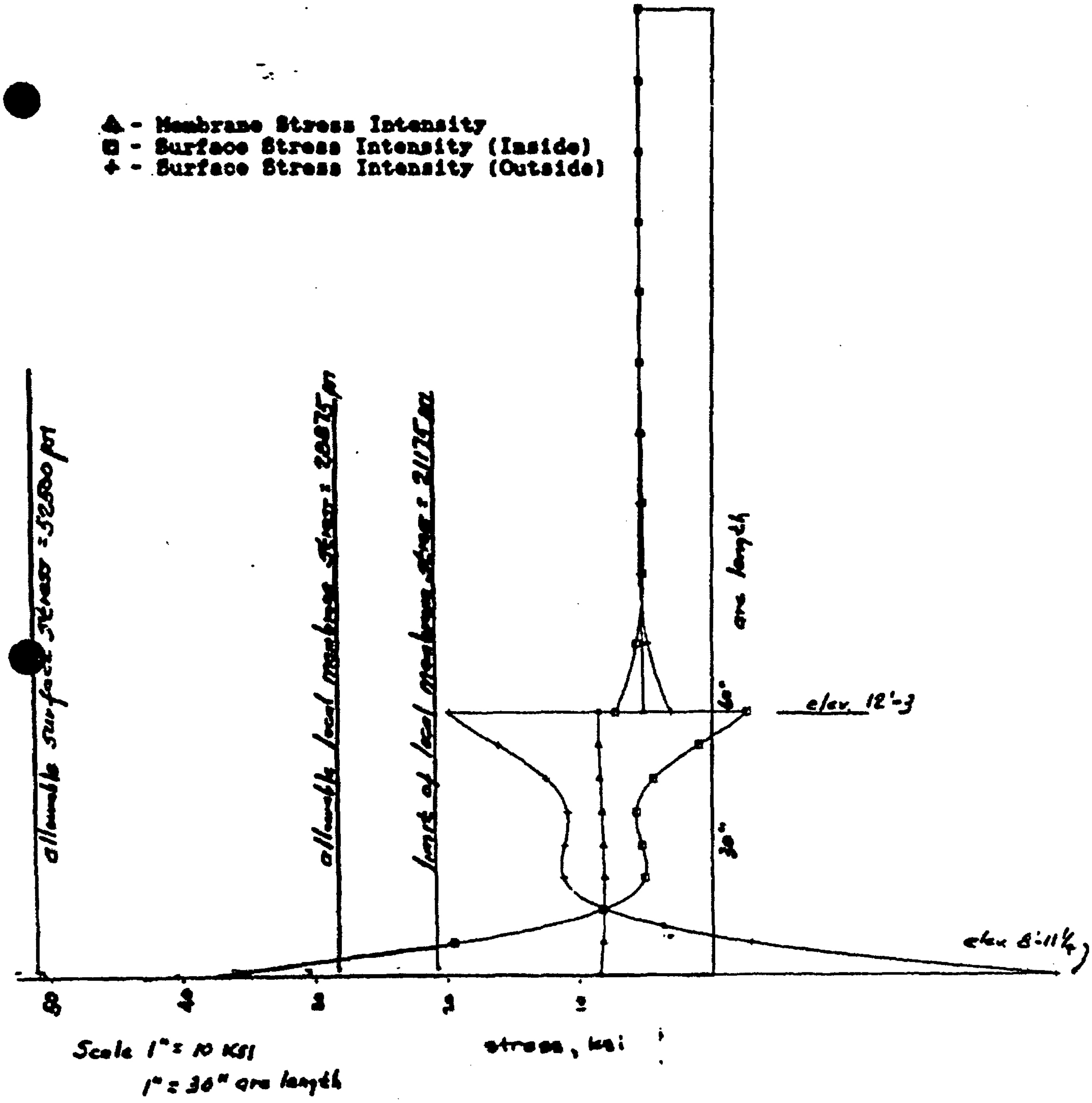
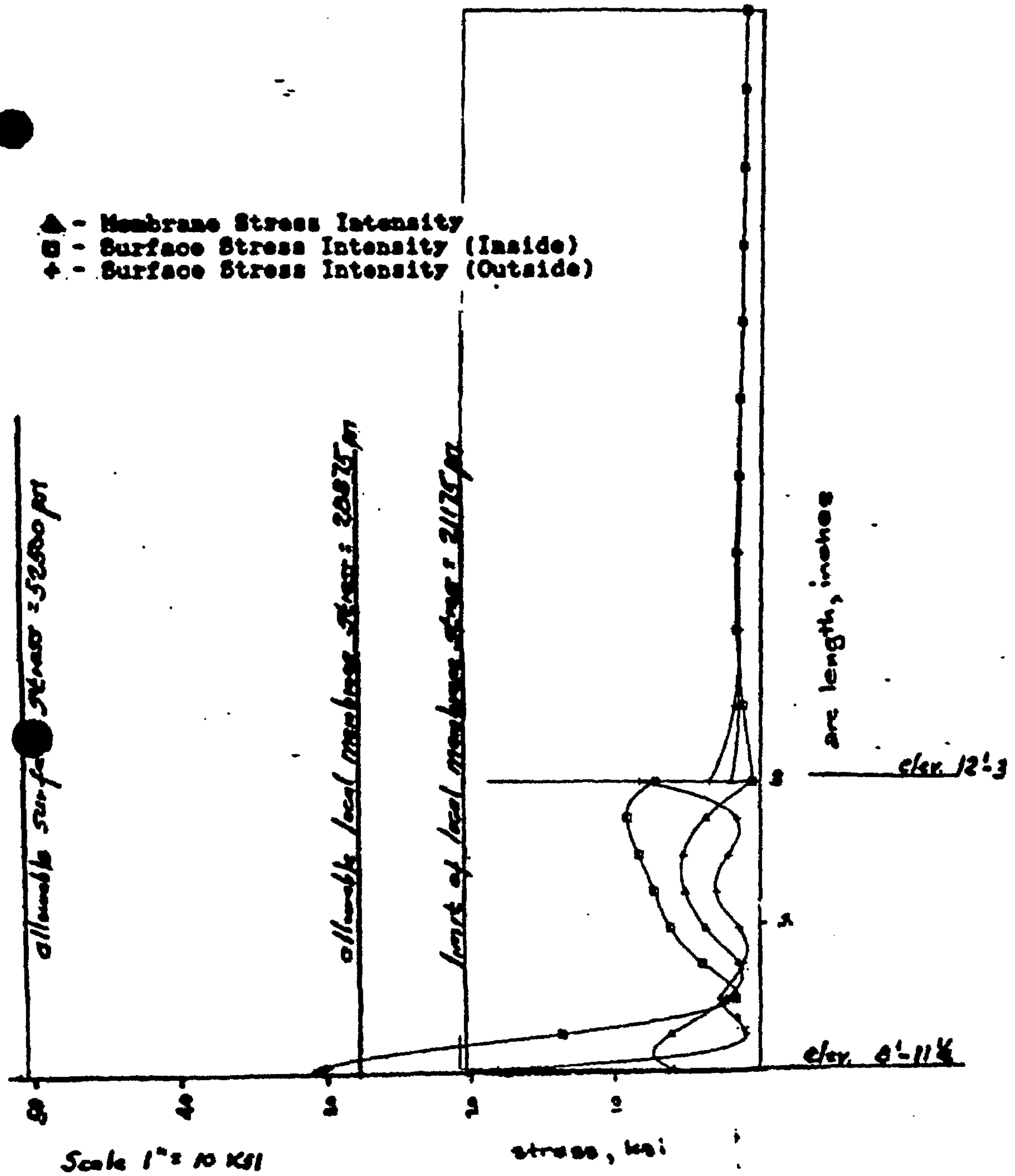


MERIDIANAL STRESS ALONG MERIDIAN
OYSTER CREEK EMBEDMENT, CASE 1: P=35 T(MAX)=281 THICK=0.70 W/O SAND
MAXIMA 43722. 8821. 26330.

SUBJECT	MADE BY	CHKD BY	REV	BY		CHARGE NO.
Oyster Creek Embedment	JSE	TJA				NG1147
Analysis - Reduced Thickness	DATE 12/16/86	DATE 12/16/86		CHKD / DATE		SHT 2.2 OF



Scale 1" = 10 KSI
1" = 36" arc length

STRESS INTENSITIES ALONG MERIDIAN
OYSTER CREEK EMBEDMENT, CASE 1: P=35 T(MAX)=281 THICK=0.70 W/O SAND
MAXIMA 30605. 7599. 18431.

SUBJECT	MADE BY	CHKD BY	REV	BY		CHARGE NO.
Oyster Creek Embedment	JSE	TJA				NG1147
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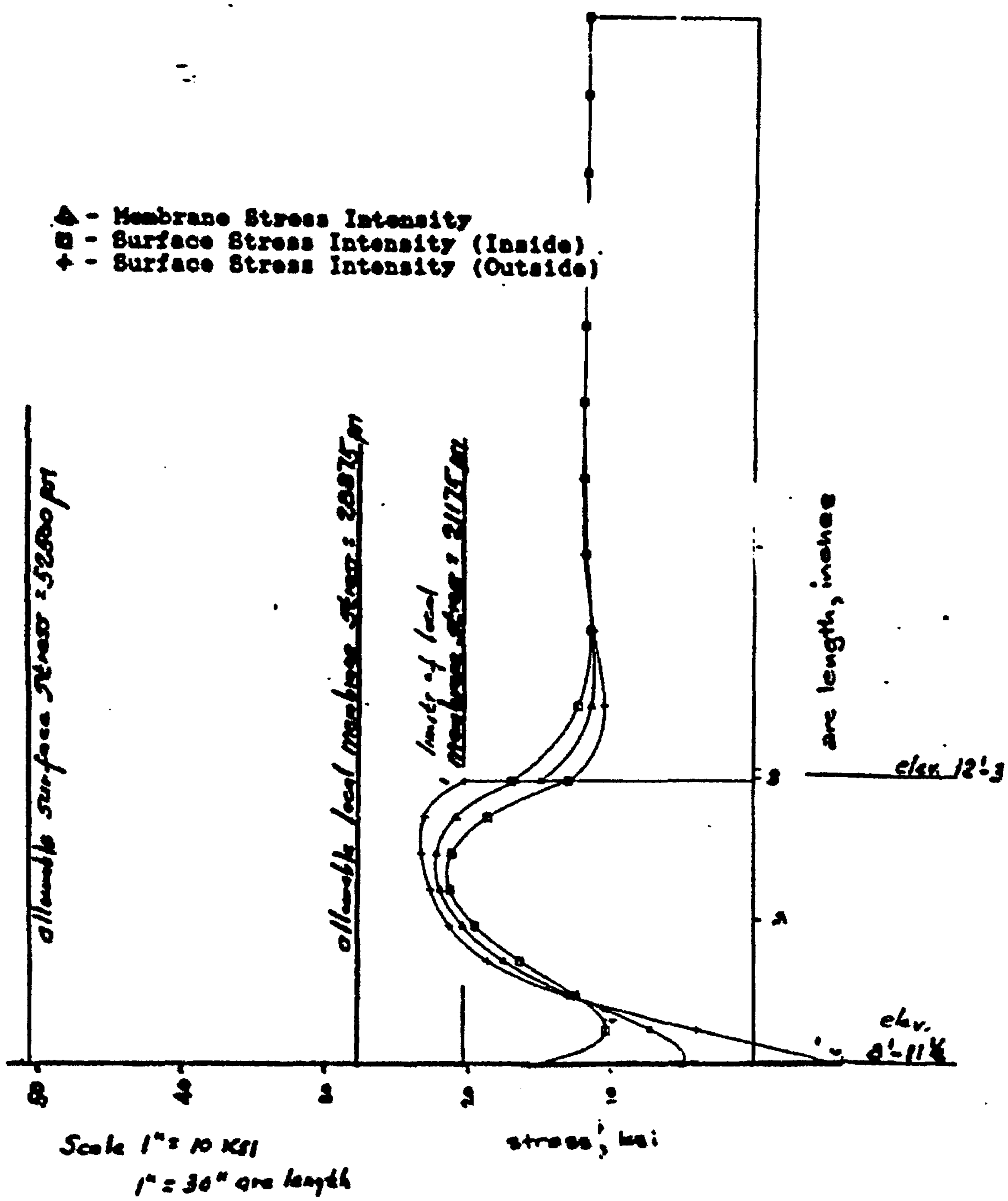
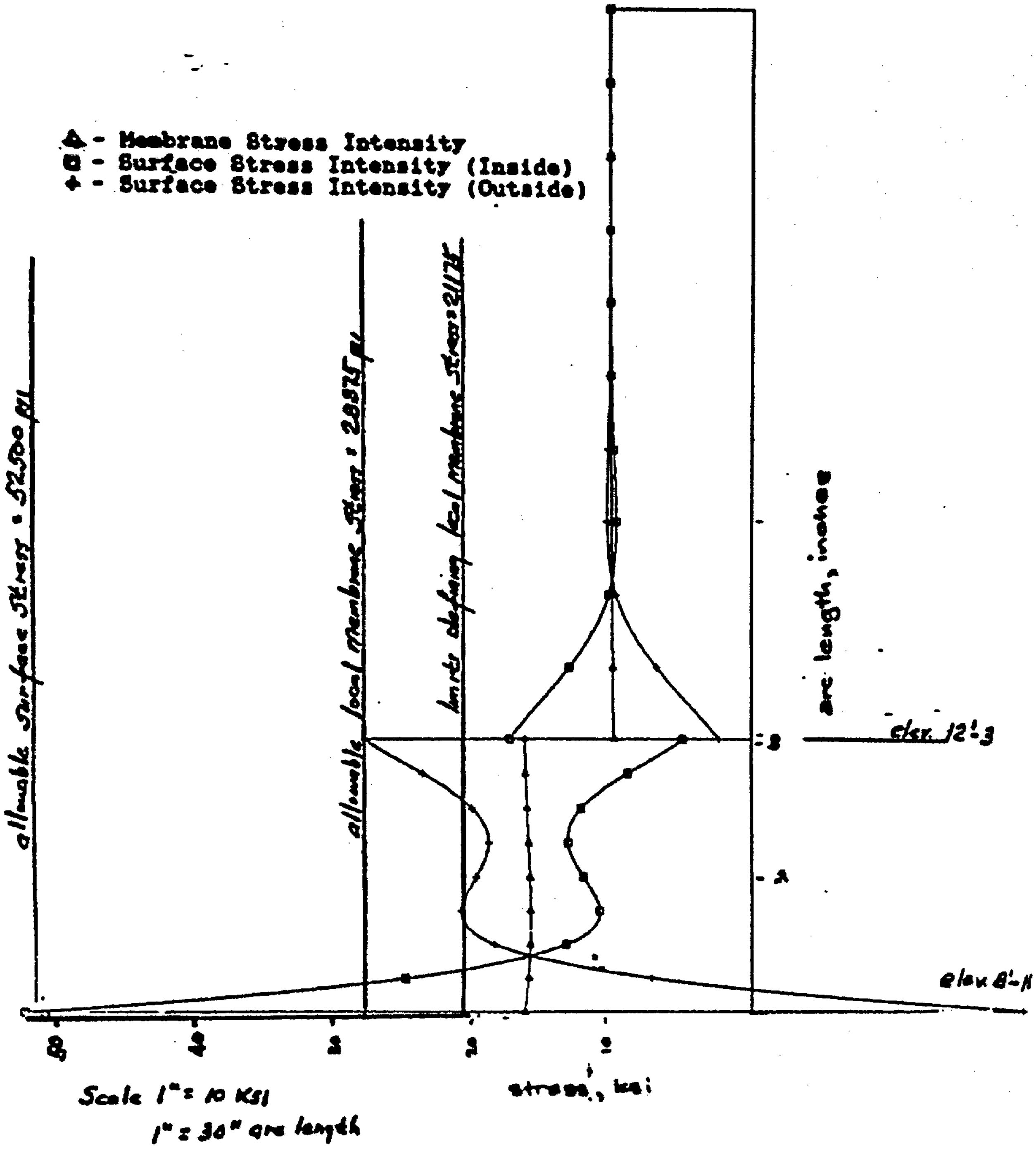


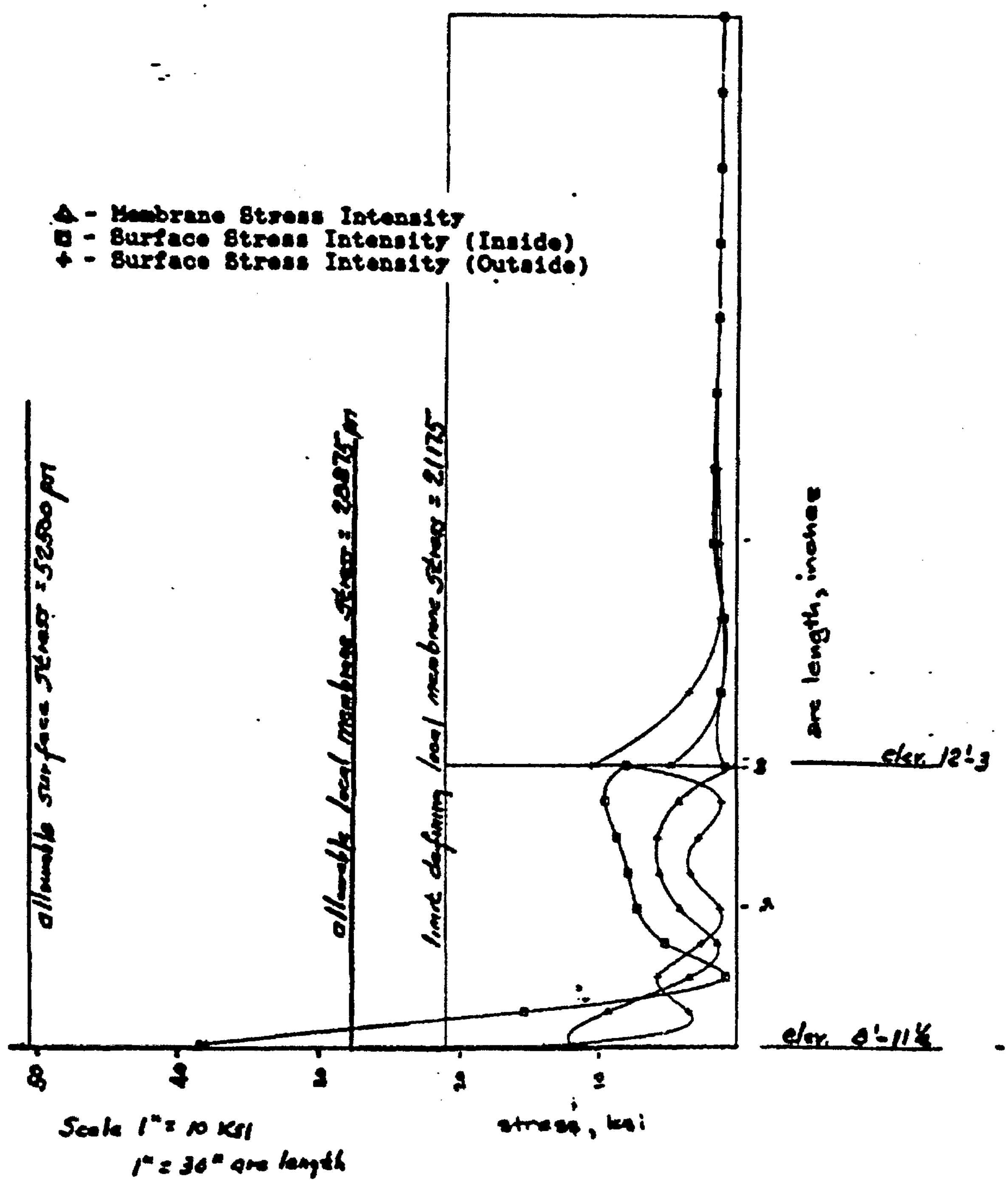
CIRCUMFERENTIAL STRESS ALONG MERIDIAN
OYSTER CREEK EMBEDMENT, CASE 2: P=62 T(MAX)=175 THICK=0.70 W/O SAND
MAXIMA 21828. 22635. 23721.

SUBJECT	MADE BY	CHKD BY	REV			CHARGE NO.
Oyster Creek Embedment	JSE	TJA		BY		NG1147
Analysis – Reduced Thickness	DATE 12/16/86	DATE 12/16/86		CHKD / DATE		SHT 2A OF



MERIDIANAL STRESS ALONG MERIDIAN
OYSTER CREEK EMBEDMENT, CASE 2: P=62 T(MAX)=175 THICK=0.70 W/O SAND
MAXIMA 53897. 16944. 28734.

SUBJECT	MADE BY	CHKD BY	REV		CHARGE NO.
Oyster Creek Embedment	JSE	DA	BY		NG1147
Analysis ~ Reduced Thickness	DATE 12/16/86	DATE 12/16/86	CHKD / DATE		SHT 25 OF



STRESS INTENSITIES ALONG MERIDIAN
OYSTER CREEK EMBEDMENT, CASE 2: P=62 T(MAX)=175 THICK=0.70 W/O SAND
MAXIMA 37728. 12257. 14006.

SUBJECT	MADE BY	CHKD BY	REV			CHARGE NO.
Oyster Creek Embedment	JSE	TJA		BY		NG1147
Analysis – Reduced Thickness	DATE 12/16/86	DATE 12/16/86		CHKD / DATE		SHT 2.6 OF

Conclusions

The preceeding analysis indicates that the reduced thickness section of the containment vessel shell located in the sand transition zone will meet the allowable stress criteria as prescribed in the original applicable code, i.e. ASME VIII, 1962 Edition and Code Cases 1270N-5, 1271N and 1272N-5. A review of the stress plots shown on sheets 1.7, 1.8, 1.10 and 1.11 for the case in which the sand is operative and pages 2.1, 2.2, 2.4 and 2.5 for the case in which the sand is inoperative shows that the local membrane stress and surface stresses are less than their respective allowables(1) The stress intensity plots shown on pages 1.9, 1.12, 2.3 and 2.6 show surface stress intensities less than the allowable as described in the 1986 Edition of ASME III. These same plots indicate that the local membrane stresses are less than the allowable of 28875, however, the length over which the local membrane stress intensity exceeds 21175 psi exceeds 1.0 $\sqrt{rt}$.

The local membrane stress as shown on page 1.9 is less than the allowable stress of 28875 psi, however the stress exceeds the 1.1S=21175 for a distance greater than 1.0$\sqrt{RT}$. Since the amplitude of the local membrane stress is significantly lower than the allowable stress, we can justify the greater length of excess by comparing the area under the actual stress curve to the area under a simiiliar curve in which the height of the curve reaches the maximum of 28875 psi over a distance of 1.0 $\sqrt{RT}$. A calculation making this comparison is shown on the following sheet. This shows that the area under the actual curve is less than the area under the allowable stress curve.

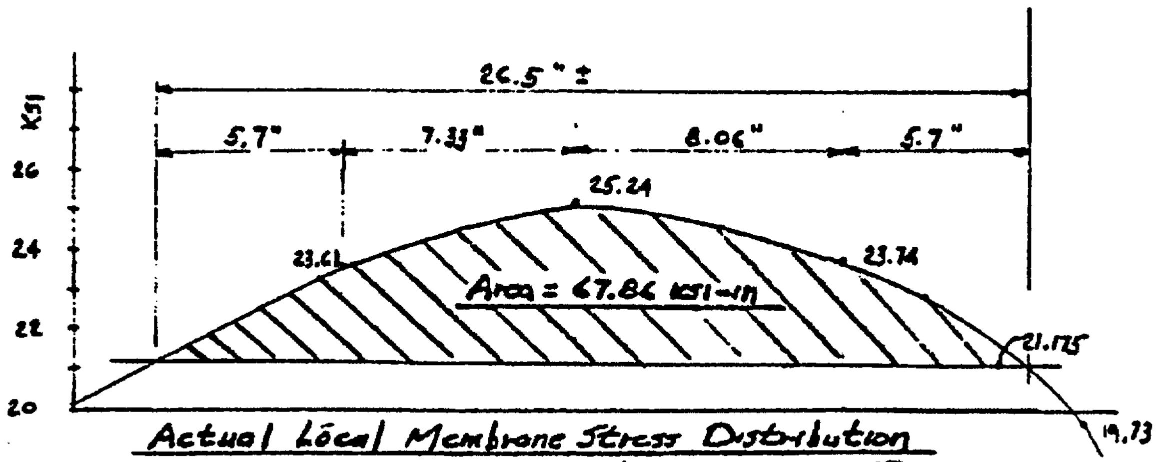
(1) It is noteworthy that the surface stress shown on page 2.5 slightly exceeds the allowable of 52500 psi. The code of record indicates that the allowable surface stress is 3 times the value listed in Table UCS-23 of Section VIII. This results in a stress of 52500 psi. Using the 1986 issue of ASME III would permit this same surface stress to be 57900 psi. Based upon this comparison, it is reasonable to permit this surface stresss which is less than today's allowable while exceeding the original stress level by 2.7%.

SUBJECT	OFFICE		REVISION	REFERENCE NO.
Oyster Creek Embedment Analysis - Reduced Thickness	CBI Oak Brook		1	NC1147
	MADE BY TJA	CHKD BY JSE	MADE BY TJA	CHKD BY JSE
	DATE 12/16/86	DATE 12/86	DATE 12/23/86	DATE 12/86

SHT 3.0 OF ___

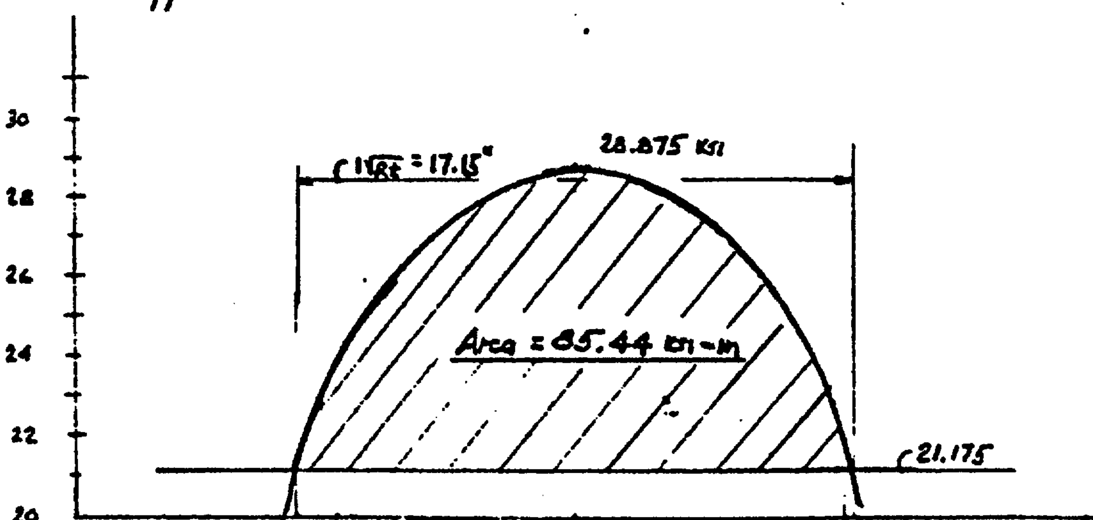
Comparison of Area Under Actual Curve to Area Under Allowable

Referring to the local membrane stress plot shown on pg. 1.9 and the stress table shown on page C1 of Appendix C, the plot of stress Intensity |Sphi - S THETA| is shown below:



Actual Local Membrane Stress Distribution

Approximate Area Under Curve above 21.175 ksi = 67.86 KSI-in



Allowable Local Membrane Stress Distribution

Allowable stress based on ideal distribution but above 21.175 ksi

Area under allowable stress/1√Rt curve = 85.44 KSI-in.

Conclusion: Actual Distribution Area is less than Allowable

SUBJECT	OFFICE	REVISION		REFERENCE NO.
Oyster Creek Embedment Analysis - Reduced Thickness Conclusions	GPU Nuclear			N61147
	MADE BY: TJA / CHKD BY: JSE	MADE BY	CHKD BY	SHT 3.1 OF ___
	DATE: 12/23/86 / DATE: 12/86	DATE	DATE	

Printed in USA

QO 84 REV SEP 84

ANALYSIS OF EMBEDMENT ZONE WITH SAND POCKET FILLED WITH GROUT

This portion of the analysis report is an assessment of the embedment zone with the sand removed and subsequently replaced with structural concrete or high strength grout. The point of complete fixity for this case is elevation [illegible]. The geometric configuration and the appropriate boundary conditions are shown on page 4.1. The thermal gradient in the axial direction is assumed to occur entirely at the point of embedment. This condition is included in this report to show that the resulting stress levels exceed the ASME allowables and that an insulating band is necessary in order to attain a suitable thermal gradient and thereby stress levels which are within the ASME allowables.

The preceeding sections of this report indicate that the surface stresses are greatest for the load case with pressure = [illegible] psi and the temperature =[illegible] degrees F and the membrane stresses are greatest for the load case with pressure = [illegible] psi and the temperature = [illegible] degrees F.. In order to assess the grouted sand pocket case, the same two loading conditions are examined. Pages 4.2, 4.3, and 4.4 are a graphical representation of the circumferential stresses, the meridional stresses, and the stress intensities for the pressure = [illegible] psi and the temperature = [illegible] degrees F loading condition. This loading condition has been presented because results in the most severe surface stress case. The surface stresses in the meridional direction are in excess of [illegible] ksi and well beyond the specified allowable of 52.5 ksi. This is clearly an indication that an iterative effort to determine a suitable thermal gradient is required.

SUBJECT	OFFICE	REVISION	REFERENCE NO.
Oyster Creek Embedment Analysis ~ Sand Pocket Filled with Grout.	CBI Oak Brook		N61147

MADE BY	CHKD BY	MADE BY	CHKD BY	SHT ___ OF ___
TJA	JSE			4.0
DATE 11/27/86	DATE 12/86	DATE	DATE	

Printed in USA

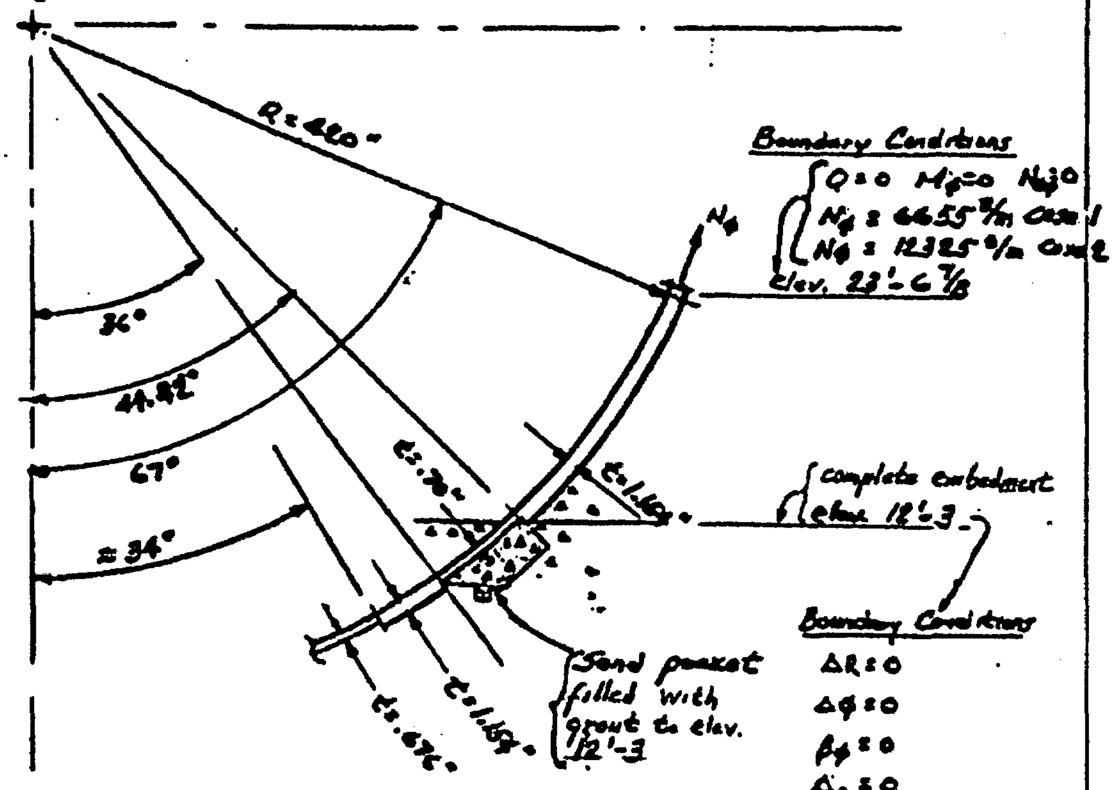
GO 64 REV SEP 84

The CBI Model used in the analysis of the grout filled embedment zone is described in the figure shown below. Complete fixity is assumed at elevation 12'3

The attenuation of the thermal gradient in the meridional direction is assumed to be completed without any finite transition length.

The embedment zone is analyzed by use of the Kalnins Shell of Revolution Computer Code. Complete fixity begins at 44.42° from vertical axis. The model continues to 67°. See Appendix A for the program description.

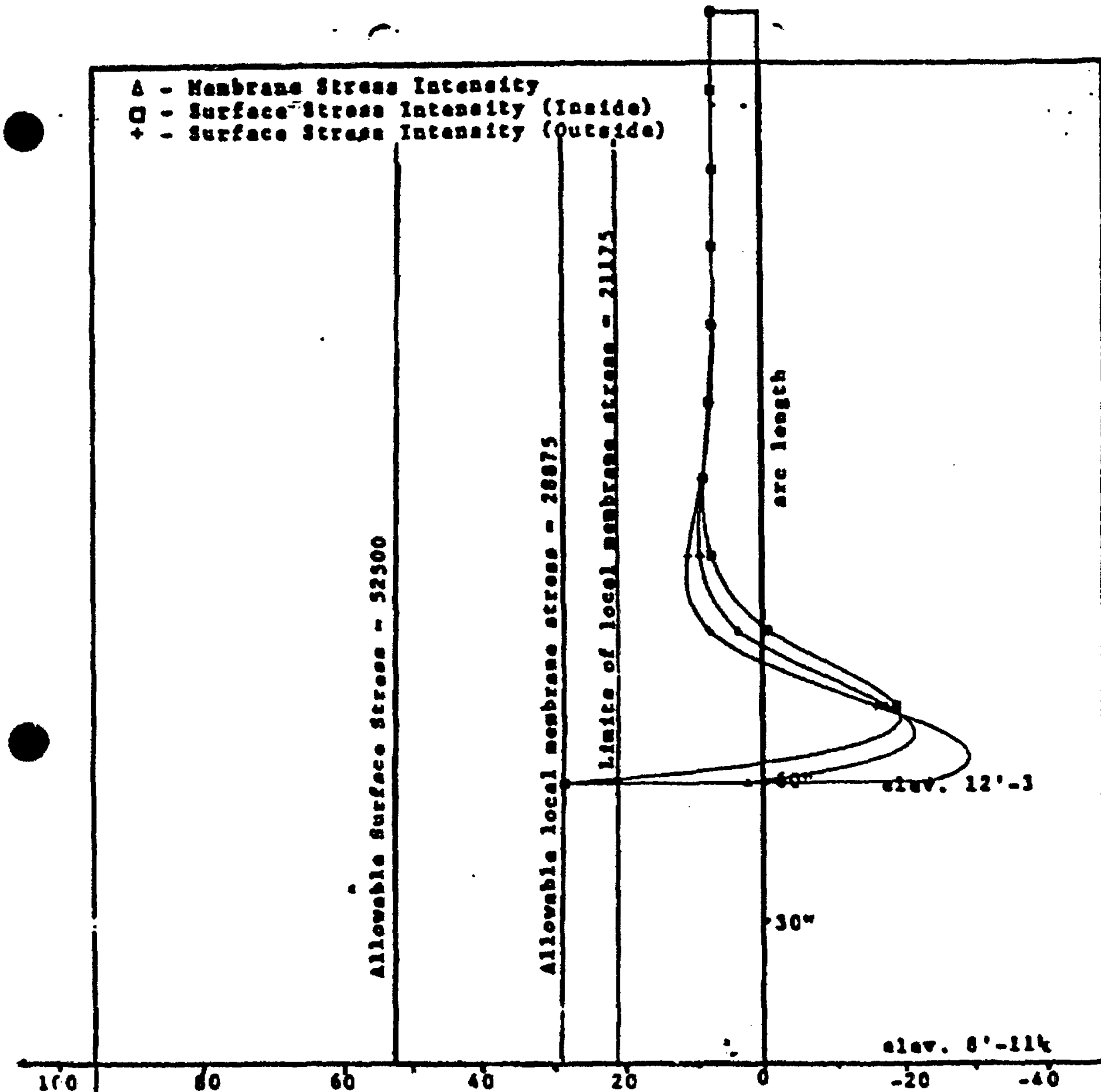
Boundary loads at elev. 23'-6 7/8 are taken from the original design.



SUBJECT	OFFICE	REVISION		REFERENCE NO.
Oyster Creek Embedment Analysis - Sand Pocket Filled with Grout	CBI Oak Brook			N61147
	MADE BY TJA / CHKD BY JSE	MADE BY	CHKD BY	SHT 4.1 OF
	DATE 12/27/86 / DATE 12/86	DATE	DATE	

Printed in USA

GO 84 REV SEP 84

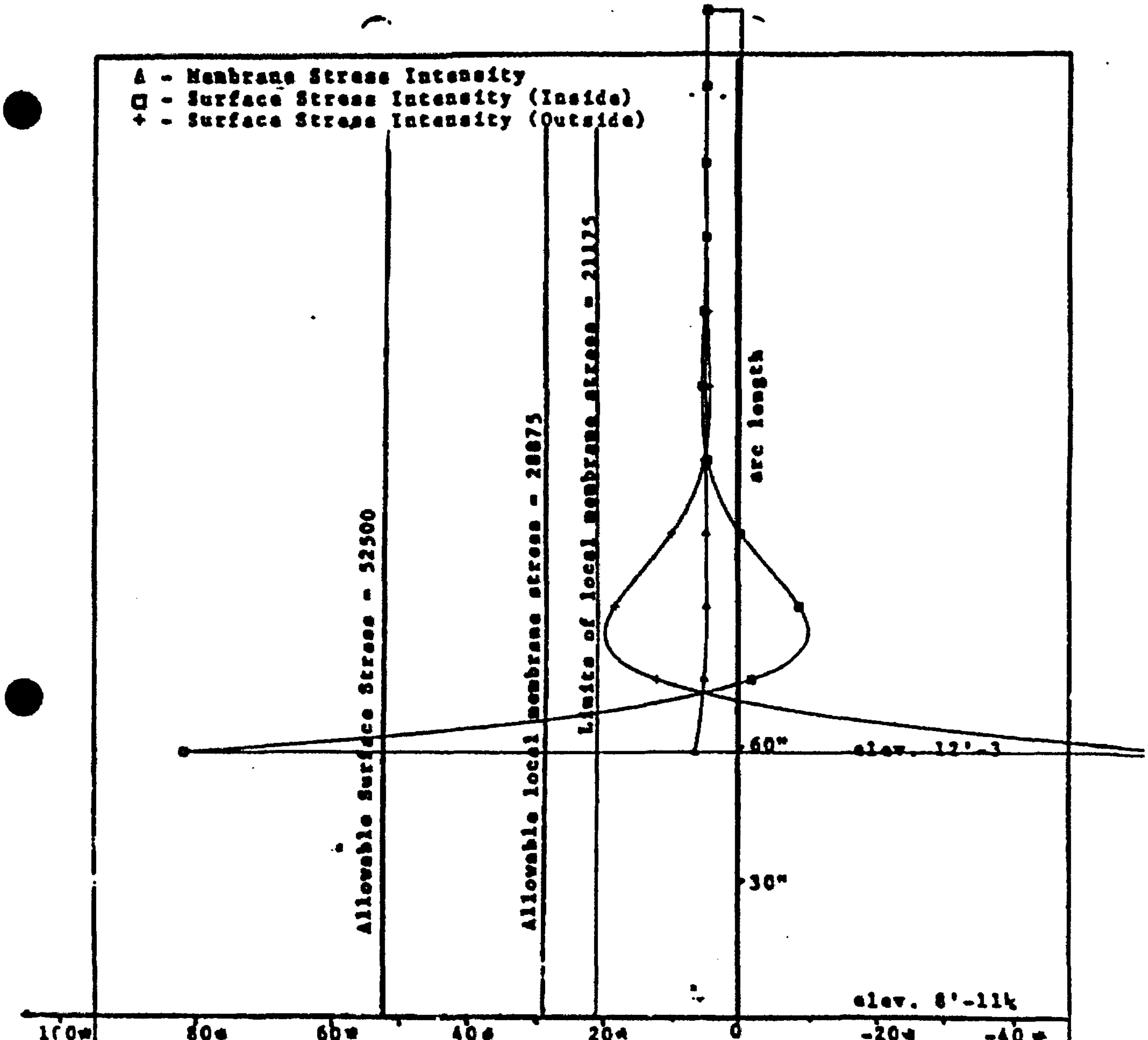


Scale 1" = 20 ksi
1" = 30" arc length

stress, ksi

CIRCUMFERENTIAL STRESS ALONG MERIDIAN
OYSTER CREEK MODIFIED EMBEDMENT, CASE 1: P=35 T(MAX)=281
MAXIMA 27850. 21238. 28925.

SUBJECT	OFFICE	REVISION		REFERENCE NO.
Oyster Creek Embedment Analysis - Reduced Thickness	Oak Brook			N61147
	MADE BY TJA / CHKD BY JSE	MADE BY	CHKD BY	SHT 4.2 OF ___
	DATE 12/29/86 / DATE 12/86	DATE	DATE	



Scale 1" = 20 ksi * stress, ksi
1" = 30" arc length

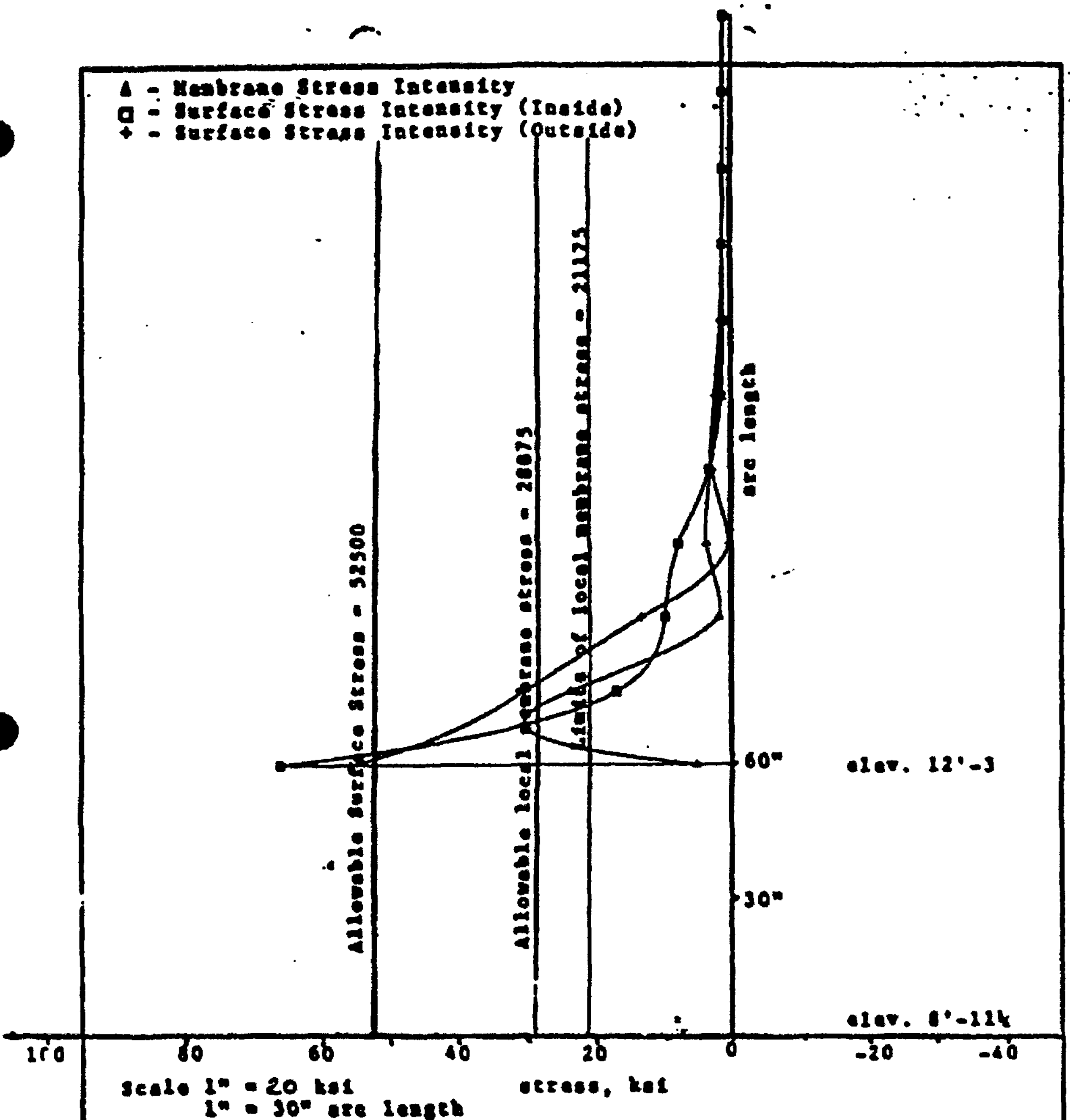
MERIDIANAL STRESS ALONG MERIDIAN

OYSTER CREEK MODIFIED EMBEDMENT, CASE 1: P=35 T(MAX)=281

MAXIMA 92539. 7274. 77991.

* Plot Scale should be multiplied by 1.128

SUBJECT	OFFICE	REVISION		REFERENCE NO.
Oyster Creek Embedment Analysis - Reduced Thickness	Oak Brook			N61147
MADE BY: TJA	CHKD BY: JSE	MADE BY	CHKD BY	SHT 43 OF
DATE: 12/21/86	DATE: 12/86	DATE	DATE	



STRESS. INTENSITIES ALONG MERIDIAN
OYSTER CREEK MODIFIED EMBEDMENT, CASE 1: P=35 T(MAX)=281
MAXIMA 64689. 29702. 54682.

SUBJECT	OFFICE	REVISION		REFERENCE NO.
Oyster Creek Embedment Analysis - Reduced Thickness	Oak Brook			N61147
	MADE BY: TJA / CHKD BY: JSE	MADE BY	CHKD BY	SHT 4A OF ___
	DATE: 12/29/86 / DATE: 12/56	DATE	DATE	

ANALYSIS OF EMBEDMENT ZONE WITH SAND REMOVED AND FILLED WITH GROUT ACCOMPANIED WITH A BAND OF INSULATION INSIDE THE CONTAINMENT VESSEL

The geometric model used for this case is essentially the same as that shown on page 4.1, except that the inside of the containment vessel has a band of insulation on the inside surface, extending upward from elevation 12'-[illegible] a distance measuring about 4[illegible] inches in the meridional direction. This band extends around the entire circumference of the vessel. The insulation would have to reach down into the vent lines in order to be effective..

Two cases have been analyzed. Case 1 with P=35 psi and T=281 degrees; and Case 2 with P=62 psi and T=175 degrees. The results are graphically on pages 4.7, 4.8, and 4.9 for Case 1 and on pages 4.10, 4.11, and 4.12 for case 2. The allowable stresses and membrane stresses shown on these pages are all within the ASME allowables.

GPUN is responsible for the design of an insulation system which will achieve the specified axial thermal gradient, i.e., dissipating 281 degrees down to [illegible] degrees within 4[illegible] inches in the meridional direction. Naturally, this insulation system will also be capable of dissipating 175 degrees down to [illegible] degrees in the same distance.

SUBJECT	OFFICE	REVISION		REFERENCE NO.
Oyster Creek Embedment Analysis - Sand pocket filled with grout and insulated.	CBI			N61147
	MADE BY TJA / CHKD BY JSE	MADE BY	CHKD BY	SHT 4.5 OF
	DATE 12/17/86 / DATE 12/86	DATE	DATE	

Printed in USA

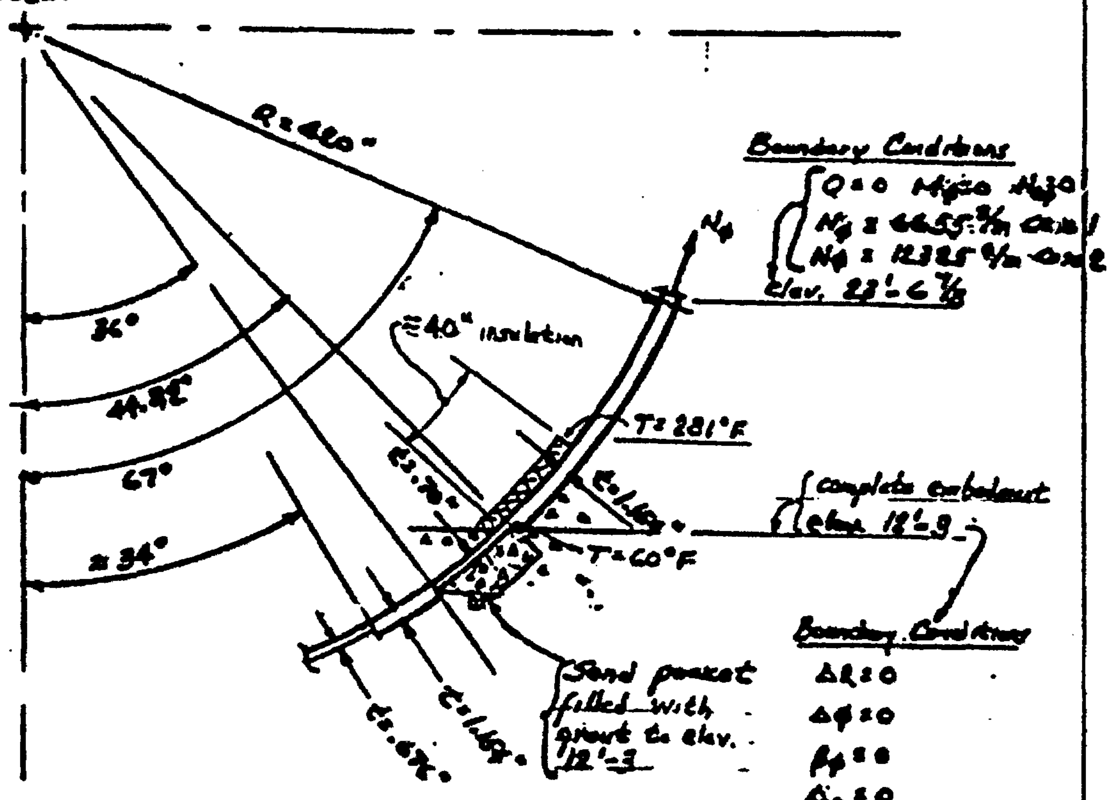
GO 84 REV SEP 84

The CBI Model used in the analysis of the grout filled embedment zone is described in the figure shown below. Complete fixity is assumed at elevation 12'3

The attenuation of the thermal gradient in the meridional direction is assumed to be completed within the ≃40 in. minimum shown on the sketch below.

The embedment zone is analyzed by use of the Kalnins Shell of Revolution Computer Code. Complete fixity begins at 44.42° from vertical axis. The model continues to 67°. See Appendix A for the program description.

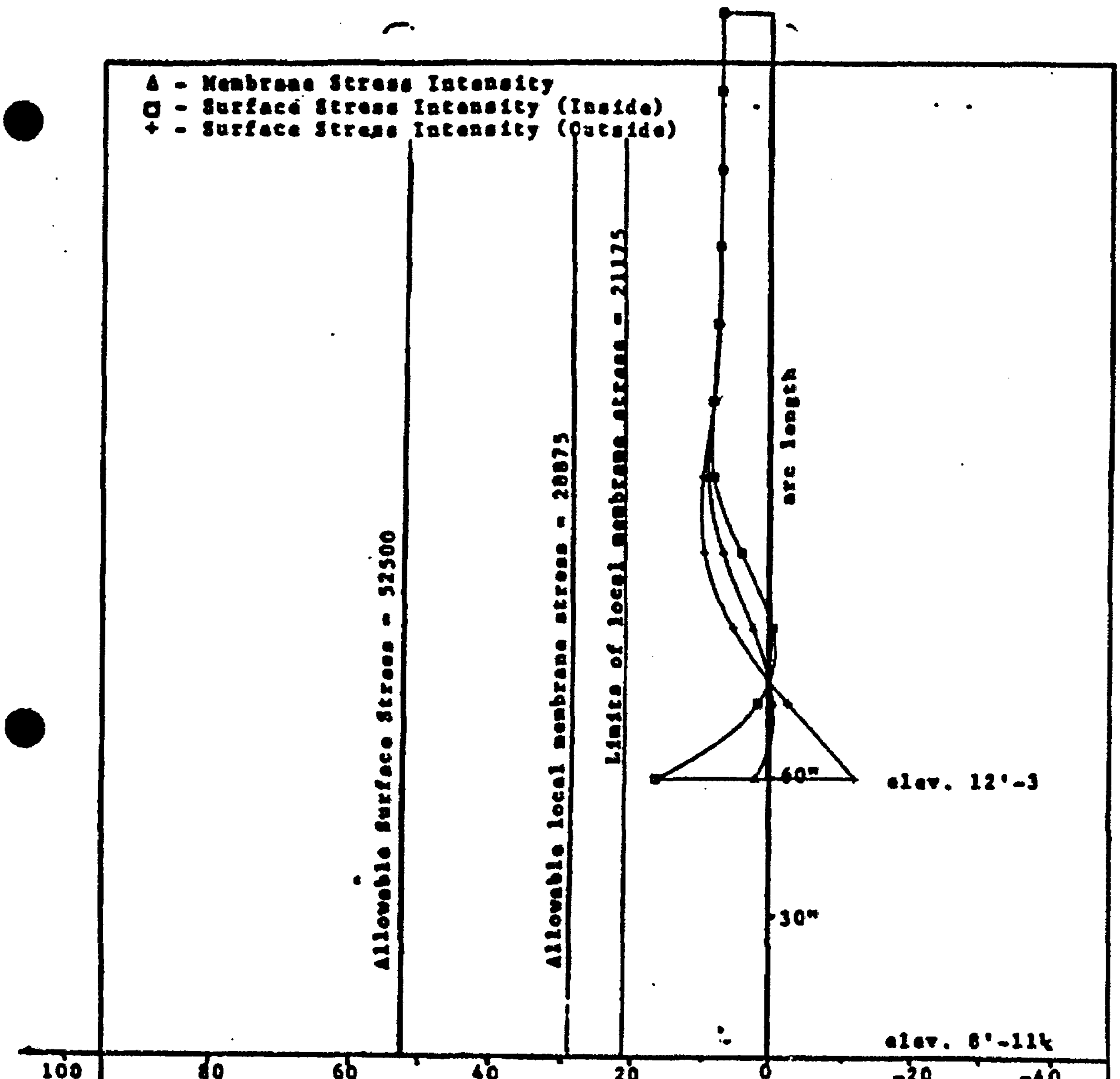
Boundary loads at elev. 23'-6 7/8 are taken from the original design.



SUBJECT	OFFICE	REVISION		REFERENCE NO.
Oyster Creek Embedment Analysis - Sand pocket filled with grout and insulated	CBI Oak Brook			NG1147
	MADE BY TJA / CHKD BY JSE	MADE BY	CHKD BY	SHT 46 OF
	DATE 12/87/86 / DATE 12/86	DATE	DATE	

Printed in USA

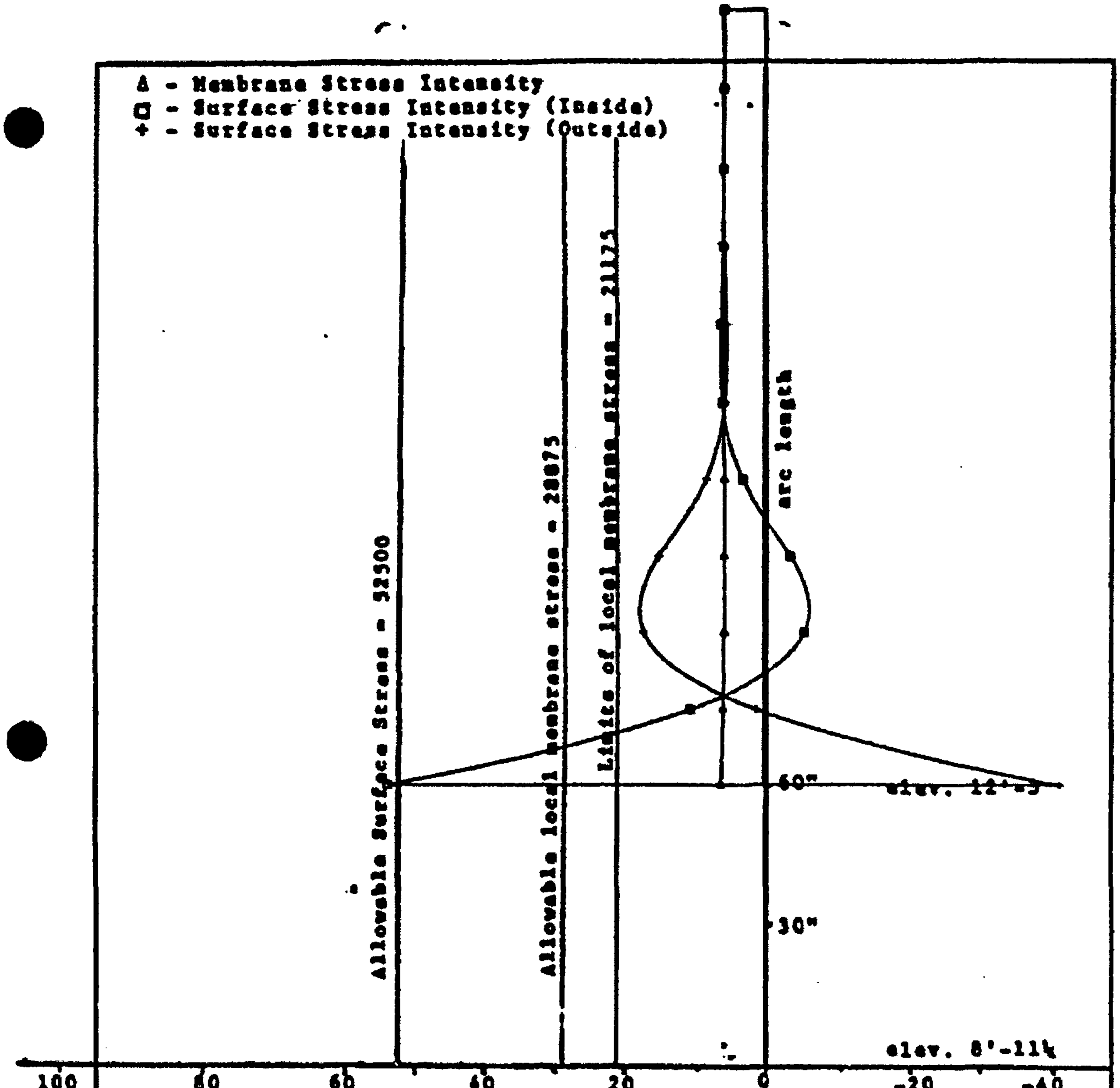
GO 84 REV SEP 84



Scale 1" = 20 ksi stress, ksi
1" = 30" arc length

CIRCUMFERENTIAL STRESS ALONG MERIDIAN
OYSTER CREEK MODIFIED EMBEDMENT, CASE 1: P=35 T(MAX)=281 W/INSULATION
MAXIMA 15766. 8496. 12171.

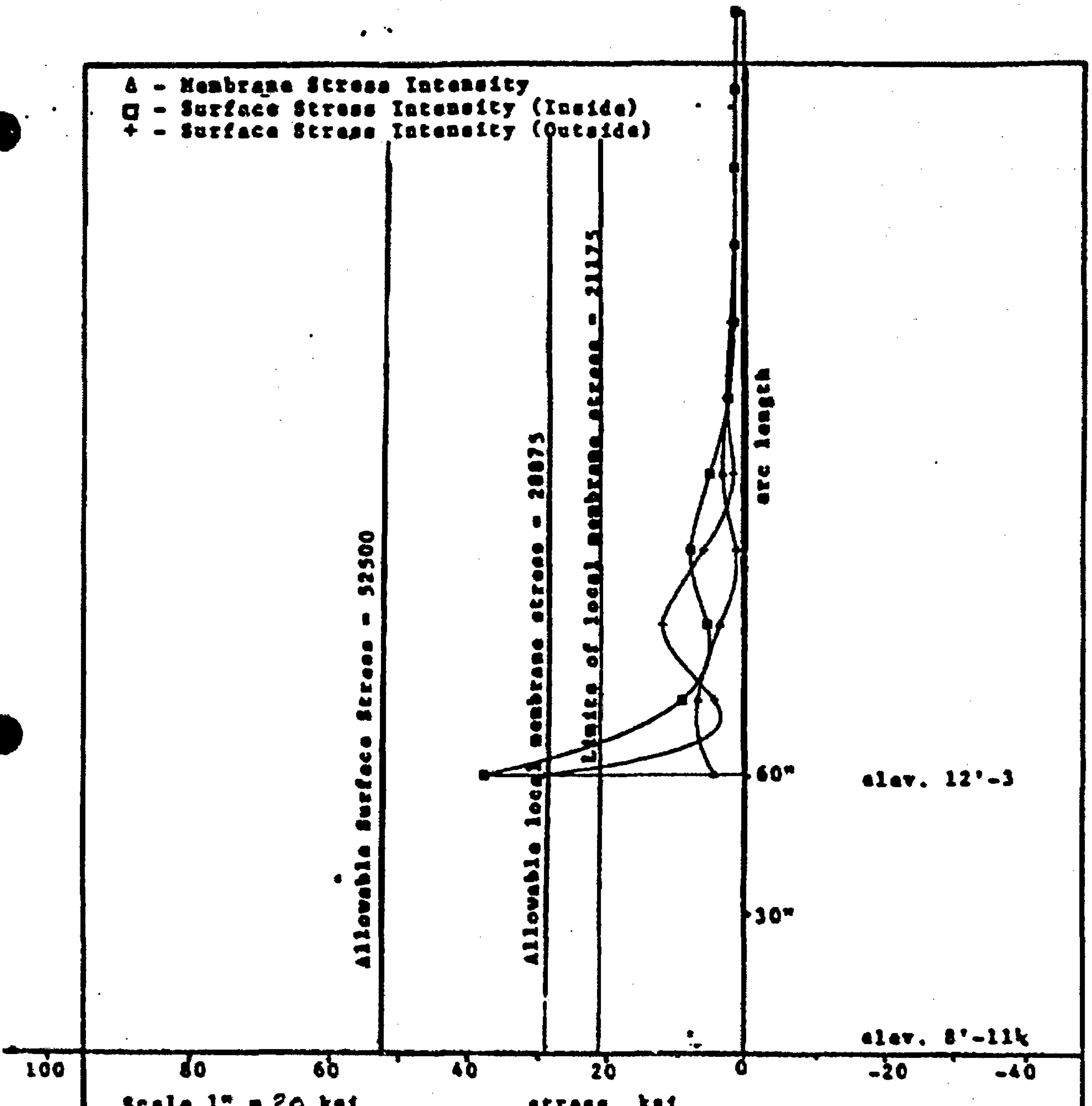
SUBJECT	OFFICE	REVISION		REFERENCE NO.
Oyster Creek Embedment Analysis - Reduced Thickness	*Oak Brook*			*N61147*
	MADE BY *TJA* / CHKD BY *JSE*	MADE BY	CHKD BY	SHT *4.7* OF ___
	DATE *12/29/86* / DATE *12/86*	DATE	DATE	



Scale 1" = 20 ksi   stress, ksi
1" = 30" arc length

MERIDIANAL STRESS ALONG MERIDIAN
OYSTER CREEK MODIFIED EMBEDMENT, CASE 1: P=35 T(MAX)=281 W/INSULATION
MAXIMA 52552. 5990. 40571.

SUBJECT	OFFICE	REVISION		REFERENCE NO.
Oyster Creek Embedment Analysis - Reduced Thickness	Oak Brook			N61147
	MADE BY TJA / CHKD BY JSE	MADE BY	CHKD BY	4.8 SHT___OF___
	DATE 12/03/86 / DATE 12/86	DATE	DATE	

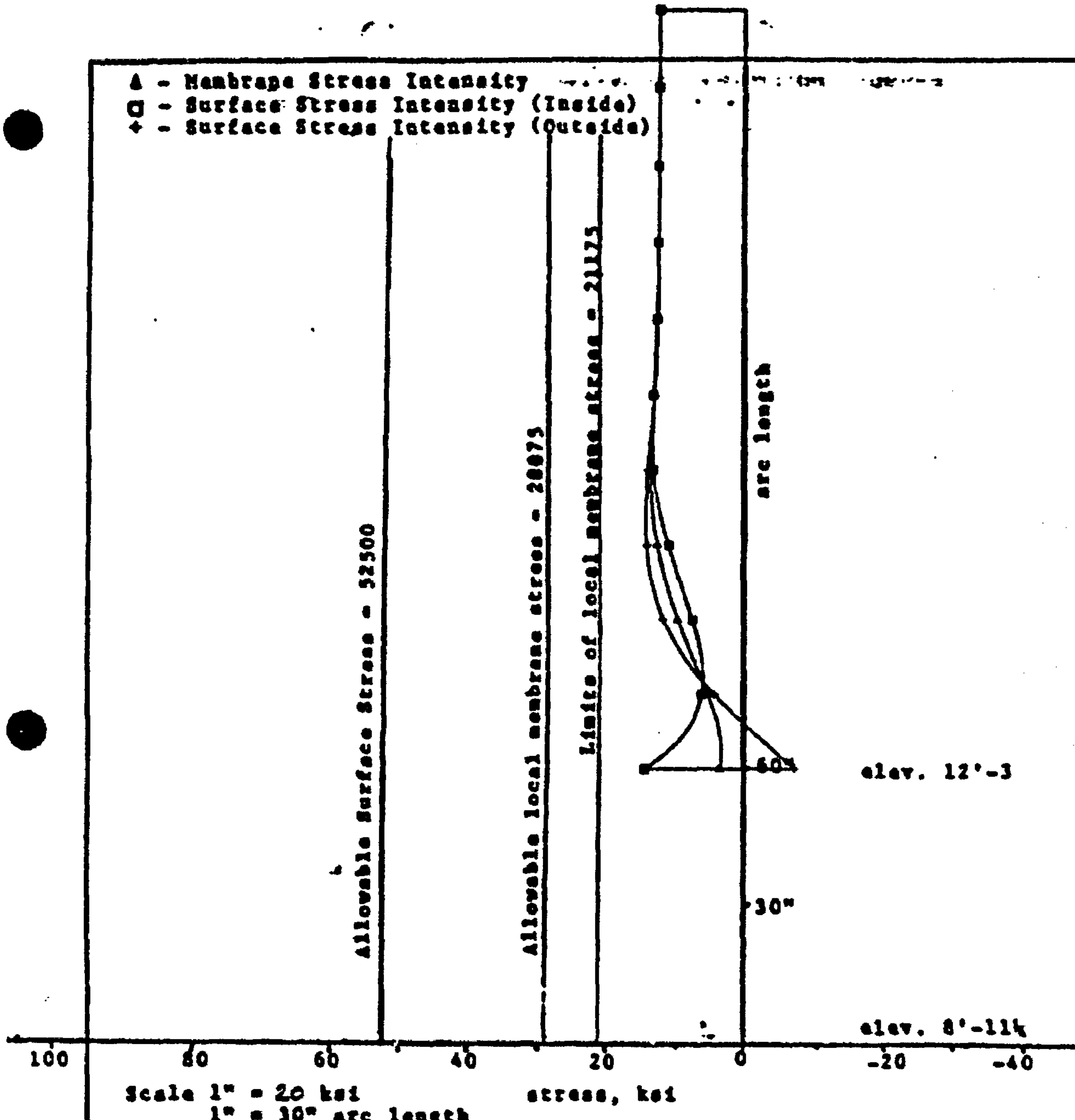


Scale 1" = 20 ksi stress, ksi
1" = 30" arc length

STRESS INTENSITIES ALONG MERIDIAN
OYSTER CREEK MODIFIED EMBEDMENT, CASE 1: P=35 T(MAX)=281 W/INSULATION
MAXIMA 36786. 6594. 28400.

SUBJECT	OFFICE	REVISION		REFERENCE NO.
Oyster Creek Embedment Analysis - Reduced Thickness	Oak Brook			N61147
	MADE BY: TJA / CHKD BY: JSE	MADE BY	CHKD BY	SHT 4.9 OF ___
	DATE: 12/29/86 / DATE: 12/5/86	DATE	DATE	

Printed in USA CD-01 REV SEP 84

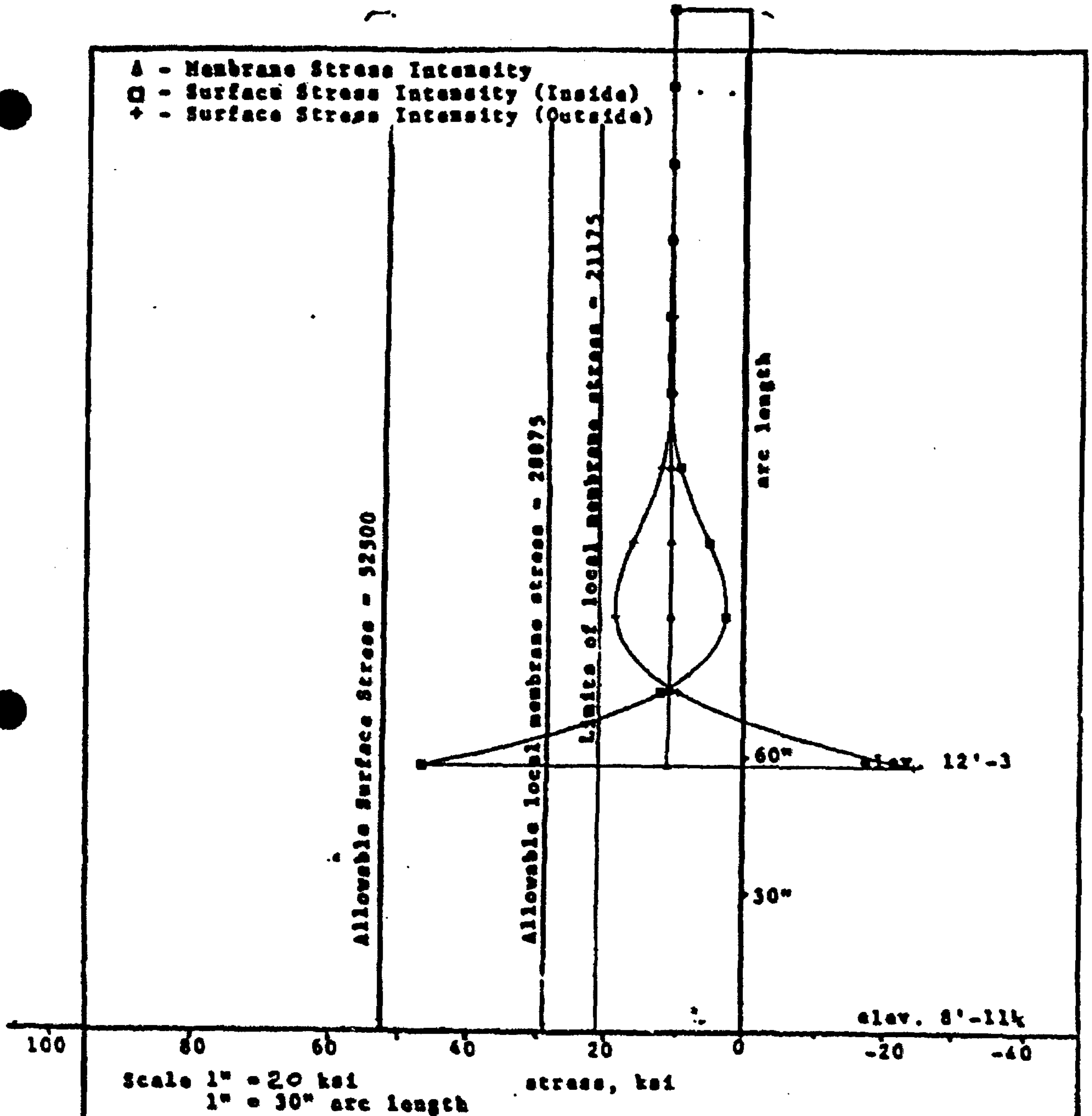


CIRCUMFERENTIAL STRESS ALONG MERIDIAN

OYSTER CREEK MODIFIED EMBEDMENT, CASE 2: P=62 T(MAX)=175 W/INSULATION

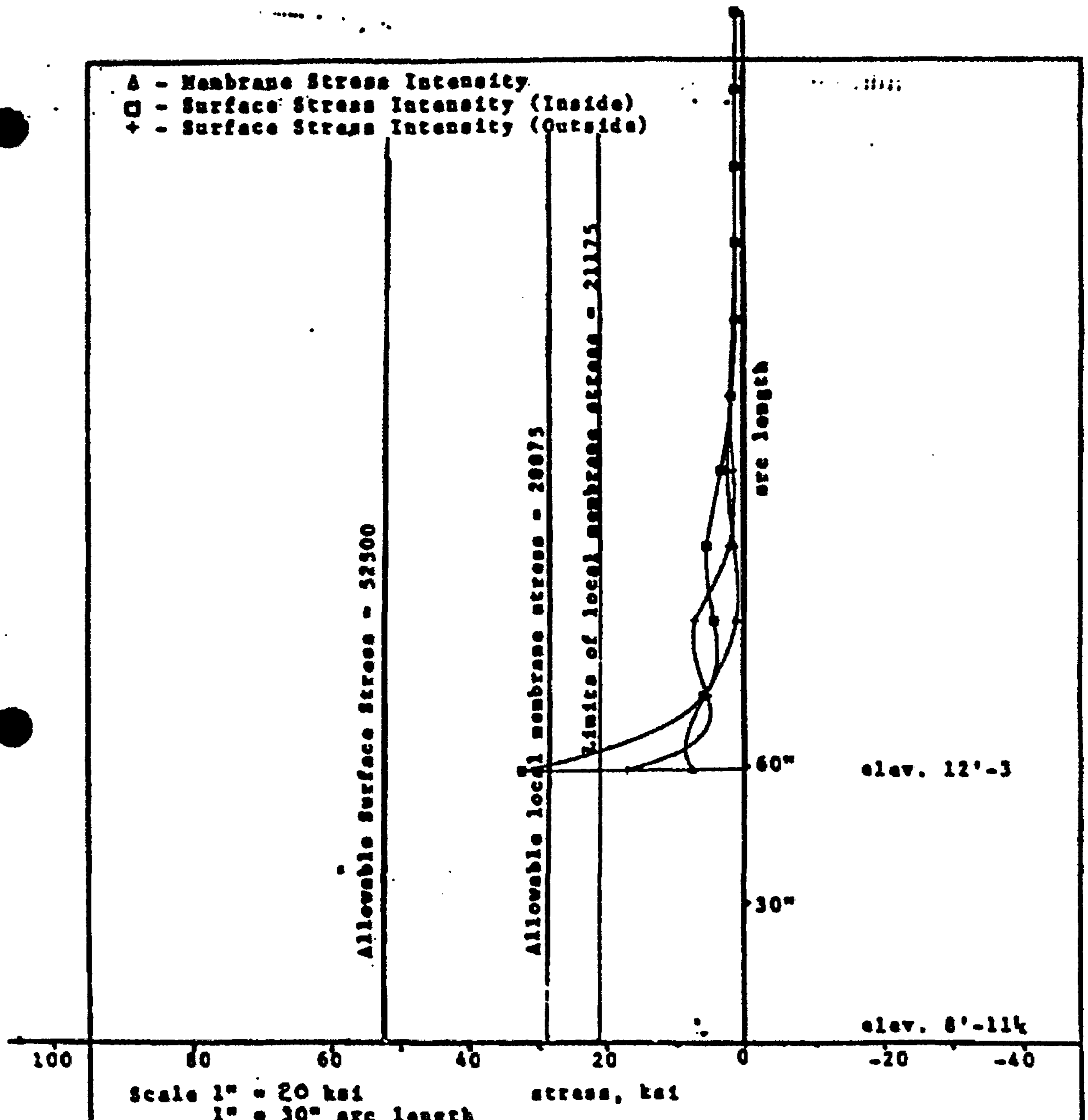
MAXIMA 13750. 12926. 13627.

SUBJECT	OFFICE	REVISION		REFERENCE NO.
Oyster Creek Embedment Analysis - Reduced Thickness	Oak Brook			NC1147
	MADE BY TJA	CHKD BY JSE	MADE BY	CHKD BY	SHT 4.10 OF
	DATE 12/29/86	DATE 12/86	DATE	DATE	



MERIDIANAL STRESS ALONG MERIDIAN
OYSTER CREEK MODIFIED EMBEDMENT, CASE 2: P=62 T(MAX)=175 W/INSULATION
MAXIMA 45834. 10836. 24162.

SUBJECT	OFFICE	REVISION		REFERENCE NO.
Oyster Creek Embedment Analysis - Reduced Thickness	Oak Brook			NC1147
	MADE BY: TJA / CHKD BY: JSE	MADE BY	CHKD BY	SHT 4.11 OF
	DATE: 12/29/86 / DATE: 12/86	DATE	DATE	



STRESS INTENSITIES ALONG MERIDIAN

OYSTER CREEK MODIFIED EMBEDMENT, CASE 2: P=62 T(MAX)=175 W/INSULATION

MAXIMA 32084. 8528. 16913.

SUBJECT	OFFICE	REVISION		REFERENCE NO.
Oyster Creek Embedment Analysis - Reduced Thickness	Oak Brook			NC1147
	MADE BY: TJA / CHKD BY: JSE	MADE BY	CHKD BY	SHT 4.12 OF
	DATE: 12/29/86 / DATE: 12/86	DATE	DATE	

Printed in USA

GO 84 REV SEP 84

Conclusions for Section 4 - Sand Pocket Filled with Grout

The filling of the sand pocket with grout up to elevation 12'-3 results in surface stresses in excess of 92 ksi. This is well beyond the ASME allowable of 52.5 ksi.

In order to reduce the surface stresses to the ASME allowable of 52.5 ksi, an insulation system is required which will ensure that the temperature of the shell is uniformly decreased from 281°F to 60°F within an arc length of 40 inches minimum.

SUBJECT	OFFICE	REVISION		REFERENCE NO.
Oyster Creek Embedment Analysis	CBI Oak Brook			N61147
	MADE BY TJA / CHKD BY JSE	MADE BY	CHKD BY	SHT 4.13 OF
	DATE 12/30/86 / DATE 12/86	DATE	DATE	

TASK 4 STABILITY ANALYSIS

OYSTER CREEK CONTAINMENT VESSEL

GLOBAL FAILURE OF THE SPHERICAL

PORTION OF THE DRYWELL

DUE TO STRUCTURAL

INSTABILITY

CBI NACON

FOR

GPUN

FEBRUARY, 1987

pg. 5.0

INTRODUCTION

This portion of the drywell analysis of the Oyster Creek Nuclear Power Plant is intended to assess the capability of the drywell shell in the "as found condition" to resist gross structural instability. This analysis includes an investigation of five loading conditions as follows:

1. Containment internal presure at 35 psig and temperature at 281°F along with a .11g horizontal earthquake and a .05g vertical earthquake. This load combination is being included because the previously presented stress information indicates that unusually high circumferential compressive stresses are present in the sand transition zone for the reduced thickness shell. The stress state used in the analysis at various points along the meridian are taken from the previously presented embedment zone analysis for points at elevations 8"-11 and 12'-3. Stress states for points at elevations above the embedment zone are taken from the stress output generated by CBI using CBI computer program 778. A description of this program is included in Appendix D. A more thorough description of this reanalysis of the containment vessel drywell is included in the following section.

2. Containment internal pressure at -2 psig and temperature at ambient along with a .11g. horizontal earthquake and a .05g vertical earthquake. This load combination is included in order to investigate the most likely operating conditio which could result in gross instability. The stress states used for the various points are taken from the original design report, page 1B9, except that the earthquake stresses have been adjusted to the .11g and .05g, horizontal and vertical earthquakes, respectively. See page 5.9 of this section for a tabulated listing.

3. Containment internal pressure at -2 psig and temperature at ambient with a .11g horizontal earthquake and a .05g vertical earthquake. This load combination is the same as that listed in 2 above, except that the stress states have been determined by use of CBI computer program 778. An explanation of the load inputs and justification of the use of the program is included in Appendix D. Analysis technique is the same as described in 1 above.

SUBJECT	OFFICE		REVISION		REFERENCE NO.
	CBI Oak Brook				N61147
	MADE BY TJA	CHKD BY PM	MADE BY	CHKD BY	SHT 5.1 OF ___
	DATE 2/6/87	DATE 2/7/87	DATE	DATE	

4. Containment flooded to elevation 74.5 feet and ambient temperature along with a .22g horizontal earthquake and a .10g vertical earthquake. The stress states have been calculated by use of CBI program 778 and for this case, the flooded drywell is assumed to act as a cantilever beam. Although the drywell is coupled to the concrete shield building at the stabilizer elevation, the effect of the stay force is assumed to be zero. The cantilever condition presents the upper bound.

5. Containment flooded to elevation 74.5ft. and ambient temperature with the same earthquake as listed in 4 above, however, in this case the drywell is examined as a propped cantilever with a stay force imposed a the elevation of the stabilizer. The concrete shield building is assumed to be stiff enough to exert a sufficiently large reaction force on the flooded drywell to reduce relative displacement to zero at that point. This is assumed to consitute a lower bound case. (See NUREG/CR-1981, pg 41 and 89 for a discussion on the effect of cantilevered vs. propped cantilever analysis)

GENERATION OF STRESS STATES

The stability analysis is based on the use of the commercial computer code BOSOR which provides a means of determining the theoretical stress state at which structural instability will occur. CBI recently obtained an improved version of the BOSOR code which allows the analyst to incorporate the elastic spring effect of the sand in the sand pocket.

SUBJECT	OFFICE	REVISION		REFERENCE NO.
	CBI Oak Brook			NG1147
	MADE BY TJA	CHKD BY PM	MADE BY	CHKD BY	SHT 52 OF
	DATE 2/6/87	DATE 2/7/87	DATE	DATE	

Printed in USA

GO 84 REV SEP 84

In order to use the BOSOR code, the stress states at approximately 10 points along the meridian of the drywell must be available as input information. In the formula for theoretical buckling from code case N-284, par. 1712.1.3(a), the stress state is assumed to be equal biaxial compression of constant magnitude throughout the vessel. The actual stress states for the five loading cases described consists of varying meridional compression with varying circumferential tension for load cases 2-5. Case 1 is circumferential compression with meridional tension.

The original design report consists of a large volume of long - hand generated calculations describing the stress states at 7 points along the meridian of the drywell. In the years following the design of the Oyster Creek containment vessel, CBI has developed a computer program 778, which performs the same type of analysis as the original design report; but allows for more rapid consideration of various loading conditions, including earthquakes of various intensity. In order to expedite the stability analysis, CBI generated an input data set for the Oyster Creek containment vessel. This data set includes a great deal of relatively non-essential input loads which are not readily available from the Oyster Creek original analysis. In order to include some representative values, the input loads from the Fermi II containment analysis were used. All essential input loads unique to Oyster Creek are incorporated into the data set. Major components such as the personnel air lock, equipment hatch and beam loads are correctly included. The Oyster Creek earthquake accelerations are also included. Appendix D includes a copy of the input data as well as the printout for load cases 1, 3, 4 and 5 (Case 2 is the original design report information)

METHOD OF ANALYSIS

The analysis approach consists of an axisymmetric shell of revolution analysis for linear bifurcation buckling. This approach produces a reasonable assessment of the buckling capacity of the structure.

Since the analysis is a linear elastic approach, it is valid only while the structure remains in an elastic state of stress. The analysis does not include any beneficial effects of penetrations or attachments which would provide some support to the vessel. Any detrimental effects of penetrations or attachments which would cause a concentration of load over a local region of the shell are not included in the analysis.

The analysis examines the structure as a free standing shell loaded by its dead load plus earthquake load using material properties at the temperature of the shell.

This case is anlalyzed using an improved version of CBI program E1443, "General Shell of Revolution Analysis with Stability and Eigenvalues (BOSOR4)," which allows the analyst to account for the elastic restraint in the sand transition zone. Linear bifurcation buckling eigenvalues are calculated considering axisymmetric loading with buckling occuring in a range of potential harmonics. No initial imperfections are included. The eigenvalue results represent a linear scale factor which when applied to the input loading produces a theoretical bifuracation buckling load. The results are then multiplied by an appropriately modified knockdown factor (reference ASME Code Case N-284, Fig. 1512-1.)

BOSOR4 Computer Program

BOSOR4 is a comprehensive computer program for the stress, stability, and vibration analysis of segmented, ring stiffened, branched shells of revolution. The program includes nonlinear prestress effects and is very general with respect to geometry of the meridian, shell wall design, edge conditions, and loading. However the wall must be thin enough so that thin shell theory is appicable and the materials must be elastic.

A summary of some of the programs's features follows:

1. Analyses: axisymmetric stresses and deflections using nonlinear theory for a stepwise increasing loading, vibration modes and frequencies, nonsymmetric buckling modes and load factors using an axisymmetric prestress, either given directly or calculated from a preproblem (either symmetric or at a given azimuth of a nonsymmetric solution); stresses and deflections due to nonsymmetric loadings.

2. Geometry: spheres, toroids, cones, cylinders, various types of rings, and general shell shapes using spline fits

3. Wall Construction: layered construction with each layer of a different material; inner and outer surfaces can vary relative to the reference surface

4. Material Properties: isotropic and orthotropic materials, special cases include fiber-wound, corrugated, monocoque, and semi-sandwich constructions

5. Boundary Conditions: displacements specified at any mesh point (including nonzero displacement), any point can be connected to any other point.

6. Loading: pressure and surface traction loading, line loading, thermal loadings including a gradient through the thickness (for linear stress analyses these all may be nonaxisymmetric loadings in the form of a longitudinal distribution times a circumferential distribution), in buckling analyses there can be fixed and variable loads

7. The stiffness of the elastic springs in the sand transition zone may be input. The springs are of equal magnitude both inside and outside the drywell.

Program Limitations:

1. Thin shell theory must be applicable as well as thin curved beam theory if rings are used.

2. Material must be elastic.

3. Structure must be axisymmetric.

4. Prebuckled deflection, while considered finite, must be no more than moderately large, i.e. the square of the meridinal rotation can be neglected compared with one.

5. In the calculation of displacements and stresses for nonsymmetrically loaded shells, small deflection theory is used.

SUBJECT	OFFICE	REVISION		REFERENCE NO.
	CBI Oak Brook			N61147
	MADE BY TJA / CHKD BY PM	MADE BY	CHKD BY	SHT 55 OF ___
	DATE 2/6/87 / DATE 2/7/87	DATE	DATE	

BUCKLING ANALYSIS SPHERICAL PORTION
CONTAINMENT VESSEL

Analysis

A. Introduction

The purpose of this analysis is to determine factor of safety against buckling of the spherical portion of the containment when subjected to various loadings using the program BOSOR4 (see preceeding 2 pages).

B. Geometry and Modelling

The dimensions of the model used in the BOSOR analysis are shown in Fig. 1.

C. Material Properties

The properties at ambient temperature for the SA - 212B, FBX, steel are taken from the ASME Sect. III code. The values used in the analysis are:

Elastic Modulus = 29600000 psi
Poisson's Ratio = 0.3

Since the eigenvalue is directly proportional to E, it can be scaled to account for other E's.

D. Loading and Boundary Conditions

The loading for each case is given in Tables 1 thru 5. These stress resultants are given to the program as an initial axisymmetric prestress conditions. The program uses linear interpolation for the values at points in between the given points.

The shell is fixed at the base of the sphere and free at the top of the knuckle. Any mode shapes that involve significant movement at the top are ignored since the knuckle is in fact not free and modes in the lower regions are desired.

The preceeding pages describe the method of determining the actual stress levels for the five loading cases and the BOSOR values which identify an amplification factor which will trigger gross buckling. The followng section is a presentation of the determination of the buckling acceptance criteria.

O.C. CONTAINMENT, BUCKLING ANALYSIS,
INITIAL UNDEFORMED STRUCTURE

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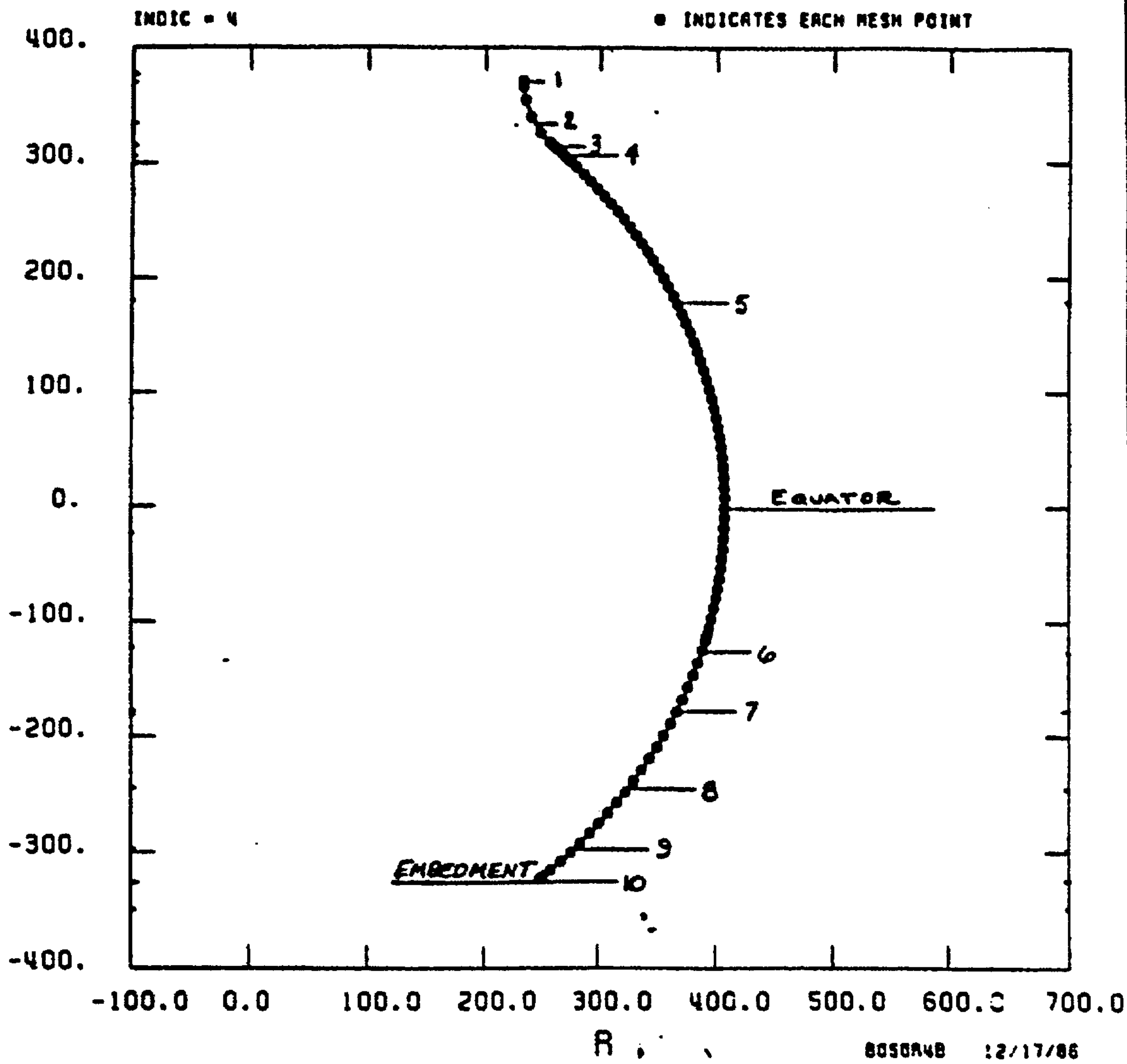

FIGURE 1

SUBJECT	OFFICE	REVISION		REFERENCE NO.
BOSOR ANALYSIS MODEL	CBI NOE			N61147
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BUCKLING CRITERIA

MODIFIED CODE CASE N-284

I. Modification of the Theoretical Buckling Value

The buckling criteria described in ASME III, Code Case N-284 is based upon determining the theoretical critical buckling stress (ref. 1712.1.3(a)) which may be taken for this case to be σ_{ct} = .605 $ET/_R$.

This theoretical buckling value as presented in the reference code case is based on a spherical shell of uniform thickness in which the unidirectional compressive stress is of a constant magnitude at all points both along the meridian and around the circumference. The orthogonal stress is understood for this formula to be equal to zero.

The loading conditions 2 thru 5 for the Oyster Creek configuration consist of a meridional compressive stress which increases in magnitude at descending elevations along the meridian. Corresponding respective circumferential tensile stresses also vary in a similar fashion. Recognizing that this loading condition cannot be realistically represented by use of the code case formula, we utilize the computer code BOSOR which is an equivalent formulation used to calculate the critical buckling value for the varying magnitude loading. The input for use in this solution consists of the calculated meridional and circumferential stresess at 10 randomly selected points along the drywell meridian (see figure on page D3). These values are shown on the following tables labeled "BOSOR Input Values". These tables also list the BOSOR output Eigenvalues. The eigenvalue is the multiplier which, when multiplied by the actual stress provides the theoretical value for critical buckling of a shell not subject to any imperfections.

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II. Modification of the Capacity Reduction Factor

The theoretical buckling value is multiplied by a "capacity reduction factor" (ref. fig. 1512-1) herein referred to as a "knockdown factor" which accounts for the additional stability of spherical shells which are less subject to imperfections of construction, mainly through the use of stiffening rings. Figure 1512-1 includes two curves; one for the case in which the stress state consists of equal biaxial compression and one in which the stress state is uniaxial compression. Although the analysis presented in this report could conservativly utilize the uniaxial compression curve, further modification may be made to account for the case wherein first direction compression is accompanied by orthogonal tension. This orthogonal tensile stress has the effect of rounding the shell and reducing the effect of imperfections experienced during the fabrication and construction phase. To arrive at a method of quantifying this effect, the following technique is used.

$S_{CR} = 0.125\,E(T/R) + \Delta\sigma_{cr}$ where $\Delta\sigma_{cr}$ is the term which accounts for the stiffening effect of the equivalent internal pressure and is found in accordance with "The Stability of Thin-Walled Unstiffened Circular Cylinders Under Axial Compression Including the Effects of Internal Pressure" by Harris, Suer, Skene and Benjamin which appeared in <u>Journal of the Aeronautical</u> Sciences - August 1957.

Using this reference, the parameter X may be determined to be

$$x = \left(\frac{P}{E}\right)\left(\frac{R}{t}\right)^2$$

The equivalent internal pressure, P, is the pressure which would result in a tensile stress equal to the calculated orthogonal stress and may be found as follows

$$Peq = \frac{2t}{R} \times S \text{ (tensile)}$$

using the Peq, determine the $\Delta\sigma_{cr}$ as follows:

$$Y = .01983 + .7886\,x - 1.5272\,x^2 + 1.5208\,x^3 - .73323\,x^4 + .13398\,x^5$$

$$\Delta\sigma_{cr} = \frac{Et}{R}\,Y$$

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Formulas are a curve fit for charts included in paper listed above.

Thus, the critical buckling stress is the sum of the Code Case N-284 theoretical critical value multiplied by an initial knockdown factor of .207 plus the modified increment which accounts for internal pressure. The result is

$$S_{cr} = .125 \, E \, t/r + \Delta\sigma_{cr}$$

The ratio of the compressive stress S_{cr} to the theoretical compressive allowable σ_{ct}, is used to determine a modified "capacity reduction factor". This will account for the enhanced ability of the shell to resist buckling. Thus; the modified knockdown factor

$$KD_{mod} = \frac{Scr}{\text{(theoretical compressive allowable } (\sigma_{ct})}$$

III Evaluation of Stability

The capacity factor margin of the containment shell compared to the appropriate allowable stress is determined as follows:

1. Determine the BOSOR Eiqenvalue from CBI computer code.

2. Determine the modified knockdown factor as described above.

3. Multiply the BOSOR Eiquevalue by the modified knockdown factor. This value is herein refered to as "Capacity Margin". These capacity margins may be compared to the ASME required factor of safety - usually 2.0 minimum.

The following table presents the "capacity margin" factors for the five cases analyzed.

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Table 1 ~ Load Case 1

BOSOR INPUT VALUES lb/in   P = 35 psi   T = 281 °F

.11g	PT. 1	PT. 2	PT. 3	PT. 4	PT. 5	PT. 6	PT. 7	PT. 8	PT. 9+	PT. 10
MERID										
+ EQ	3293	4513	6989	7012	7049	6680	6445	5473	4404	6108
− EQ	3132	4299	6706	6778	6900	6384	5847	4170	2405	2500
CIRCUM										
+ EQ	13315	26412	20212	7607	7614	8020	8298	9327	-11052	5598
− EQ	13094	25590	19496	7832	7756	8316	8899	10640	-9041	9220
									PT. 9−	
MERID										
+ EQ									4404	
− EQ									2405	
CIRCUM										
+ EQ									-6184	
− EQ									-5200	

BOSOR Eigenvalue = (7.388   m=40

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Table 2 ~ Load Case 2 Original Analysis Evaluation

BOSOR INPUT VALUES lb/in P = -2 psi T = 70°F

.11g	PT. 1	PT. 2	PT. 3	PT. 4	PT. 5	PT. 6	PT. 7	PT. 8	PT. 9+ (See Note (1))	PT. 10
MERID +EQ -EQ	-1015	-1300	-1832	-1631	-1021	-	-1864	-	-3901	-4661
CIRCUM +EQ -EQ	-1907	-5605	-5027	+714	+145	-	+1065	-	+3160	-1398
									PT. 9 -	
MERID +EQ -EQ									-3901	
CIRCUM +EQ -EQ									+1456	

Bosor Eigenvalue = 12.24 n=3

Note (1) - Original Report did not have values computed at pt. 9. Values shown have been proportioned using available data at pt. 7 and pt 10

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Table 3 Load Case 3

BOSOR INPUT VALUES lb/in P= -2 psi T= 70°F

.11g	PT. 1	PT. 2	PT. 3	PT. 4	PT. 5	PT. 6	PT. 7	PT. 8	PT. 9	PT. 10
MERID										
+ EQ	-360	-507	-766	-745	-716	-1085	-1320	-2289	-2429	-3202
- EQ	-521	-720	-1048	-979	-865	-1381	-1917	-3592	-4628	-6811
CIRCUM										
+ EQ	-997	-2610	-2374	-176	-164	245	522	1550	1905	2494
- EQ	-1218	-3432	-3091	49	-19	541.	1124	2863	3916	6116

									PT9⁻	
MERID										
+ EQ										
- EQ									-4628	
CIRCUM										
+EQ										
- EQ									+1829	

BOSOR Eigenvalue = 9.23 m=3

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Table 4 Load Case 4 Flooded to elev. 74.5 ft. in Cantilever condition ~ No stay force

BOSOR INPUT VALUES lb/in

.22g E.Q. Horiz. and .10 g Vert. EQ

.22g	PT. 1	PT. 2	PT. 3	PT. 4	PT. 5	PT. 6	PT. 7	PT. 8	PT. 9	PT. 10
MERID +EQ -EQ	-126	–	–	–	-341	-1169	-2412	-7689	-12223	-22352
CIRCUM +EQ -EQ	+257	–	–	–	+4627	+7942	+11298	+18359	+23493	-6706
									PT 9⁻	
MERID +EQ -EQ									-12223	
CIRCUM +EQ -EQ									+12808	

Eigenvalue = 2.987 m=3

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SUBJECT: Table 5 Load Case 5 — Flooded to elev. 74.5 ft. with Stop force
BOSOR INPUT VALUES lb/in .22g Horiz. E.Q. and .10g Vert. E.Q.

.22g	PT. 1	PT. 2	PT. 3	PT. 4	PT. 5	PT. 6	PT. 7	PT. 8	PT. 9+	PT. 10
MERID ± EQ	-126	-	-	-	-170	-833	-1601	-5523	-8580	-14873
CIRCUM ± EQ	+257	-	-	-	+4460	+7613	+10506	+16242	+19910	-4462

	PT. 1	PT. 2	PT. 3	PT. 4	PT. 5	PT. 6	PT. 7	PT. 8	Pt. 9 −	PT. 10
MERID ± EQ									-8580	
CIRCUM ± EQ									+11064	

Note: Values for PTS. 1, 2, 3 and 4 Not required for Bosor Analysis

Eigenvalue = 4.60 n=3

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Table 6 ~ Capacity Margins for Cases 1 thru 5
Adjustment to Code Case N 284 Knock Down Factors to account for Orthogonal Direction Tension ~ Use Stresses at point 9"

$E_{amb} = 29600000$ psi $E_{281} = 28395000$ psi $t = .70''$ $R = 420''$

Load Case	$\sigma_{compression}$ psi	$\sigma_{Tension}$ psi	$P_{eq} = \frac{2t}{R}\sigma_{Ten.}$ psi	$\Delta\sigma_{cr}$	σ_{cr}	Adjusted Knock Down Factor	Bosor Eigenvalue	Capacity Margin Bosor x KDF
① P = 35 psi, T = 281 °F	-8834 (circ.)	+6291	20.97	6939	12855	.449	7.25 m=40	3.26 5
② P = -2 psi, T = amb. [illegible] I.R.	-5573 (merid)	+2080	6.93	3765	9932	.333	12.24 m=3	4.07
③ P = -2 psi, T = amb, CBI 718	[illegible] -6611 (merid)	+2613	8.71	4339	10505	.352	9.33 m=3	3.28
④ Flooded to elev 74.5', Cantilever condition	-17461 (merid)	+18297	60.99	9536	15702	.526	3.12 m=3	1.64
⑤ Flooded to elev. 74.5 ft with Stay	-12257	+15806	52.69	9327	15494	.519	4.60 m=3	2.39

$\sigma_{CT_{281}} = .605 \times \frac{28395000 \cdot .7}{420} = 28632$ $\sigma_{CT\,amb} = 29847$

* Capacity Margins less than 1 have a potential for buckling instability

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Conclusions

The column labeled "Capacity Margin" shown on the preceeding page is a tabulation of the capability of the containment vessel to resist meridional or circumferential buckling in the sand transition zone for a minimum shell thickness of .70 inches.

These capacity margins may be compared to the ASME required "factor of safety" against buckling. The table shows that the capacity margins for load case 1, 2, and 3 are 3.26, 4.07 and 3.28, respectively. All 3 capacity margins are greater than the ASME required factor of safety of 2.0 and are considered to be acceptable.

Load cases 4 and 5 are included to provide a range of capacity margins for the "flooded to elevation 74.5 feet" cases. Case 4 shows a capacity margin of 1.64 for the containment vessel acting as a free standing cantilever. (The original stress report allowed a capacity margin of 1.0 for the flooded plus .22g earthquake condition).

Case 5 shows a capacity margin of 2.39 for the containment vessel acting as a propped cantilever. (This is the condition utilized in the original stress report). The true condition of support probably lies between the cantilever and propped cantilever condition, i.e; capacity margin of 1.64 and 2.39. Either capacity margin meets the requirements of the original design specification.

Further refinements of the earthquake loading, the coupling of adjacent structures and the fluid structure interaction is recommended. These refinements were beyond the state of the art used at the time the original design was performed. It is highly probable that additonal refined analysis will improve the capacity margins for cases 4 and 5.

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Appendix A

CBI Computer Code Description

Kalnins

Shells of Revolution Program

Kalnins Shells of Revolution Program

The Shells of Revolution Program is the Chicago Bridge & Iron Company Program 7-81. The program calculates the stresses and displacements in thin walled elastic shells of revolution when subjected to static edge, surface and/or temperature loads with arbitrary distribution over the surface of the shell. The geometry of the shell must be symmetric, but the shape of the median is arbitrary. It is possible to include up to three branch shells with the main shell in a single model. In addition, the shell wall may consist of four layers of different orthotropic materials, and the thickness of each layer and the elastic properties of each layer may vary along the median.

The 7-81 program numerically integrates the eight ordinary first order differential equations of thin shell theory derived by H. Reissner. The equations are derived such that the eight variables are chosen which appear on the boundaries of the axially symmetric shell so that the entire problem can be expressed in these fundamental variables.

Chicago Bridge & Iron Company has extensively revised the Kalnins Program. The program has been altered such that a 4 x 4 force-displacement relation can be used as a boundary condition as an alternative to the usual procedure of specifying forces or displacements. This force-displacement relation can be used to describe the forces at the boundary in terms of displacements at the boundary, or the displacements at the boundary in terms of forces or some compatible combination of the two. In this manner, it is possible to study the behavior of a large complex structure.

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Oyster Creek Embedment Analysis - Reduced Thickness Appendix A - Program Description	CBI Oak Brook				NG1147
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It is also possible to introduce a "spring matrix" at the end of any part of the stress model. This matrix must be expressed in the form, force = spring matrix x displacement. In this manner it is possible to model the restraint of the sand cushion in the transition zone at the point of embedment. In addition to the above changes, the Kalnins Program has been modified to increase the size of the problem that can be considered and to improve the accuracy of the solution.

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Oyster Creek Embedment Analysis - Reduced Thickness Appendix A - Program Description	GBI Bala Bawel				NC1147
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Analysis of Shells of Revolution Subjected to Symmetrical and Nonsymmetrical Loads[1]

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The boundary-value problem of deformation of a rotationally symmetric shell is stated in terms of a new system of first-order ordinary differential equations which can be derived for any consistent linear bending theory of shells. The dependent variables contained in this system of equations are those quantities which appear in the natural boundary conditions on a rotationally symmetric edge of a shell of revolution. A numerical method of solution which combines the advantages of both the direct integration and the finite-difference approach is developed for the analysis of rotationally symmetric shells. This method eliminates the loss of accuracy encountered in the usual application of the direct integration approach to the analysis of shells. For the purpose of illustration, stresses and displacements of a pressurized torus are calculated and detailed numerical results are presented.

The shell of revolution is an important structural element, and the literature devoted to its analysis is extensive. With regard to axisymmetric deformation, various methods have been employed to obtain solutions of the bending theory of shells of revolution by means of the H. Reissner-Meissner equations. For example, Naghdi and DeSilva [1][2] use asymptotic integration; Lohmann [2], Müns [3], Klingbeil [4], employ a direct numerical integration approach; Galletly, et al. [5] find the solution for an ellipsoidal shell of revolution by both the finite-difference and the Runge-Kutta method; and Penny [6], Radkowski, et al. [7], and Sepetoski, et al. [8] utilize the finite-difference technique. A number of additional references which deal with the solution of the H. Reissner-Meissner equations can be found in the papers cited.

For problems of bending in the absence of axial symmetry, a reduction of the governing equations of arbitrary shells of revolution to a system of four second-order differential equations involving four unknowns has been carried out by Budiansky and Radkowski [9]. A method for obtaining the solution of these equations is given in [9] which is an extension of that employed in [7] and [8]. Furthermore, treatments of nonsymmetric deformation of shells of revolution are found in papers by Goldberg and Bogdanoff [10], where a system of first-order differential equations for conical shells is derived, and by Steele [11] and Schile [12], where solutions of certain types are considered by means of asymptotic integration.

Among the papers which employ numerical analysis, two dif-

[1] National Science Foundation Grant No. 23922, Report No. 3, July, 1963.

[2] Numbers in brackets designate References at end of paper.

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Discussion of this paper should be addressed to the Editorial Department, ASME, United Engineering Center, 345 East 47th Street, New York, N. Y. 10017, and will be accepted until October 10, 1964. Discussion received after the closing date will be returned. Manuscript received by ASME Applied Mechanics Division, July 31, 1963. Paper No. 64—APM-33.

Nomenclature

- ϕ, θ, ζ = coordinates of a point of shell
- s = distance measured from an arbitrary origin along meridian in positive direction of ϕ
- t_ϕ, t_θ, n = unit vectors tangent to coordinate curves (see Fig. 1)
- R_ϕ, R_θ = principal radii of curvature of middle surface
- r = distance of a point on middle surface from axis of symmetry
- E = Young's modulus
- ν = Poisson's ratio
- h = thickness of shell
- α = coefficient of thermal expansion
- $D = Eh^3/[12(1-\nu^2)]$
- $K = Eh/(1-\nu^2)$
- u_ϕ, u_θ, w = components of displacement of middle surface
- β_ϕ, β_θ = angle of rotation of normal
- p_ϕ, p_θ, p = components of mechanical surface loads
- m_ϕ, m_θ = components of moment of surface loads
- T, T_0, T_1 = temperature increment and temperature resultants
- $N_\phi, N_\theta, N_{\phi\theta}$ = membrane stress resultants
- $M_\phi, M_\theta, M_{\phi\theta}$ = moment resultants
- Q_ϕ, Q_θ = transverse-shear resultants
- N, Q = effective-shear resultants
- $J = 1/R_\phi + \sin\phi/r$
- $U = 1/R_\phi + \nu\sin\phi/r$
- $H = 1/R_\phi - \sin\phi/r$
- n = integer, designating nth Fourier component
- β = length factor
- $(\ )_{,\alpha}$ = derivative with respect to any coordinate
- m = order of system of equations
- M = number of segments
- x = independent variable, either ϕ or s
- x_i = end point of segment
- $y(x)$ = $(m, 1)$ matrix, fundamental variables
- $A(x)$ = (m, m) matrix, coefficients of differential equations
- $B(x)$ = $(m, 1)$ matrix, nonhomogeneous coefficients
- $Y(x)$ = (m, m) matrix, homogeneous solutions
- $Z(x)$ = $(m, 1)$ matrix, nonhomogeneous solutions
- C = $(m, 1)$ matrix, arbitrary constants
- I = unit matrix

ferent methods of solution of the boundary-value problem of deformation of shells must be recognized; i.e., the direct integration [2-5] and the finite difference approach [5-9]. While the direct integration approach has certain important advantages, it also has a serious disadvantage; i.e., when the length of the shell is increased, a loss of accuracy invariably results. This phenomenon was clearly pointed out in [8]. The loss of accuracy does not result from accumulative errors in integration, but it is caused by the subtraction of almost equal numbers in the process of determination of the unknown boundary values. It follows that for every set of geometric and material parameters of the shell there is a critical length beyond which the solution loses all accuracy. The advantage of the finite-difference approach over direct integration is that it can avoid such a loss of accuracy. It is concluded from [8] that if the solution of the system of algebraic equations, which result from the finite-difference equations, is obtained by means of Gaussian elimination, then no loss of accuracy is experienced if the length of the shell is increased.

This paper is concerned with the general problem of deformation of thin, elastic shells of revolution, symmetrically or nonsymmetrically loaded, and with the development of a numerical method of its solution, which employs the direct integration technique, but eliminates the loss of accuracy owing to the length of the shell. The method developed here is applicable to any two-point boundary-value problem which is governed within an interval by a system of m first-order linear ordinary differential equations together with $m/2$ boundary conditions prescribed at each end of the interval. It is shown that the boundary-value problem of a rotationally symmetric shell can be stated in this form for any consistent linear bending theory of shells in terms of those quantities which appear in the natural boundary conditions on a rotationally symmetric edge.

The method of this paper offers definite advantages over the finite-difference approach. The main advantages are: (a) It can be applied conveniently to a large system of first-order differential equations, and (b) it permits an automatic selection of an optimum step size of integration at each step according to the desired accuracy of the solution. The first point means that the equations of the theory of shells of revolution, characterized in terms of first-order differential equations, can be integrated directly, and further reduction of the equations to a smaller number of unknowns is not necessary. The second point seems to be of great importance if a truly general method is desired which is expected to hold for arbitrary loads, shell configurations, thickness, and so on. With the finite-difference approach, a meaningful *a priori* estimate of the step size is often difficult, if not impossible, especially when rapid changes and discontinuities in the shell parameters are encountered. If a predictor-corrector direct integration approach is employed with the method of this paper, then the step size can be selected automatically at each step which ensures a prescribed accuracy of the solution and optimum efficiency in the calculation.

The method given in this paper can be divided into two parts: (a) Direct integration of $m + 1$ initial value problems over preselected segments of the total interval, and (b) the use of Gaussian elimination for the solution of the resulting system of matrix equations. The first part of this method is a generalization of that which is employed over the whole interval in [2-5]. Here, however, the initial value problems are defined over segments of the total interval, the lengths of which are within the range of the applicability of the direct integration approach. After the initial value problems are integrated over these segments, continuity conditions on all variables are written at the endpoints of the segments, and they constitute a simultaneous system of linear matrix equations. This system of matrix equations is then solved directly by means of Gaussian elimination. The result is that the direct integration method is employed and at the same time there is no loss of accuracy because the lengths of the segments are selected in such a way that the solutions of the initial value problems are kept sufficiently small. A convenient parameter is given from which the appropriate lengths of the segments can be estimated easily.

In the application of this method to the analysis of rotationally symmetric shells, the boundary-value problem is formulated in terms of first-order ordinary differential equations. For this purpose, starting with the equations of the linear classical bending theory of shells in which the thermal effects are included, first a system of equations is derived in the form of eight partial differential equations involving eight unknowns in such a manner that the system of equations contains no derivatives of the material parameters, thickness, or principal radii of curvature. The absence of the derivatives in the coefficients of the differential equations permits the calculation of the coefficients at a point without regard to the values of the shell parameters at preceding or following points. Then, assuming separability with respect to the independent variables, the desired system of eight first-order ordinary differential equations is obtained which together with the boundary conditions on two edges of the shell constitute a two-point boundary-value problem. The derived system of equations is applicable to rotationally symmetric shells with arbitrary meridional variations (including discontinuities) in Young's modulus, Poisson's ratio, radii of curvature, thickness, and coefficient of thermal expansion. While such a system of equations is derived in this paper only for one version of the classical theory of shells, it can be derived in the same way for all other consistent linear bending theories of shells, including those which account for the dynamic effects, transverse shear deformation, nonhomogeneity, and anisotropy.

Finally, with the use of the method and the equations given in this paper, stresses and displacements are calculated in a thin-walled torus subjected to internal pressure. The solution shows that the meridional membrane stress is almost identical to that predicted by membrane theory, but that the bending stresses even for a relatively thin torus may not be negligible.

Geometry and Basic Equations

The position of a point of a shell of revolution is given by the coordinates θ, ϕ, ζ measured along the triplet of unit vectors t_θ, t_ϕ, n, respectively, as shown in Fig. 1. The shape of the shell is determined by specifying the two principal radii of curvature R_ϕ, R_θ of the middle surface as functions of ϕ. Instead of R_θ, it is convenient to use the distance r from a point on the middle surface to the z-axis; from Fig. 1 it follows that

$$r = R_\theta \sin \phi \tag{1}$$

If the generating curve of the middle surface is given by $r = r(z)$ then

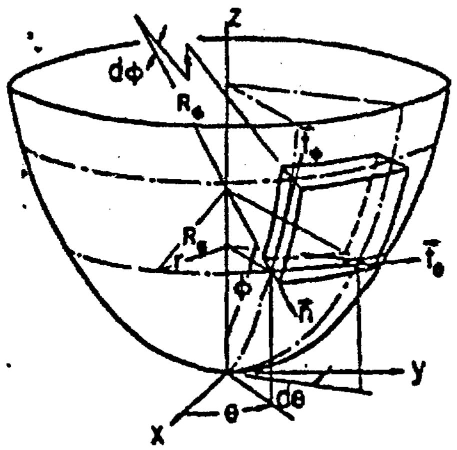

Fig. 1 Element of a shell of revolution

$$R_\phi = -\left[1+\left(\frac{dr}{dz}\right)^2\right]^{3/2} \Big/ \frac{d^2r}{dz^2}$$
$$R_\theta = r\left[1+\left(\frac{dr}{dz}\right)^2\right]^{1/2} \tag{2}$$

The following analysis requires frequent differentiation of r (or R_θ) with respect to ϕ, and it is convenient to express this derivative by the Codazzi relation

$$\frac{dr}{d\phi} = R_\phi \cos\phi \tag{3}$$

The displacement components of the middle surface of the shell and the rotations of the normal are defined by the expression of the displacement vector U of the form

$$\mathbf{U} = (u_\phi + \zeta\beta_\phi)\mathbf{t}_\phi + (u_\theta + \zeta\beta_\theta)\mathbf{t}_\theta + w\mathbf{n} \tag{4a}$$

The shell is subjected to the mechanical load vector $\mathbf{p}$, which is measured as force per unit area of the middle surface and written as

$$\mathbf{p} = p_\phi\mathbf{t}_\phi + p_\theta\mathbf{t}_\theta + p\mathbf{n} \tag{4b}$$

and the moment vector $\mathbf{m}$, which is measured as moment per unit area and given by

$$\mathbf{m} = -m_\theta\mathbf{t}_\phi + m_\phi\mathbf{t}_\theta \tag{4c}$$

With reference to Fig. 1, equations (4) serve the purpose for establishing the positive directions of the components of the displacement and mechanical load vectors.

The temperature distribution in the shell caused by some thermal loads is accounted for in the usual manner by means of the integrated temperature effect of the form

$$T_0(\phi,\theta) = \frac{1}{h}\int_{-\frac{h}{2}}^{\frac{h}{2}} T(\phi,\theta,\zeta)d\zeta \tag{5a}$$

$$T_1(\phi,\theta) = \frac{12}{h^3}\int_{-\frac{h}{2}}^{\frac{h}{2}} \zeta T(\phi,\theta,\zeta)d\zeta \tag{5b}$$

The derivation of a new set of equations carried out in the next section is based on a linear classical theory of shells given by Reissner [13]. When referred to arbitrary shells of revolution, the governing system of equations of [13] can be written in the following form. Equations of equilibrium:

$$N_{\theta,\theta} + \frac{r}{R_\phi}N_{\phi\theta,\phi} + 2\cos\phi\, N_{\theta\phi} + Q_\theta\sin\phi + rp_\theta = 0 \tag{6a}$$

$$N_{\theta\phi,\theta} + \frac{r}{R_\phi}N_{\phi,\phi} + (N_\phi - N_\theta)\cos\phi + \frac{r}{R_\phi}Q_\phi + rp_\phi = 0 \tag{6b}$$

$$Q_{\theta,\theta} + \frac{r}{R_\phi}Q_{\phi,\phi} + Q_\phi\cos\phi - N_\theta\sin\phi - \frac{r}{R_\phi}N_\phi + rp = 0 \tag{7}$$

$$M_{\theta,\theta} + \frac{r}{R_\phi}M_{\phi\theta,\phi} + 2\cos\phi\, M_{\theta\phi} - rQ_\theta + rm_\theta = 0 \tag{8a}$$

$$M_{\theta\phi,\theta} + \frac{r}{R_\phi}M_{\phi,\phi} + (M_\phi - M_\theta)\cos\phi - rQ_\phi + rm_\phi = 0 \tag{8b}$$

Stress-strain relations:

$$N_\theta = K(\epsilon_\theta + \nu\epsilon_\phi) - (1+\nu)\alpha KT_0 \tag{9a}$$

$$N_\phi = K(\epsilon_\phi + \nu\epsilon_\theta) - (1+\nu)\alpha KT_0 \tag{9b}$$

$$N_{\theta\phi} = N_{\phi\theta} = (1-\nu)K\epsilon_{\theta\phi} \tag{9c}$$

$$M_\theta = D(\kappa_\theta + \nu\kappa_\phi) - (1+\nu)\alpha DT_1 \tag{10a}$$

$$M_\phi = D(\kappa_\phi + \nu\kappa_\theta) - (1+\nu)\alpha DT_1 \tag{10b}$$

$$M_{\theta\phi} = M_{\phi\theta} = (1-\nu)D\kappa_{\theta\phi} \tag{10c}$$

Strain-displacement relations:

$$\epsilon_\theta = \frac{1}{r}(u_{\theta,\theta} + u_\phi\cos\phi + w\sin\phi) \tag{11a}$$

$$\epsilon_\phi = \frac{1}{R_\phi}(u_{\phi,\phi} + w) \tag{11b}$$

$$2\epsilon_{\theta\phi} = \frac{1}{r}(u_{\phi,\theta} - u_\theta\cos\phi) + \frac{1}{R_\phi}u_{\theta,\phi} \tag{11c}$$

$$\kappa_\theta = \frac{1}{r}(\beta_{\theta,\theta} + \beta_\phi\cos\phi) \tag{12a}$$

$$\kappa_\phi = \frac{1}{R_\phi}\beta_{\phi,\phi} \tag{12b}$$

$$2\kappa_{\theta\phi} = \frac{1}{r}(\beta_{\phi,\theta} - \beta_\theta\cos\phi) + \frac{1}{R_\phi}\beta_{\theta,\phi} \tag{12c}$$

$$\beta_\theta = -\frac{1}{r}w_{,\theta} + \frac{\sin\phi}{r}u_\theta \tag{13a}$$

$$\beta_\phi = -\frac{1}{R_\phi}w_{,\phi} + \frac{1}{R_\phi}u_\phi \tag{13b}$$

The positive directions of the stress resultants in the foregoing equations are the same as the corresponding stresses on the edge of the shell. The definitions of the stress resultants are found in [13].

The order of the system of equations (6)–(13) is eight with respect to ϕ, and consequently it is possible to reduce (6)–(13) to eight first-order differential equations which involve eight unknowns. If the eight unknowns are those quantities which enter into the natural boundary conditions at the edge ϕ = const, then the boundary-value problem of a rotationally symmetric shell can be completely stated in terms of these unknowns. For this reason, the eight differential equations, derived in the following sections, and the eight unknowns are called the fundamental set of equations and the fundamental variables, respectively.

Derivation of Fundamental Set of Equations

According to the classical theory of shells, the quantities which appear in the natural boundary conditions on a rotationally symmetric edge of a shell of revolution include the effective shear resultants N and Q defined by

8th order syst.

$$N = N_{\phi\theta} + \frac{\sin\phi}{r}M_{\phi\theta} \tag{14a}$$

8 B.C.

$$Q = Q_\phi + \frac{1}{r}M_{\phi\theta,\theta} \tag{14b}$$

4 on each bd.

Thus, the fundamental variables, which are consistent with the theory of [13], are the four generalized displacements w, u_ϕ, u_θ, β_ϕ, and the four generalized forces Q, N_ϕ, N, and M_ϕ.

In the derivation of the fundamental equations, it is more convenient to employ the distance s, measured along the meridian of the shell, rather than the angular coordinate ϕ. However, after the equations are derived, the problem can again be easily formulated in terms of ϕ by means of the relation

$$\frac{1}{R_\phi}\frac{\partial}{\partial\phi} = \frac{\partial}{\partial s}$$

As a preliminary step, it is necessary to express N_θ, M_θ, $M_{\theta\phi}$ in terms of the fundamental variables. From (9a) it follows that

$$N_\theta = \nu N_\phi + K\frac{1-\nu^2}{r}(w \sin\phi + u_{\theta,\theta} + u_\phi \cos\phi) - \alpha K(1-\nu^2)T_0 \quad (15)$$

and from (10a) that

$$M_\theta = \nu M_\phi + D\frac{1-\nu^2}{r}\left(-\frac{1}{r}w_{,\theta\theta} + \frac{\sin\phi}{r}u_{\theta,\theta} + \beta_\phi \cos\phi\right) - \alpha D(1-\nu^2)T_1 \quad (16)$$

Elimination of $u_{\theta,s}$ and $w_{,s\theta}$ from equation (12d) leads to an expression for $M_{\theta\phi}$ in the form

$$M_{\theta\phi} = LD\,\frac{1-\nu}{2r}\left[2\beta_{\phi,\theta} + \frac{2\cos\phi}{r}w_{,\theta} + Hu_\theta\cos\phi - Ju_{\phi,\theta}\right] + \frac{LD}{K}\frac{\sin\phi}{r}N \quad (17)$$

where

$$L = \frac{1}{1+\dfrac{\sin^2\phi}{r^2}\dfrac{D}{K}}$$

In the derivation of the four equations of the fundamental set which involve the derivatives of the stress resultants with respect to s, the use of (14) is essential. Elimination of Q_θ from (6a) and (8a) by means of (14a) leads to

$$N_{,s} = H\frac{\cos\phi}{r}M_{\theta\phi} - \frac{2\cos\phi}{r}N - \frac{1}{r}N_{\theta,\theta} - \frac{\sin\phi}{r^2}M_{\theta,\theta} - p_\theta - \frac{\sin\phi}{r}m_\theta \quad (18)$$

Similarly, elimination of Q_θ from (7) and (8a) gives

$$Q_{,s} = -\frac{2\cos\phi}{r^2}M_{\theta\phi,\theta} - \frac{\cos\phi}{r}Q + \frac{\sin\phi}{r}N_\theta + \frac{1}{R_\phi}N_\phi - \frac{1}{r^2}M_{\theta,\theta\theta} - p - \frac{1}{r}m_{\theta,\theta} \quad (19)$$

Solving (6b) from $N_{\phi,s}$ there results

$$N_{\phi,s} = -\frac{1}{r}N_{,\theta} + \frac{1}{r}JM_{\theta\phi,\theta} + \frac{\cos\phi}{r}(N_\theta - N_\phi) - \frac{1}{R_\phi}Q - p_\phi \quad (20)$$

and it follows from (8b) that

$$M_{\phi,s} = -\frac{2}{r}M_{\theta\phi,\theta} + \frac{\cos\phi}{r}(M_\theta - M_\phi) + Q - m_\phi \quad (21)$$

Wherever necessary, $N_{\theta\phi}$ and Q_ϕ were eliminated with the use of (14).

The fundamental set of equations consists of (18)–(21), where N_θ, M_θ, $M_{\theta\phi}$ can be replaced directly in terms of the fundamental variables by means of (15)–(17), and four additional equations involving the derivatives of w, u_ϕ, u_θ, β_ϕ with respect to s, which are obtained from (13b), (11c), (11b), (12b), respectively. Finally, the system of eight differential equations that governs the deformation of a shell of revolution can be expressed in terms of the eight fundamental variables and written as

$$w_{,s} = \frac{1}{R_\phi}u_\phi - \beta_\phi \quad (22a)$$

$$u_{\phi,s} = -Uw - \frac{\nu\cos\phi}{r}u_\phi - \frac{\nu}{r}u_{\theta,\theta} + \frac{1}{K}N_\phi + \alpha(1+\nu)T_0 \quad (22b)$$

$$u_{\theta,s} = -\frac{LD\sin 2\phi}{Kr^4}w_{,\theta} - \frac{1}{r}\left(1 - \frac{LDJ\sin\phi}{Kr}\right)u_{\phi,\theta} + \frac{\cos\phi}{r}\left(1 - \frac{LDH\sin\phi}{Kr}\right)u_\theta - \frac{2LD\sin\phi}{Kr^2}\beta_{\phi,\theta} + \frac{2}{(1-\nu)K}\left(1 - \frac{LD\sin^2\phi}{Kr^2}\right)N \quad (22c)$$

$$\beta_{\phi,s} = \frac{\nu}{r^2}w_{,\theta\theta} - \frac{\nu\sin\phi}{r^2}u_{\theta,\theta} - \frac{\nu\cos\phi}{r}\beta_\phi + \frac{1}{D}M_\phi + \alpha(1+\nu)T_1 \quad (22d)$$

$$\begin{aligned}Q_{,s} = {} & \frac{1-\nu}{r^4}\left[D(1+\nu)\frac{\partial^4}{\partial\theta^4} - 2LD\cos^2\phi\frac{\partial^2}{\partial\theta^2} + (1+\nu)Kr^2\sin^2\phi\right]w + (1-\nu)\frac{\cos\phi}{r^2}\left[\frac{1}{r}LDJ\frac{\partial^2}{\partial\theta^2} + (1+\nu)K\sin\phi\right]u_\phi \\ & - \frac{1-\nu}{r^2}\left[\frac{1}{r}LDH\cos^2\phi - (1+\nu)K\sin\phi + D(1+\nu)\frac{\sin\phi}{r^2}\frac{\partial^2}{\partial\theta^2}\right]u_{\theta,\theta} \\ & - D(1-\nu)\frac{\cos\phi}{r^2}(1+\nu+2L)\beta_{\phi,\theta\theta} + UN_\phi - \frac{\nu}{r^2}M_{\phi,\theta\theta} - \frac{LD\sin 2\phi}{Kr^4}N_{,\theta} - \frac{\cos\phi}{r}Q - p - \frac{1}{r}m_{\theta,\theta} \\ & - \alpha(1-\nu^2)\frac{1}{r}\left(K\sin\phi\,T_0 - \frac{1}{r}DT_{1,\theta\theta}\right) \quad (22e)\end{aligned}$$

$$\begin{aligned}N_{\phi,s} = {} & (1-\nu)\frac{\cos\phi}{r^2}\left[\frac{1}{r}LDJ\frac{\partial^2}{\partial\theta^2} + (1+\nu)K\sin\phi\right]w + \frac{1-\nu}{r^2}\left[(1+\nu)K\cos^2\phi - \frac{1}{2}LDJ^2\frac{\partial^2}{\partial\theta^2}\right]u_\phi \\ & + (1-\nu)\frac{\cos\phi}{r^2}\left[\frac{1}{2}LDJH + (1+\nu)K\right]u_{\theta,\theta} + JLD\frac{1-\nu}{r^2}\beta_{\phi,\theta\theta} \\ & - \frac{1}{R_\phi}Q - (1-\nu)\frac{\cos\phi}{r}N_\phi - \frac{1}{r}\left(1 - \frac{LDJ\sin\phi}{Kr}\right)N_{,\theta} - p_\phi - \alpha(1-\nu^2)K\frac{\cos\phi}{r}T_0 \quad (22f)\end{aligned}$$

$$\begin{aligned}N_{,s} = {} & \frac{1-\nu}{r^2}\left[HLD\frac{\cos^2\phi}{r} - (1+\nu)K\sin\phi + (1+\nu)D\frac{\sin\phi}{r^2}\frac{\partial^2}{\partial\theta^2}\right]w_{,\theta} \\ & - (1-\nu)\frac{\cos\phi}{r^2}\left[\frac{1}{2}LDJH + (1+\nu)K\right]u_{\phi,\theta} \\ & + \frac{1-\nu}{r^2}\left[\frac{1}{2}LDH^2\cos^2\phi - (1+\nu)\left(K + \frac{D\sin^2\phi}{r^2}\right)\frac{\partial^2}{\partial\theta^2}\right]u_\theta \\ & - D(1-\nu)\frac{\cos\phi}{r^2}\left[(1+\nu)\frac{\sin\phi}{r} - LH\right]\beta_{\phi,\theta} - \frac{\nu}{r}N_{\phi,\theta}\end{aligned}$$

$$
-\frac{\cos\phi}{r}\left(2-\frac{LDH\sin\phi}{Kr}\right)N-\frac{\nu\sin\phi}{r^2}M_{\phi,\theta}-p_\theta-\frac{\sin\phi}{r}m_\theta
$$

$$
+\alpha(1-\nu^2)\frac{1}{r}\left(KT_{0,\theta}+D\frac{\sin\phi}{r}T_{1,\theta}\right) \quad (22g)
$$

$$
M_{\phi,s}=-(1-\nu)D\frac{\cos\phi}{r^2}(1+\nu+2L)w_{,\theta\theta}+LDJ\frac{1-\nu}{r^2}u_{\phi,\theta\theta}
$$

$$
+D(1-\nu)\frac{\cos\phi}{r^2}\left[(1+\nu)\frac{\sin\phi}{r}-HL\right]u_{\theta,\theta}
$$

$$
+D\frac{1-\nu}{r^2}\left[(1+\nu)\cos^2\phi-2L\frac{\partial^2}{\partial\theta^2}\right]\beta_\phi+Q-\frac{2LD\sin\phi}{Kr^2}N_{,\theta}
$$

$$
-(1-\nu)\frac{\cos\phi}{r}M_\phi-m_\phi-\alpha(1-\nu^2)D\frac{\cos\phi}{r}T_1 \quad (22h)
$$

Equations (22), (14), and (15) to (17) determine all unknown variables except Q_θ which can be found from (8e) and written in the form

$$
Q_\theta=\frac{1}{r}M_{\theta,\theta}+M_{\phi\theta,s}+\frac{2\cos\phi}{r}M_{\phi\theta}+m_\theta \quad (23)
$$

By calculating $M_{\phi\theta,s}$ from (17) and making use of (16), it is possible to express Q_θ directly in terms of the fundamental variables. This expression is lengthy and contains derivatives with respect to s of the shell parameters. Since Q_θ does not enter into any boundary conditions on the edge s = const, it is preferable to calculate Q_θ as the last unknown directly from (23). The derivative of $M_{\phi\theta}$ can be easily obtained by numerical differentiation.

The procedure for the derivation of an equivalent set of equations for other linear classical theories of isotropic shells is identical to that given before. For general anisotropic and/or nonhomogeneous shells of revolution with rotationally symmetric properties, the fundamental set of equations is derived in the same way as (22) except that (9) and (10) must be replaced by the appropriate stress-strain relations given, for example, by Ambartsumyan [14]. Otherwise, the derivation is straightforward. For the improved theory of shells, such as the one given by Naghdi [15], in which the effects of transverse-shear deformation are accounted for, the following ten fundamental variables are required: w, u_ϕ, u_θ, β_ϕ, β_θ, Q_ϕ, N_ϕ, $N_{\phi\theta}$, M_ϕ, $M_{\phi\theta}$. Since now Q_ϕ and Q_θ appear in (13), the elimination of Q_θ from (6e), (7), (8e), is done by means of (13e). The required equations for the derivatives of the generalized forces are obtained directly from the five equations of equilibrium (6), (7), (8). The remaining five equations are derived by following a procedure similar to that of the foregoing.

Fundamental Equations for Separable Solutions

For shells of revolution which consist of complete latitude circles, the surface loads are periodic with respect to θ with a period of 2π, and they can be assumed to be of the form

$$
\{p_\phi, p, m_\phi\}=\{p_{\phi n}, p_n, m_{\phi n}\}\begin{Bmatrix}\cos n\theta\\ \sin n\theta\end{Bmatrix} \quad (24a)
$$

$$
\{T_0, T_1\}=\{T_{0n}, T_{1n}\}\begin{Bmatrix}\cos n\theta\\ \sin n\theta\end{Bmatrix} \quad (24b)
$$

$$
\{p_\theta, m_\theta\}=\{p_{\theta n}, m_{\theta n}\}\begin{Bmatrix}\sin n\theta\\ \cos n\theta\end{Bmatrix} \quad (24c)
$$

where the variables with subscripts n depend only on s, and each integral value of n in (24) can be regarded as one Fourier component in a general Fourier series expansion of arbitrary periodic surface loads.

Separable solutions of (22), corresponding to the value of n in (24), are then obtained in the form

$$
\{w, u_\phi, \beta_\phi\}=\{w_n, u_{\phi n}, \beta_{\phi n}\}\begin{Bmatrix}\cos n\theta\\ \sin n\theta\end{Bmatrix} \quad (25a)
$$

$$
\{N_\phi, M_\phi, Q\}=\{N_{\phi n}, M_{\phi n}, Q_n\}\begin{Bmatrix}\cos n\theta\\ \sin n\theta\end{Bmatrix} \quad (25b)
$$

$$
\{u_\theta, N\}=\{u_{\theta n}, N_n\}\begin{Bmatrix}\sin n\theta\\ \cos n\theta\end{Bmatrix} \quad (25c)
$$

The s-dependent coefficients with subscripts n on the right-hand side of (25) are governed by a system of equations which is obtained from (22) and, after using the assumption that the shell is thin,[4] can be written as

$$
w_{n,s}=\frac{1}{R_\phi}u_{\phi n}-\beta_{\phi n} \quad (26a)
$$

$$
u_{\phi n,s}=-Uw_n-\frac{\nu\cos\phi}{r}u_{\phi n}\mp\frac{\nu n}{r}u_{\theta n}
$$

$$
+\frac{1}{K}N_{\phi n}+\alpha(1+\nu)T_{0n} \quad (26b)
$$

$$
u_{\theta n,s}=\pm\frac{D\sin 2\phi}{Kr^3}w_n\pm\frac{n}{r}u_{\phi n}+\frac{\cos\phi}{r}u_{\theta n}
$$

$$
\pm\frac{2Dn\sin\phi}{Kr^3}\beta_{\phi n}+\frac{2}{(1-\nu)K}N \quad (26c)
$$

$$
\beta_{\phi n,s}=-\frac{\nu n^2}{r^2}w_n\mp\frac{\nu n\sin\phi}{r^2}u_{\theta n}-\frac{\nu\cos\phi}{r}\beta_{\phi n}
$$

$$
+\frac{1}{D}M_{\phi n}+\alpha(1+\nu)T_{1n} \quad (26d)
$$

$$
Q_{n,s}=\frac{1-\nu}{r^4}[(1+\nu)n^4D
$$

$$
+2n^2D\cos^2\phi+(1+\nu)Kr^2\sin^2\phi]w_n
$$

$$
+(1-\nu)\frac{\cos\phi}{r^2}\left[(1+\nu)K\sin\phi-\frac{n^2}{r}DJ\right]u_{\phi n}
$$

$$
\pm\frac{(1-\nu)n}{r^2}\left[(1+\nu)D\frac{n^2}{r^2}\sin\phi+(1+\nu)K\sin\phi\right]u_{\theta n}
$$

$$
+n^2(1-\nu)(3+\nu)D\frac{\cos\phi}{r^3}\beta_{\phi n}-\frac{\cos\phi}{r}Q_n+UN_{\phi n}
$$

$$
\mp\frac{nD\sin 2\phi}{Kr^4}N_n+\frac{\nu n^2}{r^2}M_{\phi n}-p_n\mp\frac{n}{r}m_{\theta n}
$$

$$
-\alpha(1-\nu^2)\frac{1}{r}\left(K\sin\phi\,T_{0n}+D\frac{n^2}{r}T_{1n}\right) \quad (26e)
$$

$$
N_{\phi n,s}=(1-\nu)\frac{\cos\phi}{r^2}\left[(1+\nu)K\sin\phi-\frac{n^2}{r}JD\right]w_n
$$

$$
+\frac{1-\nu}{r^2}\left[(1+\nu)K\cos^2\phi+\frac{n^2}{2}DJ^2\right]u_{\phi n}
$$

$$
\pm\frac{(1-\nu^2)nK\cos\phi}{r^2}u_{\theta n}-\frac{n^2(1-\nu)}{r^2}DJ\beta_{\phi n}
$$

$$
-\frac{1}{R_\phi}Q_n-(1-\nu)\frac{\cos\phi}{r}N_{\phi n}\mp\frac{n}{r}N_n
$$

[4] In the derivation of the system of equations (6)–(18) the assumption is made that the shell is sufficiently thin, so that $1+h^2/12R^2\approx 1$, where R denotes the minimum principal radius of curvature. This same approximation is used to obtain the following equations from (22).

$$- p_{\phi n} - \alpha(1 - \nu^2)K \frac{\cos\phi}{r} T_{1n} \quad (26f)$$

$$N_{\phi\theta n} = \pm \frac{n(1-\nu)}{r^2}\left[(1+\nu)D\frac{n^2}{r^2}\sin\phi + (1+\nu)K\sin\phi\right] w_n$$
$$\pm \frac{(1-\nu^2)nK\cos\phi}{r^2} u_{\phi n} + \frac{n^2(1-\nu^2)K}{r^2} u_{\theta n}$$
$$\pm nD\frac{1-\nu}{r^2}\cos\phi\left[(1+\nu)\frac{\sin\phi}{r} - H\right]\beta_{\phi n}$$
$$\pm n\frac{\nu}{r} N_{\phi n} - \frac{2\cos\phi}{r} N_n$$
$$\pm \frac{\nu n \sin\phi}{r^2} M_{\phi n} - p_{\theta n} - \frac{\sin\phi}{r} m_{\theta n}$$
$$\mp \alpha(1-\nu^2)\frac{1}{r}\left(KT_{1n} + D\frac{\sin\phi}{r}T_{2n}\right) \quad (26g)$$

$$M_{\phi\phi n} = n^2(1-\nu)(3+\nu)D\frac{\cos\phi}{r^3} w_n - n^2\frac{1-\nu}{r^2} JDu_{\phi n}$$
$$\pm nD\frac{1-\nu}{r^2}\cos\phi\left[(1+\nu)\frac{\sin\phi}{r} - H\right] u_{\theta n}$$
$$+ D\frac{1-\nu}{r^2}[(1+\nu)\cos^2\phi + 2n^2]\beta_{\phi n} + Q \mp \frac{2nD\sin\phi}{Kr^3} N_n$$
$$- (1-\nu)\frac{\cos\phi}{r} M_{\phi n} - m_{\phi n} - \alpha(1-\nu^2)D\frac{\cos\phi}{r} T_{2n} \quad (26h)$$

The double signs in (26) correspond to the top or bottom trigonometric function employed in (24) and (25).

The quantities which are not included in the fundamental variables can be expressed by means of separation of variables by

$$\{N_\theta, M_\theta, Q_\phi\} = \{N_{\theta n}, M_{\theta n}, Q_{\phi n}\}\begin{Bmatrix}\cos n\theta \\ \sin n\theta\end{Bmatrix} \quad (27a)$$

$$\{N_{\theta\phi}, M_{\theta\phi}, Q_\theta\} = \{N_{\theta\phi n}, M_{\theta\phi n}, Q_{\theta n}\}\begin{Bmatrix}\sin n\theta \\ \cos n\theta\end{Bmatrix} \quad (27b)$$

where the ϕ-dependent coefficients with subscripts n must satisfy a set of equations obtained from equations (14)–(17) and (23) in the form

$$N_{\theta n} = \nu N_{\phi n} + (1-\nu^2)\frac{K}{r^2}(w_n \sin\phi + u_{\phi n}\cos\phi \pm n u_{\theta n})$$
$$- \alpha(1-\nu^2)KT_{1n} \quad (28a)$$

$$M_{\theta n} = \nu M_{\phi n} + (1-\nu^2)\frac{D}{r}\left(\frac{n^2}{r}w_n + \beta_{\phi n}\cos\phi\right.$$
$$\left.\pm n\frac{\sin\phi}{r}u_{\theta n}\right) - \alpha(1-\nu^2)DT_{2n} \quad (28b)$$

$$M_{\theta\phi n} = D\frac{1-\nu}{2r}\left(\mp\frac{2n\cos\phi}{r}w_n \pm nJu_{\phi n}\right.$$
$$\left.+ H\cos\phi u_{\theta n} \mp 2n\beta_{\phi n}\right) + \frac{D}{K}\frac{\sin\phi}{r}N_n \quad (28c)$$

$$Q_{\theta n} = \mp\frac{n}{r}M_{\theta n} + M_{\theta\phi n,\phi} + \frac{2\cos\phi}{r}M_{\theta\phi n} + m_{\theta n} \quad (28d)$$

$$N_{\theta\phi n} = N_n - \frac{\sin\phi}{r}M_{\theta\phi n} \quad (28e)$$

$$Q_{\phi n} = Q_n \mp \frac{n}{r}M_{\theta\phi n} \quad (28f)$$

The double signs again correspond to the top or bottom trigonometric function employed in (24), (25), and (27).

The remainder of this paper is concerned with the solution of the system of equations (26), subject to the boundary conditions on two edges s = const. It should be noted that after the expansion of the loads in Fourier series, the solution to (26) is obtained for each integral value of n separately, and then the solutions are superimposed to form a Fourier series expansion for the unknown variables.

Reduction to Initial Value Problems

This section is concerned with the reduction of a two-point boundary-value problem governed by

$$\frac{dy(x)}{dx} = A(x)y(x) + B(x) \quad (29a)$$

to a series of initial-value problems. In (29a), $y(x)$ is an $(m, 1)$ matrix which represents m unknown functions; x is the independent variable; $A(x)$ denotes the (m, m) coefficient matrix; and $B(x)$ is the $(m, 1)$ matrix of the nonhomogeneous terms. The elements of $A(x)$ and $B(x)$ are given piecewise continuous functions of x. The object is to determine $y(x)$ in the interval $a \leq x \leq b$ subject to m boundary conditions stated in terms of linear combinations of $y(a)$ and $y(b)$ in the form

$$F_a y(a) + F_b y(b) = G \quad (29b)$$

where F_a, F_b are (m, m) matrices and G is an $(m, 1)$ matrix, which are known from the statement of the boundary conditions of the problem. It should be clear that the governing system of equations (26) derived in the preceding section is stated in the form of (29a), and that the appropriate boundary conditions for a shell of revolution can be expressed in the form of (29b).

Let the complete solution of (29a) be written as

$$y(x) = Y(x)C + Z(x) \quad (30)$$

where the $(m, 1)$ matrix C represents m arbitrary constants, and $Y(x)$ is an (m, m) and $Z(x)$ an $(m, 1)$ matrix which are defined as the homogeneous and particular solutions of (29a) in the form

$$\frac{dY(x)}{dx} = A(x)Y(x) \quad (31a)$$

$$\frac{dZ(x)}{dx} = A(x)Z(x) + B(x) \quad (31b)$$

The initial conditions for determining $Y(x)$ and $Z(x)$ are

$$Y(a) = I \quad (32a)$$

$$Z(a) = 0 \quad (32b)$$

where I is the unit matrix.

Evaluation of (30) at $x = a$ leads at once, in view of (32a, b), to $C = y(a)$, and then (30) at $x = b$ can be written as

$$y(b) = Y(b)y(a) + Z(b) \quad (33)$$

Together with (29b), equation (33) constitutes a system of $2m$ linear algebraic equations from which the $2m$ unknowns, $y(a)$ and $y(b)$, are determined. Once $y(a)$ is known, the solution at any value of x is obtained from (30) provided that the values of $Y(x)$ and $Z(x)$ at that particular x are stored. This completes the reduction of a two-point boundary-value problem defined by (29) to $m + 1$ initial-value problems given by (31, 32).

As stated in the introduction, the solution for shells obtained by means of this procedure suffers a complete loss of accuracy at some critical length of the interval. The reason for this phenomenon can be seen clearly from (33). When the initial-value problems defined by (31, 32) are solved with the use of the equa-

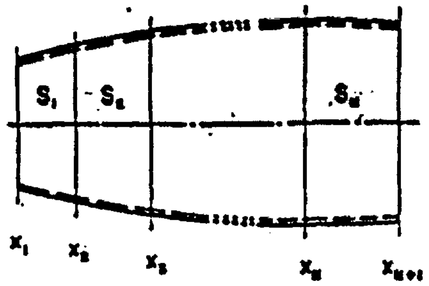

Fig. 2 Notation for division of total interval into segments

tions (26) for shells of revolution, it is observed that the elements of $Y(x)$ and $Z(x)$ increase in magnitude in such a way that if the length is increased by any factor n, then these solutions increase in magnitude approximately exponentially with n.

Consider, for example, the axisymmetric case when the deformation in the shell is caused by some prescribed edge conditions at $x = a$, say, by $M_\phi(a) = 1$ and $N_\phi(a) = Q(a) = 0$. It is reasonable to expect that the corresponding solutions at $x = b$ become smaller and smaller when the interval (a, b) is increased in length. The connection between $y(b)$ and $y(a)$ is given by the matrix equation (33) with the following magnitudes of the elements: $y(b)$-small, $Y(b)$-large, $y(a)$-unity. Clearly, the only way that the matrix product of (33) can give small values of $y(b)$ is that a number of significant digits of the large values of $Y(b)$ subtract out. When the length of the interval is increased, $Y(b)$ increase, while $y(b)$ decrease, and invariably all accuracy is lost at some critical length because all significant digits of $Y(b)$ in (33) are lost. This simple example serves as an illustration for the loss of accuracy encountered in the analysis of shells if the foregoing reduction technique is employed.

A convenient length factor, defined by

$$\beta = l[3(1 - \nu^2)]^{1/4}/(Rh)^{1/2} \qquad (34)$$

where l is the length of the meridian of the shell and R is a minimum radius of curvature, can be used for an approximate estimate of the critical length of the shell. If the solutions $Y(x)$ and $Z(x)$ are obtained with a six-digit accuracy, then the foregoing procedure gives good results in the range $\beta \leq 3 - 5$.

However, the loss of accuracy of the solution can be avoided and shells of revolution with much larger values of β can be analyzed by means of the direct integration technique if the multisegment method given in the next section is employed.

Multisegment Method of Integration

Let the shell be divided into M-segments (denoted by S_i, where $i = 1, 2, \ldots, M$) of arbitrary length in each of which $\beta \leq 3$. Denote the coordinates of the ends of the segments by $x = x_i$, where the left-hand edge of the shell is at $x = x_1$ and the right-hand edge is at $x = x_{M+1}$, as shown in Fig. 2. In analogy to (30), the solution in the total interval $x_1 \leq x \leq x_{M+1}$ now can be written as

$$y(x) = Y_i(x)y(x_i) + Z_i(x) \qquad (35)$$

where $Y_i(x)$ and $Z_i(x)$ denote the matrices corresponding to $Y(x)$ and $Z(x)$ in each segment $S_i(x_i \leq x \leq x_{i+1})$ and are given by

$$\frac{dY_i(x)}{dx} = A(x)Y_i(x) \qquad (36a)$$

$$Y_i(x_i) = I \qquad (36b)$$

$$\frac{dZ_i(x)}{dx} = A(x)Z_i(x) + B(x) \qquad (36c)$$

$$Z_i(x_i) = 0 \qquad (36d)$$

Requiring continuity of all elements of $y(x)$ at the points x_i, $i = 2, 3, \ldots, M + 1$, the following M-matrix equations are obtained from (35):

$$y(x_{i+1}) = Y_i(x_{i+1})y(x_i) + Z_i(x_{i+1}) \qquad (37)$$

where $i = 1, 2, \ldots, M$. Equations (37) involve $M + 1$ unknown $(m, 1)$ matrices: $y(x_i)$, $i = 1, 2, \ldots, M + 1$. However, if the quantities prescribed at the edges of the shell are the fundamental variables, then the total number of unknowns is reduced by m, because $m/2$ elements of $y(x_1)$ and $m/2$ elements of $y(x_{M+1})$ are known. The same is true if the boundary conditions are stated in terms of linear combinations of the fundamental variables in the form of (29b). In this case, $y(x_1)$ and $y(x_{M+1})$ should be premultiplied by nonsingular (m, m) transformation matrices F_1 and F_{M+1}, respectively, so that the elements of the products contain the quantities prescribed at each edge. After eliminating $y(x_1)$ and $y(x_{M+1})$ from (37) by means of these products, it is concluded that (37) will retain its form if, after integration and before substitution into (37), $Y_1(x_2)$ is postmultiplied by F_1^{-1}, while $Y_M(x_{M+1})$ and $Z_M(x_{M+1})$ are premultiplied by F_{M+1}. In the following, it will be regarded that this transformation is carried out and that $y(x_1)$ and $y(x_{M+1})$ contain among their elements those quantities which are prescribed at $x = x_1$ and $x = x_{M+1}$, respectively.

Thus for all boundary conditions in the form of (29b), the system of M matrix equations (37) involves exactly M times m unknowns, and formally it can be solved by any method which is applicable to a large number of equations. However, the success of the procedure given in this paper lies in the application of Gaussian elimination directly on the matrix equations (37).

First a rearrangement of elements is performed. Since those $m/2$ elements of $y(x_1)$ and $y(x_{M+1})$ which are known through the boundary conditions can be any $m/2$ of the m-elements, it is necessary to rearrange the rows of $y(x_1)$ and $y(x_{M+1})$ so that the known elements are separated from the unknown elements. It is assumed here that the first $m/2$ elements of $y(x_1)$, denoted by $y_1(x_1)$, are known and that the last $m/2$ elements, denoted by $y_2(x_1)$, are unknown. On the other hand, $y_1(x_{M+1})$ are the unknown and $y_2(x_{M+1})$ are the known elements of $y(x_{M+1})$. Since the order of the variables in the column matrix $y(x)$ is arbitrary, it should be emphasized that this separation of elements does not involve any restriction on the boundary conditions, and that any natural boundary condition in the form of (29b) can be prescribed at each edge. The separation is achieved by a simple rearrangement of the columns of $Y_1(x_2)$ and the rows of $Y_M(x_{M+1})$ and $Z_M(x_{M+1})$ after integrating the initial-value problems defined by (36) to the ends of the segments S_1 and S_M and multiplying by F_1^{-1} and F_{M+1} as stated in the foregoing.

Once it is established which parts of $y(x_1)$ and $y(x_{M+1})$ are known, the continuity conditions (37) are rewritten as a partitioned matrix product of the form

$$\begin{bmatrix} y_1(x_{i+1}) \\ \hdashline y_2(x_{i+1}) \end{bmatrix} = \begin{bmatrix} Y_i^1(x_{i+1}) & Y_i^2(x_{i+1}) \\ \hdashline Y_i^3(x_{i+1}) & Y_i^4(x_{i+1}) \end{bmatrix} \begin{bmatrix} y_1(x_i) \\ \hdashline y_2(x_i) \end{bmatrix} + \begin{bmatrix} Z_i^1(x_{i+1}) \\ \hdashline Z_i^2(x_{i+1}) \end{bmatrix} \qquad (38)$$

so that each of the equations (37) turns into a pair of equations, given by

$$\begin{aligned} Y_i^1(x_{i+1})y_1(x_i) + Y_i^2(x_{i+1})y_2(x_i) - y_1(x_{i+1}) &= -Z_i^1(x_{i+1}) \\ Y_i^3(x_{i+1})y_1(x_i) + Y_i^4(x_{i+1})y_2(x_i) - y_2(x_{i+1}) &= -Z_i^2(x_{i+1}) \end{aligned} \qquad (39)$$

The result is a simultaneous system of $2M$ linear matrix equations, in which the known coefficients $Y_i^j(x_{i+1})$ and $Z_i^j(x_{i+1})$ are $(m/2, m/2)$ and $(m/2, 1)$ matrices, respectively, and the unknowns $y_j(x_i)$ are $(m/2, 1)$ matrices. Since $y_1(x_1)$ and $y_2(x_{M+1})$ are known, there are exactly $2M$ unknowns: $y_1(x_i)$, with $i = 2, 3, \ldots, M + 1$, and $y_2(x_i)$, with $i = 1, 2, \ldots, M$.

By means of Gaussian elimination, this system of equations (39) is first brought to the form

$$\begin{bmatrix} E_1 & -I & 0 & 0 & 0 & 0 \\ 0 & C_1 & -I & 0 & 0 & 0 \\ 0 & 0 & E_2 & -I & 0 & 0 \\ 0 & 0 & 0 & C_2 & -I & 0 \\ 0 & 0 & 0 & 0 & E_M & -I \\ 0 & 0 & 0 & 0 & 0 & C_M \end{bmatrix} \begin{bmatrix} y_1(x_2) \\ y_1(x_3) \\ y_1(x_4) \\ y_1(x_M) \\ y_1(x_M) \\ y_1(x_{M+1}) \end{bmatrix} = \begin{bmatrix} A_1 \\ B_1 \\ A_2 \\ B_2 \\ A_M \\ B_M \end{bmatrix} \quad (40)$$

where the dots indicate the triangularized equations (39) with $i = 3, 4, \ldots, M - 1$. The $(m/2, m/2)$ matrices E_i, C_i are defined by

$$E_1 = Y_1^2 \quad (41a)$$

$$C_1 = Y_1^4 E_1^{-1} \quad (41b)$$

and for $i = 2, 3, \ldots, M$

$$E_i = Y_i^2 + Y_i^1 C_{i-1}^{-1} \quad (41c)$$

$$C_i = (Y_i^4 + Y_i^3 C_{i-1}^{-1}) E_i^{-1} \quad (41d)$$

The $(m/2, 1)$ matrices A_i, B_i are given by

$$A_1 = -Z_1^1 - Y_1^1 y_1(x_1) \quad (42a)$$

$$B_1 = -Z_1^2 - Y_1^3 y_1(x_1) - Y_1^4 E_1^{-1} A_1 \quad (42b)$$

and for $i = 2, 3, \ldots, M - 1$

$$A_i = -Z_i^1 - Y_i^1 C_{i-1}^{-1} B_{i-1} \quad (42c)$$

$$B_i = -Z_i^2 - Y_i^3 C_{i-1}^{-1} B_{i-1} - (Y_i^4 + Y_i^3 C_{i-1}^{-1}) E_i^{-1} A_i \quad (42d)$$

Finally, for the Mth segment

$$A_M = -Z_M^1 - Y_M^1 C_{M-1}^{-1} B_{M-1} \quad (42e)$$

$$B_M = y_1(x_{M+1}) - Z_M^2 - Y_M^3 C_{M-1}^{-1} B_{M-1} - (Y_M^4 + Y_M^3 C_{M-1}^{-1}) E_M^{-1} A_M \quad (42f)$$

For brevity, in place of $Y_i^j(x_{i+1})$ and $Z_i^j(x_{i+1})$, the symbols Y_i^j and Z_i^j have been used.

By means of (41) and (42), the unknowns of (39) are obtained by

$$y_1(x_{M+1}) = C_M^{-1} B_M \quad (43a)$$

$$y_1(x_M) = E_M^{-1}[y_1(x_{M+1}) + A_M] \quad (43b)$$

and for $i = 1, 2, \ldots, M - 1$

$$y_1(x_{M-i+1}) = C_{M-i}^{-1}[y_1(x_{M-i+2}) + B_{M-i}] \quad (43c)$$

$$y_1(x_{M-i}) = E_{M-i}^{-1}[y_1(x_{M-i+1}) + A_{M-i}] \quad (43d)$$

It should be noted that (41)–(43) must be evaluated in succession, because each equation involves the result obtained by the preceding equation.

Once all the unknowns $y(x_i)$ are found, the fundamental variables are determined from (35) at any value of x at which the solutions $Y_i(x)$ and $Z_i(x)$ are stored during the integration of the initial-value problems of (36). The integration of (36) can be accomplished by means of any of the standard direct integration methods.

On the basis of the system of equations (26) given in an earlier section and the method of solution developed in the last two sections, the author has prepared a computer program[4] which has been applied to many shell configurations having large values of β and successfully tested against known results. One example of a pressurized torus with $\beta = 57$ is presented in the next section.

The program admits arbitrary meridional variations, including discontinuities, in all shell parameters. It also admits ring loads in the form of prescribed values of N_ϕ, M_ϕ, N, or Q at any value of ϕ on the shell. Such loads introduce discontinuities in the solution for the corresponding stress resultants, and they can be represented at every x_i by an $(m, 1)$ discontinuity matrix which is simply added to the matrix $Z_i(x_{i+1})$ on the right-hand side of (37). This feature is of great value if shell joints are considered. Any discontinuity, either in geometry or in loads, is easily handled by requiring that the end point of a segment coincides with the location of the discontinuity. Since integration is restarted at the beginning of each segment, the precise effect of the discontinuity is obtained. The program outputs all fundamental variables at a number of desired points within each segment, and it also computes the values of $y(x_i)$ twice; once from (43) and then from (35). If a certain number of significant figures of these values match, then the continuity conditions are known to be satisfied to the same number of figures. In this way, a convenient error estimate of the solution is obtained for every case.

Example: Pressurized Torus

In this section the stresses and displacements are determined in a complete torus subjected to a constant internal pressure. It is well known that the solution of this problem, when obtained by means of the linear membrane theory of shells, has a discontinuity in the displacement field. It has been shown by Jordan [16] and by Sanders and Liepins [17] that a satisfactory solution with regard to the displacement field for a sufficiently thin shell can be obtained if the nonlinear membrane theory of shells is employed. Subsequently, Reissner [18] established bounds on certain parameters which show when the nonlinear membrane and when the linear bending theory is applicable. It seems worthwhile to give here the solution for a pressurized torus as predicted by the linear bending theory.

The geometry of the torus is shown in Fig. 2. With regard to the quantities employed in equations (26), the two necessary parameters for a torus are given as

$$R_\phi = b \quad (44a)$$

$$r = a + b \sin \phi \quad (44b)$$

Because of symmetry with respect to the plane XX, Fig. 2, the

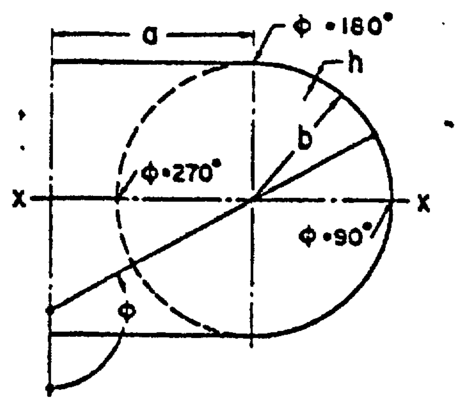

Fig. 2 Geometry of torus considered in example

[4] The program was written and all calculations were carried out by the author on the IBM 700 computer at the Yale Computer Center. The direct integration of (36) is performed by means of the Adams predictor-corrector method, which selects an optimum step size at every step according to a prescribed accuracy.

A-1c

Table 1 Stresses and displacements of a pressurized torus; $pb/Eh = 0.002$, $a/b = 1.5$, $\nu = 0.3$

ϕ \ h/b	$\sigma_{\phi m}/E \times 10^3$ 0.005	$(\sigma_{\phi b}/E) \times 10^4$ 0.05	0.02	0.005	$(w/b) \times 10^3$ 0.05	0.02	0.005
90	1.601	−0.063	−0.031	−0.016	1.249	1.234	1.208
108	1.613	−0.188	−0.003	−0.010	1.201	1.315	1.328
126	1.650	−0.886	−0.123	−0.030	1.359	1.303	1.427
144	1.720	−1.918	−0.908	−0.020	1.786	1.507	1.625
162	1.832	−0.805	−1.378	−0.910	2.820	2.580	2.150
171	1.906	1.002	0.168	−0.605	3.467	3.493	3.207
180	1.990	3.080	2.277	1.482	3.904	4.334	4.815
184.5	2.042	3.800	3.035	1.568	4.150	4.378	5.248
189	2.104	4.270	3.119	1.320	4.208	4.637	5.151
193.5	2.178	4.178	2.580	0.530	4.180	4.500	4.003
198	2.254	3.610	1.569	−0.274	3.908	4.221	4.162
216	2.642	−0.587	−0.957	−0.079	2.652	2.827	2.481
234	3.168	−1.245	−0.201	−0.066	1.273	1.200	1.200
252	3.730	−0.717	−0.344	−0.077	0.418	0.417	0.414
270	3.997	−0.824	−0.331	−0.081	0.103	0.101	0.100

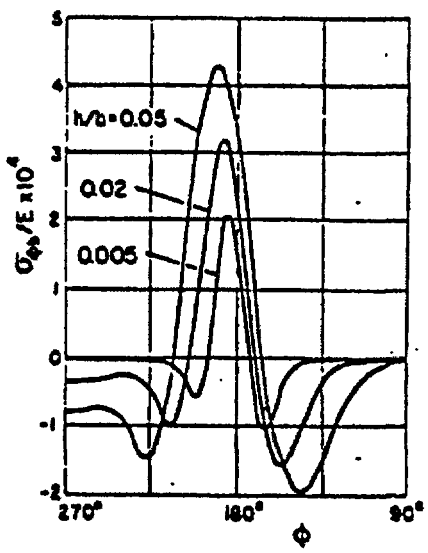

Fig. 4 Meridional bending stress $\sigma_{\phi b}$ at outer fiber versus meridional coordinate ϕ

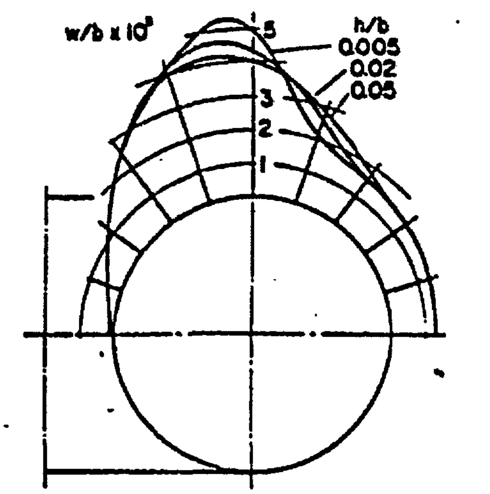

Fig. 5 Normal displacement w versus ϕ showing deformed section

Table 2 Maximum meridional bending stress and meridional membrane stress at $\phi = \phi_0$

h/b	0.05	0.02	0.005
ϕ_0	189°	180°	184.5°
$(\sigma_{\phi m}/E) \times 10^3$	2.053	2.082	2.042
$(\sigma_{\phi b}/E) \times 10^4$	0.427	0.312	0.197
$100\,(\sigma_{\phi b}/\sigma_{\phi m})$	20.8	15.0	9.6

integration of the initial-value problems is carried out from $\phi = 90°$ to $\phi = 270°$, and the boundary conditions at these endpoints are $u_\phi = \beta_\phi = Q = 0$. For the purpose of comparison with the results of [16] and [17], the load parameter is chosen as $pb/Eh = 0.002$ and $a/b = 1.5$.

The numerical values of the normal displacement, meridional membrane stress $\sigma_{\phi m} = N_\phi/h$, and meridional bending stress $\sigma_{\phi b} = 6M_\phi/h^2$ at $\zeta = h/2$ for a pressurized torus are shown in Table 1 and in Figs. 4 and 5. These results were taken from the output of the computer program prepared for an arbitrary shell of revolution after prescribing the geometric parameters as given by (44). The meridional membrane stress distribution agrees very well with that obtained in [17] by means of the membrane theory of shells and it shows only a small variation with h/b. The deformed shapes of the cross section of the torus shown in Fig. 5 for three values of h/b are in qualitative agreement with those given in [16] and [17], but their quantitative agreement cannot be expected because the values of h/b used in this example are outside the range where the bending effects are negligible. This is confirmed by the examination of the bending stresses shown in Fig. 4. The maximum value of $\sigma_{\phi b}$ occurs at $\phi = 189°$ for $h/b = 0.05$ and at $\phi = 184.5°$ for $h/b = 0.005$, which are also the points of maximum normal displacement and curvature as seen in Fig. 5. The comparison of the membrane and the maximum bending stress at various values of h/b is shown in Table 2.

It is of significance to note that even for the thickness ratio $h/b = 0.005$, which for many applications would be regarded as small, the maximum bending stress is about 10 percent of the membrane stress at the same point. Such effects of bending in a torus were previously noted by Clark [19], and they are also in agreement with the statement made by Goldenveizer [20] that when the middle surface touches a closed-plane curve, which in a torus corresponds to $\phi = 180°$, then in the vicinity of this curve bending stresses should be expected and the membrane theory is not applicable.

The boundary layer shown in Fig. 4 is also in agreement with the conclusions reached in [18] to the effect that when μ and p given by

$$\mu = [12(1-\nu^2)]^{1/4}(b/a)(b/h)$$

$$p = 12(1-\nu^2)(p/E)(b/h)^4$$

are large compared to unity, then a boundary layer in the neighborhood of $\phi = 180°$ should be anticipated. For the present example, μ ranges from 44 to 440 and p from 9 to 874. However, since p is the only load parameter of the problem, the solutions shown in Figs. 4 and 5 are proportional to p, and the boundary layer remains unaffected if p alone is varied. Of course, for very large values of p the deformation of the torus may exceed the limits of a linear theory which according to [18] restrict p to the range $p \ll \mu^{4/3}$.

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On Free and Forced Vibration of Rotationally Symmetric Layered Shells

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The purpose of this Note is to generalize the method of analysis of rotationally symmetric thin elastic shells given in two earlier papers[2,3] to cases when the shell wall consists of any number of layers of isotropic or orthotropic material. The changes which must be made[2,3] to account for such properties are confined to the stress-strain relations, which, in turn, affect only the coefficients of the eight first-order fundamental differential equations derived[2,3] for the solution of certain initial-value problems. The multisegment method given in the previous papers for the analysis of free or forced vibration or static deformation remains exactly the same if the derivatives of the fundamental variables, derived in this Note, are employed in the initial-value integration.

In the present formulation, the shell is defined by means of any convenient, rotationally symmetric, continuous reference surface, and the axisymmetric bounding surfaces of the layers of the shell wall are located with respect to the reference surface in any arbitrary manner. This feature is extremely useful in practical applications, because the reference surface can be chosen as the simplest surface of the shell and is not restricted to the "middle" surface or to a special one which is determined from the elastic properties.

Using the notation of the previous paper,[4] the relations between the ϕ-dependent separable solutions of the stress-resultants and the strain measures for a layered orthotropic shell are obtained from Ambartsumyan,[5] and, after adding the temperature terms, they can be written in the form

$$N_{\phi n} = C_{11}\epsilon_{\phi n} + C_{12}\epsilon_{\theta n} + K_{11}\kappa_{\phi n} + K_{12}\kappa_{\theta n} + H_{11}T_{0n} + H_{12}T_{1n} \quad (1a)$$

$$N_{\theta n} = C_{12}\epsilon_{\phi n} + C_{22}\epsilon_{\theta n} + K_{12}\kappa_{\phi n} + K_{22}\kappa_{\theta n} + H_{21}T_{0n} + H_{22}T_{1n} \quad (1b)$$

$$N_{n} = (C_{33} + K_{33}\sin\phi/r)(\epsilon_{n} + \omega_{n-1}) + (K_{33} + D_{33}\sin\phi/r)(\kappa_{n} + \omega_{n-1}\sin\phi/r) \quad (1c)$$

$$M_{\phi n} = D_{11}\kappa_{\phi n} + D_{12}\kappa_{\theta n} + K_{11}\epsilon_{\phi n} + K_{12}\epsilon_{\theta n} + H_{12}T_{0n} + F_{11}T_{1n} \quad (2a)$$

$$M_{\theta n} = D_{12}\kappa_{\phi n} + D_{22}\kappa_{\theta n} + K_{12}\epsilon_{\phi n} + K_{22}\epsilon_{\theta n} + H_{22}T_{0n} + F_{21}T_{1n} \quad (2b)$$

$$M_{\theta\phi n} = D_{33}(\kappa_{n} + \omega_{n-1}\sin\phi/r) + K_{33}(\epsilon_{n} + \omega_{n-1}) \quad (2c)$$

where the subscript n denotes the nth Fourier harmonic, and s is the distance measured along the meridian of the reference surface of the shell. The elastic parameters C_{jk}, K_{jk}, D_{jk}, H_{jk} and F_{jk} occurring in (1) and (2) are defined for a shell consisting of m layers, Fig. 1, in the form

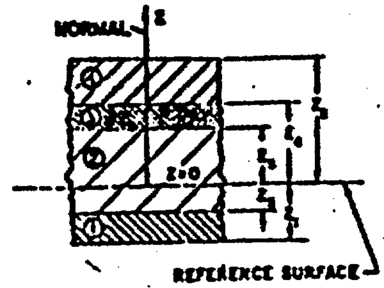

Fig. 1 Element of shell-wall consisting of layers of arbitrary thickness

$$\begin{Bmatrix} C_{jk} \\ K_{jk} \\ D_{jk} \end{Bmatrix} = \sum_{i=1}^{m} B_{jk}^{i} \begin{Bmatrix} (z_{i+1} - z_i) \\ \frac{1}{2}(z_{i+1}^2 - z_i^2) \\ \frac{1}{3}(z_{i+1}^3 - z_i^3) \end{Bmatrix}$$

$$\begin{Bmatrix} H_{11} \\ H_{12} \\ F_{11} \end{Bmatrix} = -\sum_{i=1}^{m} (B_{11}^{i}\alpha_{\phi}^{i} + B_{12}^{i}\alpha_{\theta}^{i}) \begin{Bmatrix} (z_{i+1} - z_i) \\ \frac{1}{2}(z_{i+1}^2 - z_i^2) \\ \frac{1}{3}(z_{i+1}^3 - z_i^3) \end{Bmatrix}$$

$$\begin{Bmatrix} H_{21} \\ H_{22} \\ F_{21} \end{Bmatrix} = -\sum_{i=1}^{m} (B_{12}^{i}\alpha_{\phi}^{i} + B_{22}^{i}\alpha_{\theta}^{i}) \begin{Bmatrix} (z_{i+1} - z_i) \\ \frac{1}{2}(z_{i+1}^2 - z_i^2) \\ \frac{1}{3}(z_{i+1}^3 - z_i^3) \end{Bmatrix}$$

where[6]

$$B_{11} = E_{\phi}/(1 - \nu_{\phi}\nu_{\theta})$$

$$B_{12} = \nu_{\theta}E_{\phi}/(1 - \nu_{\phi}\nu_{\theta}) = \nu_{\phi}E_{\theta}/(1 - \nu_{\phi}\nu_{\theta})$$

$$B_{22} = E_{\theta}/(1 - \nu_{\phi}\nu_{\theta})$$

$$B_{33} = G_{\phi\theta}$$

The index i denotes the ith layer bounded by the coordinates [illegible] and z_i, Fig. 1; α_{ϕ}, α_{θ} and E_{ϕ}, E_{θ} are the coefficients of ther[mal] expansion and Young's moduli in the ϕ and θ directions, res[pec]tively; ν_{ϕ}, ν_{θ} are the corresponding Poisson's ratios; and $G_{\phi\theta}$ is [the] shear modulus. For an isotropic layer of the shell-wall, $\alpha_{\phi} =$ [illegible] $= \alpha$, $E_{\phi} = E_{\theta} = E$; $\nu_{\phi} = \nu_{\theta} = \nu$, and $G_{\phi\theta} = E/2(1 + \nu)$. [illegible] temperature resultants T_{0n} and T_{1n} are defined by

$$T_{0n} = (T_{Ln}z_{m+1} - T_{Un}z_1)/(z_{m+1} - z_1)$$

$$T_{1n} = (T_{Un} - T_{Ln})/(z_{m+1} - z_1)$$

where $T_{Un}(\phi)$ and $T_{Ln}(\phi)$ are prescribed temperature distri[bu]tions of the nth harmonic on the upper ($z = z_{m+1}$) and lo[wer] ($z = z_1$) surface of the shell, respectively.[7] The symbols $\epsilon_{\phi n}$ [illegible] and $\kappa_{\phi n}$, $\kappa_{\theta n}$ designate the nth harmonics of the reference-surf[ace] strains and bending strains, respectively, and the expressi[ons] relating these strain measures to the displacement compone[nts] of the reference surface can be found in the previous paper.[3] [For] convenience, we have defined

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[2] A. Kalnins, "Analysis of Shells of Revolution Subjected to Symmetrical and Nonsymmetrical Loads," JOURNAL OF APPLIED MECHANICS, vol. 31, TRANS. ASME, vol. 86, Series E, 1964, pp. 467–476.

[3] A. Kalnins, "Free Vibration of Rotationally Symmetric Shells," Journal of the Acoustical Society of America, vol. 36, 1964, pp. 1355–1365.

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[4] It should be noted that all quantities defined previously [with] respect to the "middle" surface (such as the coordinates ϕ, θ; [dis]placement components u_{ϕ}, u_{θ}, w; radii of curvature R_{ϕ}, R_{θ}; and st[rain] measures) are now defined in the same way with respect to [the] reference surface. The coordinate along the normal of the refer[ence] surface is here denoted by z.

[5] S. A. Ambartsumyan, *Theory of Anisotropic Shells*, N[ASA] Technical Translation F-118, Washington, D. C., May, 1964, pp. [illegible] and 44.

[6] Ambartsumyan,[5] equations (12.2), p. 46.

[7] It is assumed in (4) that the transverse thermal conductivity is [the] same in all layers. A slightly more complicated expression for [illegible] and T_{1n} results if the temperature $T_n = T_{0n}^i + zT_{1n}^i$ is assumed [in] the ith layer, and the resultants are determined by requiring [con]tinuity of temperature and the flux of heat across the bounding [sur]faces of layers.

$$\epsilon_\theta = \partial v_\theta - w_{n,\phi}$$

$$\epsilon_\phi = \partial u_{\phi n} - w_{n,\phi} \sin\phi/r$$

It should be noted that R_{ij}^i, α_j^i, z_i can be arbitrary (even discontinuous) functions of ϕ, but they must be constant with respect to the circumferential coordinate θ. Consequently, the elastic parameters can be made temperature dependent for axisymmetric, but not nonsymmetric, temperature variation.

In the integration of the initial-value problems defined previously, it is necessary to calculate at a given point the values of the first derivatives of the eight fundamental variables $\{w_n$, Q_n, $v_{\phi n}$, $N_{\phi n}$, $\beta_{\phi n}$, $M_{\phi n}$, $u_{\theta n}$, $K_n\}$ when the variables themselves are known. Using (1), (2), and (3) and the strain-displacement and equilibrium equations (with the translatory inertia terms added) from the previous paper,[3] the calculation of the derivatives can be arranged in the following order:

$$\epsilon_{\theta n} = n u_{\theta n}/r + v_{\phi n} \cos\phi/r + w_n \sin\phi/r \quad (5a)$$

$$\beta_{\theta n} = n w_n/r + u_{\theta n} \sin\phi/r \quad (5b)$$

$$\kappa_{\theta n} = n\beta_{\theta n}/r + \beta_{\phi n} \cos\phi/r \quad (5c)$$

$$\epsilon_n = -n u_{\phi n}/r - u_{\theta n} \cos\phi/r \quad (5d)$$

$$\kappa_n = -2n w_n \cos\phi/r^2 + n v_{\phi n}/(rR_\phi) + (\cos\phi/r)(1/R_\phi - 2\sin\phi/r)u_{\theta n} - 2n\beta_{\phi n}/r \quad (5e)$$

$$A_1 = C_{11}D_{11} - K_{11}^2 \quad (5f)$$

$$\epsilon_{\phi n} = (1/A_1)[(N_{\phi n} - H_{11}T_{1n} - H_{12}T_{2n} - C_{12}\epsilon_{\theta n} - K_{12}\kappa_{\theta n})D_{11} - (M_{\phi n} - H_{11}T_{1n} - F_{11}T_{2n} - K_{12}\epsilon_{\theta n} - D_{12}\kappa_{\theta n})K_{11}] \quad (5g)$$

$$\kappa_{\phi n} = (1/A_1)[(M_{\phi n} - H_{11}T_{1n} - F_{11}T_{2n} - K_{12}\epsilon_{\theta n} - D_{12}\kappa_{\theta n})C_{11} - (N_{\phi n} - H_{11}T_{1n} - H_{12}T_{2n} - C_{12}\epsilon_{\theta n} - K_{12}\kappa_{\theta n})K_{11}] \quad (5h)$$

$$N_{\theta n} = C_{12}\epsilon_{\phi n} + C_{22}\epsilon_{\theta n} + K_{12}\kappa_{\phi n} + K_{22}\kappa_{\theta n} + H_{21}T_{1n} + H_{22}T_{2n} \quad (5i)$$

$$M_{\theta n} = D_{12}\kappa_{\phi n} + D_{22}\kappa_{\theta n} + K_{12}\epsilon_{\phi n} + K_{22}\epsilon_{\theta n} + H_{21}T_{1n} + F_{22}T_{2n} \quad (5j)$$

$$A_2 = C_{33} + 2K_{33} \sin\phi/r + D_{33}(\sin\phi/r)^2 \quad (5k)$$

$$u_{\theta n,\phi} = (1/A_2)[N_n - (C_{33} + K_{33}\sin\phi/r)\epsilon_n - (K_{33} + D_{33}\sin\phi/r)\kappa_n] \quad (5l)$$

$$M_{\phi\theta n} = K_{33}(\epsilon_n + u_{\theta n,\phi}) + D_{33}(\kappa_n + u_{\theta n,\phi} \sin\phi/r) \quad (5m)$$

$$w_{n,\phi} = v_{\phi n}/R_\phi - \beta_{\phi n} \quad (5n)$$

$$v_{\phi n,\phi} = \epsilon_{\phi n} - w_n/R_\phi \quad (5o)$$

$$\beta_{\phi n,\phi} = \kappa_{\phi n} \quad (5p)$$

$$N_{\phi n,\phi} = -nN_n/r + n(1/R_\phi + \sin\phi/r)M_{\phi\theta n}/r + N_{\theta n}\cos\phi/r - N_{\phi n}\cos\phi/r - Q_n/R_\phi - p_{\phi n} - \rho\omega^2 v_{\phi n} \quad (5q)$$

$$M_{\phi n,\phi} = M_{\theta n}\cos\phi/r - 2nM_{\phi\theta n}/r - M_{\phi n}\cos\phi/r + Q_n \quad (5r)$$

$$Q_{n,\phi} = -2nM_{\phi\theta n}\cos\phi/r^2 - Q_n\cos\phi/r + N_{\theta n}\sin\phi/r + N_{\phi n}/R_\phi + n^2M_{\theta n}/r^2 - p_n - \rho\omega^2 w_n \quad (5s)$$

$$N_{n,\phi} = (1/R_\phi - \sin\phi/r)M_{\phi\theta n}\cos\phi/r - 2N_n\cos\phi/r + nN_{\theta n}/r + nM_{\theta n}\sin\phi/r^2 - p_{\theta n} - \rho\omega^2 u_{\theta n} \quad (5t)$$

where the density parameter ρ has been defined by

$$\rho = \sum_{i=1}^{m} \rho^i (z_{i+1} - z_i)$$

in terms of the mass density of ρ^i of the ith layer. The definition of other symbols can be found elsewhere.[4,5]

The calculation of the derivatives of the fundamental variables starts with the evaluation of (2) from given R_{11}^i, R_{12}^i, R_{22}^i, R_{33}^i, α_ϕ^i, α_θ^i, and z_i ($i = 1, 2, \ldots, m$) at a specified value of ϕ. Then, using known values of r, R_ϕ and the fundamental variables, (5) are evaluated in succession, starting with (5a) and ending with (5t). Equations (5) can be transcribed directly as consecutive FORTRAN statements in a computer program because every quantity occurring in an equation has been defined by a previous expression.[1]

Thus equations (5) are applicable to the analysis of the steady-state response of an arbitrary rotationally symmetric shell to harmonically oscillating surface, edge, and/or thermal loads. To find the static deformation, we simply set in (5) $\omega = 0$. For a shell of revolution, spinning about its axis of symmetry with angular velocity Ω, all the loads and ω are set equal to zero, except that

$$p_n = r\Omega^2\rho\cos\phi, \quad p_{\phi n} = r\Omega^2\rho\sin\phi$$

For free-vibration problems, all loads are absent ($p_n = p_{\phi n} = p_{\theta n} = T_{1n} = T_{2n} = 0$), and then (5) can be used with the method given previously for the evaluation of the natural frequencies and mode shapes of any layered shell of revolution.

Acknowledgment

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Appendix B

Containment Vessel Drywell Configuration

and

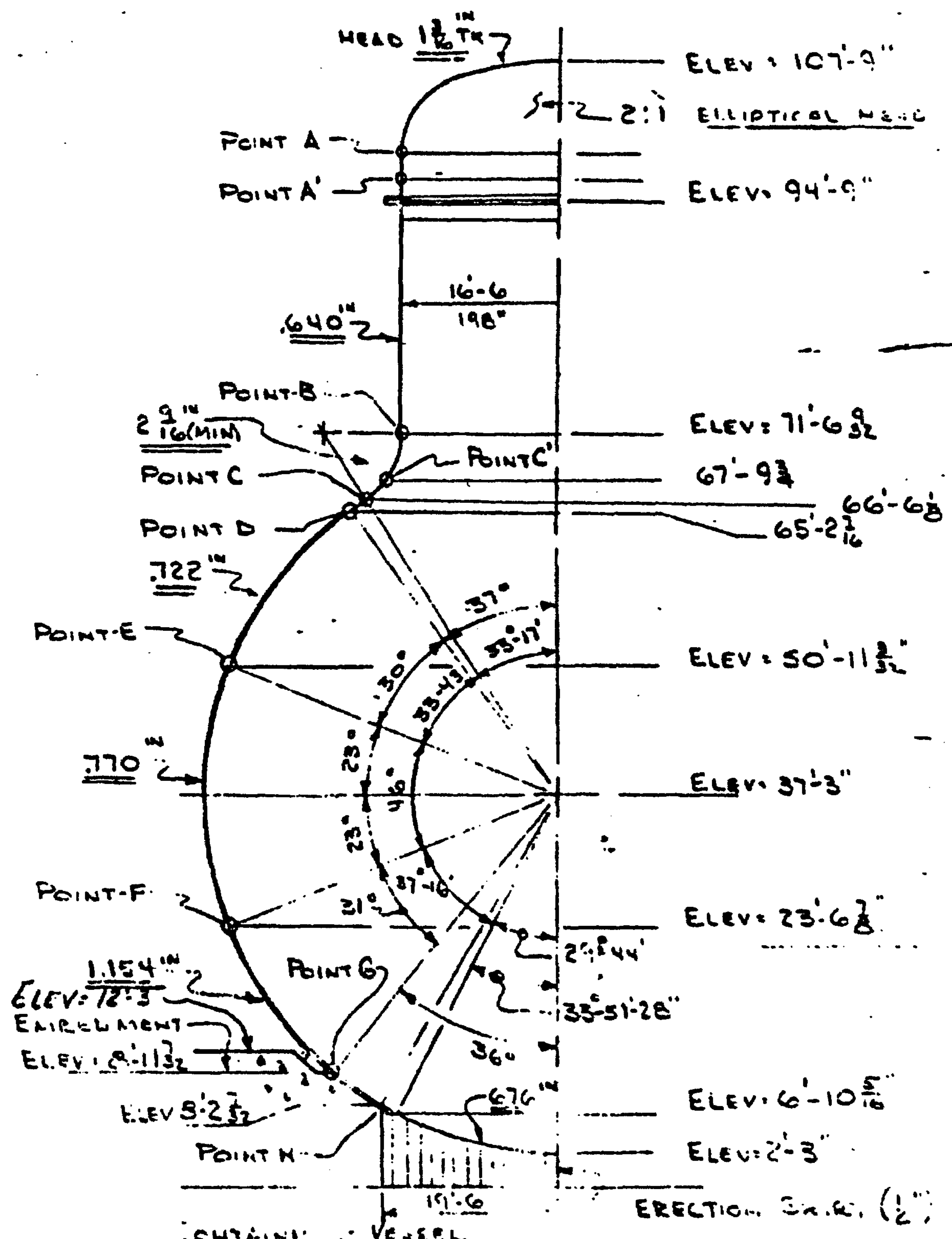
Stress Summaries

from

Original Design Report

Oyster Creek Nuclear Plant

CHICAGO BRIDGE & IRON COMPANY GREENVILLE ENGINEERING DEPT.



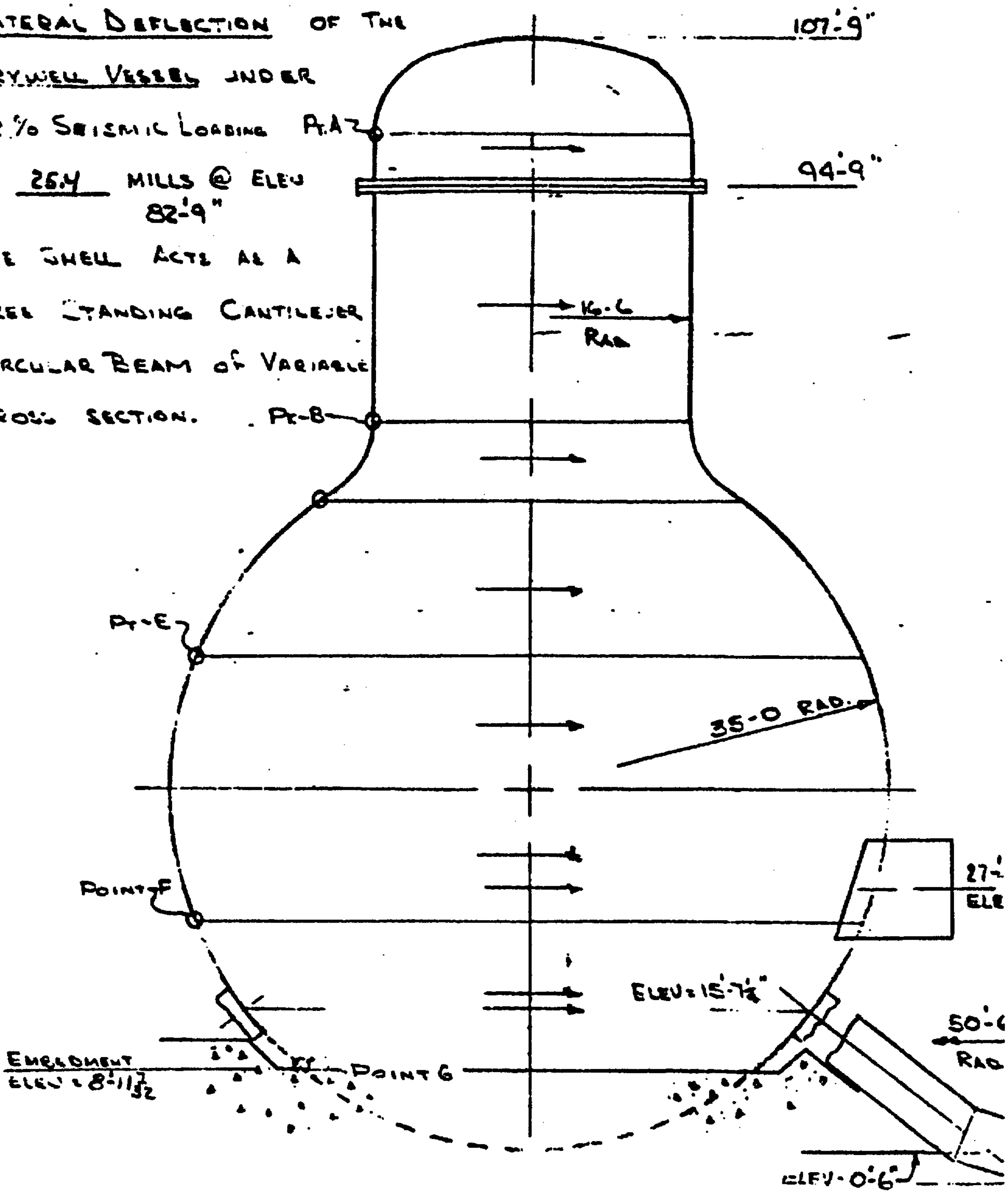
ERECTION SK. (1/2")

CONTAINMENT VESSEL

FORM ... Subject OYSTER CREEK - NEW JERSEY Cont. 9-0971 Date 10 FEB 65 By ... Sht ... of ...

LATERAL DEFLECTION OF THE DRYWELL VESSEL UNDER 22% SEISMIC LOADING Pt.A = 26.4 MILLS @ ELEV 82'-9"

THE SHELL ACTS AS A FREE STANDING CANTILEVER CIRCULAR BEAM OF VARIABLE CROSS SECTION.



PRIMARY DESIGN LOADS FOR THE REACTOR DRY WELL.

CASE I

1. DEAD wgt of STEEL
2) DEAD wgt OF APPURTENANCES
3) DESIGN PRESSURE (62 psig)
4. 22% HORR. EARTH QUAKE
5) 10% VERT EATH QUAKE
6) wgt of CONTAINED AIR

CASE II

1) DEAD wgt of STEEL & APPURTENANCES
2) GRAVITY LOADS FROM EQUIPMENT SUPPORTS
3) GRAVITY LOAD OF COMPRESSIBLE MATERIAL
4) GRAVITY LOADS WELD PADS
5 DESIGN PRESSURE (62 psig)
6) 22% HORR EARTH QUAKE
7) 10% VERT EARTH QUAKE

CASE III

1) DEAD LOAD of VESSEL & APPURTENANCES
2) GRAVITY LOADS FROM EQUIPMENT SUPPORTS
3) GRAVITY LOADS FROM COMPRESSIBLE MATERIAL
4) 22% HORR. EARTH QUAKE
5) 10% VERT EARTH QUAKE
6) GRAVITY LOADS ON WELD PADS.
7) EXTERNAL PRESSURE (-2psig)
8) LIVE LOAD ON LOCK

CASE IV

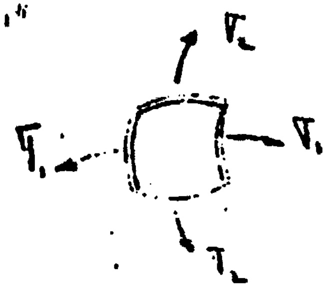
1) DEAD LOAD of SHELL & APPURTENANCES
2) GRAVITY LOADS from EQUIPMENT SUPPORTS
3) GRAVITY LOAD of COMP MATERIAL
4) 22% HORR EARTH QUAKE
5 10% VERT EATH QUAKE
6) GRAVITY LOADS ON WELD PADS
7) EXTERNAL PRESSURE (-2psig)
8) LIVE LOAD ON ACCESS OPEN
9) WATER LOAD ON WATER SEAL

GREENVILLE ENGINEERING DEPT.

CHICAGO BRIDGE & IRON COMPANY

SUMMARY OF PRIMARY MEMBRANE STRESSES IN THE SHELL #/IN

PT.	EL.	INTERNAL PRESSURE		EXTERNAL PRESSURE		STEEL DEAD LOAD		WATER SEAL		15% HORZ. EARTHQUAKE (ON SHELL)		22% HORZ. EARTHQUAKE (ON SHELL)		10% VERT. EARTHQUAKE (ON SHELL)	
		σ_2	σ_1	σ_2	σ_1	σ_2	σ_1	σ_2	σ_1	σ_2	σ_1	σ_2	σ_1	σ_2	σ_1
A	99'-6"	+6140	+6140	-198	-198	-49	+49	—	—	∓3	±3	∓5	±5	∓5	±.5
A'	97'-3	+6140	+12290	-198	-396	-60	0	—	—	∓5	0	∓7	0	∓6	0
B	71'-6 9/32	+6140	+24406	-198	-785	-164	-221	-700	-945	∓59	∓79	∓99	∓134	∓16	∓22
C'	67'-9 3/4	+8430	+48700	-272	-1570	-240	-1095	-828	-3080	∓76	∓280	∓128	∓-475	∓24	∓109
C	66'-6 1/8	+13020	+41410	-420	-1344	-349	-1102	-1100	-2600	∓99	∓234	∓167	∓348	∓35	∓110
D	65'-2 7/16	+13020	+13020	-420	-420	-324	+252	-910	+910	∓79	±79	∓134	±134	∓32	±25
E	50'-11 3/32	+13020	+13020	-420	-420	-182	+147	-389	+389	∓41	±41	∓69	±69	∓18	±15
F	23'-6 7/8	+13020	+13020	-420	-420	-271	+309	-389	+389	∓90	±90	∓153	±153	∓27	±31
G	8'-11 3/32	+13020	+13020	-420	-420	-838	+954	-955	+955	∓486	±486	∓824	±824	∓84	±95
H	8'-2 7/32	+13020	+13020	-420	-420	-945	+1061	—	—	∓584	±584	∓988	±988	∓94	±166



Subject 70' DRYWELL CONTAINMENT VESSEL Cont. 9-0771 Date 2/6 By Sh. 181 of

GREENVILLE ENGINEERING DEPT
CHICAGO BRIDGE & IRON COMPANY

(CONT.)

SUMMARY OF PRIMARY MEMBRANE STRESSES IN THE SHELL #/IN

PNT	ELEV	COMPRESSIBLE MATERIAL								WELLING LOADS					
		DEAD LOAD		10% VERT. EQ		13% HORIZ. EQ		22% HORIZ. EQ		DL & LL		13% HORIZ. EQ		22% HORIZ. EQ	
		σ_2	σ_1	σ_2	σ_1	σ_2	σ_1	σ_2	σ_1	σ_2	σ_1	σ_2	σ_1	σ_2	σ_1
A	99'-6	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A'	97'-3	—	—	—	—	—	—	—	—	—	—	—	—	—	—
B	71'-6 9/32	−13	−18	∓1	∓2	∓2	∓3	∓4	∓5	—	—	—	—	—	—
C'	67'-9 3/4	−19	−69	∓2	∓7	∓3	∓12	∓6	∓21	—	—	—	—	—	—
C	66'-6 1/8	−27	−78	∓3	∓8	∓5	∓21	∓8	∓35	−11	−27	—	—	—	—
D	65'-2 7/16	24	+22	∓2	±2	∓4	±4	∓6	±6	−9	+9	∓3	±3	∓4	±4
E	50'-11 3/32	−21	+21	∓2	±2	∓3	±3	∓5	±5	−16	+16	∓1	±1	∓2	±2
F	23'-6 7/8	−41	+42	∓4	±4	∓10	±10	∓16	±16	−16	+16	∓3	±3	∓5	±5
G	8'-11 7/32	−128	+128	∓13	±13	∓59	±59	∓99	±99	−39	+39	∓15	±15	∓25	±25
H	8'-2 7/32	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Subject 70'∅ DRYWELL CONTAINMENT VESSEL
OYSTER CREEK [illegible] Cont. 9-5771 Date 2/8 By PJP Sh. 182

(Cont.)

SUMMARY OF PRIMARY MEMBRANE STRESSES IN THE SHELL #/IN

Point	Elev.	Well Pads 10% Vert E.Q. T_2	Well Pads 10% Vert E.Q. T_1	Appurtenances Dead Load T_2	Dead Load T_1	10% Vert E.Q. T_2	10% Vert E.Q. T_1	15% Horiz E.Q. T_2	15% Horiz E.Q. T_1	22% Horiz E.Q. T_2	22% Horiz E.Q. T_1	—	—	Wind Load T_2	Wind Load T_1
A	99-6	—	—	—	—	—	—	—	—	—	—	—	—	∓ 2	± 2
A'	97-3	—	—	—	—	—	—	—	—	—	—	—	—	∓ 4	0
B	71-[illegible]	—	—	− 21	− 28	∓ 2	∓ 3	∓ 3	∓ 4	∓ 5	∓ 7			∓ 49	∓ 67
C'	67-7¾	—	—	− 25	− 93	∓ 2	∓ 9	∓ 5	∓ 18	∓ 8	∓ 30			∓ 66	∓ 244
C	66-6[illegible]	∓ 1	∓ 3	− 33	− 79	∓ 3	∓ 8	∓ 6	∓ 15	∓ 11	∓ 26			∓ 86	∓ 205
D	65-2[illegible]	∓ 1	± 1	− 28	+ 28	∓ 3	± 3	∓ 5	± 5	∓ 9	± 9			∓ 64	± 64
E	56-1[illegible]	∓ 2	± 2	− 16	+ 16	∓ 2	± 2	∓ 3	± 3	∓ 6	± 6			∓ 37	± 37
F	23-6[illegible]	∓ 2	± 2	− 86	+ 86	∓ 9	± 9	∓ 14	± 14	∓ 23	± 23			∓ 83	± 83
G	8-1[illegible]	∓ 4	± 4	− 402	+ 402	∓ 40	± 40	∓ 111	± 111	∓ 188	± 188			∓ 465	± 465
H'	8-2[illegible]			− 449	+ 449	∓ 45	± 45	∓ 138	± 138	∓ 233	± 233				

(CONT.)

SUMMARY OF PRIMARY MEMBRANE STRESSES IN THE SHELL #/IN

PT.	ELEV	FLOOR BEAMS DEAD LOADS σ_2	σ_1	FLOOR BEAMS EARTHQUAKE σ_2	σ_1	ACCESS LIVE LOAD σ_2	σ_1	REMOVABLE HEAD DEAD LOAD σ_2	σ_1	VERT E.Q. σ_2	σ_1	13% HORZ EQ σ_2	σ_1	22% HORZ EQ σ_2	σ_1
A	99'-6	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A'	97'-3	—	—	—	—	—	—	—	—	—	—	—	—	—	—
B	71'-6 9/32	—	—	—	—	—	—	−81	−110	∓8	∓11	∓33	∓126	∓56	∓214
C'	67'-4 3/4	—	—	—	—	—	—	−96	−358	∓10	∓36	∓37	∓138	∓63	∓234
C	66'-6 3/32	—	—	—	—	—	—	−128	−277	∓13	∓28	∓48	∓114	∓81	∓193
D	65'-2 7/32	—	—	—	—	—	—	−106	+106	∓11	±11	∓38	±38	∓63	±63
E	50'-1 3/32	—	—	—	—	—	—	−45	+45	∓4	±4	∓16	±16	∓27	±27
F	23'-6 3/8	−495	+495	∓167	±167	−35	+35	−45	+45	∓4	±4	∓26	±26	∓44	±44
G	8'-1 1/32	−1210	+1210	∓408	±408	−151	+151	−111	+111	∓11	±11	∓120	±120	∓203	±203
H	8'-2 7/32	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Appendix C

CBI Kalnins Computer Program

Printout of Stresses

in

Embedment Zone

SUBJECT	MADE BY	CHKD BY	REV	BY		CHARGE NO.
	JSB	TJA		CHKD		NG1147
	DATE	DATE		DATE		SHT C-1 OF
	12/56	12/12/56				

SUBJECT	MADE BY	CHKD BY	REV	BY		CHARGE NO.
	JSE	TJA				NC1147
	DATE	DATE		CHKD		
	12/56	12/16/86		DATE		SHT C2 OF

SUBJECT	MADE BY	CHKD BY	REV	BY		CHARGE NO.
	JSE	TJA				N61147
	DATE	DATE		CHKD		
	12/86	12/16/86		DATE		SHT C3 OF

MADE BY	CHKD BY	REV	BY		CHARGE NO.
JSE	TJA				NC1147
DATE 12/86	DATE 12/16/86		CHKD		
			DATE		SHT C4 OF

SUBJECT	MADE BY	CHKD BY	REV	BY		CHARGE NO.
	JSE	T/A				NG1147
	DATE	DATE		CHKD		
	12/86	12/12/86		DATE		SHT C5 OF

SUBJECT	MADE BY	CHKD BY	REV	BY		CHARGE NO.
	JSB	TJA				NC1147
	DATE	DATE		CHKD		
	12/86	12/16/86		DATE		SHT C6 OF

MADE			BY		CHARGE NO.
JSE	DA				N61147
DATE	DATE		CHKD		
12/86	16/16/86		DATE		SHT C7 OF

SUBJECT	MADE BY	CHKD BY		BY		CHARGE NO.
	JSE	TJA				NG1147
	DATE	DATE		CHKD		
	12/56	12/16/86		DATE		SHT C8 OF

SUBJECT	MADE BY	CHKD BY	REV	BY		CHARGE NO.
	JSE	TJA				N61147
	DATE	DATE		CHKD		
	12/56	12/6/86		DATE		SHT C9 OF

SUBJECT	MADE BY	CHKD BY	REV			CHARGE NO.
	JSE	DA		BY		N61147
	DATE	DATE		CHKD		
	12/86	12/16/86		DATE		SHT C10 OF

SUBJECT	MADE BY	CHKD BY	REV			CHARGE NO.
	JSG	TJA		BY		N61147
	DATE 12/86	DATE 12/16/86		CHKD		
				DATE		SHT C11 OF

SUBJECT	MADE BY	CHKD BY		BY		CHARGE NO.
	JSE	JJA		CHKD		NE1147
	DATE 12/56	DATE 12/16/56		DATE		SHT C12 OF

OYSTER CREEK MODIFIED EMBEDMENT, CASE 1: P=35 [illegible]

PART 1 *Embedment at elevation 12'-3 ~ no thermal transition layer*

FACES=-1. 1. 2.

COORD	S PHI	S THETA	S SHEAR	S1-S2	S1-S3	S2-S3
44.4	9.254E+04	2.785E+04	0.000E+00	6.469E+04	2.785E+04	9.254E+04
44.4	7.274E+03	2.271E+03	0.000E+00	5.003E+03	2.271E+03	7.274E+03
44.4	-7.799E+04	-2.331E+04	0.000E+00	5.468E+04	-7.799E+04	-2.331E+04
46.7	-2.342E+03	-1.869E+04	0.000E+00	1.635E+04	-1.869E+04	-2.342E+03
46.7	5.786E+03	-1.717E+04	0.000E+00	2.296E+04	-1.717E+04	5.786E+03
46.7	1.391E+04	-1.565E+04	0.000E+00	2.957E+04	-1.565E+04	1.391E+04
48.9	-9.818E+03	-4.198E+02	0.000E+00	9.398E+03	-9.818E+03	-4.198E+02
48.9	5.392E+03	3.774E+03	0.000E+00	1.618E+03	3.774E+03	5.392E+03
48.9	2.060E+04	7.969E+03	0.000E+00	1.263E+04	7.969E+03	2.060E+04
48.9	-1.001E+04	-7.397E+02	0.000E+00	9.270E+03	-1.001E+04	-7.397E+02
48.9	5.389E+03	3.522E+03	0.000E+00	1.868E+03	3.522E+03	5.389E+03
48.9	2.079E+04	7.783E+03	0.000E+00	1.301E+04	7.783E+03	2.079E+04
51.2	4.647E+01	7.450E+03	0.000E+00	7.403E+03	4.647E+01	7.450E+03
51.2	5.451E+03	9.040E+03	0.000E+00	3.589E+03	5.451E+03	9.040E+03
51.2	1.086E+04	1.063E+04	0.000E+00	2.257E+02	1.063E+04	1.086E+04
53.5	5.382E+03	8.345E+03	0.000E+00	2.963E+03	5.382E+03	8.345E+03
53.5	5.558E+03	8.430E+03	0.000E+00	2.872E+03	5.558E+03	8.430E+03
53.5	5.733E+03	8.514E+03	0.000E+00	2.781E+03	5.733E+03	8.514E+03
53.5	5.423E+03	8.397E+03	0.000E+00	2.974E+03	5.423E+03	8.397E+03
53.5	5.558E+03	8.468E+03	0.000E+00	2.910E+03	5.558E+03	8.468E+03
53.5	5.693E+03	8.539E+03	0.000E+00	2.845E+03	5.693E+03	8.539E+03
55.7	6.293E+03	7.600E+03	0.000E+00	1.307E+03	6.293E+03	7.600E+03
55.7	5.623E+03	7.415E+03	0.000E+00	1.792E+03	5.623E+03	7.415E+03
55.7	4.953E+03	7.230E+03	0.000E+00	2.277E+03	4.953E+03	7.230E+03
58.0	5.933E+03	7.068E+03	0.000E+00	1.135E+03	5.933E+03	7.068E+03
58.0	5.662E+03	6.991E+03	0.000E+00	1.329E+03	5.662E+03	6.991E+03
58.0	5.391E+03	6.913E+03	0.000E+00	1.522E+03	5.391E+03	6.913E+03
58.0	5.974E+03	7.119E+03	0.000E+00	1.145E+03	5.974E+03	7.119E+03
58.0	5.662E+03	7.028E+03	0.000E+00	1.366E+03	5.662E+03	7.028E+03
58.0	5.350E+03	6.937E+03	0.000E+00	1.587E+03	5.350E+03	6.937E+03
60.2	5.701E+03	6.984E+03	0.000E+00	1.283E+03	5.701E+03	6.984E+03
60.2	5.693E+03	6.981E+03	0.000E+00	1.288E+03	5.693E+03	6.981E+03
60.2	5.685E+03	6.978E+03	0.000E+00	1.293E+03	5.685E+03	6.978E+03

SUBJECT	MADE BY	CHKD BY	BY		CHARGE NO.
Oyster Creek	TJA	JBE			N61147
	DATE 12/29/86	DATE 12/15	CHKD		SHT C13 OF
			DATE		

OYSTER CREEK MODIFIED EMBEDMENT, CASE 1: P=35 TT. (J=281

COORD	S PHI	S THETA	S SHEAR	S1-S2	S1-S3	S2-S3
PART 1						
FACES=-1. 1. 2.						
62.5	5.645E+03	6.942E+03	0.000E+00	1.297E+03	5.645E+03	6.942E+03
62.5	5.720E+03	6.965E+03	0.000E+00	1.245E+03	5.720E+03	6.965E+03
62.5	5.796E+03	6.988E+03	0.000E+00	1.192E+03	5.794E+03	6.988E+03
62.5	5.687E+03	6.993E+03	0.000E+00	1.306E+03	5.687E+03	6.993E+03
62.5	5.720E+03	7.003E+03	0.000E+00	1.282E+03	5.720E+03	7.003E+03
62.5	5.754E+03	7.012E+03	0.000E+00	1.258E+03	5.754E+03	7.012E+03
64.7	5.699E+03	6.979E+03	0.000E+00	1.280E+03	5.699E+03	6.979E+03
64.7	5.745E+03	6.993E+03	0.000E+00	1.248E+03	5.745E+03	6.993E+03
64.7	5.791E+03	7.007E+03	0.000E+00	1.216E+03	5.791E+03	7.007E+03
67.0	5.722E+03	6.926E+03	0.000E+00	1.204E+03	5.722E+03	6.926E+03
67.0	5.767E+03	6.940E+03	0.000E+00	1.173E+03	5.767E+03	6.940E+03
67.0	5.812E+03	6.954E+03	0.000E+00	1.143E+03	5.812E+03	6.954E+03

Embedment at elevation 12'-3 ~ no thermal transition length

SUBJECT	MADE BY	CHKD BY	BY	CHARGE NO.
Oyster Creek	TJA	JSE		NG1147
	DATE 12/29/86	DATE [illegible]	CHKD	SHEET C14 OF
			DATE	

OYSTER CREEK MODIFIL EMBEDMENT, CASE 2: P=62 T AXI=179

PART 1 — *Embedment at elevation 12'-3 ~ no thermal transition lo…*

FACES=-1. 1. 2.

COORD	S PHI	S THETA	S SHEAR	S1-S2	S1-S3	S2-S3
44.4	6.655E+04	2.001E+04	0.000E+00	4.654E+04	2.001E+04	6.655E+04
44.4	1.150E+04	3.495E+03	0.000E+00	8.002E+03	3.495E+03	1.150E+04
44.4	-4.356E+04	-1.302E+04	0.000E+00	3.053E+04	-4.356E+04	-1.302E+04
46.7	5.365E+03	-4.534E+03	0.000E+00	9.898E+03	-4.534E+03	5.365E+03
46.7	1.056E+04	-3.568E+03	0.000E+00	1.413E+04	-3.568E+03	1.056E+04
46.7	1.576E+04	-2.602E+03	0.000E+00	1.837E+04	-2.602E+03	1.576E+04
48.9	5.678E+02	7.301E+03	0.000E+00	6.733E+03	5.678E+02	7.301E+03
48.9	1.033E+04	9.990E+03	0.000E+00	3.445E+02	9.990E+03	1.033E+04
48.9	2.010E+04	1.268E+04	0.000E+00	7.422E+03	1.268E+04	2.010E+04
48.9	3.878E+02	7.011E+03	0.000E+00	6.623E+03	3.878E+02	7.011E+03
48.9	1.033E+04	9.762E+03	0.000E+00	5.698E+02	9.762E+03	1.033E+04
48.9	2.028E+04	1.251E+04	0.000E+00	7.762E+03	1.251E+04	2.028E+04
51.2	6.901E+03	1.228E+04	0.000E+00	5.376E+03	6.901E+03	1.228E+04
51.2	1.039E+04	1.330E+04	0.000E+00	2.912E+03	1.039E+04	1.330E+04
51.2	1.388E+04	1.433E+04	0.000E+00	4.485E+02	1.388E+04	1.433E+04
53.5	1.036E+04	1.284E+04	0.000E+00	2.472E+03	1.036E+04	1.284E+04
53.5	1.048E+04	1.289E+04	0.000E+00	2.413E+03	1.048E+04	1.289E+04
53.5	1.059E+04	1.295E+04	0.000E+00	2.353E+03	1.059E+04	1.295E+04
53.5	1.039E+04	1.287E+04	0.000E+00	2.479E+03	1.039E+04	1.287E+04
53.5	1.048E+04	1.292E+04	0.000E+00	2.438E+03	1.048E+04	1.292E+04
53.5	1.057E+04	1.296E+04	0.000E+00	2.397E+03	1.057E+04	1.296E+04
55.7	1.097E+04	1.234E+04	0.000E+00	1.371E+03	1.097E+04	1.234E+04
55.7	1.054E+04	1.222E+04	0.000E+00	1.687E+03	1.054E+04	1.222E+04
55.7	1.010E+04	1.210E+04	0.000E+00	2.003E+03	1.010E+04	1.210E+04
58.0	1.076E+04	1.199E+04	0.000E+00	1.236E+03	1.076E+04	1.199E+04
58.0	1.057E+04	1.194E+04	0.000E+00	1.365E+03	1.057E+04	1.194E+04
58.0	1.039E+04	1.189E+04	0.000E+00	1.494E+03	1.039E+04	1.189E+04
58.0	1.078E+04	1.202E+04	0.000E+00	1.240E+03	1.078E+04	1.202E+04
58.0	1.057E+04	1.196E+04	0.000E+00	1.384E+03	1.057E+04	1.196E+04
58.0	1.037E+04	1.190E+04	0.000E+00	1.528E+03	1.037E+04	1.190E+04
60.2	1.062E+04	1.192E+04	0.000E+00	1.305E+03	1.062E+04	1.192E+04
60.2	1.061E+04	1.192E+04	0.000E+00	1.312E+03	1.061E+04	1.192E+04
60.2	1.059E+04	1.191E+04	0.000E+00	1.320E+03	1.059E+04	1.191E+04

SUBJECT	MADE BY	CHKD BY	REV	BY		CHARGE NO.
Oyster Creek	TJA	JSB		CHKD		N61147
	DATE 12/[illegible]/86	DATE 12/86		DATE		SHT C15 OF

OYSTER CREEK MODIFIE EMBEDMENT, CASE 2: P=62 TI XI=175

PART 1 *Embedment at elevation 12'-3" no thermal transition length*

FACES=-1. 1. 2.

COORD	S PHI	S THETA	S SHEAR	SI-S2	SI-S3	S2-S3
62.5	1.059E+04	1.189E+04	0.000E+00	1.300E+03	1.059E+04	1.189E+04
62.5	1.063E+04	1.191E+04	0.000E+00	1.271E+03	1.063E+04	1.191E+04
62.5	1.068E+04	1.192E+04	0.000E+00	1.242E+03	1.068E+04	1.192E+04
62.5	1.061E+04	1.192E+04	0.000E+00	1.304E+03	1.061E+04	1.192E+04
62.5	1.063E+04	1.192E+04	0.000E+00	1.288E+03	1.063E+04	1.192E+04
62.5	1.066E+04	1.193E+04	0.000E+00	1.272E+03	1.066E+04	1.193E+04
64.7	1.063E+04	1.190E+04	0.000E+00	1.269E+03	1.063E+04	1.190E+04
64.7	1.066E+04	1.191E+04	0.000E+00	1.248E+03	1.066E+04	1.191E+04
64.7	1.069E+04	1.192E+04	0.000E+00	1.226E+03	1.069E+04	1.192E+04
67.0	1.065E+04	1.185E+04	0.000E+00	1.204E+03	1.065E+04	1.185E+04
67.0	1.068E+04	1.186E+04	0.000E+00	1.183E+03	1.068E+04	1.186E+04
67.0	1.071E+04	1.187E+04	0.000E+00	1.162E+03	1.071E+04	1.187E+04

OYSTER CREEK MODIFIE EMBEDMENT, CASE I: P=35 T(XI=281 W/INSULATION

PART 1

FACES=-1. 1. 2.

COORD	S PHI	S THETA	S SHEAR	S1-S2	S1-S3	S2-S3
44.4	5.255E+04	1.577E+04	0.000E+00	3.679E+04	1.577E+04	5.255E+04
44.4	5.990E+03	1.797E+03	0.000E+00	4.193E+03	1.797E+03	5.990E+03
44.4	-4.057E+04	-1.217E+04	0.000E+00	2.840E+04	-4.057E+04	-1.217E+04
46.7	9.915E+03	1.300E+03	0.000E+00	8.614E+03	1.300E+03	9.915E+03
46.7	5.696E+03	-7.210E+02	0.000E+00	6.417E+03	-7.210E+02	5.696E+03
46.7	1.477E+03	-2.742E+03	0.000E+00	4.219E+03	-2.742E+03	1.477E+03
48.9	-5.612E+03	-5.208E+02	0.000E+00	5.091E+03	-5.612E+03	-5.208E+02
48.9	5.536E+03	2.303E+03	0.000E+00	3.233E+03	2.303E+03	5.536E+03
48.9	1.668E+04	5.128E+03	0.000E+00	1.156E+04	5.128E+03	1.668E+04
48.9	-5.576E+03	-4.944E+02	0.000E+00	5.081E+03	-5.576E+03	-4.944E+02
48.9	5.536E+03	2.318E+03	0.000E+00	3.218E+03	2.318E+03	5.536E+03
48.9	1.665E+04	5.130E+03	0.000E+00	1.152E+04	5.130E+03	1.665E+04
51.2	-3.447E+03	3.973E+03	0.000E+00	7.419E+03	-3.447E+03	3.973E+03
51.2	5.461E+03	6.493E+03	0.000E+00	1.032E+03	5.461E+03	6.493E+03
51.2	1.437E+04	9.014E+03	0.000E+00	5.356E+03	9.014E+03	1.437E+04
53.5	3.209E+03	7.794E+03	0.000E+00	4.585E+03	3.209E+03	7.794E+03
53.5	5.539E+03	8.496E+03	0.000E+00	2.957E+03	5.539E+03	8.496E+03
53.5	7.869E+03	9.198E+03	0.000E+00	1.329E+03	7.869E+03	9.198E+03
53.5	3.235E+03	7.835E+03	0.000E+00	4.600E+03	3.235E+03	7.835E+03
53.5	5.539E+03	8.528E+03	0.000E+00	2.989E+03	5.539E+03	8.528E+03
53.5	7.843E+03	9.221E+03	0.000E+00	1.377E+03	7.843E+03	9.221E+03
55.7	5.854E+03	7.850E+03	0.000E+00	1.997E+03	5.854E+03	7.850E+03
55.7	5.614E+03	7.798E+03	0.000E+00	2.183E+03	5.614E+03	7.798E+03
55.7	5.375E+03	7.745E+03	0.000E+00	2.370E+03	5.375E+03	7.745E+03
58.0	6.054E+03	7.255E+03	0.000E+00	1.201E+03	6.054E+03	7.255E+03
58.0	5.661E+03	7.145E+03	0.000E+00	1.485E+03	5.661E+03	7.145E+03
58.0	5.268E+03	7.036E+03	0.000E+00	1.768E+03	5.268E+03	7.036E+03
58.0	6.095E+03	7.306E+03	0.000E+00	1.211E+03	6.095E+03	7.306E+03
58.0	5.661E+03	7.183E+03	0.000E+00	1.522E+03	5.661E+03	7.183E+03
58.0	5.227E+03	7.060E+03	0.000E+00	1.833E+03	5.227E+03	7.060E+03
60.2	5.814E+03	7.029E+03	0.000E+00	1.214E+03	5.814E+03	7.029E+03
60.2	5.694E+03	6.993E+03	0.000E+00	1.300E+03	5.694E+03	6.993E+03
60.2	5.573E+03	6.958E+03	0.000E+00	1.385E+03	5.573E+03	6.958E+03

OYSTER CREEK MODIFIED ABEDMENT, CASE 1: P=35 T(?)=281 W/INSULATION

COORD	S PHI	S THETA	S SHEAR	S1-S2	S1-S3	S2-S3
PART 1						
FACES=-1. 1. 2.						
62.5	5.676E+03	6.935E+03	0.000E+00	1.259E+03	5.676E+03	6.935E+03
62.5	5.721E+03	6.949E+03	0.000E+00	1.228E+03	5.721E+03	6.949E+03
62.5	5.765E+03	6.962E+03	0.000E+00	1.197E+03	5.765E+03	6.962E+03
62.5	5.718E+03	6.986E+03	0.000E+00	1.268E+03	5.718E+03	6.986E+03
62.5	5.721E+03	6.986E+03	0.000E+00	1.266E+03	5.721E+03	6.986E+03
62.5	5.724E+03	6.987E+03	0.000E+00	1.263E+03	5.724E+03	6.987E+03
64.7	5.695E+03	6.970E+03	0.000E+00	1.275E+03	5.695E+03	6.970E+03
64.7	5.745E+03	6.985E+03	0.000E+00	1.240E+03	5.745E+03	6.985E+03
64.7	5.796E+03	7.000E+03	0.000E+00	1.204E+03	5.796E+03	7.000E+03
67.0	5.711E+03	6.920E+03	0.000E+00	1.209E+03	5.711E+03	6.920E+03
67.0	5.767E+03	6.937E+03	0.000E+00	1.171E+03	5.767E+03	6.937E+03
67.0	5.823E+03	6.955E+03	0.000E+00	1.132E+03	5.823E+03	6.955E+03

SUBJECT	MADE BY	CHKD BY	REV BY		CHARGE NO.
Oyster Creek	JJA	JSF	CHKD		NG1147
	DATE 12/29/86	DATE 12/56	DATE		SHT C18 OF

OYSTER CREEK MODIFIT EMBEDMENT, CASE 2: P=62 TF (X)=175 W/INSULATION

COORD	S PHI	S THETA	S SHEAR	S1-S2	S1-S3	S2-S3
PART 1						
FACES=-1. 1. 2.						
44.4	4.583E+04	1.375E+04	0.000E+00	3.208E+04	1.375E+04	4.583E+04
44.4	1.084E+04	3.251E+03	0.000E+00	7.585E+03	3.251E+03	1.084E+04
44.4	-2.416E+04	-7.248E+03	0.000E+00	1.691E+04	-2.416E+04	-7.248E+03
46.7	1.153E+04	5.691E+03	0.000E+00	5.834E+03	5.691E+03	1.153E+04
46.7	1.052E+04	4.882E+03	0.000E+00	5.636E+03	4.882E+03	1.052E+04
46.7	9.511E+03	4.073E+03	0.000E+00	5.438E+03	4.073E+03	9.511E+03
48.9	2.622E+03	7.103E+03	0.000E+00	4.481E+03	2.622E+03	7.103E+03
48.9	1.041E+04	9.125E+03	0.000E+00	1.281E+03	9.125E+03	1.041E+04
48.9	1.819E+04	1.115E+04	0.000E+00	7.044E+03	1.115E+04	1.819E+04
48.9	2.645E+03	7.125E+03	0.000E+00	4.480E+03	2.644E+03	7.125E+03
48.9	1.041E+04	9.139E+03	0.000E+00	1.267E+03	9.139E+03	1.041E+04
48.9	1.817E+04	1.115E+04	0.000E+00	7.015E+03	1.115E+04	1.817E+04
51.2	5.118E+03	1.050E+04	0.000E+00	5.386E+03	5.118E+03	1.050E+04
51.2	1.040E+04	1.201E+04	0.000E+00	1.609E+03	1.040E+04	1.201E+04
51.2	1.568E+04	1.351E+04	0.000E+00	2.169E+03	1.351E+04	1.568E+04
53.5	9.256E+03	1.256E+04	0.000E+00	3.300E+03	9.256E+03	1.256E+04
53.5	1.047E+04	1.293E+04	0.000E+00	2.456E+03	1.047E+04	1.293E+04
53.5	1.168E+04	1.330E+04	0.000E+00	1.613E+03	1.168E+04	1.330E+04
53.5	9.276E+03	1.259E+04	0.000E+00	3.309E+03	9.276E+03	1.259E+04
53.5	1.047E+04	1.295E+04	0.000E+00	2.479E+03	1.047E+04	1.295E+04
53.5	1.166E+04	1.331E+04	0.000E+00	1.649E+03	1.166E+04	1.331E+04
55.7	1.075E+04	1.247E+04	0.000E+00	1.722E+03	1.075E+04	1.247E+04
55.7	1.053E+04	1.242E+04	0.000E+00	1.886E+03	1.053E+04	1.242E+04
55.7	1.031E+04	1.236E+04	0.000E+00	2.050E+03	1.031E+04	1.236E+04
58.0	1.082E+04	1.209E+04	0.000E+00	1.270E+03	1.082E+04	1.209E+04
58.0	1.057E+04	1.202E+04	0.000E+00	1.449E+03	1.057E+04	1.202E+04
58.0	1.033E+04	1.195E+04	0.000E+00	1.619E+03	1.033E+04	1.195E+04
58.0	1.084E+04	1.211E+04	0.000E+00	1.274E+03	1.084E+04	1.211E+04
58.0	1.057E+04	1.204E+04	0.000E+00	1.444E+03	1.057E+04	1.204E+04
58.0	1.031E+04	1.196E+04	0.000E+00	1.653E+03	1.031E+04	1.196E+04
60.2	1.068E+04	1.194E+04	0.000E+00	1.270E+03	1.068E+04	1.194E+04
60.2	1.061E+04	1.192E+04	0.000E+00	1.318E+03	1.061E+04	1.192E+04
60.2	1.054E+04	1.190E+04	0.000E+00	1.367E+03	1.054E+04	1.190E+04

SUBJECT	MADE BY	CHKD BY		BY		CHARGE NO.
Oyster Creek	TJA	FE				N61147
	DATE 12/8/86	DATE 12/86		CHKD / DATE		SHT C19 OF

OYSTER CREEK MODIFIED EMBEDMENT, CASE 2: P=62 TIN=XI=175 W/INSULATION

COORD	S PHI	S THETA	S SHEAR	S1-S2	S1-S3	S2-S3

PART 1

FACES=-1. 1. 2.

COORD	S PHI	S THETA	S SHEAR	S1-S2	S1-S3	S2-S3
62.5	1.061E+04	1.189E+04	0.000E+00	1.281E+03	1.061E+04	1.189E+04
62.5	1.063E+04	1.190E+04	0.000E+00	1.263E+03	1.063E+04	1.190E+04
62.5	1.066E+04	1.190E+04	0.000E+00	1.245E+03	1.066E+04	1.190E+04
62.5	1.063E+04	1.191E+04	0.000E+00	1.284E+03	1.063E+04	1.191E+04
62.5	1.063E+04	1.191E+04	0.000E+00	1.279E+03	1.063E+04	1.191E+04
62.5	1.064E+04	1.191E+04	0.000E+00	1.274E+03	1.064E+04	1.191E+04
64.7	1.063E+04	1.189E+04	0.000E+00	1.267E+03	1.063E+04	1.189E+04
64.7	1.066E+04	1.190E+04	0.000E+00	1.244E+03	1.066E+04	1.190E+04
64.7	1.069E+04	1.191E+04	0.000E+00	1.220E+03	1.069E+04	1.191E+04
67.0	1.064E+04	1.185E+04	0.000E+00	1.207E+03	1.064E+04	1.185E+04
67.0	1.068E+04	1.186E+04	0.000E+00	1.182E+03	1.068E+04	1.186E+04
67.0	1.072E+04	1.187E+04	0.000E+00	1.157E+03	1.072E+04	1.187E+04

SUBJECT	MADE BY	CHKD BY	REV		CHARGE NO.
Oyster Creek	TJA	JSB	BY		N61147
	DATE 12/29/86	DATE 12/5/86	CHKD		
			DATE		SHT C20 OF

APPENDIX D

CBI COMPUTER PROGRAM

778

INPUT AND OUTPUT

FOR

STABILITY ANALYSIS

CBI PROGRAM 778

DRYWELL PRIMARY MEMBRANE STRESS ANALYSIS

This Program performs a primary membrane stress analysis of a containment vessel drywell. The drywell shell can be analyzed for any combination of 14 loading conditions, including earthquake.

The drywell shell is analyzed for stresses due to the customer specified loading combinations. Primary membrane stresses are computed for each of the loading combinations. The resulting stresses are compared to ASME Code allowables. In addition, the compressive stresses are compared to an allowable buckling stress.

The drywell primary membrane stresses are found using the general equations for an axisymmetrically loaded shell of revolution. The derivation of the general equations can be found in Chapter 14 of Theory of Plates and Shell by Timoshenko. The equations are as follows:

General Equation #1: $$\frac{N_\phi}{R_\phi} + \frac{N_\theta}{R_\theta} = P$$

General Equation #2: $$2\pi r_o N_\phi \sin\phi + z = 0$$

where N_ϕ = meridional membrane stress resultant.
N_θ = circumferential membrane stress resultant.
R_ϕ = radius of curvature in meridional plane.
R_θ = radius of curvature in circumferential plane.
P = pressure.
ϕ = angle between pole of revolution and point.
z = resultant of total load on shell.
r_o = R_0 SINϕ.

SUBJECT	OFFICE	REVISION		REFERENCE NO.
Oyster Creek Stability Analysis	CBI Oak Brook			NG1147
	MADE BY: TJA / CHKD BY: PM	MADE BY	CHKD BY	SHT 01 OF __
	DATE: 2/5/87 / DATE: 2/5/87	DATE	DATE	

HORIZONTAL EARTHQUAKE

The effect of the horizontal earthquake is to produce a shear load acting on the shell at the elevation of the load. This shear is found by multiplying the load by the horizontal earthquake factor for the elevation of the load. This factor is taken from curves for horizontal earthquake given in the customer specifications. From statics the shear load can be considered to produce a moment at a lower elevation. This moment tends to rotate the drywell shell about the plane under consideration.

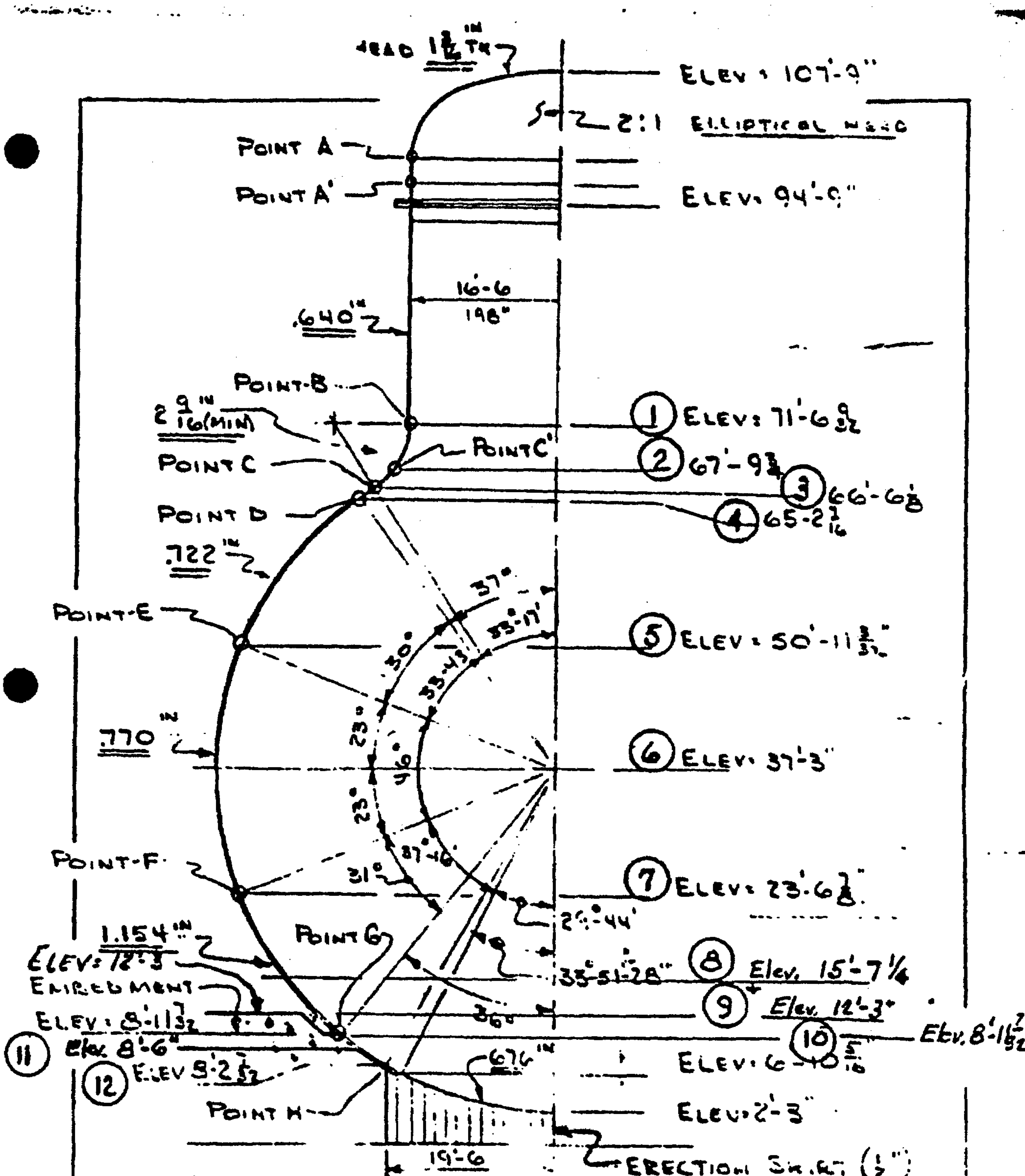
In the earthquake analysis the drywell is analyzed as a free standing, cantilevered column. However, the drywell can be supported by the surrounding building at the stabilizer elevation. This support is separated from the stabilizer of the drywell by a 10 mil gap. Thus, during the incidence of an earthquake, the vessel may generate a shear in the opposite direction to the shear of the applied loads. This shear is the reaction at the stabilizer elevation, which is treated in the same manner as the other shear loads. The reaction is found using a combination of Castigliano's First Theorem and the unit load method using the following equations:

$$\Delta = \frac{1}{E}\int \frac{M}{I}\frac{\partial M}{\partial P}\,dx + \frac{1}{G}\int \frac{V}{A}\frac{\partial V}{\partial P}\,dx$$

$$\therefore$$

$$\Delta_{\text{Imposed}} = \Delta_{\text{Hor. Eaqrthquake}} + \Delta_{\text{unit load}} \times \text{Reaction}$$

SUBJECT	OFFICE	REVISION		REFERENCE NO.
Oyster Creek Stablity Analysis	CBI Oak Brook			N61147
	MADE BY: TJA / CHKD BY: PM	MADE BY	CHKD BY	SHT D2 OF
	DATE: 2/5/87 / DATE: 2/5/87	DATE	DATE	



SUBJECT	OFFICE		REVISION		REFERENCE NO.
	CBI Oak Brook				
	MADE BY	CHKD BY	MADE BY	CHKD BY	SH- D3 OF ___
	TJA	PM			
	DATE 1/26/87	DATE 2/5/87	DATE	DATE	

Printed in USA

GO 84 REV SEP 84

INPUT FOR ANALYSIS OF NUCLEAR CONTAINMENT DRYWELL
PROGRAM 778 - REVISION 1 DATED JANUARY 1974, IS IN EFFECT.

NUMBER OF POINTS TO EMBEDMENT= 10
NUMBER OF POINTS TO SKIRT = 12
CODE FOR ANG OR EL= 1 1=ELEVATIONS INPUT
2=ANGLES INPUT
RADIUS OF SPHERE= 420.0000 IN
RADIUS OF CYLINDER= 198.0000 IN
RADIUS OF KNUCKLE = 72.0000 IN
RADIUS OF HEAD= 197.5000 IN

ELEVATION OF EQUATOR= 37.2500 FT
ELEVATION OF FLOODING= 74.5000 FT
ELEVATION OF STAY FORCE= 82.1670 FT
ELEVATION OF TOP OF HEAD= 107.7500 FT
ELEVATION OF FLANGE= 94.7500 FT

INTERNAL DESIGN PRESSURE= 35.00 PSI
INTERNAL OPERATING PRESSURE= 0.00 PSI
EXTERNAL OPERATING PRESSURE= 2.00 PSI

ALLOWABLE PRIMARY MEMBRANE STRESS= 19250.00 PSI
WEIGHT OF STEEL= 40.80 LBS/SQ.FT/IN.THK
OVERAGE(IN PERCENT)= 0.00
WEIGHT OF COMPRESSIBLE MATERIAL=10.00 LBS/SQ. FT
MODULUS OF ELASTICITY= 29600000. PSI
SHEAR MODULUS= 11500000. PSI

THICKNESS OF CYLINDER= 0.6400 IN
THICKNESS OF KNUCKLE= 2.7500 IN
THICKNESS OF HEAD = 1.1875 IN
THICKNESS OF CYLINDER ON HEAD = 2.2500 IN
THICKNESS OF CYLINDER ON BOTTOM FLANGE = 2.2500 IN
LENGTH OF CYLINDER ON BOTTOM FLANGE = 40.00 IN
THICKNESS OF CONE = 1.5000 IN
ANGLE OF CONE = 30.0000 DEGREES

IMPOSED DRYWELL DEFLECTION = 0.03 IN

JET LOADINGS ON HEAD

YIELD STRENGTH OF STEEL = 33700. PSI AT 300.0 DEGREES
JET LOAD = 34000. LBS ON AN AREA = 0.1810 SQ.FT
PERCENT OF YIELD FOR ALLOWABLE STRESS = 90.

INPUT FOR ANALYSIS OF NUCLEAR CONTAINMENT DRYWELL
PROGRAM 778 - REVISION 1 DATED JANUARY 1974, IS IN EFFECT.

POINT	ELEV	SHELL THK
1	71.5230	2.7500
2	67.8130	2.7500
3	66.5100	2.7500
4	65.2030	0.7220
5	50.9250	0.7220
6	37.2500	0.7700
7	23.5730	0.7700
8	15.6040	1.1540
9	12.2500	1.1540
10	8.9350	1.1540
11	8.5000	1.1540
12	8.1850	1.1540

CODE FOR USE OF ROUTINE

PENETRA- TION	DEAD LOAD	LIVE LOAD	WATER LOADS	CONE ON CYLINDER	SKIRT	AIR
1	1	1	1	1	1	1

EARTHQUAKE CURVE DESCRIPTION

NO.CURVES	ELEVATION IN FEET							
3	7.00	16.00	24.00	37.00	50.00	70.00	90.00	108.00

CURVE NO.	SEISMIC COEFFICIENT							
1	0.2200	0.2200	0.2200	0.2200	0.2200	0.2200	0.2200	0.2200
2	0.1100	0.1100	0.1100	0.1100	0.1100	0.1100	0.1100	0.1100
3	0.2200	0.2200	0.2200	0.2200	0.2200	0.2200	0.2200	0.2200

VERTICAL SEISMIC COEFFICIENT =0.0500

LOADS TO BE CONSIDERED IN SUMMARY

```
0 MEANS NOT CONSIDERED      1 MEANS CONSIDERED
ACCIDENT PRESSURE.......1 MEANS DESIGN PRESSURE
                        2 MEANS 1.25 X DESIGN PRESSURE
EARTHQUAKE CURVE........1 MEANS CANTILEVER
                        2 MEANS STAYED
                        3 MEANS FLOODED
```

CBI CASE NUMBER 1 ACCT(35 PSI)

ACC PRESS	OPER PRESS	EXTER PRESS	EARQU CURVE	STEEL WT	COMP MATL	PENE WT	DEAD LOAD	LIVE LOAD	REFUEL WAT LD
1	0	0	2	1	1	1	1	1	0

OUTS BELL	INS BELL	AIR WT	STAY FORCE	HORIZ EARQU	VERT EARQU	FLOOD
0	0	0	1	1	1	0

CBI CASE NUMBER 3 OPER(EX-2 PSI)

ACC PRESS	OPER PRESS	EXTER PRESS	EARQU CURVE	STEEL WT	COMP MATL	PENE WT	DEAD LOAD	LIVE LOAD	REFUEL WAT LD
0	0	1	2	1	1	1	1	1	0

OUTS BELL	INS BELL	AIR WT	STAY FORCE	HORIZ EARQU	VERT EARQU	FLOOD
1	1	0	1	1	1	0

CBI CASE NUMBER 4/5 FLD ELEV 74.50

ACC PRESS	OPER PRESS	EXTER PRESS	EARQU CURVE	STEEL WT	COMP MATL	PENE WT	DEAD LOAD	LIVE LOAD	REFUEL WAT LD
0	0	0	3	1	1	1	1	0	0

OUTS BELL	INS BELL	AIR WT	STAY FORCE	HORIZ EARQU	VERT EARQU	FLOOD
0	0	0	1	1	1	2

PENETRATIONS (TOTAL NUMBER = 48)

MARK	ELEVATION	WEIGHT IN LBS(EST)
X - 54A	87.00	1000.00
X - 5 A THRU H	16.00	150000.00
X - 6	16.00	6000.00
X - 7 A THRU D	30.00	46600.00
X - 8	26.00	2450.00
X - 9A,9B	34.00	22600.00
X - 10,11	26.00	8650.00
X - 12,45	31.00	16500.00
X - 13A,13B	33.00	15450.00
X - 14,15,39B	70.00	5750.00
X - 43,44	54.00	7850.00
X - 16A,B	73.00	9850.00
X - 17	90.00	2750.00
X - 18,19	20.00	900.00
X - 20,21,22	40.00	850.00
X - 23,24,34A,B	20.00	6000.00
X - 25	90.00	3750.00
X - 27	90.00	1000.00
X - 28A-G	34.00	5450.00
X - 30AB,32A	16.00	3700.00
X - 31AB,53	16.00	3750.00
X - 26	20.00	3900.00
X - 35A THRU G	16.00	900.00
X - 36	60.00	700.00
X - 37 A THRU D	40.00	8100.00
X - 38A THRU D	40.00	8100.00
X - 42	20.00	400.00
X - 39A	30.00	850.00
X - 40AB,46A	30.00	2400.00
X - 46B,52,	30.00	1650.00
X - 49,50	35.00	1500.00
X - 51	32.00	750.00
X - 100AB,104B	40.00	2500.00
X - 105 A,D,107A	40.00	2900.00
X - 100C,D,G,104	40.00	4150.00
X - 105B,C,106B	40.00	2550.00
X - 100E,103A,10	40.00	2500.00
X - 102B	40.00	850.00
X - 101A-F	40.00	5100.00
X - 104CD	40.00	1650.00
X - 54B	90.00	1000.00
X - 55 A,B	90.00	2000.00
X - 102A,104A,10	40.00	2550.00
X - 100F,103B	40.00	1850.00
X - 29A,B,47,48	90.00	4000.00

CHICAGO BRIDGE & IRON COMPANY OAK BROOK ENGINEERING

PENETRATIONS CONTRACT GPU/O.C. DATE 01/15/87 BY TJA SHT D7 REV 1

CHKD PM 2/6/87

PENETRATIONS

MARK	ELEVATION	WEIGHT IN LBS
X - 32B,33A,33B	16.00	3750.00
X - 40CD	36.00	1550.00
X - 41	90.00	500.00

DEAD LOADS

LOAD	ELEVATION	WEIGHT IN LBS
UPPER HEADER	60.00	36000.00
LOWER HEADER	40.00	41000.00
UPPER WELD PADS	65.00	40000.00
MIDDLE WELD PADS	60.00	40000.00
LOWER WELD PADS	56.00	48000.00
TOP FLANGE	95.75	20100.00
BOTTOM FLANGE	93.75	20700.00
INNER WATER SEAL	93.00	0.00
STABILIZERS	82.17	21650.00
UPPER BEAM SEATS	50.00	1102000.00
LOWER BEAM SEATS	22.00	1102000.00
12 FT DIA EQ DOOR	30.25	48000.00
PERSONNEL LOCK	30.00	64100.00
VENTS	15.56	50000.00
13 FT DIA EQ DOOR	30.25	57000.00
UPPER WELD PADS	65.00	12000.00
MIDDLE WELD PADS	60.00	19200.00
LOWER WELD PADS	56.00	8400.00

DRYWELL SHELL IN CANTILEVER CONDITION

CHICAGO BRIDGE & IRON COMPANY OAK BROOK ENGINEERING
DEAD LOADS CONTRACT GPU/O.C. DATE 01/15/87 BY TJA SHT D9 REV 1

CHKD PM 2/6/87

LIVE LOADS

LOAD	ELEVATION	WEIGHT IN LBS
UPPER HEADER	60.00	4200.00
LOWER HEADER	40.00	7150.00
UPPER WELD PADS	65.00	20000.00
MIDDLE WELD PADS	60.00	20000.00
LOWER WELD PADS	56.00	24000.00
UPPER BEAM SEATS	50.00	0.00
EQUIP DOOR	30.25	100000.00
PERSONNEL LOCK	30.00	15000.00
LOWER BEAM SEATS	22.00	0.00

DRYWELL SHELL IN STAYED CONDITION

CHICAGO BRIDGE & IRON COMPANY — OAK BROOK ENGINEERING
LIVE LOADS — CONTRACT GPU/O.C. DATE 01/15/87 BY TJA SHT D10 REV 1

CHKD PM 2/6/87

SUMMATION OF STRESSES, CBI CASE 1 ACCT(35 PSI)

LOAD	POINT 1 MERID LB/IN	POINT 1 CIRCUM LB/IN	POINT 2 MERID LB/IN	POINT 2 CIRCUM LB/IN	POINT 3 MERID LB/IN	POINT 3 CIRCUM LB/IN
DESIGN INTERNAL PRESSURE	3465.	13552.	4759.	27495.	7350.	21401.
OPERATING PRESS	0.	0.	0.	0.	0.	0.
EXTERNAL PRESS	0.	0.	0.	0.	0.	0.
SHELL VERTICAL LOAD	-161.	-221.	-236.	-1019.	-344.	-1099.
HORZ SEISMIC ON SHELL	49.	67.	63.	237.	82.	197.
VERT SEISMIC ON SHELL	8.	11.	12.	51.	17.	55.
COMPRESSIBLE MATERIAL	-17.	-23.	-24.	-121.	-34.	-148.
HORZ SEISMIC ON C.M.	2.	3.	3.	13.	5.	11.
VERT SEISMIC ON C.M.	1.	1.	1.	6.	2.	7.
PENETRATION LOAD	-20.	-27.	-29.	-110.	-38.	-93.
HORZ SEISMIC ON PENE	3.	5.	5.	18.	6.	16.
VERT SEISMIC ON PENE	1.	1.	1.	5.	2.	5.
DEAD LOADS	-55.	-76.	-65.	-245.	-86.	-207.
HORZ SEISMIC ON D.L.	14.	19.	18.	69.	24.	57.
VERT SEISMIC ON D.L.	3.	4.	3.	12.	4.	10.
LIVE LOADS	0.	0.	0.	0.	0.	0.
HORZ SEISMIC ON L.L.	0.	0.	0.	0.	0.	0.
VERT SEISMIC ON L.L.	0.	0.	0.	0.	0.	0.
VERTICAL AIR LOAD	0.	0.	0.	0.	0.	0.
INSIDE BELLOWS	0.	0.	0.	0.	0.	0.
OUTSIDE BELLOWS	0.	0.	0.	0.	0.	0.
REFUELING WATER	0.	0.	0.	0.	0.	0.
HORZ SEISMIC ON WATER	0.	0.	0.	0.	0.	0.
VERT SEISMIC ON WATER	0.	0.	0.	0.	0.	0.
STAY FORCE	0.	0.	0.	-1.	0.	-1.
SUMMATION (+EQ)(LBS/IN)	3293.	13315.	4513.	26412.	6989.	20212.
SUMMATION (-EQ)(LBS/IN)	3132.	13094.	4299.	25590.	6706.	19490.
SUMMATION (+EQ)(PSI)	1225.	4955.	1679.	9828.	2600.	7521.
SUMMATION (-EQ)(PSI)	1165.	4872.	1600.	9522.	2495.	7254.
BUCKLING RATIO (+EQ)	~~0.0000~~		~~0.0000~~		~~0.0000~~	
BUCKLING RATIO (-EQ)	~~0.0000~~		~~0.0000~~		~~0.0000~~	

CHKD PM 2/6/87

SUMMATION OF STRESSES, CBI CASE 1 ACCT(35 PSI)

LOAD	POINT 4		POINT 5		POINT 6	
	MERID LB/IN	CIRCUM LB/IN	MERID LB/IN	CIRCUM LB/IN	MERID LB/IN	CIRCUM LB/IN
DESIGN INTERNAL PRESSURE	7350.	7350.	7350.	7350.	7350.	7350.
OPERATING PRESS	0.	0.	0.	0.	0.	0.
EXTERNAL PRESS	0.	0.	0.	0.	0.	0.
SHELL VERTICAL LOAD	-320.	252.	-178.	145.	-187.	187.
HORZ SEISMIC ON SHELL	66.	-66.	34.	-34.	41.	-41.
VERT SEISMIC ON SHELL	16.	-13.	9.	-7.	9.	-9.
COMPRESSIBLE MATERIAL	-31.	15.	-27.	19.	-35.	35.
HORZ SEISMIC ON C.M.	4.	-4.	3.	-3.	5.	-5.
VERT SEISMIC ON C.M.	2.	-1.	1.	-1.	2.	-2.
PENETRATION LOAD	-32.	32.	-18.	18.	-31.	31.
HORZ SEISMIC ON PENE	5.	-5.	3.	-3.	4.	-4.
VERT SEISMIC ON PENE	2.	-2.	1.	-1.	2.	-2.
DEAD LOADS	-71.	71.	-122.	122.	-536.	536.
HORZ SEISMIC ON D.L.	19.	-19.	14.	-14.	54.	-54.
VERT SEISMIC ON D.L.	4.	-4.	6.	-6.	27.	-27.
LIVE LOADS	0.	0.	-30.	30.	-29.	29.
HORZ SEISMIC ON L.L.	0.	0.	2.	-2.	4.	-4.
VERT SEISMIC ON L.L.	0.	0.	2.	-2.	1.	-1.
VERTICAL AIR LOAD	0.	0.	0.	0.	0.	0.
INSIDE BELLOWS	0.	0.	0.	0.	0.	0.
OUTSIDE BELLOWS	0.	0.	0.	0.	0.	0.
REFUELING WATER	0.	0.	0.	0.	0.	0.
HORZ SEISMIC ON WATER	0.	0.	0.	0.	0.	0.
VERT SEISMIC ON WATER	0.	0.	0.	0.	0.	0.
STAY FORCE	0.	0.	0.	0.	0.	0.
SUMMATION (+EQ)(LBS/IN)	7012.	7607.	7049.	7611.	6680.	9020.
SUMMATION (-EQ)(LBS/IN)	6778.	7632.	6900.	7756.	6384.	9316.
SUMMATION (+EQ)(PSI)	9712.	10536.	9763.	10542.	6675.	10415.
SUMMATION (-EQ)(PSI)	9388.	10848.	9557.	10743.	8291.	10799.
BUCKLING RATIO (+EQ)	~~0.0000~~		~~0.0000~~		~~0.0000~~	
BUCKLING RATIO (-EQ)	~~0.0000~~		~~0.0000~~		~~0.0000~~	

CHICAGO BRIDGE & IRON COMPANY OAK BROOK ENGINEERING
ACCT(35 PSI) CONTRACT GPU/O.C. DATE 01/15/87 BY TJA SHT D12 REV 1

CHKD PM 2/6/87

SUMMATION OF STRESSES, CBI CASE 1 ACCT(35 PSI)

LOAD	POINT 7		POINT 8		POINT 9	
	MERID LB/IN	CIRCUM LB/IN	MERID LB/IN	CIRCUM LB/IN	MERID LB/IN	CIRCUM LB/IN
DESIGN INTERNAL PRESSURE	7350.	7350.	7350.	7350.	7350.	7350.
OPERATING PRESS	0.	0.	0.	0.	0.	0.
EXTERNAL PRESS	0.	0.	0.	0.	0.	0.
SHELL VERTICAL LOAD	-263.	299.	-411.	496.	-545.	663.
HORZ SEISMIC ON SHELL	75.	-75.	145.	-145.	221.	-221.
VERT SEISMIC ON SHELL	13.	-15.	21.	-25.	27.	-32.
COMPRESSIBLE MATERIAL	-54.	63.	-85.	106.	-113.	137.
HORZ SEISMIC ON C.M.	11.	-11.	22.	-22.	35.	-35.
VERT SEISMIC ON C.M.	3.	-3.	4.	-5.	6.	-7.
PENETRATION LOAD	-93.	93.	-238.	238.	-300.	300.
HORZ SEISMIC ON PENE	11.	-11.	27.	-27.	47.	-47.
VERT SEISMIC ON PENE	5.	-5.	12.	-12.	15.	-15.
DEAD LOADS	-708.	708.	-1677.	1677.	-2113.	2113.
HORZ SEISMIC ON D.L.	131.	-131.	307.	-307.	498.	-498.
VERT SEISMIC ON D.L.	35.	-35.	84.	-84.	106.	-106.
LIVE LOADS	-85.	85.	-117.	117.	-147.	147.
HORZ SEISMIC ON L.L.	10.	-10.	24.	-24.	38.	-38.
VERT SEISMIC ON L.L.	4.	-4.	6.	-6.	7.	-7.
VERTICAL AIR LOAD	0.	0.	0.	0.	0.	0.
INSIDE BELLOWS	0.	0.	0.	0.	0.	0.
OUTSIDE BELLOWS	0.	0.	0.	0.	0.	0.
REFUELING WATER	0.	0.	0.	0.	0.	0.
HORZ SEISMIC ON WATER	0.	0.	0.	0.	0.	0.
VERT SEISMIC ON WATER	0.	0.	0.	0.	0.	0.
STAY FORCE	0.	0.	0.	0.	-1.	1.
SUMMATION (+EQ)(LBS/IN)	6445.	8298.	5473.	9327.	5132.	9684.
SUMMATION (-EQ)(LBS/IN)	5847.	8999.	4170.	10640.	3133.	11695.
SUMMATION (+EQ)(PSI)	8370.	10776.	4743.	8083.	4447.	8392.
SUMMATION (-EQ)(PSI)	7594.	11558.	3614.	9220.	2715.	10134.
BUCKLING RATIO (+EQ)	~~0.0000~~		~~0.0000~~		~~0.0000~~	
BUCKLING RATIO (-EQ)	~~0.0000~~		~~0.0000~~		~~0.0000~~	

CHICAGO BRIDGE & IRON COMPANY — OAK BROOK ENGINEERING

ACCT(35 PSI) CONTRACT GPU/O.C. DATE 01/15/87 BY TJA SHT D13 REV 1

CHKD PM 2/6/87

SUMMATION OF STRESSES, CBI CASE 1 ACCT(35 PSI)

LOAD	POINT 10 MERID LB/IN	POINT 10 CIRCUM LB/IN	POINT	POINT
DESIGN INTERNAL PRESSURE	7350.	7350.		
OPERATING PRESS	0.	0.		
EXTERNAL PRESS	0.	0.		
SHELL VERTICAL LOAD	-808.	919.		
HORZ SEISMIC ON SHELL	401.	-401.		
VERT SEISMIC ON SHELL	40.	-46.		
COMPRESSIBLE MATERIAL	-168.	195.		
HORZ SEISMIC ON C.M.	65.	-65.		
VERT SEISMIC ON C.M.	8.	-10.		
PENETRATION LOAD	-424.	424.		
HORZ SEISMIC ON PENE	94.	-94.		
VERT SEISMIC ON PENE	21.	-21.		
DEAD LOADS	-2991.	2991.		
HORZ SEISMIC ON D.L.	944.	-944.		
VERT SEISMIC ON D.L.	150.	-150.		
LIVE LOADS	-208.	208.		
HORZ SEISMIC ON L.L.	72.	-72.		
VERT SEISMIC ON L.L.	10.	-10.		
VERTICAL AIR LOAD	0.	0.		
INSIDE BELLOWS	0.	0.		
OUTSIDE BELLOWS	0.	0.		
REFUELING WATER	0.	0.		
HORZ SEISMIC ON WATER	0.	0.		
VERT SEISMIC ON WATER	0.	0.		
STAY FORCE	-1.	1.		
SUMMATION (+EQ)(LBS/IN)	4554.	10277.		
SUMMATION (-EQ)(LBS/IN)	946.	13899.		
SUMMATION (+EQ)(PSI)	3946.	8906.		
SUMMATION (-EQ)(PSI)	820.	12044.		
BUCKLING RATIO (+EQ)	~~0.0000~~			
BUCKLING RATIO (-EQ)	~~0.0000~~			

CHICAGO BRIDGE & IRON COMPANY OAK BROOK ENGINEERING
ACCT(35 PSI) CONTRACT GPU/O.C. DATE 01/15/87 BY TJA SHT D14 REV 1
CHKD PM 2/4/87

SUMMATION OF STRESSES, CBI CASE 3 OPER(EX-2 PSI)

LOAD	POINT 1 MERID LB/IN	POINT 1 CIRCUM LB/IN	POINT 2 MERID LB/IN	POINT 2 CIRCUM LB/IN	POINT 3 MERID LB/IN	POINT 3 CIRCUM LB/IN
DESIGN INTERNAL PRESSURE	0.	0.	0.	0.	0.	0.
OPERATING PRESS	0.	0.	0.	0.	0.	0.
EXTERNAL PRESS	-198.	-774.	-272.	-1571.	-420.	-1223.
SHELL VERTICAL LOAD	-161.	-221.	-236.	-1019.	-344.	-1099.
HORZ SEISMIC ON SHELL	49.	67.	63.	237.	82.	197.
VERT SEISMIC ON SHELL	8.	11.	12.	51.	17.	55.
COMPRESSIBLE MATERIAL	-17.	-23.	-24.	-121.	-34.	-148.
HORZ SEISMIC ON C.M.	2.	3.	3.	13.	5.	11.
VERT SEISMIC ON C.M.	1.	1.	1.	6.	2.	7.
PENETRATION LOAD	-20.	-27.	-29.	-110.	-38.	-93.
HORZ SEISMIC ON PENE	3.	5.	5.	18.	6.	16.
VERT SEISMIC ON PENE	1.	1.	1.	5.	2.	5.
DEAD LOADS	-55.	-76.	-65.	-245.	-86.	-207.
HORZ SEISMIC ON D.L.	14.	19.	19.	69.	24.	57.
VERT SEISMIC ON D.L.	3.	4.	3.	12.	4.	10.
LIVE LOADS	0.	0.	0.	0.	0.	0.
HORZ SEISMIC ON L.L.	0.	0.	0.	0.	0.	0.
VERT SEISMIC ON L.L.	0.	0.	0.	0.	0.	0.
VERTICAL AIR LOAD	0.	0.	0.	0.	0.	0.
INSIDE BELLOWS	42.	58.	50.	189.	66.	160.
OUTSIDE BELLOWS	-33.	-45.	-38.	-145.	-51.	-123.
REFUELING WATER	0.	0.	0.	0.	0.	0.
HORZ SEISMIC ON WATER	0.	0.	0.	0.	0.	0.
VERT SEISMIC ON WATER	0.	0.	0.	0.	0.	0.
STAY FORCE	0.	0.	0.	-1.	0.	-1.
SUMMATION (+EQ)(LBS/IN)	-360.	-997.	-507.	-2610.	-766.	-2374.
SUMMATION (-EQ)(LBS/IN)	-521.	-1218.	-720.	-3432.	-1049.	-3091.
SUMMATION (+EQ)(PSI)	-134.	-371.	-189.	-971.	-285.	-894.
SUMMATION (-EQ)(PSI)	-194.	-453.	-268.	-1277.	-390.	-1150.
BUCKLING RATIO (+EQ)	~~0.0207~~		~~0.0652~~		~~0.1014~~	
BUCKLING RATIO (-EQ)	~~0.0265~~		~~0.0860~~		~~0.1337~~	

CHICAGO BRIDGE & IRON COMPANY — OAK BROOK ENGINEERING

OPER(EX-2 PSI) CONTRACT GPU/O.C. DATE 01/15/87 BY TA SHT D16 REV 1

CHKD EM 2/6/87

SUMMATION OF STRESSES, CBI CASE 3 OPER(EX-2 PSI)

LOAD	POINT 4 MERID LB/IN	POINT 4 CIRCUM LB/IN	POINT 5 MERID LB/IN	POINT 5 CIRCUM LB/IN	POINT 6 MERID LB/IN	POINT 6 CIRCUM LB/IN
DESIGN INTERNAL PRESSURE	0.	0.	0.	0.	0.	0.
OPERATING PRESS	0.	0.	0.	0.	0.	0.
EXTERNAL PRESS	-420.	-420.	-420.	-420.	-420.	-420.
SHELL VERTICAL LOAD	-320.	252.	-178.	145.	-187.	187.
HORZ SEISMIC ON SHELL	66.	-66.	34.	-34.	41.	-41.
VERT SEISMIC ON SHELL	16.	-13.	9.	-7.	9.	-9.
COMPRESSIBLE MATERIAL	-31.	15.	-27.	19.	-35.	35.
HORZ SEISMIC ON C.M.	4.	-4.	3.	-3.	5.	-5.
VERT SEISMIC ON C.M.	2.	-1.	1.	-1.	2.	-2.
PENETRATION LOAD	-32.	32.	-18.	18.	-31.	31.
HORZ SEISMIC ON PENE	5.	-5.	3.	-3.	4.	-4.
VERT SEISMIC ON PENE	2.	-2.	1.	-1.	2.	-2.
DEAD LOADS	-71.	71.	-122.	122.	-536.	536.
HORZ SEISMIC ON D.L.	19.	-19.	14.	-14.	54.	-54.
VERT SEISMIC ON D.L.	4.	-4.	6.	-6.	27.	-27.
LIVE LOADS	0.	0.	-30.	30.	-29.	29.
HORZ SEISMIC ON L.L.	0.	0.	2.	-2.	4.	-4.
VERT SEISMIC ON L.L.	0.	0.	2.	-2.	1.	-1.
VERTICAL AIR LOAD	0.	0.	0.	0.	0.	0.
INSIDE BELLOWS	55.	-55.	24.	-24.	20.	-20.
OUTSIDE BELLOWS	-42.	42.	-18.	18.	-15.	15.
REFUELING WATER	0.	0.	0.	0.	0.	0.
HORZ SEISMIC ON WATER	0.	0.	0.	0.	0.	0.
VERT SEISMIC ON WATER	0.	0.	0.	0.	0.	0.
STAY FORCE	0.	0.	0.	0.	0.	0.
SUMMATION (+EQ)(LBS/IN)	-745.	-176.	-716.	-164.	-1085.	245.
SUMMATION (-EQ)(LBS/IN)	-979.	49.	-965.	-19.	-1381.	541.
SUMMATION (+EQ)(PSI)	-1032.	-244.	-991.	-227.	-1409.	319.
SUMMATION (-EQ)(PSI)	-1356.	68.	-1198.	-27.	-1793.	703.
BUCKLING RATIO (+EQ)	~~0.4123~~		~~0.3938~~		~~0.4271~~	
BUCKLING RATIO (-EQ)	~~0.4381~~		~~0.3956~~		~~0.5435~~	

CHICAGO BRIDGE & IRON COMPANY — OAK BROOK ENGINEERING

OPER(EX-2 PSI) — CONTRACT GPU/O.C. DATE 01/15/87 BY TJA SHT D16 REV 1

CHKD PM 2/6/87

SUMMATION OF STRESSES, CBI CASE 3 OPER(EX-2 PSI)

LOAD	POINT 7 MERID LB/IN	POINT 7 CIRCUM LB/IN	POINT 8 MERID LB/IN	POINT 8 CIRCUM LB/IN	POINT 9 MERID LB/IN	POINT 9 CIRCUM LB/IN
DESIGN INTERNAL PRESSURE	0.	0.	0.	0.	0.	0.
OPERATING PRESS	0.	0.	0.	0.	0.	0.
EXTERNAL PRESS	-420.	-420.	-420.	-420.	-420.	-420.
SHELL VERTICAL LOAD	-263.	299.	-411.	496.	-545.	543.
HORZ SEISMIC ON SHELL	75.	-75.	145.	-145.	221.	-221.
VERT SEISMIC ON SHELL	13.	-15.	21.	-25.	27.	-32.
COMPRESSIBLE MATERIAL	-54.	63.	-85.	106.	-113.	137.
HORZ SEISMIC ON C.M.	11.	-11.	22.	-22.	35.	-35.
VERT SEISMIC ON C.M.	3.	-3.	4.	-5.	6.	-7.
PENETRATION LOAD	-93.	93.	-239.	238.	-300.	300.
HORZ SEISMIC ON PENE	11.	-11.	27.	-27.	47.	-47.
VERT SEISMIC ON PENE	5.	-5.	12.	-12.	15.	-15.
DEAD LOADS	-708.	708.	-1677.	1677.	-2113.	2113.
HORZ SEISMIC ON D.L.	131.	-131.	307.	-307.	493.	-498.
VERT SEISMIC ON D.L.	35.	-35.	84.	-84.	106.	-106.
LIVE LOADS	-85.	85.	-117.	117.	-147.	147.
HORZ SEISMIC ON L.L.	10.	-10.	24.	-24.	38.	-38.
VERT SEISMIC ON L.L.	4.	-4.	6.	-6.	7.	-7.
VERTICAL AIR LOAD	0.	0.	0.	0.	0.	0.
INSIDE BELLOWS	24.	-24.	32.	-32.	41.	-41.
OUTSIDE BELLOWS	-18.	18.	-25.	25.	-31.	31.
REFUELING WATER	0.	0.	0.	0.	0.	0.
HORZ SEISMIC ON WATER	0.	0.	0.	0.	0.	0.
VERT SEISMIC ON WATER	0.	0.	0.	0.	0.	0.
STAY FORCE	0.	0.	0.	0.	-1.	1.
SUMMATION (+EQ)(LBS/IN)	-1320.	522.	-2289.	1550.	-2629.	1905.
SUMMATION (-EQ)(LBS/IN)	-1917.	1124.	-3592.	2863.	-4628.	3916.
SUMMATION (+EQ)(PSI)	-1714.	678.	-1984.	1343.	-2278.	1650.
SUMMATION (-EQ)(PSI)	-2490.	1460.	-3113.	2481.	-4010.	3393.
~~BUCKLING RATIO (+EQ)~~	~~0.5195~~		~~0.4011~~		~~0.4606~~	
~~BUCKLING RATIO (-EQ)~~	~~0.7545~~		~~0.6294~~		~~0.8100~~	

CHICAGO BRIDGE & IRON COMPANY — OAK BROOK ENGINEERING

OPER(EX-2 PSI) CONTRACT GPU/O.C. DATE 01/15/97 BY TJA SHT D17 REV 1

CHKD FM 2/3 97

SUMMATION OF STRESSES, CBI CASE 3 OPER(EX-2 PSI)

LOAD	POINT 10 MERID LB/IN	POINT 10 CIRCUM LB/IN	POINT	POINT
DESIGN INTERNAL PRESSURE	0.	0.		
OPERATING PRESS	0.	0.		
EXTERNAL PRESS	-420.	-420.		
SHELL VERTICAL LOAD	-808.	919.		
HORZ SEISMIC ON SHELL	401.	-401.		
VERT SEISMIC ON SHELL	40.	-46.		
COMPRESSIBLE MATERIAL	-168.	195.		
HORZ SEISMIC ON C.M.	65.	-65.		
VERT SEISMIC ON C.M.	9.	-10.		
PENETRATION LOAD	-424.	424.		
HORZ SEISMIC ON PENE	94.	-94.		
VERT SEISMIC ON PENE	21.	-21.		
DEAD LOADS	-2991.	2991.		
HORZ SEISMIC ON D.L.	944.	-944.		
VERT SEISMIC ON D.L.	150.	-150.		
LIVE LOADS	-208.	208.		
HORZ SEISMIC ON L.L.	72.	-72.		
VERT SEISMIC ON L.L.	10.	-10.		
VERTICAL AIR LOAD	0.	0.		
INSIDE BELLOWS	58.	-58.		
OUTSIDE BELLOWS	-44.	44.		
REFUELING WATER	0.	0.		
HORZ SEISMIC ON WATER	0.	0.		
VERT SEISMIC ON WATER	0.	0.		
STAY FORCE	-1.	1.		
SUMMATION (+EQ)(LBS/IN)	-3202.	2494.		
SUMMATION (-EQ)(LBS/IN)	-6811.	6116.		
SUMMATION (+EQ)(PSI)	-2775.	2161.		
SUMMATION (-EQ)(PSI)	-5902.	5300.		
~~BUCKLING RATIO (+EQ)~~	~~0.5611~~			
~~BUCKLING RATIO (-EQ)~~	~~1.1933~~			

CHICAGO BRIDGE & IRON COMPANY OAK BROOK ENGINEERING
OPER(EX-2 PSI) CONTRACT GPU/O.C. DATE 01/15/87 BY TJA SHT D18 REV 1

CHKD PM 2/6/87

SUMMATION OF STRESSES AT EMBEDMENT, CBI CASE 4 FLOODED TO ELEVATION 74.50 FT

NOTE STRESSES DUE TO HORIZONTAL & VERTICAL EARTHQUAKE ARE + OR -.
(+) EARTHQUAKE STRESSES YIELD A (+) MERIDIONAL STRESS RESULTANT

Point 1

	MERIDIONAL + SEISMIC (LB/IN)	- SEISMIC (LB/IN)
OVERHANGING WATER	0.	0.
VERT SEISMIC ON WATER	0.	0.
WATER ABOVE FLANGE	0.	0.
VERT SEISMIC ON WATER	0.	0.
HOR SEISMIC ON ALL WATER	5.	-5.
SHELL VERTICAL LOAD	-161.	-161.
HOR SEISMIC ON SHELL	97.	-97.
VERT SEISMIC ON SHELL	16.	-16.
COMPRESSIBLE MATERIAL	-17.	-17.
HOR SEISMIC ON C.M.	4.	-4.
VERT SEISMIC ON C.M.	2.	-2.
PENETRATIONS	-20.	-20.
HOR SEISMIC ON PENE	7.	-7.
VERT SEISMIC ON PENE	2.	-2.
DEAD LOADS	-55.	-55.
HOR SEISMIC ON D.L.	28.	-28.
VERT SEISMIC ON D.L.	6.	-6.
LIVE LOADS	0.	0.
HOR SEISMIC ON L.L.	0.	0.
VERT SEISMIC ON L.L.	0.	0.
BUOYANCY	294.	294.
STAY FORCE	0.	0.
TOTAL	208	-126

MAX CIRCUMFERENTIAL = 257 LB/IN

~~ALLOW BUCKLING LOAD = 72429. LB/IN~~

~~FACTOR OF SAFETY = 0.000~~

CHICAGO BRIDGE & IRON COMPANY OAK BROOK ENGINEERING
FLD ELEV 74.5 CONTRACT GPU/O.C. DATE 01/15/87 BY TJA SHT D19 REV 1
CHKD PM 2/4/87

SUMMATION OF STRESSES AT EMBEDMENT, CBI CASE 4 FLOODED TO ELEVATION 74.50 FT

NOTE STRESSES DUE TO HORIZONTAL & VERTICAL EARTHQUAKE ARE + OR -.
(+) EARTHQUAKE STRESSES YIELD A (+) MERIDIONAL STRESS RESULTANT

Point 2

	MERIDIONAL + SEISMIC (LB/IN)	MERIDIONAL - SEISMIC (LB/IN)
OVERHANGING WATER	0.	0.
VERT SEISMIC ON WATER	0.	0.
WATER ABOVE FLANGE	0.	0.
VERT SEISMIC ON WATER	0.	0.
HOR SEISMIC ON ALL WATER	27.	-27.
SHELL VERTICAL LOAD	-236.	-235.
HOR SEISMIC ON SHELL	125.	-125.
VERT SEISMIC ON SHELL	24.	-24.
COMPRESSIBLE MATERIAL	-24.	-24.
HOR SEISMIC ON C.M.	7.	-7.
VERT SEISMIC ON C.M.	2.	-2.
PENETRATIONS	-29.	-29.
HOR SEISMIC ON PENE	10.	-10.
VERT SEISMIC ON PENE	3.	-3.
DEAD LOADS	-65.	-65.
HOR SEISMIC ON D.L.	37.	-37.
VERT SEISMIC ON D.L.	6.	-6.
LIVE LOADS	0.	0.
HOR SEISMIC ON L.L.	0.	0.
VERT SEISMIC ON L.L.	0.	0.
BUOYANCY	309.	309.
STAY FORCE	0.	0.
TOTAL	196	-286

MAX CIRCUMFERENTIAL = — LB/IN

~~ALLOW BUCKLING LOAD = 72950. LB/IN~~

~~FACTOR OF SAFETY = 0.000~~

CHICAGO BRIDGE & IRON COMPANY OAK BROOK ENGINEERING
FLD ELEV 74.5 CONTRACT GPU/O.C. DATE 01/15/87 BY TJA SHT D20 REV 1
CHKD PM 2/6/87

SUMMATION OF STRESSES AT EMBEDMENT, CBI CASE 4 FLOODED TO ELEVATION 74.50 FT

NOTE STRESSES DUE TO HORIZONTAL & VERTICAL EARTHQUAKE ARE + OR -.
(+) EARTHQUAKE STRESSES YIELD A (+) MERIDIONAL STRESS RESULTANT

Point 3

	MERIDIONAL + SEISMIC (LB/IN)	MERIDIONAL - SEISMIC (LB/IN)
OVERHANGING WATER	0.	0.
VERT SEISMIC ON WATER	0.	0.
WATER ABOVE FLANGE	0.	0.
VERT SEISMIC ON WATER	0.	0.
HOR SEISMIC ON ALL WATER	48.	-48.
SHELL VERTICAL LOAD	-348.	-348.
HOR SEISMIC ON SHELL	165.	-165.
VERT SEISMIC ON SHELL	35.	-35.
COMPRESSIBLE MATERIAL	-34.	-34.
HOR SEISMIC ON C.M.	9.	-9.
VERT SEISMIC ON C.M.	3.	-3.
PENETRATIONS	-39.	-39.
HOR SEISMIC ON PENE	13.	-13.
VERT SEISMIC ON PENE	4.	-4.
DEAD LOADS	-87.	-87.
HOR SEISMIC ON D.L.	48.	-48.
VERT SEISMIC ON D.L.	9.	-9.
LIVE LOADS	0.	0.
HOR SEISMIC ON L.L.	0.	0.
VERT SEISMIC ON L.L.	0.	0.
BUOYANCY	350.	350.
STAY FORCE	0.	0.
TOTAL	176	-492

MAX CIRCUMFERENTIAL = — LB/IN

~~ALLOW BUCKLING LOAD = 73134. LB/IN.~~

~~FACTOR OF SAFETY = 0.000~~

CHICAGO BRIDGE & IRON COMPANY OAK BROOK ENGINEERING
FLD ELEV 74.5 CONTRACT GPU/O.C. DATE 01/15/87 BY TJA SHT D2 REV 1
CHKD PM 2/6/87

SUMMATION OF STRESSES AT EMBEDMENT, CBI CASE 4 FLOODED TO ELEVATION 74.50 FT

NOTE STRESSES DUE TO HORIZONTAL & VERTICAL EARTHQUAKE ARE + OR -.
(+) EARTHQUAKE STRESSES YIELD A (+) MERIDIONAL STRESS RESULTANT

Point 4

	MERIDIONAL + SEISMIC (LB/IN)	MERIDIONAL - SEISMIC (LB/IN)
OVERHANGING WATER	0.	0.
VERT SEISMIC ON WATER	0.	0.
WATER ABOVE FLANGE	0.	0.
VERT SEISMIC ON WATER	0.	0.
HOR SEISMIC ON ALL WATER	49.	-49.
SHELL VERTICAL LOAD	-322.	-322.
HOR SEISMIC ON SHELL	132.	-132.
VERT SEISMIC ON SHELL	32.	-32.
COMPRESSIBLE MATERIAL	-32.	-32.
HOR SEISMIC ON C.M.	8.	-8.
VERT SEISMIC ON C.M.	3.	-3.
PENETRATIONS	-32.	-32.
HOR SEISMIC ON PENE	11.	-11.
VERT SEISMIC ON PENE	3.	-3.
DEAD LOADS	-71.	-71.
HOR SEISMIC ON D.L.	38.	-38.
VERT SEISMIC ON D.L.	7.	-7.
LIVE LOADS	0.	0.
HOR SEISMIC ON L.L.	0.	0.
VERT SEISMIC ON L.L.	0.	0.
BUOYANCY	336.	336.
STAY FORCE	0	0
TOTAL	162	-404

MAX CIRCUMFERENTIAL = — LB/IN

~~ALLOW BUCKLING LOAD = 6417. LB/IN~~

~~FACTOR OF SAFETY = 0.000~~

CHICAGO BRIDGE & IRON COMPANY OAK BROOK ENGINEERING
FLD ELEV 74.5 CONTRACT GPU/O.C. DATE 01/15/87 BY TJA SHT D22 REV 1
CHKD PM 2/6/87

SUMMATION OF STRESSES AT EMBEDMENT, CBI CASE 4 FLOODED TO ELEVATION 74.50 FT

NOTE STRESSES DUE TO HORIZONTAL & VERTICAL EARTHQUAKE ARE + OR -.
(+) EARTHQUAKE STRESSES YIELD A (+) MERIDIONAL STRESS RESULTANT

	Point 5 MERIDIONAL + SEISMIC (LB/IN)	- SEISMIC (LB/IN)
OVERHANGING WATER	0.	0.
VERT SEISMIC ON WATER	0.	0.
WATER ABOVE FLANGE	0.	0.
VERT SEISMIC ON WATER	0.	0.
HOR SEISMIC ON ALL WATER	150.	-150.
SHELL VERTICAL LOAD	-179.	-179.
HOR SEISMIC ON SHELL	68.	-68.
VERT SEISMIC ON SHELL	18.	-18.
COMPRESSIBLE MATERIAL	-28.	-28.
HOR SEISMIC ON C.M.	6.	-6.
VERT SEISMIC ON C.M.	3.	-3.
PENETRATIONS	-18.	-18.
HOR SEISMIC ON PENE	6.	-6.
VERT SEISMIC ON PENE	2.	-2.
DEAD LOADS	-122.	-122.
HOR SEISMIC ON D.L.	28.	-28.
VERT SEISMIC ON D.L.	12.	-12.
LIVE LOADS	0.	0.
HOR SEISMIC ON L.L.	0.	0.
VERT SEISMIC ON L.L.	0.	0.
BUOYANCY	299.	299.
STAY FORCE	0	0
TOTAL	245	-341

MAX CIRCUMFERENTIAL = 4627 LB/IN

~~ALLOW BUCKLING LOAD = 7899. LB/IN~~

~~FACTOR OF SAFETY = 46.515~~

CHICAGO BRIDGE & IRON COMPANY OAK BROOK ENGINEERING
FLD ELEV 74.5 CONTRACT GPU/O.C. DATE 01/15/87 BY TJA SHT D23 REV 1
CHKD PM 2/6/87

SUMMATION OF STRESSES AT EMBEDMENT, CBI CASE 4 FLOODED TO ELEVATION 74.50 FT

NOTE STRESSES DUE TO HORIZONTAL & VERTICAL EARTHQUAKE ARE + OR -.
(+) EARTHQUAKE STRESSES YIELD A (+) MERIDIONAL STRESS RESULTANT

	Point 6 MERIDIONAL + SEISMIC (LB/IN)	- SEISMIC (LB/IN)
OVERHANGING WATER	0.	0.
VERT SEISMIC ON WATER	0.	0.
WATER ABOVE FLANGE	0.	0.
VERT SEISMIC ON WATER	0.	0.
HOR SEISMIC ON ALL WATER	390.	-390.
SHELL VERTICAL LOAD	-165.	-135.
HOR SEISMIC ON SHELL	82.	-82.
VERT SEISMIC ON SHELL	19.	-19.
COMPRESSIBLE MATERIAL	-35.	-35.
HOR SEISMIC ON C.M.	10.	-10.
VERT SEISMIC ON C.M.	3.	-3.
PENETRATIONS	-31.	-31.
HOR SEISMIC ON PENE	8.	-8.
VERT SEISMIC ON PENE	3.	-3.
DEAD LOADS	-536.	-536.
HOR SEISMIC ON D.L.	107.	-107.
VERT SEISMIC ON D.L.	54.	-54.
LIVE LOADS	0.	0.
HOR SEISMIC ON L.L.	0.	0.
VERT SEISMIC ON L.L.	0.	0.
BUOYANCY	294.	294.
STAY FORCE	0	0
TOTAL	183	-1169

MAX CIRCUMFERENTIAL = 7942. LB/IN

~~ALLOW BUCKLING LOAD = 3953. LB/IN.~~

~~FACTOR OF SAFETY = 10.744~~

CHICAGO BRIDGE & IRON COMPANY OAK BROOK ENGINEERING
FLD ELEV 74.5 CONTRACT GPU/O.C. DATE 01/15/87 BY TJA SHT D24 REV 1
CHKD PM 2/3/87

SUMMATION OF STRESSES AT . SEDMENT, CBI CASE 4 FLOOD. TO ELEVATION 74.50 FT

NOTE STRESSES DUE TO HORIZONTAL & VERTICAL EARTHQUAKE ARE + OR -.
(+) EARTHQUAKE STRESSES YIELD A (+) MERIDIONAL STRESS RESULTANT

Point 7

	MERIDIONAL + SEISMIC (LB/IN)	MERIDIONAL - SEISMIC (LB/IN)
OVERHANGING WATER	-177.	-177.
VERT SEISMIC ON WATER	18.	-18.
WATER ABOVE FLANGE	0.	0.
VERT SEISMIC ON WATER	0.	0.
HOR SEISMIC ON ALL WATER	934.	-934.
SHELL VERTICAL LOAD	-260.	-260.
HOR SEISMIC ON SHELL	134.	-134.
VERT SEISMIC ON SHELL	26.	-26.
COMPRESSIBLE MATERIAL	-50.	-50.
HOR SEISMIC ON C.M.	19.	-19.
VERT SEISMIC ON C.M.	5.	-5.
PENETRATIONS	-89.	-89.
HOR SEISMIC ON PENE	19.	-19.
VERT SEISMIC ON PENE	9.	-9.
DEAD LOADS	-675.	-675.
HOR SEISMIC ON D.L.	226.	-226.
VERT SEISMIC ON D.L.	68.	-68.
LIVE LOADS	0.	0.
HOR SEISMIC ON L.L.	0.	0.
VERT SEISMIC ON L.L.	0.	0.
BUOYANCY	297.	297.
STAY FORCE	0	0
TOTAL	504	-2412

MAX CIRCUMFERENTIAL 11298 LB/IN

~~ALLOW BUCKLING LOAD = 19124. LB/IN~~

~~FACTOR OF SAFETY = 11.943~~

CHICAGO BRIDGE & IRON COMPANY — OAK BROOK ENGINEERING
FLO ELEV 74.5 — CONTRACT GPU/O.C. DATE 01/15/87 BY TJA SHT D25 REV 1

CHKD PM 2/6/87

7

SUMMATION OF STRESSES AT EMBEDMENT, CBI CASE 4 FLOODED TO ELEVATION 74.50 FT

NOTE STRESSES DUE TO HORIZONTAL & VERTICAL EARTHQUAKE ARE + OR -.
(+) EARTHQUAKE STRESSES YIELD A (+) MERIDIONAL STRESS RESULTANT

Point 8

	MERIDIONAL + SEISMIC (LB/IN)	MERIDIONAL - SEISMIC (LB/IN)
OVERHANGING WATER	-1621.	-1621.
VERT SEISMIC ON WATER	162.	-162.
WATER ABOVE FLANGE	0.	0.
VERT SEISMIC ON WATER	0.	0.
HOR SEISMIC ON ALL WATER	2523.	-2523.
SHELL VERTICAL LOAD	-437.	-437.
HOR SEISMIC ON SHELL	297.	-297.
VERT SEISMIC ON SHELL	44.	-44.
COMPRESSIBLE MATERIAL	-85.	-85.
HOR SEISMIC ON C.M.	45.	-45.
VERT SEISMIC ON C.M.	9.	-9.
PENETRATIONS	-238.	-238.
HOR SEISMIC ON PENE	54.	-54.
VERT SEISMIC ON PENE	24.	-24.
DEAD LOADS	-1677.	-1677.
HOR SEISMIC ON D.L.	614.	-614.
VERT SEISMIC ON D.L.	168.	-168.
LIVE LOADS	0.	0.
HOR SEISMIC ON L.L.	0.	0.
VERT SEISMIC ON L.L.	0.	0.
BUOYANCY	309.	309.
STAY FORCE	0	0
TOTAL	191	-7689

MAX CIRCUMFERENTIAL = 18359. LB/IN

~~ALLOW BUCKLING LOAD = 20060. LB/IN~~

~~FACTOR OF SAFETY = 3.632~~

CHICAGO BRIDGE & IRON COMPANY OAK BROOK ENGINEERING
FLD ELEV 74.5 CONTRACT GPU/O.C. DATE 01/15/87 BY TJA SHT D26 REV 1

CHKD PM 2/6/87

SUMMATION OF STRESSES AT E. EDMERT, CBI CASE 4 FLOODED TO ELEVATION 74.50 FT

NOTE STRESSES DUE TO HORIZONTAL & VERTICAL EARTHQUAKE ARE + OR -.
(+) EARTHQUAKE STRESSES YIELD A (+) MERIDIONAL STRESS RESULTANT

Point 9

	MERIDIONAL + SEISMIC (LB/IN)	MERIDIONAL - SEISMIC (LB/IN)
OVERHANGING WATER	-3146.	-3146.
VERT SEISMIC ON WATER	315.	-315.
WATER ABOVE FLANGE	0.	0.
VERT SEISMIC ON WATER	0.	0.
HOR SEISMIC ON ALL WATER	4055.	-4055.
SHELL VERTICAL LOAD	-578.	-578.
HOR SEISMIC ON SHELL	453.	-453.
VERT SEISMIC ON SHELL	58.	-58.
COMPRESSIBLE MATERIAL	-113.	-113.
HOR SEISMIC ON C.M.	70.	-70.
VERT SEISMIC ON C.M.	11.	-11.
PENETRATIONS	-300.	-300.
HOR SEISMIC ON PENE	94.	-94.
VERT SEISMIC ON PENE	30.	-30.
DEAD LOADS	-2113.	-2113.
[illegible] SEISMIC ON D.L.	995.	-995.
VERT SEISMIC ON D.L.	211.	-211.
LIVE LOADS	0.	0.
HOR SEISMIC ON L.L.	0.	0.
VERT SEISMIC ON L.L.	0.	0.
BUOYANCY	319.	319.
STAY FORCE	0	0
TOTAL	361	-12223

MAX CIRCUMFERENTIAL = 23493 LB/IN

~~ALLOW BUCKLING LOAD = 28358. LB/IN~~

~~FACTOR OF SAFETY = 2.373~~

HICAGO BRIDGE & IRON COMPANY — OAK BROOK ENGINEERING
LD ELEV 74.5 — CONTRACT GPU/O.C. DATE 01/15/87 BY [illegible] SHT D27 REV 1

Chkd PM 2/6/87

SUMMATION OF STRESSES AT EA DMENT, CBI CASE 4 FLOODEL 0 ELEVATION 74.50 FT

NOTE STRESSES DUE TO HORIZONTAL & VERTICAL EARTHQUAKE ARE + OR -.
(+) EARTHQUAKE STRESSES YIELD A (+) MERIDIONAL STRESS RESULTANT

Point 10

	MERIDIONAL + SEISMIC (LB/IN)	MERIDIONAL - SEISMIC (LB/IN)
OVERHANGING WATER	-6470.	-6470.
VERT SEISMIC ON WATER	647.	-647.
WATER ABOVE FLANGE	0.	0.
VERT SEISMIC ON WATER	0.	0.
HOR SEISMIC ON ALL WATER	7664.	-7664.
SHELL VERTICAL LOAD	-855.	-855.
HOR SEISMIC ON SHELL	823.	-823.
VERT SEISMIC ON SHELL	86.	-86.
COMPRESSIBLE MATERIAL	-168.	-168.
HOR SEISMIC ON C.M.	129.	-129.
VERT SEISMIC ON C.M.	17.	-17.
PENETRATIONS	-424.	-424.
HOR SEISMIC ON PENE	188.	-188.
VERT SEISMIC ON PENE	42.	-42.
DEAD LOADS	-2991.	-2991.
HOR SEISMIC ON D.L.	1888.	-1888.
VERT SEISMIC ON D.L.	299.	-299.
LIVE LOADS	0.	0.
HOR SEISMIC ON L.L.	0.	0.
VERT SEISMIC ON L.L.	0.	0.
BUOYANCY	339.	339.
STAY FORCE	0	0
TOTAL	1214	-22352

MAX CIRCUMFERENTIAL = 34200 LB/IN

~~ALLOW BUCKLING LOAD = 20645. LB/IN~~

~~FACTOR OF SAFETY = 1.388~~

CHICAGO BRIDGE & IRON COMPANY — OAK BROOK ENGINEERING
FLD ELEV 74.5 — CONTRACT GPU/O.C. DATE 01/15/87 BY TJA SHT D28 REV 1
CHKD PM 2/6/87

SUMMATION OF STRESSES AT EMBEDMENT, CBI CASE 5 FLOODED TO ELEVATION 74.50 F

NOTE STRESSES DUE TO HORIZONTAL & VERTICAL EARTHQUAKE ARE + OR -.
(+) EARTHQUAKE STRESSES YIELD A (+) MERIDIONAL STRESS RESULTANT

	Point 1 MERIDIONAL + SEISMIC (LB/IN)	- SEISMIC (LB/IN)
OVERHANGING WATER	0.	0.
VERT SEISMIC ON WATER	0.	0.
WATER ABOVE FLANGE	0.	0.
VERT SEISMIC ON WATER	0.	0.
HOR SEISMIC ON ALL WATER	5.	-5.
SHELL VERTICAL LOAD	-161.	-161.
HOR SEISMIC ON SHELL	97.	-97.
VERT SEISMIC ON SHELL	16.	-16.
COMPRESSIBLE MATERIAL	-17.	-17.
HOR SEISMIC ON C.M.	4.	-4.
VERT SEISMIC ON C.M.	2.	-2.
PENETRATIONS	-20.	-20.
HOR SEISMIC ON PENE	7.	-7.
VERT SEISMIC ON PENE	2.	-2.
DEAD LOADS	-55.	-55.
HOR SEISMIC ON D.L.	28.	-28.
VERT SEISMIC ON D.L.	6.	-6.
LIVE LOADS	0.	0.
HOR SEISMIC ON L.L.	0.	0.
VERT SEISMIC ON L.L.	0.	0.
BUOYANCY	294.	294.
STAY FORCE	0.	0.
TOTAL	208	-126

MAX CIRCUMFERENTIAL = 257 LB/IN

~~ALLOW BUCKLING LOAD = 72429. LB/IN~~

~~FACTOR OF SAFETY = 0.000~~

CHICAGO BRIDGE & IRON COMPANY OAK BROOK ENGINEERING
FLD ELEV 74.5 CONTRACT GPU/O.C. DATE 01/15/87 BY TJR SHT D29 REV 1
CHKD. PM 2/6/87

SUMMATION OF STRESSES AT EMBEDMENT, CBI CASE 5 FLOODED TO ELEVATION 74.50 FT

NOTE STRESSES DUE TO HORIZONTAL & VERTICAL EARTHQUAKE ARE + OR -.
(+) EARTHQUAKE STRESSES YIELD A (+) MERIDIONAL STRESS RESULTANT

	Point ℄ MERIDIONAL + SEISMIC (LB/IN)	- SEISMIC (LB/IN)
OVERHANGING WATER	0.	0.
VERT SEISMIC ON WATER	0.	0.
WATER ABOVE FLANGE	0.	0.
VERT SEISMIC ON WATER	0.	0.
HOR SEISMIC ON ALL WATER	27.	-27.
SHELL VERTICAL LOAD	-236.	-236.
HOR SEISMIC ON SHELL	125.	-125.
VERT SEISMIC ON SHELL	24.	-24.
COMPRESSIBLE MATERIAL	-24.	-24.
HOR SEISMIC ON C.M.	7.	-7.
VERT SEISMIC ON C.M.	2.	-2.
PENETRATIONS	-29.	-29.
HOR SEISMIC ON PENE	10.	-10.
VERT SEISMIC ON PENE	3.	-3.
DEAD LOADS	-65.	-65.
HOR SEISMIC ON D.L.	37.	-37.
VERT SEISMIC ON D.L.	6.	-6.
LIVE LOADS	0.	0.
HOR SEISMIC ON L.L.	0.	0.
VERT SEISMIC ON L.L.	0.	0.
BUOYANCY	309.	309.
STAY FORCE	0.	0.
TOTAL	196	-286

MAX CIRCUMFERENTIAL = — LB/IN

~~ALLOW BUCKLING LOAD = 72958. LB/IN~~

~~FACTOR OF SAFETY = 0.000~~

CHICAGO BRIDGE & IRON COMPANY
FLD ELEV 74.5

OAK BROOK ENGINEERING
CONTRACT GPU/O.C. DATE 01/15/87 BY DA SHT D30 REV 1
CHKD PM 2/6/87

SUMMATION OF STRESSES AT EMBEDMENT, CBI CASE 5 . FLOODED TO ELEVATION 74.50 F

NOTE STRESSES DUE TO HORIZONTAL & VERTICAL EARTHQUAKE ARE + OR -.
(+) EARTHQUAKE STRESSES YIELD A (+) MERIDIONAL STRESS RESULTANT

Point 3

	MERIDIONAL + SEISMIC (LB/IN)	- SEISMIC (LB/IN)
OVERHANGING WATER	0.	0.
VERT SEISMIC ON WATER	0.	0.
WATER ABOVE FLANGE	0.	0.
VERT SEISMIC ON WATER	0.	0.
HOR SEISMIC ON ALL WATER	48.	-48.
SHELL VERTICAL LOAD	-348.	-348.
HOR SEISMIC ON SHELL	165.	-165.
VERT SEISMIC ON SHELL	35.	-35.
COMPRESSIBLE MATERIAL	-34.	-34.
HOR SEISMIC ON C.M.	9.	-9.
VERT SEISMIC ON C.M.	3.	-3.
PENETRATIONS	-39.	-39.
HOR SEISMIC ON PENE	13.	-13.
VERT SEISMIC ON PENE	4.	-4.
DEAD LOADS	-87.	-87.
HOR SEISMIC ON D.L.	48.	-48.
VERT SEISMIC ON D.L.	9.	-9.
LIVE LOADS	0.	0.
HOR SEISMIC ON L.L.	0.	0.
VERT SEISMIC ON L.L.	0.	0.
BUOYANCY	350.	350.
STAY FORCE	0.	0.
TOTAL	176	-492

MAX CIRCUMFERENTIAL = — LB/IN

~~ALLOW BUCKLING LOAD = 73134. LB/IN~~

~~FACTOR OF SAFETY = 0.000~~

CHICAGO BRIDGE & IRON COMPANY OAK BROOK ENGINEERING
FLD ELEV 74.5 CONTRACT GPU/O.C. DATE 01/15/87 BY TJA SHT D31 REV 1
CHKD PM 2/6/87

SUMMATION OF STRESSES AT EMBEDMENT, CBI CASE 8 FLOODED TO ELEVATION 74.50 FT

NOTE STRESSES DUE TO HORIZONTAL & VERTICAL EARTHQUAKE ARE + OR -.
(+) EARTHQUAKE STRESSES YIELD A (+) MERIDIONAL STRESS RESULTANT

Point 4

	MERIDIONAL + SEISMIC (LB/IN)	MERIDIONAL - SEISMIC (LB/IN)
OVERHANGING WATER	0.	0.
VERT SEISMIC ON WATER	0.	0.
WATER ABOVE FLANGE	0.	0.
VERT SEISMIC ON WATER	0.	0.
HOR SEISMIC ON ALL WATER	49.	-49.
SHELL VERTICAL LOAD	-322.	-322.
HOR SEISMIC ON SHELL	132.	-132.
VERT SEISMIC ON SHELL	32.	-32.
COMPRESSIBLE MATERIAL	-32.	-32.
HOR SEISMIC ON C.M.	8.	-8.
VERT SEISMIC ON C.M.	3.	-3.
PENETRATIONS	-32.	-32.
HOR SEISMIC ON PENE	11.	-11.
VERT SEISMIC ON PENE	3.	-3.
DEAD LOADS	-71.	-71.
HOR SEISMIC ON D.L.	38.	-38.
VERT SEISMIC ON D.L.	7.	-7.
LIVE LOADS	0.	0.
HOR SEISMIC ON L.L.	0.	0.
VERT SEISMIC ON L.L.	0.	0.
BUOYANCY	336.	336.
STAY FORCE	0	0
TOTAL	162	-404

MAX CIRCUMFERENTIAL = — LB/IN

~~ALLOW BUCKLING LOAD = 6417. LB/IN~~

~~FACTOR OF SAFETY = 0.000~~

CHICAGO BRIDGE & IRON COMPANY OAK BROOK ENGINEERING
FLD ELEV 74.5 CONTRACT GPU/O.C. DATE 01/15/87 BY TJA SHT D32 REV 1
CHKD PM 2/6/87

SUMMATION OF STRESSES AT EMBEDMENT, CBI CASE 5 FLOODED TO ELEVATION 74.50 FT

NOTE STRESSES DUE TO HORIZONTAL & VERTICAL EARTHQUAKE ARE + OR -.
(+) EARTHQUAKE STRESSES YIELD A (+) MERIDIONAL STRESS RESULTANT

Point 5

	MERIDIONAL + SEISMIC (LB/IN)	MERIDIONAL - SEISMIC (LB/IN)
OVERHANGING WATER	0.	0.
VERT SEISMIC ON WATER	0.	0.
WATER ABOVE FLANGE	0.	0.
VERT SEISMIC ON WATER	0.	0.
HOR SEISMIC ON ALL WATER	150.	-150.
SHELL VERTICAL LOAD	-179.	-179.
HOR SEISMIC ON SHELL	68.	-68.
VERT SEISMIC ON SHELL	18.	-18.
COMPRESSIBLE MATERIAL	-28.	-28.
HOR SEISMIC ON C.M.	6.	-6.
VERT SEISMIC ON C.M.	3.	-3.
PENETRATIONS	-18.	-18.
HOR SEISMIC ON PENE	6.	-6.
VERT SEISMIC ON PENE	2.	-2.
DEAD LOADS	-122.	-122.
HOR SEISMIC ON D.L.	28.	-28.
VERT SEISMIC ON D.L.	12.	-12.
LIVE LOADS	0.	0.
HOR SEISMIC ON L.L.	0.	0.
VERT SEISMIC ON L.L.	0.	0.
BUOYANCY	299.	299.
STAY FORCE	-167.	167.
TOTAL	75.	-170.

MAX CIRCUMFERENTIAL = 4460. LB/IN

~~ALLOW BUCKLING LOAD = 7899. LB/IN~~

~~FACTOR OF SAFETY = 46.515~~

CHICAGO BRIDGE & IRON COMPANY OAK BROOK ENGINEERING
FLD ELEV 74.5 CONTRACT GPU/O.C. DATE 01/15/87 BY TJA SHT D33 REV 1
CHKD PM 2/6/87

SUMMATION OF STRESSES AT EMBEDMENT, CBI CASE 5 FLOODED TO ELEVATION 74.50 FT

NOTE STRESSES DUE TO HORIZONTAL & VERTICAL EARTHQUAKE ARE + OR -.
(+) EARTHQUAKE STRESSES YIELD A (+) MERIDIONAL STRESS RESULTANT

	Point 6 MERIDIONAL + SEISMIC (LB/IN)	- SEISMIC (LB/IN)
OVERHANGING WATER	0.	0.
VERT SEISMIC ON WATER	0.	0.
WATER ABOVE FLANGE	0.	0.
VERT SEISMIC ON WATER	0.	0.
HOR SEISMIC ON ALL WATER	390.	-390.
SHELL VERTICAL LOAD	-185.	-185.
HOR SEISMIC ON SHELL	82.	-82.
VERT SEISMIC ON SHELL	19.	-19.
COMPRESSIBLE MATERIAL	-35.	-35.
HOR SEISMIC ON C.M.	10.	-10.
VERT SEISMIC ON C.M.	3.	-3.
PENETRATIONS	-31.	-31.
HOR SEISMIC ON PENE	8.	-8.
VERT SEISMIC ON PENE	3.	-3.
DEAD LOADS	-536.	-536.
HOR SEISMIC ON D.L.	107.	-107.
VERT SEISMIC ON D.L.	54.	-54.
LIVE LOADS	0.	0.
HOR SEISMIC ON L.L.	0.	0.
VERT SEISMIC ON L.L.	0.	0.
BUOYANCY	294.	294.
STAY FORCE	-329.	329.
TOTAL	-153.	-833.

MAX CIRCUMFERENTIAL = 7613. LB/IN

~~ALLOW BUCKLING LOAD = 3953. LB/IN~~

~~FACTOR OF SAFETY = 10.744~~

CHICAGO BRIDGE & IRON COMPANY OAK BROOK ENGINEERING
FLD ELEV 74.5 CONTRACT GPU/O.C. DATE 01/15/87 BY TJA SHT D34 REV 1
CHKD PM 2/6/87

SUMMATION OF STRESSES AT EMBEDMENT, CBI CASE 5 FLOODED TO ELEVATION 74.50 FT

NOTE STRESSES DUE TO HORIZONTAL & VERTICAL EARTHQUAKE ARE + OR -.
(+) EARTHQUAKE STRESSES YIELD A (+) MERIDIONAL STRESS RESULTANT

Point 7

	MERIDIONAL + SEISMIC (LB/IN)	MERIDIONAL - SEISMIC (LB/IN)
OVERHANGING WATER	-177.	-177.
VERT SEISMIC ON WATER	18.	-18.
WATER ABOVE FLANGE	0.	0.
VERT SEISMIC ON WATER	0.	0.
HOR SEISMIC ON ALL WATER	934.	-934.
SHELL VERTICAL LOAD	-260.	-260.
HOR SEISMIC ON SHELL	134.	-134.
VERT SEISMIC ON SHELL	26.	-26.
COMPRESSIBLE MATERIAL	-50.	-50.
HOR SEISMIC ON C.M.	19.	-19.
VERT SEISMIC ON C.M.	5.	-5.
PENETRATIONS	-89.	-89.
HOR SEISMIC ON PENE	19.	-19.
VERT SEISMIC ON PENE	9.	-9.
DEAD LOADS	-675.	-675.
HOR SEISMIC ON D.L.	226.	-226.
VERT SEISMIC ON D.L.	68.	-68.
LIVE LOADS	0.	0.
HOR SEISMIC ON L.L.	0.	0.
VERT SEISMIC ON L.L.	0.	0.
BUOYANCY	297.	297.
STAY FORCE	-792.	792.
TOTAL	-307.	-1601.

MAX CIRCUMFERENTIAL = 10506. LB/IN

~~ALLOW BUCKLING LOAD = 19124. LB/IN~~

~~FACTOR OF SAFETY = 11.943~~

CHICAGO BRIDGE & IRON COMPANY OAK BROOK ENGINEERING
FLD ELEV 74.5 CONTRACT GPU/O.C. DATE 01/15/87 BY TJA SHT D35 REV 1
CHKD PM 2/3/87

7

SUMMATION OF STRESSES AT EMBEDMENT, CBI CASE 5 FLOODED TO ELEVATION 74.50 FT

NOTE STRESSES DUE TO HORIZONTAL & VERTICAL EARTHQUAKE ARE + OR -.
(+) EARTHQUAKE STRESSES YIELD A (+) MERIDIONAL STRESS RESULTANT

Point B

	MERIDIONAL + SEISMIC (LB/IN)	MERIDIONAL - SEISMIC (LB/IN)
OVERHANGING WATER	-1621.	-1621.
VERT SEISMIC ON WATER	162.	-162.
WATER ABOVE FLANGE	0.	0.
VERT SEISMIC ON WATER	0.	0.
HOR SEISMIC ON ALL WATER	2523.	-2523.
SHELL VERTICAL LOAD	-437.	-437.
HOR SEISMIC ON SHELL	297.	-297.
VERT SEISMIC ON SHELL	44.	-44.
COMPRESSIBLE MATERIAL	-85.	-85.
HOR SEISMIC ON C.M.	45.	-45.
VERT SEISMIC ON C.M.	9.	-9.
PENETRATIONS	-238.	-238.
HOR SEISMIC ON PENE	54.	-54.
VERT SEISMIC ON PENE	24.	-24.
DEAD LOADS	-1677.	-1677.
HOR SEISMIC ON D.L.	614.	-614.
VERT SEISMIC ON D.L.	168.	-168.
LIVE LOADS	0.	0.
HOR SEISMIC ON L.L.	0.	0.
VERT SEISMIC ON L.L.	0.	0.
BUOYANCY	309.	309.
STAY FORCE	-2117.	2117.
TOTAL	-1977.	-5523.

MAX CIRCUMFERENTIAL = 16242. LB/IN

~~ALLOW BUCKLING LOAD = 20060. LB/IN~~

~~FACTOR OF SAFETY = 3.632~~

CHICAGO BRIDGE & IRON COMPANY OAK BROOK ENGINEERING
FLD ELEV 74.5 CONTRACT GPU/O.C. DATE 01/15/87 BY TJA SHT D36 REV 1

CHKD PM 2/6/87

B

SUMMATION OF STRESSES AT E. .EOMENT, CBI CASE 5 FLOODED .O ELEVATION 74.50 FT

NOTE STRESSES DUE TO HORIZONTAL & VERTICAL EARTHQUAKE ARE + OR -.
(+) EARTHQUAKE STRESSES YIELD A (+) MERIDIONAL STRESS RESULTANT

Point 9

	MERIDIONAL + SEISMIC (LB/IN)	MERIDIONAL - SEISMIC (LB/IN)
OVERHANGING WATER	-3146.	-3146.
VERT SEISMIC ON WATER	315.	-315.
WATER ABOVE FLANGE	0.	0.
VERT SEISMIC ON WATER	0.	0.
HOR SEISMIC ON ALL WATER	4055.	-4055.
SHELL VERTICAL LOAD	-578.	-578.
HOR SEISMIC ON SHELL	453.	-453.
VERT SEISMIC ON SHELL	58.	-58.
COMPRESSIBLE MATERIAL	-113.	-113.
HOR SEISMIC ON C.M.	70.	-70.
VERT SEISMIC ON C.M.	11.	-11.
PENETRATIONS	-300.	-300.
HOR SEISMIC ON PENE	94.	-94.
VERT SEISMIC ON PENE	30.	-30.
DEAD LOADS	-2113.	-2113.
HOR SEISMIC ON D.L.	995.	-995.
VERT SEISMIC ON D.L.	211.	-211.
LIVE LOADS	0.	0.
HOR SEISMIC ON L.L.	0.	0.
VERT SEISMIC ON L.L.	0.	0.
BUOYANCY	319.	319.
STAY FORCE	-3583.	3583.
TOTAL	-3282.	-8580.

MAX CIRCUMFERENTIAL = 19910. LB/IN

~~ALLOW BUCKLING LOAD = 28356. LB/IN~~

~~FACTOR OF SAFETY = 2.575~~

CHICAGO BRIDGE & IRON COMPANY OAK BROOK ENGINEERING
FLD ELEV 74.5 CONTRACT GPU/O.C. DATE 01/15/87 BY TJA SHT D37 REV 1
CHKD PM 2/6/87

SUMMATION OF STRESSES AT EMBEDMENT, CBI CASE 5 FLOODED TO ELEVATION 74.50 FT

NOTE STRESSES DUE TO HORIZONTAL & VERTICAL EARTHQUAKE ARE + OR -.
(+) EARTHQUAKE STRESSES YIELD A (+) MERIDIONAL STRESS RESULTANT

Point 10

	MERIDIONAL + SEISMIC (LB/IN)	MERIDIONAL - SEISMIC (LB/IN)
OVERHANGING WATER	-6470.	-6470.
VERT SEISMIC ON WATER	647.	-647.
WATER ABOVE FLANGE	0.	0.
VERT SEISMIC ON WATER	0.	0.
HOR SEISMIC ON ALL WATER	7664.	-7664.
SHELL VERTICAL LOAD	-855.	-855.
HOR SEISMIC ON SHELL	823.	-823.
VERT SEISMIC ON SHELL	86.	-86.
COMPRESSIBLE MATERIAL	-168.	-168.
HOR SEISMIC ON C.M.	129.	-129.
VERT SEISMIC ON C.M.	17.	-17.
PENETRATIONS	-424.	-424.
HOR SEISMIC ON PENE	188.	-188.
VERT SEISMIC ON PENE	42.	-42.
DEAD LOADS	-2991.	-2991.
HOR SEISMIC ON D.L.	1888.	-1888.
VERT SEISMIC ON D.L.	299.	-299.
LIVE LOADS	0.	0.
HOR SEISMIC ON L.L.	0.	0.
VERT SEISMIC ON L.L.	0.	0.
BUOYANCY	339.	339.
STAY FORCE	-7394.	7394.
TOTAL	-6266.	-14873.

MAX CIRCUMFERENTIAL = 26806. LB/IN

~~ALLOW BUCKLING LOAD = 20645. LB/IN~~

~~FACTOR OF SAFETY = 1.300~~

CHICAGO BRIDGE & IRON COMPANY OAK BROOK ENGINEERING
FLD ELEV 74.5 CONTRACT GPU/O.C. DATE 01/15/87 BY TJA SHT D34 REV 1
CHKD PM 2/6/87

Appendix E

Computer Program Documentation

and

Verification Information

The following CBI Computer Programs have been used in the preparation of this report:

1. Program Number and Name: E0778A Analysis of Containment Vessels

   Description: Program performs a primary membrane stress analysis of a containment vessel drywell. The drywell shell can be analyzed for any combination of 10 loading conditions, including earthquake.

   Revision Identification: Rev. 1 Dated January, 1974

   Computer Type: IBM 4381 Mainframe

   Verification: Documentation data is on file at Oak Brook office.

   Inputs/Outputs: Inputs and outputs are shown in Appendix D of this report and are on file at CBI's Oak Brook office.

2. Program Number and Name:	E0781A General Shell of Revolution Stress Analysis
Description:	Program calculates the stresses and displacements in thin-walled elastic shell of revolution, when subjected to static edge, surface, and/or temperature loads with arbitrary distribution over the surface of the shell. The geometry of the shell must be symmetric but the shape of the meridian is arbitrary. Since the program is based on classical shell theory, it has the same limitations. Some of the features of this program are: The shell thickness, physical properties of the materials, and loading may all vary arbitrarily along the meridian. The loading, including temperatures, may vary arbitrarily around the circumference (by using Fourier Series). There may be junctions or branches (maximum or three parts meeting at one point). A variety of forms are available in order to describe the shape of the shell (cylinders, cones, spheres, torroids, ellipses, and parabolas).
Revision Identification:	Last Rev. June, 1982
Computer Type:	IBM 4381 Mainframe
Verification:	Documentation data is on file at Oak Brook office.
Inputs/Outputs:	Inputs and outputs are partially shown in Appendices A, B and C and complete listings are on file at CBI's Oak Brook office.

SUBJECT	MADE BY	CHKD BY	REV			CHARGE NO.
Oyster Creek Embedment Analysis	TJA	PM		BY		N61147
	DATE 3/23/87	DATE 3/25/87		CHKD		SHT E2 OF
				DATE		

3. **Program Number and Name:** E1443D BOSOR4B

Description: BOSOR4 is a comprehensive computer program for the stress, stability, and vibration analysis of segmented, ring, stiffened branched shells of revolution. The program includes nonlinear prestress effects and is very general with respect to geometry of the meridian, shell wall design, edge conditions, and loading. However the wall must be thin enough so that thin shell theory is applicable and the materials must be elastic.

Revision Identification: Rev. 3/XX/85 and revised version purchased 1/12/87

Computer Type: IBM 4381 Mainframe

Verification: Documentation data is on file at Oak Brook office.

Inputs/Outputs: Inputs and outputs are on file at CBI's Oak Brook office.

SUBJECT	MADE BY	CHKD BY	REV			CHARGE NO.
Oyster Creek Embedment	TJA	EM		BY		NG 1'47
Analysis	DATE 3/23/87	DATE 3/25/87		CHKD		
				DATE		SHT E3 OF

(1)

NUCLEAR ENERGY
BUSINESS OPERATIONS

GENERAL ELECTRIC

F&PMT Transmittal
No. 87-178-003 Rev. 1

FUEL & PLANT MATERIALS TECHNOLOGY

CORROSION EVALUATION OF THE OYSTER CREEK DRYWELL

Date: March 6, 1987

Prepared By: [signature]
B.M. Gordon, Principal Engineer
Plant Materials Performance

Approved By: [signature]
G.M. Gordon, Manager
Fuel & Plant Materials Technology

BMG8706.11

1.0 INTRODUCTION

GPU Nuclear's Oyster Creek BWR is characterized by a Mark I containment as shown in Figure 1. During the 1980 refueling outage water was noted around penetrations at elevation 86'0" and running down the wall to floor elevation 75'3". Water was also observed at a penetration at elevation 47'0" and running down the wall to floor elevation 23'6".[1] The presence of water at these locations indicated that an intrusion of water into the annular space between the drywell shell and concrete shield wall had occurred. Water collection was also observed during this outage on the torus room floor which originated from the leak drains in bays 3, 11 and 15, as shown in Figure 2. Water on the torus room floor was also noted following construction.

When water samples were withdrawn from the drains in 1980 and were subsequently radiologically analyzed, the results indicated an activity level similar to primary water.[1] It was concluded at this time that the probable sources of water were the (1) equipment storage pool, (2) reactor cavity, or (3) fuel pool. It was further concluded that the leakage occurred only during refueling when the reactor cavity, the equipment storage pool, and the fuel pool are flooded.

When water was again noted leaking from the sand bed drains during the refueling outage in 1983, it was decided that corrosion of the drywell shell could be a concern and an inspection would be performed during the next outage (1986). However, prior to discussing the details of the program, it is critical to examine the geometrical configuration and construction of the Oyster Creek drywell.

2.0 OYSTER CREEK PRIMARY CONTAINMENT GEOMETRY

The Oyster Creek Mark I containment consists of a pressure suppression system with two large chambers as illustrated in Figure 3. The main chamber is 70' diameter spherical shell with a 33' diameter by 23' high cylindrical shell extending from the top. The pressure absorption chamber is a shell in the shape of a 30' diameter torus located below and around the base of the drywell. The two chambers are interconnected by 10 vent pipes 6'6" in diameter equally spaced around the circumference of the pressure absorption chamber, Figure 4.

The drywell interior is filled with the concrete to an elevation 10'3" to provide a floor. Concrete curbs follow the contour of the vessel up to elevation 12'3" with cutouts around the vent lines, Figure 5.

The drywell exterior is encapsulated in concrete of varying thickness from the base elevation up to the elevation of the top head, Figure 3. From this juncture, the concrete continues vertically to the level of the top of the spent fuel pool. The proximity of the concrete surface to the shell varies with elevation. The concrete is in full contact with the shell over the bottom of the sphere at its invert elevation 2'3" up to elevation 8'11.25". At that transition, the concrete is radially stepped back 15" to create a pocket which continues up to elevation 12'3", Figure 4. This pocket is filled with sand which creates a cushion to smooth the transition of the shell plate from a fully clamped condition between two concrete masses to a free standing condition. The sand pocket is connected to drains to allow drainage of any water which might enter the sand. It is within this sand cushion contact area with the drywell shell where corrosion was identified.

Above elevation 12'3" the concrete is radially stepped back 3" from the shell. This gap is created during construction by applying a compressible, inelastic material to the outside of the shell prior to concrete installation. This material was later permanently compressed by controlled vessel expansion to create a gap between the vessel and the concrete

2.1 Drywell Materials

2.1.1 Drywell Steel

The drywell shell is fabricated of ASTM A212 B made to ASTM A-300 requirements. This material is basically a high tensile (70 Ksi) carbon-silicon steel with a basic composition listed in Table 1 and is equivalent to SA-516 Grade 70 steel. [redacted] inside surface with an inorganic zinc (Carboline [redacted]) and with "[redacted]" (Pb_3O_4) [redacted]. [redacted] the entire exterior of the vessel from [redacted].

2.1.2 Sand Cushion

The sand cushion was filled with sand specified as ASTM 633 from elevation 8'11.25" to elevation 12'3". The sand was a natural sand composed primarily of silica (SiO_2) with some alumina (Al_2O_3). Since the sand was stored at a local dealer uncovered and exposed to the environment during storage and installation, it is a safe assumption that the sand was placed into the sand cushion region in a moist or wet condition. There is no information concerning the method or condition of the backfilling of the sand into the sand cushion gap.

Both GPUN and GE performed leachate studies on the sand. Table 2 presents the GPUN leachate results on various sand samples plus an insulation sample which will be discussed in Section 2.1.3. The results of the GPUN analysis of the wet Bay 11 sand indicates measurable quantities of Na, K, Ca, Pb, Mg and Cl which are naturally occurring in sand. The Mg and Cl are also present in the insulation as will be discussed in Section 2.1.3. The Fe present is probably from any corrosion product incorporated into the sand; the Pb is from the red lead primer.

The sand samples from core samples 19C and 15A (to be discussed in detail in Section 5.0) also indicate nominal values of contaminants with the exception of plug 19C which has a significantly higher Fe content. Since this plug is characterized by considerable corrosion, this result is not unexpected. Plug 15A, which initially was considered "pitted" but actually had inclusions with essentially no corrosion, has a significantly lower Fe content in the sand behind it.

GPUN also performed an energy-dispersive x-ray analysis (EDX or EDAX) with a scanning electron microscope (SEM) on some sand and small pebbles as shown in Figure 6. The EDAX spectrum confirms the presence of silica and alumina plus chloride. The presence of Cl is consistent with the leachate analysis.

The GE leachate chemical analysis of the sand cushion specimen (plus other samples to be discussed later) is presented in Table 3.[2] Table 4 lists the ionic constituents of leachate samples in units of milliequivalents per liter. These values are calculated from the chemical analysis results using some assumptions of metal species. Note that this charge balance calculation sum of the anions differs from the sum of the cations by no more than 14% for any of the test solutions. This degree of agreement tends to verify the quality of the chemical analysis. Finally, Table 5 provides the chemical analysis results of Table 3 expressed relative to the original samples by multiplying the concentrations reported for the leachates (in mg/L) by the leachate volume (L) then dividing by the weight of the leached material (g).

A comparison of the GE sand leachate analysis "torus sand", with the Table 5, GPUN analysis Bay 11 sand, Table 2, reveals similar results, (note ppm vs. ppb units). The major difference, albeit of little technical consequence, is the level of Fe. The Bay 11 sand contains 1.0-5.0 ppb of Fe while the GE analysis of the torus sand contained <0.04 ppb Fe. Since the sand sample may be from different locations the results are not significant. The lead content in the Bay 11 sand sample also appears to be higher.

2.1.3 Insulation

At all elevations above the sand layer, the external concrete mass is set back from the surface at the steel shell an amount calculated to allow unimpeded expansion of the shell during any design condition. As noted in Section 2.0, this gap was created by applying a compressible, inelastic material to the exterior surface of the vessel prior to pouring concrete. The material properties were selected to provide resistance to crushing by the pressure induced by the head of concrete but of low compressive strength to allow collapsing by induced vessel expansion. Design considerations[1] necessitated that a gap of 2" was required from elevation 12'3" to elevation 23'6" and a gap of 3" above 23'6".

The criteria used to select the gap material was as follows:

1. Tight adherence to curved, painted steel plate surfaces in horizontal and vertical positions.

2. Insignificant deformation under fluid pressure of wet concrete estimated at 3 psi.

3. Would be reduced in thickness inelastically by approximately one inch from an initial thickness of 2 to 3 inches under a pressure of not more than 10 psi.

4. Dimensionally stable at the reduced thickness without significant flaking or powdering.

5. Unaffected by long term exposure to radiation and heat.

6. Unaffected when exposed on the vessel prior to concrete installation.

2.1.3.1 Duct Insulation

The 2" gap discussed above was formed by using Owens-Corning Fiberglass SF Vapor Seal Duct Insulation and was applied to the vessel shell from elevation 12'3" to 23'6". The material was applied as individual boards 2" thick with a factory applied laminated asphalt kraft paper (high in sulfur and chlorine) water proof exterior face and was attached to the vessel with mastic and insulation pins. The fiberglass strands were embedded in phenol formaldehyde. Joints between the boards, edges and penetrations were sealed with glass fabric reinforced mastic.

2.1.3.2 Firebar-D Insulation

2.1.3.2.1 Background

The gap material used above elevation 23'6" was Firebar-D, a proprietary asbestos fiber-magnesite cement product applied as a spray coat. The manufacturer of this material was All Purpose Fireproofing Corporation. The material was subsequently modified by Certified Industrial Products, Inc. to achieve a reduced density. The solid materials, asbestos fibers, magnesite and magnesium sulfate (≈75% asbestos), were premixed and combined in a mortar mixing machine with water and, to control density, with foam (aerosol PK, a protein, as a foaming agent) to form a slurry suitable for spray application. The first coat ([illegible] inch thick) was standard density while the second and third coat (one inch thick each) was at a reduced density. After application and drying, the material surface was faced with Griffolyn (chloride content not known) 4 mil clear polyethylene sheet with all edges sealed by tape and held in by insulation pins. The polyethylene sheets formed the bond-breaker for the concrete pour.

It is important to note that the Firebar-D is said to be 75% asbestos in magnesite. To a geologist, magnesite is the mineral form of magnesium carbonate, $MgCO_3$.[3] Complete calcination or dead burning of magnesite produces magnesium oxide, MgO. Commercially however, magnesite refers to "dead burnt" magnesium oxychloride, also known as Sorel's cement.[3] This material is produced by the exothermic action of a 20% solution of magnesium chloride, $MgCl_2$, and a blend of magnesia, MgO, by calcining magnesite and magnesia obtained from brines $3\ MgO + MgCl_2 + 11\ H_2O \longrightarrow 3\ MgO \cdot MgCl_2 \cdot 11\ H_2O$.

The resulting crystalline oxychloride contributes the cementing action to the commercial cements. The product is hard and strong but is dimensionally unstable, lacks resistance to weathering, and most importantly is readily attacked by water which leaches out the $MgCl_2$ and thus is highly corrosive.

2.1.3.2.2 Firebar-D Analysis

Leachate analysis of the Firebar-D was performed by both GPUN and GE. As shown in Table 2 for the GPUN analysis of this insulation, Firebar-D consisted of a mixture of fiber, foam and concrete had high levels Na, K, Ca, Mg, Cl, NO_3, SO_4 and total organic carbon (TOC). The Na, K and Ca are contained in asbestos. The Mg is also present in asbestos and of course the Firebar-D. The Cl and SO_4 are major compositional factors of the Firebar-D. The TOC of 1056 ppm is most likely due to the foaming agent Aerosol PK which is a protein. [This material along with the sulfate could serve as a food for any microbiologically influenced corrosion (MIC). However, this subject is beyond the scope of this report.] Although the source of the nitrate is not obvious, it is present in small quantities in seawater.

The GE analysis of a 14 gram insulation leachate is shown in Tables 3-5. A comparison between the GPUN and GE results, Table 2 and 5, respectively, revealed similar results. For example, 573 vs 610 ppb Cl, 1936 vs. 1400 ppb Mg, 2850 vs. 2500 SO_4, 132 vs. 130 NO_3^-, 1056 vs. 900 ppb total organic carbon, etc. were observed for the GPUN and GE analysis, respectively.

3.0 POTENTIAL SOURCES OF WATER INTRUSION

3.1 Leakage Paths and History

As noted in Section 1.0, leakage of water from the sand bed drains were observed during the 1980 and 1983 refueling outages. A series of investigations were performed by GPUN to identify the source of the water and its leak path. Since the same range of radioactivity was found in this leakage water as is found within the reactor, the leak path was believed to have been from the reactor cavity located immediately above the drywell. This cavity is filled with water during refueling operations. It was believed that a leak from this cavity through the bellows seal, Figures 7 and 8, at the bottom drained into the space between the drywell and the space filled with Firebar-D. Extensive leak tests finally revealed that the most probable source of the water was the drain line gasket, Figure 8. This gasket was replaced and subsequent leak tests performed on the bellows revealed no additional leaks. Inspections of the areas previously characterized by leakage indicated that the leakage had been arrested.

However, this history of leakage, which may have initiated at the first refueling outage plus any condensation in the gap between the Firebar-D and the drywell shell, means that the Firebar-D could have been intermittently wetted and leached of corrosive $MgCl_2$ which collected in the sand cushion. As will be discussed later, the establishment of this electrolyte in the sand is considered the key factor in the drywell corrosion phenomenon.

3.2 Leakage Water Analysis

During the 1986 Oyster Creek refueling outage, water samples were obtained from a drain line and analyzed by GPUN and GE. In addition to tritium, these samples were analyzed for contaminants.

The results of the GPUN analysis is shown in Table 6. Significant amounts of Na, K, Mg, Cl and SO_4 are present. The sources of these substances include the natural substances found in sand, a marine environment and the Firebar-D. The conductivity is high (680-1100 µS/cm as compared to 0.2, 1, 70 and 1000 µS/cm for good reactor water, good quality distilled water, excellent quality raw water, and 0.05% NaCl solution, respectively) and thus clearly indicates that the drain line water would serve as a suitable electrolyte for corrosion.

The results of the GE analysis, Table 3, of the leakage water again reveals similar results for elements K, Na, Ca, Mg, Al, Cl, NO_3, SO_4, TOC and conductivity. The only measurable differences between the two analyses was in the Fe and Sr.

3.3 Deposit Analysis

Various scrapings from horizontal and vertical surfaces were obtained between the torus and drywell at Oyster Creek. These deposits were analyzed by inductive couple plasma by GPUN, Table 7, and by EDAX and leachate by GE, Tables 8 and 5, respectively. Table 7 reveals the presence of various metal oxides with Fe_2O_3, hematite ("rust") being the dominant material for material removed by Bay 7 and 11. The only unusual oxide is the B_2O_3 which suggests the presence of reactor water. The GE analysis of a scraping from Bay 7 only as investigated by EDAX, Table 8, revealed high percentages of Fe, Cl, K, S and Pb. The results of the GE analysis is fairly consistent with GPUN's investigation although different analytical methods were utilized. The quantity of Fe is consistent and anticipated. The presence of lead, Pb, is consistent with the red lead primer coat. Manganese may be due to the presence of manganese sulfides in the steel. Although the existence of Na, Cl, and K are consistent with the presence of Firebar-D, the presence of these three elements plus bromine is suggestive of a marine environment since Br is also found in seawater.

The results of the leachate analysis of the Bay 7 deposit is presented in Table 5. The results are consistent with the other analytical results from this sample in that significant amounts of SO_4, Cl, Ca, K and Na leached out of the specimen. Pb, B, Sr, Ba and Al were also identified. With the exception of Pb, all of these elements are present in seawater.

4.0 DRYWELL THICKNESS MEASUREMENTS

Motivated by the presence of water in the drain lines and other penetrations, GPUN performed extensive ultrasonic thickness measurements of the drywell to determine if degradation was occurring. Approximately 1000 ultrasonic testing (UT) measurements were obtained through the use of an ultrasonic thickness gauge device (D-meter). The D-meter measures the time for a longitudinal ultrasound wave to travel to a reflection (backwall or midwall reflector) and back. Expanded UT examinations were accomplished through the use of a "A-Scan" UT technique where the character, location and amplitude of various ultrasound reflectors are displayed on a cathode ray tube.

The initial UT measurements (D-meter) were made from the inside of the drywell at elevations of 51' and the 11'3" sand cushion, Figure 9. The sand cushion measurements obtained in the bays corresponding to known water leaks indicated that wall thinning had occurred. Measurements just above these area in the same plate and at the 51' elevation indicate nominal plate thicknesses. Measurements were obtained with both the inside surface coating of Carbo zinc 11 in place and removed.

As a result of the initial low thickness readings, additional thickness measurements were obtained as described in detail elsewhere.[1] To determine the vertical profile of the thinning, a trench was excavated into the concrete floor in Bay 17 and Bay 5. Bay 17 was chosen since the extent of thinning at the floor level was the most severe. The additional thickness measurements indicated that thinning below the initial measurements were no more severe and become less severe at the lower portions of the sand cushion. Bay 5 was selected to determine if the thinning line was lower than the floor level in areas where no thinning was identified. No significant indication of thinning was found in the sub floor region of Bay 5. Aside from UT thickness measurements performed by the GPUN staff, independent analysis was performed by the EPRI NDE Center and the GE Ultra Image III "C" scan topographical mapping system. The EPRI investigation verified GPUN's thickness and mid-wall reflector 7 results and the GE mapping confirmed a corrosion transition at seven to eight inches up from the concrete curb in Bay 19. The Ultra Image results will be used as a baseline profile to track continued wastage.

GPUN also used a UT integration method (30-70-70 technique) to detect minor changes in back wall surface conditions. This technique was able to verify the roughness condition of wastage and the light corrosion areas of the containment wall as compared to reference standards. Finally, UT investigations of various plate to plate welds and heat affected zones revealed no indications of wastage or cracking.[1]

5.0 CORE SAMPLING

To evaluate if the UT measurements were valid, characterize the form of damage, and determine the cause (i.e., due to the presence of contaminants, microbiological species, or both), it was considered prudent to obtain core samples from various bay locations. Areas that were characterized by sharp deviations in thickness of less than half the 1.154" nominal wall were designated "pitted/inclusion" areas. Regions that had UT indications of thinning were designated as "wastage" areas. Regions above the wastage area and within the sand cushion region that appeared to have no thinning or "pitting" were also selected as candidate core sample sites. Table 9 summarizes the UT characterizations by bay number.

Core samples of the drywell wall were obtained at seven locations. To produce an adequate sample size, an opening large enough to allow removal of sand samples and insertion of a miniature video camera and allow a simple plug design, the sample diameter was optimized at 2" in diameter. Table 10 summarizes the seven core sample locations, the type of samples obtained and the organization who performed the subsequent analysis.

The core samples were cut in such a manner to eliminate any possible contamination from the cutting operation. Distilled water was used during the initial cutting operation as a coolant. The final cut through the wall was performed without coolant and the shell temperature was maintained below ~150°F to prevent the premature death of any viable microorganisms. Biological samples were taken from four plugs and analyzed by another party for GPUN. The next five sections present the results of the core sample analysis.

5.1 Core Sample 15A - Minimum Thickness Specimen - GPUN

Core sample 15A which was removed from Bay 15 was the key specimen for detailed analysis. This particular area was characterized by the lowest through-wall thickness (0.490") as observed randomly by UT examination, surrounded by adjacent areas with nominal thickness of 1.17". Therefore, the question was whether this area was suffering from some sort of localized "pitting" attack or did the plate in this location contain inclusions.

The removal of plug 15A immediately revealed that there was no pitting or in fact any serious corrosion attack. The sample measured 1.17" average thickness and was covered with a uniform dark brown (magnetic) scale. Elemental analysis of this oxide by EDAX indicated that Fe was the major (>10 $^w/o$) constituent, followed by Pb (>1 $^w/o$) from the red lead primer and traces (<1 $^w/o$) of Al, Si, Ca, Cl, K, S and Mn, Table 11. Figures 10 and 11 present overall cross-section view of plug 15A and detail region where EDAX was performed, respectively. Figure 12 presents the energy dispersion line profile of plug 15A which clearly reveals a constant low level distribution of Cl and a high level concentration of Fe in the scale. EDAX analysis of a sand sample from plug 15A revealed that Si was the major constituent (>10 $^w/o$) with minor amounts of Al and Fe (>1 $^w/o$) and trace amounts of Cl, K, Pb and Ti (<1 $^w/o$), Table 12.

GPUN also prepared metallographic specimens from this core plug in both the rolling direction and perpendicular to the rolling direction, Figure 13. As shown in Figure 10 and 11, minor pitting (<5 mils) was observed on the surface. The mid-plane of the specimen was characterized by a band of aluminide stringers, Figures 14 and 15. These inclusions are sufficiently dense to produce a reflection for ultrasound. In fact, the measured depth of these inclusions correlated with the depth determined by the initial UT examination. The validity of the overall UT thickness measurements was also confirmed by actual thickness measurements. The ability of the A-scan to identify areas of inclusions, as opposed to pits, was also confirmed.

5.2 Core Sample 19C — Wastage – GPUN

When core sample 19C was cut, GPUN noticed that a hard black crust remained in the hole at the sand interface. The crust was approximately 0.5" thick and was subsequently removed for analysis. Other wastage samples were also characterized by this corrosion product crust.

Figure 16 presents an overall view of plug 19C. The surface has the classic appearance of general corrosion. The measured thickness was approximately 0.825" which corresponds with the UT determination of 0.815". The surface was covered with a thick black powder deposit which varied in thickness up to ~30 mils. EDAX analysis of the surface, Table 11, revealed that again Fe was the major constituent (>10 w/o) as was the case of plug 15A. However, for this wastage sample the minor element (>1 w/o) was Cl and not Pb. Trace amount of Al, Si and Mn were also identified, Figure 17. A cross-section of plug 19C, Figure 18, prepared through one of the valleys on the corroded surface reveals the corrosion product. An EDAX analysis along the indicated profile location, Figure 19, reveals a chloride peak in a 2 mil thick region adjacent to the steel surface. EDAX analysis of the magnetic crust/flake deposit removed with plug 19C revealed that the primary constituent was Fe (>10 w/o) with only trace amounts of Si and Cl (<1 w/o), Table 13. The pH, as determined by litmus paper, of the scale was measured at 4.

Metallographic examination of the plug sample 19C also revealed that scale contained manganese-sulfide inclusions, Figure 20, Manganese inclusions were also found beneath the surface of the plug, Figure 21. These two figures clearly indicate that the wastage is proceeding through the wall and is capable of retaining inert materials in the original position and orientation. This result also explains the presence of Mn in the EDAX analysis presented in Figure 17.

5.3 Core Sample 17D - Wastage - CE

This plug sample was also characterized by general corrosion/wastage. The pre-removal UT thickness was determined to be approximately 0.840". Upon removal actual thickness measurement revealed an average thickness of ~0.860".

SEM examination of the surface of plug 17D, Figure 22, revealed a fairly uniform distribution of oxide particles. An EDAX analysis of this surface revealed a high concentration of Cl (3.71 - 4.92 w/o) and Fe (92.73 - 94.60 w/o), Table 14. Similar results were obtained for an analysis, Figure 23, of the cross-section of the oxide, Table 15, where 3.45 w/o Cl and 94.40 w/o Fe was identified. This analysis confirms the GFUN studies on wastage sample 19C where a high chloride peak was associated with the significant general corrosion attack.

The corrosion product crust removed from plug 17D was analyzed by both EDAX and x-ray diffraction (XRD). The EDAX analysis of the crust reveals that Fe is present in the highest concentrations (88.32 - 98.26 w/o), Table 16, followed by Mn (1.54 - 10.42 w/o), Si (0.00 - 0.63) and Cl (200 - 3800 ppm). XRD analysis of this dark brown to black crust was performed on magnetically separated material as discussed below.

The results of the XRD analysis revealed that the non-magnetic aliquot was composed of major amounts of alpha quartz (α - SiO_2) with small amounts of face-centered-cubic (FCC) M_3O_4 spinel type phase plus trace amounts (<2 w/o) of an unidentified phase.[5] The magnetic aliquot composition was essentially just the opposite of the non-magnetic sample, that is, the magnetic aliquot consisted of a major phase (>90 $^{w}/o$) of FCC M_3O_4 spinal with small to trace amounts of α SiO_2. The lattice parameter value for the spinal phases was determined to be a_o = 8.387 ± 0.004 A. This value is close to the lattice parameter of stoichiometric Fe_3O_4 at a_o = 8.3963 A. The slightly smaller measured lattice parameter of this magnetic phase can be most likely attributed to small amounts of other transition elements in substitutional solid solution with the major element Fe. It should also be noted that the error on the lattice parameter could indicate no change in composition has occurred and the spinel phase could be pure Fe_3O_4.

Other compounds such as $FeCl_2$, $FeCl_3$, α Fe_2O_3 and γ Fe_2O_3 were specifically analyzed for in the sample, but none were identified with the possible exception of a weak trace of α Fe_2O_3. The detection limit for these types of phase in this type of material is estimated to be one to two weight percent.

Metallogrpahic examination of plug 17D revealed similar corrosion product buildup as seen on wastage plug 19C, as seen by comparing Figure 18 with Figures 24 and 25. The microstructure of the steel, Figure 24, and the hardness values (R_B 81-84) were typical for this type of steel.

The leachate analysis of the sand behind plug 17D revealed significantly less contaminants than observed for plugs 19C and 15A. The only contaminant present in significant quantities is 19 ppm K, 9 ppm Na and 4 ppm Ca. The chloride content in this sand, 1.8 ppm, is significantly less than observed in the sand behind plugs 19C and 15A at 45 and 93 ppm, respectively. It should be noted, however, that the plug core sand samples were received in plastic jars and not as a core sample per se. Therefore, any higher concentration of contaminate adjacent at the plug/sand interface could have been diluted by mixing.

5.4 Core Sample 19A - Wastage - GE

This sample was the second wastage sample received by GE for analysis. The pre-removal UT thickness measured by GPUN averaged 0.830". The post-removal average thickness was 0.847".

SEM examination of the surface of plug 19A, Figure 26, revealed a surface which is quite different than that observed on the previous wastage sample plug 17D. Only a very fine powder deposit is observed on this surface. An EDAX analysis of this surface revealed primarily Fe (96.07 - 97.45 $^{w}/o$) with lower amounts of Cl (0.34 - 1.25 $^{w}/o$) than plug 17D, Table 14. The lower chloride content could explain the difference in surface morphology. The cross-section analysis, Figure 27, of plug 19A, Table 15, revealed the absence of many of the elements observed in plug 17D. Again Fe dominates the analysis (98.37 $^{w}/o$) followed by Mn (1.24 $^{w}/o$). The source of Mn is most likely the manganese-sulfide inclusions in the steel.

The corrosion product crust removed from plug 19A was also analyzed by EDAX and XRD, Table 16. In this case, plug 19A crust was characterized by Fe (64.69 - 93.36 $^{w}/o$), Si (3.81 - 30.34 $^{w}/o$), Mn (up to 1.50 $^{w}/o$), Ti (up to 2.98 $^{w}/o$) and Cl (3300 to 19,300 ppm). The XRD analysis revealed a non-magnetic and magnetic phase compositions that are nearly identical to that obtained on plug 17D.[5] The only difference found was that the lattice parameter for the M_3O_4 spinel was $a_o = 8.396 \pm 0.003$ for plug 19A which is exactly the value for stoichiometric Fe_3O_4. As was also the case of the crust from plug 17D, no $FeCl_2$, $FeCl_3$, α-Fe_2O_3 or γ-Fe_2O_3 were identified in any measurable amounts.

Metallographic examination of wastage plug 19A, Figures 28 and 29, revealed similar results as observed on plug 17D, that is, thick corrosion product on the surface, normal microstructure and hardness values (R_B 80-81).

The leachate analysis of the sand behind plug 19A reveals similar results to that obtained behind plug 17D, Table 5, but again different results as compared to the two GPUN analyzed plugs.

5.5 Core Sample 11A - H - Above Wastage - GE

This core sample was removed from above the wastage region of the drywell but still in a region in contact with the sand cushion. The thickness measured by UT was 1.170". After removal of the plug, the thickness measurement measured at the center of the plug was 1.19". Thus there was essentially no corrosion on this specimen.

SEM examination of the surface of plug 11A-H (H = high, i.e., above sample 11A), Figure 30, revealed a surface with isolated islands of deposits. Higher magnification examination (1500X) revealed the presence of a non-uniform powdery scale. The EDAX analysis indicated the Pb (52.61 - 59.77 w/o) and not Fe (21.72 - 28.87) dominate the surface, Table 14. This indicates that the red lead paint (Pb_3O_4) was still present on the surface. This result is anticipated since this plug suffered no corrosion. It is important to note that the Pb is present because no corrosion occurred at this area and not that the red lead inhibited the corrosion. The high presence of S in both the surface analysis and cross-section analysis (Figure 31 and Table 15) may be due to the affinity of sulfate to combine with the red lead paint to produce $PbSO_4$. The sulfate may be a leachate from the Firebar-D or from the marine environment. Significant amounts of chloride are also present.

Since plug 11A-H had essentially no corrosion, there was no crust to analyze by EDAX or XRD.

Metallographic examination of plug 11A-H, Figures 32, 33 and 34, revealed the absence of severe corrosion. There was only mild attack observed at higher magnifications (125X) on the cross-section of the plug, Figure 33. Hardness measurements again revealed nominal values (R_B 80-81).

The leachate analysis for the sand behind low-corrosion plug 11A-H reveals some interesting differences as compared to plugs 17D and 19A. For example, despite the fact that this sand was characterized by an order of magnitude higher chloride (26 vs. 2 ppm), sulfate (40 vs. 4 ppm) and magnesium (16 vs. ~3 ppm) content, this plug had essentially no corrosion. This result is consistent with the GPUN results for plugs 19C and 15A sand, where no-corrosion plug 15A was characterized by higher chloride, sulfate and magnesium in the sand. The key difference in corrosion response lies not with the relative contamination levels in the sand, but rather the moisture content. As is shown in Table 5, the sand sample behind plug 11A-H was dry as opposed to 1.1 - 2.6% moisture for plugs 17D and 19A, respectively. The absolute difference in the contamination levels of the sand are significant on a percentage basis, but not on a corrosion basis. The key here is the absence of an electrolyte.

6.0 DISCUSSION

The results presented in the previous sections on the analysis of various sand, plug, deposit and water samples indicate that a suitable environment for the corrosion of carbon steel is present in the sand cushion area. In other words, the corrosion of the drywell as exposed to this particular environment could not be considered unexpected. The question is whether the amount of corrosion is particularly high and what role did other factors such as the Firebar-D insulation, contaminants, differential aeration, red lead primer, or concrete play in the corrosion phenomenon.

6.1 General Factors Affecting the Corrosivity of the Sand Cushion

There are numerous factors which would affect the corrosivity of the sand cushion relative to the carbon steel drywell. These factors include the sand porosity, electrolyte conductivity, contaminant level, moisture level, acidity/alkalinity and the presence of bacteria.

The relative porosity of the sand cushion would be affected by the method of back-filling the sand into the sand cushion region during construction, the settling of the sand, the initial moisture content of the sand, whether it was subsequently wetted after installation, etc. The porosity of the sand would affect the moisture that could be retained in the sand cushion and the establishment of local areas of high aeration. The more porous the sand the more moisture would be present over an extended period of time and the more optimum the degree of aeration. Both of these factors would tend to increase the initial corrosion rate. The degree of aeration of the sand would also affect the type of corrosion products formed on the steel surface.

For example, studies by Romanoff[6] have indicated that in well-aerated soils the rate of pitting/corrosion, although initially high, falls off rapidly with time because in the presence of an abundant supply of oxygen, oxidation and precipitation of iron as ferric hydroxide [$Fe(OH)_3$] occurs close to the metal surface, and the protective membrane formed in this manner decreases the subsequent corrosion rate. As noted on the plug specimens from the Oyster Creek drywell only shallow pitting was observed on some of the specimens. In poorly aerated regions, Romanoff noted that the initial rate of corrosion decreases slowly, if at all, with time. Under such conditions the corrosion products, remaining in the deoxidized state, tend to diffuse outward into the soil, offering little or no protection to the corroding metal. (The actual corrosion products observed on the drywell will be discussed in more detail below.)

The role of conductivity of the sand cushion is more straight forward. The higher the conductivity, the greater amount of corrosion would be anticipated. The conductivity of water samples removed from various drain lines at Oyster Creek ranged from 680 to 1100 μS/cm. The conductivity of pure water at similar temperatures is three orders of magnitude lower than these values. Hence, the sand/water environment was sufficiently conductive to establish a viable electrolyte for corrosion.

As noted in Tables 2 through 6, the sand, scrapings and drain water had high levels of contaminants which would be expected to increase the corrosion rate of carbon steel. In particular, high levels of detrimental chloride and sulfate were noted in virtually all the samples analyzed.

The mere fact that corrosion occurred at Oyster Creek indicates that moisture was present in the sand cushion. As discussed in Section 3.0, the sources of moisture include a known leakage of water from the fuel pool which most likely occurred through a drain line gasket, installation of moist sand during construction, water "squeezed" out of the Firebar-D slurry during pressure testing of the drywell and condensation. The moisture content of the sand samples as measured by GE ranged from 1.1 to 12.6%. The only dry sand sample was from plug 11A-H, which did not suffer any significant corrosion.

High pH is beneficial for the corrosion resistance of iron base alloys. The pH observed from sand and drain water samples ranged from 5.99 to 8.90, Table 2, 3 and 6. Most of the pH values were somewhat greater than neutral pH 7. However, average pH values alone can be misleading. As will be discussed later, the establishment of local anode and cathodic sites due to differential aeration will affect the local pH values. Deaerated anodic regions will have a lower pH while the cathodic regions will have a higher pH. Also sections of the drywell adjacent to the concrete would benefit from the high alkalinity of concrete.

Corrosion induced by microbes is a widely recognized phenomenon in a number of systems such as oil wells, pipe lines and municipal sewage. Microbiologically influenced corrosion (MIC) has also been identified in nuclear power plants. However, the role of MIC in this particular system is being independently investigated and is therefore beyond the scope of this report. It should be noted that preliminary evidence presented during discussions of the drywell corrosion at Oyster Creek have indicated that the role of MIC, if any, is not considered to be significant.

6.2 Specific Influences on Oyster Creek Drywell Corrosion

6.2.1 Firebar-D

Due to the known high corrosivity of Firebar-D on steel,[3,4] one of the primary motivations in the investigation of the corrosion of the Oyster Creek drywell was the determination of the role of Firebar-D on the corrosion mechanism. As noted in Section 2.1.3.2, Firebar-D is composed of MgO, $MgCl_2$ and water. Studies by Bilinski, et al[7] have revealed that $5Mg(OH_2) \cdot MgCl_2 \cdot 8H_2O$ is the predominant reaction product in mechanically-sound hardened magnesium oxychloride cement. This material is extremely sensitive to exposure to water since there is an extremely narrow concentration range of magnesium and chloride ions in solution in which $5Mg(OH)_2 \cdot MgCl_2 \cdot 8H_2O$ is stable. It is the presence of leachable $MgCl_2$ which can produce severe corrosion problems.

The specific corrosivity of magnesium oxychloride cements has been investigated by Kawaller.[8] Observations of steel exposed to direct contact with damp magnesium oxychloride reveals a distinctive dark black rust (γ-Fe_2O_3), typical of corrosion which occurs in either a low oxygen or a caustic environment. XRD investigations by GE specifically designed to determine the presence of γ-Fe_2O_3 were negative.

An analysis of the chemical structure by Kawaller revealed that when magnesium oxychloride is exposed to 100% humidity, leaching of surplus magnesium chloride results in the formation of magnesium hydroxide. Carbon dioxide extracted from the atmosphere combines with this material to form a surface layer of magnesium chlorocarbonate $[Mg(OH)_2 \cdot MgCl_2 \cdot 2MgCO_3 \cdot 6H_2O]$. This surface layer slows the leaching process. As additional $MgCl_2$ is leached, a surface crust of hydromagnesite $(5MgCO_2 \cdot 4CO_2 \cdot 5H_2O)$ is formed. These insoluble carbonates and hydromagnesites help to improve the weathering stability of magnesium oxychloride materials.

The lack of $\gamma\text{-}Fe_2O_3$ in the oxide on the core plug surface/crust, the relatively low amount of Mg in the sand samples and the absence of corrosion at the 51' elevation level suggests that the role of Firebar-D in the degradation of the Oyster Creek drywell corrosion phenomena is not significant. The levels of chloride and magnesium identified in the various laboratory samples may be as much the result of the marine environment as the leaching of the Firebar-D. The formation of the insoluble carbonates and hydromagnesites discussed above may have reduced any potential contribution of Firebar-D to the corrosion reaction.

6.2.2 Contaminants

Table 17 presents the typical constituents of seawater.[9] A comparison of Table 17 and the results of leachate analyses, Tables 2 and 3, the drain water analysis, Table 6, and the deposit analyses, Tables 7 and 8, reveal that many of the contaminants observed in these analyses could be from the Oyster Creek marine environment. In particular, the presence of Ba, Al, Br, B, Ca and Sr can be explained. However, the boron and strontium may be from the fuel pool as discussed in Section 3.0.

The primary role of any of the ions in the corrosion of the Oyster Creek drywell would be the enhancement of the electrolyte, that is, an increase in the conductivity. A secondary role for these ions, and in particular, chloride and sulfate, would be the breakdown of any passive film established on the carbon steel surface. As seen in Figure 19, higher concentrations of chloride are observed at the drywell wall-oxide layer interface. The presence of the higher chloride at this interface may be the result of the alternate wetting and drying of the sand cushion.

Regardless of the source of the contamination, that is, the marine environment and/or the Firebar-D, the presence of such known "bad actors" as chloride and sulfate will increase the corrosion rate of the drywell.

6.2.3 Differential Aeration

In most systems which are in contact with atmospheric oxygen, geometrical situations arise where transport of oxygen through the solution by convection (natural or forced) and diffusion to one part of the metal occurs rapidly, whereas it is slow or even negligible at another. The areas characterized by high oxygen will serve as cathodes where the reduction of oxygen to hydroxyl occurs:

$$O_2 + 2H_2O + 4e^- \longrightarrow 4OH^-$$

Areas depleted in oxygen will become anodic with the corrosion of the carbon steel:

$$Fe \longrightarrow Fe^{2+} + 2e^-$$

Therefore, areas of the sand cushion adjacent to ready oxygen access such as lower regions near the drain line and upper regions near the insulation gap would become cathodic while areas in the middle of the sand cushion would become anodic. UT measurements appear to verify this topographical evaluation. Also, differences in local concentrations of NaCl may result in differences in oxygen concentration as suggested by Schaschl and Marsh.[10] The higher the salt concentration the lower the solubility of oxygen so that these depleted zones become the anodic zones of the differential aeration cell.

6.2.4 Role of the Red Lead Primer

The outside of the drywell was painted with red lead which is lead oxide, Pb_3O_4, or more accurately Pb_2PbO_4, in linseed oil. Water reaching the surface dissolves a certain amount of pigment and makes the water less "corrosive." In general, corrosion inhibiting pigments must be soluble enough to supply the minimum concentration of inhibiting ions necessary to reduce the corrosion rate, yet not so soluble that the are soon leached out of the paint.

The inhibiting ion for red lead is probably PbO_4^{-4} which can passivate steel. However, in the presence of SO_4 or CO_2 the passivating effects of red lead can rapidly disappear. Sulfate was identified in many of the analyses and carbon dioxide is readily available in the atmosphere.

It was noted throughout the analysis of the removed core plugs that lead was found on the surfaces of the plugs that suffered minimal or essentially no corrosion. It is strongly believed that lead was found on such samples because no corrosion occurred due to the lack of moisture (dry sand) and not due to corrosion inhibition of the red lead paint. Red lead paint alone simply does not provide long term corrosion protection.

6.2.5 Role of Adjacent Concrete

Concrete provides an alkaline environment and, under moist conditions, passivates iron and steel. Regions of the sand cushion/drywell adjacent to the concrete could be benefited by this local alkaline environment. This factor can explain why the lower regions of the drywell below the 8'11.25" elevation which are in direct contact with the concrete did not suffer any measurable corrosion.

Since part of the drywell is in contact with the passivating concrete and part of the drywell in contact with the moist-high conductivity sand; a macro-galvanic cell is established. This will result in the acceleration of the corrosion of the drywell in contact with the wet sand cushion. As will be discussed in Section 6.3, the presence of chloride in the sand will only amplify this effect.

6.3 Relevant Corrosion Reactions

It is considered prudent to briefly examine the possible corrosion reactions which are occurring on the surface of the drywell embedded in moist sand. Iron (steel) ions will go into solution at anodic areas in an amount electrochemically equivalent to the reaction at the cathodic areas. As noted earlier, the anodic areas of the drywell are characterized by the following basic oxidation reaction:

$$Fe \longrightarrow Fe^{++} + 2e^-$$

The relevant cathodic reaction in aerated solutions is the reduction of oxygen to hydroxyl ions:

$$O_2 + H_2O + 4e^- \longrightarrow 4OH^-$$

However, the corrosion of iron or steel is not as straight forward as illustrated above. As shown in Figure 35, numerous corrosion reactions can occur depending on the local oxygen concentration, inter alia. As will be discussed below, the presence of chloride and sulfate as observed in the Oyster Creek sand cushion, also affects the corrosion reactions.

In the absence of chloride and sulfate, Figure 35, hydrous ferrous oxide ($FeO \cdot nH_2O$) or ferrous hydroxide [$Fe(OH)_2$] composes the diffusion barrier adjacent to the iron surface through which oxygen must then diffuse.[11] The pH of saturated $Fe(OH)_2$ is approximately 9.5. Pure $Fe(OH)_2$ is typically white in color but rapidly oxidizes in air to green to greenish black. At the outer surface of the oxide film, access to dissolved oxygen allows the ferrous oxide to react to form hydrous ferric oxide or ferric hydroxide:

$$Fe\,(OH)_2 + 1/2\,H_2O + 1/4\,O_2 \longrightarrow Fe\,(OH)_3$$

Hydrous ferric oxide is orange to red brown in color and is the main constituent of "rust." It primarily exists as non-magnetic αFe_2O_3 (hematite) or magnetic γFe_2O_3 where hematite is more stable. Saturated $Fe(OH)_3$ has a nearly neutral pH. A magnetic hydrous ferrous ferrite, $Fe_3O_4 \cdot nH_2O$, often forms a black intermediate layer between the hydrous Fe_2O_3 and FeO, Figure 35. Therefore, as observed on some of the core samples from the drywell, rust films of various colors (states of oxidation) can exist simultaneously.

Motivated by the denting of carbon steel support plates in PWR steam generators, more sophisticated studies had been performed on the "rusting" of carbon steel. It is believed that this work performed by Pourbaix, et al[9] is particularly relevant to Oyster Creek. In particular, Pourbaix, et al were looking for conditions which would produce acid chloride attack of the carbon steel. The mechanism proposed to explain this formation of acid is the hydrolysis of soluble corrosion products with formation, inter alia, of non-protective magnetite which is found in large quantities where denting has occurred. If no contaminants are present (contaminants are ions other than H^+, OH^- and Fe^{2+}), no acid hydrolysis would occur. When contaminants (such as Cl^-, Br^-, $SO_4^=$) are present, no acid hydrolysis will occur provided there are no oxidants (such as dissolved oxygen) and no concentration by evaporation. Problems may result from the presence of contaminants when concentration by evaporation occurs even without oxidants and from the presence of contaminants when oxidants are present, even without evaporation. Since the Oyster Creek sand cushion is most likely characterized by all three factors (contaminants, oxidants and alternate wetting and drying concentration mechanisms), acid formation is expected.

The hydrolysis of ferrous ions in the presence of chloride or sulfate leads to acid and concentrated ferrous chloride or ferrous sulfate solutions:

$$Fe \longrightarrow Fe^{2+} + 2e^-$$
$$Fe^{2+} + H_2O \longrightarrow FeOH^+ + H^+$$
$$FeOH^+ + 2H^+ + 3Cl^- \longrightarrow FeCl_2 + HCl + H_2O$$
$$FeOH^+ + 4H^+ + 2SO_4^= \longrightarrow FeSO_4 + H_2SO_4 + H_2O$$

The corrosion rates of iron in these solutions are higher than in neutral or alkaline solutions.

For example, instantaneous corrosion rates were measured by Pourbaix, et al, at 212°F (higher than the drywell) in 4 molar $FeCl_2$ solution in closed system without an oxidant was 1.6 mils per year (mpy). When in contact with magnetite, the instantaneous corrosion rate of iron increased to 8 mpy, and was well over 120 mpy when ferric contaminants were present. Magnetite, as was identified in the plug crusts at Oyster Creek, is considered by Pourbaix as such an oxidizer and not a stable form of iron in mildly oxidizing environments. The oxidizing power of magnetite is illustrated in Figure 36. The stable form of iron is a ferric oxide or a ferric hydroxide.

Magnetite was considered as the normal and stable corrosion product of iron in boiler conditions because most boilers operate satisfactorily. However, the opinion that protection is due to ferric oxide, and not to magnetite, now receives more and more support.[9] At room temperature it has also been more and more generally accepted that magnetite is not protective in the presence of aqueous solutions. The passive films on iron in aqueous solutions at room temperatures appears to consist of Fe_3O_4 at the metal-oxide interface of of γFe_2O_3 maghemite at the oxide-solution interface. Although γFe_2O_3 is difficult to distinguish from magnetite since maghemite is also black and magnetic, and has the same XRD lines as magnetite, it was not identified in the GE analysis. However, this similarity between magnetite and maghemite could be responsible for the long accepted opinion that magnetite is the protective oxide in boiler waters.

When magnetite particles are removed from the steel surface, they can be oxidized to hematite (αFe_2O_3), maghemite (αFe_2O_3) or goethite ($\alpha FeOOH$), in the presence of water containing as little as 1 ppb dissolved oxygen.[9]

6.4 Corrosion Rate of Oyster Creek Drywell

It is mandatory that the corrosion rate of the Oyster Creek drywell be estimated so that the present design life can be calculated. A comparison of this value with corrosion rate data available in the open literature will also be useful in determining the relative corrosion performance of the drywell.

An estimation of the Oyster Creek drywell corrosion rate is straight forward since the reduced shell thickness as measured on the removed core plugs, Table 18, was approximately 0.85" and the initial thickness was approximately 1.15", the typical loss in thickness is ~0.3". If it is assumed that the corrosion initiated with the installation of the sand 17 years ago, the average corrosion rate is approximately 20 mpy. The assumed initiation date is considered realistic since the sand was installed in at least a "moist" condition, was wetted/rewetted during the expansion of the drywell which squeezed out the water from the Firebar-D slurry, and exposed to numerous condensation cycles. If it is assumed that corrosion only initiated 6 years ago when the first fuel pool leak was noted, then the estimated corrosion rate increases to approximately 50 mpy.

A review of the open literature[12-15] on investigations concerning the corrosion of carbon steel in air saturated environments is summarized in Table 19 and Figure 37. Data was selected for only tests with reasonable exposure periods, that is, corrosion test data based on 24 hours exposure were not used. In some cases, however, the exposure period was not provided. A more recent literature review performed for GPUN/EPRI on this subject by Pednekar of Battelle Columbus Division also reveals similar corrosion rates.[16]

It is interesting to note that the 20 mpy corrosion rate estimate for the Oyster Creek drywell falls among the data for carbon steel exposed to water ranging in quality from distilled to ambient seawater to a mixture of soils. If the 6 year-based average of 50 mpy is used, the results are comparable to Warsaw tap water or warm seawater.

The results of this comparison may, at first, appear somewhat surprising. The discussion and results from Section 6.3 suggests that the sand cushion environment with high chloride and sulfate, oxygen, high conductivity, etc. would create an environment which would produce higher corrosion rates than specimens immersed in air saturated high quality water. However, there are a few factors which may be reducing the overall corrosion rate of the drywell. First, when a metal corrodes in a substance like sand, the sand tends to retain the corrosion products in place which physically stifles further corrosion. For a specimen immersed in water, the corrosion products can be transported away from the surface allowing corrosion to continue physically uninhibited. Second, during operation the sand cushion adjacent to the drywell may dry out and thus temporarily terminate any corrosion reaction. When the sand is revetted due to condensation and/or leaks, corrosion reinitiates. This last scenario would evolve an overall lower average corrosion rate, that is, a combination of high corrosion followed by long periods of dormancy.

Pednekar[16] notes that the corrosion rates, corrosion pfoducts, and pH changes observed in the Oyster Creek drywell corrosion are those that are observed for corrosion of carbon steels in aerated, chloride solutions.

6.5 *Possible Corrosion Scenario of Oyster Creek Drywell Degradation*

As illustrated in Figure 38, a series of factors/events most likely affected the corrosion of the Oyster Creek drywell. Such a corrosion scenario is listed below:

1. Backfilling of moist sand into the transition zone creates an initial electrolyte. Sand is contaminated by open exposure to marine environment during storage and installation. Backfilling also affects porosity of sand which affects moisture retention quality and creates random air pockets.

2. Expansion of drywell during pressure testing "squeezes" water out of the Firebar-D slurry which flows down into the sand bed. This water contains initial high quantities of chloride and sulfate.

3. Corrosion of the steel drywell initiates. Red lead primer provides some initial protection due to the formation of PbO_4^{-4}. However, carbon dioxide from the air and sulfate from the sand/or Firebar-D accelerate the breakdown of the limiting inhibitive qualities of the red lead primer.

4. Areas with more ready access to oxygen such as the insulation gap and drain become local cathodes.

5. Areas adjacent to concrete are provided some corrosion protection due to local alkalinity. A macro-galvanic cell is established between the steel adjacent to the concrete and the steel adjacent to the sand cushion.

6. Condensation cycles and leaks from fuel pool bellows gasket contribute air saturated water to maintain moist sand cushion. Additional chloride and sulfate may leach out of Firebar-D and be carried into the sand cushion.

7. Some regions of the sand cushion see alternate wetting and drying during startup/shutdown cycles. This results in a concentration of chloride at the metal/sand interface.

8. Sand maintains corrosion products close to metal surface and thus physically stifles corrosion rate.

9. Corrosion proceeds intermittently during "wetting" periods (condensation, leaks) or on a continuous basis.

7.0 RECOMMENDATIONS

The loss of containment integrity at Oyster Creek is an obvious concern. The corrosion mechanism is fairly well defined and an estimated overall corrosion rate of ~20 mpy has been established. It is now time to address this problem and identify potential mitigation steps for this phenomenon. At the specific request of GPUN, three areas of mitigation have been analyzed by GE; 1) polymer replacement/addition to the sand cushion; 2) corrosion inhibitors, and, albeit superficially, 3) cathodic protection.

7.1 Polymer Replacement/Addition to Sand Cushion[17]

It has been suggested that the removal of the sand cushion could be accomplished by sluicing. If the sand cushion was removed and if the subsequent void was dessicated, corrosion of the drywell would essentially stop. However, due to structural requirements on the containment, which are beyond the scope of this paper, it may be necessary to refill the sand cushion void with an alternate material which would have suitable mechanical properties. Therefore, GPUN has requested that a brief review be performed on candidate cushion materials with particular emphasis on polymers.

The first concern for a polymer replacement would be identifying a suitable means of injecting the material into the void. It would be possible to spray pellets of plastic through numerous core holes cut through the containment. Although there would be some procedural difficulties, it should be possible to obtain a relatively uniform distribution of plastic pellets. Scrap material such as polycarbonate resin (e.g. Lexan) and thermoplastic resin (e.g. Noryl) are available.

Lexan and Noryl can withstand doses of approximately $8X10^6$ and $1X10^8$ rads, respectively, before any structural damage occurs. Above these total dose levels, the materials would experience degradation by cracking. However, this cracking and eventual fracturing would probably have little effect on its structural qualities to serve as a transition cushion. Since, in this particular application, the sand and plastic would obtain their respective spring constants more from the voids in the cushion rather than any intrinsic material property, both materials should have similar spring constraints. However, it is recommended that this assumption be confirmed by a soil geologist.

If it is desired to have a cushion with more support strength, then any candidate polymer should be able to be applied in a sufficiently fluid state so that it could be poured into place. This material could then completely cover the steel surface and fill the sand cushion void. Since there will probably be no opportunity for heat curing, then the candidate material should be characterized by an ambient temperature cure.

If a particular polymer is not completely wettable, it may form a crevice against the steel surface which can promote localized corrosion if any electrolyte is allowed access. Therefore, assurance that any poured-in-place polymer adheres well to the steel must be obtained. Good adhesion will also depend on the skill with which the monomer or partially polymerized resin is installed.

Epoxies would probably be the best candidates for an intrawall resin injection since any remaining sand would behave as a filler. The epoxies would also be likely to adhere to steel surfaces. The short "pot life" and the viscosity of the epoxy resins would make application troublesome; in addition epoxies are relatively costly. Coal tar epoxies would probably be the best candidates. Presumably a "Nuclear Grade" material (i.e., one especially low in halogens, sulfur, and embrittling metals) would not be needed.

An epoxy spray paint could be used if the main concern is to protect the steel surface. If the sand can be removed, possibly a coal tar epoxy paint could be sprayed or poured into the intrawall region (i.e., Napko 538 Amine Coal Tar Epoxy). Then dry sand might be re-installed into the intrawall area for mechanical support, if necessary. Napka 539 Aluminum Mastic Epoxy is an aluminum powder-filled polyamide epoxy paint that is good for application to "minimally cleaned" surfaces. It satisfactorily penetrates residual rust on steel surfaces and generally wets steel surfaces thereby assuring more thorough coverage. Napko 682 Splash Zone Barrier Coating is an epoxy amide capable of application under water, if required.

If the sand is <u>not</u> removed, a paint may still be used since spray paint versions of epoxies or other resins would be more fluid than the corresponding resin and would be more likely to penetrate the sand and reach the steel surface. There is no obvious way to assure that complete steel surface coverage in the sand area is obtained. The most that might be accomplished would be assuring that excess paint is introduced to the intrawall region i.e., there is enough paint present for the sand to be saturated and coat all the entire drywell wall.

For fillers that may provide support as a substitute for or an addition to the sand, materials generally used as temporary sealants for valves, flanges, and pipes might be suitable. These materials would be the elastomers (fiber-reinforced, the fiber usually being glass) used for leak sealing by Leak Repairs Inc. (Division of Team Inc., Houston, TX) or by Furmanite Inc. (Virginia Beach, VA). It would not be possible to use these materials with fiberglass if the sand was not removed. However, it may still be desirable to paint the steel surfaces first.

If a polymer with good mechanical strength is desired, then materials might be used that are applied like "potting" polymers used for electrical insulation of motors (i.e., pouring of the prepolymerized material into place in a large holding container). However, the highest strength material, (20 ksi UTS) would be 20% glass-reinforced polyaryletheretherketone (i.e., PEEK). The polymer is castable at 700°F but is currently rather costly. It is available from ICI Americas Inc., (Wilmington, DE) or from a licensee (Greene, Tweed Engineered Plastics, Harleysville, PA) under the trademark "Arlon". Arlon is injection-moldable. Arlon 1260 (carbon fiber-reinforced PEEK) has a 30 ksi UTS. Addition of polymer resin to existing sand precludes the use of fiber-containing resins. There is no assurance that sand as a polymer filler would add to the strength of a polymer; such a filler, in fact, usually results in a weaker product. A high hardness polyetherurethane polymer would provide up to 7 ksi UTS and a 15% carbon fiber-reinforced aromatic polyetherurethane would provide approximately 18 ksi UTS. A styrene-maleic anhydride copolymer with 20% glass fiber reinforcement and proper processing may have a 10 to 14 ksi UTS.

The only other high strength materials approaching that of PEEK, are the fiber-reinforced epoxies. Injection-grade, 20% glass fiber-reinforced ABS have a 10 to 13 ksi UTS. Silicone/nylon 6, 6 pseudo interpenetrating networks (i.e., Petrach Systems, Bristol, PA), made by mixing the two components into a powder or granular form, may achieve 10 to 12 ksi UTS.

7.2 Corrosion Inhibitors[17]

The primary problem with corrosion inhibitors involves obtaining a uniform distribution over the entire surface of the steel or, as with the paint discussed above, corrosion may become focused at unprotected areas. At the same time, some prohibited inhibitors (i.e., chromates) may have to be avoided. Limited life or short-term inhibitors are not useful unless the sand cushion area is made virtually airtight. Therefore, inhibitors that operate by scavenging oxygen may not be usable. However, those that promote protective oxide formation on steel surfaces appear to be the most promising.

The difficulty is in identifying all of the required properties for this inhibitor in one inhibitor. Volatile inhibitors are usually of the type that scavenge oxygen thereby making them limited-life inhibitors. Yet water-soluble but volatile corrosion inhibitors would be most likely to provide complete coverage of the steel surface of the sand cushion area. Molybdate could be used as a replacement for chromate to provide an inhibitor that promotes protective oxide film formation on steel; but molybdate is not available in a volatile form. Sodium molybdate is available from Noah Chemical, Farmingdale, NY. Molybdate corrosion inhibitors, but only for cooling water, have been studied by Houseman (Burnham) Ltd. of the Portals Water Treatment Group in Great Britain. Molybdates are also available from Climax Molybdenum Co., Calgon Corp., Exxon Chemical Co., Magna Corp., Nalco Chemical Co., Newage Industries Inc., and R.T. Vanderbuilt Co.

A water-soluble (in case of the presence of any liquid-phase moisture), volatile corrosion inhibitor such as one that might be used for packaging or in long-term storage is the only type feasible for sand cushion use to inhibit further steel wall corrosion. Cortec Corporation (St. Paul, MN; contact Boris Miksic) is outstanding in this area. They have produced a volatile, water-soluble inhibitor dicyclohexylammonium chromate (U.S. Patent 4,275,835; June 30, 1981). They may also have the molybdate version of this inhibitor or the chromate may possibly be acceptable for Oyster Creek since it is not likely to escape the sand cushion region).

Just as was the case for coatings, incomplete coverage by an inhibitor can concentrate corrosion in unprotected areas. However, some corrosion inhibitors pose another problem. Nitrites, for example, should be avoided since there are certain moderate concentration ranges (depending on other environmental parameters) which would promote corrosion instead of inhibiting it.

If the presently existing sand is not removed, volatile corrosion inhibitors may not work. The sand will readily absorb this type of corrosion inhibitor. In fact, this would also be true of any inhibitor applied as a solution, aqueous or otherwise. The same problem exists here as it did for considering the use of resinous fillers or paints in the presence of the existing sand: a sufficient excess of inhibitor, as a solution or as a vapor, must be used so as to assure that the inhibitor reaches the steel wall and coats it completely. Otherwise localized corrosion may occur. Since liquids will be absorbed throughout the sand more readily than vapor, an oil-soluble version of an inhibitor may be suitable for application in this case.

Cortec Corporation has oil-soluble versions of its inhibitors. Using one that is oil-soluble and volatile may be suitable since it would help ensure coating of the steel wall with the inhibitor in one manner or another. Cortec VCI-320 would be one such product. Preservative petroleum lubricating oils could also be suitable. Examples are Oilcoat VT and Oilcoat A (formerly Gulf products but now Chevron products), Mobil VaporTech Light Oil, SACI-100 (Witco Chemical Corp.) and Tower 640RP (Tower Chemical Corp., Palmer, PA). Similar materials may be available from other sources, but it is best to use a product containing a volatile corrosion inhibitor. (Note that these materials are bound to very flammable.)

Pednekar also provides a list of organic and inorganic inhibitors for carbon steel in aerated chloride solutions[16]

7.3 Cathodic Protection

Basically, cathodic protection is a means of reducing the corrosion of a component by making the metal a cathode by means of an impressed current or attachment to a sacrificial anode (such as magnesium, aluminum or zinc). Since the cathodic protection (CP) system forces electrons into the metal creating this cathode, the basic principle of applying CP is quite simple. In general, the practical application of this corrosion control method is much more difficult. For the specific case of the Oyster Creek drywell, it may be extremely difficult.

For example, CP systems are designed to protect coated structures, that is, provide protection against any defects (holidays) in the coating. This minimizes the required applied current for protection. For Oyster Creek, the drywell is presently uncoated and therefore significant and perhaps prohibitive currents may be required. Other concerns include what source of direct current should be use; can a suitable anode be designed and, in fact, installed around the entire sand cushion; and how can it be ascertained, on completely buried structure, whether or not the entire surface has, in fact, been made a cathode and all corrosion mitigated.

Information which can answer such questions are beyond the scope of this report.

7.4 Mitigation Recommendation

It appears that a multiple approach should be used for the mitigation of corrosion of the Oyster Creek drywell. Since it appears that the main source of the corrosion problem is the wet chemically contaminated sand, the most suitable mitigation step would be the removal of the sand and drying of the cavity. This, by itself, would reduce the corrosion rate of the drywell to a vanishingly small level.

If no structural support is required, a further corrosive mitigation improvement would be a back spray painting of the drywell to provide coating protection with an aluminum powder-filled polyamide epoxy paint followed by application of a volatile corrosion inhibitor to mitigate any holidays in the coating.

If the sand cannot be removed, then the application of an excess quantity of an oil-soluble vapor phase inhibitor may be the best approach. If excess water is a problem, then an application of an excess of a sufficiently diluted epoxy paint such as Napko 682 Splash Zone Barrier epoxy amide may be the best choice. This paint application could then be followed by the excess application of an oil-soluble volatile corrosion inhibitor.

As noted above, the use of cathodic protection as a suitable corrosion mitigation step is considered beyond the scope of this review and therefore will not be discussed.

8.0 CONCLUSIONS

The results of metallurgical analysis by both GPUN and GE, data from the open literature and the above discussions have indicated the following conclusions concerning the corrosion of the Oyster Creek drywell:

1. The corrosion/wastage of the drywell is due to the presence of oxygenated moist/wet sand and exacerbated by the presence of chloride and sulfate in the sand cushion. A contaminate concentrating mechanism due to alternate wetting and drying of the sand cushion may have also contributed to the corrosion phenomenon.

2. Although Firebar-D is a known corrosive agent to steel, its role in this phenomenon is probably secondary. The source of contaminants in the sand cushion may have been primarily from the local marine environment.

3. Since the wall thickness measured by UT are extremely close to those measured on actual removed specimens, UT appears to be an accurate non-destructive method of monitoring wall thickness.

4. The estimated corrosion rate of the Oyster Creek drywell is ~20 mpy. This rate reflects the average corrosion over 17 years of service regardless of the relative continuity of the corrosion reaction, i.e. there may be periods of high corrosion rate activity during wetting cycles followed by dormancy during "dry" periods.

5. Excluding cathodic protection which is beyond the scope of this report, the optimum method of mitigation of the corrosion of the Oyster Creek drywell appears to be the combination of sand removal, back spraying of a protective paint and application of a volatile corrosion inhibitor.

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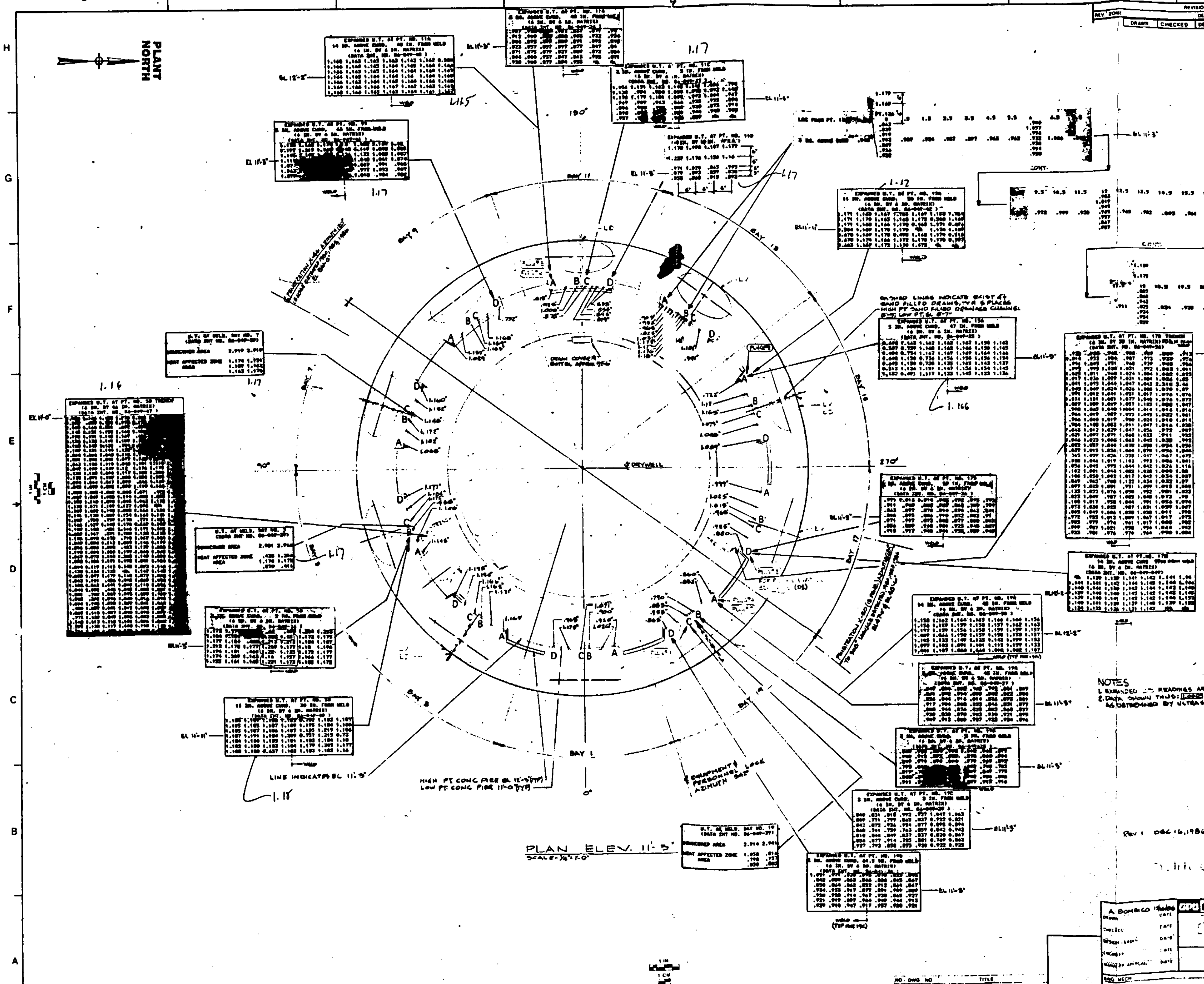
TABLE 1

DRYWELL STEEL

SPECIFICATION:	ASTM: A-212-61T Gr B
	FIREBOX FINE GRAIN - NORMALIZED
CHEMISTRY:	C - .23
(TYPICAL)	Mn - 1.06
	P - .010
	S - .023
	Si - .21
STRENGTH:	TENSILE - 75,000 PSI
(TYPICAL)	YIELD - 50,000 PSI
	ELONG - 35%

NOTE: MATERIAL WAS IMPACT TESTED



LEGEND
LD: LEAK DRAIN
LV: LEAK RESISTANCE (VENT)

CORE PLUG LOCATIONS

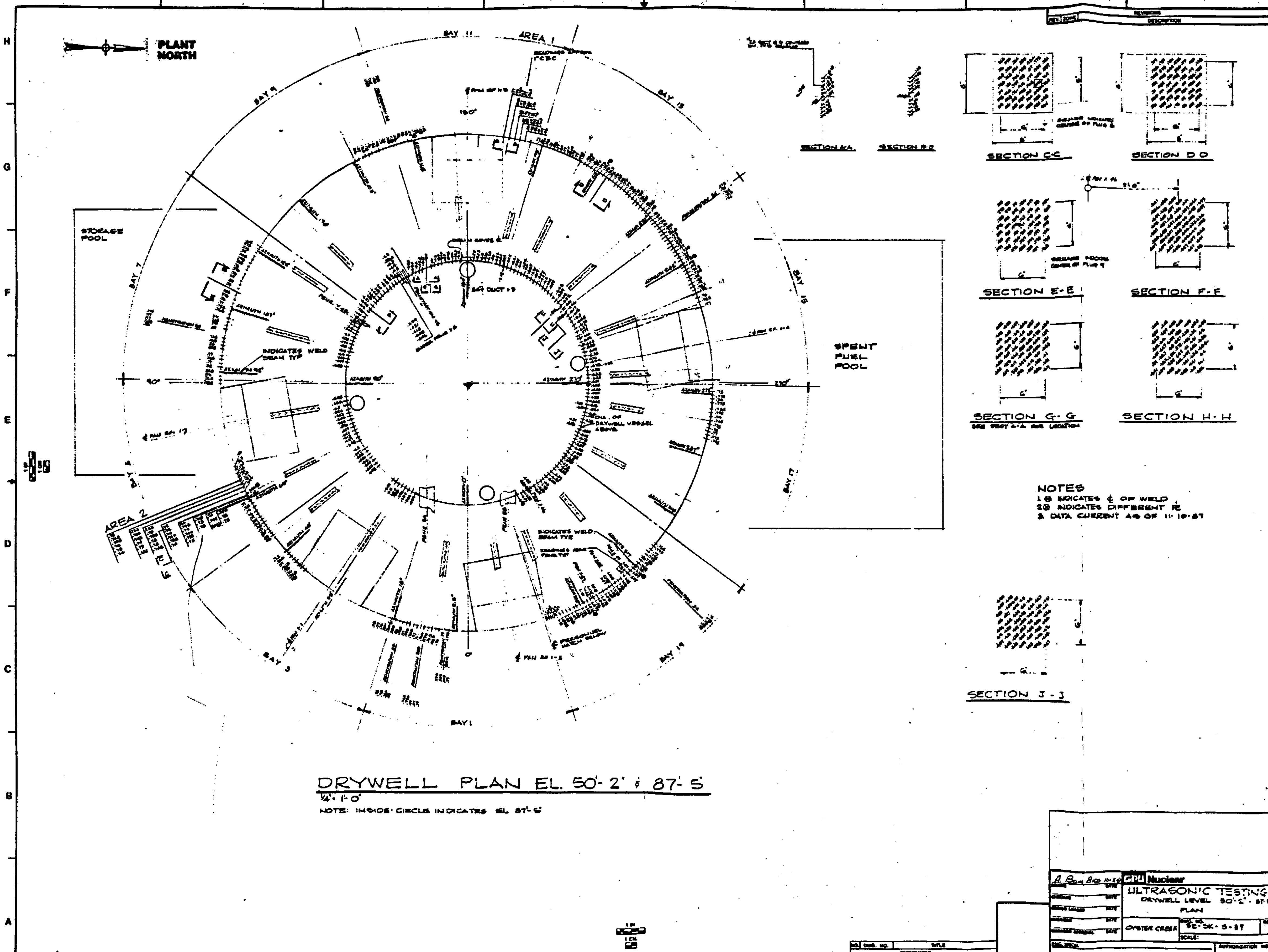
PLUG NUMBERS	BAY	ELEVATION
1	19C	11'-3 5/8"
2	16A	11'-5 1/4"
3	17D	11'-5 3/4"
4	19A	11'-3 3/8"
5	11A	11'-3"
6	9A	11'-2 3/4"
7	19A	12'-1"

NOTES
1. EXPANDED U.T. READINGS ARE 1" APART UNLESS OTHERWISE NOTED.
2. DATA SHOWN THUS: [1.000] INDICATES THICKNESS APPR. IN INCHES AS DETERMINED BY ULTRASONIC TEST PERFORMED IN SAID AREA

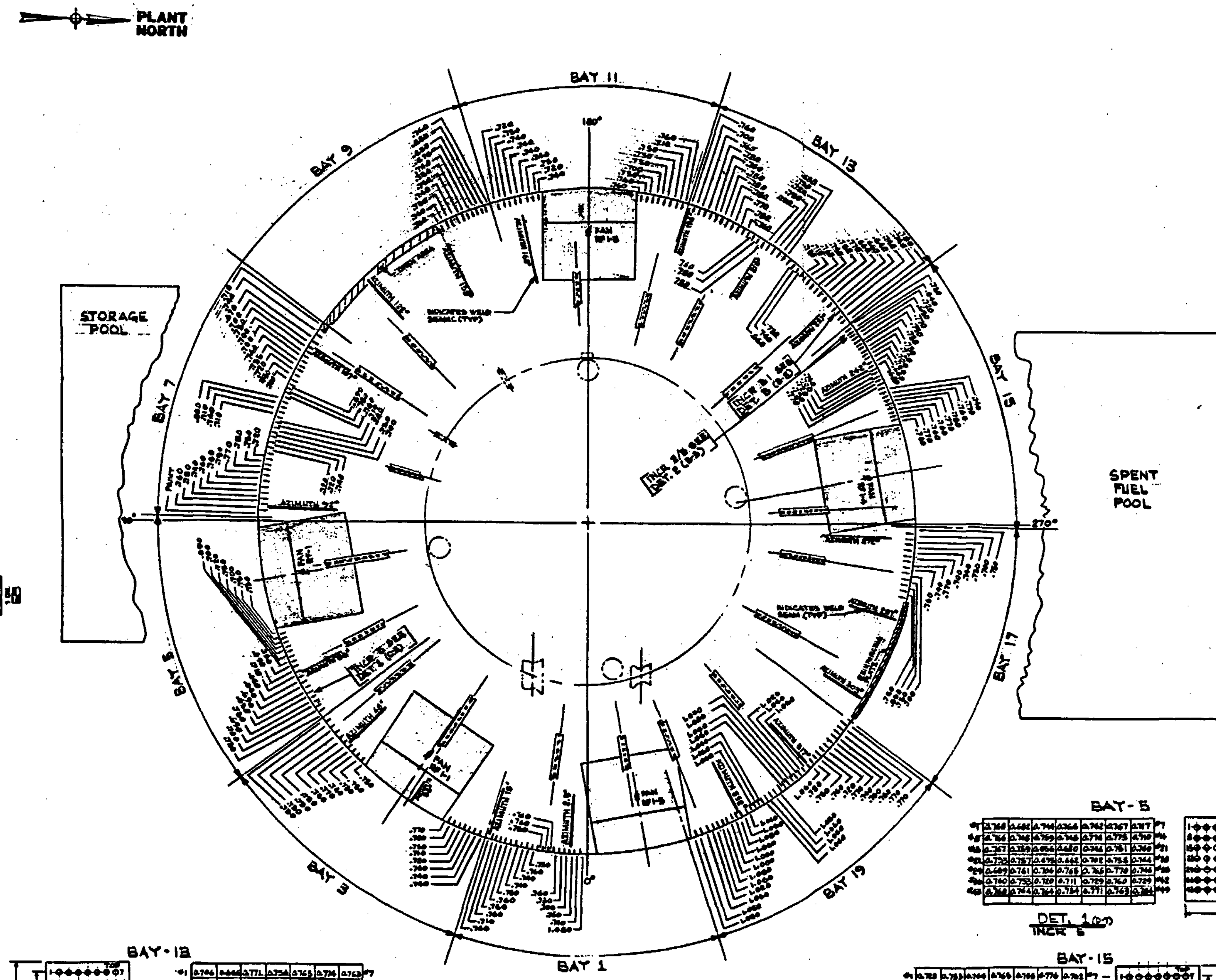
Rev 1 DEC 16,1986

A. BONACCO — DRAWN
CHECKED
DESIGN LEADER
ENGINEER
MANAGER APPROVAL
ENG. MECH

GPU Nuclear
DRYWELL DATA U.T. LOCATION PLAN
DWG. NO 3E-SK-S-85 REV 1
SCALE
AUTHORIZATION NO.



PLANT NORTH
AREA 1
AREA 2
BAY 1
BAY 3
BAY 5
BAY 7
BAY 9
BAY 11
BAY 13
BAY 15
BAY 17
BAY 19
STORAGE POOL
SPENT FUEL POOL
INDICATES WELD SEAM TYP
90°
180°
270°
0°
SECTION A-A
SECTION B-B
SECTION C-C
SECTION D-D
SECTION E-E
SECTION F-F
SECTION G-G
SECTION H-H
SECTION J-J
NOTES
1. ⊕ INDICATES ℄ OF WELD
2. ⊗ INDICATES DIFFERENT ℞
3. DATA CURRENT AS OF 11-19-87
DRYWELL PLAN EL. 50'-2" & 87'-5"
¼" = 1'-0"
NOTE: INSIDE CIRCLE INDICATES EL 87'-5"
GPU Nuclear
ULTRASONIC TESTING
DRYWELL LEVEL 50'-2" - 87'-5"
PLAN
OYSTER CREEK
DWG. NO. SE-SK-S-87
SCALE:



DRYWELL PLAN EL. 50'-2"

SCALE 1/4" = 1'-0

BAY - 5

#1	0.768	0.686	0.746	0.766	0.762	0.767	0.787	#7
#8	0.766	0.746	0.759	0.748	0.774	0.775	0.710	#14
#15	0.767	0.759	0.656	0.680	0.746	0.761	0.760	#21
#22	0.735	0.757	0.675	0.662	0.762	0.758	0.744	#28
#29	0.689	0.761	0.704	0.765	0.765	0.770	0.746	#35
#36	0.740	0.753	0.720	0.711	0.729	0.760	0.729	#42
#43	0.768	0.764	0.764	0.734	0.771	0.763	0.784	#49

DET. 1 (D-7)
INCR 5

BAY - 13

#1	0.746	[illegible]	0.771	0.754	0.765	0.774	0.763	#7
#8	0.599	[illegible]	0.770	0.753	0.784	0.785	0.772	#14
#15	0.649	0.678	0.764	0.736	0.719	0.766	0.756	#21
#22	0.717	0.760	0.754	0.690	0.769	0.771	0.785	#28
#29	0.646	0.766	0.708	0.761	0.768	0.772	0.754	#35
#36	0.755	[illegible]	0.686	0.767	0.785	0.793	0.766	#42
#43	0.734	[illegible]	0.763	0.779	0.763	0.717	0.779	#49

DET. 3 (F-2)
INCR 31

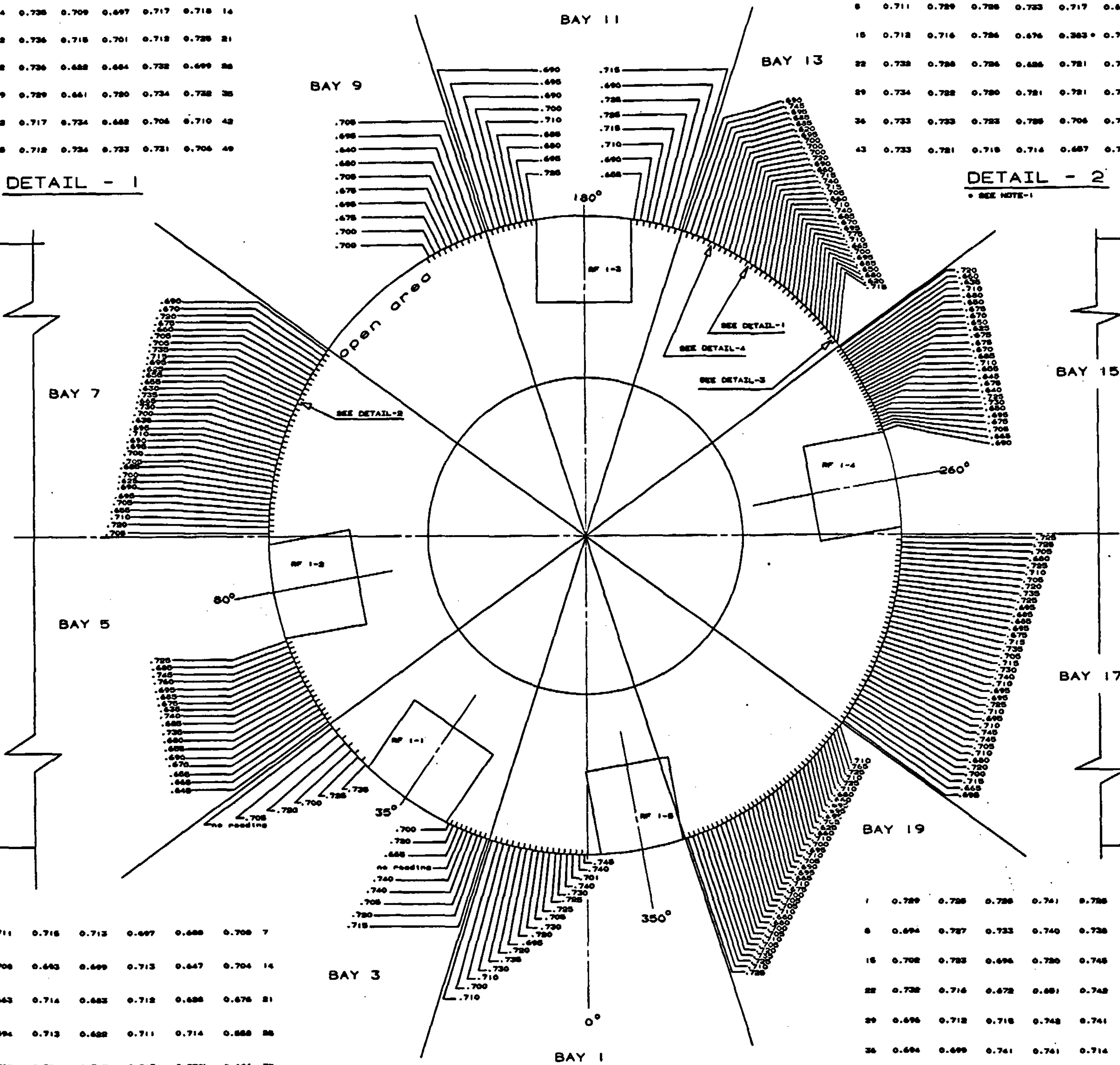
BAY - 15

#1	0.788	0.783	0.764	0.769	0.768	0.776	0.782	#7
#8	0.764	0.760	0.781	0.764	0.761	0.783	0.761	#14
#15	0.766	0.758	0.781	0.746	0.737	0.764	0.761	#21
#22	0.766	0.766	0.760	0.757	0.645	0.756	0.775	#28
#29	0.757	0.750	0.763	0.749	0.746	0.750	0.763	#35
#36	0.788	0.768	0.756	0.748	0.719	0.781	0.762	#42
#43	0.786	0.762	0.767	0.755	0.695	0.759	0.762	#49

DET. 2 (E-4)
INCR 2/3

NOTE:
1. DATA WAS TAKEN BY "A" SCAN OVER 6 INCH INCREMENTS WITH LOWEST MEASUREMENTS RECORDED AND SHOWN ON THIS DRAWING.

T. GAROFALO 4-8-90
GPU Nuclear
ULTRASONIC TESTING
DRYWELL LEVEL 50'-2"
MARCH 1990 READINGS
DWG. NO. 3E-SK-M-275 REV. 0



1	0.702	0.700	0.726	0.726	0.684	0.724	0.691	7
8	0.710	0.734	0.735	0.709	0.697	0.717	0.718	14
15	0.704	0.732	0.736	0.715	0.701	0.712	0.725	21
22	0.716	0.732	0.736	0.682	0.684	0.732	0.699	28
29	0.696	0.709	0.729	0.661	0.720	0.734	0.732	35
36	0.712	0.703	0.717	0.734	0.682	0.706	0.710	42
43	0.720	0.718	0.712	0.734	0.733	0.731	0.706	49

DETAIL - 1

1	0.724	0.729	0.734	0.702	0.708	0.720	0.712	7
8	0.711	0.729	0.726	0.733	0.717	0.697	0.717	14
15	0.712	0.716	0.726	0.676	0.383 *	0.727	0.487 *	21
22	0.732	0.726	0.726	0.686	0.721	0.702	0.723	28
29	0.734	0.722	0.720	0.721	0.721	0.711	0.712	35
36	0.733	0.733	0.723	0.728	0.706	0.705	0.712	42
43	0.733	0.721	0.718	0.714	0.687	0.701	0.733	49

DETAIL - 2

* SEE NOTE-1

NOTES:
1. DETAIL-2, AREAS 19 & 21 CHARACTERIZED AS LAMINATIONS

1	0.718	0.711	0.716	0.713	0.697	0.688	0.700	7
8	0.712	0.706	0.643	0.699	0.713	0.647	0.704	14
15	0.719	0.643	0.714	0.683	0.712	0.686	0.676	21
22	0.716	0.594	0.713	0.622	0.711	0.714	0.688	28
29	0.719	0.702	0.720	0.717	0.717	0.732	0.696	35
36	0.713	0.713	0.722	0.721	0.719	0.721	0.667	42
43	0.720	0.712	0.720	0.721	0.720	0.719	0.687	49

DETAIL - 3

DRYWELL PLAN @ EL. 51'-10"

1	0.729	0.725	0.726	0.741	0.726	0.733	0.737	7
8	0.694	0.727	0.733	0.740	0.738	0.728	0.710	14
15	0.702	0.723	0.696	0.720	0.745	0.742	0.740	21
22	0.732	0.716	0.672	0.681	0.742	0.728	0.738	28
29	0.696	0.712	0.718	0.742	0.741	0.736	0.739	35
36	0.694	0.699	0.741	0.741	0.714	0.738	0.739	42
43	0.733	0.732	0.726	0.741	0.739	0.709	0.734	49

DETAIL - 4

CAD FILE: [illegible]
THIS IS A COMPUTER GENERATED DWG. DO NOT REVISE IT MANUALLY

GPU Nuclear

ULTRASONIC TESTING
DRYWELL LEVEL 51'-10"
APRIL 1990 READINGS

STANKIEWICZ 12/27/90 DRAWN	DATE
CHECKED	DATE
DESIGN LEADER	DATE
ENGINEER	DATE
MANAGER APPROVAL	DATE

OYSTER CREEK — DWG. NO. 3E-SKM-358 — SH. — REV. 0 — SCALE: 1:1

ENG. MECH. — BA — TASK

REFERENCES — NO. — DWG. NO. — TITLE

REVISIONS — REV. — ZONE — DESCRIPTION

DWG. NO. 3E-SKM-358 SH.

TELECOPIED TO J. CHARTERINA 1/28/88

GPU Nuclear

Memorandum

FEB 01 1988

Subject: OYSTER CREEK REACTOR CAVITY LEAKAGE

Date: January 28, 1988

From: Manager Mechanical Components - R. H. Greenwood

Location: Morris Corp. Center
5310-88-018

To:
Director Engineering Projects - D. K. Croneberger
Engineer - A. Collado
Engineer - J. A. Martin
Engineer - J. Charterina
H/X & Pressure Vessels Manager - J. D. Abramovici
Manager Plant Engineering - J. DeBlasio
Manager Special Projects - B. D. Elam
Materials Engineering Manager - R. L. Miller
Plant Engineering Director - A. Rone
Project Engineer - A. Spivak
Supv. Mechanical Engineering - C. Schilling

The following are resolutions and action items from our meeting Tuesday, January 27, 1988. The next meeting will be Thursday, February 4 in F1A to review the cavity coating options and to develope an integrated schedule for the repairs.

CAVITY STEPS

The reactor cavity steps were inspected per Procedure 6130 Q AP 7209 that included visual examination with PT of suspect areas. Defects were not identified from inspections conducted 1983 nor 1987. The step plate thickness was verified to be 1/4 inch for the top three steps and 1 inch for the bottom step landing. It was agreed that this inspection should be repeated. The top three steps can be inspected as soon as the top three concrete shield plugs are removed using the fourth shield plug as a platform. Provisions need to be made for access to inspect the last step after the last shield plug is removed. (ACTION - J. Charterina)

9073d/343

N70648 (06-86)

CHANNEL

The transfer channel from the cavity to the fuel pool and to the equipment pool is lined with 1/4 inch plate. There is still a question as to the existence of leak tracing on the weld attachment to the pool liners. There is no record of any inspections of these channel areas or of its attachment to the vertical 12 gage liner. (ACTION - J. Martin)

Since the channel area is subjected to loading similar to the steps when the shield gates are put in place, it was decided that these areas also need to be inspected. This will require that the fuel be moved away from the gate area prior to removal of the shield plugs to prevent shine through the fuel pool dam. (ACTION - J. Charterina)

WELD REPAIRS

Should there be any defects found in the step area or the channel area a weld repair procedure will be needed. Although there is a procedure in place it needs to be reviewed and updated. A separate procedure is needed for repairing the liner in the areas where samples were removed or where there is unacceptable liner damage. (ACTION - R. Miller)

RELINER

Two coatings are being considered as a permanent fix for sealing the cavity liner. (1) Ceilcote 222HT, a vinyl ester with flake glass fill that would require grit blasting and two coats; (2) A Dow silicone requiring two coats but may not need grit blasting. The Ceilcote coating meets the coating selection criteria. It is unclear at this time as to whether the Silicone coating meets all GPUN requirements. Additional details are being sought for the Silicone coating. The option of using Hypolon sheets was discounted since it degrades at high temperatures. (ACTION - R. Miller)

A strippable coating option, Isotron, is being pursued. This material is supposedly suitable for underwater service but would have to be removed after each use. Its advantages are that it can be sprayed rolled or brushed without any surface preparation and it provides an additional benefit by removing radiological contamination. More information is needed on its strippability to assure it remains in place until it is intended to be removed. Another concern is the leach ability of impurities and its teflon content. Should this option be selected, the inspection or repair of the steps or channel area would not be needed. An economic evaluation needs to be prepared to compare these three options. (ACTION - R. Miller)

TROUGH

Access to the concrete trough will be obtained through a 6 inch hole drilled through the steel trough. The concrete will require repair at two locations. One being at the drain and the other about 60 degrees clockwise from the drain. These areas were identified from the camera inspections and indicated that the lip of the trough was not sufficient to assure that water would not enter the area between the concrete and the containment. Video enhancements of these suspect areas were made to determine if cracked concrete existed. No evidence of cracking was observed. A repair procedure is needed. (ACTION - J. Martin)

Additional video camera inspection will be needed to precisely locate the areas to be repaired. A locating method will be needed to assure that the repair hole is drilled at the correct locations. (ACTION - A Spivak)

CONCRETE REPAIR

The concrete may be repaired with Ceilcote 665 or an available Belzona Magna Quarts. A wood mock-up of the steel trough area is to be assembled so that the technician can practice the repair since he will have to watch his activities through a video monitor. If this can not be done, it may be necessary to drill two holes for each repair. Drawings of a wood mock-up model of the work area are complete. (ACTION - J. Charterina)

DRAIN REPAIR

Since it was reported that the 2 inch drain pipe appeared to be clear of obstructions no pre-outage borascope inspection of the pipe up to the concrete trough was advised. However, when the access hole is drilled to repair the edge of the concrete trough, the drain will be examined. A sump hole about 4 inches in diameter and a few inches deep will then be drilled adjacent and intersecting the drain. The objective will be to provide a drain pot to collect then direct the flow from the trough. Removal of the concrete plug and section of the drain pipe needs to be reviewed for feasibility. (ACTION - J. Martin)

TROUGH SEALING

The 6 inch access holes in the steel trough will be plugged and seal welded shut. The bottom of the steel trough will be hydrolazed and coated with Ceilcote 665 or promotec lose applied in a liquid state to cover all of the carbon steel welds. It was reported that the bellows assembly area had been factory welded and leak tested after installation including the SS/CS weld on the lower part of the bellows. There is a video record of this lower weld, and it was reported to be in good condition but should be reviewed. (ACTION - R. Miller)

Video inspection of the underside of the bellows area was discounted since the air pressure test gave confidence of the bellows integrity. A plan was presented that the air pressure test would be repeated should leakage be detected in the drain line. An extension plate would be installed over the notch at the drain bellows access plate cover so that the air bubble behind the bellows cover would include the SS/CS weld. Introduction of air in this area would reduce the detected leakage should it be coming from the bellows or the weld. If it was determined that leakage existed, a leak rate monitor would be used to supply a constant supply of air to limit water leak through. Provisions needs to be made so that air can be supplied to this area. (ACTION - J. Charterina)

FUNDING

The distribution of funding between capitol and Operation & Maintenance would depend on the repair method for the cavity. The repair of the trench and inspections will be Plant O&M. (ACTION - A. Spivak)

RHG:am

R. H. Greenwood
Extension 7404

cc:
Director Engineering & Design - G. R. Capodanno
Mgr. Mat. Engrng./Chem Support - F. S. Giacobbe
Plant Systems Director - D. Slear
ED&CC - 328227
CARIRS

9073d/343

GPU Nuclear

Technical Functions
Safety/Environmental Determination and 50.59 Review
(EP-016)

UNIT Oyster Creek

DOCUMENT/ACTIVITY TITLE Temporary Repair of Rx Cavity

DOCUMENT NO. OCIS-328257-002 (if applicable) DOC REV. NO. 0

PAGE 1 OF 13

SE Rev. No. 4

SE No. 328257-002

Type of Activity Repair

(Modification, procedure, test, experiment, or document)

1. Is this activity/document listed in Section I or II of the matrices in Corporate Procedure 1000-ADM-1291.01? ☒Yes ☐No

   If the answer to question 1 is "no" stop here. (Section IV activities/documents should be reviewed on a case-by-case basis to determine if this procedure is applicable.) This procedure is not applicable and no documentation is required. If the answer is "yes" proceed to question 2.

2. Is this a new activity/document or a substantive revision to an activity/document? (See Exhibit 3, paragraph 3, this procedure for examples of non-substantive changes) ☒Yes ☐No

   If the answer to question 2 is "no" stop here. This procedure is not applicable and no documentation is required. If the answer is "yes" proceed to answer all remaining questions. These answers become the Safety/Environmental Determination and 50.59 Review.

3. Does this activity/document have the potential to adversely affect nuclear safety or safe plant operations? ☒Yes ☐No

4. Does the activity/document require revision of the system/component description in the FSAR or otherwise require revision of the Technical Specifications or any other part of the SAR? ☐Yes ☒No

5. Does the activity/document require revision of any procedural or operating description in the FSAR or otherwise require revision of the Technical Specifications or any other part of the SAR? ☐Yes ☒No

6. Are tests or experiments conducted which are not described in the FSAR, the Technical Specifications or any other part of the SAR? ☐Yes ☒No

   No because Installation/Application of the waterproof liner is a temporary repair which will be removed after refueling and draining of the cavity.

   Documents checked:

   If any of the answers to questions 3, 4, 5 or 6 are yes, prepare a written safety evaluation on a Safety Evaluation form.

   If the answers to 3, 4, 5, and 6 are no, this precludes the occurrence of an Unreviewed Safety Question or Technical Specifications change. Provide a written statement in the space provided above (attach additional sheet if necessary) to support the determination, and list the documents you checked.

7. Does this document involve any potential Non-Nuclear environmental impact? ☐Yes ☒No

8. Are the design criteria as outlined in TMI-1 SDD-T1-000 Div. I or OC-SDD-000 Div. I Plant Level Criteria affected by, or do they affect the activity/document? ☐Yes ☒No

   If yes, indicate how resolved

If the answer to question 7 is yes, either redesign or provide supporting documentation which will permit Environmental Licensing to determine if an adverse environmental impact exists and if regulatory approval is required (Ref. 1000-ADM-1216.03). If in doubt, consult the Radiological and Environmental Controls Division or Environmental Licensing for assistance in completing the evaluation.

Signatures	Date
Engineer/Originator S. K. Saha [signature]	10/19/88
Section Manager for F. S. Giacobbe [signature]	10-19-88
Responsible Technical Reviewer [signature]	10-19-88
Other Reviewer(s)	

GPU Nuclear

Technical Functions Safety Evaluation (EP-016)

UNIT Oyster Creek

ACTIVITY/DOCUMENT TITLE Temporary Repair of Rx Cavity Liner

DOCUMENT NO. (If applicable) OCIS-328257-002 Rev. No. 0

SE No. 328257-002

Rev. No. 4

Type of Activity/Document Repair
(Modification, procedure, test, experiment, or document)

This Safety Evaluation provides the basis for determining whether this activity/document involves an Unreviewed Safety Question or impacts on nuclear safety.

Answer the following questions and provide reason(s) for each answer per Exhibit 7. A simple statement of conclusion in itself is not sufficient. The scope and depth of each reason should be commensurate with the safety significance and complexity of the proposed change.

1. Will implementation of the activity/document adversely affect nuclear safety or safe plant operations? ☐Yes ☒No

   The following questions comprise the 50.59 considerations and evaluation to determine if an Unreviewed Safety Question exists:

2. Is the probability of occurrence or the consequences of an accident or malfunction of equipment important to safety previously evaluated in the Safety Analysis Report increased? ☐Yes ☒No

3. Is the possibility for an accident or malfunction of a different type than any evaluated previously in the Safety Analysis Report created? ☐Yes ☒No

4. Is the margin of safety as defined in the basis for any Technical Specification reduced? ☐Yes ☒No

   If any answer above is "yes" an impact on nuclear safety or an Unreviewed Safety Question exists. If an adverse impact on nuclear safety exists revise or redesign. If an unreviewed safety question with no adverse impact on nuclear safety exists forward to Licensing with any additional documentation to support a request for NRC approval prior to implementing approval.

5. Specify whether or not any of the following are required, and if "yes" indicate how it was resolved

	Yes	TR/TFWR/Other	No
a. Does the activity/document require an update of the FSAR?			X

Explain: Application of the water proof barrier(s) are temporary and they will be removed after refueling.

	Yes	TR/TFWR/Other	No
b. Does the activity/document require a Technical Specification Amendment?			X

Explain: Same as Item 5 (a).

c. Does the activity/document require a Quality Classification List (QCL) Amendment?

Yes	TR/TFWR/Other	No
		X

Explain: Same as Item 5 (a).

d. Other: (If none, use NA) N/A

This form with the reasons for the answers, together with all applicable continuation sheets constitutes a written Safety Evaluation.

List of Effective Pages

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2	4	12	1		
3	4	13	1		
4	2				
5	2				
6	2				
7	0				
8	2				
9	0				
10	2				

Signatures		Date
Engineer/Originator	S. K. Saha [signature]	10/19/88
Section Manager	for F. S. Giacobbe [signature]	10-19-88
Responsible Technical Reviewer	[signature]	10-19-88
Independent Safety Reviewer	[signature] David ...	10-19-88
Other Reviewer(s)		

1.0 PURPOSE

1.1 The purpose of this safety evaluation is to address the adequacy of design and safety impact of installation of a temporary barrier on the carbon steel trough and the stainless steel liner, of OC-Reactor Cavity Pool to prevent leakage of water during refueling operation.

2.0 SYSTEMS AFFECTED

2.1 During the proposed activities, the following systems will be affected:

- Reactor vessel & recirculating system
- Main steam system
- Condensate and feedwater systems
- Reactor Core Components
- Control rod drive system
- Standby liquid control system
- Reactor cleanup system
- Reactor shutdown cooling system
- Fuel storage and handling
- Spent fuel pool loading
- Radioactive waste system
- Stand by gas treatment system

2.2 GPUN Drawings:

2.2.1 GPUN 3E-153-02-001 through 009, "General Arrangement Reactor Building".

2.3 General Electric Drawings:

2.3.1 Dwg. No. 237E516 Sh. 1 -- Fuel Storage Pool Arrangement

2.3.2 Dwg. No. 237E547 Sh. 1 & 4 -- Arrangement of Fuel Storage Pool

2.3.3 Dwg. No. 237E975 Sh. 1 & 2 -- Study Refueling Equipment Storage Arrangement

2.3.4 Dwg. No. 3E-153-88-014 -- "Reactor Cavity Cross Section"

2.4 Burns & Roe Drawings:

2.4.1 Dwg. No. 4056 -- R.B. 4th Floor el 95'-3 Plan & Section
2.4.2 Dwg. No. 4057 -- R.B. 5th Floor el 119'-3 Plan & Section
2.4.3 Dwg. No. 4068 -- Rx Bldg. Storage Pool Section & Details

2.5 OC Final Safety Analysis Report (FSAR) - Section 9 - "Auxiliary Systems".

3.0 EFFECTS ON SAFETY

3.1 Safety Functions

Documents that define the safety functions of the system are:
3.1.1 OCNGS FSAR - Chapter 9

3.2 Description and Function of the Systems Affected

The reactor refueling cavity at OC is a SS lined concrete cavity which is located between elevations 91'9" and 119'3". It is approximately 37' in diameter and it completely surrounds the drywell head. The Rx refueling cavity is connected through gates and channels to Equipment Storage Pool and Spent Fuel Storage Pool. During refueling, the cavity is flooded with demineralized water from Condensate Storage Tank which is at ambient temperature. The water from CS tank flows through the reactor into the cavity and the level of water in the cavity is maintained to an elevation of 114' maximum. The temperature of water is maintained below 125°F during refueling operation which lasts approximately 10 weeks. The transfer of new and spent fuels is carried out under water to reduce radiation level. Upon completion of refueling, the reactor cavity and equipment storage cavity are drained, after installing the refueling gates, through lines at the bottom of these pools to the suction of the fuel pool pumps and hence to the Main Condenser hotwell or to radwaste. Supplementary drains from these cavities are directed to the Reactor Building Equipment Drain Tank. There is a curb around the cavities to direct any overflow to drains.

3.3 Statement of the Problem

During a recent inspection of a portion of the stainless steel liner on wall of the Rx Cavity by Liquid penetrant test, numerous unacceptable defects were found. A large number of such defects were found to be through wall defects by vacuum test. Two samples containing defects were removed from liner wall for investigation of the failure. The failure mode was determined to be fatigue (Ref. 1). No evidence of stress corrosion cracking was found on these samples. Although no such tests/examinations were carried out on the CS trough, it was perceived that the trough floor can also be a contributor to the water leakage due to the presence of about 600 linear feet of fillet welds and 117 plug welds all of which have experienced some deterioration over time.

Based upon the finding, it was postulated that numerous through wall defects will allow leakage of demineralized water from the cavity into the concrete wall.

If this leakage of water (when the cavity is flooded during refueling) is not rectified, the demineralized water may deteriorate the concrete wall and will corrode the drywell shell from OD. To prevent water leakage through the cavity liner two major options were considered i.e. (a) - weld repair of the defects and (b) temporary barrier over the entire cavity liner. The weld repair option has following drawbacks - (a) too many defects (b) weld repair of so many defects will produce large residual stresses and warping of the liner and (c) the repair areas will eventually fail by the same fatigue mechanism in the future. Therefore the latter option (i.e. temporary barrier) was selected to prevent water leakage. To prevent water leakage through trough floor the options considered were (a) weld repair and (b) temporary repair. The temporary barrier option was chosen since weld repair will involve large manhours and manrem exposure.

3.4 Proposed Rectification

3.4.1 Cavity Liner Repair

The proposed cavity liner repair consists of a combination of welding of larger defects, application of ss adhesive tape over certain size defects followed by application of a temporary coating barrier. The coating barrier(s) and ss tape will be qualified to Ref. 3 and 4 respectively. During application of the coating barriers, the reactor head will be kept on to prevent introduction of foreign materials. After completion of the refueling, the polymer barrier and ss tapes will be stripped off. The removable temporary barriers have been selected because no proven permanent barrier material could be found which could successfully withstand both operating and refueling environment detailed in Para. 3.6.

3.4.2 Cavity Trough Repair:

The trough will be hydrolased to remove rust, oil, grease or other debris followed by drying and solvent wiping to remove any trace of oil or grease. It shall then be coated with the same temporary polymer barrier as qualified for the stainless steel liner removed later after refueling is complete.

3.5 Materials of Construction

3.5.1 The existing Rx cavity liner is fabricated from ASTM-A240 Type 304 stainless steel in the following thicknesses:

Walls:	0.109 inch
Floors:	0.250 inch
Shield Plug Steps:	1.00 inch lowest step base
	.500 inch remaining steps

3.5.2 The cavity trough is fabricated from ASTM-A212 Grade B material in the following thicknesses:

Bottom Plate:	2 - 3/4"
Bottom Plate:	1"
Side Plate Expansion Joint	7/8"

3.6 Environments

3.6.1 Refueling Environment

(a) The medium is demineralized water of the following quality:

Parameter	Admin. Limit
Chloride	$\leq$ 50 ug/L
Conductivity @ 25°C	$\leq$ 2.0 µmho/cm
pH	5.3 - 7.5
Silica	$\leq$ 100 µg/L
Total Organic Carbon	$\leq$ 500 µg/L

(b) The temperature of the water during refueling is less than 125°F. The temperature of the liner before flooding can be as high as 140°F.

(c) The pressure on the liner will be hydrostatic pressure of the water, i.e., maximum of 10 psig.

(d) The radiation level of the cavity prior to flooding is estimated to be 20-100 mR/Hr - General area and 50-3000 mR/Hr contact with drywell head on.

3.6.2 Operation Environment

(a) The medium is dry air (enclosed by shield plug).

(b) The temperature on the liner can vary from 225°F to 280°F (Ref. 8).

(c) The radiation level at the liner location can be as high as 100 Rem/Hr of gamma radiation during reactor operation.

3.7 Technical and Safety Concerns on the Proposed Repairs

Concerns which must be addressed and dispositioned include 1) Will the coating(s) be able to seal various types and sizes of defects, 2) will the coating(s) be able to withstand refueling environment without delaminating or allowing water leakage, 3) will an explosion hazard be created by the application process, 4) will the Standby Gas Treatment System (SGTS) charcoal filters become fouled with solvent vapors during coating application, 5) will the leachates from the coating material adversely affect the reactor water/fuel pool water chemistry, 6) will loss of cooling system during refueling affect the coating adhesion and/or water chemistry, 7) does the coating application and removal produce any health or safety hazards, 8) is there any adverse reaction between coating and the substrate, 9) what are the impacts of residual coatings left inadvertently on the liner during operation, and 10) what are the impacts of inadvertent introduction of liner pieces into Reactor or Spent fuel pool cleaning system.

The evaluation of the above items of concerns are summarized below:

3.7.1 Reference 6 is a GPUN evaluation of test results on the performance of stainless adhesive foil. The subject tests were carried out as per Reference 3. The test results and the evaluation indicate that a) the SS foil seals defects up to 1/4" width as evidenced by vacuum box testing of the foil repaired areas in air. The force/pressure generated by the vacuum test is greater than the expected maximum hydrostatic pressure on the repaired areas, b) the SS foil maintains adequate peel strength in contact with water as evidenced by the immersion test results. Since peel strength did not show any appreciable loss of adhesion during 5-10 week immersion test, it can be deducted that the water sealing capability of the SS foil will be maintained over areas containing defects up to 1/4" width, c) the test results show that the foil by itself can provide an acceptable barrier on the liner under anticipated refueling environments against water leakage.

Reference 7 is a GPUN evaluation on the performance of sprayable coatings. The subject tests were carried out to the requirements of Reference 4. The test results indicate that the subject coating a) can seal defects up to 40 mils in width under simulated refueling environment, b) maintain adhesion to the substrate under water as evidenced by immersion test results, and c) can provide an acceptable barrier against water leakage under anticipated refueling environment.

Based upon review of test results of the sprayable temporary polymer coating on the smooth stainless steel surface, it has been concluded that the same coating will perform equally well on the carbon steel surfaces. Since carbon steel surfaces will be rougher in texture thereby providing a greater adhesion of the subject coating.

3.7.2 Reference 9 is a GPUN Fire Hazard Analysis Report. It shows total amount of solvent that will be released by the application processes. Explosion can occur upon ignition of concentrated solvent vapors in a confined area. The lowest concentration (%) at which this can occur is defined as the lower explosion limit (LEL). The FHA report concludes that the solvent vapor concentration in and around Reactor Cavity area will be significantly less than the LEL anytime during coating application process when manufacturer's recommended coating application procedure is followed.

3.7.3 Reference 10 is a Nucon Evaluation report on the effect of solvent releases on the SBGT system and resulting contamination of the charcoal filter. The report evaluated solvent release from spraying the Rx cavity with approved strippable coating system. The report concluded that the impact on SBGT system from Rx cavity coating application is not expected to be significant considering the low solvent content of the coating. In addition to the above, Plant Surveillance procedures require testing of the SBGT system charcoal filter efficiency prior to plant start up

3.7.4 In order to ensure that the proposed coating work (or its removal) will have no adverse effect on safety, plant personnel or public health, the following precautions have been required:

a. The use of welding, grinding equipment or open flame is forbidden in or around the Rx cavity area during coating.

b. The amount of solvents and other materials utilized in the Reactor Building which could be absorbed by the carbon filters has been limited. Use of solvents to be utilized in the Reactor Building has been restricted. No solvents other than those associated with the coating will be utilized in the reactor building at the time of coating application. The Reactor Building normal ventilation system will operate during coating and during the drying period. This will allow any solvents generated to be exhausted and discharged to outside.

c. Use of solvents prior to coating for degreasing will be restricted.

d. All coating operations shall be terminated upon loss of the normal exhaust ventilation.

e. There shall be complete compliance to the following plant procedures:

119 Housekeeping

119.4 Consumable Materials Chemistry Control

120 Fire Hazard

120.4 Fire

120.5 Control of Combustibles

All of the above controls will also reduce fire hazards and fouling of charcoal filters as discussed previously under Para. 3.7.2 and 3.7.3.

3.7.5 Reference 11 is a calculation for total leachates expected in the Rx cavity water due to use of GPUN approved strippable coatings. The results indicate that water chemistry of the affected systems will remain within acceptable limits.

3.7.6 The loss of shutdown and fuel pool cooling system has been reviewed. It has been estimated that a temperature rise to 212°F can be expected due to total loss of cooling systems.

The test results (Ref. 6 and 7) on approved strippable coating and stainless foil products reveal that all of the barrier materials can withstand 212°F boiling water environment for 8 hours without significant loss of adhesion.

3.7.7 Any chemical or metallurgical reaction between the coating materials and the stainless substrate was evaluated. It has been concluded that coating materials (i.e., latex, or the foil adhesive) have no chemical reactivity with the SS substrate up to 212°F in presence or absence of water. Similarly, no metallurgical reactions are expected since the temperature during application or service is too low. Electrochemical/corrosion reactions are not expected since 1) the coatings/adhesives are electrochemically inert and 2) demineralized water is a poor conductor.

3.7.8 Some coating may be tightly trapped into cracks and crevices of the liner and trough floor such that 100% removal may not be feasible.
The operation environment (Para. 3.6.2) and its prolonged exposure is expected to embrittle the trapped coating/adhesive material. The anticipated movements (e.g., crack propagation or differential thermals expansion or contraction etc.) within the cracks/crevices are expected to dislodge the trapped materials in future. Since 1) the amount of such trapped material will be very small, 2) the leachate/bulk analysis showed no harmful effect on the fuel pool water chemistry, no adverse effect is expected.

3.7.9 The question of inadvertent introduction of the coating barrier materials into the reactor was evaluated. It was determined by immersion and boiling tests (Ref. 6 and 7) that the approved coating materials will maintain its adhesion and will neither spall off nor fragment into small pieces. In addition, during coating application either the reactor head will be kept on or the Rx head opening will be securely covered up. All of the above should preclude introduction of coating materials into the reactor.

3.7.10 The quality standards of the cavity are not affected by the proposed coating work since the objective of this work is to prevent water leakage through liner and trough during refueling. The first barrier to prevent water leak is the strippable polymer Coating. The SS foil tape over the known areas of leakage on the liner is the second barrier.

3.7.11 <u>Natural Phenomena</u>

Not affected. The use of temporary barrier material will not change seismic classification or tornado/hurricane flood protection.

3.7.12 <u>Fire Protection</u>

Not affected. The existing fire protection systems are not affected by this activity.

3.7.13 Environmental Qualification

Not affected. The Rx cavity coating does neither affect existing EQ components nor the criteria used to qualify the components.

3.7.14 Missile Protection

Not applicable. The Rx cavity is located inside RB.

3.7.15 High Energy Line Break

Not applicable. No high energy line is affected by this activity.

3.7.16 Electrical Separation/Isolation

Not applicable. No electrical system is involved in this activity.

3.7.17 Single Failure Criteria

Not applicable. No electrical system is involved in this activity.

3.7.18 Containment Isolation

Not applicable. The strippable coatings will neither be applied at any containment isolation boundary nor is required to perform any containment isolation function.

3.7.19 Material Compatibility

The compatibility of the coatings with the existing materials has been tested and evaluated under Ref. 6 and 7. Para. 3.7.7 summarizes the test conclusions that the coating materials have no adverse effects on the existing materials.

4.0 Effects on Licensing Basis

4.1 After completion, the proposed coating work will not increase the probability of occurrence of the consequence of an accident since there will be no changes to the physical configuration or the operating parameters of the effected systems because all of the coatings are temporary which will be removed after refueling.

4.2 The proposed coating work will not increase the probability of occurrence or the consequences of a malfunction of ITS equipment for the same reasons discussed above.

4.3 The proposed coating work will not adversely affect nuclear safety or safe plant operations since all coatings will be removed after refueling and plant startup, along with the additional considerations addressed in para. 3.7.8.

4.4 The proposed coating work does not create a possibility for an accident or malfunction of a different type than previously analyzed. The configuration and function of each affected system is unchanged.

4.5 The proposed coating work does not reduce the margin of safety as defined in the SAR or any Technical Specification for the reasons discussed above. The coating will prevent water leakage through liner and therefore reduce potential for degradation of concrete and/or drywell.

4.6 No Oyster Creek Technical Specification violations are produced by the proposed coating work.

4.7 The proposed coating work does not violate any license requirements or regulations.

4.8 Coating work does not produce a radiological concern. The impact of airborne solvent in exhaust air passing through the SGTS in the unlikely event of emergency SGTS activation, simultaneous with coating, will not significantly affect iodine releases from the plant.

4.9 No changes to the FDSAR are required.

4.10 Plant Procedures do not need to be changed.

5.0 Effects on Environment

5.1 None. The secondary containment integrity will be maintained during coating application and removal. Therefore no release of coating material is expected during application or removal processes to the outside environment. Since solvent contents of the coating material is very low, the release of the solvent vapor to the outside environment (via RB ventilation) will not pose any environmental concerns.

6.0 Conclusion

The proposed coating work will not reduce the performance of the affected systems, affect the safety functions of these systems, increase the probability of occurrence or consequence of an accident, create a possibility for an accident, decrease the margin of safety as defined in the bases of Oyster Creek Technical Specifications, violate any licensing requirements, cause a radiological concern, and will not affect the environmental permits.

7.0 References

1. GE -F&PMT Transmittal # 88-178-005 - "Corrosion Evaluation of the OC Cavity Seal" dated March 17, 1988.

2. GPUN Tech. Spec. SP-1302-22-006, Rev. 4, "OCNGS - Repair of Reactor Cavity and Storage Pool Lining."

3. GPUN Tech. Spec. SP-1302-56-107, Rev. 0, "OCNGS - Selection Criteria for Temporary Water Tight Metal Foil for Rx Cavity Liner Repair."

4. GPUN Tech. Spec. SP-1302-56-106 Rev. 0 "OCNGS - Selection Criteria for Temporary Water Tight Coating for Rx Cavity Liner".

5. GPUN Tech. Spec. IS-323505-002, Rev. 0, "OCNGS - Application of Temporary Polymer Coating for Rx Cavity Liner."

6. GPUN TDR #937 Rev. 0, "Test Data on Qualification of Coating Science's SS Metal Foil".

7. GPUN TDR #938 Rev. 1, "Test Data on Qualification of Isotron Products". I R3

8. GPUN TDR #713 Rev. 0 - OCNGS Upper Drywell Shield Wall Thermal Analysis.

9. Fire Hazard Analysis. - FPE No. 328257-001 Rev. 0.

10. NuCon evaluation of Coating Materials solvent release on SGTS charcoal filter DRF #067072.

11. Calculation for leachates/bulk analysis. - Calculation No. C-1302-243-5340-046.

GPU Nuclear

DOCUMENT NO. SE 328257-002

TITLE Temporary Repair of Rx Cavity Liner

REV	SUMMARY OF CHANGE	APPROVAL	DATE
2	Substantial changes to include application of temporary polymer coating on carbon steel trough floor in the Rx Cavity. Paragraphs 1.1, 2.3, 3.3, 3.4, 3.5, 3.7.1, 3.7.8, 3.7.9 and 3.7.10 expanded to include the above change.	SKS/DDB Sg	10/19/88
3	Para. 7.0 - Ref. 7 - GPUN TDR 938, Rev. 0 revised to extend the test immersion time from 10 weeks to 12 weeks at $125^{o}F$ for Isolock 300 modified Latex coating system.	SKS/DDB Sg	1/3/89
4	Pages 1 and 2 - Non Substantial Change - Correct Design Document No. and Rev. No. provided.	SKS/DDB	1/11/91

GPU Nuclear

Technical Data Report

	TDR No. 851	Revision No. 0
	Budget Activity No. 328227	Page 1 of 21
Project: ASSESSMENT OF OYSTER CREEK DRYWELL SHELL	Department/Section E & D / MECH. COMPONENTS	
	Release Date 12/27/88	Revision Date

Document Title: ASSESMENT OF OYSTER CREEK DRYWELL SHELL

Originator Signature	Date	Approval(s) Signature	Date
John A. Martin [signature]	12/21/88	[signature]	12-27-88
		Approval for External Distribution	Date

Does this TDR include recommendation(s)? ☐Yes ☒No If yes, TFWR/TR# ____________

*	Distribution

Abstract: STATEMENT OF PROBLEM

This TDR covers the taking of the U.T., preparation and removal of core samples gathered in the evaluation from 1986 to November 1987 of the drywell containment pressure vessel shell. The concern for this assessment of the vessel shell thickness arose out of the continued observation of leakage of water from around drywell penetrations at reactor building floor elev. 75'-0" and 23'-0" and the drains from the torus rooms (sand cushion entrenchment). This observation generated concern regarding possible corrosion of the shell.

KEY RESULTS

The U.T. data indicated reductions in drywell shell thickness in a band at approximately elevation 10 feet. This band corresponds to the sand entrenchment region of the drywell.

Based on data collected in November, 1986 the lowest wall thickness in this area is 0.87 inches. The "as specified" nominal thickness is 1.154 inches.

U.T. data taken at elevation 50'-2" indicated some areas of local thinning. The lowest average thickness at elevation 50'-2" is 0.757 inches in plate that has nominal thickness of 0.770 inches. This is based on data collected in November, 1987.

The lowest average thickness at elevation 87'-5" is 0.619 inches in plate specified as 0.640 inch plate. This is based on data collected in November, 1987.

(For Additional Space Use Side 2)

* Abstract Only

CONCLUSION

At the present time a specification (Ref. 6) has been initiated for continued monitoring of the drywell containment vessel wall thickness as required during unscheduled "outage of opportunites and refueling outages". This data will be evaluated as it is generated and captured in TDR 948, Statistical Analysis of Drywell Thickness Data.

TABLE OF CONTENTS

1.0 PURPOSES

This TDR captures the technical information gathered for the evaluation of the drywell containment pressure vessel shell thickness. The concern to make this assessment of the vessel shell thickness was born out of the continued observation of leakage of water from around drywell penetration observed from reactor building floor elev. 86'-0", 23'-0" and the drains from the torus room (sand cushion entrenchment). A program was undertaken to accomplish a sampling of thickness readings using ultrasonics at various elevations. This sampling of data was taken and evaluated at each outage of opportunity (10 foot elevation only). For the purpose of this TDR and as a guide, the data collected will be referred to in the following nominal elevations.

(a) Elevation 10 foot
(b) Elevation 51 foot
(c) Elevation 87 foot

Because of these wetting conditions, there was concern that repeated exposure of the drywell steel to water could result in degradation of the drywell in the sand cushion region.

2.0 METHODS

2.1 DRYWELL THICKNESS MEASUREMENTS

Measurements of the drywell portion of the containment shell were made to verify its thickness during the 11R outage. These measurements were made using UT, a Non Destructive Examination (NDE) method, that is able to accurately determine the thickness of material or presence of abnormalities, i.e., nonmetallic inclusions. UT plate thickness measurements were made on the Oyster Creek drywell. Approximately 1,000 UT readings were eventually taken utilizing an ultrasonic thickness gauge device (D-meter) (Attachment 1). Measurements were obtained by transmitting ultrasound through the plate and measuring the time it takes for the longitudinal wave mode to travel to a reflector (front wall interface of mid-wall reflector or backwall) and back. Since the electronic measurement of time results in the digital thickness measurement of the first significant sound reflector, the probability of mid-wall reflector being measured versed the backwall is dependent on the size of the reflector relative to the surface area of the ultrasonic transducer. The larger the mid-wall reflector, the more likely the digital thickness reading will be the mid-wall number, and not the backwall value.

To further characterize the drywell an "A-Scan" UT technique was also employed. "A-Scan" is important for the expanded analysis of the character, location and amplitude of various ultrasound reflectors. The "A" scan is the ultrasonic indication displayed on cathode ray tube (CRT). The front surface pip or amplitude appears first, and the back surface pip or amplitude appears sometime later in the CRT sweep display. The space between the pips is a measure of the distance between the surfaces. Pips in between the front and back surfaces may be mid-wall reflectors such as laminations, inclusions or isolated holes and/or pits.

Other characteristics of the reflector can be observed by a qualified technician when using an "A" scan that are not available with a D-Meter. Profile of the amplitude, break pattern at the baseline, number of doublets following the amplitude pip, multiples of original reflectors, and amplitude height on the screen and other characteristics all give information that may be useful in analyzing the origins of ultrasound reflectors.

The "D" meter was chosen for the continued surveillance of thickness readings because of its

- Accuracy
- Ease of reading
- Repeatability

2.2 <u>MEASUREMENT LOCATION</u>

Initial UT measurements in 1983 were made from the inside of the drywell containment at elevations 51 feet and 10 feet. A digital UT system was used. The measurements opposite the sand cushion at the 10 ft. elevation in the Bays corresponding to where water leaks were observed, indicated that the containment wall was thinner than expected. Measurements above these areas in the same plate indicated thicknesses within the original plate thickness variability. Additional UT readings in the same Bay quadrants at elevation 51 indicated no abnormal thickness variations. Although there are no specific requirements for surveillance of the containment wall thickness, it was considered prudent to make these measurements due to the wetted conditions that had occurred.

The above initial measurements were made through the protective coatings on the inside of the containment. Since the effect of the protective coating on the UT measurements was questioned, special test blocks were made that included the coating material to quantify the effects of the coating on the UT readings. The accuracy of the UT system was established for the coating thickness of the upper portions of the drywell. The effects of Carboline Carbo-Zinc 11 coating on the accuracy of UT measurements was verified through an experiment conducted by GPUN. Two carbon steel plates approximately 1.15-inch thick and six by six-inch square were coated with Carbo Zinc. One plate had five mils of coating and the other plate had 10 mils ofcoating. Both plates had a half inch wide strip on one edge left uncoated. Both plates were laid out in a half inch grid pattern across the entire partially coated side including the uncoated strip. Similar equipment (D-meter of same make and model) transducers, and couplant as used in the field was utilized and measurements taken. Approximately 149 readings of thickness were taken for each plate. Additionally each grid (excluding the uncoated strip) was measured by Dry Film Technique (DFT) gauge to determine the coating thickness. The uncoated strip for each was measured by micrometer. The three readings: 1) ultrasonic (coated and uncoated); 2) dry film technique; and 3) micrometer (uncoated strip) were compiled, averaged and final factors developed. The uncoated micrometer reading, plus the DFT reading was treated as the true reading of combined thickness. The UT reading was found to overcall 0.3% for 5 mil coatings and 1.5% for 10 mil coatings after subtracting the DFT reading from the combined UT reading of steel and coating thickness. It should be noted that the coating application on the test plates and the upper portion of the drywell were consistently uniform. The coating along the basement floor(elevation 10), however, was found to be considerably thicker at locations where UT readings were taken.

For this reason the coating was removed and a new set of UT measurements were made in 1986. The new readings continued to indicate that the containment wall was thinner than expected in several areas along the basement floor as with prior measurements, the areas of indicated thinning were adjacent to the sand cushion.

2.3 EXTENDED UT MEASUREMENTS

As a result of the UT readings taken in 1986 adjacent to the sand cushion being considerably thinner than expected, a program was initiated to obtain detailed measurements to determine the extent and characterization of the thinning. UT measurements were made in each Bay at the lowest accessible locations.

Where thinning was detected, additional measurements were made in a cross pattern determine the extent. The cross pattern had the lowest reading as the center and was a 1" center with a 5x5 pattern after the cross pattern was completed the lowest reading was then used to expand the UT to a 6x6 grid on 1" center with the lowest reading as its center.

To determine the vertical profile of the thinning, trenches were excavated into the floor in Bay 17 and Bay 5. The concrete floor and rebar was removed to expose a portion of the drywell wall about 18 inches wide and sufficiently deep to allow measurement to the bottom of the sand cushion area. Bay 17 was selected since the extent of thinning at the floor level was greatest in that area. It was measured that the thinning at elevations below the initial measurements were no more severe and became less severe at the lower portions of the sand cushion. Bay 5 was excavated to determine if the thinning line was lower than the floor level in areas where no thinning was detected. Although several inclusions were found, there were no significant indications of thinning. As a result of the above, the area above the concrete was considered to be conservatively representative of the trenches and no further readngs were taken. A repair specification Ref. 1 was initiated to provide instructions for the repair of the concrete floor after the readings were taken: specifically the repair consisted of filling up the cavity with silicone elastomers in order to restore the insulation properties of the removed concrete.

Additional U.T. measurements for the continuous monitoring program will be obtained during future outages to ensure that:

1. Cathodic protection is being properly implemented in the sand bed region. In addition, we cannot monitor C.P. effectiveness without U.T. in the frame area because a reference cell cannot be installed in the frame area from the torus room side of the sand bed.

2. Previously uncorroded bays remain that way.

3. Finding standing water in the core hole of bay 11 during the C.P. implementation would be properly assessed.

2.4 HEAT AFFECTED ZONES & REINFORCEMENT STRUCTURE

Other areas of concern requiring additional UT investigation were the plate to plate welds under the torus vents and the vent opening reinforcement plates. These areas were given extra consideration on the basis that material sensitized by welding may have been attacked by a corrosion mechanism with greater damage or cracking occurring at those locations. The extra UT investigation was conducted at three spots equal distance along side each toe of the vertical plate to plate weld and on either side of the bottom center gusset of the vent opening reinforcement plate.

Eight D-meter thickness measurements were taken at each bay, or Bays 5, 7 and 19. These readings were on each bay of the welds.(4 each hole). At these Bay sites the six locations were also 45° shear tested to interrogate the weld Heat Affected Zone (HAZ). The 45° shear wave test was especially done to detect HAZ cracking. The top two locations were also the sites from which the plate to torus vent reinforcement plate weld was examined for HAZ cracking. No crack indications were found and no wastage of the torus vent reinforcement plate was found. The plate to plate weld HAZ as well as the weld when measured using a 6x6 grid indicated wastage similar to the surrounding plate wastage.

2.5 ALTERNATE UT TECHNIQUES AND VERIFICATIONS

EPRI NDE Center UT personnel were invited to independently analyze the containment vessel plate. Their objective was to independently analyze the conditon of the drywell liner. They scanned two areas using a "Zero Degree Longitudinal Wave Method". One area compared was just above the curb that we indicated had general wastage. Another area was where we had indications of mid-wall deflections or laminar inclusions. Their observation and measurements independently verified GPUN's results.

Mapping of the wall profile indicated a corrosion transition at seven to eight inches up from the concrete curb in Bay 19. This detailed map was generally corroborated by the GE Ultra Image III "C" Scan top graphical mapping system.

GPUN experimentally utilized the I.D. Creeper of "30-70-70" technique (a UT integration method) to detect minor changes in back wall surface conditions. This technique compared "A" scan presentations from one inch thick corroded samples to the results from Bay 13 locations "A" and "E". Reference standards were utilized representing light, moderate and heavy corrosion conditions. This 30-70-70 technique defined surface roughness conditions by matching "A" Scan presentations from materials that have light, medium and heavy corrosion on their back surfaces. It was able to verify the roughness condition of wastage and the light corrosion areas of the containment wall.

The "A" scan displays from the vessel plate were categorized by comparing them to the reference "A" scan displays. Location A of Bay 13 (0"-6" up from concrete curb) showed typical "A" scan display of moderate corrosion on average. Local sites of heavy corrosion also were identified. Bay 13 locations "A" and "E" indicated heavy corrosion between 0 to 6 inches above the curb, moderate corrosion 6 to 14 1/2 inches above the curb, and very low or no corrosion 14 1/2 to 17 inches above the curb.

2.6 METHODOLOGY OF CORE SAMPLE LOCATION

The selection of areas to obtain the core samples was made to evaluate if the UT measurements represented indicated material wastage of if there was localized "pitting". Those measurement areas that indicated thickness readings of less than half of the thickness expected, i.e., .4 to .7 inches, and had adjacent measurements of the expected thicknesses (nominally 1.154"), were designated as "pitted" areas. Area that had indicated thinning at adjacent measurements were designated as wastage areas. A third area, above the wastage area, and within the sand cushion that appeared to have a thinning or "pits", was also selected as a sample site. The core sampling sequence and logic were to first obtain a sample of a suspected "pitted" area and two samples of a wastage areas but in different bays. Should the "pitted" sample turn out to be an inclusion as suspected from the UT, additional samples of areas that were suspected as being "pitted" would not be required. It was decided, therefore, that core samples should be removed (Ref. 2)from the drywell in each of these different regions in order to achieve the following goals:

a) Verify UT thickness reading
b) Characterize the form of corrosion
c) Obtain sand samples and samples or other annulus materials
d) If corrosion existed, characterize corrosion products and environment
e) Provide access for visual examination of the outside surface of the drywell
d) Allow for sampling of sand and/or corrosion products for bacteria

With these goals in mind, a first cut was made at selecting regions for sampling of the drywell steel. Twelve regions were selected: four from wastage regions, four from "pitted" regions, two from above the wastage region and two from below the concrete level. These initial selections were, however, modified slightly as the program progressed and additional information became available from ultrasonic testing and initial core sample examinations.
Table 1 identifies each of the seven core sample locations ultimately chosen and the types of samples obtained.

TABLE 1
Core Samples

Sample No.	Bay/ Location	Reason for Sample Removal	Elevation
1	19C	Wastage	11'-3 5/8"
2	15A	Pitting/ Inclusion	11'-5 1/4"
3	17D	Wastage	11'-3 3/4"
4	19A	Wastage	11'-3 3/8"
5	11A	Wastage	11'-3"
6	11A	Minor wastage	12"- 2 3/4"
7	19A	Minor wastage	12'-1"

2.7 METHODOLOGY FOR MEASUREMENTS OF WALL THICKNESS ABOVE 23' ELEVATION (NOVEMBER 1987)

Wall thickness measurements using "D" meter equipment, were taken at elevation 50'2" approximately eleven inches below the seam weld on the joint to the next highest plate. Readings were taken in a one inch wide circumferential band extending around the drywell. Readings were taken in all accessible areas (areas that could be accessed from existing floors or gratings without scaffolds or equipment removal). UT readings were obtained on six inch centers. If four consecutive readings (on six inch centers) yielded readings more than 25 mils lower than nominal thickness, the interval between readings was shortened to one inch centers.

In addition to this band, "D" meter readings, on six inch centers, were taken in a two foot long one inch wide circumferential band above accessible drywell penetrations between elevations 46'6" and 49'.

At elevation 87'5" a one inch wide circumferential band was scanned with an "A" scan in all accessible areas to characterize the outside surface of the drywell wall. Readings were also taken with a "D" meter on six inch centers. As done on elevation 50'2", the reading interval was shortened to one inch on center if four consecutive readings were more than 25 mils less than nominal wall.

If a drywell penetration intersected the inspected band at elevation 87'5" then an additional two foot band (centered one foot on each side of the penetration) located six inches below the penetration was inspected.

In three areas on the 50'2" elevation and four areas of the 87'5" elevation, a six inch grid of 49 UT measurements was taken to provide additional data on the extent of wall thinning.

2.8 METHODOLOGY FOR ASSESSMENT OF CORROSION

Assessment of corrosion was performed by removing two core samples from elevation 50'2" (Table 2). A metallurgical assessment of the plugs was performed to characterize the form of corrosion, obtain Firebar samples, characterize corrosion products and environment and provide access for visual examination of the outside surface of the drywell if a gap exists between the Firebar and the drywell (Ref. 5 & 6).

TABLE 2

50'2" ELEVATION THICKNESS EVALUATION

Sample No.	Location	Type of Sample
8	Bay 5	Uniform Thinning
9	Bay 7	Uniformly at or above nominal with low spots

2.9 METHODOLOGY FOR SELECTING THE SIZE OF THE DRILLED (CORED) HOLE

The selection of a 2" dia. steel core from the drywell containment wall was chosen to facilitate,

1. Surfaces meaningful to evaluate the corrosion mechanism.
2. A hole large enough to facilitate examining the backside of the drilled hole with a miniature video camera.
3. A hole large enough to extract sand samples.
4. Routine test and repair of drilled hole. A larger opening would have required a more complex plug design to restore the structure to its original condition.

2.10 METHODOLOGY FOR DRILLING OF CORE SAMPLE

It was agreed to drill the carbon steel area with a 2" Milwaukee "STEEL HAWG" with carbide teeth(Ref. 2). This drill bit was combined with an electric drill motor attached to a magnetic base for positioning on the drywell wall. A drilling sequence was developed to keep the temperature of the plug sample during the drilling operation below 150°F. so that the sample could be evaluated for Microbiologically Induced Corrosion. This was accomplished by using two (2) drill bit assemblies. The first drill assembly was used with a self contained distilled water spray. The second drill assembly was specially designed and rigged with a magnet slotted to fit inside of the drill bit to attach to the plug so that it would not fall through the newly drilled hole.
This second phase of the drilling operation was done slowly and without coolant to keep from contaminating the plug core backside so that it could be evaluated in its pristine state by the laboratory. This design combined with operator skill allowed a clean even cut of the plug sample. In addition, at no time did the sample temperature exceed 150°F.
Prior to doing the actual drilling, the drill operation was qualified with identical equipment. This training session further guaranteed a successful operation.

2.11 METHODOLOGY FOR REPAIRING DRILLED (CORED) HOLE

Repair of 2" dia. hole in drywell wall was accomplished using specification (Ref. 3) which outlined the plug manufacture requirements and instructions for replacement of the drywell core samples. Specifically, the plug replacement covered the following sequence:

- Filling sample core hole (optional)
- Surface preparation of the hole
- Manufacturing of the plugs
- Welding
- Post Weld NDE
- Leak Testing
- Painting and corrosion protection
- Preparation of final document package

In addition the design of the drywell plug and groove weld stresses was shown by calculation and verified (Ref. 4).

3.0 RESULTS

3.1 DATA SUMMARY (Below 23' Elevation)

The thickness measurements obtained adjacent to the sand cushion are tabulated on GPUN drawing number 3E-SK-S-85 (Ref. 7). Initial measurements were taken at four locations near the lower curb at each torus vent. Four locations, A-B-C-D, were selected to provide two thickness measurements of the left and right drywell plates that make up each Bay section. Each tabulation heading defines the location of the tabulated matrix of measurements with respect to the top of the curb and to the weld between the two plates at the center of the vent line. The matrix of measurements are at one inch increments both vertical and horizontal. Those measurements around heat affected zones and on the vent line reinforcement were taken one inch on each side of the weld. No degradation or wastage was indicated on the reinforcement plate or around the reinforcement plate to the containment plate weld. Wall thinning indications on the containment plate on each side of the containment plate weld were the same magnitude as surrounding areas indicating that the weld heat effected zone did not cause or accelerate wastage.

3.1.1 U.T. Data Reduction

UT drywell thickness data was collected in each of the ten bays. The UT data is presented on GPUN Drawing NO. 3E-SK-5-85 (Ref. 7). The primary concentration of data was within a 6 inch wide circumferential band above the drywell floor curb since data above this band indicated minimal wastage of the drywell wall material due to lack of sand bed region.

3.2 UT DATA INTERPRETATION (Below 23' Elevation)

Prior to core sample removal possible causes of the low UT thickness readings were attributed to external corrosion, laminations or a field of inclusions within the plate. Because the very low readings were localized it was expected that they would be a result of laminations. The general wastage, however, extended from plate to plate and the affected areas of the shell were within the sand bed only. Thus it was concluded that the plate thinning was most likely due to corrosion. In addition, a qualitative assessment of the plate condition was made using an "A" scan presentation with a 5 mghz transducer. This data was also indicative of corrosion on the outside.

Numerous ultrasonic thickness readings were taken in all bays in the drywell particularly at the elevation of 11' 3". Review of this ultrasonic test data showed that significant corrosion damage appeared to be confined to regions in Bays 11, 13, 17 and 19. Furthermore, the thinned parts of the drywell were limited to those areas which were in contact with the sand bed from elevation 10' to 11'9". Numerical analysis of this data determined the minimum mean remaining wall thickness was 0.87".

UT thickness readings below the concrete floor elevation showed the thickness to be greater than 0.87" and at the bottom of the sand bed to be nearly nominal design thickness.

After the completion of the ultrasonic testing (UT) of each of the drywell bays above the concrete floor, the data was assembled and reviewed. This data indicated that there were at least three regions which showed different characteristics. One set of data showed regions of overall general wall reduction which we characterized as wastage. Another set showed regions with little or no general wall reduction but localized areas with large wall reduction which we characterized as pitting/inclusions. The last set of data showed regions of little or no wall reduction and no random large reductions, which we characterized as minor wastage. The characterization of each bay is summarized in Table 3.

TABLE 3

1	Minor wastage
3	Minor wastage
5	Pitting/inclusion
7	Minor wastage
9	Pitting/inclusion
11	Wastage
13	Wastage
15	Pitting/inclusion
17	Wastage
19	Wastage

In addition to the above general characterizations, it was also observed from the UT readings that above an elevation of approximately 11'9" the wall thickness would return to the nominal value. This occurred been though the readings were still within the sand bed and there was wastage below this elevation. Likewise, there were regions of the sand bed below the concrete which heretofore had not been ultrasonic tested and hence no characterization could be made.

3.3 UT MEASUREMENTS (Above 23' Elevation)

UT data obtained at the upper elevations of the drywell is presented on GPUN Sketch Drawing No. 3E-SK-S-89 (Ref. 8).

3.3.1 MEASUREMENTS AT ELEVATION 50'-2"

Data was taken on a one inch wide circumferential band at elevation 50'2" covered over half of the drywell's circumference. Approximately 230 readings, on six inch centers, were taken in plate specified as 0.770 inch. 90% of the readings were within 25 mils of specified wall thickness. Approximately 30 readings were taken on plate specified as 1.063 inch. Three readings were less than nominal. Of these two isolated readings were more than 25 mils below nominal. The wall thickness for the 0.770 inch specified wall plates ranged from 0.705 to 0.800 inch. The wall thickness for the 1.063 inch plates ranged from 1.04 to 1.11 inches. There were two areas where the reading interval was shortened to one inch due to consecutive low readings (as outlined in Section 2). The two areas were at approximate azimuth 188 to 194° (area 1) and between approximate azimuth 63 to 66° (area 2) (see GPUN Dwg. 3E-SK-S-89 Ref. 8).

Area 1 included several of the lowest readings (.705 inch) and is directly above Bay 11 and below the refueling bellows drain cover plate. To surround the lowest reading, five additional measurements one inch above and five measurements one inch below the site were taken on one inch centers. The thickness readings in this area ranged from .705 to .770 indicating that the thickness of the wall was not uniform. The area 2 readings indicated an approximately uniform wall thickness ranging from .730 inch to .755 inch.

All of the 49 points in a grid were averaged.

3.3.2 MEASUREMENTS AT ELEVATION 87'5"

All of the plates at this elevation are specified as .640 inch thick. Data was taken on a one inch band at elevation 87'5" covering approximately 75% of the drywell circumference. "A" scan presentation was relatively smooth with occasional depressions.

Approximately 150 "D" meter readings, on six inch centers were taken. About 90% of the readings were within 25 mils of nominal wall. All of the low readings were isolated with the single lowest reading being 0.540 inch. There were no instances where consecutive low readings required the interval between readings to be shortened.

Of the grids at this elevation the lowest average thickness was .619 inch. Incremental averaging of the data in a circumferential band has yielded a minimum average within three mils (lower) than the 0.619 inchminimum grid average.

3.4 ASSESSMENT OF WALL THICKNESS MEASUREMENTS AT ELEVATION 50'2"

The "D" meter measurements indicated some thinning of the drywell shell.

3.5 ASSESSMENT OF WALL THICKNESS MEASUREMENTS AT ELEVATION 87'5"

A-scan of the evaluated band indicated a smooth outside surface with occasional depressions. "D" meter readings indicated some wall thinning.

3.6 CORE PLUG SELECTION AND VISUAL ASSESSMENT

The basis for selection of the core plug locations is as follows:

Plug 8 was removed from an area of apparent general thinning. Plug 9 was removed from an area where the UT indicated that nominal thickness or above existed with isolated low readings. This plug was centered between a reading of 0.798" and 0.710". See Table 2 for details.

Both plugs removed from the elevation had surface corrosion. The Firebar in the region of the drywell surface for both plugs was "chunky" and denser than the Firebar toward the concrete which fell apart rather easily. There was no visible gap between the Firebar and drywell. There was no visible evidence of water or moisture on either plug or Firebar sample.

3.7 REPAIR OF DRILLED (CORED) HOLE

The openings in the Drywell wall were repaired and sealed with a special design and fabricated steel plug. The final repairs were accepted by the Authorized Nuclear Inspector (ANI) after successfully completing a visual magnetic particle examination and a vacuum box bubble test on each plug weld. In addition a local leak rate test was conducted on each plug and met the integrated leak rate requirements of the Code of Federal Regulations 10CFR50 Appendix J. Actual leak rate measurement at each plug was standard liters per minute at 35 psi.

3.7.1 The repair of all seven (7) core sample holes below the 23' level (Dec. '86) was accomplished with no undue problems. Two holes were found with indications using magnaflux and weld repaired and one hole was found with a pin hole leak using vacuum box test and weld repaired. A successful local leak rate test was performed using a special test cup held in place with the same magnetic drill used for the drilling operations.

3.7.2 The repair of the two (2) core sample holes at 51' level (Nov. '87) was again accomplished with no undue problems. The repaired area was magnafluxed, vacuum box tested and given a successful leak rate tested.

3.8 In December 1988 the scope of UT was expanded to:

1) Provide basis for verification of CP effectiveness.

2) Provide baseline data to monitor these sand bed areas not protected by CP.

3) Verify that the presence of standby water in the sand beds did not adversely affect previous results.

4.0 CONCLUSION

4.1 The ultrasonic thickness probing of the drywell containment has been confirmed to give accurate results with physical measurement of the plug thicknesses being consistent with UT but, in general, about 2% greater. Therefore, the UT measurements have been a conservative assessment of thickness.

4.2 In the sand entrenchment region, broad areas of exterior corrosion seem to be localized at an elevation corresponding to the exterior sand cushion.

Measurements of drywell thickness below the level of the interior concrete floor (which were made by removal of the interior concrete at two locations down to a depth of about two feet, bay 5 and 17) show that wastage below the floor level is no greater than measured just above floor level. In fact, measurements at the location where general wastage was indicated above the floor show the drywell below the floor to be about 50 mils thicker than the immediately adjacent above floor area.

4.3 At elevations 50-2" and 87'5" the wall loss is 33 mils and 46 mils respectively. This is estimated from the "average" drywell wall thickness in areas of general wall thinning compared to the maximum encountered wall thickness. Use of an "average" wall thickness is appropriate in evaluating the shell strength; individualized localized pits will not alter the structural integrity of the drywell.

4.4 Details of the UT measurements, metallurgical results, and chemical analyses are more fully summarized in TDR 854 (Ref. 5).

5.0 RECOMMENDATIONS

5.1 Eliminate or re-direct water intrusions. This effort is ongoing via BA's 328257 and 323505.

5.2 A cathodic protection system has been selected to avert the corrosion in the sandbed. This is being installed via BA 402873.

5.3 Monitor (UT) the drywell containment vessel wall as required during an unscheduled "Outage of Opportunity". This is established by means of Ref. 6. & Ref. 9

6.0 REFERENCES

1 GPUN OCIS-328227-003, Repair of Concrete Floor Removed for U.T. Readings

2 GPUN IS-328227-001, Drywell shell Vessel Sample

3 GPUN IS-328227-002, Replacement or Drywell Vessel Core Sample Plugs

4 GPUN C-1302-243-5310-030, Calculation of Drywell Plug and Groove Weld Stress

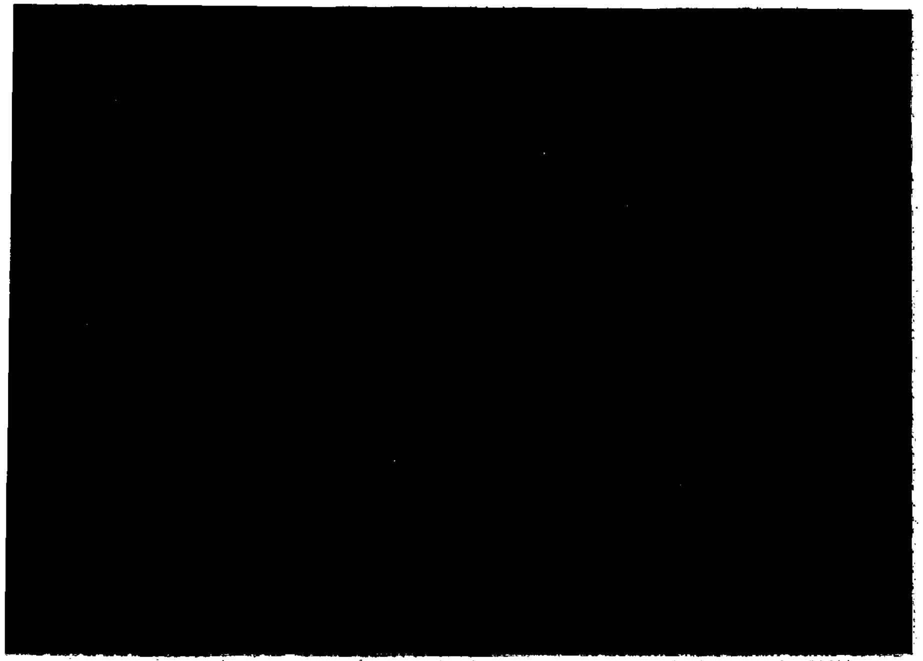
5 TDR 854, Drywell Corrosion Assessment

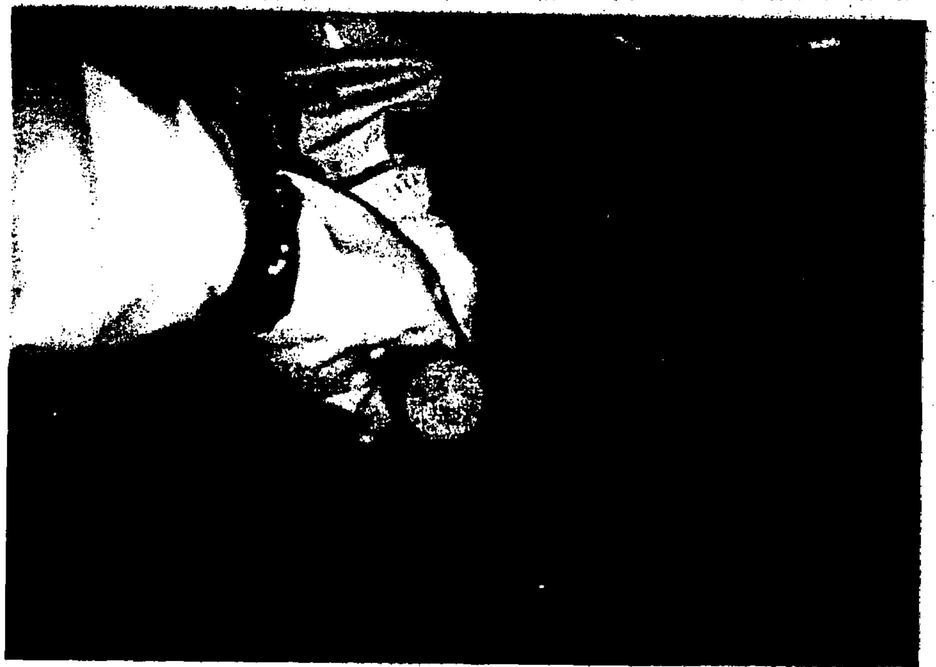
6 GPUN IS-325227-004, Functional Requirements for Drywell Thickness Evaluations

7 GPUN DRG 3E-SK-S-85, Ultrasonic Testing Level 11'-6"

8 GPUN DRG 3E-SK-S-89, Ultrasonic Testing Level 50'-2" - 87'-5"

9 GPUN Memo 5360-88-304 Rev. 1 dated 11/22/88 Expanded UT & Thickness Inspection of Drywell.





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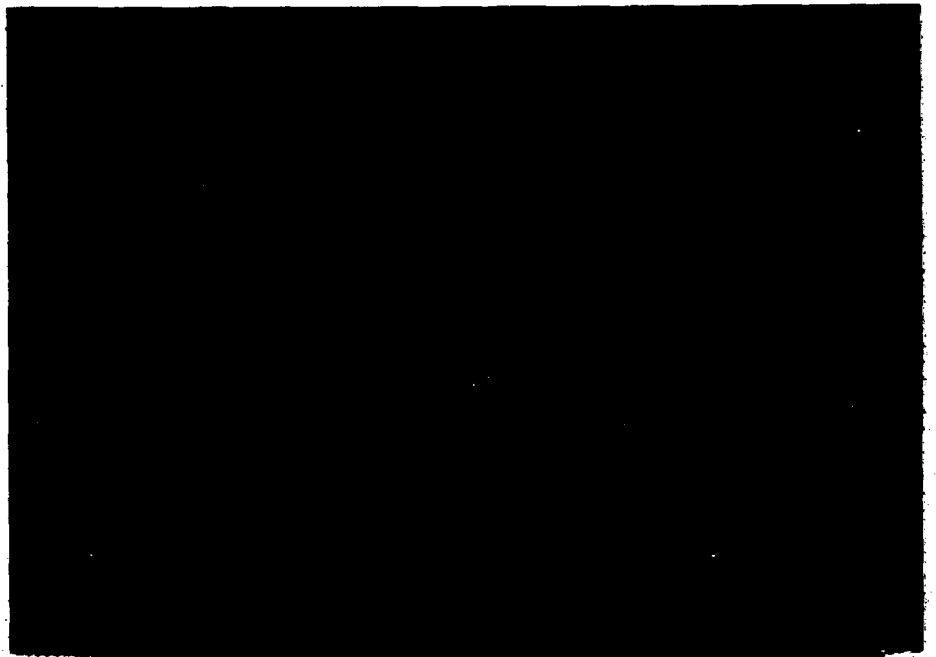

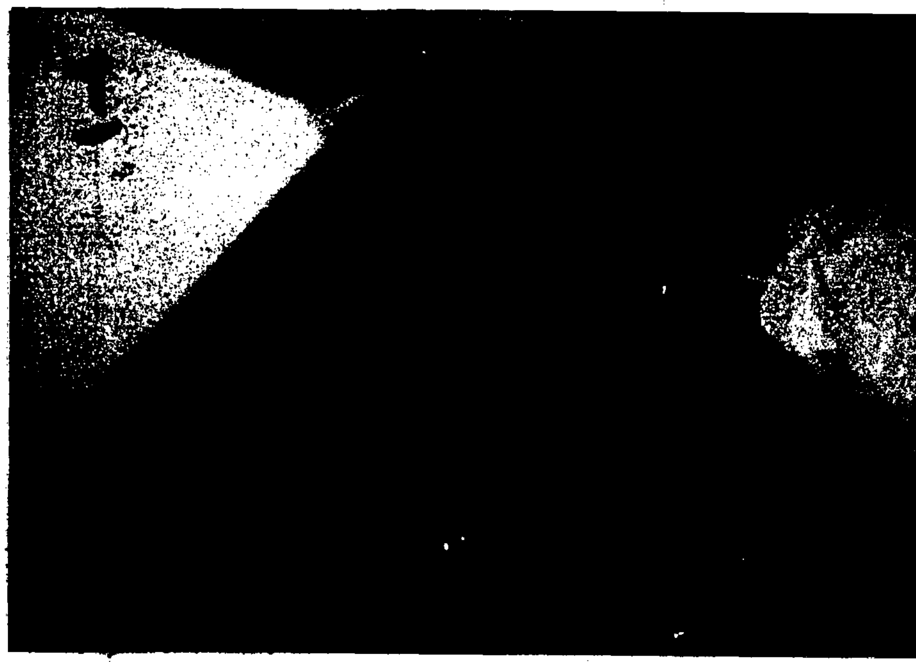

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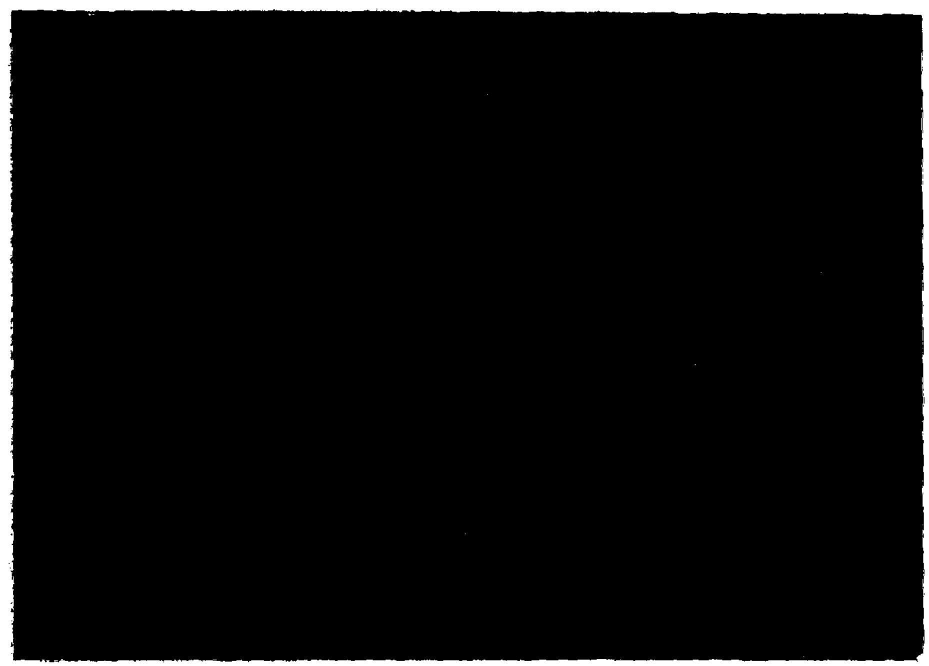

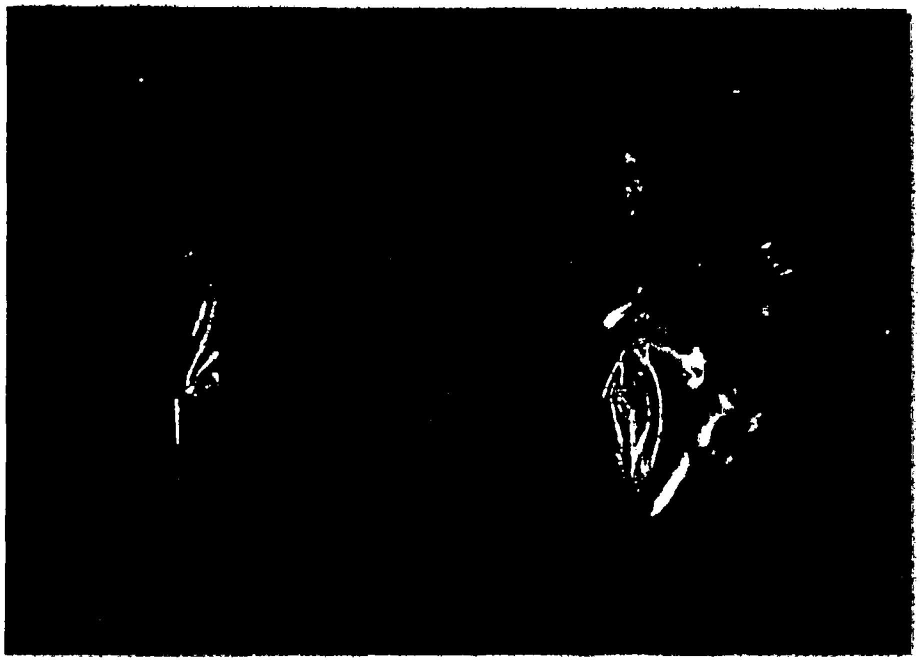

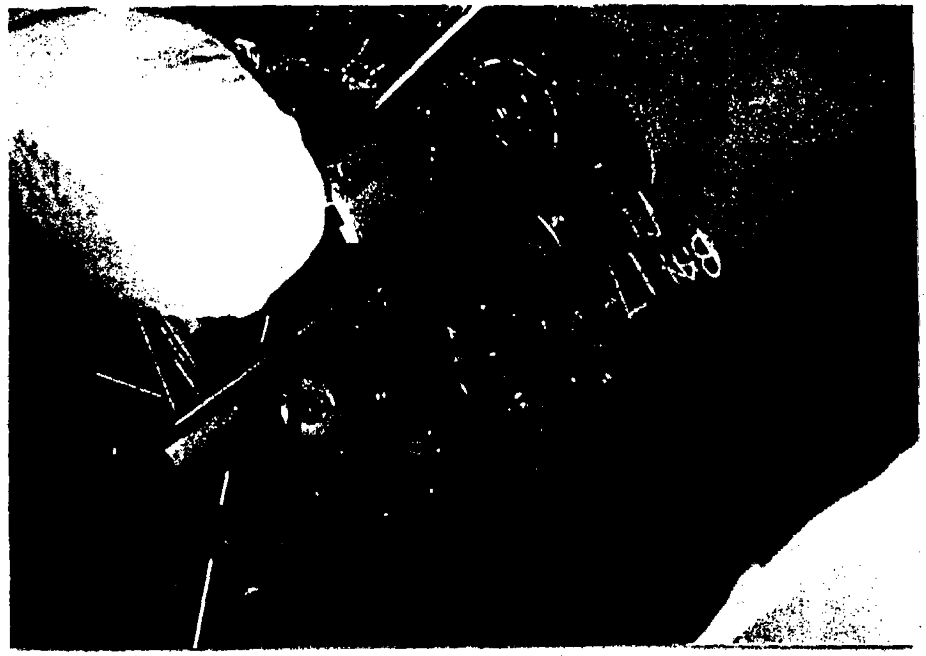

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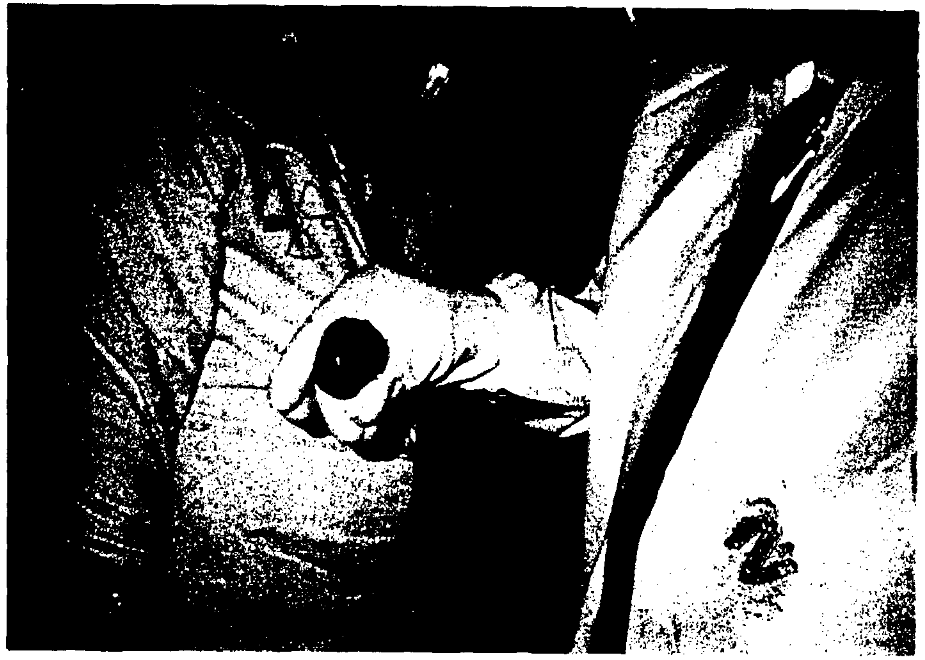

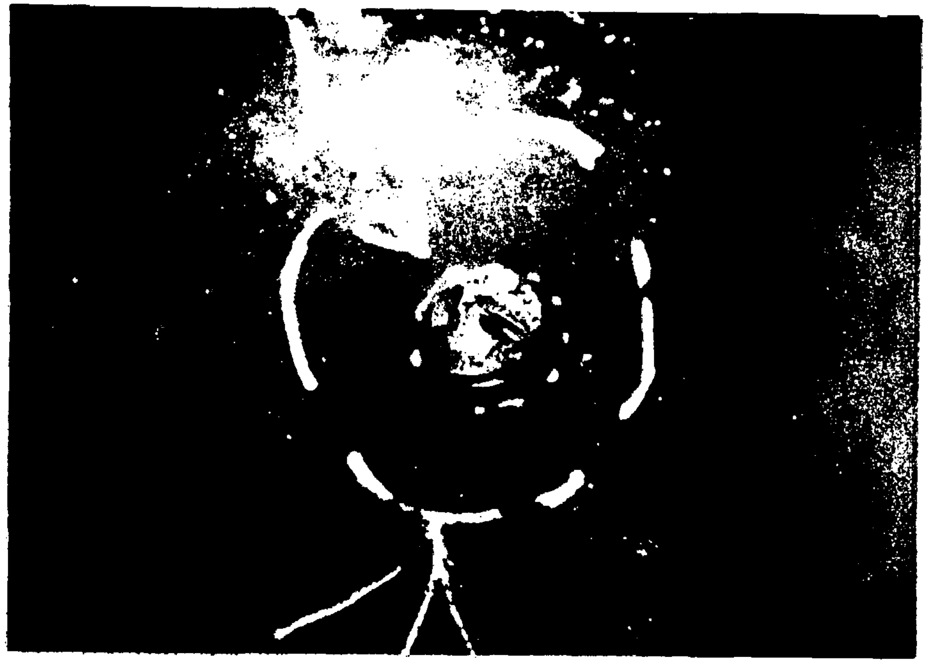

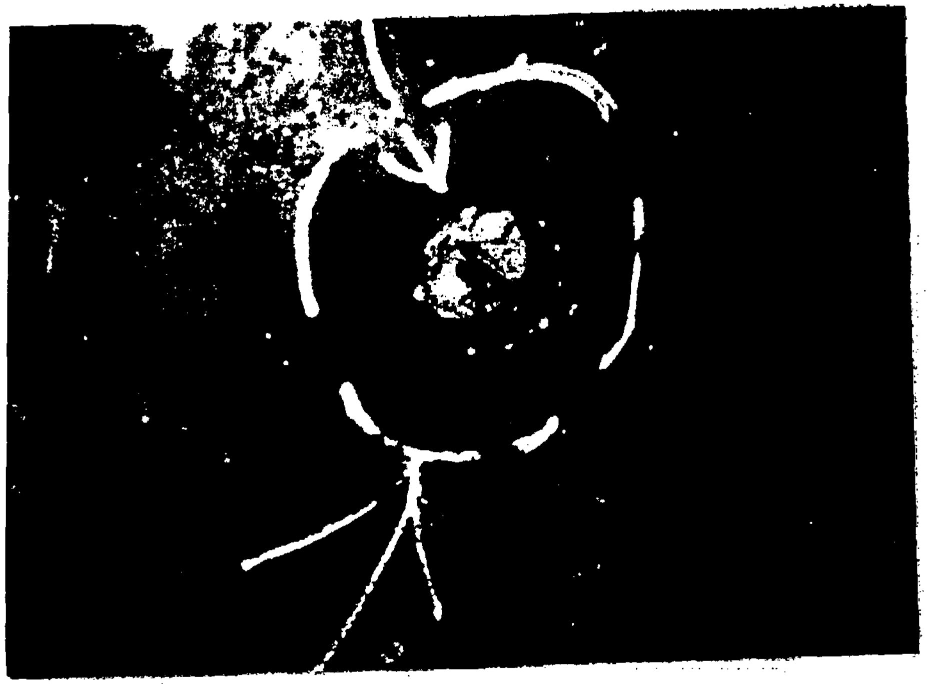

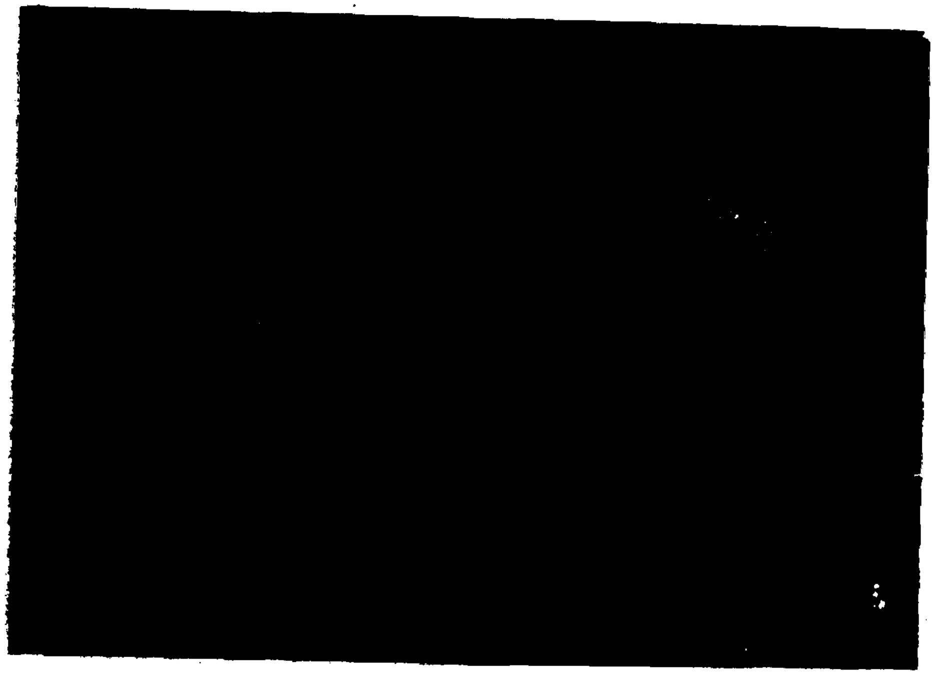

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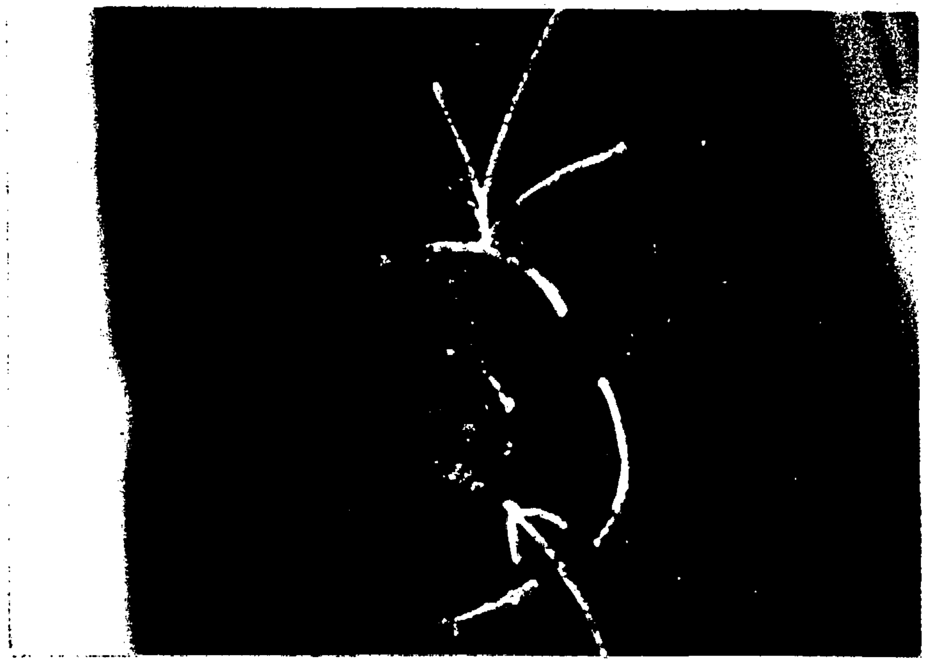

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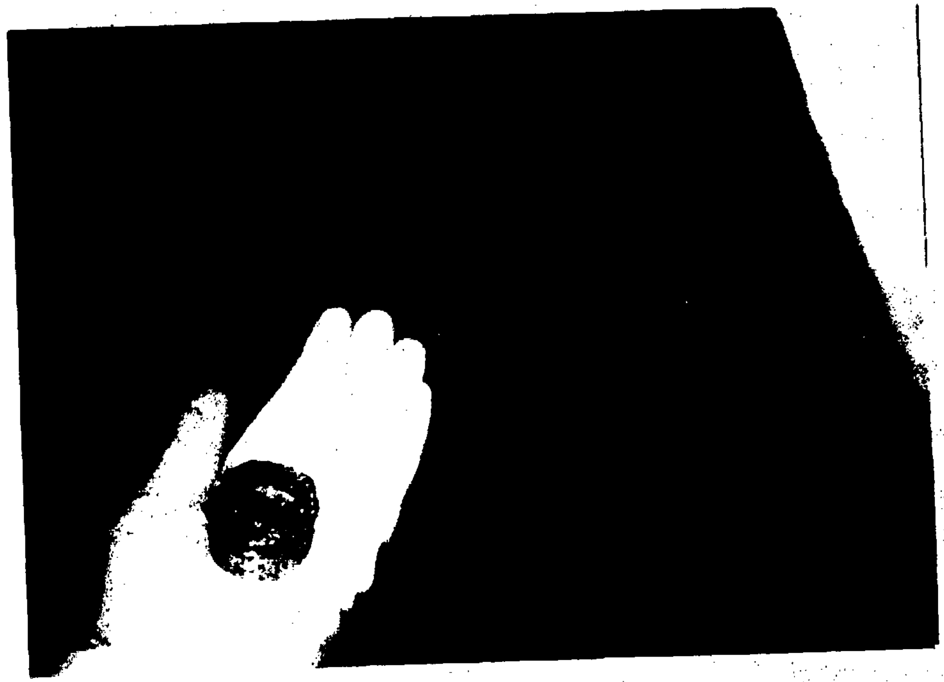




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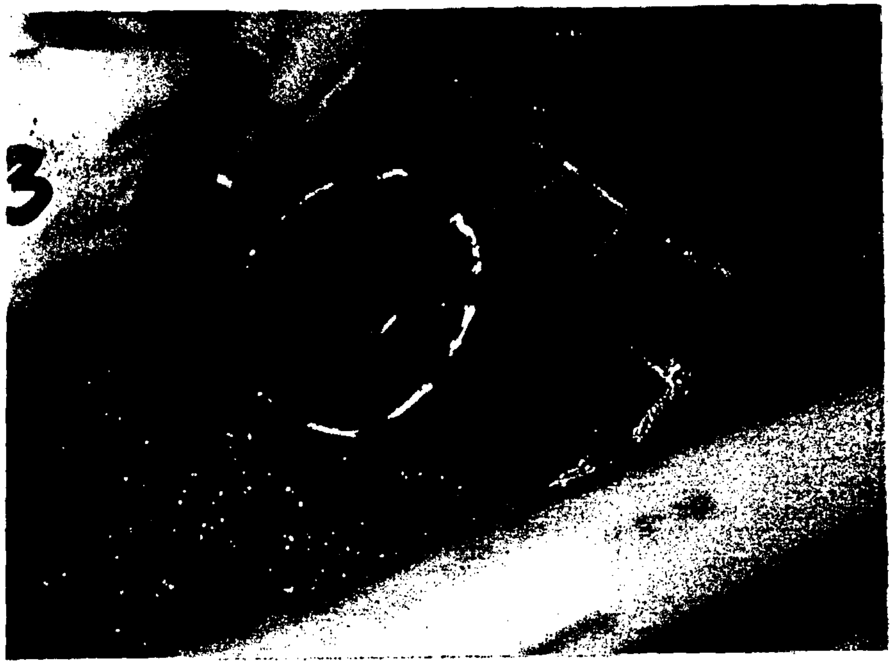
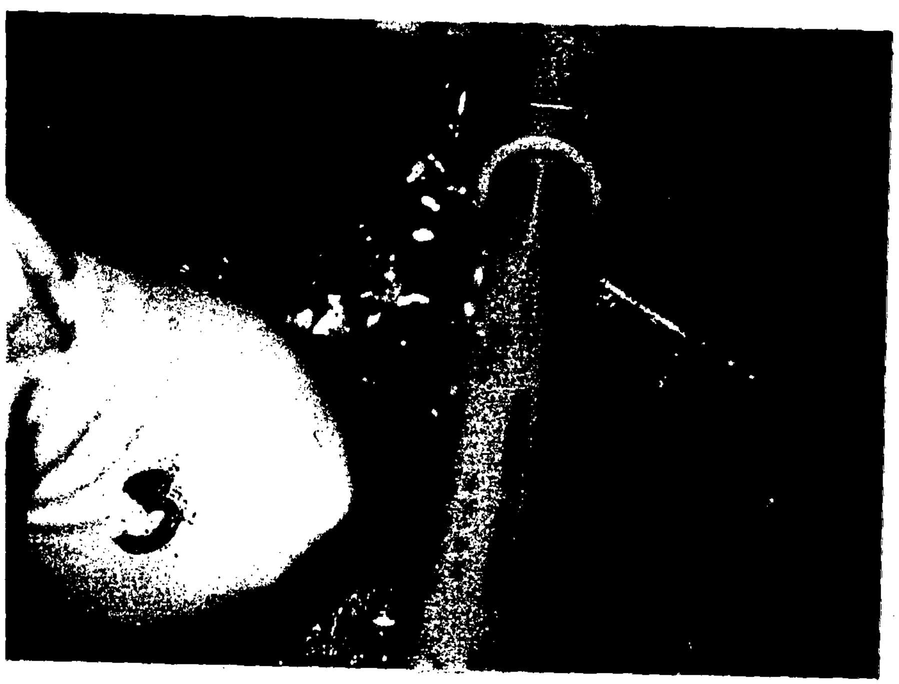
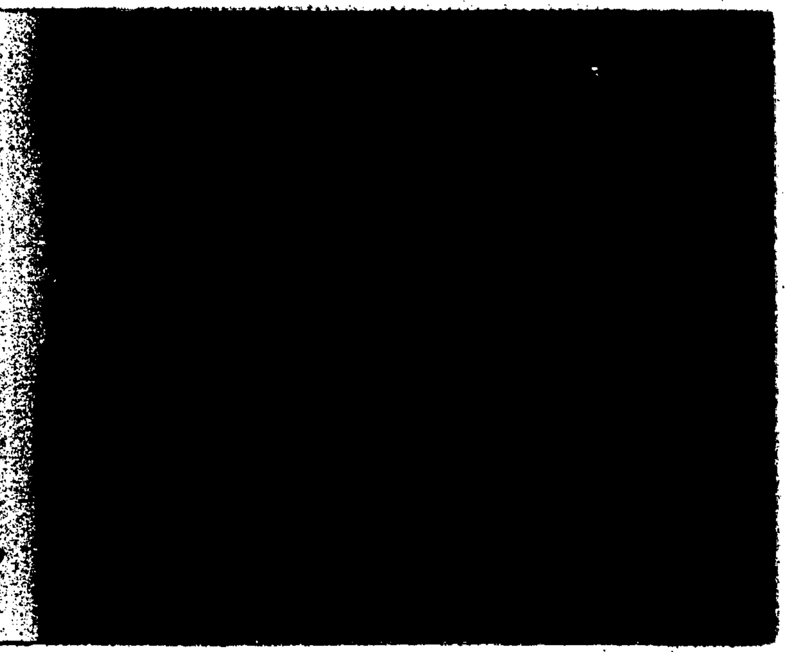




786 DAY 19A F



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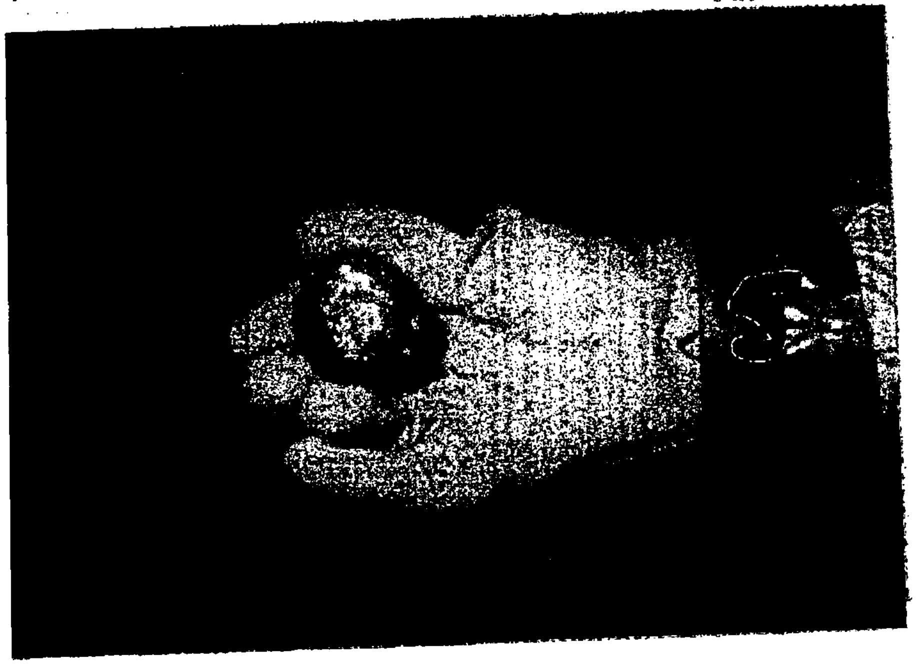
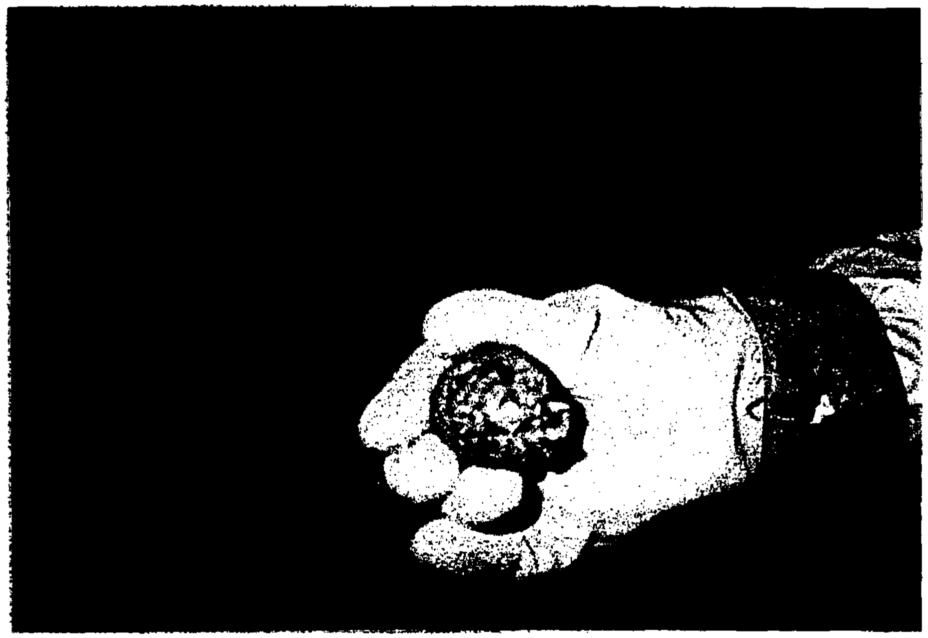
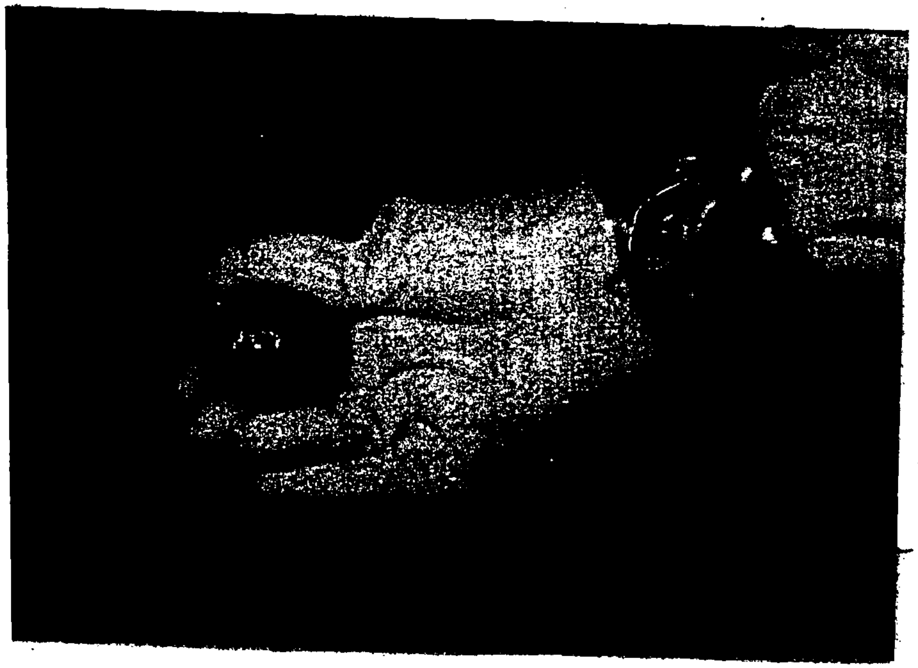


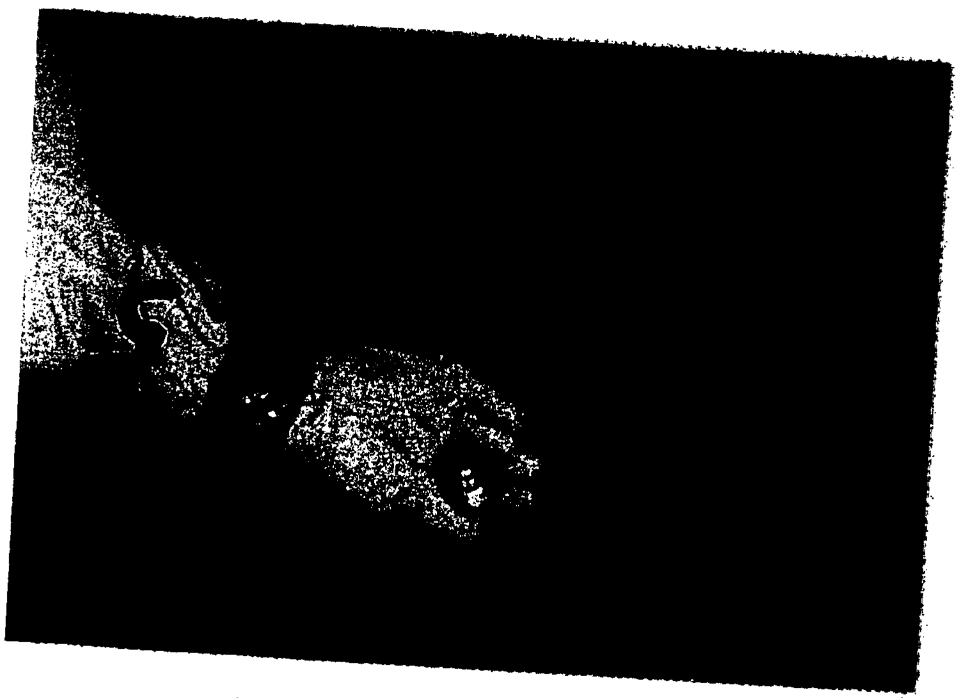

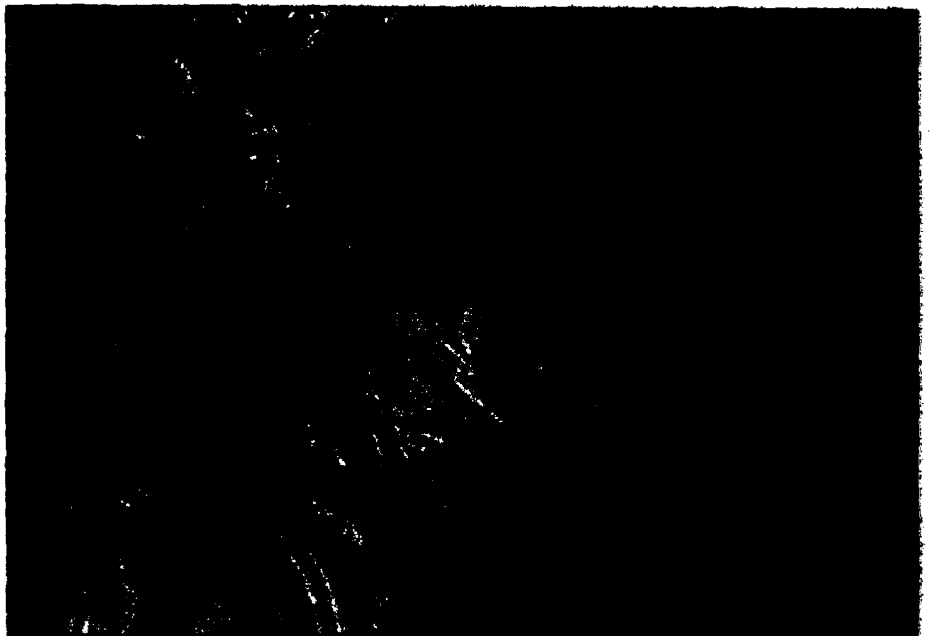

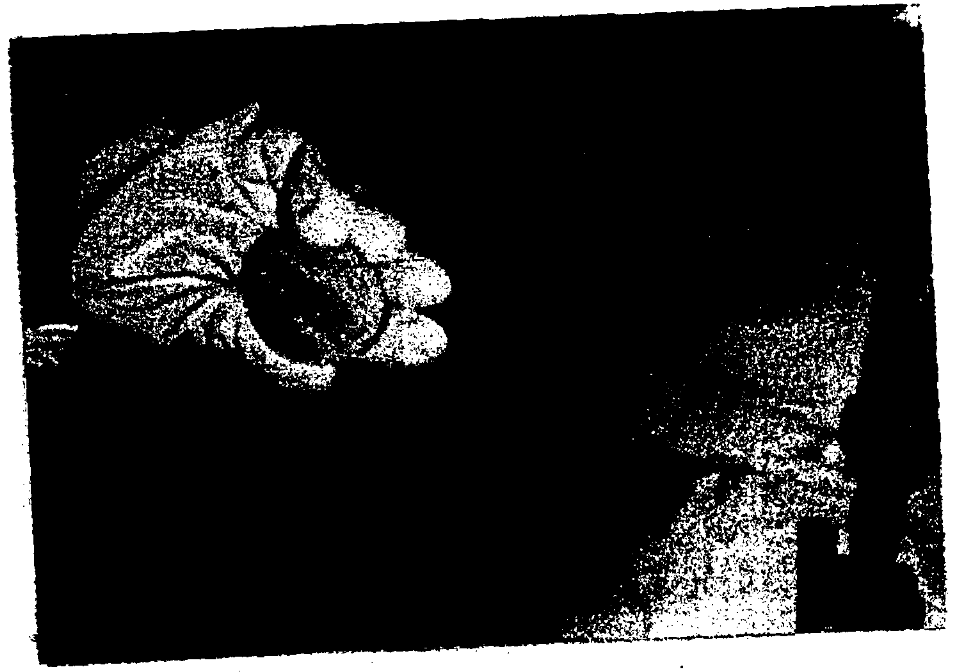

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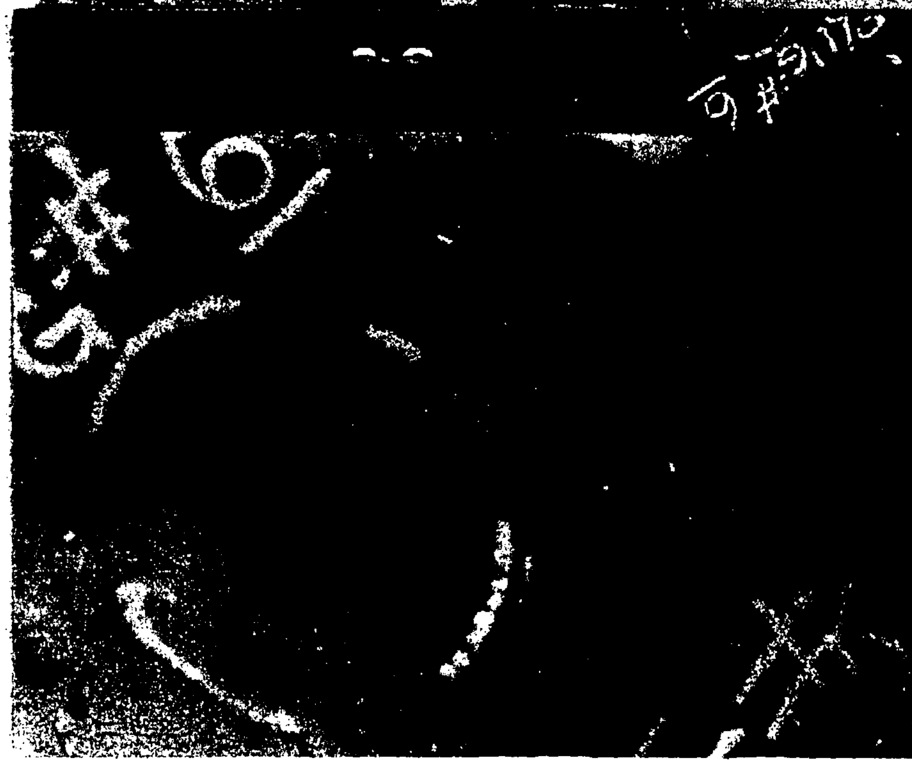

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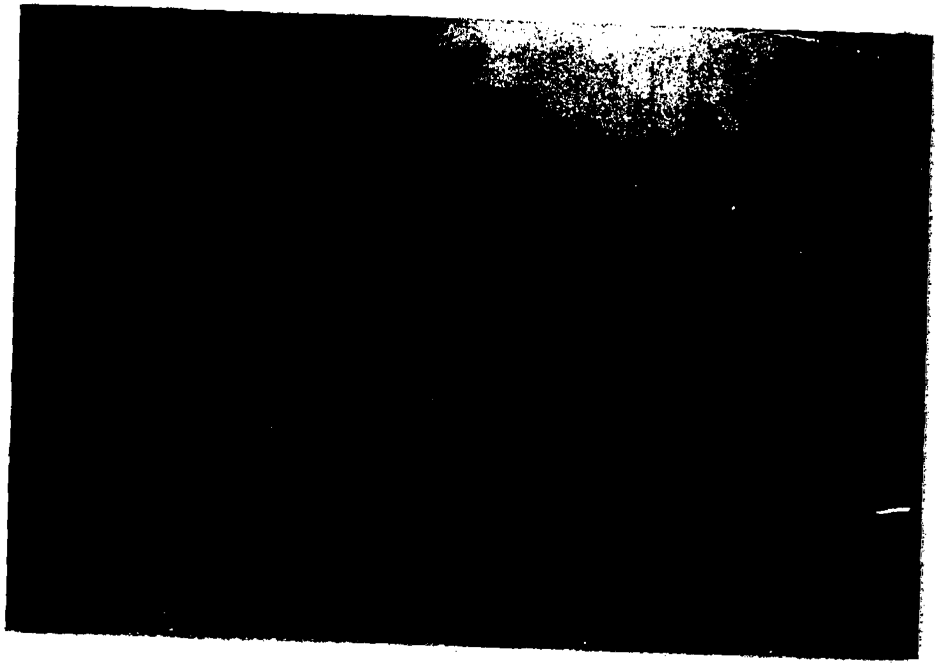
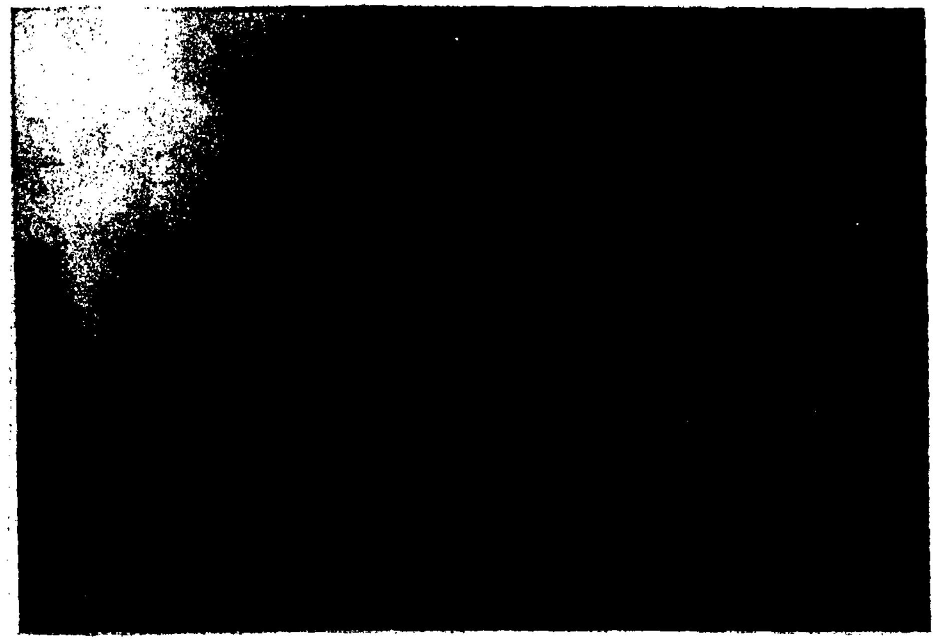
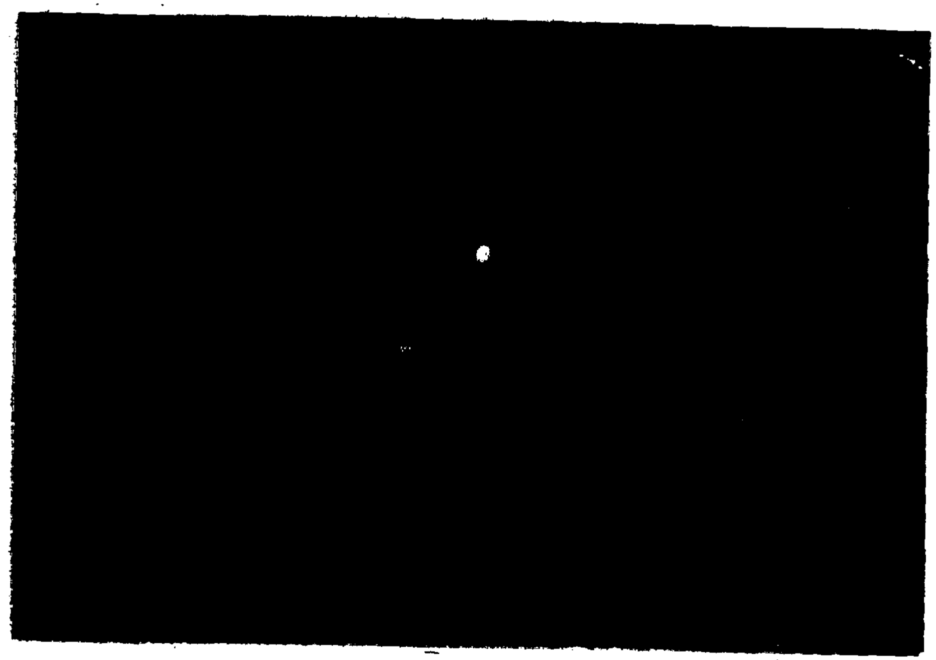
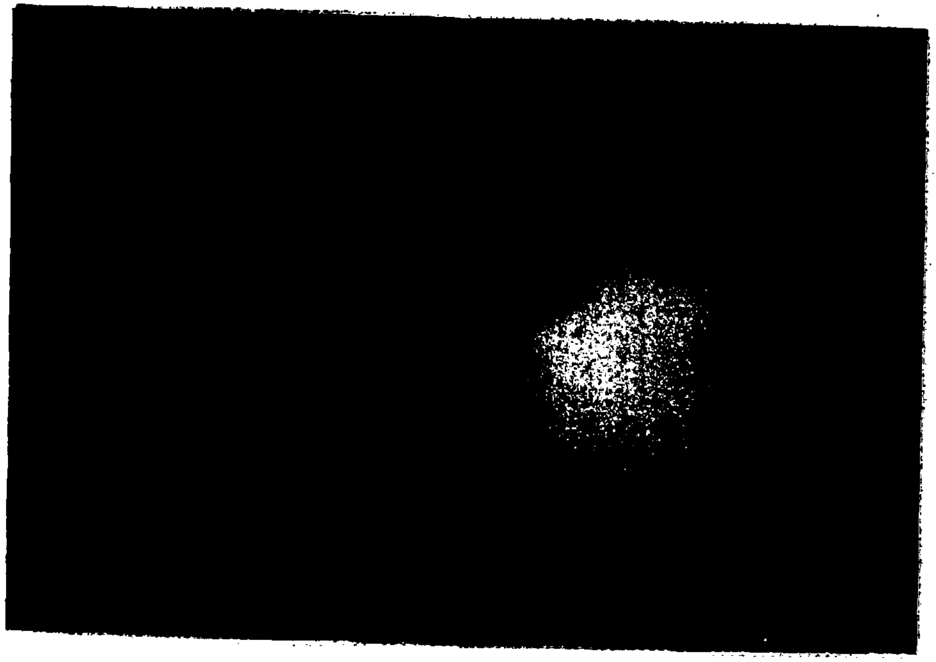
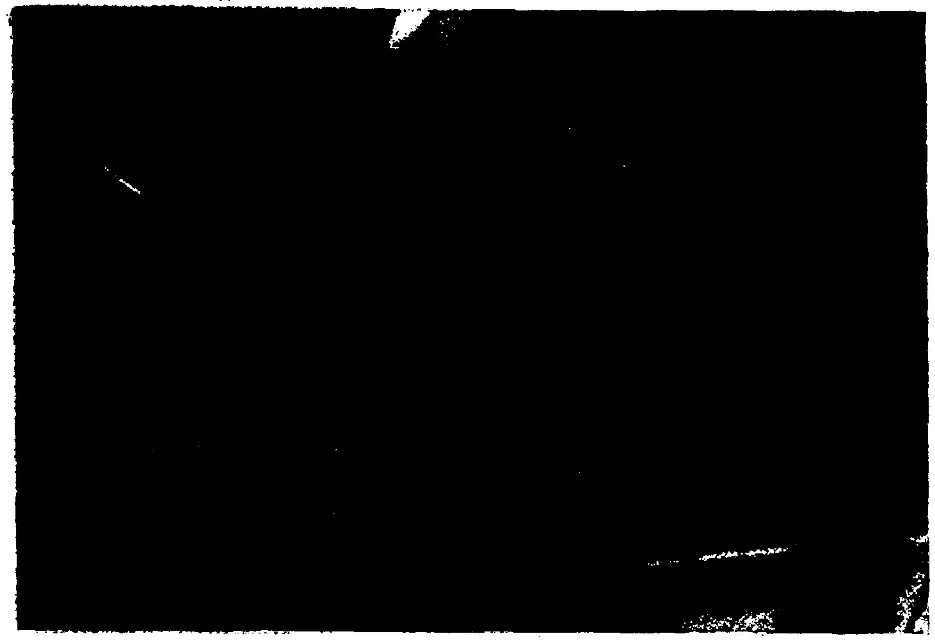
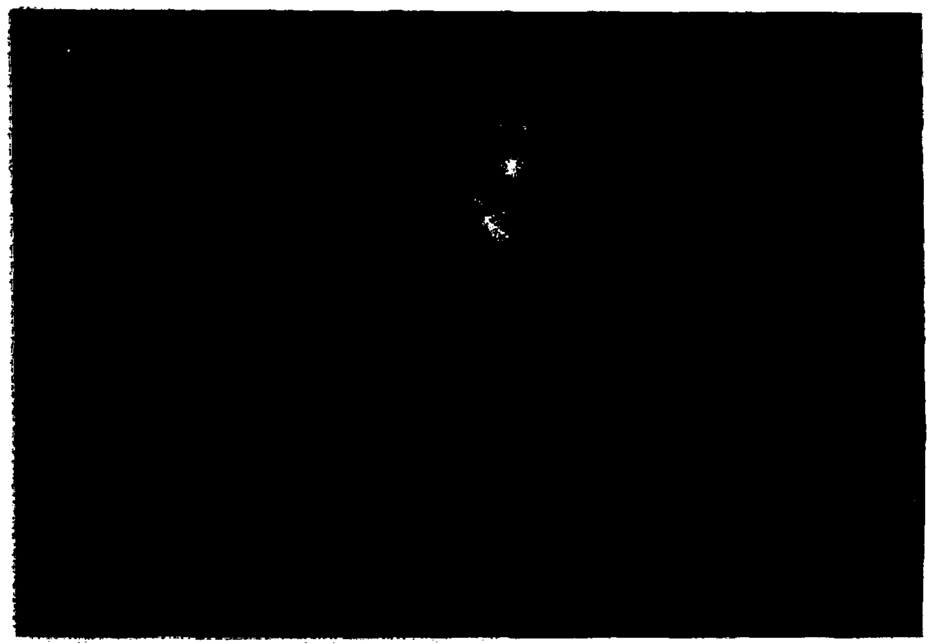
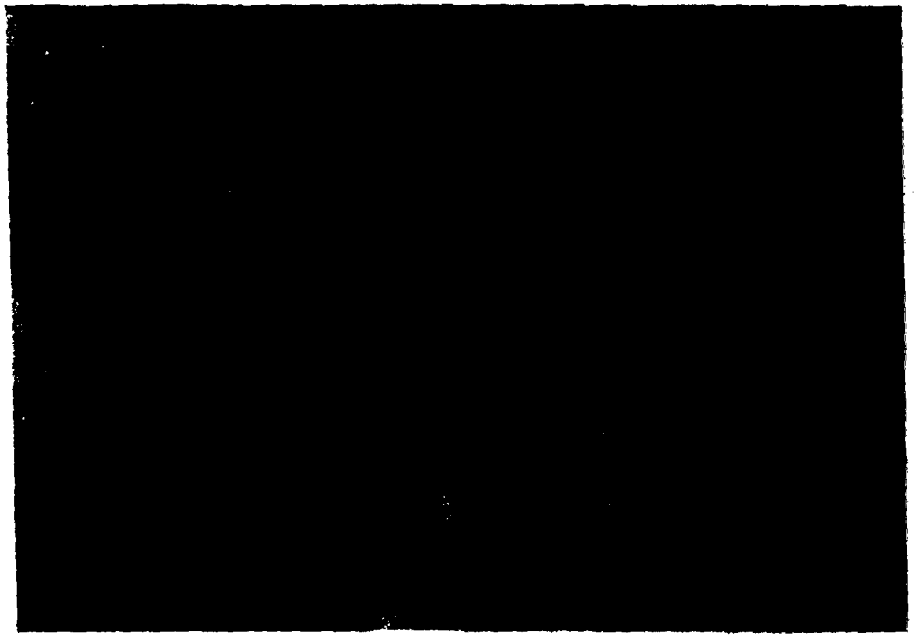
986 BAY 19A

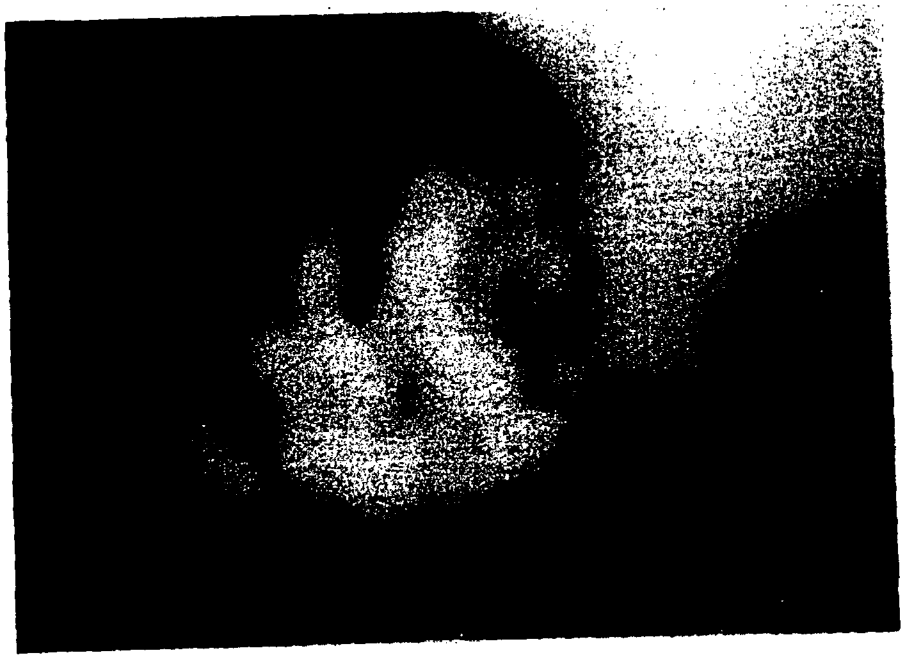





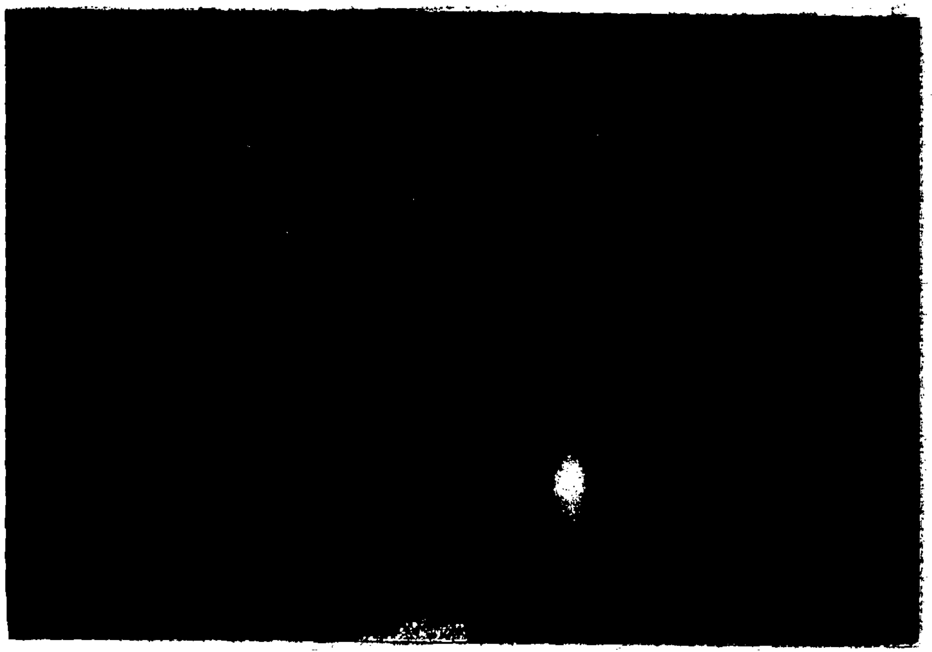
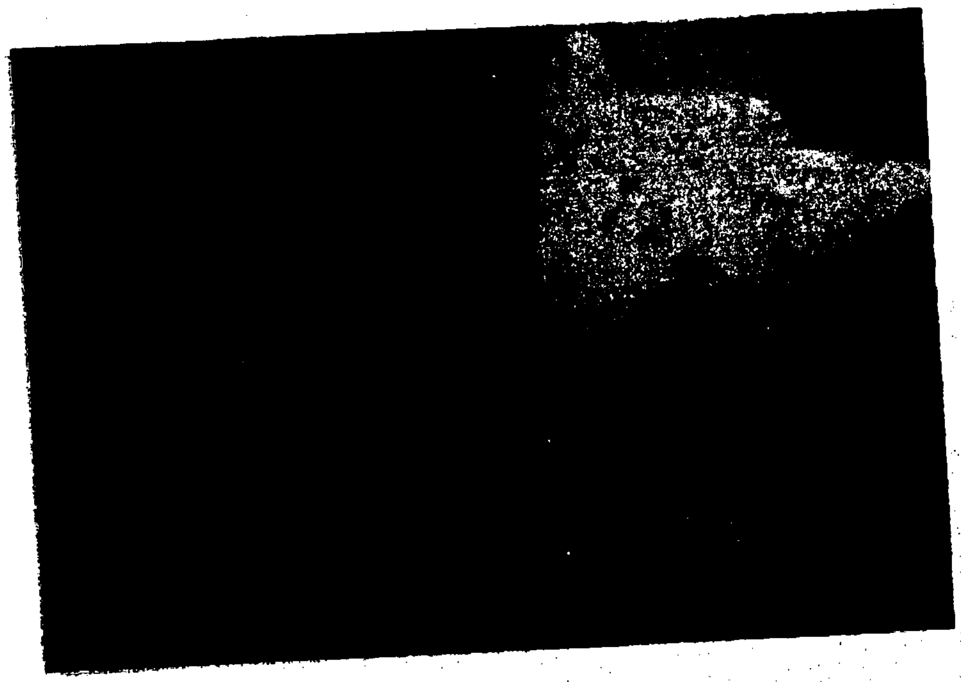





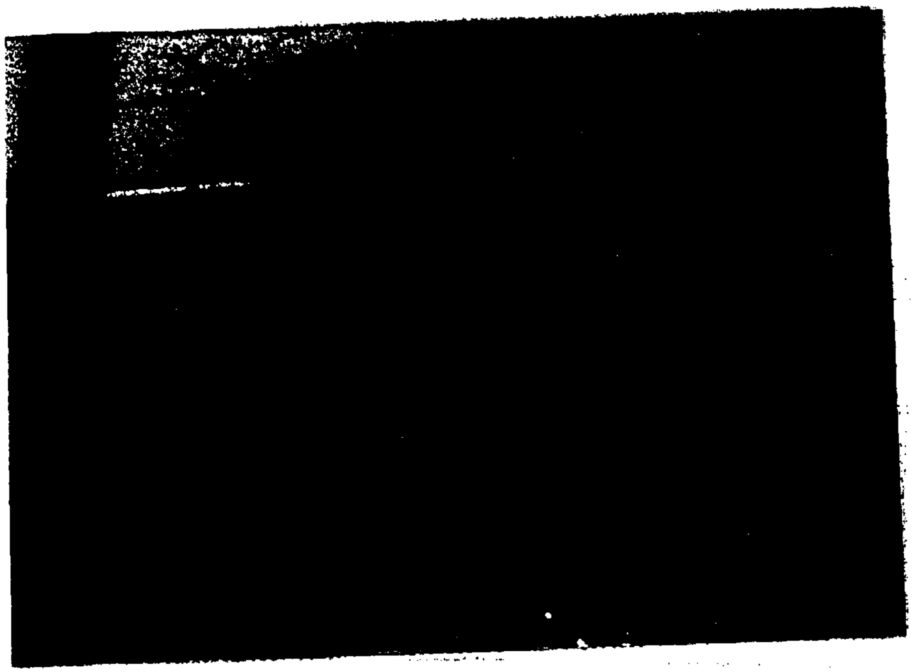
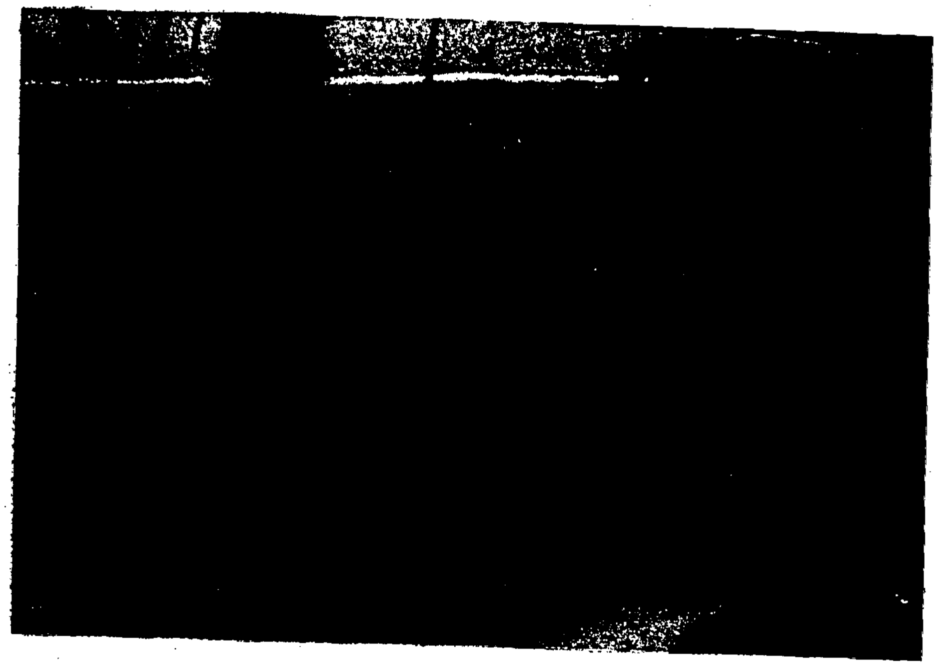


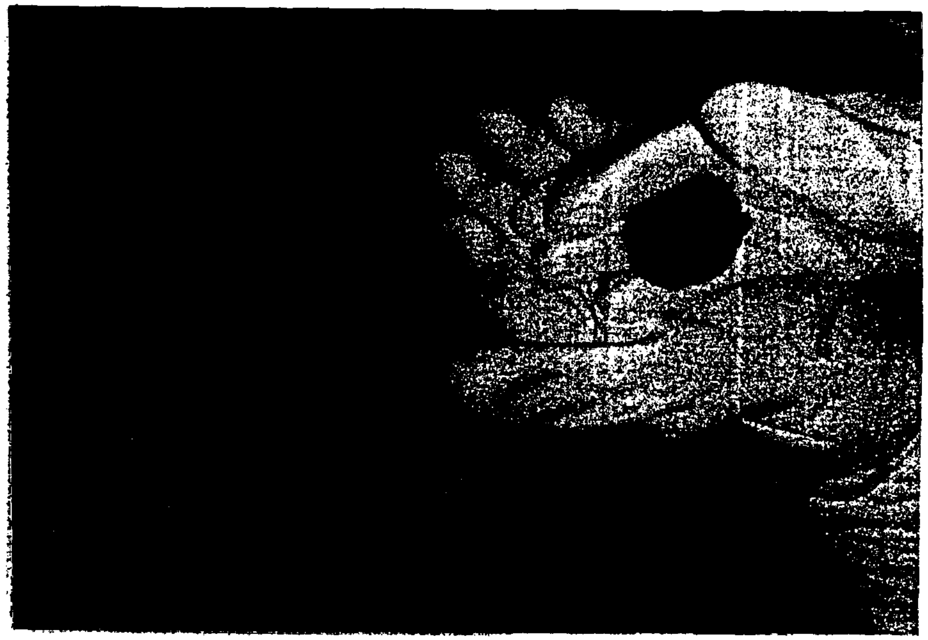
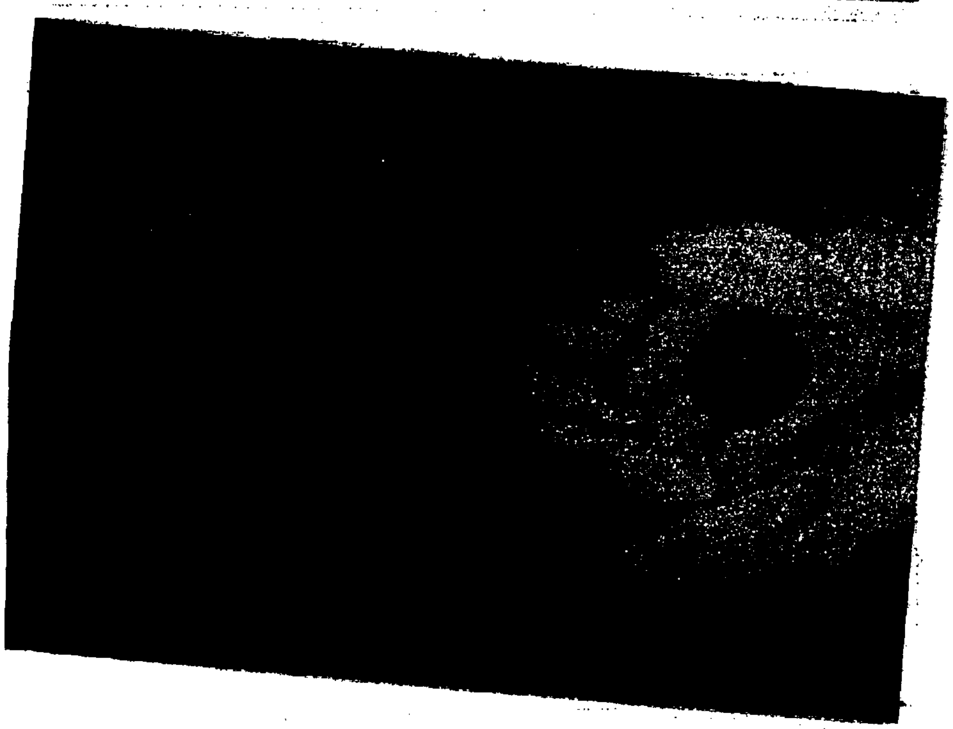
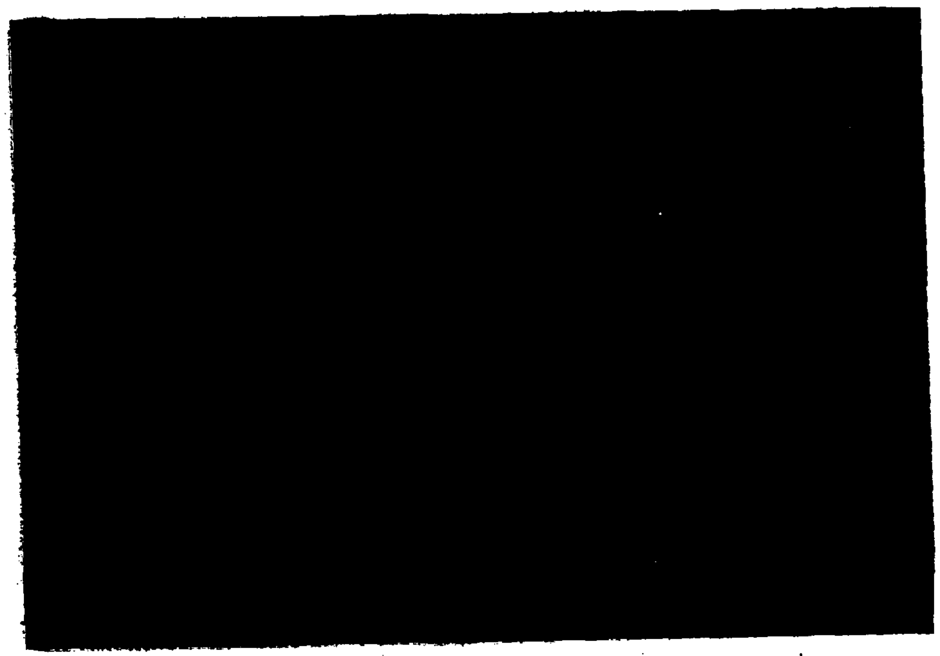


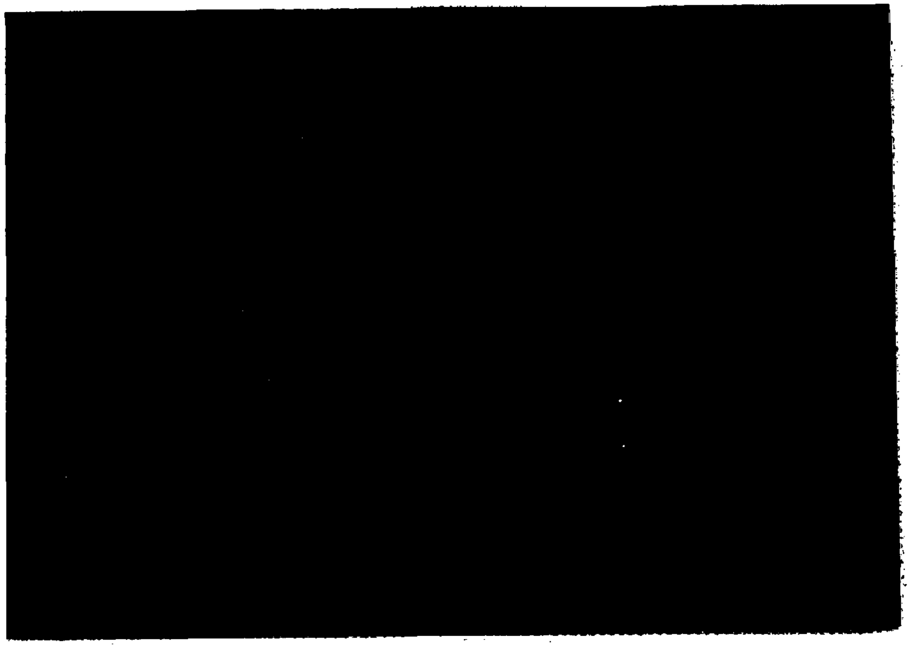


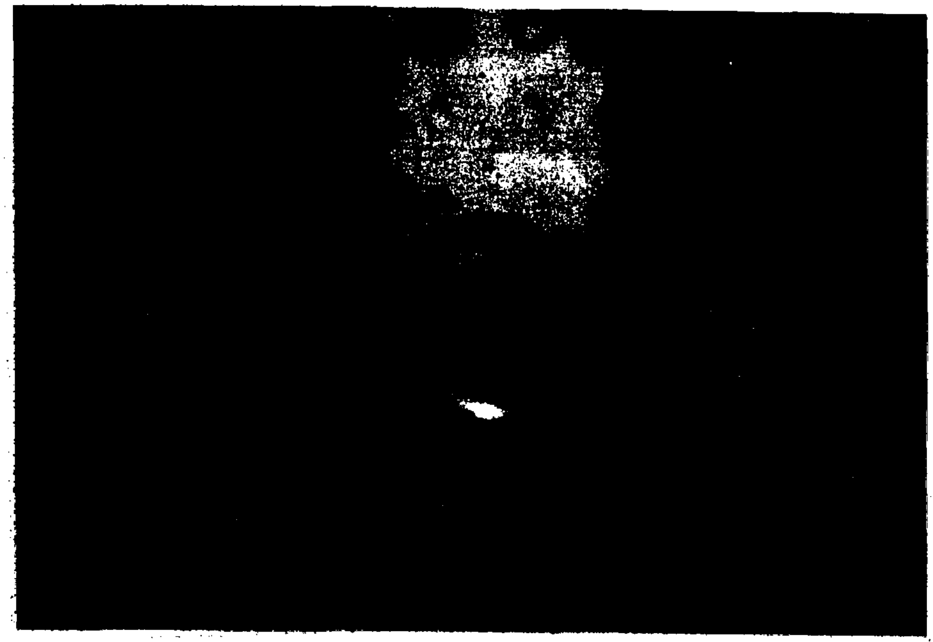




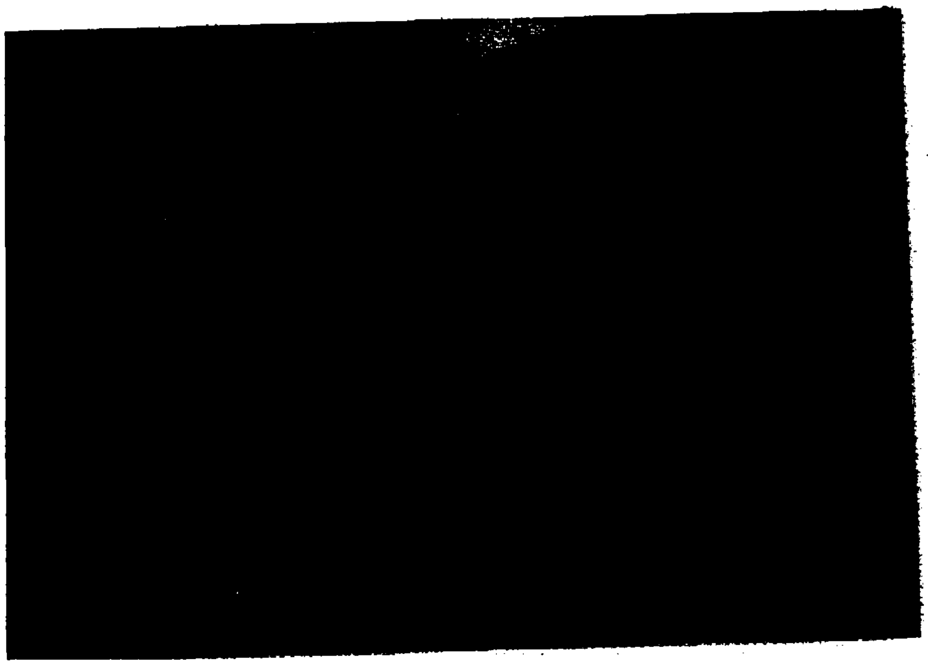


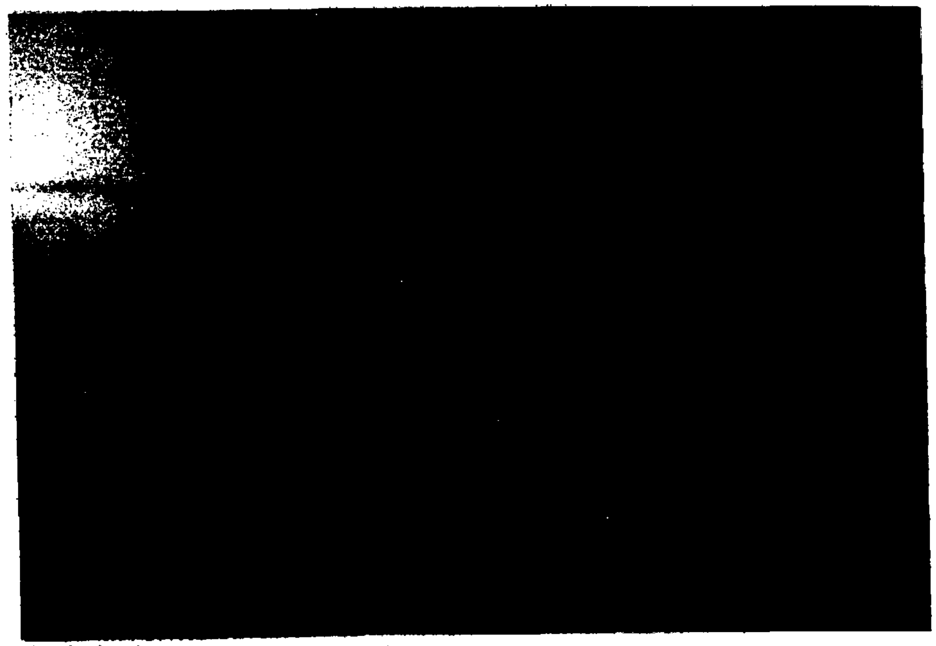



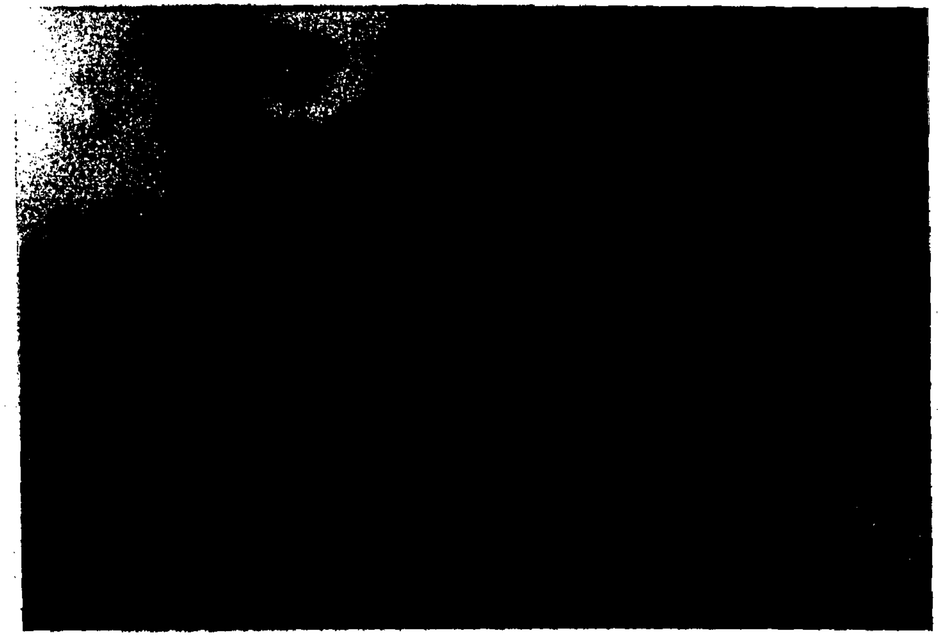





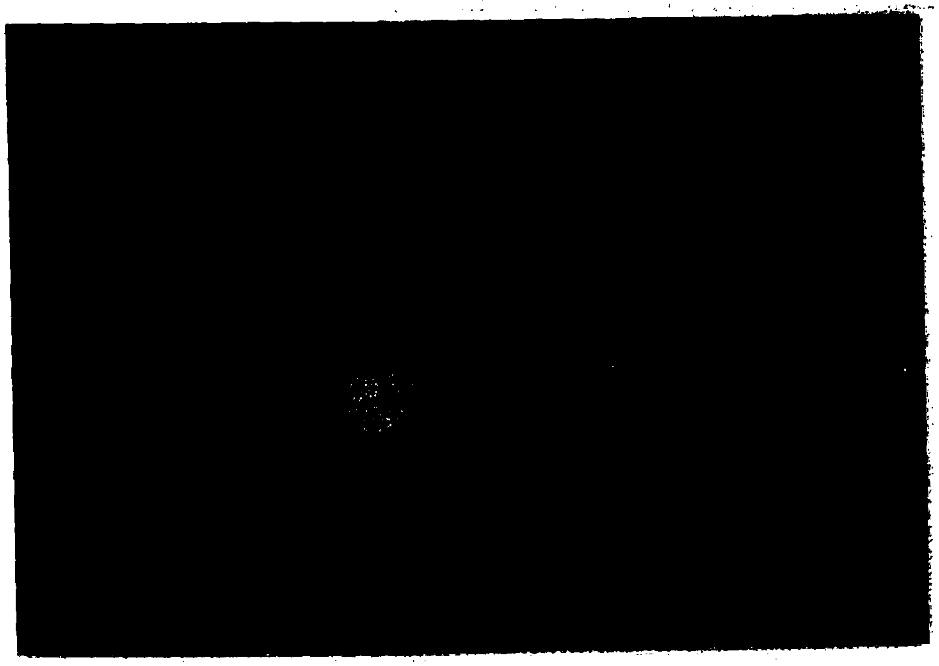


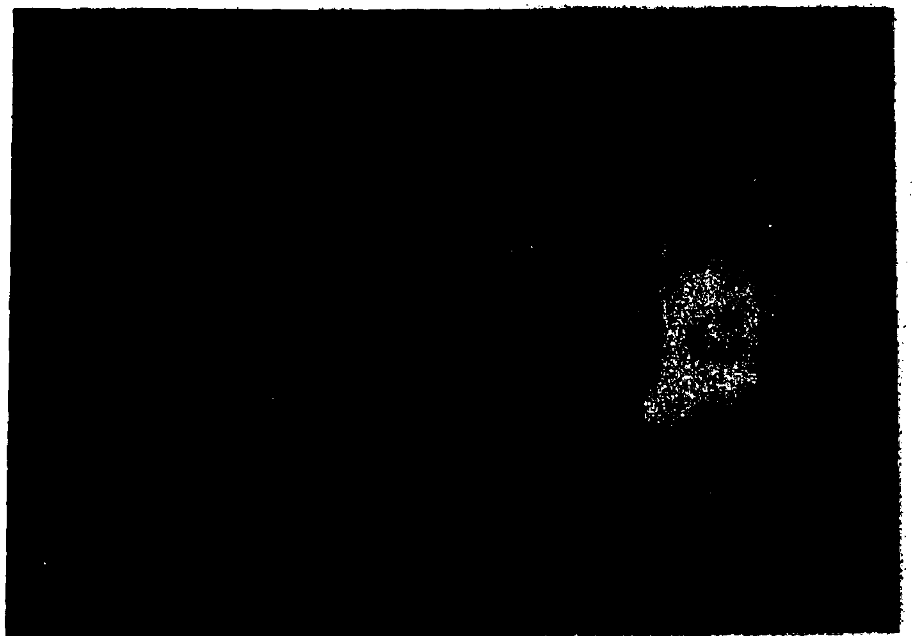


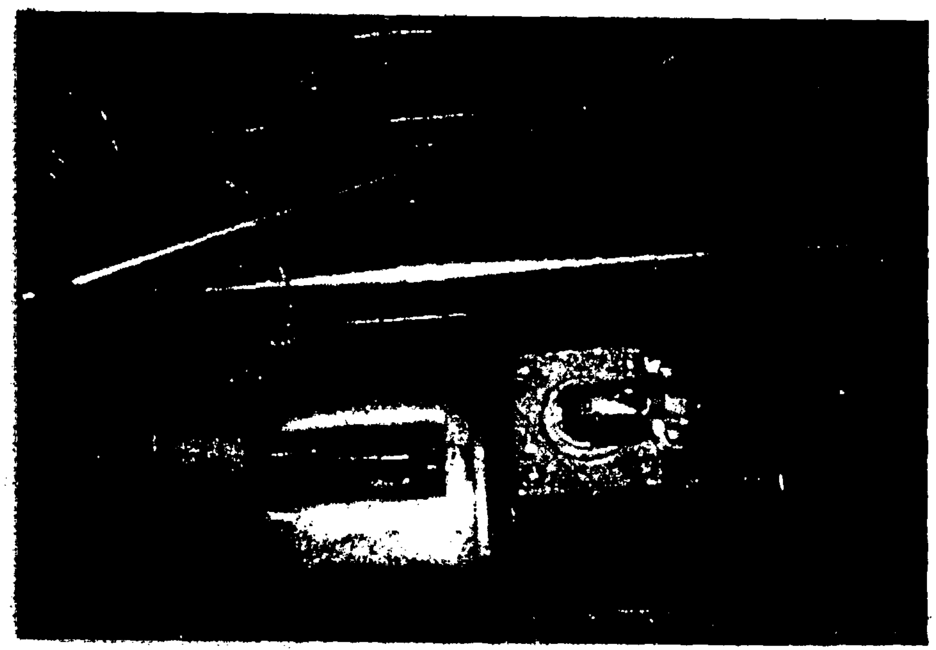




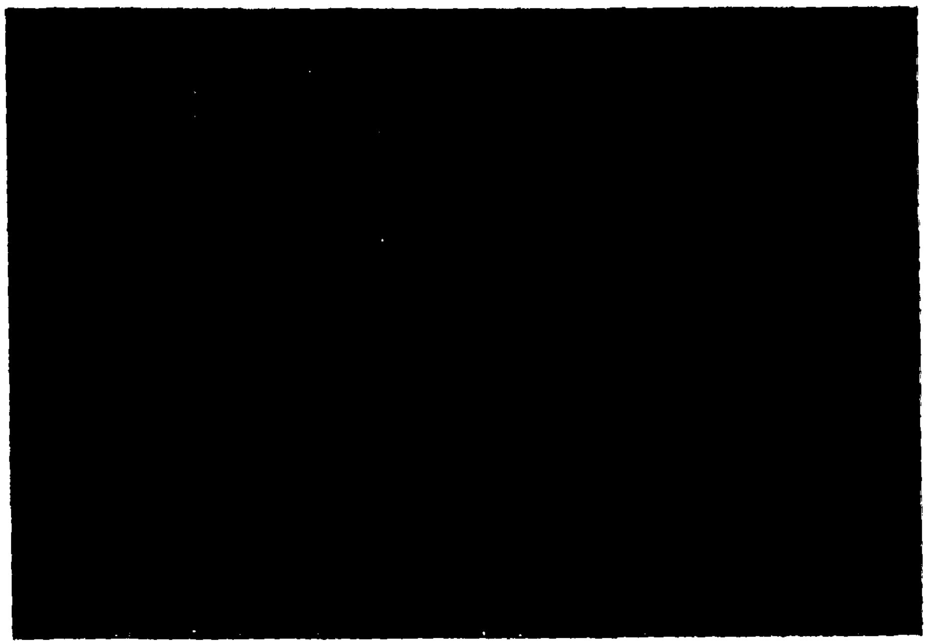
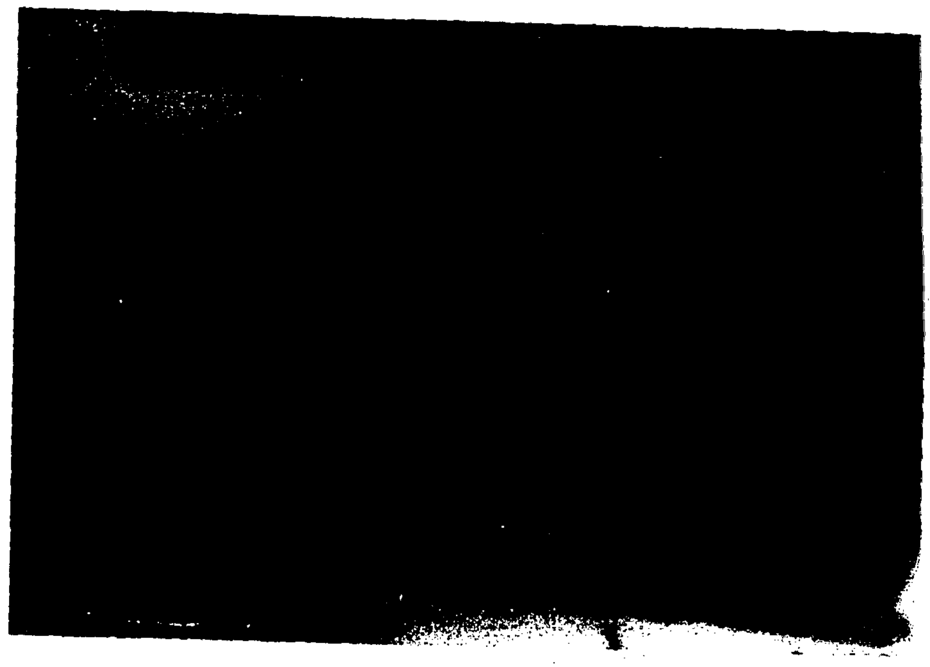


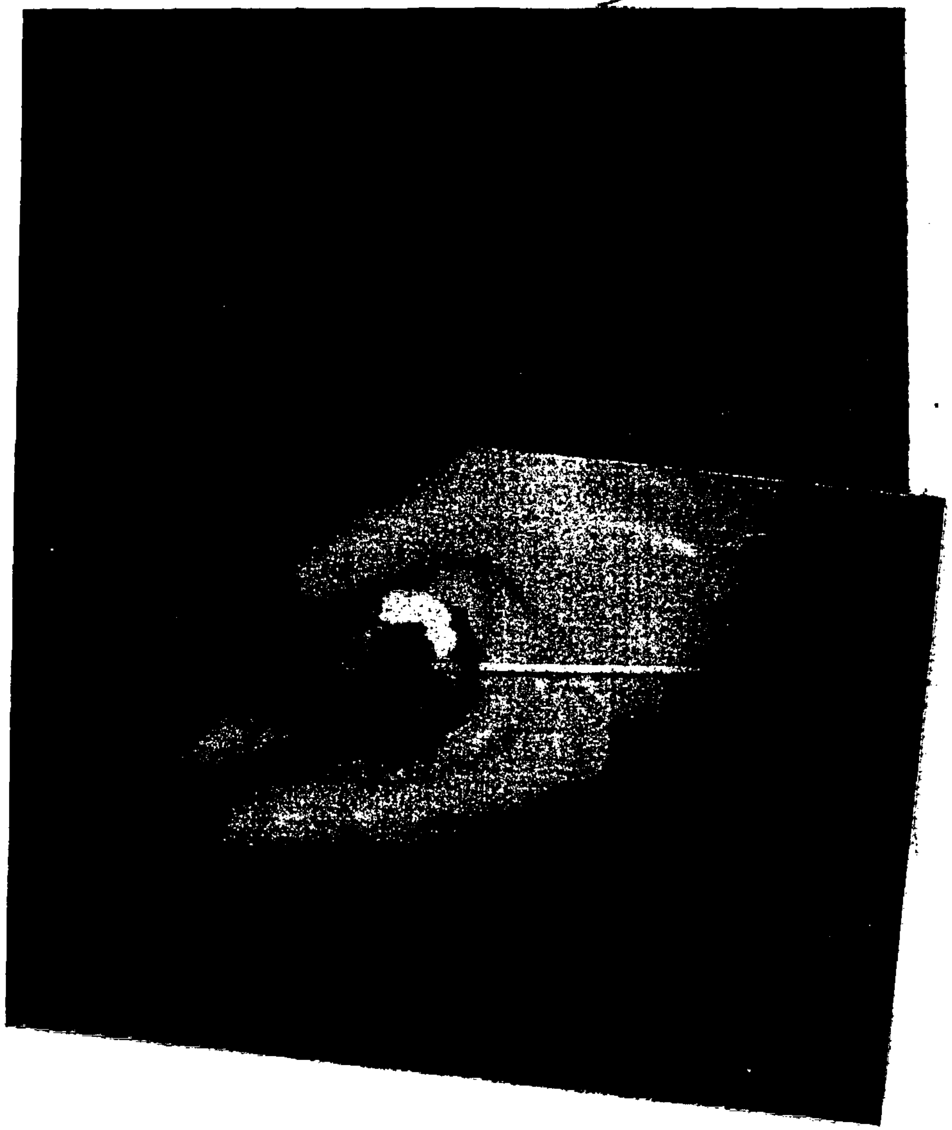


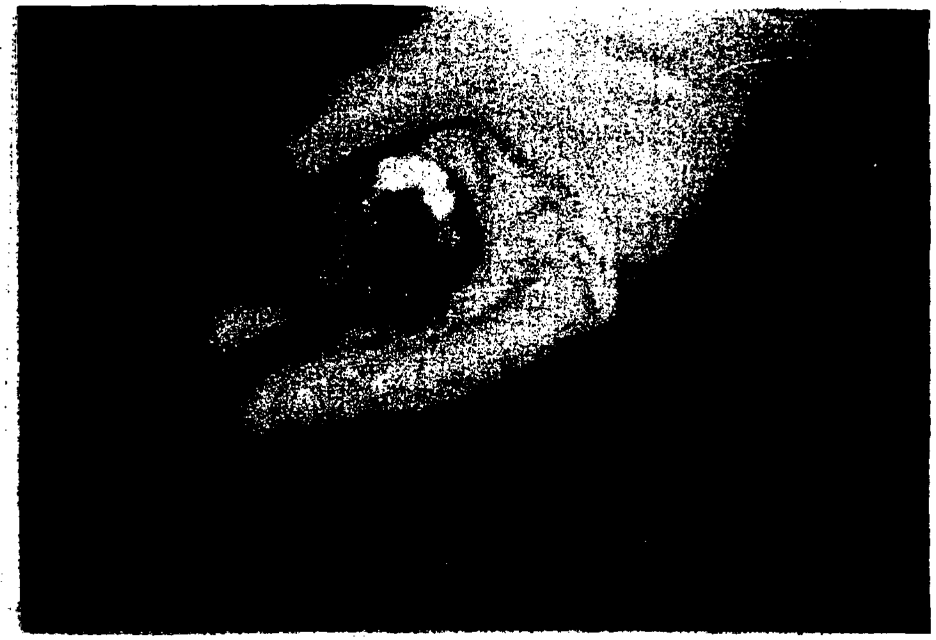


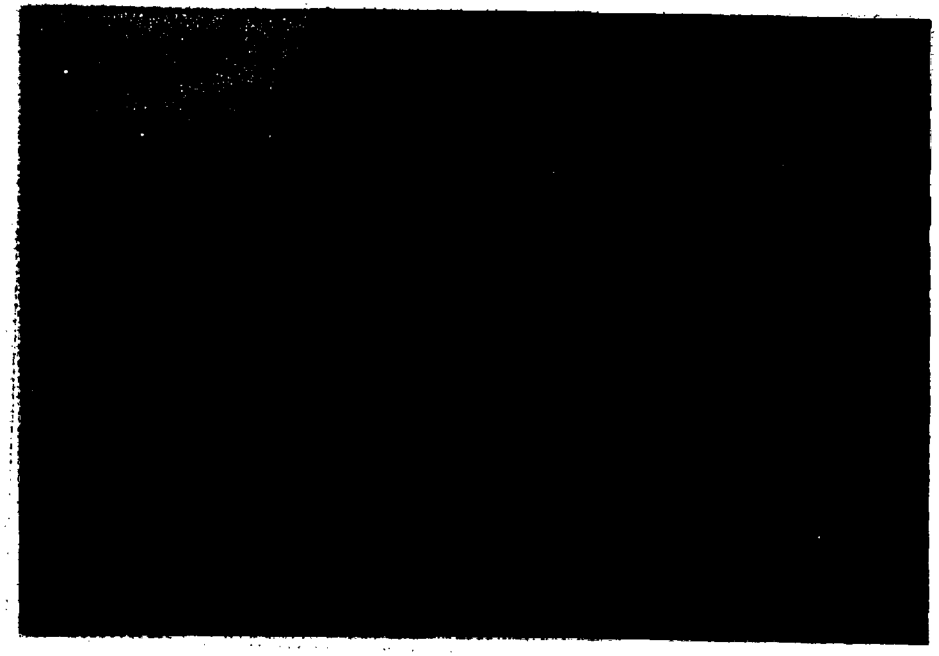



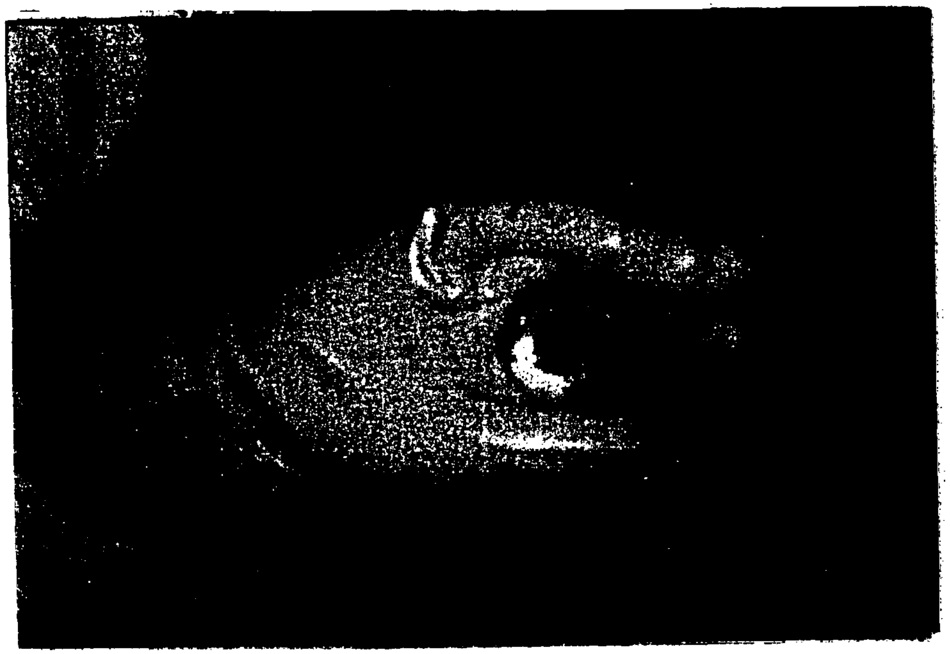


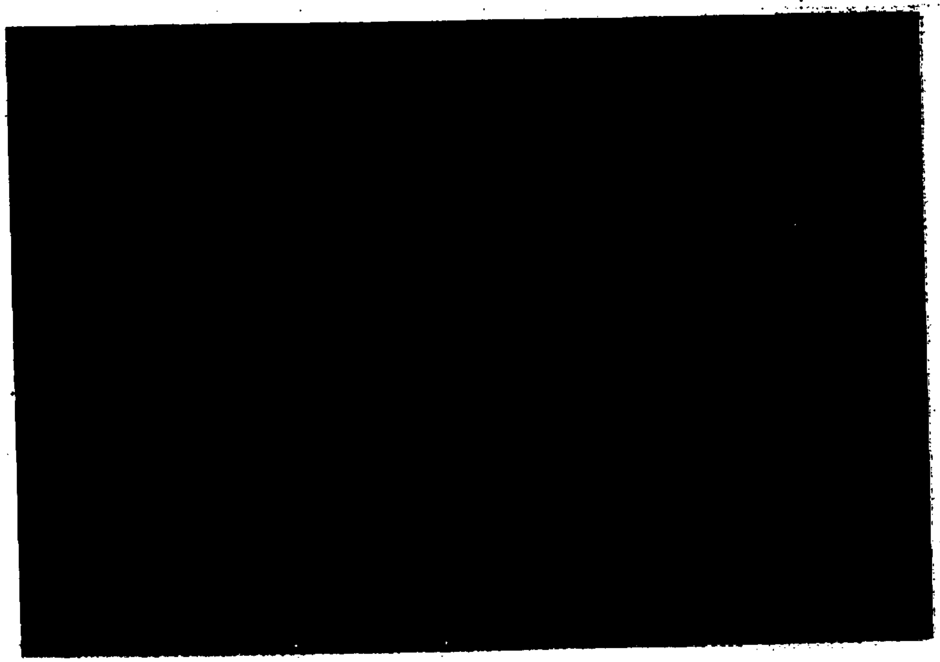
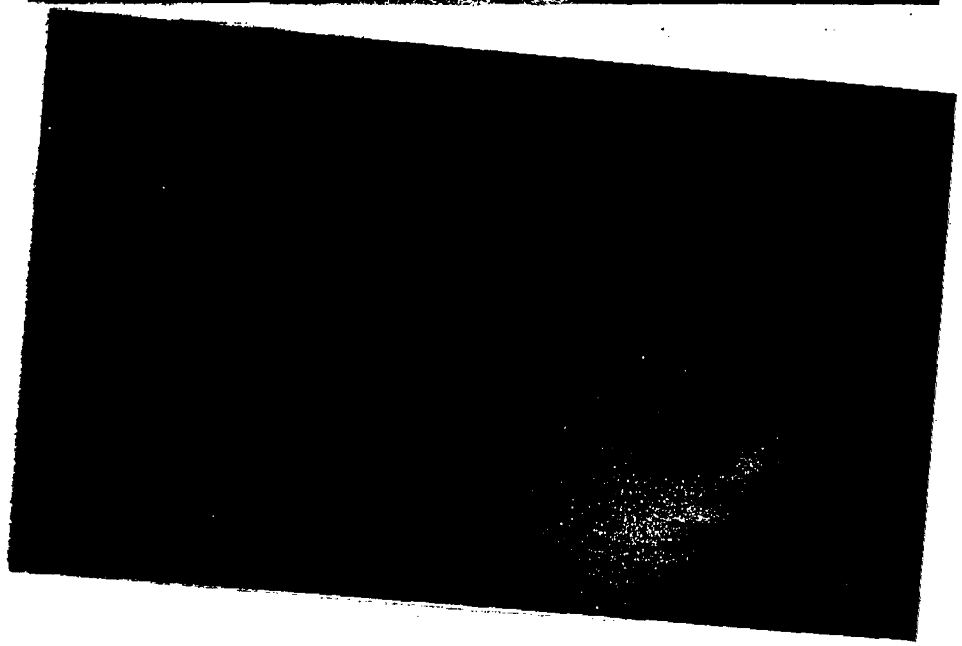











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GPU Nuclear **Calculation Sheet**

Subject	Calc No	Rev No	Sheet No
STATISTICAL ANALYSIS OF DRYWELL ~~THICKNESS DATA THRU 12-31-88~~	C-1302-187-5300-005	0	1 of 198
Originator: J P Moore Jr Date: 1-31-89	Reviewed by: S.D. Leshnoff; Fred P. Barbieri	Date: 2/1/89; 2/2/89	

1.0 PROBLEM STATEMENT

1.1 Background

The design of the carbon steel drywell includes a sand bed which is located around the outside circumference between elevations 8'-11-1/4" and 12'-3". Leakage was observed from the sand bed drains during the 1980, 1983 and 1986 refueling outages indicating that water had intruded into the annular region between the drywell shell and the concrete shield wall.

The drywell shell was inspected in 1986 during the 10R outage to determine if corrosion was occurring. The inspection methods, results and conclusions are documented in Ref. 3.1, 3.2, and 3.3. As a result of these inspections it was concluded that a long term monitoring program would be established. This program includes repetitive Ultrasonic Thickness (UT) measurements in the sand bed region at a nominal elevation of 11'-3" in bays 11A, 11C, 17D, 19A, 19B, and 19C.

The continued presence of water in the sand bed raised concerns of potential corrosion at higher elevations. Therefore, UT measurements were taken at the 51' and 87' elevations in November 1987 during the 11R outage. As a result of these inspections, repetitive measurements in Bay 5 at elevation 51' and in Bays 9, 13 and 15 at the 87' elevation were added to the long term monitoring program to confirm that corrosion is not occurring at these higher elevations.

A cathodic protection system is being installed in selected regions of the sand bed during the 12R outage to minimize corrosion of the drywell. The long term monitoring program was also expanded during the 12R outage to include measurements in the sand bed region of Bays 1D, 3D, 5D, 7D, 9A, 13A, 13C, 13D, 15A, 15D and 17A which are not covered by the cathodic protection system. It also includes measurements in the sand bed region between Bays 17 and 19 which is covered by the cathodic protection system, but does not have a reference electrode to monitor its effectiveness in this region.

Some measurements in the long term monitoring program are to be taken at each outage of opportunity, while others are taken during each refueling outage. The functional requirements for these inspections are documented in Ref. 3.4. The primary purpose of the UT measurements in the sand bed region is to determine the corrosion rate and monitor it over time. When the cathodic protection system is installed and operating, these data will be used to monitor its effectiveness. The purpose of the measurements at other locations is to confirm that corrosion is not occurring in those regions.

1.2 Purpose

The purpose of this calculation is to:

(1) Statistically analyze the thickness measurements for Bays 11A, 11C, 17D, 19A, 19B and 19C in the sand bed region to determine the mean thickness and corrosion rate.

(2) Statistically analyze the thickness measurements for Bay 5 at elevation 51' and Bays 9, 13 and 15 at elevation 87' to determine the mean thickness corrosion rate.

(3) To the extent possible, statistically analyze the limited data for the 6" x 6" grids in the sand bed region of Bays 9D, 13A, 15D and 17A to calculate the mean thickness and determine if there is ongoing corrosion.

(4) To the extent possible, statistically analyze the limited data for the 6" x 1" horizontal strips in the sand bed region of Bays 1D, 3D, 5D, 7D, 9A, 13C and 15A to calculate the mean thickness and determine if there is ongoing corrosion.

Statistically compare the thickness data from December 1986 and December 1988 for the trench in Bay 17D to calculate the mean thickness at various elevations in the trench and determine if there is ongoing corrosion.

(5) Statistically analyze the thickness data from December 1988 for the Frame Cutout between Bays 17 and 19 to calculate the mean thickness.

2.0 SUMMARY OF RESULTS

Bay & Area	Location	Corrosion Rate**	Mean Thickness***
2.1 6"x6" Grids in Sand Bed Region at Original Locations			
11A	Sand Bed	Not significant	908.6 ±5.0 mils
11C	Sand Bed	Indeterminable	916.6 ±10.4 mils
17D	Sand Bed	-27.6 ±6.1 mpy	864.8 ±6.8 mils
19A	Sand Bed	-23.7 ±4.3 mpy	837.9 ±4.8 mils
19B	Sand Bed	-29.2 ±0.5 mpy	856.5 ±0.5 mils
19C	Sand Bed	-25.9 ±4.1 mpy	860.9 ±4.0 mils
2.2 6"x6" Grids in Sand Bed Region at New Locations			
9D	Sand Bed	Indeterminable*	1021.4 ±9.7 mils
13A	Sand Bed	Not significant*	905.3 ±10.1 mils
15D	Sand Bed	Possible*	1056.0 ±9.1 mils
17A	Sand Bed	Indeterminable*	957.4 ±9.2 mils
2.3 6"x6" Grids at Upper Elevations			
5	51' Elev.	-4.3 ±0.03 mpy	750.0 ±0.02 mils
9	87' Elev.	Not significant	620.3 ±1.0 mils
13	87' Elev.	Not significant	635.6 ±0.7 mils
15	87' Elev.	Not significant	634.8 ±0.7 mils
2.4 Multiple 6"x6" Grids in Trench			
17D	Trench	Not significant*	981.2 ±6.7 mils
17/19	Frame Cutout	Indeterminable*	981.7 ±4.4 mils
2.5 6" Strips in Sand Bed Region			
1D	Sand Bed	Indeterminable*	1114.7 ±30.6 mils
3D	Sand Bed	Not significant*	1177.7 ±5.6 mils
5D	Sand Bed	Not significant*	1174.0 ±2.2 mils
7D	Sand Bed	Possible*	1135.1 ±4.9 mils
9A	Sand Bed	Indeterminable*	1154.6 ±4.8 mils
13C	Sand Bed	Not significant*	1147.4 ±3.7 mils
13D	Sand Bed	Not significant*	962.1 ±22.3 mils
15A	Sand Bed	Not significant*	1120.0 ±12.6 mils

2.6 Evaluation of Individual Measurements Below 800 Mils

One data point in Bay 19A and one data point in Bay 5 Elev. 51' fell outside the 99% confidence interval and thus are statistically different from the mean thickness.

*Based on limited data. See text for interpretation.
**Mean corrosion rate in mils per year ± standard error of the mean
***Current mean thickness in mils ± standard error of the mean

3.0 REFERENCES

3.1 GPUN Safety Evaluation SE-000243-002, Rev. 0, "Drywell Steel Shell Plate Thickness Reduction at the Base Sand Cushion Entrenchment Region"

3.2 GPUN TDR 854, Rev. 0, "Drywell Corrosion Assessment"

3.3 GPUN TDR 851, Rev. 0, "Assessment of Oyster Creek Drywell Shell"

3.4 GPUN Installation Specification IS-328227-004, Rev. 3, "Functional Requirements for Drywell Containment Vessel Thickness Examination"

3.5 Applied Regression Analysis, 2nd Edition, N.R. Draper & H. Smith, John Wiley & Sons, 1981

3.6 Statistical Concepts and Methods G.K. Bhattacharyya & R.A. Johnson, John Wiley & sons, 1977

4.0 ASSYUMPTIONS & BASIC DATA

4.1 Selection of Areas to be Monitored

A program was initiated during the 11R outage to characterize the corrosion and to determine its extent. The details of this inspection program are documented in Ref. 3.3. The greatest corrosion was found via UT measurements in the sand bed region at the lowest accessible locations. Where thinning was detected, additional measurements were made in a cross pattern at the thinnest section to determine the extent in the vertical and horizontal directions. Having found the thinnest locations, measurements were made over a 6"-6" grid.

To determine the vertical profile of the thinning, a trench was excavated into the floor in Bay 17 and Bay 5. Bay 17 was selected since the extent of thinning at the floor level was greatest in that area. It was determined that the thinning below the top of the curb was no more severe than above the curb, and became less severe at the lower portions of the sand cushion. Bay 5 was excavated to determine if the thinning line was lower than the floor level in areas where no thinning was detected above the floor. There were no significant indications of thinning in Bay 5.

It was on the basis of these findings that the 6"x6" grids in Bays 11A, 11C, 17D, 19A, 19B and 19C were selected as representative locations for longer term monitoring. The initial measurements at these locations were taken in December 1986 without a template or markings to identify the location of each measurement. Subsequently, the location of the 6"x6" grids were permanently marked on the drywell shell and a template is used in conjunction with these markings to locate the UT probe for successive measurements. Analyses have shown that including the non-template data in the data base creates a significant variability in the thickness data. Therefore, to minimize the effects of probe location, only those data sets taken with the template are included in the analyses.

The presence of water in the sand bed also raised concern of potential corrosion at higher elevations. Therefore, UT measurements were taken at the 51' and 87' elevations in 1987 during the 11M outage. The measurements were taken in a band on 6-inch centers at all accessible regions at these elevations. Where these measurements indicated potential corrosion, the measurements spacing was reduced to 1-inch on centers. If these additional readings indicated potential corrosion, measurements were taken on a 6"x6" grid using the template. It was on the basis of these inspections that the 6"x6" grids in Bay 5 at elevation 51' and in bays 9, 13 and 15 at the 87' elevation were selected as representative locations for long term monitoring.

The long term monitoring program was expanded as follows during the 12R outage:

(1) Measurements on 6"x6" grids in the sand bed region of Bays 9D, 13A, 15D and 17A. The basis for selecting these locations is that they were originally considered for cathodic protection but are not included in the system being installed.

(2) Measurements on 1-inch centers along a 6-inch horizontal strip in the sand bed region of Bays 1D, 3D, 5D, 7D, 9A, 13C, and 15A. These locations were selected on the basis that they are representative of regions which have experienced nominal corrosion and are not within the scope of the cathodic protection system.

(3) A 6"x6" grid in the curb cutout between Bays 17 and 19. The purpose of these measurements is to monitor corrosion in this region which is covered by the cathodic protection system but does not have a reference electrode to monitor its performance.

4.2 UT Measurements

The UT measurements within the scope of the long term monitoring program are performed in accordance with Ref. 3.4. This involves taking UT measurements using a template with 49 holes laid out on a 6"x6" grid with 1" between centers on both axes. The center row is used in those bays where only 7 measurements are made along a 6-inch horizontal strip.

The first set of measurements were made in December 1986 without the use of a template. Ref. 3.4 specifies that for all subsequent readings, QA shall verify that locations of UT measurements performed are within ±1/4" of the location of the 1986 UT measurements. It also specifies that all subsequent measurements are to be within ±1/8" of the designated locations.

4.3 Data at Plug Locations

Seven core samples, each approximately two inches in diameter were removed from the drywell vessel shell. These samples were evaluated in Ref. 3.2. Five of these samples were removed within the 6"x6" grids for Bays 11A, 17D, 19A, 19C and Bay 5 at elevation 51'. These locations were repaired by welding a plug in each hole. Since these plugs are not representative of the drywell shell, UT measurements at these locations on the 6"x6" grid must be dropped from each data set.

The following specific grid points have been deleted:

Bay Area	Points
11A	23, 24, 30, 31
17D	15, 16, 22, 23
19A	24, 25, 31, 32
19C	20, 26, 27, 33,
5	20, 26, 27, 28, 33, 34, 35

4.4 Bases for Statistical Analysis of 6"x6" Grid Data

4.4.1 Assumptions

The statistical evaluation of the UT measurement data to determine the corrosion rate at each location is based on the following assumptions:

(1) Characterization of the scattering of data over each 6"x6" grid is such that the thickness measurements are normally distributed.

(2) Once the distribution of data for each 6"x6" grid is found to be normal, then the mean value of the thickness is the appropriate representation of the average condition.

(3) A decrease in the mean value of the thickness with time is representative of the corrosion occurring within the 6"x6" grid.

(4) If corrosion has ceased, the mean value of the thickness will not vary with time except for random errors in the UT measurements.

(5) If corrosion is continuing at a constant rate, the mean thickness will decrease linearly with time. In this case, linear regression analysis can be used to fit the mean thickness values for a given zone to a straight line as a function of time. The corrosion rate is equal to the slope of the line.

The validity of these assumptions is assured by:

(a) Using more than 30 data points per 6"x6" grid

(b) Testing the data for normality at each 6"x6" grid location.

(c) Testing the regression equation as an appropriate model to describe the corrosion rate.

These tests are discussed in the following section. In cases where one or more of these assumptions proves to be invalid, non-parametric analytical techniques can be used to evaluate the data.

4.4.2 Statistical Approach

The following steps are performed to test and evaluate the UT measurement data for those locations where 6"x6" grid data has been taken at least three times:

(1) Edit each 49 point data set by setting all invalid points to zero. Invalid points are those which are declared invalid by the UT operator or are at a plug location. (The computer programs used in the following steps ignore all zero thickness data points.)

(2) Perform a chi-squared goodness of fit test of each 49 point data set to ensure that the assumption of normality is valid at the 95% and 99% confidence levels.

(3) Calculate the mean thickness of each 49 point data set.

(4) Using the mean thickness values for each 6"x6" grid, perform linear regression analysis over time at each location.

(a) Perform F-test for significance of regression at the 95% confidence level. The result of this test indicates whether or not the regression model is more appropriate than the mean model. In other words, it tests to see if the variation of the regression model is statistically significant over that of a mean model.

(b) Calculate the co-efficient of determination (R^2) to assess how well the regression model explains the percentage of total error and thus how useful the regression line will be as a predictor.

(c) Determine if the residual values for the regression equations are normally distributed.

(d) If the regression model is found to be appropriate, calculate the y-intercept, the slope and their respective standard errors. The y-intercept represents the fitted mean thickness at time zero, the slope represents the corrosion rate, and the standard errors represent the uncertainty or random error of these two parameters.

(5) Use a z score of 2.56 and the standard deviation to establish a 99% confidence interval about the mean thickness values for each 6"x6" grid location to determine whether low thickness measurements or "outliers" are statistically significant. If the data points are greater than the 99% lower confidence limit, then the difference between the value and the mean is deemed to be due to expected random error. However, if the data point is less than the lower 99% confidence limit, this implies that the difference is statistically significant and is probably not due to chance.

4.5 Analysis of Two 6"x6" Grid Data Sets

Regression analysis is inappropriate when data is available at only two points in time. However, the t-Test can be used to determine if the means of the two data sets are statistically different.

4.5.1 Assumptions

This analysis is based upon the following assumptions:

(1) The data in each data set is normally distributed.

(2) The variances of the two data sets are equal.

4.5.2 Statistical Approach

The evaluation takes place in three steps:

(1) Perform a chi-squared test of each data set to ensure that the assumption of normality is valid at the 95% and 99% confidence levels.

(2) Perform an F-test of the two data sets being compared to ensure that the assumption of equal variances is valid at the 95% and 99% confidence levels.

(3) Perform a two-tailed t-Test for two independent samples to determine if the means of the two data sets are statistically different at the 0.05 and 0.01 levels of significance.

A conclusion that the means are not statistically different is interpreted to mean that significant corrosion did not occur over the time period represented by the data. However, if equality of the means is rejected, this implies that the difference is statistically significant and could be due to corrosion.

4.6 Analysis of Single 6"x6" Grid Data Set

In those cases where a 6"x6" data set is taken at a given location for the first time during the current outage, the only other data to which they can be compared are the UT survey measurements taken in 1986 to identify the thinnest regions of the drywell shell in the sand bed region. For the most part, these are single point measurements which were taken in the vicinity of the 49-point data set, but not at the exact location. Therefore, rigorous statistical analysis of these single data sets is impossible. However, by making certain assumptions, they can be compared with the previous data points. If more extensive data is available at the location of the 49-point data set, the t-test can be used to compare the means of the two data sets as described in paragraph 2.5.

When additional measurements are made at these exact locations during future outages, more rigorous statistical analyses can be employed.

4.6.1 Assumptions

The comparison of a single 49-point data sets with previous data from the same vicinity is based on the following assumptions:

(1) Characterization of the scattering of data over the 6"x6" grid is such that the thickness measurements are normally distributed.

(2) Once the distribution of data for the 6"x6" grid is found to be normal, then the mean value of the thickness is the appropriate representation of the average condition.

(3) The prior data is representative of the condition at this location in 1986.

4.6.2 Statistical Approach

The evaluation takes place in four steps:

(1) Perform a chi-squared test of each data set to ensure that the assumption of normality is valid at the 95% and 99% confidence levels.

(2) Calculate the mean and the standard error of the mean of the 49-point data set.

(3) Determine the two-tailed t value from a t distribution table at levels of significance of 0.05 and 0.01 for n-1 degrees of freedom.

(4) Use the t value and the standard error of the mean to calculate the 95% and 99% confidence intervals about the mean of the 49-point data set.

(5) Compare the prior data point(s) with these confidence intervals about the mean of the 49-point data sets.

If the prior data falls within the 95% confidence intervals, it provides some assurance that significant corrosion has not occurred in this region in the period of time covered by the data. If it falls within the 99% confidence limits but not within the 95% confidence limits, this implication is not as strong. In either case, the corrosion rate will be interpreted to be "Not Significant".

If the prior data falls above the upper 99% confidence limit, it could mean either of two things: (1) significant corrosion has occurred over the time period covered by the data, or (2) the prior data point was not representative of the condition of the location of the 49-point data set in 1986. There is no way to differentiate between the two. In this case, the corrosion rate will be interpreted to be "Possible".

If the prior data falls below the lower 99% confidence limit, it means that it is not representative of the condition at this location in 1986. In this case, the corrosion rate will be interpreted to be "Indeterminable".

4.7 Analysis of Single 7-Point Data Set

In those cases where a 7-point data set is taken at a given location for the first time during the current outage, the only other data to which they can be compared are the UT survey measurements taken in 1986 to identify the thinnest regions of the drywell shell in the sand bed region. For the most part, these are single point measurements which were taken in the vicinity of the 7-point data sets, but not at the exact locations. However, by making certain assumptions, they can be compared with the previous data points. If more extensive data is available at the location of the 7-point data set, the t-test can be used to compare the means of the two data sets as described in paragraph 2.5.

When additional measurements are made at these exact locations during future outages, more rigorous statistical analyses can be employed.

4.7.1 Assumptions

The comparison of a single 7-point data sets with previous data from the same vicinity is based on the following assumptions:

(1) The corrosion in the region of each 7-point data set is normally distributed.

(2) The prior data is representative of the condition at this location in 1986.

The validity of these assumptions cannot be verified.

4.7.2. Statistical Approach

The evaluation takes place in four steps:

(1) Calculate the mean and the standard error of the mean of the 7-point data set.

(2) Determine the two-tailed t value using the t distribution tables at levels of significance of 0.05 and 0.01 for n-1 degrees of freedom.

(3) Use the t value and the standard error of the mean to calculate the 95% and 99% confidence intervals about the mean of the 7-point data set.

(4) Compare the prior data point(s) with these confidence intervals about the mean of the 7-point data sets.

If the prior data falls within the 95% confidence intervals, it provides some assurance that significant corrosion has not occurred in this region in the period of time covered by the data. If it falls within the 99% confidence limits but not within the 95% confidence limits, this implication is not as strong. In either case, the corrosion rate will be interpreted to be "Not Significant".

If the prior data falls above the upper 99% confidence interval, it could mean either of two things: (1) significant corrosion has occurred over the time period covered by the data, or (2) the prior data point was not representative of the condition of the location of the 7-point data set in 1986. There is no way to differentiate between the two. In this case, the corrosion rate will be interpreted to be "Possible".

If the prior data falls below the lower 99% confidence limit, it means that it is not representative of the condition at this location in 1986. In this case, the corrosion rate will be interpreted to be "Indeterminable".

4.8 Evaluation of Drywell Mean Thickness

This section defines the methods used to evaluate the drywell thickness at each location within the scope of the long term monitoring program.

4.8.1 Evaluation of Mean Thickness Using Regression Analysis

The following procedure is used to evaluate the drywell mean thickness at those locations where regression analysis has been deemed to be more appropriate than the mean model.

(1) The best estimate of the mean thickness at these locations is the point on the regression line corresponding to the time when the most recent set of measurements was taken. In the SAS Regression Analysis output (Ref. 3.7), this is the last value in the column labeled "PREDICT VALUE".

(2) The best estimate of the standard error of the mean thickness is the standard error of the predicted value used above. In the SAS Regression Analysis output, this is the last value in the column labeled "STD ERR PREDICT".

(3) The two-sided 95% confidence interval about the mean thickness is equal to the mean thickness plus or minus t times the estimated standard error of the mean. This is the interval for which we have 95% confidence that the true mean thickness will fall within. The value of t is obtained from a t distribution table for <u>equal tails</u> at n-2 degrees of freedom and 0.05 level of significance, where n is the number of sets of measurements used in the regression analysis. The degrees of freedom is equal to n-2 because two parameters (the y-intercept and the slope) are calculated in the regression analysis with n mean thicknesses as input.

(4) The one-sided 95% lower limit of the mean thickness is equal to the estimated mean thickness minus t times the estimated standard error of the mean. This is the mean thickness for which we have 95% confidence that the true mean thickness does not fall below. In this case, the value of t is obtained from a t distribution table for <u>one tail</u> at n-2 degrees of freedom and 0.05 level of significance.

4.8.2 <u>Evaluation of Mean Thickness Using Mean Model</u>

The following procedure is used to evaluate the drywell mean thickness at those locations where the mean model is deemed to be more appropriate than the linear regression model. This method is consistent with that used to evaluate the mean thickness using the regression model.

(1) Calculate the mean of each set of UT thickness measurements.

(2) Sum the means of the sets and divide by the number of sets to calculate the grand mean. This is the best estimate of the mean thickness. In the SAS Regression Analysis output (Ref. 3.7), this is the value labelled "DEP MEAN".

(3) Using the means of the sets from (1) as input, calculate the standard error. This is the best estimate of the standard error of the mean thickness.

(4) The two-sided 95% confidence interval about the mean thickness is equal to the mean thickness plus or minus t times the estimated standard error of the mean. This is the interval for which we have 95% confidence that the true mean thickness will fall within. The value of t is obtained from a t distribution table for equal tails at n-1 degrees of freedom and 0.05 level of significance.

(5) The one-sided 95% lower limit of the mean thickness is equal to the estimated mean thickness minus t times the estimated standard error of the mean. This is the mean thickness for which we have 95% confidence that the true mean thickness does not fall below. In this case, the value of t is obtained from a t distribution table for one tail at n-1 degrees of freedom and 0.05 level of significance.

4.8.3 Evaluation of Mean Thickness Using Single Data Set

The following procedure is used to evaluate the drywell thickness at those locations where only one set of measurements is available.

(1) Calculate the mean of the set of UT thickness measurements. This is the best estimate of the mean thickness.

(2) Calculate the standard error of the mean for the set of UT measurements. This is the best estimate of the standard error of the mean thickness.

Confidence intervals about the mean thickness cannot be calculated with only one data set available.

5.0 CALCULATIONS

5.1 6"x6" Grids in Sand Bed Region at Original Locations

5.1.1 Bay 11A: 5/1/87 to 10/8/88

Six 49-point data sets were available for this bay covering the time period from May 1, 1987 to October 8, 1988. Since a plug lies within this region, four of the points were voided in each data set. The data were analyzed as described in paragraphs 2.4 and 2.8.2.

(1) The data are normally distributed.

(2) The mean model is more appropriate than the regression model.

(3) The current mean thickness ± standard error is 908.6 ±5.0 mils.

(4) There was no significant corrosion from May 1, 1987 to October 8, 1988.

PROGRAM: DWCHISQ
ENTER NAME OF DATA LIST e11a
ENTER PT NUMBER LIST int=(1,49)
ENTER NAME OF DATE LIST dates11a

N	E11A
*	*******
1	E11A612
2	E11A704
3	E11A705
4	E11A708
5	E11A709
6	E11A807
7	E11A810

ENTER NO. OF DESIRED DATA 2,3,4,5,6,7

	DATES11A	MEANTHK	SD	STDERR	DFM2
*******	********	*******	*******	********	****
E11A704	4/29/87	.91866	.052163	.0081466	2
E11A705	5/1/87	.90464	.040982	.0061783	2
E11A708	8/1/87	.92209	.037247	.0056152	2
E11A709	9/10/87	.9052	.049865	.0075174	2
E11A807	7/12/88	.91297	.045901	.0079903	2
E11A810	10/08/88	.88822	.038926	.0058027	2

CHISQ	CHI952	CHI992
********	******	******
2.0875	5.99	9.21
.098813	5.99	9.21
1.5175	5.99	9.21
2.6733	5.99	9.21
6.7947	5.99	9.21
3.438	5.99	9.21

OBS						EXP					
7	9	9	10	11	12	8.6863	9.3218	9.3218	9.3218	6.9914	9.5337
11	8	10	8	2	4	7.767	8.3354	8.3354	8.3354	6.2515	8.5248
8	9	6	12	4	10	8.0934	8.6856	8.6856	8.6856	6.5142	8.883
6	8	10	5	8	8	7.767	8.3354	8.3354	8.3354	6.2515	8.5248
9	10	9	9	8	11	8.6863	9.3218	9.3218	9.3218	6.9914	9.5337

GRAND MEAN THICKNESS = .90863
STANDARD ERROR OF THE GRAND MEAN = .0049825

January 18, 1989
12:54 PM

E11A704

.991	.995	1.051	.975	1.009	.951	.903
.909	.944	.966	.788	.938	0	.883
.846	.86	.9	.896	.9	.861	.909
.884	0	0	.877	.892	.961	.919
.9	0	0	0	.949	.906	.887
.838	.931	.889	.868	1.006	0	.707
.941	.922	.959	0	.968	.871	.915

E11A705

.967	.962	.923	.919	.964	.947	.873
.904	.914	.893	.891	.903	.896	.922
.849	.893	.932	.854	.875	.836	.869
.854	0	0	.882	.9	.883	.909
.907	0	0	0	.726	.89	.851
.812	.941	.851	.895	.948	.902	.915
.989	.958	.97	.932	.932	.833	.938

E11A708

.955	.941	.964	.929	.966	.943	.868
.942	.934	.905	.91	.927	.904	.897
.872	.84	.904	0	.887	.899	.913
.859	0	0	.882	.899	.874	.895
.945	0	0	.894	.964	.938	.902
.96	.999	.881	.978	.968	.945	.936
.926	.914	.949	1.011	.928	.891	.934

E11A709

.955	.959	1.058	.915	.992	.942	.974
.898	.916	.896	.887	.899	.903	.884
.847	.822	.9	.846	.863	.848	.872
.845	0	0	.845	.893	.86	.905
.936	0	0	.91	.929	.915	.937
.821	.941	.877	.895	.946	.861	.882
0	.885	.978	1.011	.953	.88	.949

E11A807

.983	.965	.903	0	.954	.929	.857
.918	.943	.917	.873	.932	.927	.864
.87	.86	.895	.874	.857	.86	0
.885	0	0	0	.858	.947	.945
0	0	0	.944	0	0	.809
.97	0	0	0	.982	0	0
.96	.922	0	.947	.964	.858	.956

E11A810

.937	.944	.832	.89	.947	.911	.85
.881	.897	.905	.94	.876	.885	.857
.833	.81	.889	.831	.824	.829	.857
.874	0	0	.881	.898	.853	.898
.925	0	0	.906	.922	.872	.884
.822	.935	.876	.879	.944	.881	.924
.915	.894	.952	.943	.913	.841	.913

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF BAY 11A 3" ABOVE CURB

OBS	YEARS	MILS
1	0.00	918.7
2	0.00	904.6
3	0.26	922.1
4	0.37	905.2
5	1.21	913.0
6	1.45	888.2

Calc No C-1302-187-5380-005 Rev No 0 Sheet No 180

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF BAY 11A 3" ABOVE CURB

VARIABLE	N	MEAN	STANDARD DEVIATION	STD ERROR OF MEAN	T	PR>|T|
MILS	6	908.63333333	12.22565608	4.99110320	182.05	0.0001

Mean Thickness = 908.6 ± 5.6 mils

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF BAY 11A 3" ABOVE CURB

DEP VARIABLE MILS

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	248.59865	248.59865	1.994	0.2308
ERROR	4	498.73469	124.68367		
C TOTAL	5	747.33333			

ROOT MSE	11.16618	R-SQUARE	0.3326
DEP MEAN	908.6333	ADJ R-SQ	0.1658
C.V.	1.228899		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|	TYPE I SS	STANDARDIZED ESTIMATE
INTERCEP	1	914.79762	6.31177940	144.935	0.0001	4953687.21	0
YEARS	1	-11.24185554	7.96147274	-1.412	0.2308	248.59865	-0.57675611

COLLINEARITY DIAGNOSTICS

NUMBER	EIGENVALUE	CONDITION NUMBER	VAR PROP INTERCEP	VAR PROP YEARS
1	1.691650	1.000000	0.1542	0.1542
2	0.308350	2.342249	0.8458	0.8458

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT	RESIDUAL
1	918.7	914.8	6.3118	897.3	932.3	879.2	950.4	3.9024
2	904.6	914.8	6.3118	897.3	932.3	879.2	950.4	-10.1976
3	922.1	911.9	5.1039	897.7	926.0	877.8	946.0	10.2253
4	905.2	910.6	4.7746	897.4	923.9	876.9	944.4	-5.4381
5	913.0	901.2	6.9664	881.9	920.5	864.7	937.7	11.8050
6	888.2	898.5	8.5037	874.9	922.1	859.5	937.5	-10.2969

SUM OF RESIDUALS 1.19371E-12
SUM OF SQUARED RESIDUALS 498.7347
PREDICTED RESID SS (PRESS) 1443.379

$t95(6-2) = 2.776$

10/25/06 14:28:07

Calc No C-1302-187-5360-005 | Rev No 0 | Sheet No 20 of --

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF BAY 11A 3" ABOVE CURB

DEP VARIABLE: MILS

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	248.59865	248.59865	1.994	0.2308
ERROR	4	498.73469	124.68367		
C TOTAL	5	747.33333			

ROOT MSE	11.16618	R-SQUARE	0.3326
DEP MEAN	908.6333	ADJ R-SQ	0.1658
C.V.	1.228899		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	914.79762	6.31177940	144.935	0.0001
YEARS	1	-11.24185554	7.96147274	-1.412	0.2308

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT	RESIDUAL	STD ERR RESIDUAL
1	918.7	914.8	6.3118	897.3	932.3	879.2	950.4	3.9024	9.2111
2	904.6	914.8	6.3118	897.3	932.3	879.2	950.4	-10.1976	9.2111
3	922.1	911.9	5.1039	897.7	926.0	877.8	946.0	10.2253	9.9314
4	905.2	910.6	4.7746	897.4	923.9	876.9	944.4	-5.4381	10.0939
5	913.0	901.2	6.9664	881.9	920.5	864.7	937.7	11.8050	8.7266
6	888.2	898.5	8.5037	874.9	922.1	859.5	937.5	-10.2969	7.2368

OBS	STUDENT RESIDUAL	-2-1-0 1 2	COOK'S D
1	0.4237	| | |	0.042
2	-1.1071	| **| |	0.288
3	1.0296	| |** |	0.140
4	-0.5388	| *| |	0.032
5	1.3528	| |** |	0.583
6	-1.4229	| **| |	1.398

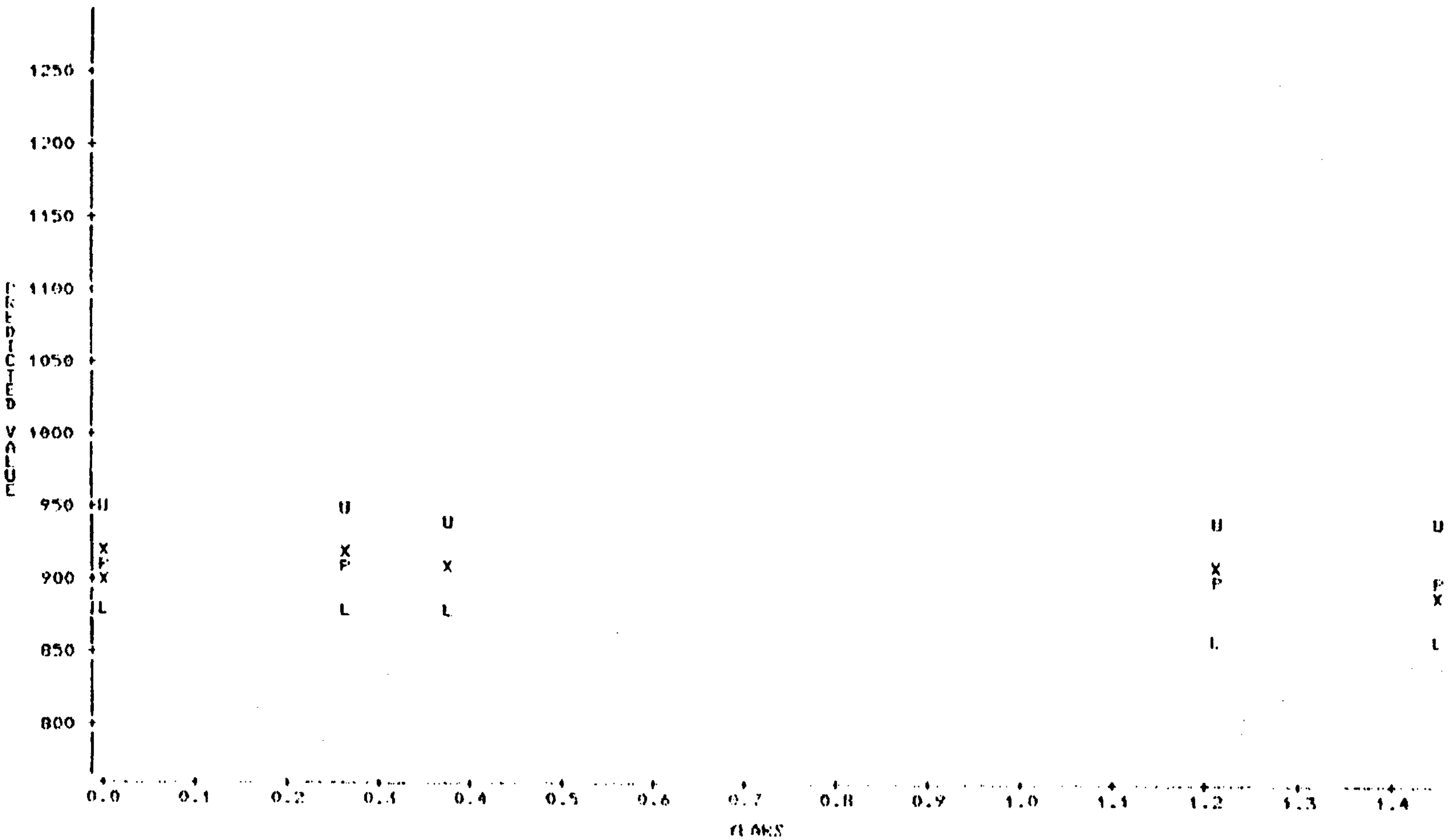
SUM OF RESIDUALS 1.19371E-12
SUM OF SQUARED RESIDUALS 498.7347
PREDICTED RESID SS (PRESS) 1443.379

10/25/06 14:28:07

Calc No C-1302-187-5380-085 Rev No 0 Sheet No 2 of -

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF BAY 11A 3" ABOVE CURB

PLOT OF MILS*YEARS SYMBOL USED IS X
PLOT OF PRED*YEARS SYMBOL USED IS P
PLOT OF U95*YEARS SYMBOL USED IS U
PLOT OF L95*YEARS SYMBOL USED IS L



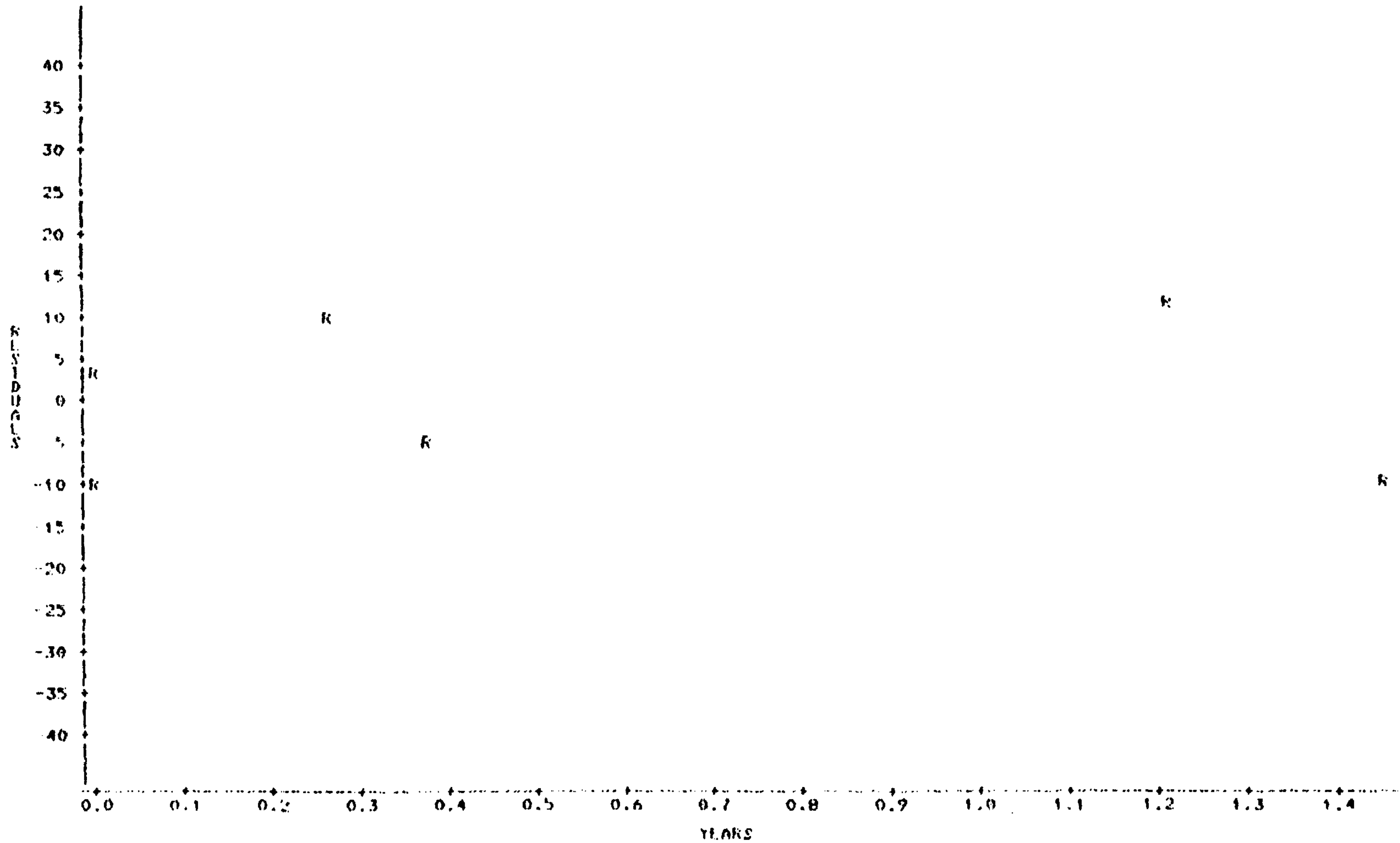
NOTE: 4 OBS HIDDEN

Calc No C-1302-187-5300-005 | Rev No Ø | Sheet No 220f.

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF BAY 11A 3" ABOVE CURB

8:57 WEDNESDAY, JANUARY 4, 1989 67

PLOT OF RESIDUAL*YEARS SYMBOL USED IS R



10/25/06 14:28:07

Calc No C-1302-187-5300-005 Rev. No 0 Sheet No 23 of ...

5.1.2 Bay 11C: 5/1/87 to 10/8/88

Five 49-point data sets were available for this bay covering the time period from May 1, 1987 to October 8, 1988. These data were analyzed as described in paragraphs 2.4 and 2.8.2. The initial analysis of this data indicated that the data are not normally distributed. The lack of normality was tentatively attributed to minimal corrosion in the upper half of the 6"x6" grid with more extensive corrosion in the lower half of the grid. To test this hypothesis, each data set was divided into two subsets, with one containing the top three rows and the other containing the bottom four rows.

The top subset was normally distributed but the bottom subset was not. For both subsets, the mean model is more appropriate than the regression model.

Since there is an observable decrease in the mean thickness with time, there appears to be some on-going corrosion at this location. Further analysis is required.

The current mean thickness ± standard error is 916.6 ±10.4 mils for the lower subset and 1057.6 ±16.9 mils for the upper subset.

PROGRAM: DWCHISQ
ENTER NAME OF DATA LIST d11c
ENTER PT NUMBER LIST ints(1,49)
ENTER NAME OF DATE LIST d34567

N	D11C
*	*******
1	D11C612
2	D11C705
3	D11C708
4	D11C709
5	D11C807
6	D11C810

ENTER NO. OF DESIRED DATA 2,3,4,5,6

	D34567	MEANTHK	SD	STDERR	DFM2
*******	********	*******	*******	*******	****
D11C705	5/1/87	.96735	.092336	.013614	2
D11C708	8/1/87	1.0182	.10737	.015498	2
D11C709	9/10/87	.97744	.10944	.016315	2
D11C807	7/12/88	.9579	.099895	.016885	2
D11C810	10/08/88	.94133	.094979	.013568	2

CHISQ	CHI952	CHI992
******	******	******
40.419	5.99	9.21
14.689	5.99	9.21
60.493	5.99	9.21
22.223	5.99	9.21
27.804	5.99	9.21

OBS					EXP				
**************					************************************				
4	9	1	3	6	9.7456	10.169	9.5337	7.4151	10.381
25	18	28	17	23	8.7142	9.0931	8.5248	6.6304	9.2826
4	8	5	6	6	9.0804	9.4752	8.883	6.909	9.6726
3	2	1	2	3	8.7142	9.0931	8.5248	6.6304	9.2826
10	11	10	7	11	9.7456	10.169	9.5337	7.4151	10.381

GRAND MEAN THICKNESS = .97243
STANDARD ERROR OF THE GRAND MEAN = .0129

January 18, 1989
12:55 PM

D11C705

0	0	.906	.978	.858	.932	.998
1.199	1.169	1.113	1.129	1.151	1.15	0
1.115	1.105	1.062	1.074	1.006	.971	.91
.895	.882	.865	.907	.906	.913	.941
.921	.904	.931	.945	.918	.915	.905
.922	.908	.919	.947	.928	.932	.917
1.013	.91	.928	.912	.897	.902	.887

D11C708

1.117	.958	0	1.017	.953	.992	1.143
1.243	1.191	1.276	1.244	1.23	1.243	1.137
1.108	1.163	1.061	1.081	1.008	1.004	.983
.933	.926	.924	.949	.922	.916	.966
.923	.967	.983	1.029	.934	.938	.964
.926	.984	.925	.919	.936	.991	1.026
1.015	.95	.94	.939	.951	1.034	.892

D11C709

0	1.102	.962	.975	.828	.967	1
0	1.263	1.113	1.148	1.149	1.175	1.133
1.138	1.216	1.22	1.054	0	0	.902
.91	.939	.907	.905	.905	.899	.956
.914	.915	.927	.945	.903	.909	.918
.924	.92	.908	.915	.917	.925	.908
.903	.906	.924	.901	.891	.949	.897

D11C807

0	0	.993	.954	.843	.963	0
1.176	1.177	1.114	1.158	1.149	0	0
1.096	0	1.104	0	0	.958	.905
.904	.855	0	.892	.884	.91	.862
.897	.934	.934	0	.88	.884	0
.91	.939	.888	.896	.904	.913	.888
0	0	0	1.017	.884	.901	.917

D11C810

1.167	.905	.855	.945	.817	.907	.957
1.142	1.099	1.071	1.126	1.117	1.136	1.078
1.06	1.071	1.027	.982	.96	.924	.9
.87	.856	.84	.892	.879	.877	.851
.901	.895	.904	.933	.875	.885	.979
.72	.995	.883	.889	.904	.909	.889
.885	.902	.963	.894	.886	.887	.896

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 11C

DEP VARIABLE: MEASURE

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	1490.70825	1490.70825	2.441	0.2161
ERROR	3	1832.09175	610.69725		
C TOTAL	4	3322.80000			

ROOT MSE	24.71229	R-SQUARE	0.4486
DEP MEAN	972.2	ADJ R-SQ	0.2648
C.V.	2.541894		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|	TYPE I SS	STANDARDIZED ESTIMATE
INTERCEP	1	992.11087	16.86860259	58.814	0.0001	4725864.20	0
YEAR	1	-30.59444577	19.58209912	-1.562	0.2161	1490.70825	-0.66979859

COLLINEARITY DIAGNOSTICS

NUMBER	EIGENVALUE	CONDITION NUMBER	VAR PROP INTERCEP	VAR PROP YEAR
1	1.755488	1.000000	0.1223	0.1223
2	0.244512	2.679471	0.8777	0.8777

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT	RESIDUAL
1	967.0	992.1	16.8686	938.4	1045.8	896.9	1087.3	-25.1109
2	1018.0	984.4	13.5324	941.3	1027.5	894.7	1074.1	33.5989
3	977.0	981.1	12.4235	941.5	1020.6	893.0	1069.1	-4.0663
4	958.0	955.4	15.4207	906.3	1004.5	862.7	1048.1	2.6025
5	941.0	948.0	19.0152	887.5	1008.5	848.8	1047.3	-7.0243

SUM OF RESIDUALS	5.11591E-13
SUM OF SQUARED RESIDUALS	1832.092
PREDICTED RESID SS (PRESS)	4858.022

$t95(5-2) = 3.182$

10/25/06 14:28:07

Calc No C-1302-187-5380-005 Rev No 0 Sheet No 270f

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 11C

DEP VARIABLE: MEASURE

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	1490.70825	1490.70825	2.441	0.2161
ERROR	3	1832.09175	610.69725		
C TOTAL	4	3322.80000			

ROOT MSE	24.71229	R-SQUARE	0.4486
DEP MEAN	972.2	ADJ R-SQ	0.2648
C.V.	2.541894		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	992.11087	16.86860259	58.814	0.0001
YEAR	1	-30.59444577	19.58209912	-1.562	0.2161

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT	RESIDUAL	STD ERR RESIDUAL	STUDENT RESIDUAL	-2-1-0 1 2
1	967.0	992.1	16.8686	938.4	1045.8	896.9	1087.3	-25.1109	18.0596	-1.3904	| **|
2	1018.0	984.4	13.5324	941.3	1027.5	894.7	1074.1	33.5989	20.6778	1.6249	| |***
3	977.0	981.1	12.4235	941.5	1020.6	893.0	1069.1	-4.0663	21.3624	-0.1903	| |
4	958.0	955.4	15.4207	906.3	1004.5	862.7	1048.1	2.6025	19.3106	0.1348	| |
5	941.0	948.0	19.0152	887.5	1008.5	848.8	1047.3	-7.0243	15.7835	-0.4450	| |

OBS	COOK'S D
1	0.843
2	0.565
3	0.006
4	0.006
5	0.144

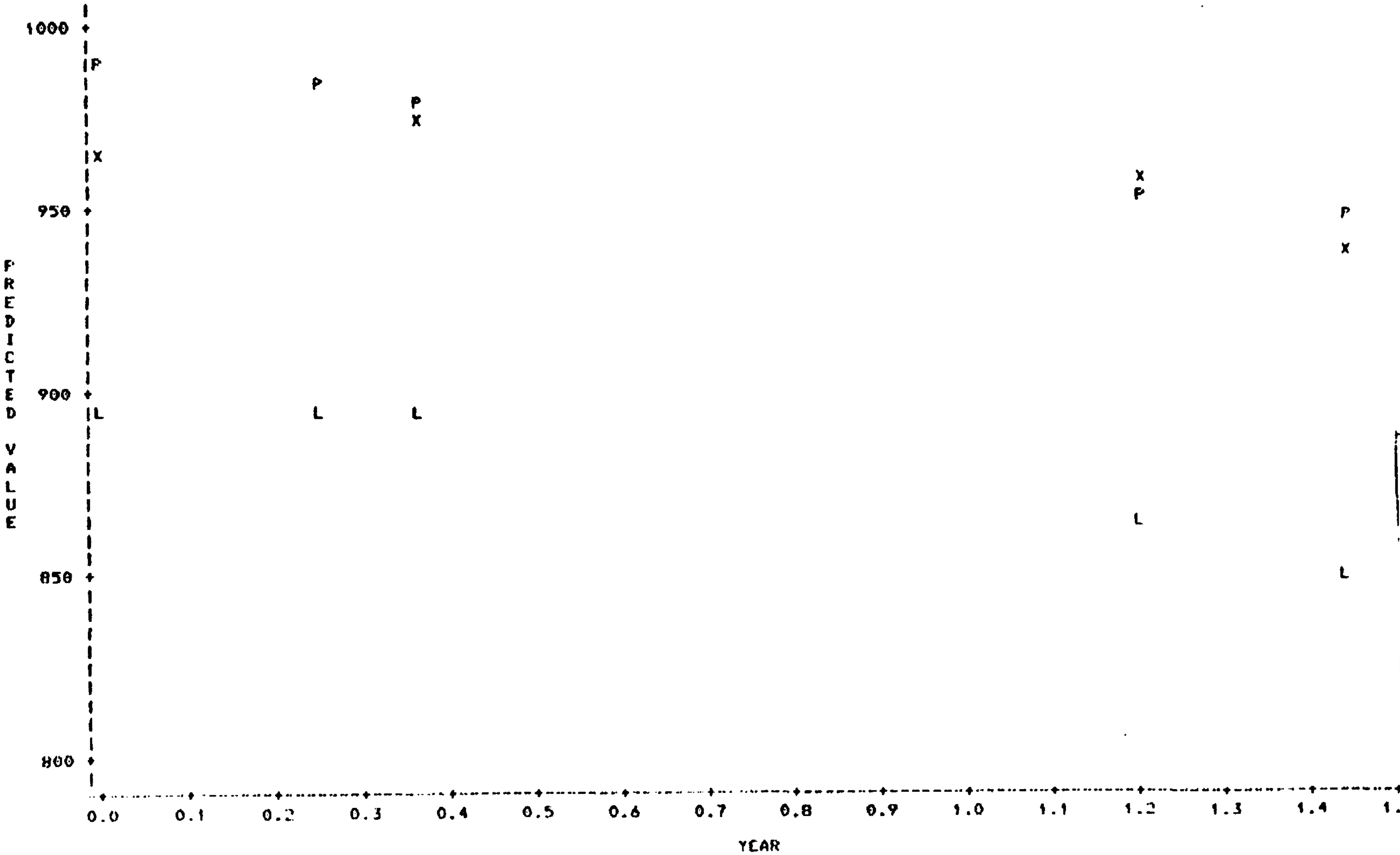
SUM OF RESIDUALS 5.11591E-13
SUM OF SQUARED RESIDUALS 1832.092
PREDICTED RESID SS (PRESS) 4858.022

10/25/06 14:26:07

Calc No C-1302-187-5300-005 Rev No 0 Sheet No 28 of

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 11C

PLOT OF MEASURE*YEAR	SYMBOL USED IS X
PLOT OF PRED*YEAR	SYMBOL USED IS P
PLOT OF U95*YEAR	SYMBOL USED IS U
PLOT OF L95*YEAR	SYMBOL USED IS L



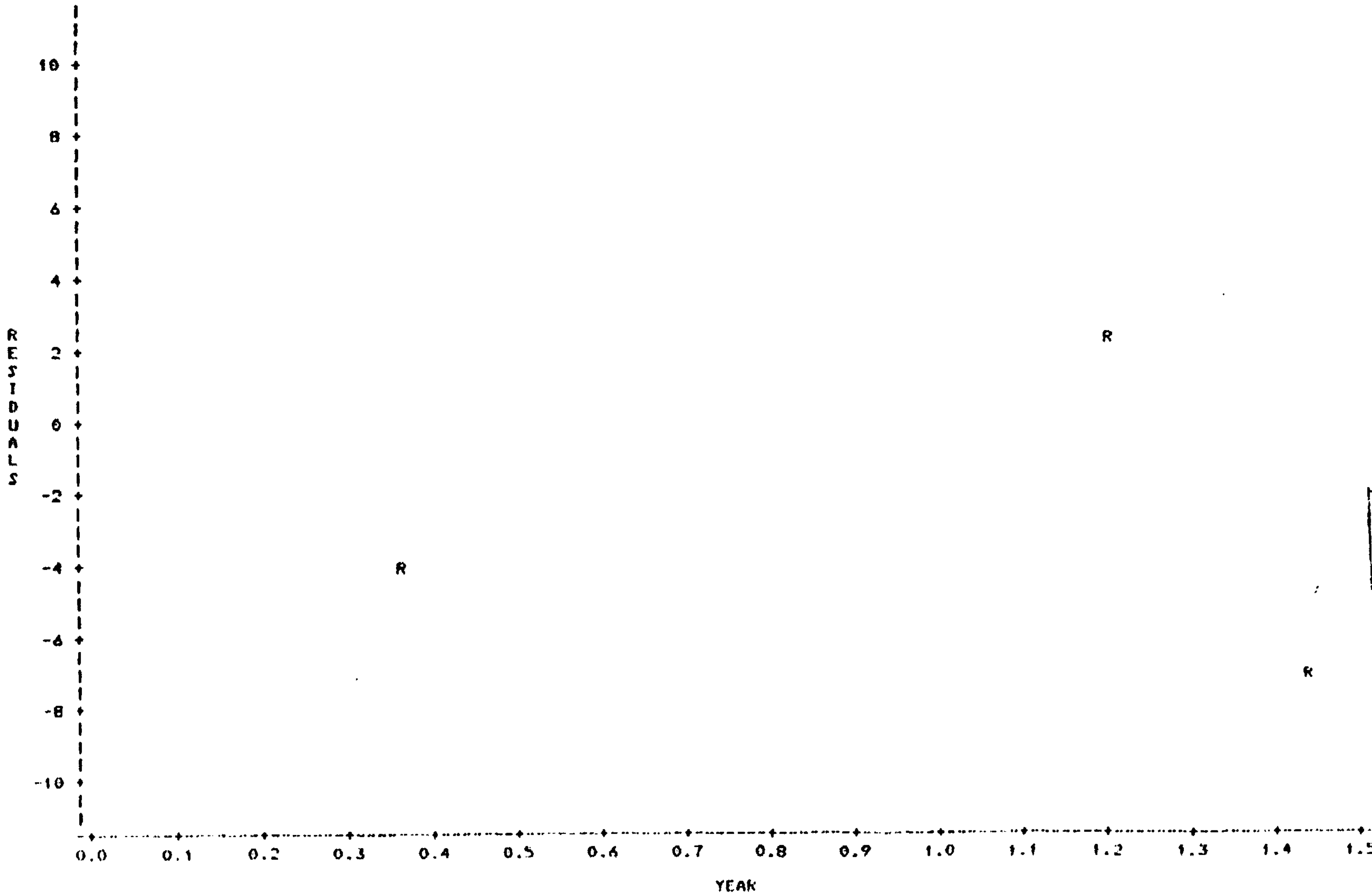
NOTE 6 OBS HAD MISSING VALUES OR WERE OUT OF RANGE

10/25/06 14:28:07

Calc No C-1302-187-5300-005 Rev No 0 Sheet No 29 of -

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 11C

PLOT OF RESID*YEAR   SYMBOL USED IS R



NOTE: 2 OBS HAD MISSING VALUES OR WERE OUT OF RANGE

10/25/06 14:26:07

Calc No C-1302-187-5300-005 Rev No 0 Sheet No 30 of

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 11C

UNIVARIATE

VARIABLE=RESID   RESIDUALS

MOMENTS

N	5	SUM WGTS	5
MEAN	1.023E-13	SUM	5.116E-13
STD DEV	21.4015	VARIANCE	458.023
SKEWNESS	0.922373	KURTOSIS	1.97891
USS	1832.09	CSS	1832.09
CV	99999	STD MEAN	9.57103
T:MEAN=0	1.069E-14	PROB>|T|	1
SGN RANK	-1.5	PROB>|S|	0.787406
NUM ^= 0	5		
W:NORMAL	0.932876	PROB<W	0.545

QUANTILES(DEF=4)

100% MAX	33.5989	99%	33.5989
75% Q3	18.1007	95%	33.5989
50% MED	-4.06627	90%	33.5989
25% Q1	-16.0676	10%	-25.1109
0% MIN	-25.1109	5%	-25.1109
		1%	-25.1109
RANGE	58.7098		
Q3-Q1	34.1683		
MODE	-25.1109		

EXTREMES

LOWEST	HIGHEST
-25.1109	-25.1109
-7.02427	-7.02427
-4.06627	-4.06627
2.60247	2.60247
33.5989	33.5989

```
STEM LEAF                          #
   3 4                             1
   2
   1
   0 3                             1
  -0 74                            2
  -1
  -2 5                             1
     ----+----+----+----+
  MULTIPLY STEM.LEAF BY 10**+01
```

```
BOXPLOT
   |
   |
+-----+
|  +  |
*-----*
+-----+
   |
```

```
                        NORMAL PROBABILITY PLOT
 35+                                               *  ++++
   |                                           +++++
   |                                      +++++
  5+                                 ++++++
   |                            *+++++*
   |                       +++++
-25+                  *++++
    +----+----+----+----+----+----+----+----+----+----+
        -2        -1         0        +1        +2
```

10/25/06 14:28:07

Calc No C-1302-187-5380-005 | Rev No 0 | Sheet No __ of __

PROGRAM: OCDWCONF
BAY: 11C TOP3

D11CTOP3
****
1046
1198.6
1079.1
1045.4
1008.9

MEAN THICKNESS = 1057.6
STANDARD ERROR OF THE MEAN = 16.909
T(.95/2, 4)= 2.7763
T(.01/2, 4)= 4.6041

CONFIDENCE INTERVALS FOR THE MEAN
****

95% UPPER BOUND = 1104.5
95% LOWER BOUND = 1010.7

99% UPPER BOUND = 1135.5
99% LOWER BOUND = 979.75

January 20, 1989
12:56 PM

ENTER NAME OF DATA LIST d11c
ENTER PT NUMBER LIST ints(1,21)
ENTER NAME OF DATE LIST d34567

N	D11C
*	*******
1	D11C612
2	D11C705
3	D11C708
4	D11C709
5	D11C807
6	D11C816

ENTER NO. OF DESIRED DATA 2,3,4,5,6

	D34567	MEANTHK	SD	DFM2	CHISQ	CHI952
*******	********	*******	******	****	******	******
D11C705	5/1/87	1.046	.10344	2	2.4172	5.99
D11C708	8/1/87	1.1086	.10847	2	3.7563	5.99
D11C709	9/10/87	1.0791	.12189	2	5.1211	5.99
D11C807	7/13/88	1.0454	.11354	2	3.3861	5.99
D11C810	10/08/88	1.0089	.10077	2	3.4682	5.99

OBS					EXP				
4	7	5	3	6	3.8135	4.2372	3.6016	2.7542	4.4491
4	2	1	3	4	3.4099	3.7888	3.2205	2.4627	3.9782
1	2	2	0	1	3.5532	3.948	3.3558	2.5662	4.1454
4	4	6	3	4	3.4099	3.7888	3.2205	2.4627	3.9782
5	5	3	4	6	3.8135	4.2372	3.6016	2.7542	4.4491

10/25/06 14:28:07

Calc No C-1302-187-5300-005 Rev No 0 Sheet No 331-

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF BAY 11C UPPER 3 ROWS

OBS	YEARS	MILS
1	0.00	1046.0
2	0.25	1108.6
3	0.36	1079.1
4	1.20	1045.4
5	1.44	1008.9

10/25/06 14:28:07

Calc No C-1302-187-5300-005 Rev No Ø Sheet No 34 of

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF BAY 11C UPPER 3 ROWS

VARIABLE	N	MEAN	STANDARD DEVIATION	STD ERROR OF MEAN	T	PR>|T|
MILS	5	1057.60000000	37.80985321	16.90908040	62.55	0.0001

MEAN THICKNESS = 1057.6 ± 16.9 mils

10/25/06 14:28:07

Calc No C-1302-187-5300-005 Rev No 0 Sheet No 35 of

DEP VARIABLE: MILS

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	2593.30987	2593.30987	2.490	0.2127
ERROR	3	3125.03013	1041.67671		
C TOTAL	4	5718.34000			

ROOT MSE	32.27502	R-SQUARE	0.4535
DEP MEAN	1057.6	ADJ R-SQ	0.2713
C.V.	3.051722		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|	TYPE I SS	STANDARDIZED ESTIMATE
INTERCEP	1	1083.82439	22.01311259	49.235	0.0001	5592588.80	0
YEARS	1	-40.34521717	25.57003534	-1.578	0.2127	2593.30987	-0.67342963

COLLINEARITY DIAGNOSTICS

NUMBER	EIGENVALUE	CONDITION NUMBER	VAR PROP INTERCEP	VAR PROP YEARS
1	1.755028	1.000000	0.1225	0.1225
2	0.244972	2.676604	0.8775	0.8775

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT	RESIDUAL
1	1046.0	1083.8	22.0131	1013.8	1153.9	959.5	1208.2	-37.8244
2	1108.6	1073.7	17.6903	1017.4	1130.0	956.6	1190.9	34.8617
3	1079.1	1069.3	16.2272	1017.7	1120.9	954.3	1184.3	9.7999
4	1045.4	1035.4	20.1524	971.3	1099.5	914.3	1156.5	9.9899
5	1008.9	1025.7	24.8272	946.7	1104.7	896.1	1155.3	-16.8273

SUM OF RESIDUALS 1.13687E-12
SUM OF SQUARED RESIDUALS 3125.03
PREDICTED RESID SS (PRESS) 9624.182

10/25/06 14:28:07

Calc No C-1302-187-5380-005 Rev No 0 Sheet No 360

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF BAY 11C UPPER 3 ROWS

DEP VARIABLE: MILS

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	2593.30987	2593.30987	2.490	0.2127
ERROR	3	3125.03013	1041.67671		
C TOTAL	4	5718.34000			

ROOT MSE	32.27502	R-SQUARE	0.4535
DEP MEAN	1057.6	ADJ R-SQ	0.2713
C.V.	3.051722		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	1083.82439	22.01311259	49.235	0.0001
YEARS	1	-40.34521717	25.57003534	-1.578	0.2127

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT	RESIDUAL	STD ERR RESIDUAL
1	1046.0	1083.8	22.0131	1013.8	1153.9	959.5	1208.2	-37.8244	23.6030
2	1108.6	1073.7	17.6903	1017.4	1130.0	956.6	1190.7	34.8619	26.9950
3	1079.1	1069.3	16.2272	1017.7	1120.9	954.3	1184.3	9.7999	27.8990
4	1045.4	1035.4	20.1524	971.3	1099.5	914.3	1156.5	9.9899	25.2103
5	1008.9	1025.7	24.8272	946.7	1104.7	896.1	1155.3	-16.8273	20.6225

OBS	STUDENT RESIDUAL	-2-1-0 1 2	COOK'S D
1	-1.6025	| ***| |	1.117
2	1.2914	| |** |	0.358
3	0.3513	| | |	0.021
4	0.3963	| | |	0.050
5	-0.8160	| *| |	0.482

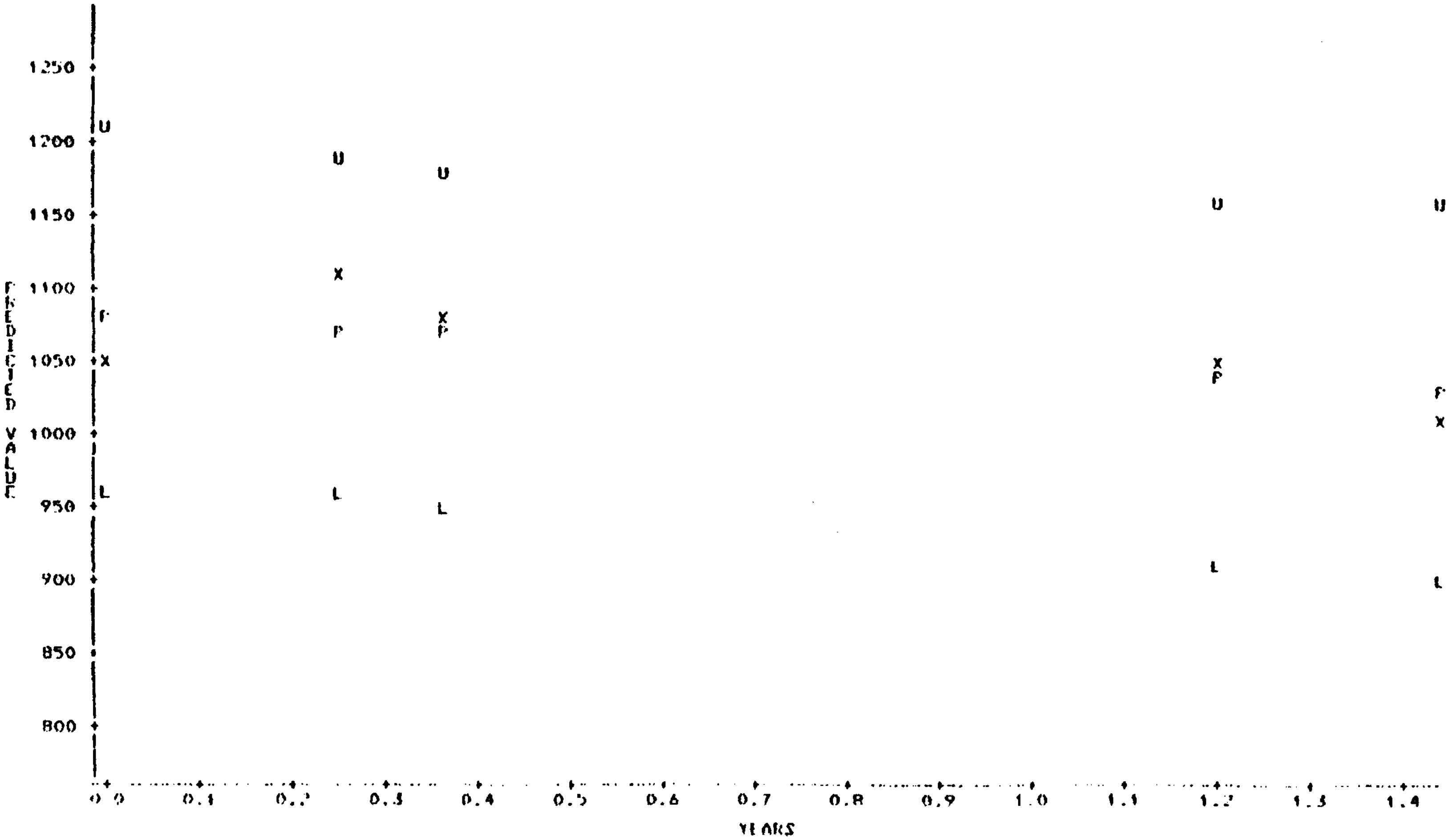
SUM OF RESIDUALS	1.13687E-12
SUM OF SQUARED RESIDUALS	3125.03
PREDICTED RESID SS (PRESS)	9624.182

10/25/06 14:28:07

Calc No C-1302-187-5300-005 Rev No 0 Sheet No 39 of _

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF BAY 11C UPPER 3 ROWS

PLOT OF MILS*YEARS SYMBOL USED IS X
PLOT OF PRED*YEARS SYMBOL USED IS P
PLOT OF U95*YEARS SYMBOL USED IS U
PLOT OF L95*YEARS SYMBOL USED IS L



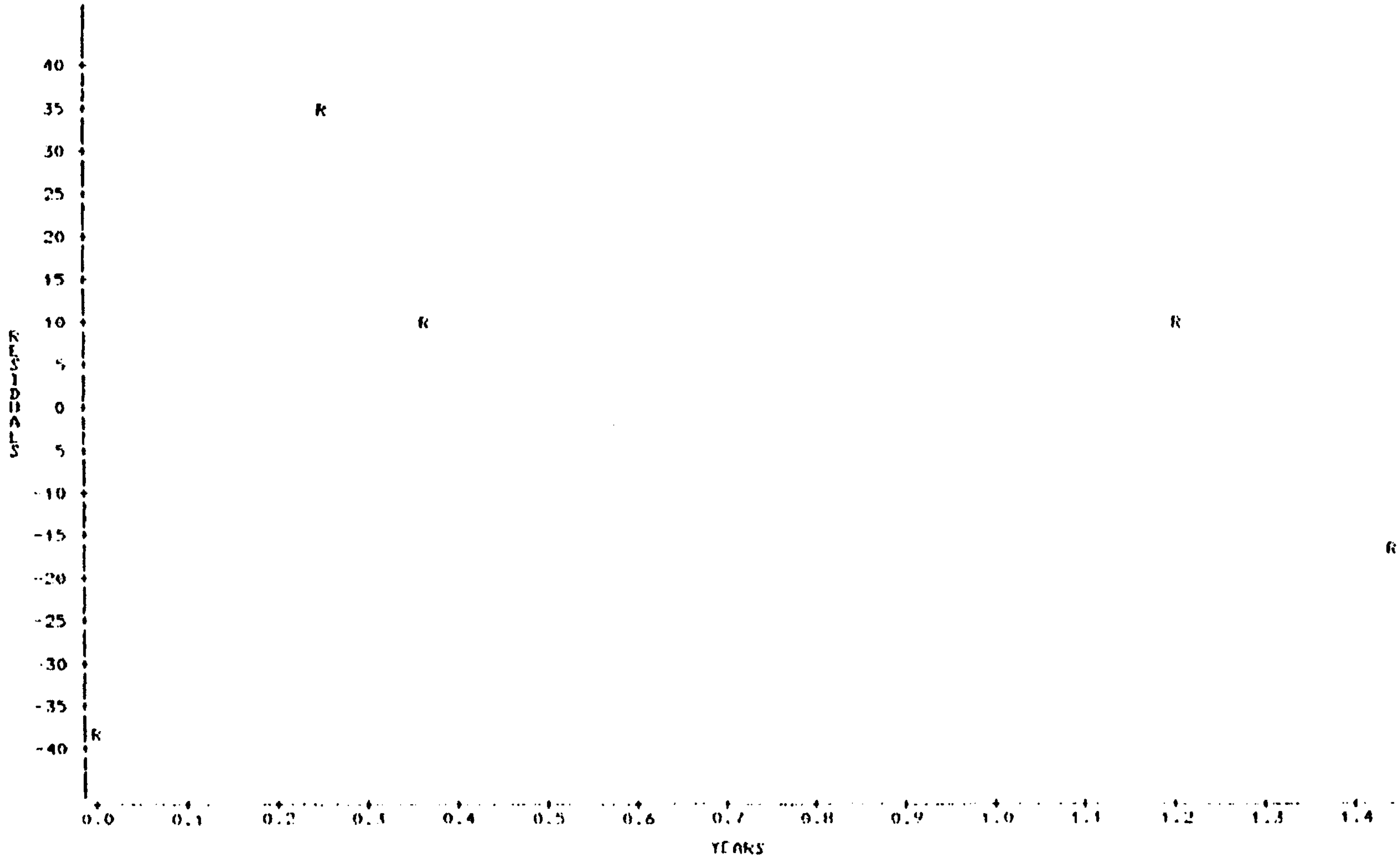
10/25/06 14:28:07

Calc No C-1302-187-5380-005 Rev No Ø Sheet No 38 of

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF BAY 11C UPPER 3 ROWS

8:57 WEDNESDAY, JANUARY 4, 1989 58

PLOT OF RESIDUAL*YEARS SYMBOL USED IS R



10/25/06 14:28:07

Calc No C-1302-187-5300-005 Rev No Ø Sheet No 39 of

PROGRAM: OCDWCONF
BAY: 11C BOT4

D11CBOT4
****
916.8
953.6
915.7
906.1
890.7

MEAN THICKNESS = 916.58
STANDARD ERROR OF THE MEAN = 10.37
T(.05/2, 4)= 2.7763
T(.01/2, 4)= 4.6041

CONFIDENCE INTERVALS FOR THE MEAN
****

95% UPPER BOUND = 945.37
95% LOWER BOUND = 887.79

99% UPPER BOUND = 964.33
99% LOWER BOUND = 868.83

January 20, 1989
12:58 PM

```
ENTER NAME OF DATA LIST d11c
ENTER PT NUMBER LIST ints(22,49)
ENTER NAME OF DATE LIST d34567
```

N	D11C
*	*******
1	D11C612
2	D11C705
3	D11C708
4	D11C709
5	D11C807
6	D11C810

```
ENTER NO. OF DESIRED DATA 2,3,4,5,6
```

	D34567	MEANTHK	SD	DFM2	CHISQ	CHI952
*******	********	*******	*******	****	*******	*****
D11C705	5/1/87	.91679	.026409	2	4.0555	5.99
D11C708	8/1/87	.95364	.037589	2	5.7803	5.99
D11C709	9/10/87	.91571	.015972	2	5.4832	5.99
D11C807	7/12/88	.90605	.035148	2	10.256	5.99
D11C810	10/08/88	.89068	.048046	2	16.389	5.99

OBS					EXP				
4	5	4	2	3	5.9321	5.9321	5.9321	4.6609	5.9321
8	10	10	9	4	5.3043	5.3043	5.3043	4.1677	5.3043
8	3	5	6	14	5.5272	5.5272	5.5272	4.3428	5.5272
4	4	5	1	3	5.3043	5.3043	5.3043	4.1677	5.3043
4	6	4	4	4	5.9321	5.9321	5.9321	4.6609	5.9321

10/25/06 14:28:07

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF BAY 11C LOWER 4 ROWS

OBS	YEARS	MILS
1	0.00	916.8
2	0.25	953.6
3	0.36	915.7
4	1.20	906.1
5	1.44	890.7

10/25/06 14:26:07

Calc No C-1302-187-5380-005 Rev No Ø Sheet No 420

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF BAY 11C LOWER 4 ROWS

VARIABLE	N	MEAN	STANDARD DEVIATION	STD ERROR OF MEAN	T	PR>|T|
MILS	5	916.58000000	23.18894133	10.37040983	88.38	0.0001

Mean thickness = 916.5 ± 10.4 mils

10/25/06 14:28:07

Calc No	Rev No	Sheet No
C-1302-187-5300-005	∅	43 of ..

DEP VARIABLE: MILS

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	1050.22535	1050.22535	2.862	0.1892
ERROR	3	1100.68265	366.89422		
C TOTAL	4	2150.90800			

ROOT MSE	19.15448	R-SQUARE	0.4883
DEP MEAN	916.58	ADJ R-SQ	0.3177
C.V.	2.089778		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|	TYPE I SS	STANDARDIZED ESTIMATE
INTERCEP	1	933.26858	13.06427793	71.437	0.0001	4200594.48	0
YEARS	1	-25.67474266	15.17523008	-1.692	0.1892	1050.22535	-0.69876369

COLLINEARITY DIAGNOSTICS

NUMBER	EIGENVALUE	CONDITION NUMBER	VAR PROP INTERCEP	VAR PROP YEARS
1	1.755028	1.000000	0.1225	0.1225
2	0.244972	2.676604	0.8775	0.8775

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT	RESIDUAL
1	916.8	933.3	13.0643	891.7	974.8	859.5	1007.1	-16.4686
2	953.6	926.8	10.4988	893.4	960.3	857.3	996.4	26.7501
3	915.7	924.0	9.6305	893.4	954.7	855.8	992.3	-8.3257
4	906.1	902.5	11.9600	864.4	940.5	830.6	974.3	3.6411
5	890.7	896.3	14.7344	849.4	943.2	819.4	973.2	-5.5970

SUM OF RESIDUALS 6.25278E-13
SUM OF SQUARED RESIDUALS 1100.683
PREDICTED RESID SS (PRESS) 2758.051

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Calc No C-1302-187-5380-005 Rev No Ø Sheet No 44 of —

DEP VARIABLE: MILS

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	1050.22535	1050.22535	2.862	0.1892
ERROR	3	1100.68265	366.89422		
C TOTAL	4	2150.90800			

ROOT MSE	19.15448	R-SQUARE	0.4883
DEP MEAN	916.58	ADJ R-SQ	0.3177
C.V.	2.089778		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	933.26858	13.06427793	71.437	0.0001
YEARS	1	-25.67474266	15.17523008	-1.692	0.1892

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT	RESIDUAL	STD ERR RESIDUAL
1	916.8	933.3	13.0643	891.7	974.8	859.5	1007.1	-16.4686	14.0078
2	953.6	926.8	10.4988	893.4	960.3	857.3	996.4	26.7501	16.0209
3	915.7	924.0	9.6305	893.4	954.7	855.8	992.3	-8.3257	16.5574
4	906.1	902.5	11.9600	864.4	940.5	830.6	974.3	3.6411	14.9617
5	890.7	896.3	14.7344	849.4	943.2	819.4	973.2	-5.5970	12.2390

OBS	STUDENT RESIDUAL	-2-1-0 1 2	COOK'S D
1	-1.1757	| **| |	0.601
2	1.6697	| |*** |	0.599
3	-0.5028	| *| |	0.043
4	0.2434	| | |	0.019
5	-0.4573	| | |	0.152

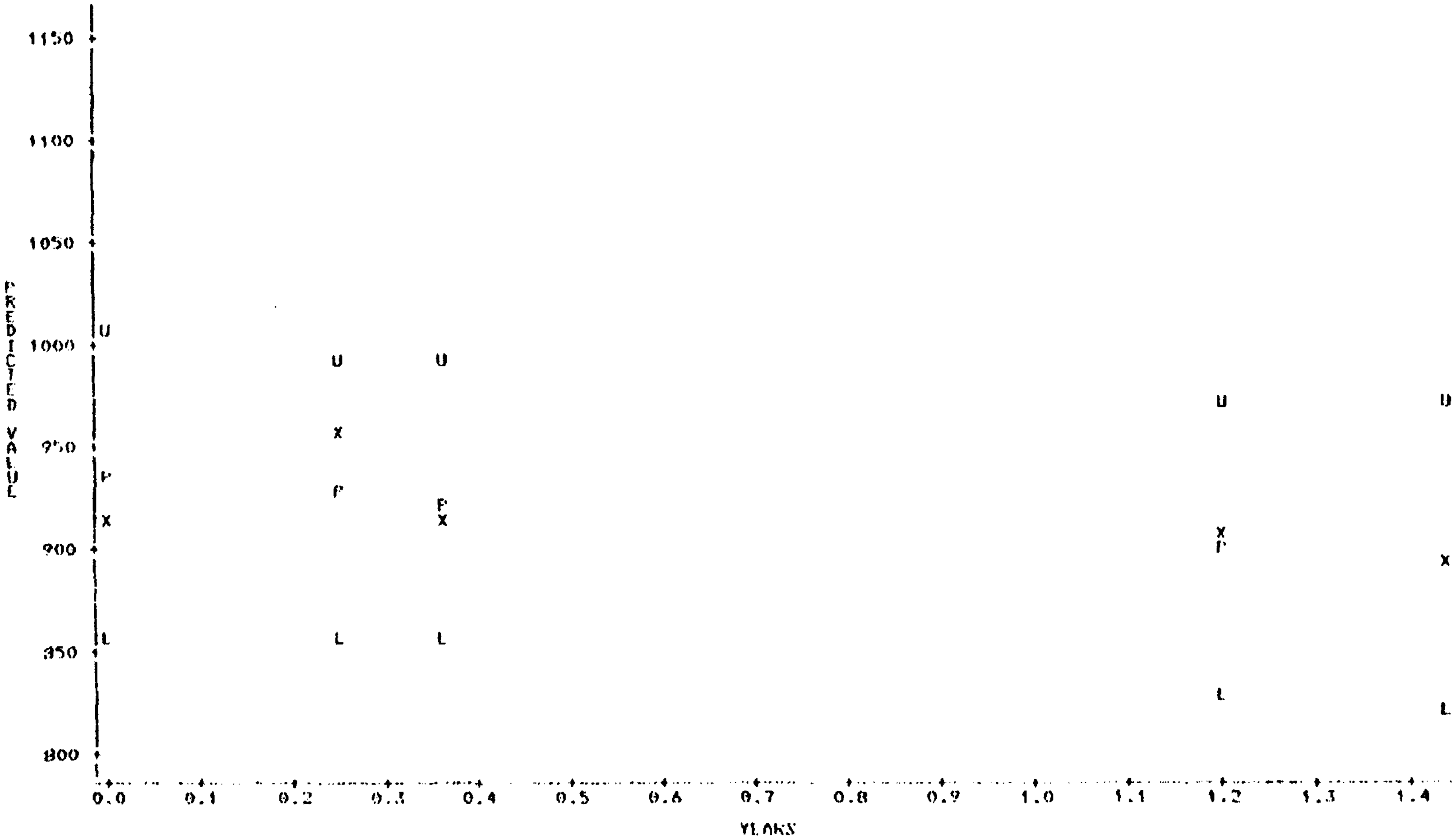
SUM OF RESIDUALS	6.25278E-13
SUM OF SQUARED RESIDUALS	1100.683
PREDICTED RESID SS (PRESS)	2758.051

10/25/06 14:28:07

Calc No C-1302-187-5300-005 Rev No 0 Sheet No 45 of __

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF BAY 11C LOWER 4 ROWS

PLOT OF MILS*YEARS SYMBOL USED IS X
PLOT OF PRED*YEARS SYMBOL USED IS P
PLOT OF U95*YEARS SYMBOL USED IS U
PLOT OF L95*YEARS SYMBOL USED IS L



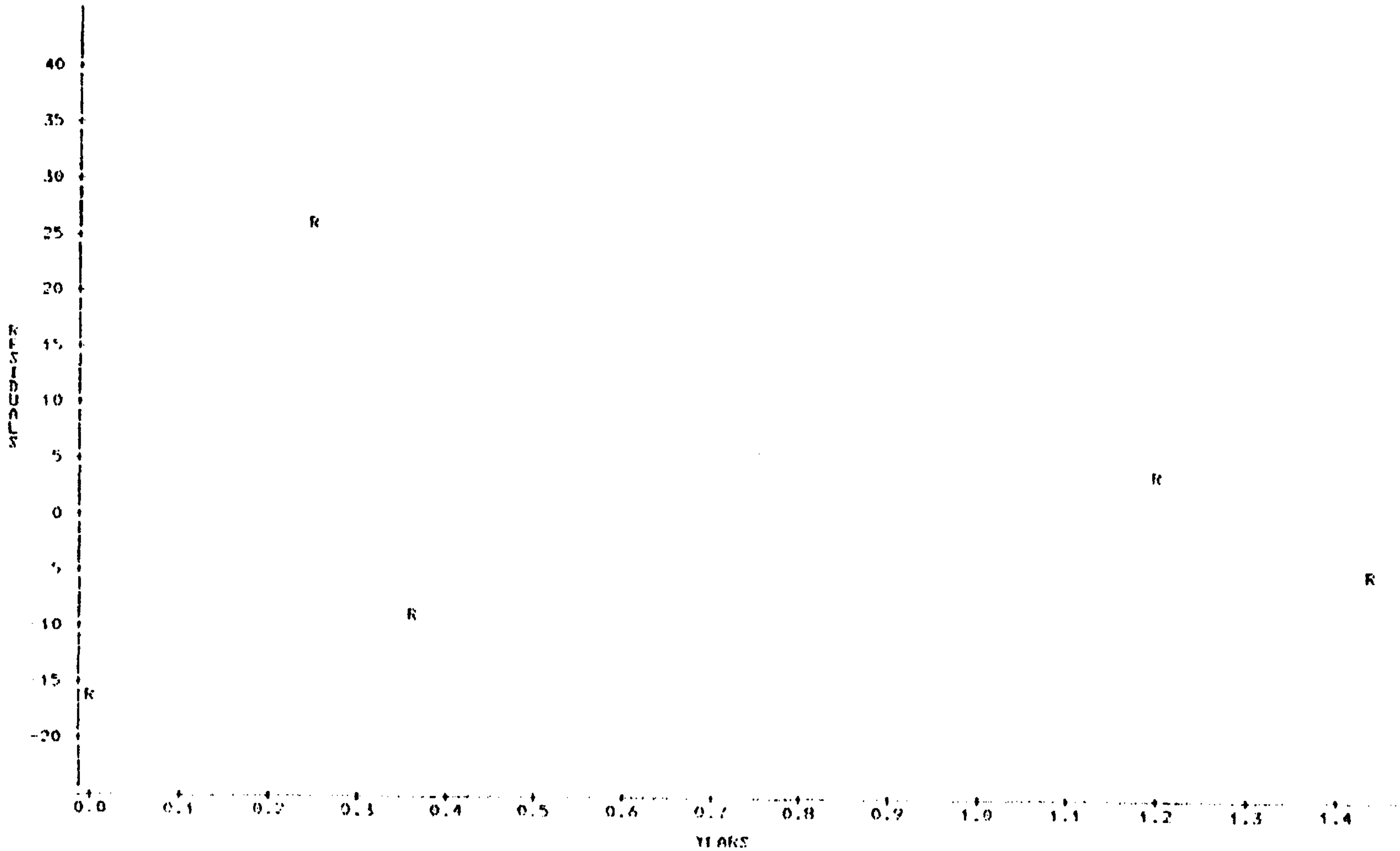
NOTE: 5 OBS HIDDEN

Calc No C-1302-187-5300-005 Rev No Ø Sheet No 410

10/25/06 14:28:07

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF BAY 11C LOWER 4 ROWS

PLOT OF RESIDUAL*YEARS SYMBOL USED IS R



10/25/06 14:28:07

Calc No C-1302-187-5300-005 Rev No Ø Sheet No 47 of -

5.1.3 Bay 17D: 2/17/87 to 10/8/88

Six 49-point data sets were available for this bay covering the time period from February 17, 1987 to October 8, 1988. Since a plug lies within this region, four of the points were voided in each data set. The data were analyzed as described in paragraphs 2.4 and 2.8.1.

(1) The data are normally distributed.

(2) The regression model is appropriate.

(3) The regression model explains 84% of the total variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 864.8 ±6.8 mils.

(6) The corrosion rate ± standard error is -27.6 ±6.1 mils per year.

(7) The measurements below 800 mils were tested and determined not to be statistically different from the mean thickness.

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Calc No	Rev No	Sheet No
C-1302-187-5300-005	Ø	49 of ..

```
PROGRAM: DWCHISQ
ENTER NAME OF DATA LIST e17d
ENTER PT NUMBER LIST ints(1,49)
ENTER NAME OF DATE LIST d234567

 N     E17D
 *   *******
 1   E17D612
 2   E17D702
 3   E17D705
 4   E17D708
 5   E17D709
 6   E17D807
 7   E17D810

ENTER NO. OF DESIRED DATA 2.3,4,5.6.7
```

	D234567	MEANTHK	SD	STDERR	DFM2
*******	********	*******	*******	********	****
E17D702	2/17/87	.92217	.061283	.0094561	2
E17D705	5/1/87	.89507	.051215	.0076346	2
E17D708	8/1/87	.89069	.054341	.0081006	2
E17D709	9/10/87	.89528	.061832	.0094294	2
E17D807	7/12/88	.87793	.061168	.0094384	2
E17D810	10/08/88	.86222	.055095	.0082131	2

CHISQ	CHI952	CHI992
*******	******	******
7.5153	5.99	9.21
2.8389	5.99	9.21
2.1086	5.99	9.21
.43573	5.99	9.21
2.0383	5.99	9.21
1.2028	5.99	9.21

OBS						EXP					
9	9	11	9	8	9	8.8981	9.5337	9.5337	9.11	8.8981	9.5337
4	8	5	8	8	8	7.9565	8.5248	8.5248	8.1459	7.9565	8.5248
13	12	10	10	10	7	8.2908	8.883	8.883	8.4882	8.2908	8.883
11	5	10	7	5	11	7.9565	8.5248	8.5248	8.1459	7.9565	8.5248
5	11	9	9	11	10	8.8981	9.5337	9.5337	9.11	8.8981	9.5337

GRAND MEAN THICKNESS = .89056
STANDARD ERROR OF THE GRAND MEAN = .0081735

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E17D702

.93	.923	.913	.943	.827	.812	.912
.909	.918	.869	.964	.909	.874	.849
0	0	.862	.858	.863	.909	.856
0	0	.932	.93	.89	.942	.883
.837	.916	0	.938	.959	0	.943
.89	.991	.954	0	.97	1.02	.94
.922	.945	.909	.955	1.018	.987	1.161

E17D705

1.002	.945	.943	.966	.997	.988	.801
.928	.894	.83	.871	.856	.843	.813
0	0	.855	.884	.938	.839	.801
0	0	.819	.863	.836	.88	.883
.842	.871	.885	.871	.892	.898	.905
.87	.897	.939	.942	.923	.922	.89
.896	.963	.889	.893	.928	.977	.91

E17D708

.924	.882	.912	.945	.967	.987	.783
.908	.88	.825	.856	.797	.815	.802
0	0	.844	.886	.889	.843	.804
0	0	.815	.862	.829	.925	.888
.842	.869	.889	.868	.888	.904	.923
.867	.878	.938	.928	.925	.941	.921
.89	.964	.918	.915	.954	.979	1.012

E17D709

.914	.888	.922	1.063	1.025	.979	.784
.904	.872	.812	.853	.795	.912	.798
0	0	.881	.873	0	.879	.786
0	0	.835	.866	.828	.902	.883
.836	.869	.882	.871	.905	.937	.908
.867	.921	.938	.946	.927	.966	0
.904	.965	.915	.955	.953	.973	.905

E17D807

.935	.941	.898	0	.97	.962	.764
.892	.863	.775	.846	.77	.831	.757
0	0	.86	.914	.918	0	.757
0	0	.794	.892	.821	.858	.881
.834	.857	.874	.849	.874	.874	.889
.828	.86	.964	.895	.948	.937	.883
.92	.971	.87	.95	0	.945	.952

E17D810

.891	.883	.915	.917	.954	.95	.771
.883	.847	.812	.838	.762	.805	.752
0	0	.796	.85	.878	.825	.731
0	0	.787	.842	.802	.882	.85
.837	.859	.867	.841	.876	.905	.88
.827	.859	.822	.883	.904	.905	.868
.921	.945	.863	.907	.925	.944	.939

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 17D

DEP VARIABLE: MEASURE

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	1673.42584	1673.42584	20.403	0.0107
ERROR	4	328.07416	82.01854045		
C TOTAL	5	2001.50000			

ROOT MSE	9.056409	R-SQUARE	0.8361
DEP MEAN	890.5	ADJ R-SQ	0.7951
C.V.	1.017003		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|	TYPE I SS	STANDARDIZED ESTIMATE
INTERCEP	1	910.07272	5.69613550	159.770	0.0001	4757941.50	0
YEAR	1	-27.60608793	6.11163839	-4.517	0.0107	1673.42584	-0.91437730

COLLINEARITY DIAGNOSTICS

NUMBER	EIGENVALUE	CONDITION NUMBER	VAR PROP INTERCEP	VAR PROP YEAR
1	1.760718	1.000000	0.1196	0.1196
2	0.239282	2.712624	0.8804	0.8804

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT	RESIDUAL
1	922.0	910.1	5.6961	894.3	925.9	880.4	939.8	11.9273
2	895.0	904.6	4.8319	891.1	918.0	876.1	933.1	-9.5515
3	891.0	897.6	4.0171	886.4	908.7	870.1	925.1	-6.5948
4	895.0	894.6	3.8063	884.0	905.2	867.3	921.9	0.4143
5	878.0	871.4	5.6129	855.8	887.0	841.8	901.0	6.5758
6	862.0	864.8	6.7908	845.9	883.6	833.3	896.2	-2.7711

SUM OF RESIDUALS	7.38964E-13
SUM OF SQUARED RESIDUALS	328.0742
PREDICTED RESID SS (PRESS)	789.4397

t95(6-2) = 2.776

Mean [illegible] = 864.8 ± 68

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LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 17D

DEP VARIABLE: MEASURE

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	1673.42584	1673.42584	20.403	0.0107
ERROR	4	328.07416	82.01854045		
C TOTAL	5	2001.50000			

ROOT MSE	9.056409	R-SQUARE	0.8361
DEP MEAN	890.5	ADJ R-SQ	0.7951
C.V.	1.017003		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	910.07272	5.69613550	159.770	0.0001
YEAR	1	-27.60608793	6.11163839	-4.517	0.0107

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT	RESIDUAL	STD ERR RESIDUAL	STUDENT RESIDUAL	-2-1-0 1 2
1	922.0	910.1	5.6961	894.3	925.9	880.4	939.8	11.9273	7.0408	1.6940	| |*** |
2	895.0	904.6	4.8319	891.1	918.0	876.1	933.1	-9.5515	7.6597	-1.2470	| **| |
3	891.0	897.6	4.0171	886.4	908.7	870.1	925.1	-6.5948	8.1168	-0.8125	| *|
4	895.0	894.6	3.8063	884.0	905.2	867.3	921.9	0.4143	8.2177	0.0504	| |
5	878.0	871.4	5.6129	855.8	887.0	841.8	901.0	6.5758	7.1073	0.9252	| |*
6	862.0	864.8	6.7908	845.9	883.6	833.3	896.2	-2.7711	5.9920	-0.4625	| |

OBS	COOK'S D
1	0.939
2	0.309
3	0.081
4	0.000
5	0.267
6	0.137

SUM OF RESIDUALS	7.38964E-13
SUM OF SQUARED RESIDUALS	328.0742
PREDICTED RESID SS (PRESS)	789.4397

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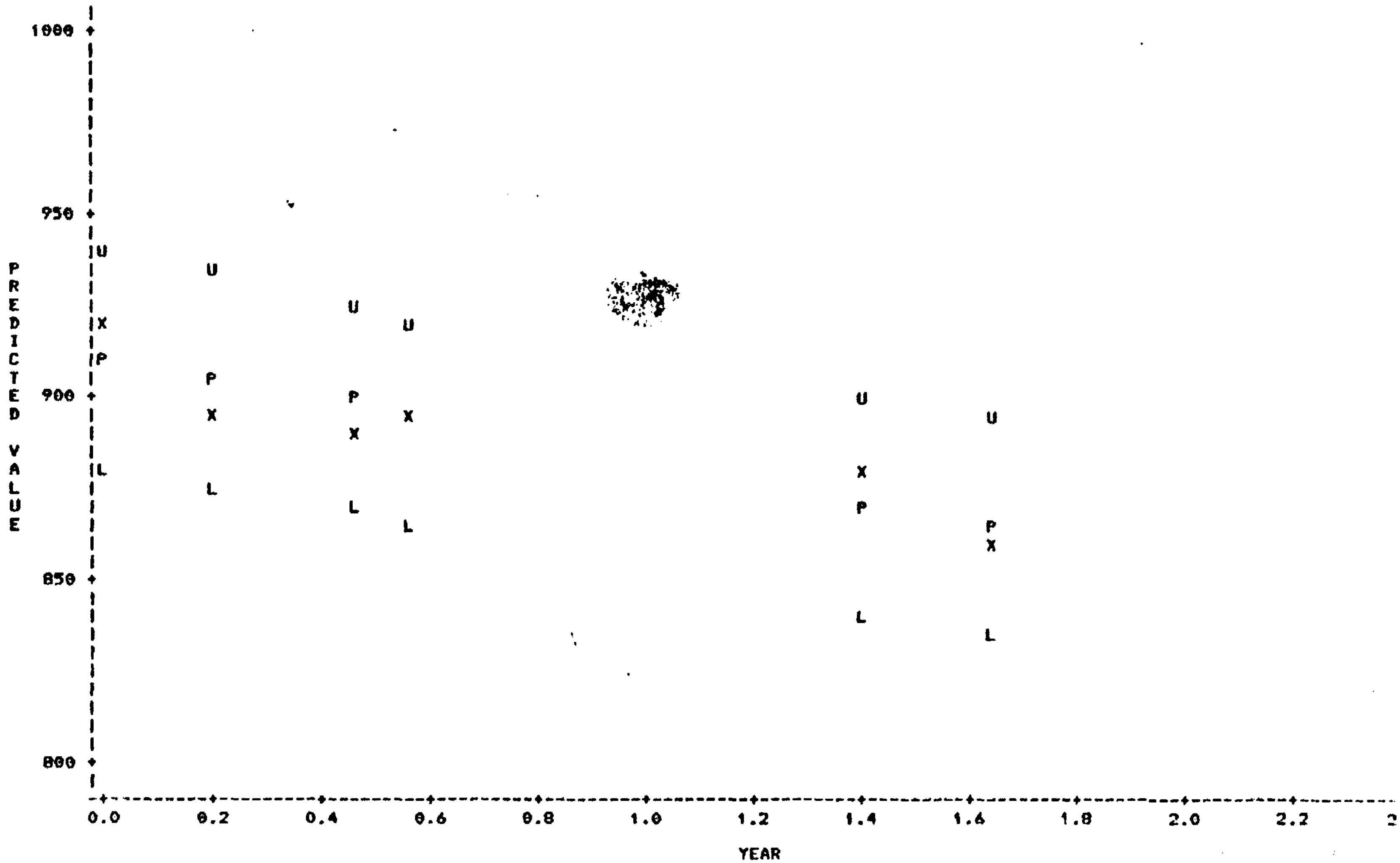
Calc No C-1302-187-5300-005 Rev No 0 Sheet No 52 of __

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 17D

PLOT OF MEASURE*YEAR SYMBOL USED IS X
PLOT OF PRED*YEAR SYMBOL USED IS P
PLOT OF U95*YEAR SYMBOL USED IS U
PLOT OF L95*YEAR SYMBOL USED IS L

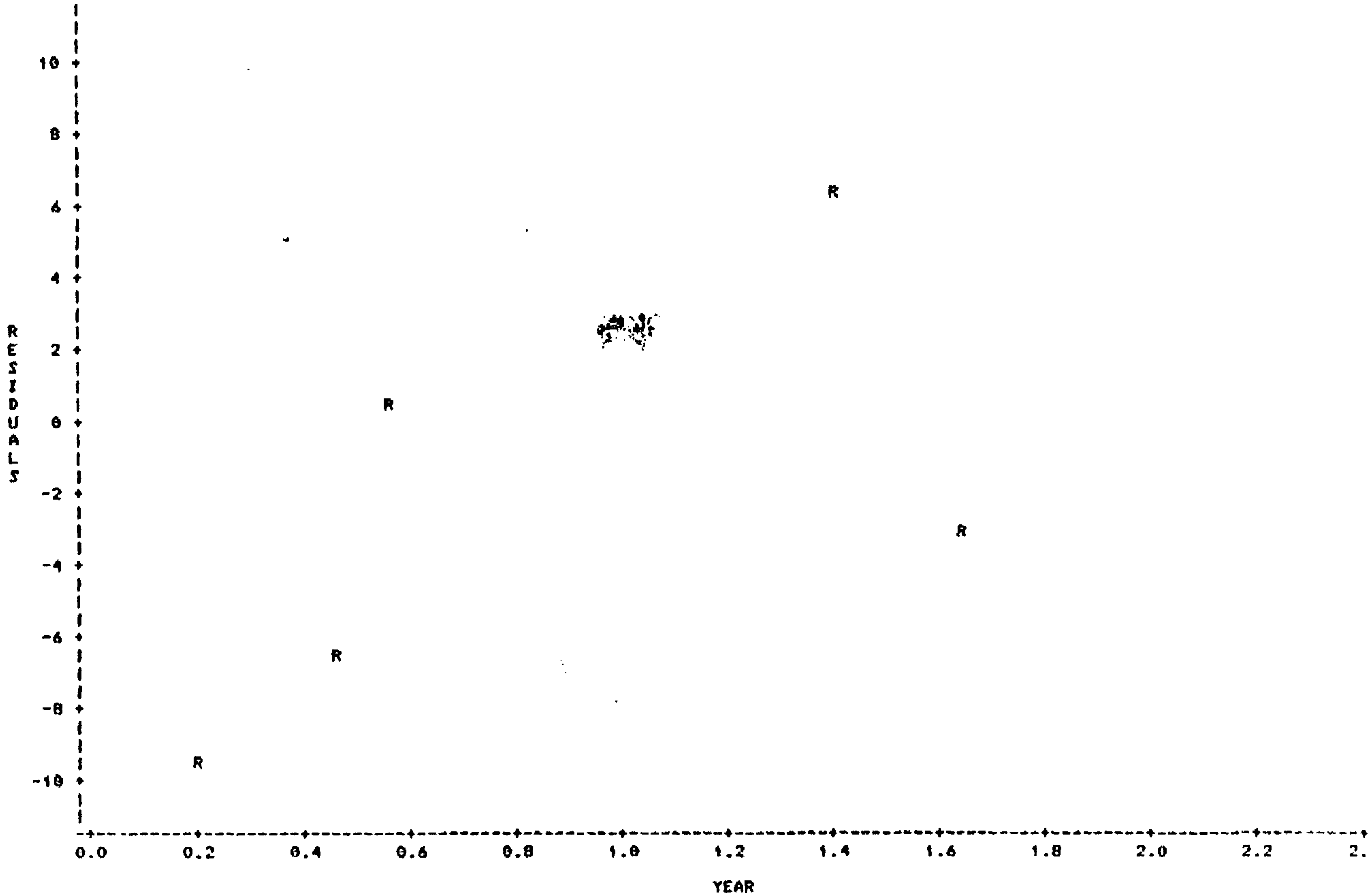


NOTE: 1 OBS HIDDEN

Calc No C-1302-187-5300-005 Rev No Ø Sheet No 53 of _

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 17D

PLOT OF RESID*YEAR   SYMBOL USED IS R



NOTE: 1 OBS HAD MISSING VALUES OR WERE OUT OF RANGE

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Calc No C-1302-187-5300-005
Rev No Ø
Sheet No 54 of __

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 17D

UNIVARIATE

VARIABLE=RESID   RESIDUALS

MOMENTS

N	6	SUM WGTS	6
MEAN	1.232E-13	SUM	7.390E-13
STD DEV	8.1003	VARIANCE	65.6148
SKEWNESS	0.452516	KURTOSIS	-0.985121
USS	328.074	CSS	328.074
CV	99999	STD MEAN	3.30693
T:MEAN=0	3.724E-14	PROB>|T|	1
SGN RANK	-0.5	PROB>|S|	1
NUM ^= 0	6		
W:NORMAL	0.964309	PROB<W	0.818

QUANTILES(DEF=4)

100% MAX	11.9273	99%	11.9273
75% Q3	7.91368	95%	11.9273
50% MED	-1.17841	90%	11.9273
25% Q1	-7.33395	10%	-9.5515
0% MIN	-9.5515	5%	-9.5515
		1%	-9.5515
RANGE	21.4788		
Q3-Q1	15.2476		
MODE	-9.5515		

EXTREMES

LOWEST	HIGHEST
-9.5515	-6.59476
-6.59476	-2.77113
-2.77113	0.414299
0.414299	6.57581
6.57581	11.9273

```
STEM LEAF                      #        BOXPLOT
   1 2                         1           |
   0 7                         1        +-----+
   0                                    |  +  |
  -0 30                        2        *-----*
  -0 07                        2        +-----+
     ----+----+----+----+
  MULTIPLY STEM.LEAF BY 10**+01
```

```
                      NORMAL PROBABILITY PLOT
  12.5+                                          ******
      |                                   *******
   2.5+                              *******
      |                         ******
  -7.5+                    ********
       +----+----+----+----+----+----+----+----+----+----+
           -2        -1         0        +1        +2
```

10/25/88 14:28:07

Calc No C-1302-187-5300-005 Rev No 0 Sheet No 55 of ...

5.1.4 Bay 19A: 2/17/87 to 10/8/88

Six 49-point data sets were available for this bay covering the time period from February 17, 1987 to October 8, 1988. Since a plug lies within this region, four of the points were voided in each data set. The data were analyzed as described in paragraphs 2.4 and 2.8.1.

(1) The data are nearly normally distributed.

(2) The regression model is appropriate

(3) The regression model explains 88% of the total variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 837.9 ±4.8 mils.

(6) The corrosion rate ± standard error is -23.7 ±4.3 mpy.

(7) One data point that was below 800 mils at two different times was tested and determined to be statistically different from the mean thickness. The probability of this occurring is less than 1% at each specific time.

```
PROGRAM: DWCHISQ
ENTER NAME OF DATA LIST e19a
ENTER PT NUMBER LIST ints(1,49)
ENTER NAME OF DATE LIST d234567

 N    E19A
 *   *******
 1   E19A612
 2   E19A702
 3   E19A705
 4   E19A708
 5   E19A709
 6   E19A807
 7   E19A810

ENTER NO. OF DESIRED DATA 2,3,4,5,6,7

          D234567   MEANTHK     SD       STDERR    DFM2
*******  ********  *******  *******   ********   ****
E19A702  2/17/87   .88364   .050725   .0076472    2
E19A705  5/1/87    .87293   .056352   .0084004    2
E19A708  8/1/87    .8586    .05677    .0084628    2
E19A709  9/10/87   .85829   .053896   .0080344    2
E19A807  7/12/88   .84857   .061395   .0092557    2
E19A810  10/08/88  .83691   .063663   .0094903    2

 CHISQ    CHI952   CHI992
*******   ******   ******
4.8162    5.99     9.21
9.1305    5.99     9.21
8.6057    5.99     9.21
8.9579    5.99     9.21
2.3979    5.99     9.21
 .11302   5.99     9.21

           OBS                                  EXP
****************    ****************************************
12 10  9  8  7  9   9.3218 9.5337 9.5337 9.5337 9.3218 9.5337
 8 14 15 15 11  9   8.3354 8.5248 8.5248 8.5248 8.3354 8.5248
 7  2  4  5  9  9   8.6856 8.883  8.883  8.883  8.6856 8.883
 4  8  6  5  6  8   8.3354 8.5248 8.5248 8.5248 8.3354 8.5248
13 11 11 12 11 10   9.3218 9.5337 9.5337 9.5337 9.3218 9.5337

GRAND MEAN THICKNESS = .85982
STANDARD ERROR OF THE GRAND MEAN = .0068177

January 18, 1989
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```

E19A702

.776	.91	.861	.837	.862	.854	.868
.826	.852	.818	.817	.835	.842	.837
.809	.929	.872	.86	.844	.82	.872
.866	.962	0	0	.84	.909	.929
.941	.875	0	0	.843	.875	.953
.939	.872	.948	.902	.945	.921	.956
.967	.884	.951	.965	.942	.894	0

E19A705

.768	.845	.857	.737	.846	.804	.811
.853	.849	.904	.813	.827	.805	.921
.857	.857	.944	.822	.858	.847	.918
.923	.937	0	0	.871	.815	.826
.969	.904	0	0	.834	.838	1.011
.93	.837	.853	.89	.918	.919	.919
.942	.864	.846	.897	.968	.915	.913

E19A708

.766	.843	.808	.729	.827	.785	.791
.841	.822	.899	.792	.807	.781	.839
.868	.844	.9	.83	.822	.835	.836
.917	.925	0	0	.83	.813	.827
1.007	.948	0	0	.828	.839	.894
.934	.835	.854	.881	.925	.898	.916
.912	.86	.847	.916	.958	.906	.902

E19A709

.801	.838	.814	.712	.826	.772	.788
.857	.821	.893	.799	.818	.786	.847
.834	.844	.915	.844	.82	.834	.836
.921	.923	0	0	.836	.811	.828
.938	.897	0	0	.825	.839	.898
.925	.834	.854	.884	.923	.893	.926
.92	.861	.856	.932	.977	.905	.918

E19A807

.729	.841	.831	.714	.804	.74	.767
.858	.843	.911	.769	.794	.757	.84
.852	.823	.896	.859	.839	.824	.815
.912	.913	0	0	.821	.804	.804
.946	.897	0	0	.814	.818	.898
.938	.812	.839	.884	.903	.882	.925
.927	.856	0	.899	.999	.866	.874

E19A810

.724	.806	.793	.668	.76	.73	.753
.842	.807	.874	.78	.78	.747	.819
.854	.828	.906	.783	.865	.852	.831
.901	.891	0	0	.829	.793	.814
.947	.889	0	0	.818	.81	.88
.883	.799	.845	.869	.907	.904	.903
.884	.842	.825	.921	1	.877	.828

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 19A

DEP VARIABLE: MEASURE

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	1236.97830	1236.97830	30.351	0.0053
ERROR	4	163.02170	40.75542519		
C TOTAL	5	1400.00000			

ROOT MSE	6.383998	R-SQUARE	0.8836
DEP MEAN	860	ADJ R-SQ	0.8544
C.V.	0.7423253		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|	TYPE I SS	STANDARDIZED ESTIMATE
INTERCEP	1	876.82786	4.01529084	218.372	0.0001	4437600.00	0
YEAR	1	-23.73464127	4.30818502	-5.509	0.0053	1236.97830	-0.93997656

COLLINEARITY DIAGNOSTICS

NUMBER	EIGENVALUE	CONDITION NUMBER	VAR PROP INTERCEP	VAR PROP YEAR
1	1.760718	1.000000	0.1196	0.1196
2	0.239282	2.712624	0.8804	0.8804

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT	RESIDUAL
1	884.0	876.8	4.0153	865.7	888.0	855.9	897.8	7.1721
2	873.0	872.1	3.4061	862.6	881.5	852.0	892.2	0.9191
3	859.0	866.1	2.8317	858.2	874.0	846.7	885.5	-7.0998
4	858.0	863.5	2.6831	856.1	871.0	844.3	882.7	-5.5127
5	849.0	843.6	3.9566	832.6	854.6	822.7	864.5	5.4006
6	837.0	837.9	4.7869	824.6	851.2	815.7	860.0	-0.8793

SUM OF RESIDUALS 7.95808E-13
SUM OF SQUARED RESIDUALS 163.0217
PREDICTED RESID SS (PRESS) 346.3443

$t_{95}(n-2) = 2.776$

Mean thickness = 837.9 ± 4.8 mils

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LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 19A

DEP VARIABLE: MEASURE

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	1236.97830	1236.97830	30.351	0.0053
ERROR	4	163.02170	40.75542519		
C TOTAL	5	1400.00000			

ROOT MSE	6.383998	R-SQUARE	0.8836
DEP MEAN	860	ADJ R-SQ	0.8544
C.V.	0.7423253		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	876.82786	4.01529084	218.372	0.0001
YEAR	1	-23.73464127	4.30818502	-5.509	0.0053

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT	RESIDUAL	STD ERR RESIDUAL	STUDENT RESIDUAL	-2-1-0 1 2
1	884.0	876.8	4.0153	865.7	888.0	855.9	897.8	7.1721	4.9632	1.4451	| |**
2	873.0	872.1	3.4061	862.6	881.5	852.0	892.2	0.9191	5.3995	0.1702	| |
3	859.0	866.1	2.8317	858.2	874.0	846.7	885.5	-7.0998	5.7216	-1.2409	| **|
4	858.0	863.5	2.6831	856.1	871.0	844.3	882.7	-5.5127	5.7928	-0.9517	| *|
5	849.0	843.6	3.9566	832.6	854.6	822.7	864.5	5.4006	5.0100	1.0780	| |**
6	837.0	837.9	4.7869	824.6	851.2	815.7	860.0	-0.8793	4.2238	-0.2082	| |

OBS	COOK'S D
1	0.683
2	0.006
3	0.189
4	0.097
5	0.362
6	0.028

SUM OF RESIDUALS	7.95808E-13
SUM OF SQUARED RESIDUALS	163.0217
PREDICTED RESID SS (PRESS)	346.3443

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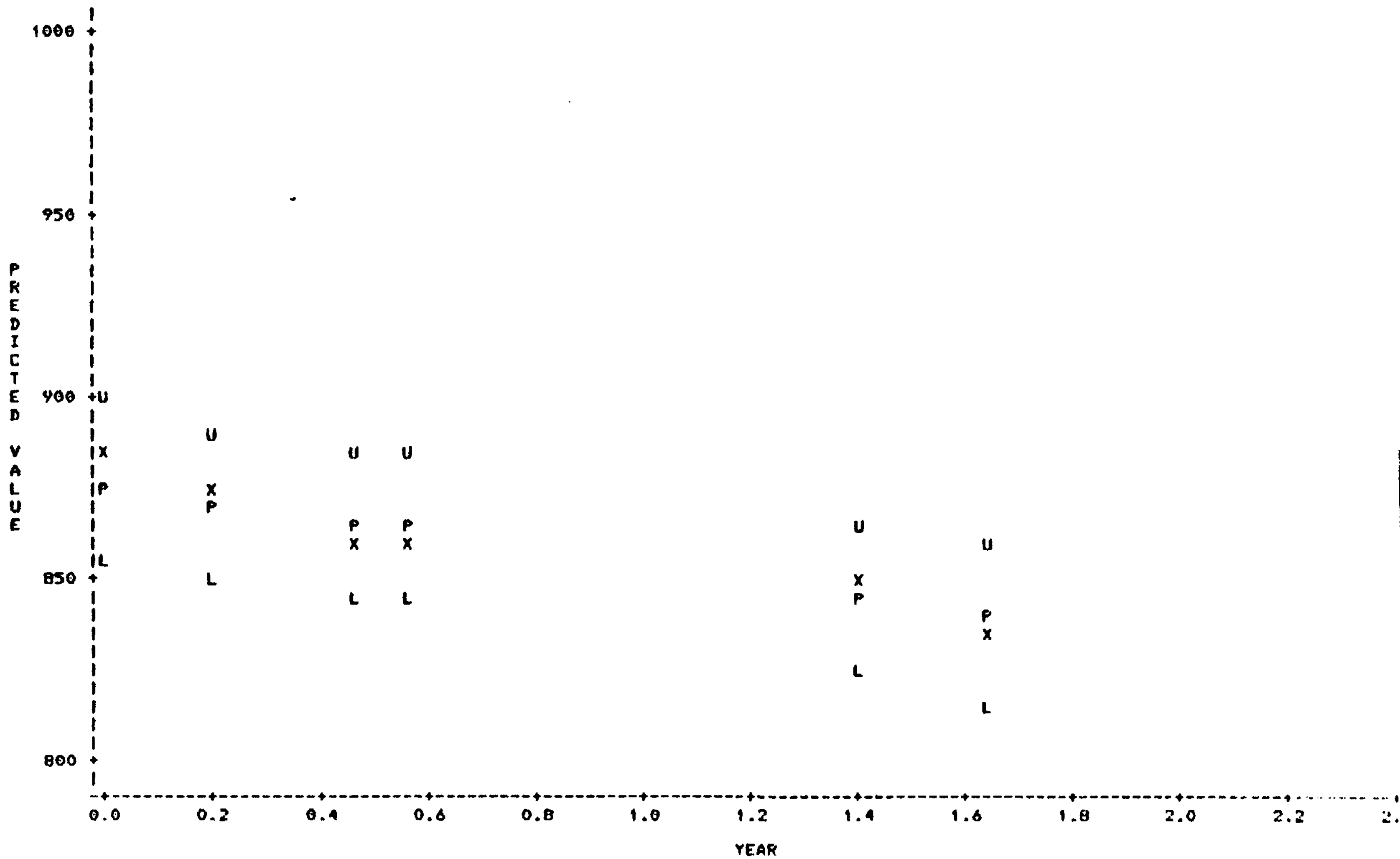
LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 19A

PLOT OF MEASURE*YEAR SYMBOL USED IS X
PLOT OF PRED*YEAR SYMBOL USED IS P
PLOT OF U95*YEAR SYMBOL USED IS U
PLOT OF L95*YEAR SYMBOL USED IS L



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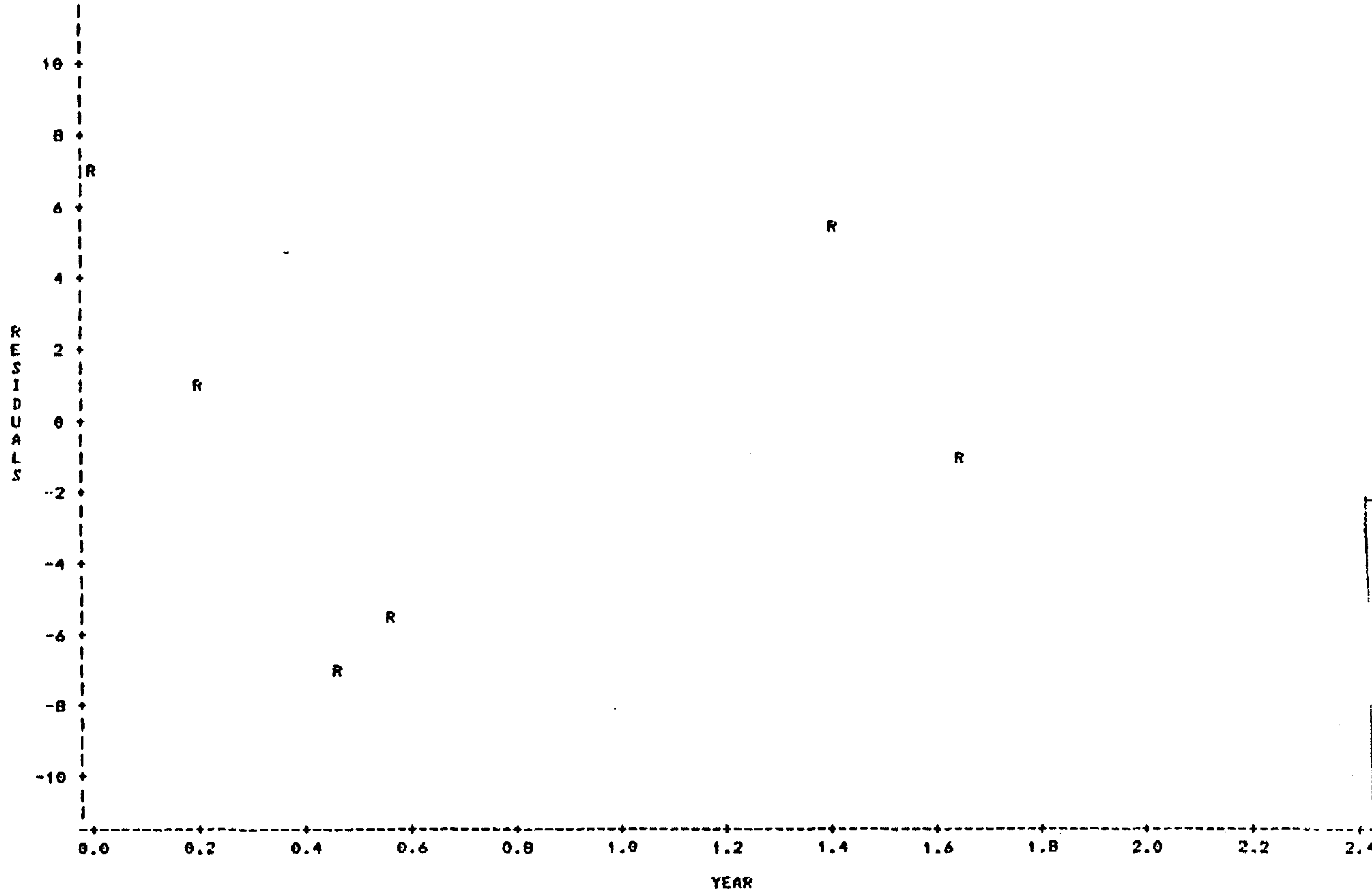
Calc No C-1302-187-5300-005
Rev No Ø
Sheet No 60f --

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 19A

PLOT OF RESID*YEAR SYMBOL USED IS R



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LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 19A

UNIVARIATE

VARIABLE=RESID RESIDUALS

MOMENTS

N	6	SUM WGTS	6
MEAN	1.326E-13	SUM	7.958E-13
STD DEV	5.71002	VARIANCE	32.6043
SKEWNESS	0.0018278	KURTOSIS	-1.66529
USS	163.022	CSS	163.022
CV	99999	STD MEAN	2.33111
T:MEAN=0	5.690E-14	PROB>|T|	1
SGN RANK	0.5	PROB>|S|	1
NUM ^= 0	6		
W:NORMAL	0.942873	PROB<W	0.635

QUANTILES(DEF=4)

100% MAX	7.17214	99%	7.17214
75% Q3	5.84351	95%	7.17214
50% MED	0.0198766	90%	7.17214
25% Q1	-5.9095	10%	-7.0998
0% MIN	-7.0998	5%	-7.0998
		1%	-7.0998
RANGE	14.2719		
Q3-Q1	11.753		
MODE	-7.0998		

EXTREMES

LOWEST	HIGHEST
-7.0998	-5.51273
-5.51273	-0.879314
-0.879314	0.919068
0.919068	5.40064
5.40064	7.17214

```
STEM LEAF                #             BOXPLOT
   0 57                  2             +-----+
   0 1                   1             *--+--*
  -0 1                   1             |     |
  -0 76                  2             +-----+
     ----+----+----+----+
  MULTIPLY STEM.LEAF BY 10**+01
```

```
                     NORMAL PROBABILITY PLOT
  7.5+                                    *  +++++++++
     |                              ++*+++++++
     |                      ++++++++*+
 -7.5+          +++++++++  *
      +----+----+----+----+----+----+----+----+----+----+
          -2        -1         0        +1        +2
```

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5.1.5 Bay 19B: 5/1/87 to 10/8/88

Five 49-point data sets were available for this bay covering the time period from May 1, 1987 to October 8, 1988. The data were analyzed as described in paragraphs 2.4 and 2.8.1.

(1) The data are normally distributed.

(2) The regression model is appropriate.

(3) The regression model explains 99% of the total variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 856.5 ±0.5 mils.

(6) The corrosion rate ± standard error is -29.2 ±0.5 mpy.

(7) The measurements below 800 mils were tested and determined not to be statistically different from the mean thickness.

```
PROGRAM: DWCHISQ
ENTER NAME OF DATA LIST d19b
ENTER PT NUMBER LIST ints(1,49)
ENTER NAME OF DATE LIST d34567

 N     D19B
 *   *******
 1   D19B612
 2   D19B705
 3   D19B708
 4   D19B709
 5   D19B807
 6   D19B810

ENTER NO. OF DESIRED DATA 2,3,4,5,6
```

	D34567	MEANTHK	SD	STDERR	DFM2
*******	********	*******	*******	********	****
D19B705	5/1/87	.89763	.057606	.0082294	2
D19B708	8/1/87	.89221	.059923	.0086491	2
D19B709	9/10/87	.8876	.05759	.0088864	2
D19B807	7/12/88	.86398	.056871	.0088817	2
D19B810	10/08/88	.85641	.053922	.0077031	2

CHISQ	CHI952	CHI992
*******	******	******
3.2344	5.99	9.21
2.3594	5.99	9.21
.74185	5.99	9.21
2.3425	5.99	9.21
2.8577	5.99	9.21

OBS					EXP				
13	11	8	9	12	10.381	10.169	8.8981	8.6863	10.381
10	10	10	8	5	9.2826	9.0931	7.9565	7.767	9.2826
5	10	8	7	12	9.6726	9.4752	8.2908	8.0934	9.6726
9	5	7	11	10	9.2826	9.0931	7.9565	7.767	9.2826
12	12	9	6	10	10.381	10.169	8.8981	8.6863	10.381

```
GRAND MEAN THICKNESS = .87956
STANDARD ERROR OF THE GRAND MEAN = .0081549

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```

D19B705

.954	.905	.892	.975	.971	.999	.829
.881	.882	.846	.916	.976	.855	.883
.941	.937	.839	.962	.973	.934	.907
.822	.856	.859	.882	.817	.867	.842
.86	.837	.886	.838	.928	.789	.884
.865	.847	.915	.954	.971	.917	.836
.999	.896	.98	.878	.933	.974	.935

D19B708

.927	.887	.877	.95	.988	.999	.817
.868	.86	.836	.859	.964	.894	0
.936	.885	.831	.964	.958	.985	.936
.883	.838	.8	.866	.881	.8	.809
.858	.879	.847	.951	.861	.782	.887
.862	.907	.973	.932	.974	.931	.82
.975	.893	1.002	.873	.901	.956	.984

D19B709

.974	.889	.88	.955	0	0	.814
.873	.905	.836	.865	.961	0	.854
1.024	.897	.847	.964	.947	.9	.859
0	.847	.846	0	.792	.793	.807
.869	.842	.881	.852	.933	.815	.805
.9	.92	.949	0	.979	.911	.801
.911	.888	.961	.882	.917	0	.914

D19B807

.945	.875	.904	.98	0	0	.847
.882	.855	.82	.855	.957	.857	.846
.882	.9	.83	0	.967	.877	.885
0	.871	.795	.836	.78	.771	.783
.849	.84	.8	.818	0	.759	.778
.853	.839	.897	0	.942	.901	.8
.892	.891	.972	0	.895	0	.897

D19B810

.917	.862	.863	.949	.903	.903	.808
.89	.848	.809	.85	.918	.818	.854
.916	.889	.826	.887	.921	.868	.852
.875	.836	.795	.862	.773	.77	.769
.817	.805	.792	.813	.897	.758	.733
.855	.834	.891	.896	.941	.851	.772
.886	.846	.941	.896	.869	.952	.888

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 19B

DEP VARIABLE: MEASURE

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	1361.79728	1361.79728	2912.472	0.0001
ERROR	3	1.40272314	0.46757438		
C TOTAL	4	1363.20000			

ROOT MSE	0.6837941	R-SQUARE	0.9990
DEP MEAN	879.6	ADJ R-SQ	0.9986
C.V.	0.07773921		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|	TYPE I SS	STANDARDIZED ESTIMATE
INTERCEP	1	898.63049	0.46675769	1925.261	0.0001	3868480.80	0
YEAR	1	-29.24169165	0.54184069	-53.967	0.0001	1361.79728	-0.99948537

COLLINEARITY DIAGNOSTICS

NUMBER	EIGENVALUE	CONDITION NUMBER	VAR PROP INTERCEP	VAR PROP YEAR
1	1.755488	1.000000	0.1223	0.1223
2	0.244512	2.679471	0.8777	0.8777

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT	RESIDUAL
1	898.0	898.6	0.4668	897.1	900.1	896.0	901.3	-0.6305
2	892.0	891.3	0.3744	890.1	892.5	888.8	893.7	0.7384
3	888.0	888.1	0.3438	887.0	889.2	885.6	890.5	-0.0742
4	864.0	863.5	0.4267	862.2	864.9	861.0	866.1	0.4595
5	856.0	856.5	0.5262	854.8	858.2	853.7	859.2	-0.4932

SUM OF RESIDUALS	3.97904E-13
SUM OF SQUARED RESIDUALS	1.402723
PREDICTED RESID SS (PRESS)	4.544196

$t95(n-2) = 3.182$

Mean Thickness = 856.5 ± 0.5 mils

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LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 19B

DEP VARIABLE: MEASURE

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	1361.79728	1361.79728	2912.472	0.0001
ERROR	3	1.40272314	0.46757438		
C TOTAL	4	1363.20000			

ROOT MSE	0.6837941	R-SQUARE	0.9990
DEP MEAN	879.6	ADJ R-SQ	0.9986
C.V.	0.07773921		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	898.63049	0.46675769	1925.261	0.0001
YEAR	1	-29.24169165	0.54184069	-53.967	0.0001

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT	RESIDUAL	STD ERR RESIDUAL	STUDENT RESIDUAL	-2-1-0 1 2
1	898.0	898.6	0.4668	897.1	900.1	896.0	901.3	-0.6305	0.4997	-1.2617	| **|
2	892.0	891.3	0.3744	890.1	892.5	888.8	893.7	0.7384	0.5722	1.2906	| |**
3	888.0	888.1	0.3438	887.0	889.2	885.6	890.5	-0.0742	0.5911	-0.1256	| |
4	864.0	863.5	0.4267	862.2	864.9	861.0	866.1	0.4595	0.5343	0.8600	| |*
5	856.0	856.5	0.5262	854.8	858.2	853.7	859.2	-0.4932	0.4367	-1.1293	| **|

OBS	COOK'S D
1	0.694
2	0.357
3	0.003
4	0.236
5	0.926

SUM OF RESIDUALS	3.97904E-13
SUM OF SQUARED RESIDUALS	1.402723
PREDICTED RESID SS (PRESS)	4.544196

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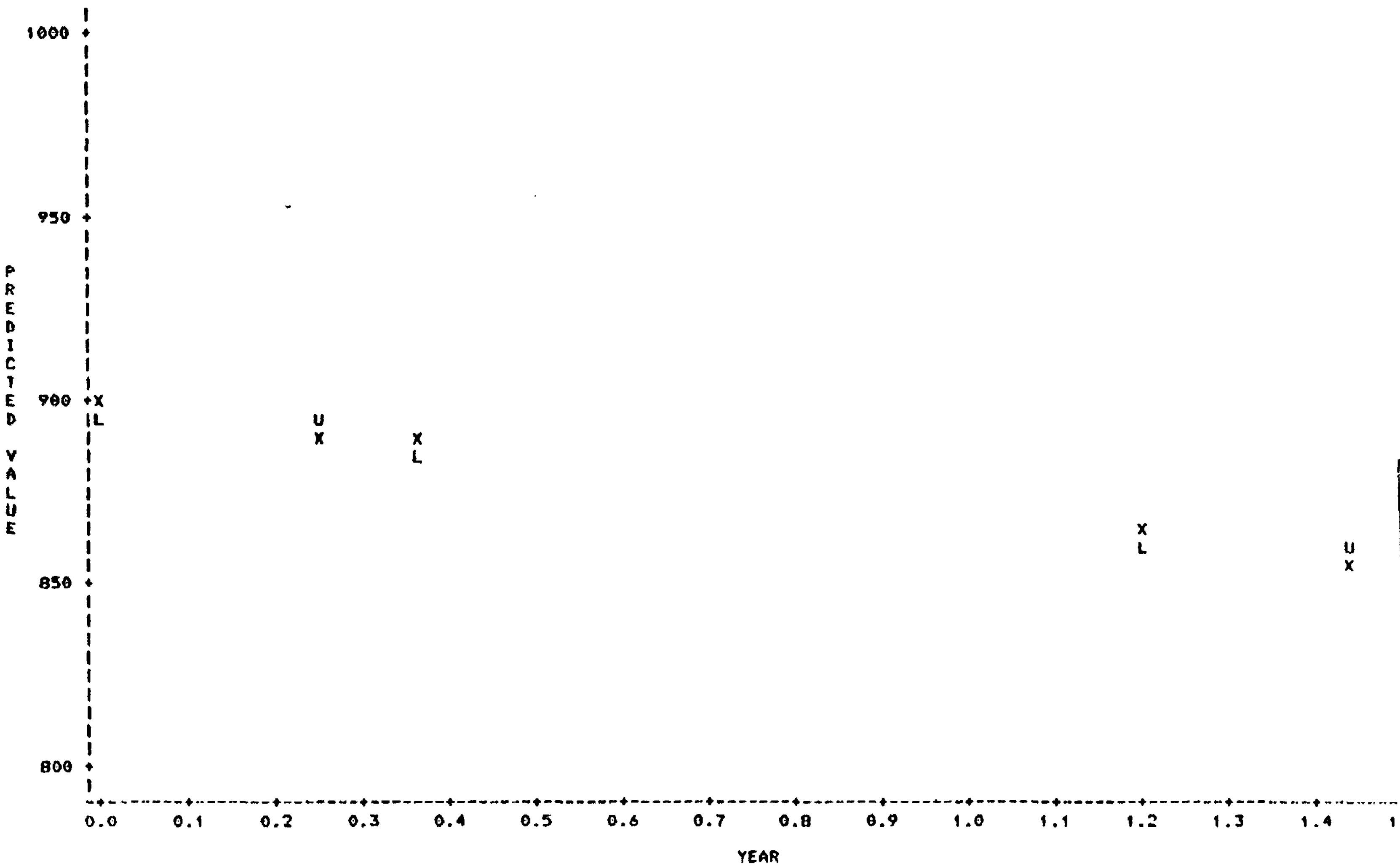
LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 19B

PLOT OF MEASURE*YEAR   SYMBOL USED IS X
PLOT OF PRED*YEAR   SYMBOL USED IS P
PLOT OF U95*YEAR   SYMBOL USED IS U
PLOT OF L95*YEAR   SYMBOL USED IS L



NOTE   10 OBS HIDDEN

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Calc No C-1302-187-5300-005
Rev No Ø
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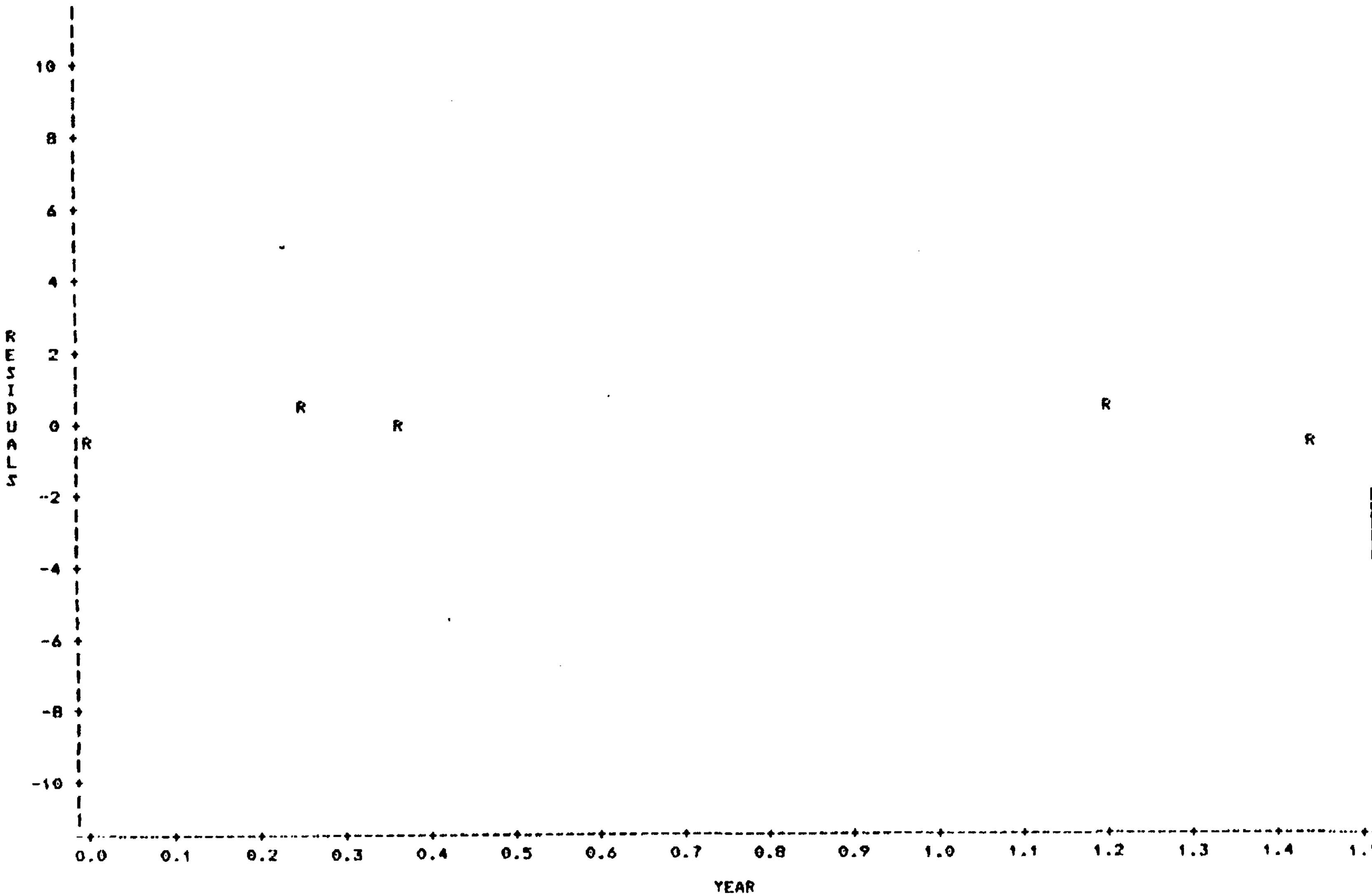
LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 19B

PLOT OF RESID*YEAR   SYMBOL USED IS R



Calc No C-1302-187-5360-005 Rev. No Ø Sheet No 170

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LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 19B

UNIVARIATE

VARIABLE=RESID   RESIDUALS

MOMENTS

N	5	SUM WGTS	5
MEAN	7.958E-14	SUM	3.979E-13
STD DEV	0.592183	VARIANCE	0.350681
SKEWNESS	0.258109	KURTOSIS	-2.31676
USS	1.40272	CSS	1.40272
CV	99999	STD MEAN	0.264832
T:MEAN=0	3.005E-13	PROB>|T|	1
SGN RANK	-0.5	PROB>|S|	1
NUM ^= 0	5		
W:NORMAL	0.925954	PROB<W	0.497

QUANTILES(DEF=4)

100% MAX	0.738413	99%	0.738413
75% Q3	0.598975	95%	0.738413
50% MED	-0.0742422	90%	0.738413
25% Q1	-0.561854	10%	-0.630493
0% MIN	-0.630493	5%	-0.630493
		1%	-0.630493
RANGE	1.36891		
Q3-Q1	1.16083		
MODE	-0.630493		

EXTREMES

LOWEST	HIGHEST
-0.630493	-0.630493
-0.493215	-0.493215
-0.0742422	-0.0742422
0.459537	0.459537
0.738413	0.738413

```
STEM LEAF                     #        BOXPLOT
   6 4                        1           |
   4 6                        1        +-----+
   2                                   |     |
   0                                   |  +  |
  -0 7                        1        *-----*
  -2                                   |     |
  -4 9                        1        +-----+
  -6 3                        1           |
     ----+----+----+----+
  MULTIPLY STEM.LEAF BY 10**-01

                    NORMAL PROBABILITY PLOT
   0.7+                                               +*+
      |                                       * ++++
      |                                     +++
      |                                 ++++
      |                             ++++*
      |                         +++
      |                   ++++ *
  -0.7+               +*+
       +----+----+----+----+----+----+----+----+----+----+
           -2        -1         0        +1        +2
```

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5.1.6 Bay 19C: 5/1/87 to 10/8/88

Five 49-point data sets were available for this bay covering the time period from May 1, 1987 to October 8, 1988. Since a plug lies within this region, four of the points were voided in each data set. The data were analyzed as described in paragraphs 2.4 and 2.8.1.

(1) The data are normally distributed.

(2) The regression model is appropriate.

(3) The regression model explains 91% of the total variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 860.9 ±4.0 mils.

(6) The corrosion rate ± standard error is -25.9 ±4.1 mpy.

(7) The measurements below 800 mils were tested and determined not to be statistically different from the mean thickness.

```
PROGRAM: DWCHISQ
ENTER NAME OF DATA LIST e19c
ENTER PT NUMBER LIST ints(1,49)
ENTER NAME OF DATE LIST d34567

 N     E19C
 *   *******
 1   E19C612
 2   E19C705
 3   E19C708
 4   E19C709
 5   E19C807
 6   E19C810

ENTER NO. OF DESIRED DATA 2.3.4,5,6

            D34567    MEANTHK     SD       STDERR    DFM2
*******    ********   *******   *******   ********   ****
E19C705    5/1/87     .90051    .08125    .012112     2
E19C708    8/1/87     .88816    .081154   .012234     2
E19C709    9/10/87    .88831    .063771   .0098401    2
E19C807    7/12/88    .87346    .081282   .013016     2
E19C810    10/08/88   .85627    .072399   .010915     2

 CHISQ   CHI952   CHI992
******   ******   ******
2.793     5.99     9.21
3.2861    5.99     9.21
1.2392    5.99     9.21
1.2081    5.99     9.21
1.3084    5.99     9.21

      OBS                          EXP
**************   **********************************
10 12 11 10  7   9.5337 9.3218 8.8981 8.2625 9.3218
 6  4  6  5 10   8.5248 8.3354 7.9565 7.3882 8.3354
12 10  8  8  8   8.883  8.6856 8.2908 7.6986 8.6856
10  8  7  8 10   8.5248 8.3354 7.9565 7.3882 8.3354
 7 10 10  8  9   9.5337 9.3218 8.8981 8.2625 9.3218

GRAND MEAN THICKNESS = .88134
STANDARD ERROR OF THE GRAND MEAN = .0075929

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```

E19C705

.969	.927	.92	1.067	.996	1.112	1.104
.775	.81	.839	.929	.894	1.03	.891
.882	.85	.936	.965	.908	0	.912
.882	.767	.761	.785	0	0	.939
.833	.823	.843	.864	0	.834	.89
.926	.878	.92	.796	.894	.813	.856
.887	.921	.936	.889	.926	.955	.989

E19C708

0	.818	.864	1.06	.952	1.016	.961
.767	.804	.797	.874	.807	.933	.895
.83	1.01	.979	.947	.868	0	.998
.882	.715	.752	.788	0	0	.93
.833	.814	.822	.879	0	.901	.894
.914	.874	.915	.789	.898	.775	.91
.918	.864	.894	.97	.973	1.039	.956

E19C709

.927	.802	.891	1.02	.961	.999	.944
0	.792	.785	.859	.812	.938	.874
.859	0	.923	.929	.887	0	.903
.83	0	.761	.833	0	0	.928
.875	.821	.827	.85	0	.837	.893
.942	.884	.926	.839	.898	.791	.858
.866	.942	.944	.926	.958	.982	.993

E19C807

.872	.781	.874	1.066	1.005	1.056	.947
.708	.78	.757	.847	.786	.959	.866
.897	0	.92	.947	.855	0	.906
.853	.735	.794	.78	0	0	.933
0	.804	0	.87	0	0	.879
0	.867	.917	.803	.879	.809	.817
0	.853	.916	.902	.944	.932	.949

E19C810

0	.777	.865	1.002	.907	.975	.935
.705	.727	.76	.848	.803	.931	.864
.856	.815	.911	.905	.85	0	.897
.834	.691	.735	.768	0	0	.934
.82	.799	.965	.812	0	.808	.86
.878	.874	.903	.812	.884	.812	.813
.862	.878	.901	.921	.905	.941	.933

10/25/06 14:28:07

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF BAY 19C 3" ABOVE CURB

OBS	YEARS	MILS
1	0.00	900.5
2	0.25	888.2
3	0.36	888.3
4	1.20	873.5
5	1.44	856.3

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Calc No C-1302-187-5300-005 Rev No Ø Sheet No 75 of

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF BAY 19C 3' ABOVE CURB

VARIABLE	N	MEAN	STANDARD DEVIATION	STD ERROR OF MEAN	T	PR>|T|
MILS	5	881.36000000	16.96372601	7.58640890	116.18	0.0001

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Calc No C-1302-187-5300-005 Rev No Ø Sheet No 76

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF BAY 19C 3" ABOVE CURB

DEP VARIABLE: MILS

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	1071.12484	1071.12484	40.194	0.0079
ERROR	3	79.94715692	26.64905231		
C TOTAL	4	1151.07200			

ROOT MSE	5.162272	R-SQUARE	0.9305
DEP MEAN	881.36	ADJ R-SQ	0.9074
C.V.	0.5857166		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|	TYPE I SS	STANDARDIZED ESTIMATE
INTERCEP	1	898.21302	3.52071761	255.108	0.0001	3883977.35	0
YEARS	1	-25.92894803	4.08983452	-6.340	0.0079	1071.12484	-0.96464785

COLLINEARITY DIAGNOSTICS

NUMBER	EIGENVALUE	CONDITION NUMBER	VAR PROP INTERCEP	VAR PROP YEARS
1	1.755028	1.000000	0.1225	0.1225
2	0.244972	2.676604	0.8775	0.8775

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT	RESIDUAL
1	900.5	898.2	3.5209	887.0	909.4	878.3	918.1	2.2862
2	888.2	891.7	2.8295	882.7	900.7	873.0	910.5	-3.5316
3	888.3	888.9	2.5955	880.6	897.1	870.5	907.3	-0.5794
4	873.5	867.1	3.2233	856.8	877.4	847.7	886.5	6.4009
5	856.3	860.9	3.9710	848.2	873.5	840.1	881.6	-4.5761

SUM OF RESIDUALS	1.19371E-12
SUM OF SQUARED RESIDUALS	79.94716
PREDICTED RESID SS (PRESS)	280.0524

$t95(n-2) = 3.182$

Mean Thickness = 860.9 ± 4.0 mils

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Calc No C-1302-187-5380-005 | Rev No 0 | Sheet No 77 of --

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF BAY 19C 3" ABOVE CURB

DEP VARIABLE: MILS

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	1071.12484	1071.12484	40.194	0.0079
ERROR	3	79.94715692	26.64905231		
C TOTAL	4	1151.07200			

ROOT MSE	5.162272	R-SQUARE	0.9305
DEP MEAN	881.36	ADJ R-SQ	0.9074
C.V.	0.5857166		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	898.21382	3.52091761	255.108	0.0001
YEARS	1	-25.92894803	4.08983452	-6.340	0.0079

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT	RESIDUAL	STD ERR RESIDUAL
1	900.5	898.2	3.5209	887.0	909.4	878.3	918.1	2.2862	3.7752
2	888.2	891.7	2.8295	882.7	900.7	873.0	910.5	-3.5316	4.3177
3	888.3	888.9	2.5955	880.6	897.1	870.5	907.3	-0.5794	4.4623
4	873.5	867.1	3.2233	856.8	877.4	847.7	886.5	6.4009	4.0323
5	856.3	860.9	3.9710	848.2	873.5	840.1	881.6	-4.5761	3.2985

OBS	STUDENT RESIDUAL	-2-1-0 1 2	COOK'S D
1	0.6056	| |* |	0.159
2	-0.8179	| *| |	0.144
3	-0.1278	| | |	0.003
4	1.5874	| |*** |	0.805
5	-1.3873	| **| |	1.395

SUM OF RESIDUALS	1.19371E-12
SUM OF SQUARED RESIDUALS	79.94716
PREDICTED RESID SS (PRESS)	280.0524

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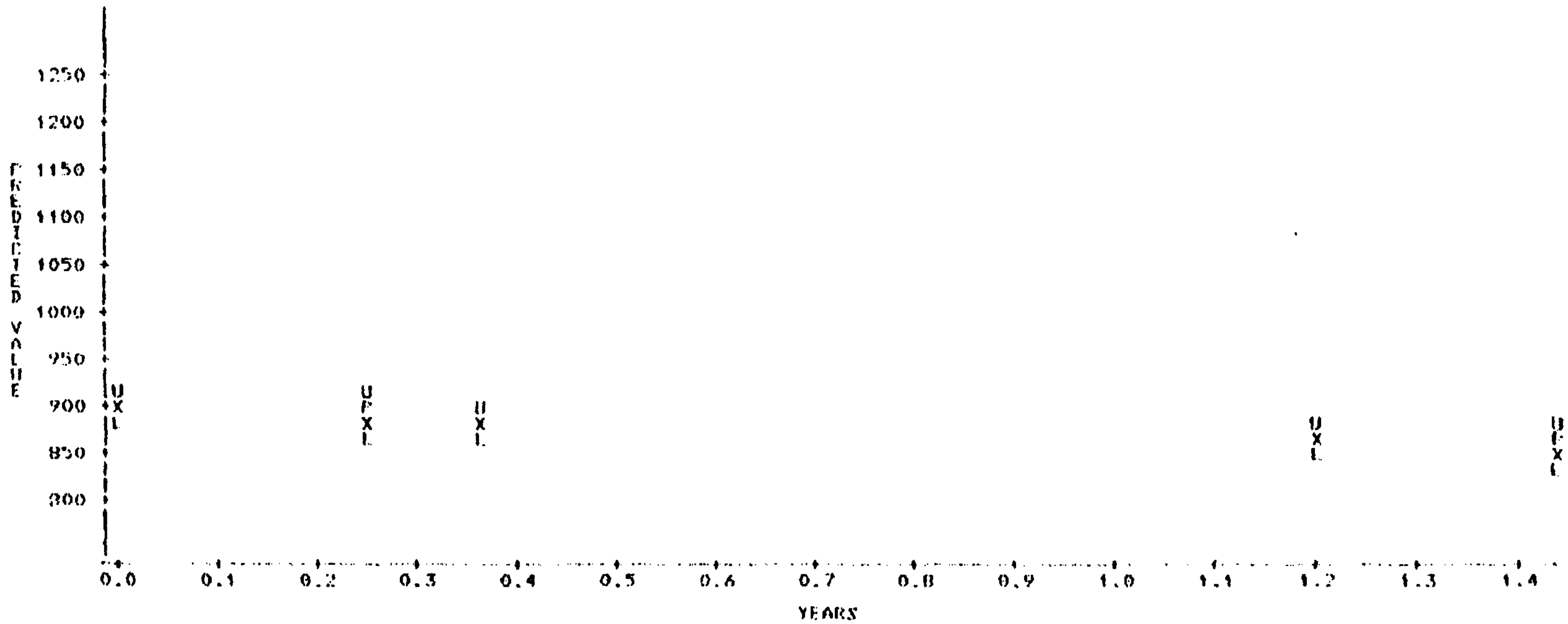
Calc No C-1302-187-5380-005 Rev No 0 Sheet No 78 of

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF BAY 19C 3" ABOVE CURB

13 03 WEDNESDAY, JANUARY 4, 1989 11

PLOT OF MILS*YEARS SYMBOL USED IS X
PLOT OF PRED*YEARS SYMBOL USED IS P
PLOT OF U95*YEARS SYMBOL USED IS U
PLOT OF L95*YEARS SYMBOL USED IS L



NOTE 3 OBS HIDDEN

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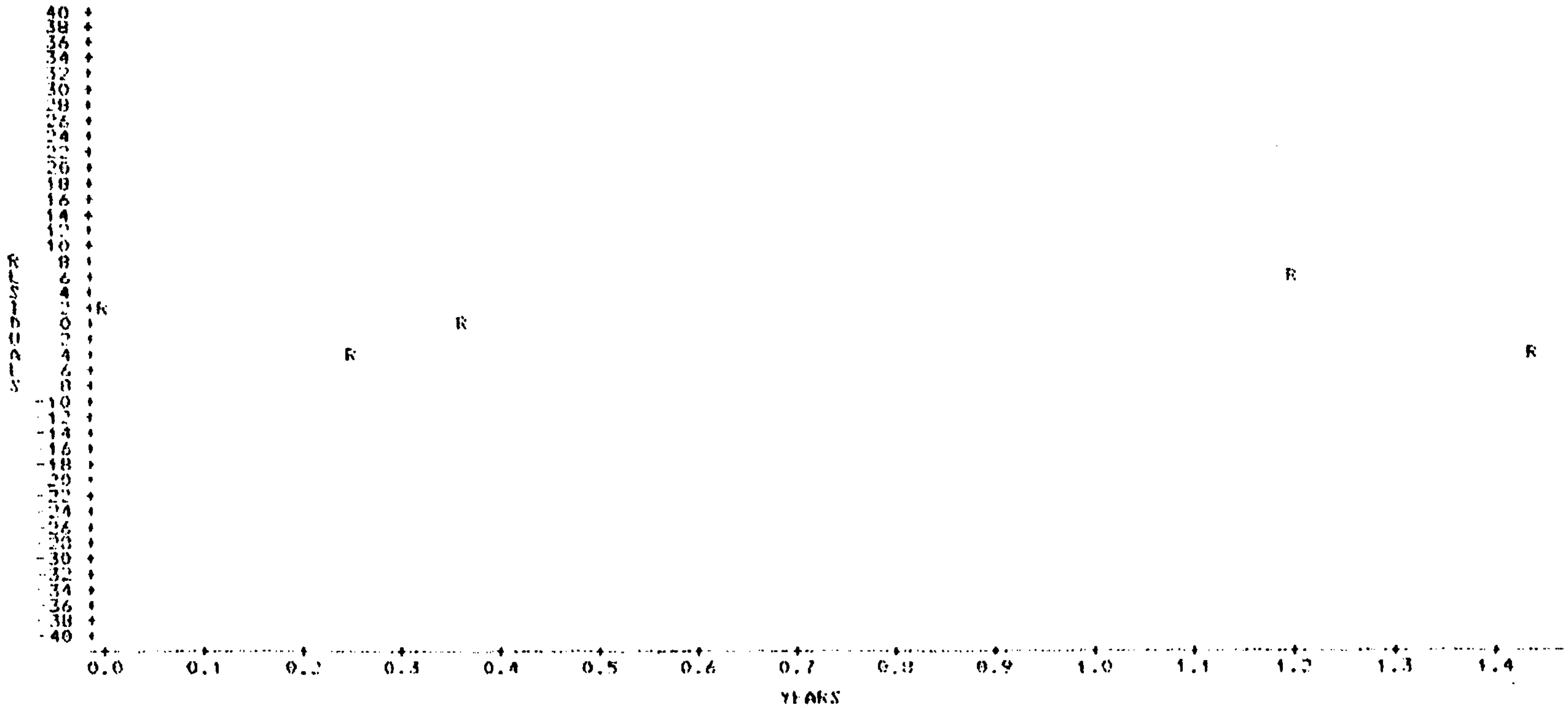
Calc No C-1302-187-5380-005 Rev. No 0 Sheet No 79 of -

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF BAY 19C 3' ABOVE CURB

PLOT OF RESIDUAL*YEARS SYMBOL USED IS R



10/25/06 14:28:07

Calc No C-1302-187-5300-005 Rev No Ø Sheet No 80 of

5.2 6"x6" Grids in Sand Bed Region at New Locations

5.2.1 Bay 9D: 11/25/86 to 12/19/88

The 6"x6" grid data was taken in December 1988 during the 12R outage. This bay was considered for cathodic protection, but is not within the scope of the cathodic protection system being installed. The primary purpose of this data is to establish a base line to monitor corrosion in the future. However, previous measurements were taken in November 1986 in a 10-point 6"x6" cruciform pattern. Measurements were also taken in a 6"x6" grid in December 1986. The new data were compared with both of the previous data sets. These comparisons were made using the chi-squared test, F-test and two-tailed t-test as described in paragraph 2.5. The mean thickness was determined as described in paragraph 2.8.3.

(1) The data are normally distributed.

(2) The variances are equal in both comparisons.

(3) It is appropriate to use the two-tailed t-test in both comparisons.

(4) The difference between the means of the 1988 49-point data set and the 1986 10-point data set is not significant. However, there is a significant difference between the means of the 1988 49-point data set and the 1986 49-point data set. Therefore, significance of the corrosion rate is classified as "Indeterminable".

(5) The current mean thickness $\pm$ standard error is 1021.4 $\pm$9.7 mils.

10/25/06 14:28:07

GPU Nuclear **Calculation Sheet**

Subject		Calc No	Rev No	Sheet No
		C-1302-187-5300-005	0	82 of .
Originator: [signature]	Date: 1-16-89	Reviewed by	Date	

5.2.1 BAY 9D (CONT'D)

PROGRAM: OCDWCONF 12-19-88
BAY: 9D

D8702659

1.077	1.104	1.034	1.144	1.09	1.14	1.157
.949	.964	1.029	1.089	.993	1.084	1.109
.827	.953	1.054	1.077	1.031	1.117	1.154
.919	.959	.976	1.038	1.038	1.038	1.056
.971	1.046	.922	.991	.947	.983	1.031
.987	.947	1.021	1.026	1.041	1.015	.959
1.02	1	.975	1.021	1.022	.947	.976

MEAN THICKNESS = 1.0214
STANDARD ERROR OF THE MEAN = .0097164
T(.05/2, 48)= 2.0106
T(.01/2, 48)= 2.6822

CONFIDENCE INTERVALS FOR THE MEAN
****

95% UPPER BOUND = 1.0409
95% LOWER BOUND = 1.0019

99% UPPER BOUND = 1.0474
99% LOWER BOUND = .99533

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PROGRAM: OCDWCONF 12-4-86
BAY: 9D

D8604941

1.175	1.162	1.174	1.13	1.182	1.162	1.12
1.197	1.219	1.168	1.143	1.119	1.045	1.025
1.145	1.107	1.085	1.126	1.132	1.085	1.082
1.119	1.119	1.031	1.038	1.048	1.061	1.074
1.07	.963	1.03	1.051	1.007	.991	.983
1.063	1.059	1.059	.968	.977	1.052	.987
1.079	.987	1.049	.926	1.018	.984	.928

MEAN THICKNESS = 1.0715
STANDARD ERROR OF THE MEAN = .010397
T(.05/2, 48)= 2.0106
T(.01/2, 48)= 2.6822

CONFIDENCE INTERVALS FOR THE MEAN
****

95% UPPER BOUND = 1.0924
95% LOWER BOUND = 1.0506

99% UPPER BOUND = 1.0994
99% LOWER BOUND = 1.0436

January 16, 1989
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GPU Nuclear **Calculation Sheet**

Subject	Calc No	Rev No	Sheet No
	C-1302-187-5300-005	Ø	83 of

Originator	Date	Reviewed by	Date
JP Moore	1-16-89		

5.2.1. Bay 9D (Cont'd)

```
PROGRAM: OCDWCONF
BAY: 9D

 D8604919        11-25-86
 ********
  1.114
  1.054
   .997
   .732
   .985
  1.015
  1.058
  1.06
   .981
   .994

MEAN THICKNESS = .999
STANDARD ERROR OF THE MEAN = .032583
T(.05/2, 9 )= 2.2622
T(.01/2, 9 )= 3.2498

CONFIDENCE INTERVALS FOR THE MEAN
*********************************

95% UPPER BOUND = 1.0727
95% LOWER BOUND = .92529

99% UPPER BOUND = 1.1049
99% LOWER BOUND = .89311

January 16, 1989
 5:30 PM
```

EVALUATION:

THE BEST ESTIMATE OF MEAN THICKNESS ON EACH OF THESE DATES IS THE MEAN OF THE DATA FOR THAT DATE.

DATE	MEAN THK
11-25-86	0.999 ± 0.033"
12-04-86	1.0715 ± 0.010"
12-19-88	1.0214 ± 0.010"

PROGRAM: DWCHISQ1
BAY: 9D

********	DATADATE ********	MEANTHK *******	SD *******	STDERR ********	DFM2 ****
D8702659	12/19/88	1.0214	.068015	.0097164	2

CHISQ ******	CHI952 ******	CHI992 ******
4.4488	5.99	9.21

OBS ***	EXP *******
11	10.381
9	9.2826
13	9.6726
4	9.2826
12	10.381

PTNOS *****	PTNOS *****	PTNOS *****	PTNOS *****	PTNOS *****
1	11	21	31	41
2	12	22	32	42
3	13	23	33	43
4	14	24	34	44
5	15	25	35	45
6	16	26	36	46
7	17	27	37	47
8	18	28	38	48
9	19	29	39	49
10	20	30	40	

January 18, 1989
1:17 PM

GPU Nuclear **Calculation Sheet**

Subject:	Calc No	Rev No	Sheet No
	C-1302-187-5300-005		85
Originator: JP Moore Date 1-16-89	Reviewed by	Date	

5.2.1 BAY 9D (CONT'D)

SINCE MULTIPOINT DATA SETS ARE AVAILABLE FOR EACH DATE, CORROSION IS EVALUATED USING A TWO-TAILED t-TEST FOR TWO INDEPENDENT SAMPLES PER PARA. 4.5.

PROGRAM: DWCHISQ1
BAY: 9D

DATASET	DATADATE	MEANTHK	SD	DFM2	CHISQ	CHI95
********	********	*******	*******	****	******	******
D8702659	12/19/88	1.0214	.068015	2	4.4488	5.99

OBS	EXP
***	*******
11	10.381
9	9.2826
13	9.6726
4	9.2826
12	10.381

PTNOS	PTNOS	PTNOS	PTNOS	PTNOS
*****	*****	*****	*****	*****
1	11	21	31	41
2	12	22	32	42
3	13	23	33	43
4	14	24	34	44
5	15	25	35	45
6	16	26	36	46
7	17	27	37	47
8	18	28	38	48
9	19	29	39	49
10	20	30	40	

January 6, 1989
1:17 PM

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Calc No	Rev No	Sheet No
C-1302-187-5300-005	Ø	860f.

PROGRAM: DWCHISQ1
BAY: 9D

	DATADATE	MEANTHK	SD	STDERR	DFM2
********	********	*******	*******	*******	****
D8604941	12/04/86	1.0715	.072782	.010397	2

CHISQ	CHI952	CHI992
******	******	******
1.5167	5.99	9.21

OBS	EXP
***	*******
11	10.381
10	9.2826
10	9.6726
6	9.2826
12	10.381

PTNOS	PTNOS	PTNOS	PTNOS	PTNOS
*****	*****	*****	*****	*****
1	11	21	31	41
2	12	22	32	42
3	13	23	33	43
4	14	24	34	44
5	15	25	35	45
6	16	26	36	46
7	17	27	37	47
8	18	28	38	48
9	19	29	39	49
10	20	30	40	

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1:18 PM

PROGRAM: DWCHISQ1
BAY: 9D

DATASET	DATADATE	MEANTHK	SD	STDERR	DFM2
********	********	*******	******	*******	****
D8604919	11/25/86	.999	.10304	.032583	2

CHISQ	CHI952	CHI992
******	******	******
8.3595	5.99	9.21

OBS	EXP
***	******
1	2.1186
0	1.8944
5	1.974
3	1.8944
1	2.1186

PTNOS
*****
1
2
3
4
5
6
7
8
9
10

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2:08 PM

GPU Nuclear **Calculation Sheet**

Subject	Calc No	Rev No	Sheet No
	C-1302-187-5300-005	∅	188 of ...

Originator	Date	Reviewed by	Date
JP Moore	1-16-89		

5.2.1 BAY 9D (CONT'D)

COMPARISON OF MEANS USING TWO-TAILED T-TEST
****

BAY	DATASHTS	DATASETS	DATADATE	MEANTHK
9D	8702659	D8702659	12/19/88	1.0214
	8604919	D8604919	11/25/86	.999

D8702659
****

1.077	1.104	1.034	1.144	1.09	1.14	1.157
.949	.964	1.029	1.089	.993	1.084	1.109
.827	.953	1.054	1.077	1.031	1.117	1.154
.919	.959	.976	1.038	1.038	1.038	1.056
.971	1.046	.922	.991	.947	.983	1.031
.987	.947	1.021	1.026	1.041	1.015	.959
1.02	1	.975	1.021	1.022	.947	.976

D8604919
****

1.114
1.054
.997
.732
.985
1.015
1.058
1.06
.981
.994

F TEST FOR EQUAL POPULATION VARIANCES
****

VARA	VARB	DFA	DFB
.010616	.004626	9	48

F = 2.2949
F(.05/2, 9 , 48) = 2.3925
F(.01/2, 9 , 48) = 3.1133

TWO-TAILED T-TEST
****
DF = 57
ALPHA = .19551
T = .86434
T(.05/2, 57) = 2.0025
T(.01/2, 57) = 2.6649
January 13, 1989
5:52 PM

$t < t(95)$ ∴ DO NOT REJECT EQUALITY OF THE MEANS

10/25/06 14:28:07

GPU Nuclear **Calculation Sheet**

Subject		Calc No C-1302-187-5300-005	Rev No Ø	Sheet No 89 of —
Originator JD Moore	Date 1-16-89	Reviewed by	Date	

5.2.1 BAY 9D (CONT'D)

COMPARISON OF MEANS USING TWO-TAILED T-TEST
****

BAY	DATASHTS	DATASETS	DATADATE	MEANTHK
***	********	********	********	*******
9D	8702659	D8702659	12/19/88	1.0214
	8604941	D8604941	12/04/86	1.0715

D8702659
****

1.077	1.104	1.034	1.144	1.09	1.14	1.157
.949	.964	1.029	1.089	.993	1.084	1.109
.827	.953	1.054	1.077	1.031	1.117	1.154
.919	.959	.976	1.038	1.038	1.038	1.056
.971	1.046	.922	.991	.947	.983	1.031
.987	.947	1.021	1.026	1.041	1.015	.959
1.02	1	.975	1.021	1.022	.947	.976

D8604941
****

1.175	1.162	1.174	1.13	1.182	1.162	1.12
1.197	1.219	1.168	1.143	1.119	1.045	1.025
1.145	1.107	1.085	1.126	1.132	1.085	1.082
1.119	1.119	1.031	1.038	1.048	1.061	1.074
1.07	.963	1.03	1.051	1.007	.991	.983
1.063	1.059	1.059	.968	.977	1.052	.987
1.079	.987	1.049	.926	1.018	.984	.928

F TEST FOR EQUAL POPULATION VARIANCES
****

VARA	VARB	DFA	DFB
********	*******	***	***
.0052973	.004626	48	48

F = 1.1451
F(.05/2, 48 , 48) = 1.7728
F(.01/2, 48 , 48) = 2.13

TWO-TAILED T-TEST
****
DF = 96
ALPHA = 3.2857E-4
T = 3.5221
T(.05/2, 96) = 1.985
T(.01/2, 96) = 2.628
January 13, 1989
5:49 PM

$t > t(99)$ ∴ REJECT EQUALITY OF THE MEANS

GPU Nuclear **Calculation Sheet**

Subject	Calc No	Rev No	Sheet No
	C-1302-187-5300-005	Ø	90 of ...

Originator	Date	Reviewed by	Date
JL Moore	1-16-89		

5.2.1 BAY 9D (CONT'D)

SINCE t-TESTS REJECTS EQUALITY OF THE MEANS IN ONE COMPARISON BUT NOT IN THE OTHER, THE CORROSION IS CLASSIFIED AS "INDETERMINABLE"

5.2.2 Bay 13A: 11/25/86 to 12/17/88

The 6"x6" grid data was taken for the first time in December 1988 during the 12R outage. This bay was considered for cathodic protection, but is not within the scope of the cathodic protection being installed. The primary purpose of this data is to establish a base line to monitor corrosion in the future. However, previous measurements were taken in November 1986 in abutting 6"x6" cruciform patterns across the entire bay. As a best approximation, 13 of these data points are at the same location as the new 6"x6" grid data set. Therefore, the new data were first compared with these 13 data points, and then with 21 data points which include the 13 plus 8 additional points within one inch on either side. These comparisons were made using the chi-squared test, F-test and two-tailed t-test as described in paragraph 2.5. The mean thickness was determined as described in paragraph 2.8.3.

(1) The data are normally distributed.

(2) The variances are equal in both comparisons.

(3) It is appropriate to use the two-tailed t-test in both comparisons.

(4) The difference between the means of the data sets is not signficant. Therefore, the corrosion is classified as "Not Significant".

(5) The current mean thickness $\pm$ standard error is 905.3 $\pm$10.1 mils.

GPU Nuclear **Calculation Sheet**

Subject	Calc No	Rev No	Sheet No
	C-1302-187-5360-005	Ø	142

Originator	Date	Reviewed by	Date
J. Moore	12-31-88		

BAY 13A 3" ABOVE CURB

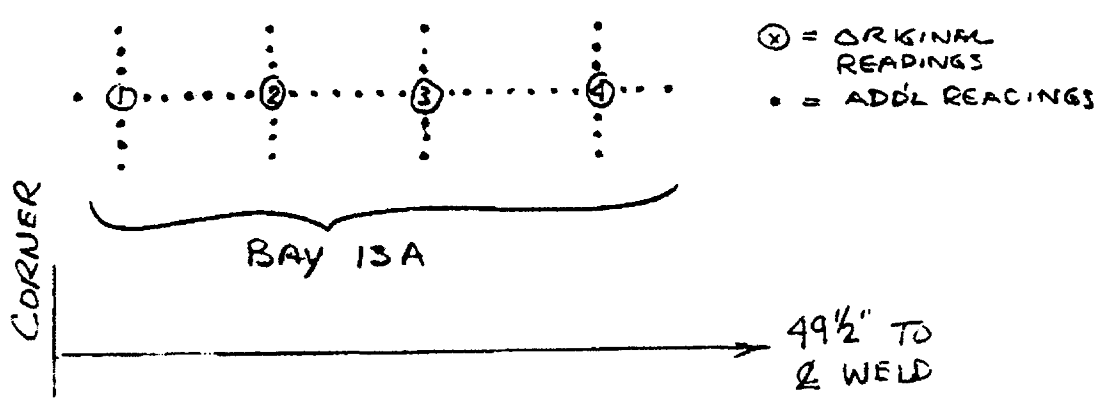
THERE ARE TWO SETS OF DATA FOR THIS LOCATION:

DATE	DATA SHEET	DATA SETS
11-15-86	86-049-09	(SEE BELOW)
12-17-88	87-026-58	D13A812

THE 11-15-86 DATA WAS TAKEN IN TWO STAGES:

(1) NINE READINGS WERE TAKEN ABOUT 7 INCHES APART FROM THE CORNER TO THE ℄ OF THE WELD WHICH IS A SPAN OF 49 1/2". THIS INCLUDES BAYS 13A AND 13B. THESE DATA ARE LISTED UNDER "UNCOATED UT FINAL THICKNESS ON PAGE 1 OF DATA SHEET 86-049-09.

(2) ADDITIONAL READINGS WERE TAKEN AT 1-INCH INCREMENTS BETWEEN THE ORIGINAL READINGS IN BAY 13A. ALSO THREE ADDITIONAL READINGS WERE TAKEN ABOVE AND THREE BELOW THE ORIGINAL READINGS AT 1-INCH INCREMENTS



GPU Nuclear Calculation Sheet

Subject	Calc No	Rev No	Sheet No
	C-1302-187-5300-005	Ø	93 of ...

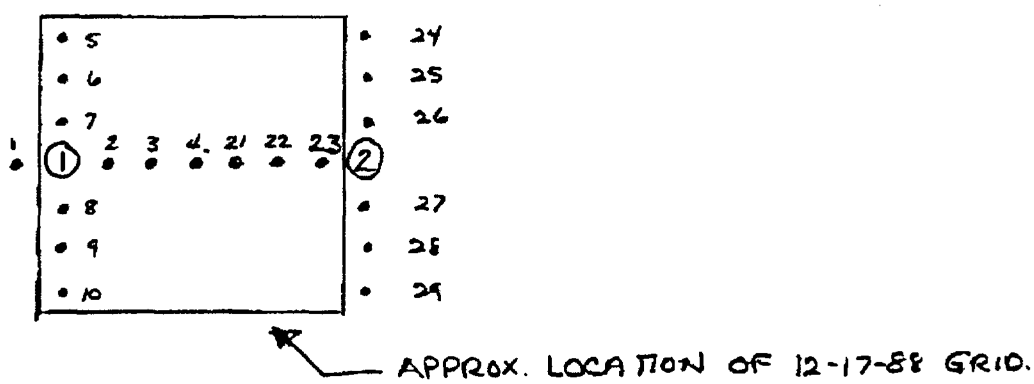
Originator	Date	Reviewed by	Date
JP Moore	12-31-88		

BAY 13A

THE ADDITIONAL READINGS ARE TABULATED ON PAGE 2 OF 86-049-09

THE 12-17-88 DATA IS A 6" x 6" GRID ON 1-INCH CENTERS WITH THE GRID CENTERED 45" FROM THE WELD ℄.

AS A BEST APPROXIMATION, THE CENTER OF THE 12-17-88 GRID (PT. NO. 25) IS LOCATED AT ADD'L DATA PT. NO. 4 OF THE 11-15-86 DATA.



THE 11-15-86 DATA POINTS WITHIN THE BOX ARE CALLED DATA SET D13A 8601.

THESE POINTS PLUS THOSE SHOWN 1-INCH EITHER SIDE OF THE BOX ARE CALLED DATA SET D13A 86Ø2.

GPU Nuclear Calculation Sheet

Subject		Calc No C-1302-187-5300-065	Rev No ø	Sheet No 94 of __
Originator J.P. Moore	Date 12-31-88	Reviewed by	Date	

BAY 13A

WITH ONLY TWO SETS OF DATA, IT WOULD BE INAPPROPRIATE TO USE LINEAR REGRESSION TO EVALUATE THE CORROSION RATE. HOWEVER, THE T-TEST CAN BE USED TO COMPARE THE MEANS OF THE TWO DATA SETS TO DETERMINE IF THE DIFFERENCE IS STATISTICALLY SIGNIFICANT.

THE 12-17-88 DATA SET (D13A812) WAS FIRST COMPARED WITH THE 11-15-86 DATA SET (D13A86ø1)

SINCE THE RELATIVE LOCATIONS ARE APPROXIMATE, THE 12-17-88 DATA SET WAS ALSO COMPARED WITH THE EXPANDED 11-15-86 DATA SET (D13A86ø2).

EACH EVALUATION TOOK PLACE IN THREE STEPS:

(1) χ^2-TEST OF EACH DATA SET TO CHECK FOR NORMAL DISTRIBUTION OF THE DATA.

(2) FMAX TEST OF THE TWO DATA SETS BEING COMPARED TO CHECK FOR EQUAL VARIANCES.

(3) TWO-TAILED T-TEST TO COMPARE THE MEANS OF THE TWO DATA SETS.

GPU Nuclear **Calculation Sheet**

Subject	Calc No	Rev No	Sheet No
	C-1302-187-5300-005	Ø	95 of ...

Originator	Date	Reviewed by	Date
J. P. Moore	1-2-89		

BAY 13A

THE χ^2 TEST WAS PERFORMED USING THE SPEAKEZ PROGRAM "DWCHISQ1". SEE APPENDIX 6.1 FOR A LISTING AND DESCRIPTION OF THE PROGRAM.

THE F TEST AND THE T TEST WERE PERFORMED USING THE SPEAKEZ PROGRAM "T2TAIL". SEE APPENDIX 6.2 FOR A LISTING AND DESCRIPTION OF THE PROGRAM

RESULTS:

(1) χ^2 TESTS - IN EACH CASE, THE NULL HYPOTESIS THAT THE DATA SETS ARE NORMALLY DISTRIBUTED IS NOT REJECTED AT LEVEL OF SIGNIFICANCE OF 0.05.

(2) F TEST - THE NULL HYPOTHEIS THAT THE VARIANCES ARE EQUAL IS NOT REJECTED AT LEVEL OF SIGNIFICANCE OF 0.01.

(3) T TEST - THE NULL HYPOTHESIS THAT THE DATA SET MEANS ARE EQUAL IS NOT REJECTED AT LEVEL OF SIGNIFICANCE OF 0.05.

CONCLUSION:

SIGNIFICANT CORROSION DID NOT OCCUR AT THIS LOCATION OVER THE PERIOD FROM 11-15-86 TO 12-17-88.

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C-1302-187-5300-005	Ø	96 of --

PROGRAM: OCDWCONF
BAY: 13A

D13A812
****

.941	.862	.88	.963	1.016	1.046	.9
.85	.9	1.141	.94	.892	.884	.802
.837	.959	.849	.861	.809	.784	.855
.907	.936	.908	.911	.843	.897	.951
.962	.834	.902	.927	.357	.925	.935
1.108	.863	.829	.998	.845	.876	.881
.908	.898	.839	.879	.899	.967	.902

MEAN THICKNESS = .90527
STANDARD ERROR OF THE MEAN = .010109
T(.05/2, 48)= 2.0106
T(.01/2, 48)= 2.6822

CONFIDENCE INTERVALS FOR THE MEAN
****

95% UPPER BOUND = .92559
95% LOWER BOUND = .88494

99% UPPER BOUND = .93238
99% LOWER BOUND = .87815

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Calc No	Rev No	Sheet No
C-1302-187-5300-005	Ø	99 of -

PROGRAM: DWCHISQ1
BAY: 13A

DATASET	DATADATE	MEANTHK	SD	STDERR	DFM2
*******	********	*******	******	*******	****
D13A812	12/17/88	.90527	.07076	.010109	2

CHISQ	CHI952	CHI992
******	******	******
2.2627	5.99	9.21

OBS	EXP
***	*******
9	10.381
12	9.2826
12	9.6726
8	9.2826
8	10.381

PTNOS	PTNOS	PTNOS	PTNOS	PTNOS
*****	*****	*****	*****	*****
1	11	21	31	41
2	12	22	32	42
3	13	23	33	43
4	14	24	34	44
5	15	25	35	45
6	16	26	36	46
7	17	27	37	47
8	18	28	38	48
9	19	29	39	49
10	20	30	40	

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REF: DATA SHT 87-026-58, PAGE 2

PROGRAM: DWCHISQ1
BAY: 13A

DATASET	DATADATE	MEANTHK	SD	STDERR	DFM2
********	********	*******	*******	*******	****
D13A8601	11/15/86	.91908	.041422	.011488	2

CHISQ	CHI952	CHI992
******	******	******
.58781	5.99	9.21

OBS	EXP
***	******
2	2.7542
3	2.4627
2	2.5662
3	2.4627
3	2.7542

PTNOS
*****
1
2
3
4
5
6
7
8
9
10
11
12
13

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REF: DATA SHT 86-049-09

PROGRAM: DWCHISQ1
BAY: 13A

DATASET	DATADATE	MEANTHK	SD	STDERR	DFM2
********	********	*******	*******	*******	****
D13A8602	11/15/86	.9361	.045934	.010024	2

CHISQ	CHI952	CHI992
******	******	******
3.7292	5.99	9.21

OBS	EXP
***	******
4	4.4491
2	3.9782
7	4.1454
5	3.9782
3	4.4491

PTNOS	PTNOS
*****	*****
1	12
2	13
3	14
4	15
5	16
6	17
7	18
8	19
9	20
10	21
11	

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REF: DATA SHT 86-049-09

Calc No	Rev No	Sheet No
C-1302-187-5300-005	Ø	100 of --

COMPARISON OF MEANS USING TWO-TAILED T-TEST

BAY	DATASHTS	DATASETS	DATADATE	MEANTHK
13A	8604909	D13A8601	11/15/86	.91908
	8702658	D13A812	12/17/88	.90527

D13A8601
.903
.987
.934
.937
.862
.839
.919
.887
.926
.932
.897
.963
.962

D13A812

.941	.862	.88	.963	1.016	1.046	.9
.85	.9	1.141	.94	.892	.884	.802
.837	.959	.849	.861	.809	.784	.855
.907	.936	.908	.911	.843	.897	.951
.962	.834	.902	.927	.857	.925	.935
1.108	.863	.829	.998	.845	.876	.881
.908	.898	.839	.879	.899	.967	.902

F TEST FOR EQUAL POPULATION VARIANCES

VARA	VARB	DFA	DFB
.0050069	.0017157	48	12

F = 2.9182
F(.05/2, 48 , 12) = 2.8771
F(.01/2, 48 , 12) = 4.1754

TWO-TAILED T-TEST

DF = 60
ALPHA = .25229
T = .67134
T(.05/2, 60) = 2.0003
T(.01/2, 60) = 2.6603

$t < t(95)$

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COMPARISON OF MEANS USING TWO-TAILED T-TEST
****

BAY	DATASHTS	DATASETS	DATADATE	MEANTHK
***	********	********	********	*******
13A	8604909	D13A8602	11/15/86	.9361
	8702658	D13A812	12/17/88	.90527

D13A8602	D13A8602
********	********
.903	.963
.987	.962
.934	.943
.937	.932
.862	.98
.839	1.057
.919	.956
.887	.93
.926	.954
.932	.958
.897	

D13A812
****

.941	.862	.88	.963	1.016	1.046	.9
.85	.9	1.141	.94	.892	.884	.802
.837	.959	.849	.861	.809	.784	.855
.907	.936	.908	.911	.843	.897	.951
.962	.834	.902	.927	.857	.925	.935
1.108	.863	.829	.998	.845	.876	.881
.908	.898	.839	.879	.899	.967	.902

F TEST FOR EQUAL POPULATION VARIANCES
****

VARA	VARB	DFA	DFB
********	********	***	***
.0050069	.0021099	48	20

F = 2.3731
F(.05/2, 48 , 20) = 2.2557
F(.01/2, 48 , 20) = 2.9692

TWO-TAILED T-TEST
****
DF = 68
ALPHA = .035529
T = 1.8338
T(.05/2, 68) = 1.9955
T(.01/2, 68) = 2.6501 $t < t(95)$
January 13, 1989
6:00 PM

5.2.3 Bay 15D: 11/25/86 to 12/17/88

The 6"x6" grid data was taken for the first time in December 1988 during the 12R outage. This bay was considered for cathodic protection, but is not within the scope of the cathodic protection being installed. The primary purpose of this data is to establish a base line to monitor corrosion in the future. However, a previous 1-point measurement was taken in November 1986. The location of this point may have been somewhat removed from the location of the new 6"x6" grid data set. The previous measurement was compared with the new data set using the methods described in paragraph 2.6. The mean thickness was determined as described in paragraph 2.8.3.

(1) The new data are normally distributed.

(2) The previous measurement falls above the 99% upper bound of the new data.

(3) This implies that the corrosion may have occurred in the time period covered by this data. Therefore, the corrosion is classified as "Possible".

(4) The current mean thickness ± standard error is 1056.0 ±9.1 mils.

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PROGRAM: DWCHISQ1
BAY: 15D

DATASET	DATADATE	MEANTHK	SD	STDERR	DFM2
*******	********	*******	*****	********	****
D15D812	12/17/88	1.056	.0636	.0090857	2

CHISQ	CHI952	CHI992
******	******	******
1.8429	5.99	9.21

OBS	EXP
***	*******
10	10.381
11	9.2826
8	9.6726
7	9.2826
13	10.381

PTNOS	PTNOS	PTNOS	PTNOS	PTNOS
*****	*****	*****	*****	*****
1	11	21	31	41
2	12	22	32	42
3	13	23	33	43
4	14	24	34	44
5	15	25	35	45
6	16	26	36	46
7	17	27	37	47
8	18	28	38	48
9	19	29	39	49
10	20	30	40	

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PROGRAM: OCDWCONF
BAY: 15D

D15D812

****

1.127	1.131	1.127	1.136	1.143	1.125	1.139
1.091	1.11	1.088	1.142	1.127	1.128	1.133
1.033	1.035	1.03	1.064	1.105	1.097	1.091
.989	1.023	.995	1.036	1.036	1.09	1.066
.996	1.022	.842	1.053	1.113	1.063	1.047
.944	.994	1.035	1.047	1.026	1.054	1.038
.955	.968	.96	.99	1.016	1.071	1.074

MEAN THICKNESS = 1.056
STANDARD ERROR OF THE MEAN = .0090857
T(.05/2, 48)= 2.0106
T(.01/2, 48)= 2.6822

CONFIDENCE INTERVALS FOR THE MEAN
****

95% UPPER BOUND = 1.0743
95% LOWER BOUND = 1.0378

99% UPPER BOUND = 1.0804
99% LOWER BOUND = 1.0317

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12:48 PM

PREVIOUS DATA

DATA SHT : 86-049-13
DATE : 11-25-86
LOC'N : 3" ABOVE CURB, IN CORNER
THICKNESS : 1.089"

EVALUATION

PREVIOUS DATA PT FALLS ABOVE 99% UPPER BOUND.
IMPLIES CORROSION IS "POSSIBLE".

5.2.4 Bay 17A: 11/25/86 to 12/17/88

The 6"x6" grid data was taken for the first time in December 1988 during the 12R outage. This bay was considered for cathodic protection, but is not within the scope of the cathodic protection being installed. The primary purpose of this data is to establish a base line to monitor corrosion in the future. However, a previous 1-point measurement was taken in November 1986. The location of this point may have been somewhat removed from the location of the new 6"x6" grid data set. The previous measurement was compared with the new data set using the methods described in paragraph 2.6. The mean thickness was determined as described in paragraph 2.8.3.

(1) The new data are not normally distributed. However, the top three rows and the bottom four rows are each normally distributed.

(2) The previous measurement falls below the 99% confidence interval for the top three rows, and above the 99% confidence interval for the bottom four rows.

(3) The corrosion is classified as "Indeterminable".

(4) The current mean thickness ± standard error is 1133.1 ±6.9 milsfor the top three rows and 957.4 ±9.2 mils for the bottom four rows.

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PROGRAM: DWCHISQ1
BAY: 17A

DATASET	DATADATE	MEANTHK	SD	STDERR	DFM2
*******	********	*******	*******	*******	****
D17A812	12/17/88	1.0327	.097293	.013899	2

CHISQ	CHI952	CHI992
******	******	******
11.601	5.99	9.21

OBS	EXP
***	*******
12	10.381
12	9.2826
4	9.6726
4	9.2826
17	10.381

PTNOS	PTNOS	PTNOS	PTNOS	PTNOS
*****	*****	*****	*****	*****
1	11	21	31	41
2	12	22	32	42
3	13	23	33	43
4	14	24	34	44
5	15	25	35	45
6	16	26	36	46
7	17	27	37	47
8	18	28	38	48
9	19	29	39	49
10	20	30	40	

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PROGRAM: DWCHISQ1
BAY: 17A

DATASET	DATADATE	MEANTHK	SD	STDERR	DFM2
*******	********	*******	*******	********	****
D17A812	12/17/88	1.1331	.031463	.0068657	2

CHISQ	CHI952	CHI992
******	******	******
5.4566	5.99	9.21

OBS	EXP
***	******
4	4.4491
2	3.9782
3	4.1454
8	3.9782
4	4.4491

PTNOS	PTNOS
*****	*****
1	12
2	13
3	14
4	15
5	16
6	17
7	18
8	19
9	20
10	21
11	

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PROGRAM: DWCHISQ1
BAY: 17A

DATASET	DATADATE	MEANTHK	SD	STDERR	DFM2
*******	********	*******	*******	********	****
D17A812	12/17/88	.95736	.048671	.0091979	2

CHISQ	CHI952	CHI992
******	******	******
.65529	5.99	9.21

OBS	EXP
***	******
6	5.9321
4	5.3043
5	5.5272
6	5.3043
7	5.9321

PTNOS	PTNOS	PTNOS
*****	*****	*****
22	32	41
23	33	42
24	34	43
25	35	44
26	36	45
27	37	46
28	38	47
29	39	48
30	40	49
31		

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10/25/06 14:26:07

Calc No	Rev No	Sheet No
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PROGRAM: OCDWCONF
BAY: 17A

D17A812

****

1.168	1.157	1.16	1.142	1.141	1.173	1.172
1.129	1.153	1.135	1.148	1.134	1.148	1.142
1.063	1.146	1.113	1.115	1.098	1.089	1.069
1	.993	1.001	1.011	1.035	1.006	.968
.976	.925	.934	.965	.89	.969	1.023
.879	.983	.916	.873	.846	.952	1.012
.992	.97	.951	.924	.929	.912	.971

MEAN THICKNESS = 1.0327
STANDARD ERROR OF THE MEAN = .013899
T(.05/2, 48)= 2.0106
T(.01/2, 48)= 2.6822

CONFIDENCE INTERVALS FOR THE MEAN
****

95% UPPER BOUND = 1.0606
95% LOWER BOUND = 1.0047

99% UPPER BOUND = 1.07
99% LOWER BOUND = .99539

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1:30 PM

PROGRAM: OCDWCONF
BAY: 17A TOP3

D17ATOP3

****

1.168	1.157	1.16	1.142	1.141	1.173	1.172
1.129	1.153	1.135	1.148	1.134	1.148	1.142
1.063	1.146	1.113	1.115	1.098	1.089	1.069

MEAN THICKNESS = 1.1331
STANDARD ERROR OF THE MEAN = .0068657
T(.05/2, 20)= 2.086
T(.01/2, 20)= 2.8453

CONFIDENCE INTERVALS FOR THE MEAN
****

95% UPPER BOUND = 1.1474
95% LOWER BOUND = 1.1188

99% UPPER BOUND = 1.1526
99% LOWER BOUND = 1.1136

January 20, 1989
1:36 PM

THE 11-25-86 THICKNESS OF 0.999"
FALLS BELOW THE 99% LOWER BOUND.

PROGRAM: OCDWCONF
BAY: 17A BOT4

D17ABOT4

****

1	.993	1.001	1.011	1.035	1.006	.968
.976	.925	.934	.965	.89	.969	1.023
.879	.983	.916	.873	.846	.952	1.012
.992	.97	.951	.924	.929	.912	.971

MEAN THICKNESS = .95736
STANDARD ERROR OF THE MEAN = .0091979
T(.05/2, 27)= 2.0518
T(.01/2, 27)= 2.7707

CONFIDENCE INTERVALS FOR THE MEAN
****

95% UPPER BOUND = .97623
95% LOWER BOUND = .93848

99% UPPER BOUND = .98284
99% LOWER BOUND = .93187

January 20, 1989
1:36 PM

THE 11-25-86 THICKNESS OF 0.999"
FALLS ABOVE THE 99% UPPER BOUND.

5.3 6"x6" Grids at Upper Elevations

5.3.1 Bay 5 51' Elevation: 11/01/87 to 10/8/88

Three 49-point data sets were available for this bay covering the time period from November 1, 1987 to October 8, 1988. The data were analyzed as described in paragraphs 2.4 and 2.8.1.

(1) Except for the first data set, the data are normally distributed.

(2) The regression model is appropriate.

(3) The regression model explains 99% of the total variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 750.0 ±0.02 mils.

(6) The corrosion rate ± standard error is -4.3 ±0.03 mpy.

(7) One data point was determined to be statistically different from the mean thickness. The probability of this occurring due to expected random error is less than 1% at each specific time.

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```
PROGRAM: DWCHISQ                                BAY 5  ELEV 51'
ENTER NAME OF DATA LIST ud12
ENTER PT NUMBER LIST ints(1,49)
ENTER NAME OF DATE LIST date51

 N     UD12
 *   ********
 1   E8702626
 2   E8702640
 3   E8702650

ENTER NO. OF DESIRED DATA 1,2,3

             DATE51    MEANTHK      SD        STDERR     DFM2
 ********   ********   *******   ********   ********    ****
 E8702626   11/01/87   .75385    .024144    .0037706     2
 E8702640   7/12/88    .75095    .0086446   .0013339     2
 E8702650   10/08/88   .75019    .01716     .0026478     2

  CHISQ    CHI952   CHI992
 *******   ******   ******
 25.367    5.99      9.21
  1.608    5.99      9.21
  9.1733   5.99      9.21

    OBS              EXP
 ********   ********************
  4  7  7   8.6863 8.8981 8.8981
  4 10  3   7.767  7.9565 7.9565
 11  9 15   8.0934 8.2908 8.2908
 19  6  7   7.767  7.9565 7.9565
  3 10 10   8.6863 8.8981 8.8981

GRAND MEAN THICKNESS = .75167
STANDARD ERROR OF THE GRAND MEAN = .001116

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 1:00 PM
```

BAY 5 ELEV 51'

E8702626

****

.765	.735	.764	.735	.754	.772	.761
.76	.706	.761	.748	.77	.747	.757
.765	.763	.766	.73	.777	0	.767
.786	.761	.759	.716	0	0	0
.77	.768	.761	.758	0	0	0
.776	.763	.75	.739	.766	.758	.748
.638	0	.751	.76	.758	.758	.761

E8702640

****

.757	.728	.765	.746	.749	.765	.743
.756	.746	.754	.745	.761	.747	.748
.759	.761	.76	.747	.75	0	.753
.759	.748	.752	.75	0	0	0
.759	.748	.753	.751	0	0	0
.768	.762	.744	.731	.754	.748	.737
.745	.739	.741	.754	.753	.75	.754

E8702650

****

.772	.73	.765	.748	.747	.764	.75
.752	.696	.753	.743	.764	.723	.778
.756	.756	.758	.721	.747	0	.745
.759	.746	.756	.706	0	0	0
.763	.764	.755	.751	0	0	0
.769	.75	.742	.73	.752	.746	.734
.746	.77	.774	.752	.772	.749	.754

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 51

DEP VARIABLE: MEASURE

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	8.66615345	8.66615345	16886.103	0.0049
ERROR	1	0.000513212	0.000513212		
C TOTAL	2	8.66666667			

ROOT MSE	0.02265419	R-SQUARE	0.9999
DEP MEAN	751.6667	ADJ R-SQ	0.9999
C.V.	0.003013861		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|	TYPE I SS	STANDARDIZED ESTIMATE
INTERCEP	1	753.99542	0.02218620	33984.879	0.0001	1695008.33	0
YEAR	1	-4.27817350	0.03292257	-129.947	0.0049	8.66615345	-0.99997039

COLLINEARITY DIAGNOSTICS

NUMBER	EIGENVALUE	CONDITION NUMBER	VAR PROP INTERCEP	VAR PROP YEAR
1	1.807748	1.000000	0.0961	0.0961
2	0.192252	3.066429	0.9039	0.9039

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT	RESIDUAL
1	754.0	754.0	0.0222	753.7	754.3	753.6	754.4	.0045809
2	751.0	751.0	0.0140	750.8	751.2	750.7	751.4	-0.0178
3	750.0	750.0	0.0184	749.8	750.2	749.6	750.4	0.0132

SUM OF RESIDUALS 2.27374E-13
SUM OF SQUARED RESIDUALS 0.0005132119
PREDICTED RESID SS (PRESS) 0.01488667

$t(n-2) = 12.706$

[illegible] 750 ± 0.02 mils

10/25/86 14:28:07

Calc No C-1302-187-5300-005 Rev No 0 Sheet No 1/5

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 51

DEP VARIABLE: MEASURE

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	8.66615345	8.66615345	16886.103	0.0049
ERROR	1	0.000513212	0.000513212		
C TOTAL	2	8.66666667			

ROOT MSE	0.02265419	R-SQUARE	0.9999
DEP MEAN	751.6667	ADJ R-SQ	0.9999
C.V.	0.003013861		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	753.99542	0.02218620	33984.879	0.0001
YEAR	1	-4.27817350	0.03292257	-129.947	0.0049

<table>
<tr><th>OBS</th><th>ACTUAL</th><th>PREDICT VALUE</th><th>STD ERR PREDICT</th><th>LOWER95% MEAN</th><th>UPPER95% MEAN</th><th>LOWER95% PREDICT</th><th>UPPER95% PREDICT</th><th>RESIDUAL</th><th>STD ERR RESIDUAL</th><th>STUDENT RESIDUAL</th><th>-2-1-0 1 2</th></tr>
<tr><td>1</td><td>754.0</td><td>754.0</td><td>0.0222</td><td>753.7</td><td>754.3</td><td>753.6</td><td>754.4</td><td>.0045809</td><td>.0045809</td><td>1.0000</td><td>| |*</td></tr>
<tr><td>2</td><td>751.0</td><td>751.0</td><td>0.0140</td><td>750.8</td><td>751.2</td><td>750.7</td><td>751.4</td><td>-0.0178</td><td>0.0178</td><td>-1.0000</td><td>| *|</td></tr>
<tr><td>3</td><td>750.0</td><td>750.0</td><td>0.0184</td><td>749.8</td><td>750.2</td><td>749.6</td><td>750.4</td><td>0.0132</td><td>0.0132</td><td>1.0000</td><td>| |*</td></tr>
</table>

OBS	COOK'S D
1	11.728
2	0.309
3	0.966

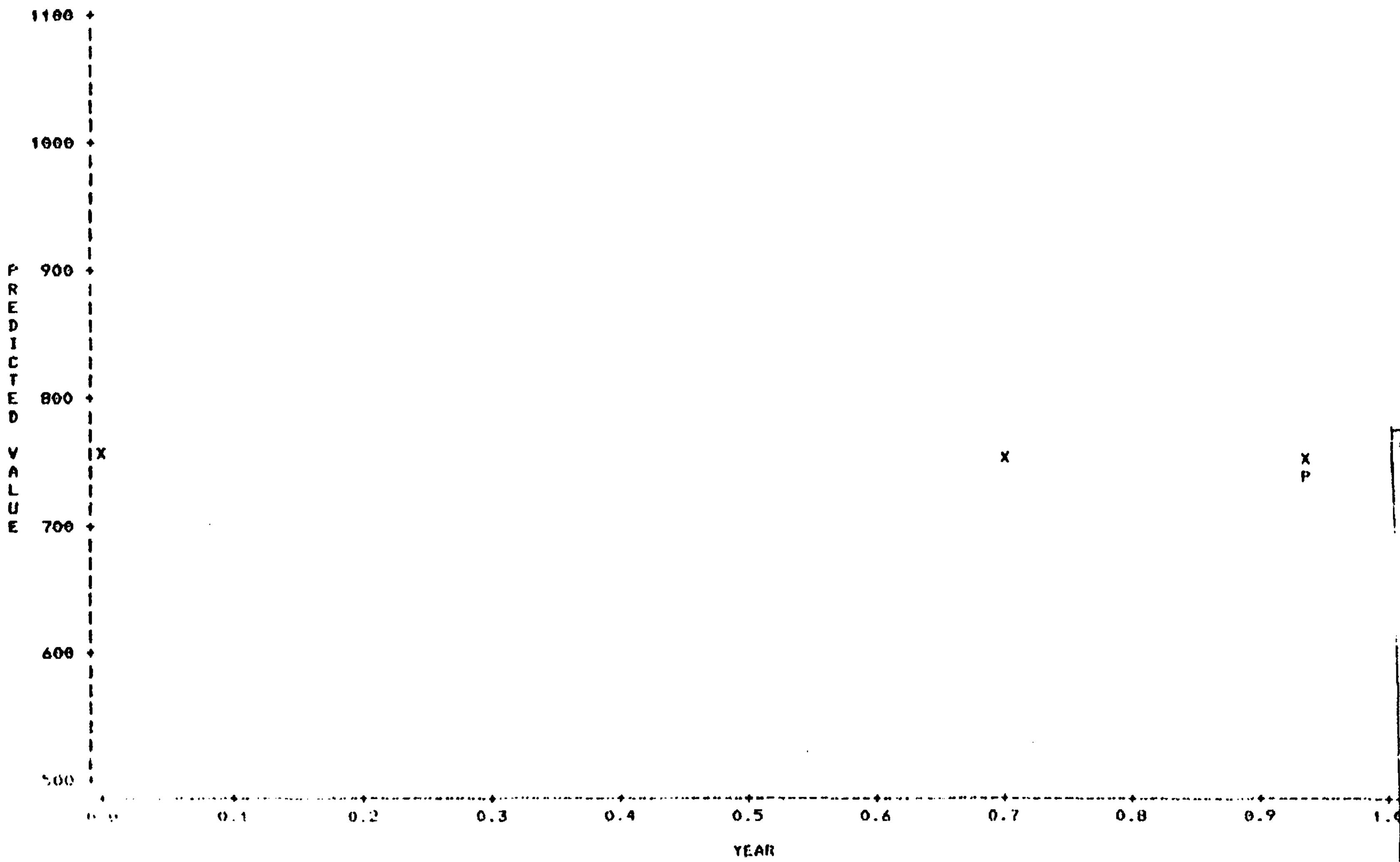
SUM OF RESIDUALS	2.27374E-13
SUM OF SQUARED RESIDUALS	0.0005132119
PREDICTED RESID SS (PRESS)	0.01488667

10/25/06 14:28:07

Calc No C-1302-187-5380-005 Rev No Ø Sheet No 116

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 51

PLOT OF MEASURE*YEAR	SYMBOL USED IS X
PLOT OF PRED*YEAR	SYMBOL USED IS P
PLOT OF U95*YEAR	SYMBOL USED IS U
PLOT OF L95*YEAR	SYMBOL USED IS L



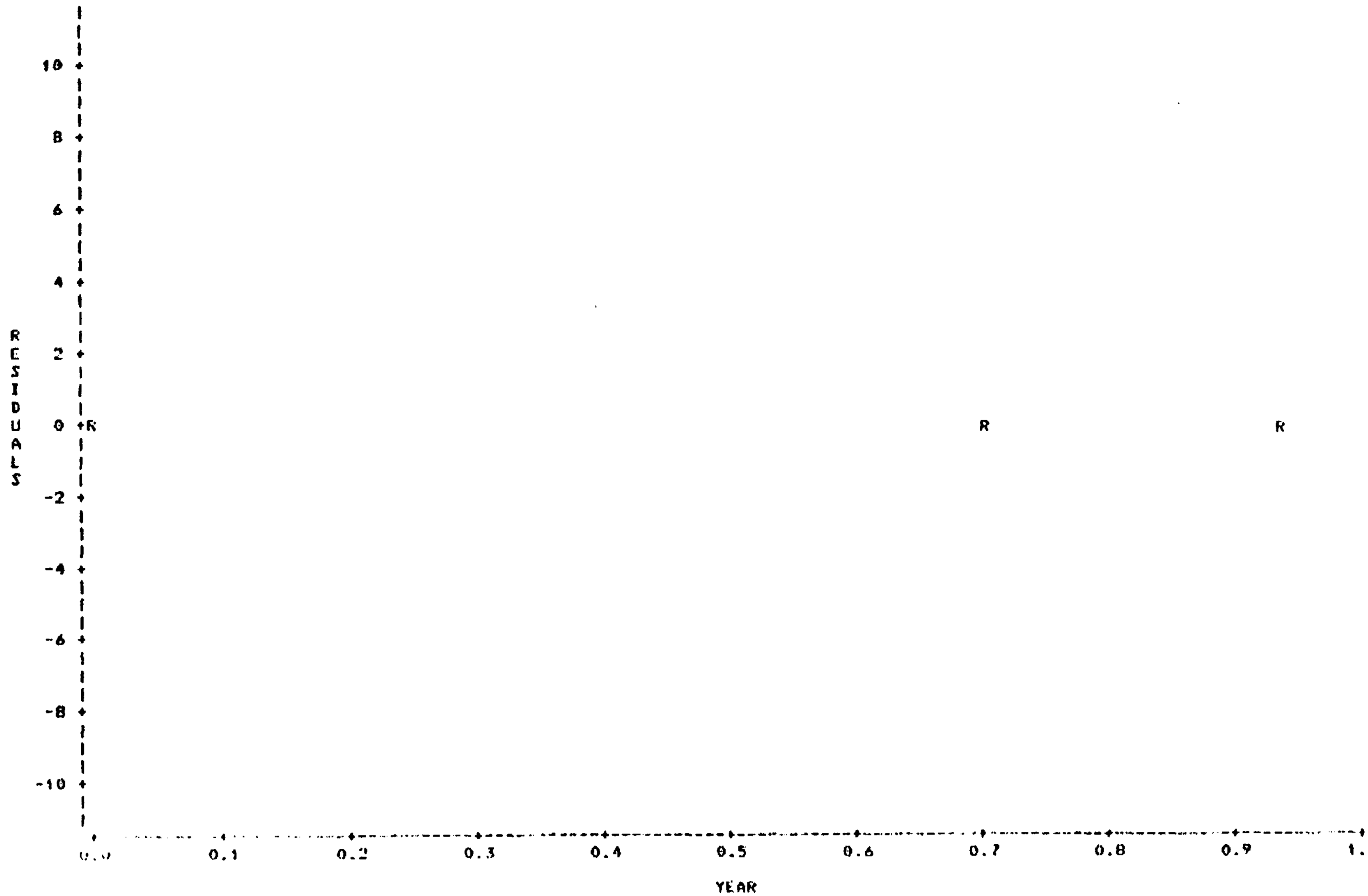
NOTE 8 OBS HIDDEN

10/25/06 14:28:07

Calc No C-1302-187-5300-005 Rev No 0 Sheet No 117

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 51

PLOT OF RESID*YEAR   SYMBOL USED IS R



10/25/06 14:28:07

Calc No C-1302-187-5300-005 | Rev No Ø | Sheet No 118

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 51

UNIVARIATE

VARIABLE=RESID RESIDUALS

MOMENTS

N	3	SUM WGTS	3
MEAN	7.579E-14	SUM	2.274E-13
STD DEV	0.0160189	VARIANCE	.000256606
SKEWNESS	-1.18162	KURTOSIS	.
USS	.000513212	CSS	.000513212
CV	99999	STD MEAN	0.00924853
T:MEAN=0	8.195E-12	PROB>|T|	1
SGN RANK	0	PROB>|S|	1
NUM ^= 0	3		
W:NORMAL	0.938649	PROB<W	0.452

QUANTILES(DEF=4)

100% MAX	0.0132295	99%	0.0132295
75% Q3	0.0132295	95%	0.0132295
50% MED	0.00458089	90%	0.0132295
25% Q1	-0.0178104	10%	-0.0178104
0% MIN	-0.0178104	5%	-0.0178104
		1%	-0.0178104
RANGE	0.0310398		
Q3-Q1	0.0310398		
MODE	-0.0178104		

EXTREMES

LOWEST	HIGHEST
-0.0178104	.
0.00458089	.
0.0132295	-0.0178104
.	0.00458089
.	0.0132295

```
STEM LEAF                      #         BOXPLOT                         NORMAL PROBABILITY PLOT
   1 3                         1         +-----+         0.0125+                              ++*
   0 5                         1         |     |               |                          +++
   0                                     *-----*               |                      ****
  -0                                     |  +  |        -0.0025+                  ++++
  -0                                     |     |               |               +++
  -1                                     |     |               |           +++
  -1 8                         1         +-----+        -0.0175+       ++++*
     ----+----+----+----+                                      +----+----+----+----+----+----+----+----+----+----+
  MULTIPLY STEM.LEAF BY 10**-02                                     -2        -1         0        +1        +2
```

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Calc No C-1302-187-5300-005 Rev No 0 Sheet No 49 of --

Probably Bad Reading Since it occurs once & is next to a bad reading

E8702624

.765	.735	.764	.735	.754	.772	.761
.76	(.746)	.761	.748	.77	.747	.757
.765	.763	.766	.73	.777	0	.767
.784	.761	.759	.715	0	0	0
.77	.768	.761	.758	0	0	0
.774	.763	.75	.739	.766	.758	.748
(.338)	0	.751	.76	.759	.759	.761

$.75385 \pm 2.58 * 0.024144 = 0.69156$

E8702640

.757	[.728]	.765	.746	.749	.765	.743
.756	.746	.754	.745	.761	.747	.748
.759	.761	.76	.747	.75	0	.753
.759	.748	.752	.75	0	0	0
.759	.748	.753	.751	0	0	0
.768	.762	.744	.731	.754	.748	.737
.745	.739	.741	.754	.753	.75	.754

$.75095 \pm 2.58 * 0.0086446 = 0.728647$

E8702650

.772	.73	.765	.748	.747	.764	.75
.752	(.696)	.753	.743	.764	.723	.778
.756	.756	.758	.721	.747	0	.745
.759	.746	.756	[.706]	0	0	0
.763	.764	.755	.751	0	0	0
.769	.75	.742	.73	.752	.746	.734
.746	.77	.774	.752	.772	.749	.754

$0.75019 \pm 2.58 * 0.01716 = 0.705917$

Low Reading

5.3.2 Bay 9 87' Elevation: 11/6/87 to 10/8/88

Three 49-point data sets were available for this bay covering the time period from November 6, 1987 to October 8, 1988. The data were analyzed as described in paragraphs 2.4 and 2.8.2.

(1) The data are normally distributed.

(2) The mean model is appropriate than the regression model.

(3) There was no significant corrosion from November 6, 1987 to October 8, 1988.

(4) The current mean thickness ± standard error is 620.3 ±1.0 mils.

PROGRAM: DWCHISQ
ENTER NAME OF DATA LIST u20
ENTER PT NUMBER LIST ints(1,49)
ENTER NAME OF DATE LIST date20

BAY 9 ELEV 87'

N	U20
*	********
1	D8702630
2	D8702641
3	D8702651

ENTER NO. OF DESIRED DATA 1,2,3

	DATE20	MEANTHK	SD	STDERR	DFM2
********	********	*******	*******	********	****
D8702630	11/06/87	.61892	.014675	.0020965	2
D8702641	7/20/88	.62233	.014447	.0020639	2
D8702651	10/8/88	.61957	.013885	.0019836	2

CHISQ	CHI952	CHI992
******	******	******
7.4024	5.99	9.21
2.8986	5.99	9.21
1.2047	5.99	9.21

OBS			EXP		
********			**********************		
9	8	10	10.381	10.381	10.381
8	8	7	9.2826	9.2826	9.2826
13	14	12	9.6726	9.6726	9.6726
12	10	10	9.2826	9.2826	9.2826
7	9	10	10.381	10.381	10.381

GRAND MEAN THICKNESS = .62027
STANDARD ERROR OF THE GRAND MEAN = .0010444

January 18, 1989
1:03 PM

Calc No	Rev No	Sheet No
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BAY 9 ELEV 87'

D8702630

****

.622	.628	.629	.604	.627	.601	.634
.608	.615	.618	.617	.621	.585	.639
.618	.614	.615	.628	.628	.604	.631
.616	.604	.62	.585	.627	.626	.623
.624	.607	.666	.641	.618	.641	.61
.624	.618	.617	.622	.616	.629	.641
.608	.609	.593	.598	.621	.626	.611

D8702641

****

.633	.625	.625	.627	.625	.601	.631
.605	.614	.619	.617	.633	.638	.638
.612	.628	.615	.623	.628	.627	.622
.623	.66	.628	.585	.633	.627	.619
.623	.603	.647	.639	.616	.633	.599
.623	.617	.62	.638	.614	.625	.637
.615	.603	.592	.597	.622	.643	.622

D8702651

****

.635	.629	.629	.607	.633	.601	.634
.606	.616	.618	.617	.623	.587	.639
.609	.62	.619	.626	.627	.61	.623
.62	.6	.623	.584	.63	.637	.624
.626	.615	.644	.64	.618	.635	.6
.629	.617	.617	.624	.615	.628	.639
.614	.608	.593	.598	.622	.634	.616

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 20

DEP VARIABLE: MEASURE

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	0.50567679	0.50567679	0.092	0.8125
ERROR	1	5.49432321	5.49432321		
C TOTAL	2	6.00000000			

ROOT MSE	2.343997	R-SQUARE	0.0843
DEP MEAN	620	ADJ R-SQ	-0.8314
C.V.	0.3780641		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|	TYPE I SS	STANDARDIZED ESTIMATE
INTERCEP	1	619.43455	2.30336565	268.926	0.0024	1153200.00	0
YEAR	1	1.04263256	3.43678113	0.303	0.8125	0.50567679	0.29030926

COLLINEARITY DIAGNOSTICS

NUMBER	EIGENVALUE	CONDITION NUMBER	VAR PROP INTERCEP	VAR PROP YEAR
1	1.809199	1.000000	0.0954	0.0954
2	0.190801	3.079305	0.9046	0.9046

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT	RESIDUAL
1	619.0	619.4	2.3034	590.2	648.7	577.7	661.2	-0.4345
2	622.0	620.2	1.4629	601.6	638.8	585.1	655.3	1.8314
3	619.0	620.4	1.8823	596.5	644.3	582.2	658.6	-1.3969

SUM OF RESIDUALS	2.27374E-13
SUM OF SQUARED RESIDUALS	5.494323
PREDICTED RESID SS (PRESS)	184.3369

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Calc No C-1302-187-5380-005 Rev No 0 Sheet No 124

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 20

DEP VARIABLE: MEASURE

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	0.50567679	0.50567679	0.092	0.8125
ERROR	1	5.49432321	5.49432321		
C TOTAL	2	6.00000000			

ROOT MSE	2.343997	R-SQUARE	0.0843
DEP MEAN	620	ADJ R-SQ	-0.8314
C.V.	0.3780641		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	619.43455	2.30336565	268.926	0.0024
YEAR	1	1.04263256	3.43678113	0.303	0.8125

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT	RESIDUAL	STD ERR RESIDUAL	STUDENT RESIDUAL	-2-1-0 1 2
1	619.0	619.4	2.3034	590.2	648.7	577.7	661.2	-0.4345	0.4345	-1.0000	| *|
2	622.0	620.2	1.4629	601.6	638.8	585.1	655.3	1.8314	1.8314	1.0000	| |*
3	619.0	620.4	1.8823	596.5	644.3	582.2	658.6	-1.3969	1.3969	-1.0000	| *|

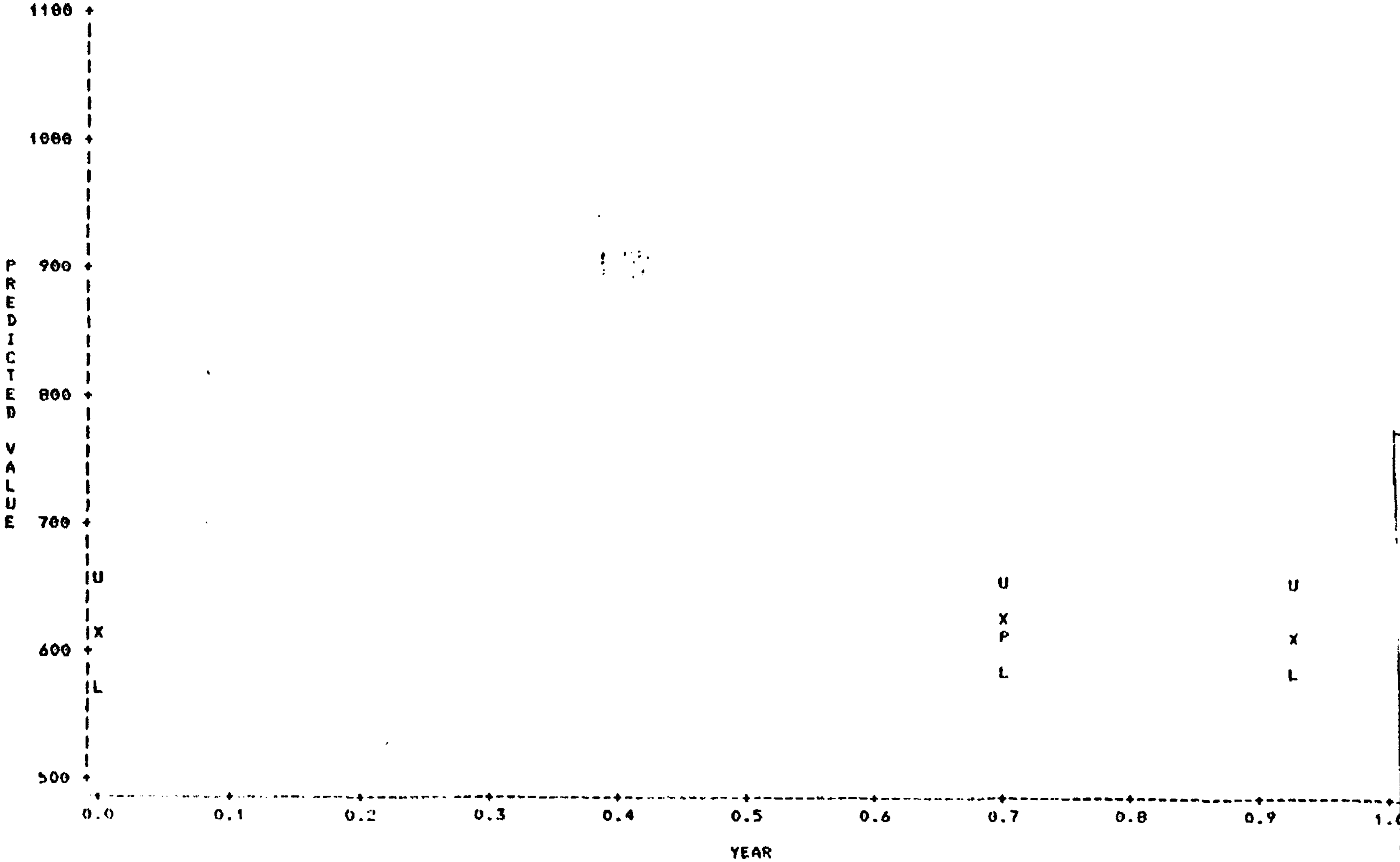
OBS	COOK'S D
1	14.048
2	0.319
3	0.908

SUM OF RESIDUALS	2.27374E-13
SUM OF SQUARED RESIDUALS	5.494323
PREDICTED RESID SS (PRESS)	184.3369

Calc No C-1302-187-5380-005 Rev No 0 Sheet No 125

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 20

PLOT OF MEASURE*YEAR SYMBOL USED IS X
PLOT OF PRED*YEAR SYMBOL USED IS P
PLOT OF U95*YEAR SYMBOL USED IS U
PLOT OF L95*YEAR SYMBOL USED IS L



NOTE 2 OBS HIDDEN

Calc No C-1302-187-5300-005 Rev No 0 Sheet No 120

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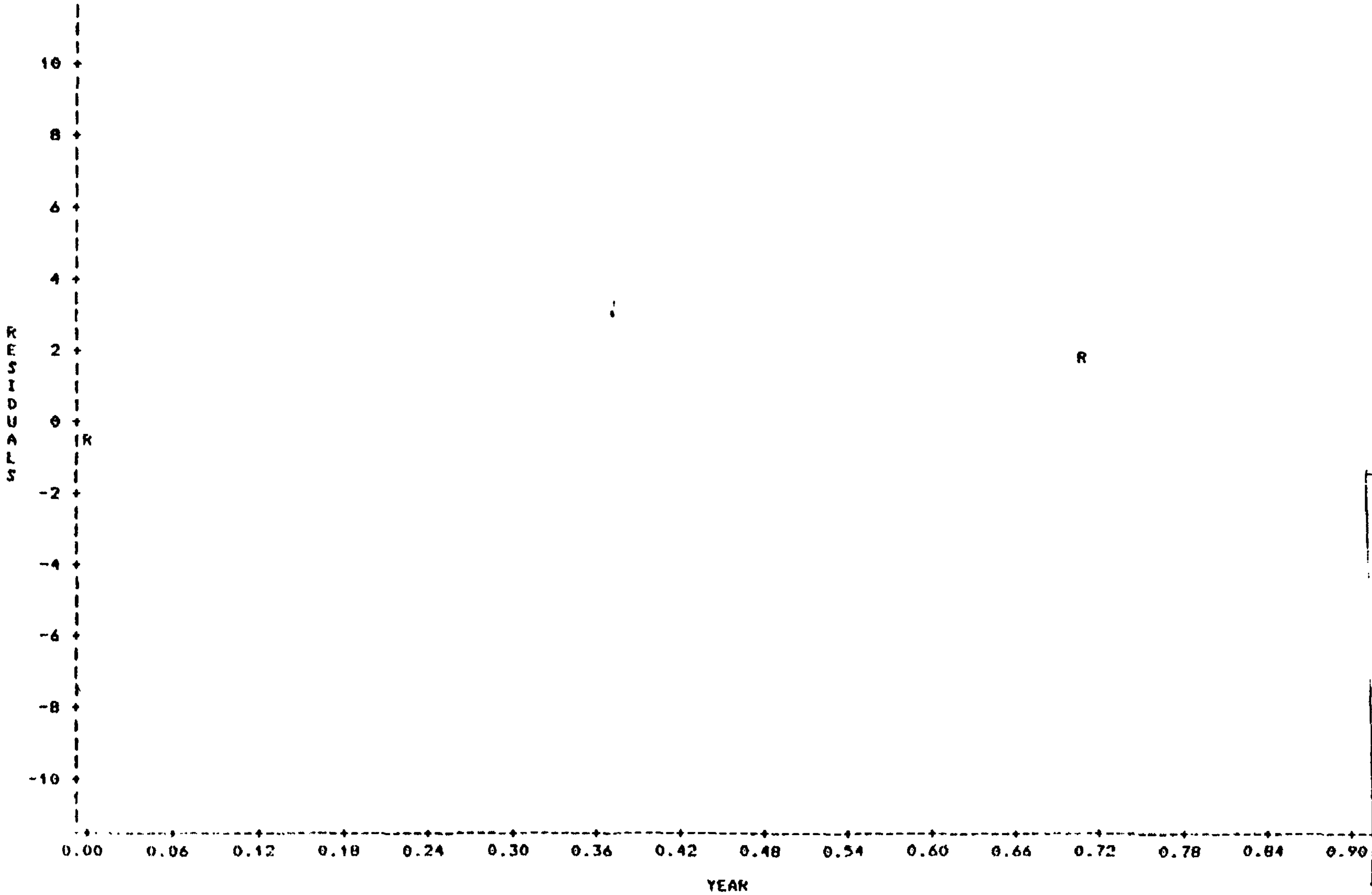
LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 20

PLOT OF RESID*YEAR SYMBOL USED IS R



Calc No C-1302-187-5300-005 Rev No 0 Sheet No 127

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 20

UNIVARIATE

VARIABLE=RESID RESIDUALS

MOMENTS

N	3	SUM WGTS	3
MEAN	7.579E-14	SUM	2.274E-13
STD DEV	1.65746	VARIANCE	2.74716
SKEWNESS	1.0987	KURTOSIS	.
USS	5.49432	CSS	5.49432
CV	99999	STD MEAN	0.956933
T:MEAN=0	7.920E-14	PROB>|T|	1
SGN RANK	0	PROB>|S|	1
NUM ^= 0	3		
W:NORMAL	0.948429	PROB<W	0.475

QUANTILES(DEF=4)

100% MAX	1.83144	99%	1.83144
75% Q3	1.83144	95%	1.83144
50% MED	-0.434546	90%	1.83144
25% Q1	-1.3969	10%	-1.3969
0% MIN	-1.3969	5%	-1.3969
		1%	-1.3969
RANGE	3.22834		
Q3-Q1	3.22834		
MODE	-1.3969		

EXTREMES

LOWEST	HIGHEST
-1.3969	.
-0.434546	.
1.83144	-1.3969
.	-0.434546
.	1.83144

```
STEM LEAF                    #          BOXPLOT
   1 8                       1          +-----+
   1                                    |     |
   0                                    |     |
   0                                    |  +  |
  -0 4                       1          *-----*
  -0                                    |     |
  -1 4                       1          +-----+
     ----+----+----+----+
```

```
                         NORMAL PROBABILITY PLOT
 1.75+                                             *+++
     |                                         +++
     |                                     +++
 0.25+                                 ++++
     |                              +++*
     |                          +++
-1.25+                      *++
     +----+----+----+----+----+----+----+----+----+----+
         -2        -1         0        +1        +2
```

10/25/06 14:26:07

Calc No C-1302-187-5380-005 Rev No 0 Sheet No 128

5.3.3 Bay 13 87' Elevation: 11/10/87 to 10/8/88

Three 49-point data sets were available for this bay covering the time period from November 10, 1987 to October 8, 1988. The data were analyzed as described in paragraphs 2.4 and 2.8.2.

(1) The data are normally distributed.

(2) The mean model is more appropriate than the regression model.

(3) There was no significant corrosion from November 10, 1987 to October 8, 1988.

(4) The current mean thickness $\pm$ standard error is 635.6 $\pm$0.7 mils.

10/25/06 14:28:07

Calc No	Rev No	Sheet No
C-1302-187-5300-005	Ø	130

```
PROGRAM: DWCHISQ
ENTER NAME OF DATA LIST u28
ENTER PT NUMBER LIST ints(1,49)
ENTER NAME OF DATE LIST date28
```

Bay 13 ELEV 87'

```
N     U28
*   ********
1   D8702637
2   D8702642
3   D8702652

ENTER NO. OF DESIRED DATA 1,2,3

               DATE28     MEANTHK      SD        STDERR      DFM2
********     ********    *******    *******    ********    ****
D8702637     11/10/87    .637       .019096    .002728     2
D8702642     7/20/88     .63453     .01956     .0028532    2
D8702652     10/8/88     .63533     .018936    .0027051    2

 CHISQ    CHI952   CHI992
******    ******   ******
1.2401    5.99     9.21
7.7853    5.99     9.21
2.477     5.99     9.21

   OBS                   EXP
********    *********************
 9  7  8    10.381   9.9574  10.381
 8  9  7     9.2826  8.9037   9.2826
 9  6 12     9.6726  9.2778   9.6726
12 16 12     9.2826  8.9037   9.2826
11  9 10    10.381   9.9574  10.381

GRAND MEAN THICKNESS = .63562
STANDARD ERROR OF THE GRAND MEAN = 7.2738E-4

January 18, 1989
 1:05 PM
```

BAY 13 ELEV 87'

D8702637

.602	.613	.645	.643	.643	.653	.633
.627	.639	.652	.653	.625	.642	.62
.623	.64	.649	.621	.646	.651	.655
.602	.637	.63	.575	.61	.656	.654
.629	.627	.652	.629	.649	.655	.66
.59	.639	.638	.662	.651	.641	.661
.641	.639	.628	.66	.653	.618	.652

D8702642

.596	.608	.643	.64	.643	.645	.627
.626	.638	.648	.648	0	0	.621
.624	.641	.647	.617	.646	.649	.652
.596	.635	.633	.572	.602	.655	.651
.627	.624	.647	.626	.646	.652	.657
.587	.643	.64	.657	.654	.636	.652
.636	.632	.621	.658	.65	.629	.646

D8702652

.595	.611	.647	.647	.646	.656	.623
.632	.643	.65	.651	.63	.64	.626
.628	.645	.651	.62	.646	.649	.656
.6	.636	.638	.579	.601	.657	.654
.631	.626	.642	.627	.649	.657	.659
.585	.639	.639	.657	.642	.639	.652
.638	.633	.628	.637	.634	.612	.648

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 28

DEP VARIABLE: MEASURE

$$F = \frac{\Sigma(\hat{Y}-\bar{Y})^2}{\Sigma(Y_i-\hat{Y})^2} = \frac{MSTR}{MSE}$$

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	3.32654781	3.32654781	2.482	0.3600
ERROR	1	1.34011886	1.34011886		
C TOTAL	2	4.66666667			.05

ROOT MSE	1.157635	R-SQUARE	0.7128
DEP MEAN	635.3333	ADJ R-SQ	0.4257
C.V.	0.1822091		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|	TYPE I SS	STANDARDIZED ESTIMATE
INTERCEP	1	636.78260	1.13703886	560.036	0.0011	1210945.33	0
YEAR	1	-2.70891515	1.71937330	-1.576	0.3600	3.32654781	-0.84429359

COLLINEARITY DIAGNOSTICS

NUMBER	EIGENVALUE	CONDITION NUMBER	VAR PROP INTERCEP	VAR PROP YEAR
1	1.809000	1.000000	0.0955	0.0955
2	0.191000	3.077534	0.9045	0.9045

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT	RESIDUAL
1	637.0	636.8	1.1370	622.3	651.2	616.2	657.4	0.2174
2	634.0	634.9	0.7215	625.7	644.1	617.6	652.2	-0.9053
3	635.0	634.3	0.9311	622.5	646.1	615.4	653.2	0.6879

SUM OF RESIDUALS	1.13687E-13
SUM OF SQUARED RESIDUALS	1.340119
PREDICTED RESID SS (PRESS)	43.98571

$t_{95}(n-2) = 12.706$

10/25/06 14:28:07

Calc No C-1302-187-5300-005 Rev No 0 Sheet No B2

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 28

DEP VARIABLE: MEASURE

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	3.32654781	3.32654781	2.482	0.3600
ERROR	1	1.34011886	1.34011886		
C TOTAL	2	4.66666667			

ROOT MSE	1.157635	R-SQUARE	0.7128
DEP MEAN	635.3333	ADJ R-SQ	0.4257
C.V.	0.1822091		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	636.78260	1.13703886	560.036	0.0011
YEAR	1	-2.70891515	1.71937330	-1.576	0.3600

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT	RESIDUAL	STD ERR RESIDUAL	STUDENT RESIDUAL	-2-1-0 1 2
1	637.0	636.8	1.1370	622.3	651.2	616.2	657.4	0.2174	0.2174	1.0000	| |*
2	634.0	634.9	0.7215	625.7	644.1	617.6	652.2	-0.9053	0.9053	-1.0000	| *|
3	635.0	634.3	0.9311	622.5	646.1	615.4	653.2	0.6879	0.6879	1.0000	| |*

OBS	COOK'S D
1	13.678
2	0.318
3	0.916

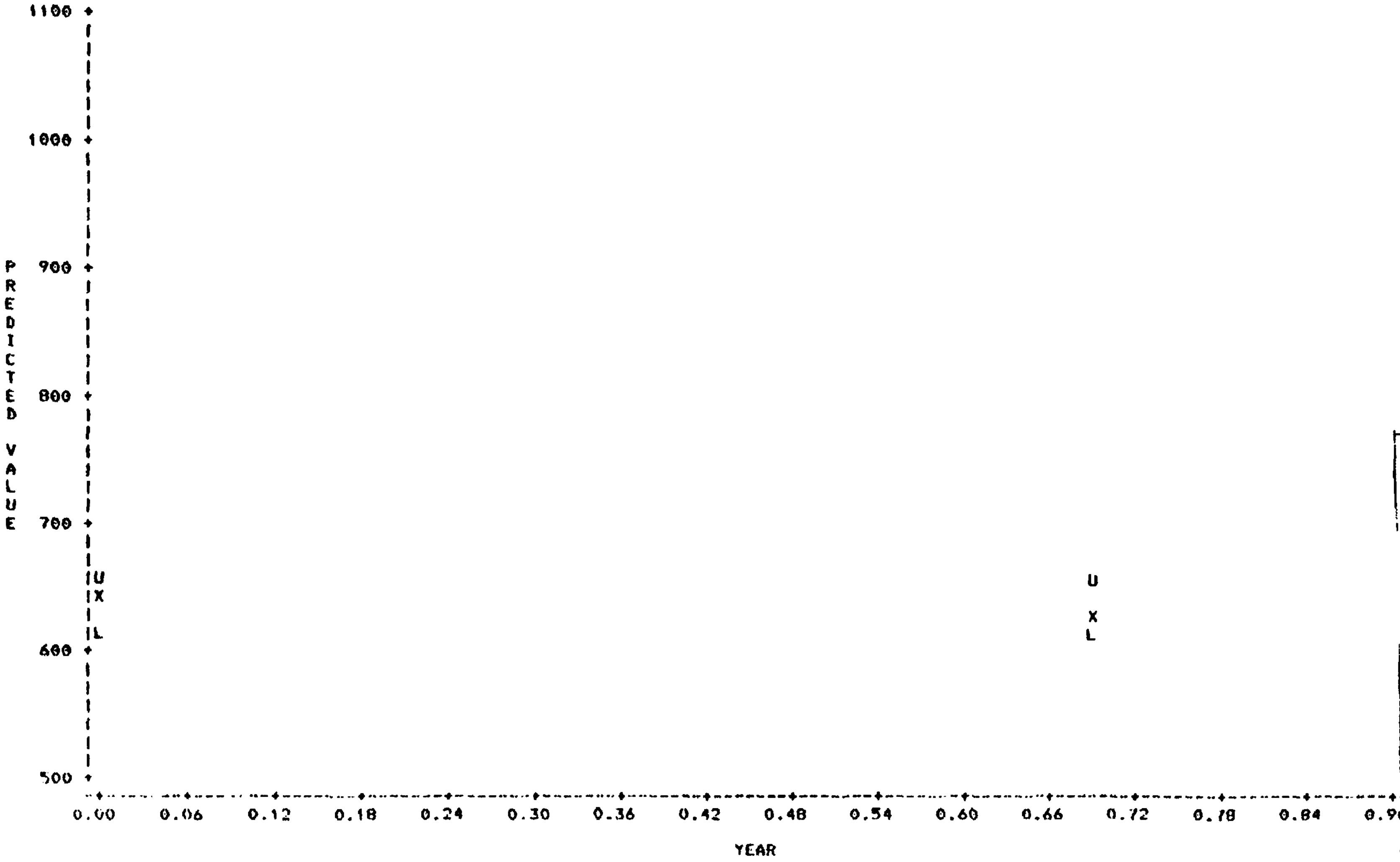
SUM OF RESIDUALS	1.13687E-13
SUM OF SQUARED RESIDUALS	1.340119
PREDICTED RESID SS (PRESS)	43.98571

10/25/06 14:28:07

Calc No C-1302-187-5300-005 Rev No 0 Sheet No 133

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 28

PLOT OF MEASURE*YEAR SYMBOL USED IS X
PLOT OF PRED*YEAR SYMBOL USED IS P
PLOT OF U95*YEAR SYMBOL USED IS U
PLOT OF L95*YEAR SYMBOL USED IS L



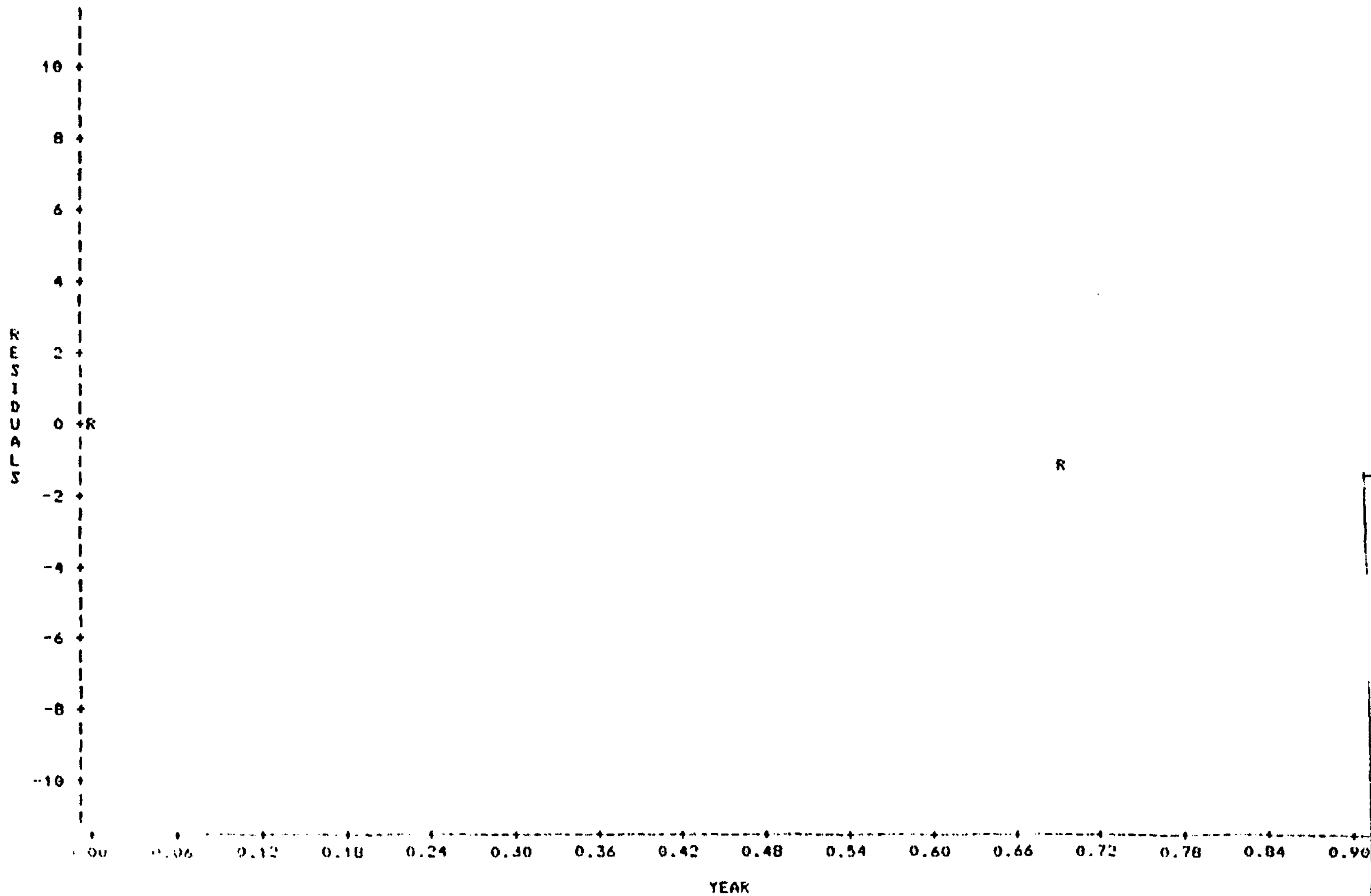
NOTE: 3 OBS HIDDEN

10/25/06 14:28:07

Calc No C-1302-187-5300-005 Rev No 0 Sheet No 124

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 2B

PLOT OF RESID*YEAR   SYMBOL USED IS R



Calc No C-1302-187-5300-005 Rev No 0 Sheet No 125

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 28

UNIVARIATE

```
VARIABLE=RESID          RESIDUALS

                 MOMENTS                                          QUANTILES(DEF=4)                                EXTREMES

N                   3  SUM WGTS            3        100% MAX   0.687928      99%     0.687928          LOWEST     HIGHEST
MEAN        3.790E-14  SUM         1.137E-13         75% Q3    0.687928      95%     0.687928       -0.905325         .
STD DEV      0.818572  VARIANCE     0.670059         50% MED   0.217397      90%     0.687928        0.217397         .
SKEWNESS     -1.11082  KURTOSIS            .         25% Q1   -0.905325      10%    -0.905325        0.687928  -0.905325
USS           1.34012  CSS           1.34012          0% MIN  -0.905325       5%    -0.905325               .   0.217397
CV              99999  STD MEAN     0.472603                                  1%    -0.905325               .   0.687928
T:MEAN=0    8.018E-14  PROB>|T|            1        RANGE       1.59325
SGN RANK            0  PROB>|S|            1        Q3-Q1       1.59325
NUM ^= 0            3                               MODE      -0.905325
W:NORMAL     0.947082  PROB<W          0.472

STEM LEAF                          #          BOXPLOT                                    NORMAL PROBABILITY PLOT
   0 7                             1          +-----+               0.75+                                      ++++++
   0 2                             1          *--+--*                   |                              *++++++
  -0                                          |     |                   |                        ++++++
  -0 9                             1          +-----+              -0.75+                  ++++++
     ----+----+----+----+                                                +----+----+----+----+----+----+----+----+----+----+
                                                                            -2        -1         0        +1        +2
```

10/25/06 14:26:07

Calc No C-1302-187-5380-005 Rev No 0 Sheet No 120

5.3.4 Bay 15 87' Elevation: 11/10/87 to 10/8/88

Three 49-point data sets were available for this bay covering the time period from November 10, 1987 to October 8, 1988. The data were analyzed as described in paragraphs 2.4 and 2.8.2.

(1) The data are normally distributed.

(2) The mean model is more appropriate than the regression model.

(3) There was no significant corrosion from November 10, 1987 to October 8, 1988.

(4) The current mean thickness ± standard error is 634.8 ±0.7 mils.

```
PROGRAM: DWCHISQ
ENTER NAME OF DATA LIST u31
ENTER PT NUMBER LIST ints(1,49)
ENTER NAME OF DATE LIST date31

 N      U31
 *   ********
 1   D8702638
 2   D8702643
 3   D8702653

ENTER NO. OF DESIRED DATA 1,2,3

            DATE31    MEANTHK     SD       STDERR    DFM2
********   ********   *******   *******   ********   ****
D8702638   11/10/87   .6361     .017368   .0024811    2
D8702643   7/20/88    .63402    .01673    .00239      2
D8702653   10/8/88    .63422    .016904   .0024149    2

  CHISQ     CHI952   CHI992
 *******    ******   ******
  .82927     5.99     9.21
 1.5885      5.99     9.21
 2.5838      5.99     9.21

    OBS                EXP
 ********   **********************
  8  9  8   10.381   10.381   10.381
  9  7  7    9.2826   9.2826   9.2826
 11 10 13    9.6726   9.6726   9.6726
 10 12 11    9.2826   9.2826   9.2826
 11 11 10   10.381   10.381   10.381

GRAND MEAN THICKNESS = .63478
STANDARD ERROR OF THE GRAND MEAN = 6.6249E-4

January 18, 1989
 1:07 PM
```

Bay 15 Elev 87'

D8702638

****

.655	.648	.639	.65	.62	.627	.641
.659	.643	.646	.64	.634	.651	.641
.628	.657	.673	.639	.654	.629	.632
.65	.652	.646	.638	.619	.633	.634
.656	.633	.637	.623	.634	.568	.62
.65	.63	.625	.607	.625	.606	.614
.649	.648	.615	.649	.628	.628	.647

D8702643

****

.651	.645	.633	.643	.615	.626	.634
.651	.642	.643	.641	.651	.644	.638
.627	.654	.654	.633	.65	.652	.634
.644	.652	.654	.635	.616	.634	.632
.652	.63	.64	.622	.635	.566	.623
.645	.627	.619	.604	.624	.605	.617
.648	.646	.613	.639	.622	.619	.643

D8702653

****

.651	.645	.632	.642	.618	.622	.636
.655	.641	.644	.638	.63	.643	.637
.629	.654	.645	.635	.649	.649	.643
.651	.65	.619	.636	.616	.632	.636
.664	.63	.635	.619	.634	.562	.626
.65	.646	.622	.605	.63	.608	.622
.654	.645	.612	.642	.628	.622	.643

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 31

DEP VARIABLE: MEASURE

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	2.52560013	2.52560013	17.904	0.1477
ERROR	1	0.14106654	0.14106654		
C TOTAL	2	2.66666667			

ROOT MSE	0.3755883	R-SQUARE	0.9471
DEP MEAN	634.6667	ADJ R-SQ	0.8942
C.V.	0.05917882		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|	TYPE I SS	STANDARDIZED ESTIMATE
INTERCEP	1	635.92947	0.36890594	1723.825	0.0004	1208405.33	0
YEAR	1	-2.36037395	0.55784111	-4.231	0.1477	2.52560013	-0.97319065

COLLINEARITY DIAGNOSTICS

NUMBER	EIGENVALUE	CONDITION NUMBER	VAR PROP INTERCEP	VAR PROP YEAR
1	1.809000	1.000000	0.0955	0.0955
2	0.191000	3.077534	0.9045	0.9045

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT	RESIDUAL
1	636.0	635.9	0.3689	631.2	640.6	629.2	642.6	0.0705
2	634.0	634.3	0.2341	631.3	637.3	628.7	639.9	-0.2937
3	634.0	633.8	0.3021	629.9	637.6	627.7	639.9	0.2232

SUM OF RESIDUALS	2.27374E-13
SUM OF SQUARED RESIDUALS	0.1410665
PREDICTED RESID SS (PRESS)	4.63012

10/25/06 14:20:07

Calc No C-1302-187-5300-005 Rev No 0 Sheet No 140

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 31

DEP VARIABLE: MEASURE

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	2.52560013	2.52560013	17.904	0.1477
ERROR	1	0.14106654	0.14106654		
C TOTAL	2	2.66666667			

ROOT MSE	0.3755883	R-SQUARE	0.9471
DEP MEAN	634.6667	ADJ R-SQ	0.8942
C.V.	0.05917882		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	635.92947	0.36890594	1723.825	0.0004
YEAR	1	-2.36037395	0.55784111	-4.231	0.1477

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT	RESIDUAL	STD ERR RESIDUAL	STUDENT RESIDUAL	-2-1-0 1 2
1	636.0	635.9	0.3689	631.2	640.6	629.2	642.6	0.0705	0.0705	1.0000	| |*
2	634.0	634.3	0.2341	631.3	637.3	628.7	639.9	-0.2937	0.2937	-1.0000	| *|
3	634.0	633.8	0.3021	629.9	637.6	627.7	639.9	0.2232	0.2232	1.0000	| |*

OBS	COOK'S D
1	13.678
2	0.318
3	0.916

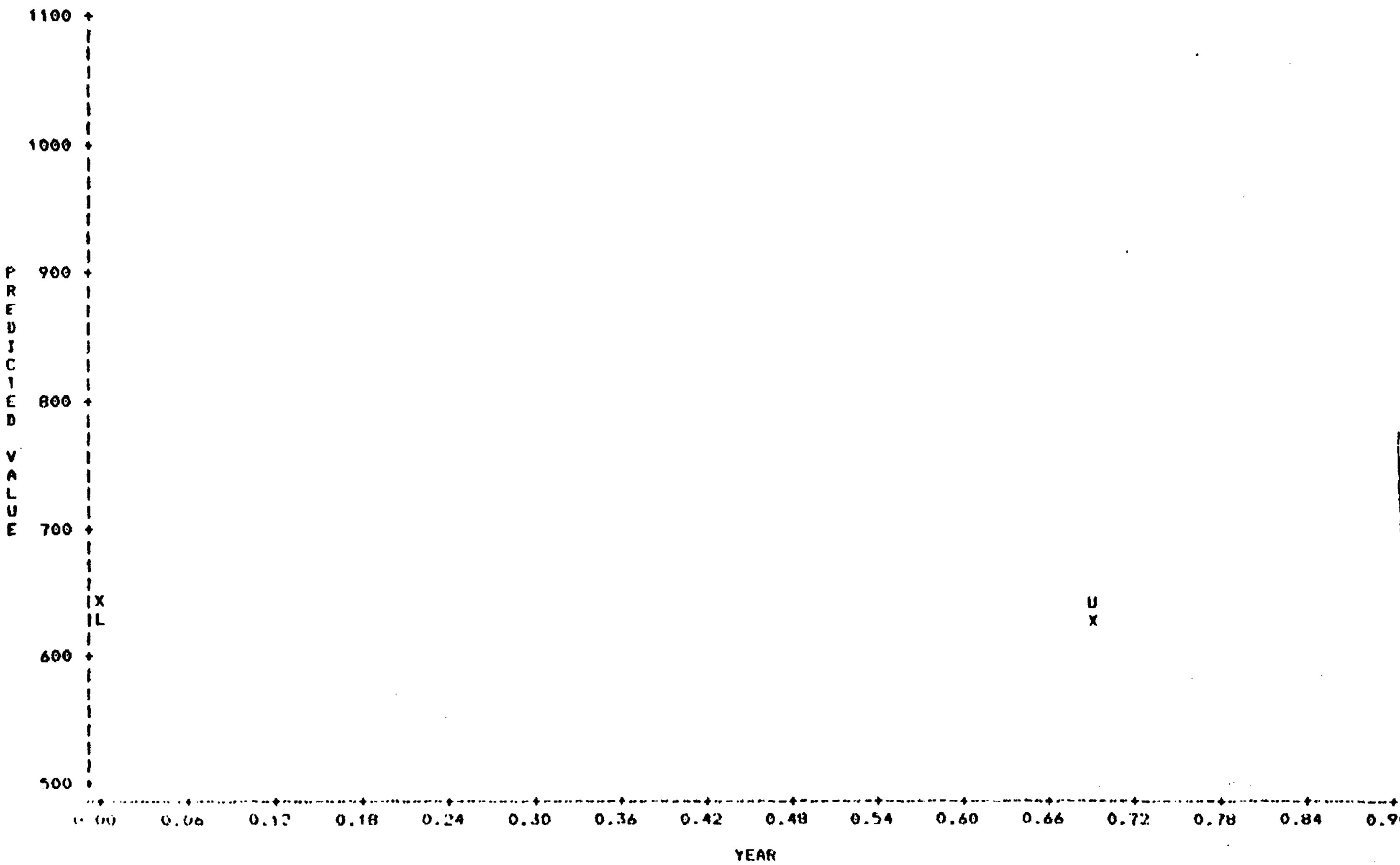
SUM OF RESIDUALS	2.27374E-13
SUM OF SQUARED RESIDUALS	0.1410665
PREDICTED RESID SS (PRESS)	4.63012

10/25/05 14:28:07

Calc No C-1302-187-5380-005 Rev No 0 Sheet No 14 of --

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 31

PLOT OF MEASURE*YEAR   SYMBOL USED IS X
PLOT OF PRED*YEAR   SYMBOL USED IS P
PLOT OF U95*YEAR   SYMBOL USED IS U
PLOT OF L95*YEAR   SYMBOL USED IS L



NOTE: 6 OBS HIDDEN

10/25/06 14:28:57

Calc No C-1302-187-5300-005 Rev No 0 Sheet No 142

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 31

UNIVARIATE

VARIABLE=RESID   RESIDUALS

MOMENTS

N	3	SUM WGTS	3
MEAN	7.579E-14	SUM	2.274E-13
STD DEV	0.265581	VARIANCE	0.0705333
SKEWNESS	-1.11082	KURTOSIS	.
USS	0.141067	CSS	0.141067
CV	99999	STD MEAN	0.153333
T:MEAN=0	4.943E-13	PROB>|T|	1
SGN RANK	0	PROB>|S|	1
NUM ¬= 0	3		
W:NORMAL	0.947082	PROB<W	0.472

QUANTILES(DEF=4)

100% MAX	0.223194	99%	0.223194
75% Q3	0.223194	95%	0.223194
50% MED	0.0705332	90%	0.223194
25% Q1	-0.293728	10%	-0.293728
0% MIN	-0.293728	5%	-0.293728
		1%	-0.293728
RANGE	0.516922		
Q3-Q1	0.516922		
MODE	-0.293728		

EXTREMES

LOWEST	HIGHEST
-0.293728	.
0.0705333	.
0.223194	-0.293728
.	0.0705333
.	0.223194

```
STEM LEAF                     #
   2 2                        1
   1
   0 7                        1
  -0
  -1
  -2 9                        1
     ----+----+----+----+
 MULTIPLY STEM.LEAF BY 10**-01
```

```
BOXPLOT
+-----+
|     |
*--+--*
|     |
|     |
+-----+
```

NORMAL PROBABILITY PLOT

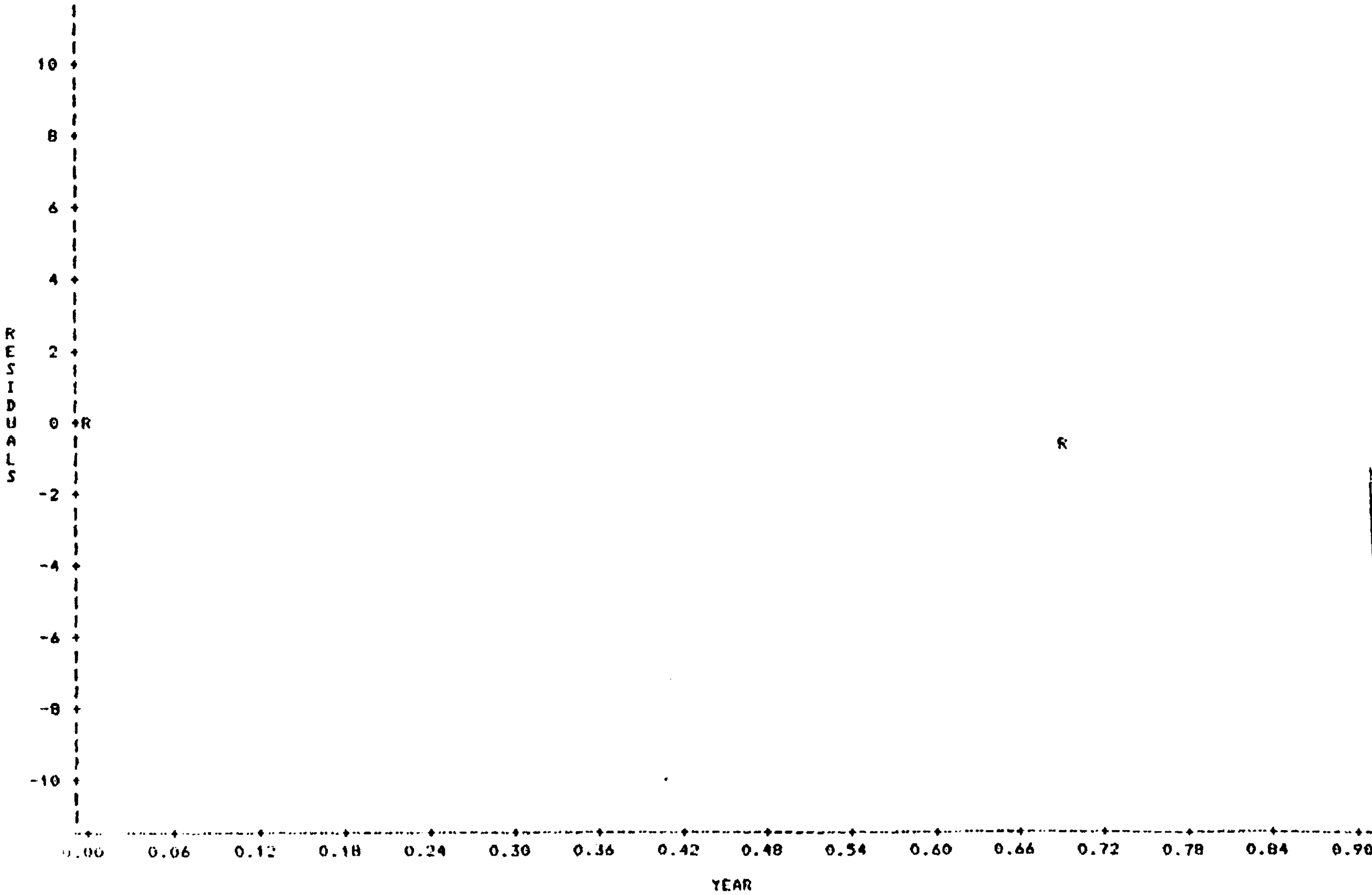
```
  0.25+                                            ++++
      |                                        ++++
      |                                   ++++
      |                              +++
      |                         ++++
 -0.25+                     ++++
       +----+----+----+----+----+----+----+----+----+----+
           -2        -1         0        +1        +2
```

10/25/06 14:28:07

Calc No C-1302-187-5300-005 Rev No Ø Sheet No 143

LINEAR REGRESSION PLOT
FOR DW WALL THINNING ANALYSIS
OF SECTION 31

PLOT OF RESID*YEAR   SYMBOL USED IS R



10/25/06 14:28:07

Calc No C-1302-187-5380-005 Rev No Ø Sheet No 114

5.4 Multiple 6"x6" Grids in Trench

5.4.1 Bay 17D Trench: 12/9/86 to 12/23/88

The two sets of measurements in the Bay 17D Trench were taken on December 9, 1986 and December 23, 1988. The 1986 data is a 7 column by 36 row array. The 1988 data is a 7 column by 42 row array. The 1986 data is at the same elevation as the lower 36 rows of the 1988 data, but is centered about 3-/12 inches to the left of the 1988 data. To compare these two data sets, the 1986 data set and the lower 36 rows of the 1988 data set were each subdivided into six 7 column by 6 row subsets. Each pair of subsets was compared as described in paragraphs 2.5 and 2.8.3.

Fourth Subset From The Top:

The chi-squared statistic for the fourth subset from the top from the 1986 data set slightly exceeded the critical value for level of significance of 0.05, but was within the critical value for level of significance of 0.01. Also, the *F* statistic exceeded the critical value for levels of significance of 0.05 and 0.01. Therefore, it is inappropriate to apply the two-tailed t-test based on equal variances. However, the approximate t-test based on unequal variances can be applied. From the results of this test, it is concluded that the difference between the mean thicknesses is not significant. This implies that corrosion at this location was not significant.

All Other Subsets:

(1) The data are normally distributed.

(2) The variances are equal.

(3) Comparison of the means using the two-tailed t-test is appropriate.

(4) The difference between the means of the subsets was not significant. This implies that there was no significant corrosion in the period from December 9, 1986 to December 23, 1988.

(5) The current mean thickness ± standard error of the top subset is 981.2 ±6.7 mils. This is the thinnest area in the trench.

10/25/06 14:28:07

Calc No	Rev No	Sheet No
C-1302-187-5300-005	Ø	146

86-049-56

```
:_tabulate(d17d612t:nosplit)
```

D17D612T

.93	[illegible]	.943	.958	.927	.889	.913
1.014	.952	.984	.987	.973	.939	.956
.991	1.005	.951	.968	.939	.945	.956
.995	.995	1.038	1.031	.992	1.003	1.011
1.025	1.011	.968	1.024	1.004	1.002	1.055
1.017	1.036	1.029	1.031	1.084	1.026	1.05
1.041	1.055	1.044	1.047	1.043	1.318	1.46
1.045	1.009	1.024	1.026	1.008	1.07	1.07
.991	1.012	1.041	1.031	1.017	1.076	1.076
1.031	1.101	1.081	1.077	1.04	1.076	1.072
1.087	1.059	1.069	1.057	1.102	1.088	1.047
.998	1.065	1.048	1.004	1.014	1.016	1.016
.964	1.019	.987	1.055	1.045	1.022	1.061
.906	1.04	1.019	.98	1.024	1.01	1.014
.964	1.105	1.083	1.011	1.047	1.016	1.028
1.063	1.012	1.029	1.047	1.056	.972	.907
1.021	1.097	1.071	1.068	1.033	.911	.952
1.066	1.023	1.006	1.063	1.045	1.035	.992
1.052	1.037	1.044	1.078	1.05	1.054	1.051
1.037	1.015	1.026	1.064	1.07	1.056	1.044
1.065	1.059	1.026	1.058	1.047	1.067	1.095
1.088	1.046	1.019	1.103	.993	1.086	1.041
1.056	1.045	.995	1.044	1.042	1.026	1.116
1.102	1.001	1.044	1.082	1.028	1	1.08
1.106	1.05	1.002	1.017	1.042	1.034	1.037
1.069	.965	.988	1.122	1.034	1.032	1.07
1.097	1.028	1.051	.951	1.059	1.015	1.005
1.135	1.022	1.076	1.058	.952	.981	1.023
1.023	1.049	.987	1.085	1.048	1.072	.98
1.1	1.017	.958	1.044	.991	1.056	1.074
1.053	1.03	1.025	.987	1.031	1.059	1.087
1.005	1.049	1.006	1.058	1.058	1.011	.992
.972	.983	1.012	1.009	1.067	1.017	.972
.986	.979	.974	.961	1.017	1.008	.982
.999	.987	1.021	.958	.954	1.064	.942
.923	.981	.976	[illegible]	.964	.99	1.004

BAD DATA SET THESE TWO POINTS EQUAL TO ZERO.

```
:_journal off
```

GPU Nuclear Calculation Sheet

Subject	Calc No	Rev No	Sheet No
	C-1302-187-5300-005	Ø	147 of --

Originator	Date	Reviewed by	Date
J. P. Moore	12-31-88		

BAY 17D TRENCH

THERE ARE TWO SETS OF DATA FOR THIS LOCATION:

DATE	DATA SHEET	DATA SET
12-9-86	86-049-56	D17D612T
12-23-88	87-026-64	D17D812T

THE 12-9-86 DATA WAS TAKEN WITHOUT TEMPLATES.

THE 12-23-88 DATA WAS TAKEN USING THE STANDARD 6"x6" TEMPLATE. THE DATA IS GROUPED IN SIX FRAMES NUMBERED FROM THE BOTTOM AS SHOWN ON SHT 2 OF DATA SHT 87-026-64. THESE DATA ARE TABULATED ON SHTS 9, 12, 15, 18, 21 & 24 OF 87-026-64.

NOTE: WHEN THE DATA FROM THE INDIVIDUAL FRAMES WERE MERGED TO PRODUCE THE COMPOSITE DATA LISTINGS ON SHTS 3 & 6 OF 87-026-64, THEY GOT ROWS AND COLUMNS MIXED UP SO THAT THE ORIGINAL SHTS 3 & 6 ARE NO GOOD.

PER SITE QA, POINT # 27 IN FRAME #6 (RDG = 1.105") IS CENTERED ON PLUG #3. SEE DATA SHEET 86-049-45 FOR THE LOCATION OF THIS PLUG.

THE 12-9-86 DATA IS A 7 COLUMN x 36 ROW ARRAY.
THE 12-23-88 DATA IS A 7 COLUMN x 42 ROW ARRAY.

THE 12-9-86 DATA IS AT THE SAME ELEVATION AS THE BOTTOM 36 ROWS OF THE 12-23-88 DATA.

GPU Nuclear — **Calculation Sheet**

Subject	Calc No	Rev No	Sheet No
	C-1302-187-5300-005	ø	148

Originator	Date	Reviewed by	Date
R. Moore	12-31-88		

BAY 17D TRENCH

THE 12-9-86 DATA WAS CENTERED AT 55½" FROM THE ℄ OF THE WELD.

THE 6"x6" GRID SHOWING THE LOCATION OF PLUG # 3 ON 86-049-45 IS CENTERED 59" FROM THE ℄ OF THE WELD.

SINCE READING # 27 IN FRAME 6 OF THE 12-23-88 DATA IS AT THE CENTER OF PLUG # 3, THIS DATA IS SHIFTED LEFT 1" FROM 86-049-45. THUS IT IS CENTERED 58" FROM THE ℄ OF THE WELD.

THEREFORE, THE 12-23-88 DATA IS CENTERED ABOUT 3½" TO THE RIGHT OF THE 12-9-86 DATA.

WITH ONLY TWO SETS OF DATA, IT WOULD BE INAPPROPRIATE TO USE LINEAR REGRESSION TO EVALUATE THE CORROSION RATE. HOWEVER, THE T-TEST CAN BE USED TO COMPARE THE MEANS OF THE TWO DATA SETS TO DETERMINE IF THEY ARE STATISTICALLY DIFFERENT.

GPU Nuclear **Calculation Sheet**

Subject	Calc No C-1302-187-5360-005	Rev No	Sheet No 149
Originator [signature] Date 12-31-88	Reviewed by	Date	

BAY 17D TRENCH

TO MAKE THIS COMPARISON, THE TWO DATA SETS WERE SUBDIVIDED INTO 7 COLUMN x 6 ROW ARRAYS AS SHOWN BELOW.

D17D612T	D17D812T
	(NOT USED)
OLD 1	NEW1
OLD 2	NEW 2
OLD 3	NEW 3
OLD 4	NEW 4
OLD 5	NEW 5
OLD 6	NEW 6

GPU Nuclear
Calculation Sheet

Subject	Calc No	Rev No	Sheet No
	C-1302-187-5300-005	Ø	150

Originator	Date	Reviewed by	Date
J. Moore	12-31-88		

BAY 17D TRENCH

THE EVALUATION TOOK PLACE IN THREE STEPS:

(1) χ^2 TEST OF EACH 6X7 DATA SET TO CHECK FOR NORMAL DISTRIBUTION OF THE DATA.

(2) FMAX TEST OF THE TWO 6x7 DATA SETS BEING COMPARED TO CHECK FOR EQUAL VARIANCES.

(3) TWO-TAILED T-TEST TO COMPARE THE MEANS OF THE TWO 6x7 DATA SETS.

THE χ^2 TEST WAS PERFORMED USING THE SPEAKEZ PROGRAM "DWCHISQ1". SEE APPENDIX 6.1 FOR A LISTING AND DESCRIPTION OF THE PROGRAM.

THE F TEST AND THE T-TEST WERE PERFORMED USING THE SPEAKEZ PROGRAM "T2TAIL". SEE APPENDIX 6.2 FOR A LISTING AND DESCRIPTION OF THE PROGRAM.

```
:_$ bay 17d
:_* Bay 17D Trench
:_* Top 6"x5" Grid
:_$ Data Sets OLD1 and NEW1
:_old1=d17ds12t(ints(1,6),)
:_new1=d17d812t(ints(7,12).)
:_thkmean=mean(old1) mean(new1)

  THKMEAN (A 2 COMPONENT ARRAY)
  .98762   .98121

:_thkall=old1.new1
:_stddev=standdev(thkall)
:_stderr=standerror(thkall)
:_t95=abs(tprobinverse(.975,1))
:_meanthk=mean(thkall)
:_l95mean = meanthk-t95*stderr
:_u95mean = meanthk+t95*stderr
:_tabulate meanthk.stderr.t95.l95mean.u95mean

 MEANTHK   STDERR    T95    L95MEAN   U95MEAN
 *******   *******  ******  *******   *******
 .98442    .004792  12.706  .92467    1.9442
```

GPU Nuclear **Calculation Sheet**

Subject	Calc No	Rev. No	Sheet No
	C-1302-187-5300-005	4	152

Originator	Date	Reviewed by	Date
JPMoore	12-31-88		

BAY 17D TRENCH

DATA SHT: 86-049-56
DATE: 12-9-86

D17D612T

.93	.932	.943	.958	.927	.889	.913
1.014	.953	.984	.987	.973	.939	.956
.991	1.005	.951	.968	.939	.945	.956
.995	.995	1.038	1.031	.992	1.003	1.011
1.025	1.011	.968	1.024	1.004	1.002	1.055
1.017	1.036	1.029	1.031	1.084	1.026	1.05
1.041	1.055	1.044	1.047	1.043	0	0
1.045	1.009	1.024	1.026	1.008	1.07	1.07
.991	1.012	1.041	1.031	1.017	1.076	1.076
1.031	1.101	1.081	1.077	1.04	1.076	1.072
1.087	1.059	1.069	1.057	1.102	1.088	1.047
.998	1.065	1.048	1.004	1.014	1.016	1.016
.964	1.019	.987	1.055	1.045	1.022	1.061
.906	1.04	1.019	.98	1.024	1.01	1.014
.964	1.105	1.083	1.011	1.047	1.016	1.028
1.063	1.012	1.029	1.047	1.056	.972	.907
1.021	1.097	1.071	1.068	1.033	.911	.952
1.066	1.023	1.006	1.063	1.045	1.035	.992
1.052	1.037	1.044	1.078	1.05	1.054	1.051
1.037	1.015	1.026	1.064	1.07	1.056	1.044
1.065	1.059	1.026	1.058	1.047	1.067	1.095
1.088	1.046	1.019	1.103	.993	1.086	1.041
1.056	1.045	.995	1.044	1.042	1.026	1.116
1.102	1.001	1.044	1.082	1.028	1	1.08
1.106	1.05	1.002	1.017	1.042	1.034	1.037
1.069	.965	.988	1.122	1.034	1.032	1.07
1.097	1.028	1.051	.951	1.059	1.015	1.005
1.135	1.022	1.076	1.058	.952	.981	1.023
1.023	1.049	.987	1.085	1.048	1.072	.98
1.1	1.017	.958	1.044	.991	1.056	1.074
1.053	1.03	1.025	.987	1.031	1.059	1.087
1.005	1.049	1.006	1.058	1.058	1.011	.992
.972	.985	1.012	1.009	1.067	1.017	.975
.985	.979	.974	.961	1.017	1.008	.982
.999	.987	1.021	.958	.954	1.064	.942
.923	.981	.976	.97	.964	.99	1.004

```
:_old1 = d17d612t(ints(1,6),)
:_old2 = d17d612t(ints(7,12),)
:_old3 = d17d612t(ints(13,18),)
:_old4 = d17d612t(ints(19,24),)
:_old5 = d17d612t(ints(25,30),)
:_old6 = d17d612t(ints(31,36),)
```

GPU Nuclear Calculation Sheet

Subject	Calc No	Rev No	Sheet No
	C-1302-187-5300-005	Ø	153 -

Originator	Date	Reviewed by	Date
JP Moore	12-31-88		

BAY 17D TRENCH

OLD1

****

.93	.932	.943	.958	.927	.889	.913
1.014	.953	.984	.987	.973	.939	.956
.991	1.005	.951	.968	.939	.945	.956
.995	.995	1.038	1.031	.992	1.003	1.011
1.025	1.011	.968	1.024	1.004	1.002	1.055
1.017	1.036	1.029	1.031	1.084	1.026	1.05

OLD2

****

1.041	1.055	1.044	1.047	1.043	0	0
1.045	1.009	1.024	1.026	1.008	1.07	1.07
.991	1.012	1.041	1.031	1.017	1.076	1.076
1.031	1.101	1.081	1.077	1.04	1.076	1.072
1.087	1.059	1.069	1.057	1.102	1.088	1.047
.998	1.065	1.048	1.004	1.014	1.016	1.016

OLD3

****

.964	1.019	.987	1.055	1.045	1.022	1.061
.906	1.04	1.019	.98	1.024	1.01	1.014
.964	1.105	1.083	1.011	1.047	1.016	1.028
1.063	1.012	1.029	1.047	1.056	.972	.907
1.021	1.097	1.071	1.068	1.033	.911	.952
1.066	1.023	1.006	1.063	1.045	1.035	.992

OLD4

****

1.052	1.037	1.044	1.078	1.05	1.054	1.051
1.037	1.015	1.026	1.064	1.07	1.056	1.044
1.065	1.059	1.026	1.058	1.047	1.067	1.095
1.088	1.046	1.019	1.103	.993	1.086	1.041
1.056	1.045	.995	1.044	1.042	1.026	1.116
1.102	1.001	1.044	1.082	1.028	1	1.08

OLD5

****

1.106	1.05	1.002	1.017	1.042	1.034	1.037
1.069	.965	.988	1.122	1.034	1.032	1.07
1.097	1.028	1.051	.951	1.059	1.015	1.005
1.135	1.022	1.076	1.058	.952	.981	1.023
1.023	1.049	.987	1.085	1.048	1.072	.98
1.1	1.017	.958	1.044	.991	1.056	1.074

OLD6

****

1.053	1.03	1.025	.987	1.031	1.059	1.087
1.005	1.049	1.006	1.058	1.058	1.011	.992
.972	.985	1.012	1.009	1.067	1.017	.975
.985	.979	.974	.961	1.017	1.008	.982
.999	.987	1.021	.958	.954	1.064	.942
.923	.981	.976	.97	.964	.99	1.004

GPU Nuclear — Calculation Sheet

Subject	Calc No	Rev No	Sheet No
	C-1302-187-5300-005	Ø	54

Originator	Date	Reviewed by	Date
JE Moore	12-31-88		

BAY 17D TRENCH

DATA SHT: 87-026-64
DATE: 12-23-88

D17D812T

```
**************************************************
1.003   .949   .887   .843   .864   .845   .78
 .885   .801   .734   .811   .858   .806   .77
 .793  1.072   .807   .841   .824   .839   .859
 .815  1.105  1.123   .807   .851   .891  1.031
 .823   .836   .852   .893   .859   .898   .927
 .842   .85    .875   .928   .899   .917   .941
 .914   .861   .707   .889   .948   .979   .977
 .983   .945   .969  1.034  1.003   .974  1.004
 .957  1.053   .966   .949   .95    .985  1.001
 .915   .981   .949   .963  1.012  1.026  1.009
 .962   .99   1.008   .964  1.013  1.009  1.039
 .984  1.005  1.016  1.01   1.03   1.013  1.065
1.039  1.014  1.022  1.027  1.104  1.012  1.033
1.013  1.015  1.005  1.025  1.056  1.058  1.095
1.051  1.023  1.021  1.06   1.085  1.054  1.134
1.057  1.048  1.048  1.194  1.056  1.055  1.017
1.071  1.016  1.044  1.062  1.052  1.077  1.08
1.037  1.043  1.014  1.037  1.028  1.069  1.054
1.031   .988  1.033  1.047  1.071  1.007  1.062
1.017  1.024   .974  1.024  1.075  1.016  1.063
1.012  1.057  1.04   1.068  1.022  1.01    .986
 .976  1.03   1.039  1.057   .969   .927   .949
1.06   1.041  1.06   1.043   .974   .953   .938
1.006   .983  1.07   1.054  1.03    .976   .956
1.044  1.011  1.03   1.019  1.105  1.068  1.002
1.078  1.045  1.029  1.107  1.016  1.036  1.065
1.02    .968  1.024   .964   .962  1.035  1.041
1.085  1.089  1.065  1.097  1.025  1.089  1.027
1.042  1.049  1.115   .985  1.11   1.051  1.07
1.088   .925  1.038  1.095   .971  1.032  1.058
1.05   1.023   .974  1.002  1.035   .993  1.059
1.049  1.015  1.052  1.083  1.029  1.001  1.015
1.073  1.021  1.003   .975  1.078   .947  1.03
 .982   .989  1.11   1.055   .951   .95   1.056
1.039  1.074  1.025  1.124  1.045  1.026  1.087
1.028  1.003  1.045   .983  1.056  1.112  1.065
1.078  1.02    .999   .993  1.027  1.05   1.033
1.032   .992  1.035  1.052   .989   .952   .989
 .986  1.011  1.051   .995  1.041  1.002   .991
 .98    .964  1.007   .953  1.025   .975   .972
 .949   .986  1.016   .977   .949  1.083   .932
 .965   .942   .941   .936   .961   .977   .972
```

```
:_new1 = d17d812t(ints(7,12),)
:_new2 = d17d812t(ints(13,18),)
:_new3 = d17d812t(ints(19,24),)
:_new4 = d17d812t(ints(25,30),)
:_new5 = d17d812t(ints(31,36),)
:_new6 = d17d812t(ints(37,42),)
```

GPU Nuclear **Calculation Sheet**

Subject	Calc No	Rev No	Sheet No
	C-1302-187-5300-005	Ø	155

Originator	Date	Reviewed by	Date
JD Moore	12-31-88		

BAY 17D TRENCH

NEW1

.914	.861	.907	.889	.948	.979	.977
.983	.945	.969	1.034	1.003	.974	1.004
.957	1.053	.966	.949	.95	.985	1.001
.915	.981	.949	.963	1.012	1.026	1.009
.962	.99	1.008	.964	1.013	1.009	1.039
.984	1.005	1.016	1.01	1.03	1.013	1.065

NEW2

1.039	1.014	1.022	1.027	1.104	1.012	1.033
1.013	1.015	1.005	1.025	1.056	1.058	1.095
1.051	1.023	1.021	1.06	1.085	1.054	1.134
1.057	1.048	1.048	1.194	1.056	1.055	1.017
1.071	1.016	1.044	1.062	1.052	1.077	1.08
1.037	1.043	1.014	1.037	1.028	1.069	1.054

NEW3

1.031	.988	1.033	1.047	1.071	1.007	1.062
1.017	1.024	.974	1.024	1.075	1.016	1.063
1.012	1.057	1.04	1.068	1.022	1.01	.986
.976	1.03	1.039	1.057	.969	.927	.949
1.06	1.041	1.06	1.043	.974	.953	.938
1.006	.983	1.07	1.054	1.03	.976	.956

NEW4

1.044	1.011	1.03	1.019	1.105	1.068	1.002
1.078	1.045	1.029	1.107	1.016	1.036	1.065
1.02	.968	1.024	.964	.962	1.035	1.041
1.085	1.089	1.065	1.097	1.025	1.089	1.027
1.042	1.049	1.115	.985	1.11	1.051	1.07
1.088	.925	1.038	1.095	.971	1.032	1.058

NEW5

1.05	1.023	.974	1.002	1.035	.993	1.059
1.049	1.015	1.052	1.083	1.029	1.001	1.015
1.073	1.021	1.003	.975	1.078	.947	1.03
.982	.989	1.11	1.055	.951	.95	1.056
1.039	1.074	1.025	1.124	1.045	1.026	1.087
1.028	1.003	1.045	.983	1.056	1.112	1.065

NEW6

1.078	1.02	.999	.993	1.027	1.05	1.033
1.032	.992	1.035	1.052	.989	.952	.989
.986	1.011	1.051	.995	1.041	1.002	.991
.98	.964	1.007	.953	1.025	.975	.972
.949	.986	1.016	.977	.949	1.083	.932
.965	.942	.941	.936	.961	.977	.972

Calc No	Rev No	Sheet No
C-1302-187-5300-005	Ø	156 -

```
PROGRAM: DWCHISQ
ENTER NAME OF DATA LIST old
ENTER PT NUMBER LIST ints(1,42)
ENTER NAME OF DATE LIST olddates

 N    OLD
 *    ****
 1    OLD1
 2    OLD2
 3    OLD3
 4    OLD4
 5    OLD5
 6    OLD6

ENTER NO. OF DESIRED DATA 1,2,3,4,5,6

        OLDDATES   MEANTHK    SD        STDERR     DFM2
 ****   ********   *******    *******   ********   ****
 OLD1   12/9/86     .98762    .043169   .0066611    2
 OLD2   12/9/86    1.0468     .029404   .0046492    2
 OLD3   12/9/86    1.0207     .046986   .0072501    2
 OLD4   12/9/86    1.0508     .029182   .0045029    2
 OLD5   12/9/86    1.0358     .045087   .0069571    2
 OLD6   12/9/86    1.003      .037224   .0057438    2

  CHISQ    CHI952   CHI992
 ******    ******   ******
 2.1073     5.99     9.21
 2.4368     5.99     9.21
 5.9912     5.99     9.21
 6.1309     5.99     9.21
  .3404     5.99     9.21
 2.7275     5.99     9.21

        OBS                                  EXP
 ****************   ************************************************
 11 10  8  9  9  8   8.8981 8.4744 8.8981 8.8981 8.8981 8.8981
  6  4  3  5  8 12   7.9565 7.5776 7.9565 7.9565 7.9565 7.9565
  6  9 13 14  7  8   8.2908 7.896  8.2908 8.2908 8.2908 8.2908
  8  7  9  5  9  6   7.9565 7.5776 7.9565 7.9565 7.9565 7.9565
 11 10  9  9  9  8   8.8981 8.4744 8.8981 8.8981 8.8981 8.8981

GRAND MEAN THICKNESS = 1.0241
STANDARD ERROR OF THE GRAND MEAN = .010251

January 18, 1989
 1:09 PM
```

MIN MEANTHK = 987.62 ± 6.66 mils (1986)

```
PROGRAM: DWCHISQ
ENTER NAME OF DATA LIST new
ENTER PT NUMBER LIST ints(1,42)
ENTER NAME OF DATE LIST newdates
```

N	NEW
*	****
1	NEW1
2	NEW2
3	NEW3
4	NEW4
5	NEW5
6	NEW6

ENTER NO. OF DESIRED DATA 1,2,3,4,5,6

	NEWDATES	MEANTHK	SD	STDERR	DFM2
****	********	*******	*******	********	****
NEW1	12/23/88	.98121	.043301	.0066815	2
NEW2	12/23/88	1.0501	.035922	.0055275	2
NEW3	12/23/88	1.0171	.040598	.0062644	2
NEW4	12/23/88	1.0423	.044753	.0069055	2
NEW5	12/23/88	1.0312	.043294	.0066804	2
NEW6	12/23/88	.99476	.038463	.005935	2

CHISQ	CHI952	CHI992
******	******	******
3.0481	5.99	9.21
4.8554	5.99	9.21
4.2277	5.99	9.21
1.5117	5.99	9.21
1.1584	5.99	9.21
1.5888	5.99	9.21

OBS						EXP					
6	9	11	7	9	9	8.8981	8.8981	8.8981	8.8981	8.8981	8.8981
10	9	3	9	6	8	7.9565	7.9565	7.9565	7.9565	7.9565	7.9565
8	13	8	10	9	10	8.2908	8.2908	8.2908	8.2908	8.2908	8.2908
11	5	9	6	10	5	7.9565	7.9565	7.9565	7.9565	7.9565	7.9565
7	6	11	10	8	10	8.8981	8.8981	8.8981	8.8981	8.8981	8.8981

GRAND MEAN THICKNESS = 1.0194
STANDARD ERROR OF THE GRAND MEAN = .011071

January 18, 1989
1:10 PM

MIN MEANTHK = 981.21 ± 6.68 mils (1988)

Calc No	Rev No	Sheet No
C-1302-187-5300-005	Ø	18

COMPARISON OF MEANS USING TWO-TAILED T-TEST
****

BAY	DATASHTS	DATASETS	DATADATE	MEANTHK
***	********	********	********	*******
17D	8604956	OLD1	12/09/86	.98762
	8702664	NEW1	12/23/88	.98121

OLD1
****

.93	.932	.943	.958	.927	.889	.913
1.014	.953	.984	.987	.973	.939	.956
.991	1.005	.951	.968	.939	.945	.956
.995	.995	1.038	1.031	.992	1.003	1.011
1.025	1.011	.968	1.024	1.004	1.002	1.055
1.017	1.036	1.029	1.031	1.084	1.026	1.05

NEW1
****

.914	.861	.907	.889	.948	.979	.977
.983	.945	.969	1.034	1.003	.974	1.004
.957	1.053	.966	.949	.95	.985	1.001
.915	.981	.949	.963	1.012	1.026	1.009
.962	.99	1.008	.964	1.013	1.009	1.039
.984	1.005	1.016	1.01	1.03	1.013	1.065

F TEST FOR EQUAL POPULATION VARIANCES
****

VARA	VARB	DFA	DFB
*******	********	***	***
.001875	.0018636	41	41

F = 1.0061
F(.05/2, 41 , 41) = 1.8604
F(.01/2, 41 , 41) = 2.2716

TWO-TAILED T-TEST
****
DF = 82
ALPHA = .24957
T = .67885
T(.05/2, 82) = 1.9893
T(.01/2, 82) = 2.6371
January 13, 1989
6:08 PM

COMPARISON OF MEANS USING TWO-TAILED T-TEST
****

BAY	DATASHTS	DATASETS	DATADATE	MEANTHK
17D	8604956	OLD2	12/09/86	1.0468
	8702664	NEW2	12/23/88	1.0501

OLD2

1.041	1.055	1.044	1.047	1.043	0	0
1.045	1.009	1.024	1.026	1.008	1.07	1.07
.991	1.012	1.041	1.031	1.017	1.076	1.076
1.031	1.101	1.081	1.077	1.04	1.076	1.072
1.087	1.059	1.069	1.057	1.102	1.088	1.047
.998	1.065	1.048	1.004	1.014	1.016	1.016

NEW2

1.039	1.014	1.022	1.027	1.104	1.012	1.033
1.013	1.015	1.005	1.025	1.056	1.058	1.095
1.051	1.023	1.021	1.06	1.085	1.054	1.134
1.057	1.048	1.048	1.194	1.056	1.055	1.017
1.071	1.016	1.044	1.062	1.052	1.077	1.08
1.037	1.043	1.014	1.037	1.028	1.069	1.054

F TEST FOR EQUAL POPULATION VARIANCES
****

VARA	VARB	DFA	DFB
.0012832	8.6459E-4	41	39

F = 1.4842
F(.05/2, 41 , 39) = 1.8803
F(.01/2, 41 , 39) = 2.305

TWO-TAILED T-TEST
****
DF = 80
ALPHA = .32681
T = .45043
T(.05/2, 80) = 1.9901
T(.01/2, 80) = 2.6387
January 13, 1989
6:10 PM

COMPARISON OF MEANS USING TWO-TAILED T-TEST
****

BAY	DATASHTS	DATASETS	DATADATE	MEANTHK
***	********	********	********	*******
17D	8604956	OLD3	12/09/86	1.0207
	8702664	NEW3	12/23/88	1.0171

OLD3
****

.964	1.019	.987	1.055	1.045	1.022	1.061
.906	1.04	1.019	.98	1.024	1.01	1.014
.964	1.105	1.083	1.011	1.047	1.016	1.028
1.063	1.012	1.029	1.047	1.056	.972	.907
1.021	1.097	1.071	1.068	1.033	.911	.952
1.066	1.023	1.006	1.063	1.045	1.035	.992

NEW3
****

1.031	.988	1.033	1.047	1.071	1.007	1.062
1.017	1.024	.974	1.024	1.075	1.016	1.063
1.012	1.057	1.04	1.068	1.022	1.01	.986
.976	1.03	1.039	1.057	.969	.927	.949
1.06	1.041	1.06	1.043	.974	.953	.938
1.006	.983	1.07	1.054	1.03	.976	.956

F TEST FOR EQUAL POPULATION VARIANCES
****

VARA	VARB	DFA	DFB
********	********	***	***
.0022077	.0016482	41	41

F = 1.3395
F(.05/2, 41 , 41) = 1.8604
F(.01/2, 41 , 41) = 2.2716

TWO-TAILED T-TEST
****
DF = 82
ALPHA = .35423
T = .37522
T(.05/2, 82) = 1.9893
T(.01/2, 82) = 2.6371
January 13, 1989
6:11 PM

COMPARISON OF MEANS USING TWO-TAILED T-TEST
****

BAY	DATASHTS	DATASETS	DATADATE	MEANTHK
***	********	********	********	*******
17D	8604956	OLD4	12/09/86	1.0508
	8702664	NEW4	12/23/88	1.0423

OLD4
****

1.052	1.037	1.044	1.078	1.05	1.054	1.051
1.037	1.015	1.026	1.064	1.07	1.056	1.044
1.065	1.059	1.026	1.058	1.047	1.067	1.095
1.088	1.046	1.019	1.103	.993	1.086	1.041
1.056	1.045	.995	1.044	1.042	1.026	1.116
1.102	1.001	1.044	1.082	1.028	1	1.08

NEW4
****

1.044	1.011	1.03	1.019	1.105	1.068	1.002
1.078	1.045	1.029	1.107	1.016	1.036	1.065
1.02	.968	1.024	.964	.962	1.035	1.041
1.085	1.089	1.065	1.097	1.025	1.089	1.027
1.042	1.049	1.115	.985	1.11	1.051	1.07
1.088	.925	1.038	1.095	.971	1.032	1.058

F TEST FOR EQUAL POPULATION VARIANCES
****

VARA	VARB	DFA	DFB
********	********	***	***
.0020028	8.516E-4	41	41

F = 2.3518
F(.05/2, 41 , 41) = 1.8604
F(.01/2, 41 , 41) = 2.2716

F > F(99%)

∴ REJECT HYPOTHESIS THAT VARIANCES ARE EQUAL

TWO-TAILED T-TEST
****
DF = 82
ALPHA = .15277
T = 1.0311
T(.05/2, 82) = 1.9893
T(.01/2, 82) = 2.6371
January 13, 1989
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SEE NEXT PAGE FOR T-TEST WITH UNEQUAL VARIANCES

GPU Nuclear Calculation Sheet

Subject	Calc No	Rev No	Sheet No
	C-1302-187-5300-005	0	162

Originator	Date	Reviewed by	Date
J P Moore	1-23-89		

17D TRENCH - 4TH SUBSET

t - TEST FOR EQUALITY OF MEANS WITH UNEQUAL VARIANCES

REF: STATISTICAL THEORY WITH ENGINEERING APPLICATIONS, A. HALD, JOHN WILEY & SONS, 1952

HYPOTHESIS: $\delta = \bar{X}_1 - \bar{X}_2 = 0$

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}} \qquad [15.4.15]$$

Where:

		FROM PREV. PG.
$\bar{X}_1$ =	MEANTHK (OLD4)	= 1.0508
$\bar{X}_2$ =	MEANTHK (NEW4)	= 1.0423
$(S_1)^2$ =	VARIANCE (OLD4)	= 2.0028 E-3
$(S_2)^2$ =	VARIANCE (NEW4)	= 8.516 E-4
n_1 =	NUMBER OF ELEMENTS IN OLD4	= 42
n_2 =	NUMBER OF ELEMENTS IN NEW4	= 42
f_1 =	DEGREES OF FREEDOM OF OLD4	= 41
f_2 =	DEGREES OF FREEDOM OF NEW4	= 41

$$c = \frac{(S_1)^2/n_1}{\frac{(S_1)^2}{n_1} + \frac{(S_2)^2}{n_2}} \qquad [15.4.16]$$

SINCE $n_1 = n_2$

$$C = \frac{S_1^2}{S_1^2 + S_2^2}$$

$$c = \frac{(2.0028E-3)}{(2.0028E-3)+(8.516E-4)}$$

$$c = 0.7017$$

$$\frac{1}{f} = \frac{c^2}{f_1} + \frac{(1-c)^2}{f_2} \qquad [15.4.17]$$

WHERE:

f = DEGREES OF FREEDOM OF t-PARAMETER GIVEN BY EQN. 15.4.15.

$$\frac{1}{f} = \frac{(0.7017)^2}{41} + \frac{(1-0.7017)^2}{41}$$

$$\frac{1}{f} = 0.0142$$

$$f = 70.53 = 71$$

$t = 1.0311$ (FROM PREVIOUS PAGE)

$t(0.05/2, 71) = 1.9939$
$t(0.01/2, 71) = 2.6469$

$t < t(95\%)$

∴ DO NOT REJECT HYPOTHESIS THAT MEANS ARE EQUAL.

THIS IMPLIES THAT THE CORROSION IS NOT SIGNIFICANT.

COMPARISON OF MEANS USING TWO-TAILED T-TEST
****

BAY	DATASHTS	DATASETS	DATADATE	MEANTHK
***	********	********	********	*******
17D	8604956	OLD5	12/09/86	1.0358
	8702664	NEW5	12/23/88	1.0312

OLD5
****

1.106	1.05	1.002	1.017	1.042	1.034	1.037
1.069	.965	.988	1.122	1.034	1.032	1.07
1.097	1.028	1.051	.951	1.059	1.015	1.005
1.135	1.022	1.076	1.058	.952	.981	1.023
1.023	1.049	.987	1.085	1.048	1.072	.98
1.1	1.017	.958	1.044	.991	1.056	1.074

NEW5
****

1.05	1.023	.974	1.002	1.035	.993	1.059
1.049	1.015	1.052	1.083	1.029	1.001	1.015
1.073	1.021	1.003	.975	1.078	.947	1.03
.982	.989	1.11	1.055	.951	.95	1.056
1.039	1.074	1.025	1.124	1.045	1.026	1.087
1.028	1.003	1.045	.983	1.056	1.112	1.065

F TEST FOR EQUAL POPULATION VARIANCES
****

VARA	VARB	DFA	DFB
********	********	***	***
.0020328	.0018744	41	41

F = 1.0845
F(.05/2, 41 , 41) = 1.8604
F(.01/2, 41 , 41) = 2.2716

TWO-TAILED T-TEST
****
DF = 82
ALPHA = .31752
T = .47643
T(.05/2, 82) = 1.9893
T(.01/2, 82) = 2.6371
January 13, 1989
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COMPARISON OF MEANS USING TWO-TAILED T-TEST

BAY	DATASHTS	DATASETS	DATADATE	MEANTHK
17D	8604956	OLD6	12/09/86	1.003
	8702664	NEW6	12/23/88	.99476

OLD6

1.053	1.03	1.025	.987	1.031	1.059	1.087
1.005	1.049	1.006	1.058	1.058	1.011	.992
.972	.985	1.012	1.009	1.067	1.017	.975
.985	.979	.974	.961	1.017	1.008	.982
.999	.987	1.021	.958	.954	1.064	.942
.923	.981	.976	.97	.964	.99	1.004

NEW6

1.078	1.02	.999	.993	1.027	1.05	1.033
1.032	.992	1.035	1.052	.989	.952	.989
.986	1.011	1.051	.995	1.041	1.002	.991
.98	.964	1.007	.953	1.025	.975	.972
.949	.986	1.016	.977	.949	1.083	.932
.965	.942	.941	.936	.961	.977	.972

F TEST FOR EQUAL POPULATION VARIANCES

VARA	VARB	DFA	DFB
.0014794	.0013856	41	41

F = 1.0677
F(.05/2, 41 , 41) = 1.8604
F(.01/2, 41 , 41) = 2.2716

TWO-TAILED T-TEST

DF = 82
ALPHA = .16005
T = 1.0003
T(.05/2, 82) = 1.9893
T(.01/2, 82) = 2.6371
January 13, 1989
6:14 PM

5.4.2 Bays 17/19 Frame Cutout: December 1988

Two sets of 6"x6" grid measurements were taken in December 1988. The upper one is located 25" below the top of the high curb and the other below the floor. There is no previous data. The upper location has been added to the long term monitoring program. With no prior data, the only possible analysis was to check the data sets for normality using the chi-squared test.

The data at the upper location are not normally distributed. The lack of normality was tentatively attributed to minimal corrosion in the lower half of the 6"x6" grid with more extensive corrosion in the upper half of the grid. To test this hypothesis, each data set was divided into two subsets, with one containing the top three rows and the other containing the bottom four rows. These subsets proved to be normally distributed, thus confirming the hypothesis. The current mean thickness ± standard error is 981.7 ±4.4 mils for the top three rows and 1003.8 ±6.6 mils for the bottom four rows.

The data at the location below the floor is normally distributed. Also, the mean thickness is higher than at the upper location. The mean thickness ± standard error is 1034.1 ±6.8 mils.

D8702666

.986	.98	.97	.975	.975	.97	.928
.982	.986	.97	1.01	.931	.973	.959
.986	.983	1.001	.993	.975	1.032	1.001
1.122	1.012	.983	.997	1.015	1.01	.978
1.005	1.003	.975	.986	.979	.997	.96
1.028	1.038	.985	.978	.939	.97	1.017
.976	1.012	1.052	1.011	1.049	1.01	1.019

D8702663

1.027	1.057	.993	.958	1.062	1.025	.897
.988	.973	1.011	.99	1.048	1.141	1.101
1.079	1.113	1.033	1.017	1.076	1.064	1.04
1.017	1.007	1.051	1.021	1.028	.97	1.039
1.064	1.005	1.052	.983	.96	.991	1.042
1.087	1.014	1.054	1.049	1.039	1.017	1.044
1.142	1.017	1.019	1.001	1.059	1.109	1.095

PROGRAM: OCDWCONF
BAY: 17/19FR

D8702666
****

.986	.98	.97	.975	.975	.97	.929
.982	.986	.97	1.01	.981	.973	.959
.986	.983	1.001	.993	.975	1.032	1.001
1.122	1.012	.983	.997	1.015	1.01	.978
1.005	1.003	.975	.986	.979	.997	.96
1.028	1.038	.985	.978	.939	.97	1.017
.976	1.012	1.052	1.011	1.049	1.01	1.019

MEAN THICKNESS = .99433
STANDARD ERROR OF THE MEAN = .0044713
T(.05/2, 48)= 2.0106
T(.01/2, 48)= 2.6822

CONFIDENCE INTERVALS FOR THE MEAN
****

95% UPPER BOUND = 1.0033
95% LOWER BOUND = .98534

99% UPPER BOUND = 1.0063
99% LOWER BOUND = .98233

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10/25/06 14:26:07

Calc No	Rev No	Sheet No
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PROGRAM: DWCHISQ1
BAY: 17/19

********	DATADATE	MEANTHK	SD	STDERR	DFM2
********	********	*******	*******	********	****
D8702666	12/30/88	.99433	.031299	.0044713	2

CHISQ	CHI952	CHI992
******	******	******
28.617	5.99	9.21

OBS	EXP
***	*******
4	10.381
23	9.2826
5	9.6726
11	9.2826
6	10.381

PTNOS	PTNOS	PTNOS	PTNOS	PTNOS
*****	*****	*****	*****	*****
1	11	21	31	41
2	12	22	32	42
3	13	23	33	43
4	14	24	34	44
5	15	25	35	45
6	16	26	36	46
7	17	27	37	47
8	18	28	38	48
9	19	29	39	49
10	20	30	40	

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PROGRAM: DWCHISQ1
BAY: 17/19

	DATADATE	MEANTHK	SD	STDERR	DFM2
********	********	*******	*******	********	****
D8702666	12/30/88	.98171	.020352	.0044412	2

CHISQ	CHI952	CHI992
*****	******	******
7.884	5.99	9.21

OBS	EXP
***	******
2	4.4491
7	3.9782
7	4.1454
1	3.9782
4	4.4491

PTNOS	PTNOS
*****	*****
1	12
2	13
3	14
4	15
5	16
6	17
7	18
8	19
9	20
10	21
11	

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PROGRAM: DWCHISQ1
BAY: 17/19

********	DATADATE ********	MEANTHK *******	SD *******	STDERR ********	DFM2 ****
D8702666	12/30/88	1.0038	.034903	.0065961	2

CHISQ ******	CHI952 ******	CHI992 ******
4.3034	5.99	9.21

OBS ***	EXP ******
4	5.9321
7	5.3043
9	5.5272
4	5.3043
4	5.9321

PTNOS *****	PTNOS *****	PTNOS *****
22	32	41
23	33	42
24	34	43
25	35	44
26	36	45
27	37	46
28	38	47
29	39	48
30	40	49
31		

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PROGRAM: DWCHISQ1
BAY: 17/19

	DATADATE	MEANTHK	SD	STDERR	DFM2
********	********	*******	*******	********	****
D8702666	12/30/88	.99046	.032714	.0061823	2

CHISQ	CHI952	CHI992
******	******	******
11.812	5.99	9.21

OBS	EXP
***	******
2	5.9321
11	5.3043
7	5.5272
6	5.3043
2	5.9321

PTNOS	PTNOS	PTNOS
*****	*****	*****
1	11	20
2	12	21
3	13	22
4	14	23
5	15	24
6	16	25
7	17	26
8	18	27
9	19	28
10		

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PROGRAM: DWCHISQ1
BAY: 17/19

********	DATADATE ********	MEANTHK *******	SD *******	STDERR ********	DFM2 ****
D8702666	12/30/88	.99948	.029286	.0063907	2

CHISQ ******	CHI952 ******	CHI992 ******
.69258	5.99	9.21

OBS ***	EXP ******
5	4.4491
4	3.9782
3	4.1454
5	3.9782
4	4.4491

PTNOS *****	PTNOS *****
29	40
30	41
31	42
32	43
33	44
34	45
35	46
36	47
37	48
38	49
39	

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Calc No	Rev No	Sheet No
C-1302-187-5300-005	Ø	174 --

PROGRAM: OCDWCONF
BAY: 17/19FR

DS702663

****

1.027	1.057	.993	.958	1.062	1.025	.997
.988	.973	1.011	.99	1.048	1.141	1.101
1.079	1.113	1.033	1.017	1.076	1.064	1.04
1.017	1.007	1.051	1.021	1.028	.97	1.039
1.064	1.005	1.052	.983	.96	.991	1.042
1.087	1.014	1.054	1.049	1.039	1.017	1.044
1.142	1.017	1.019	1.001	1.059	1.109	1.095

MEAN THICKNESS = 1.0341
STANDARD ERROR OF THE MEAN = .0067931
T(.05/2, 48)= 2.0106
T(.01/2, 48)= 2.6822

CONFIDENCE INTERVALS FOR THE MEAN
****

95% UPPER BOUND = 1.0477
95% LOWER BOUND = 1.0204

99% UPPER BOUND = 1.0523
99% LOWER BOUND = 1.0158

January 20, 1989
10:43 AM

PROGRAM: DWCHISQ1
BAY: 17/19 (BELOW FLOOR)

	DATADATE	MEANTHK	SD	STDERR	DFM2
********	********	*******	*******	********	****
D8702663	12/23/88	1.0341	.047551	.0067931	2

CHISQ	CHI952	CHI992
******	******	******
.61772	5.99	9.21

OBS	EXP
***	*******
10	10.381
11	9.2826
9	9.6726
10	9.2826
9	10.381

PTNOS	PTNOS	PTNOS	PTNOS	PTNOS
*****	*****	*****	*****	*****
1	11	21	31	41
2	12	22	32	42
3	13	23	33	43
4	14	24	34	44
5	15	25	35	45
6	16	26	36	46
7	17	27	37	47
8	18	28	38	48
9	19	29	39	49
10	20	30	40	

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5.5 6" Strips in Sand Bed Region

5.5.1 Bay 1D: 11/25/86 to 12/17/88

The 7-point data set was taken in December 1988 and a single point measurement was taken in November 1986. The data were compared as described in paragraph 2.7. The previous measurement falls below the 99% lower bound of the new 7-point data set. Thus, the corrosion rate is classified as indeterminable. The current mean thickness ± standard error is 1114.7 ±30.6 mils.

NOTE: ALL OF THE 11-25-86 SINGLE POINT READINGS ARE DOCUMENTED ON DATA SHEET 86-049-13.

10/25/06 14:28:07

GPU Nuclear **Calculation Sheet**

Subject		Calc No	Rev No	Sheet No
		C-1302-187-5300-005	Ø	175
Originator: J Moore	Date: 1-16-89	Reviewed by	Date	

5.5.1 BAY 1D (CONT'D)

```
PROGRAM  OCDWCONF
BAY: 1D

 D8702654
 ********
   .932
  1.148
  1.159
  1.143
  1.146
  1.136
  1.139

MEAN THICKNESS = 1.1147
STANDARD ERROR OF THE MEAN = .03058
T(.05/2, 6 )= 2.4469
T(.01/2, 6 )= 3.7074

CONFIDENCE INTERVALS FOR THE MEAN
*********************************

95% UPPER BOUND = 1.1895
95% LOWER BOUND = 1.0399

99% UPPER BOUND = 1.2281
99% LOWER BOUND = 1.0013

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THE 11-26-86 THICKNESS OF 0.965" FALLS BELOW THE 99% LOWER BOUND.

PER ¶ 4.7, THE CORROSION IS CLASSIFIED AS "INDETERMINABLE."

5.5.2 Bay 3D: 11/25/86 to 12/17/88

The 7-point data set was taken in December 1988 and a single point measurement was taken in November 1986. The data were compared as described in paragraph 2.7. The previous measurement falls within the 99% upper and lower bounds of the new 7-point data set. This implies that significant corrosion has not occurred at this location in the time period covered by the data. The current mean thickness ± standard error is 1177.7 ±5.6 mils.

GPU Nuclear **Calculation Sheet**

Subject	Calc No	Rev No	Sheet No
	C-1302-187-5300-005	Ø	179

Originator	Date	Reviewed by	Date
JC Moore	1-16-89		

5.5.2 BAY 3D (CONT'D)

```
PROGRAM: OCDWCONF
BAY: 3D

 D8702655
 ********
  1.194
  1.187
  1.192
  1.171
  1.154
  1.18
  1.166

MEAN THICKNESS = 1.1777
STANDARD ERROR OF THE MEAN = .0055751
T(.05/2, 6 )= 2.4469
T(.01/2, 6 )= 3.7074

CONFIDENCE INTERVALS FOR THE MEAN
*********************************

95% UPPER BOUND = 1.1914
95% LOWER BOUND = 1.1641

99% UPPER BOUND = 1.1984
99% LOWER BOUND = 1.157

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THE 11-25-86 THICKNESS OF 1.195" FALLS WITHIN THE 99% CONFIDENCE INTERVAL.

PER ¶ 4.7, THE CORROSION IS CLASSIFIED AS "NOT SIGNIFICANT".

5.5.3 <u>Bay 5D: 11/25/86 to 12/17/88</u>

The 7-point data set was taken in December 1988 and a single point measurement was taken in November 1986. The data were compared as described in paragraph 2.7. The previous measurement falls within the 95% upper and lower bounds of the new 7-point data set. This implies that significant corrosion has not occurred at this location in the time period covered by the data. The current mean thickness rate ± standard error is 1174.0 ±2.2 mils.

GPU Nuclear Calculation Sheet

Subject	Calc No	Rev No	Sheet No
	C-1302-187-5300-005	Ø	181

Originator	Date	Reviewed by	Date
JP Moore	1-16-89		

5.5.3 BAY 5D (CONT'D)

```
PROGRAM: OCDWCONF
BAY: 5D

 D8702656
 ********
  1.162
  1.177
  1.179
  1.177
  1.174
  1.171
  1.178

MEAN THICKNESS = 1.174
STANDARD ERROR OF THE MEAN = .0022467
T(.05/2, 6 )= 2.4469
T(.01/2, 6 )= 3.7074

CONFIDENCE INTERVALS FOR THE MEAN
*********************************

95% UPPER BOUND = 1.1795
95% LOWER BOUND = 1.1685

99% UPPER BOUND = 1.1823
99% LOWER BOUND = 1.1657

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THE 11-25-86 THICKNESS OF 1.177" FALLS WITHIN THE 95% CONFIDENCE INTERVAL.

PER ¶ 4.7, THE CORROSION IS CLASSIFIED AS "NOT SIGNIFICANT".

5.5.4 Bay 7D: 11/25/86 to 12/17/88

The 7-point data set was taken in December 1988 and a single point measurement was taken in November 1986. The data was compared as described in paragraph 2.7. The previous measurement falls just above the 99% upper bound of the new 7-point data set. This implies that corrosion has possibly occurred at this location in the time period covered by the data. The current mean thickness ± standard error is 1135.1 ±4.9 mils.

GPU Nuclear Calculation Sheet

Subject		Calc No	Rev No	Sheet No
		C-1302-187-5300-005	Ø	183
Originator: JD Moore	Date: 1-16-89	Reviewed by	Date	

5.5.4 BAY 7D (CONT'D)

```
PROGRAM: OCDWCONF
BAY: 7D

 D8702657
 ********
  1.146
  1.146
  1.147
  1.141
  1.129
  1.121
  1.116

MEAN THICKNESS = 1.1351
STANDARD ERROR OF THE MEAN = .0049156
T(.05/2, 6 )= 2.4469
T(.01/2, 6 )= 3.7074

CONFIDENCE INTERVALS FOR THE MEAN
*********************************

95% UPPER BOUND = 1.1472
95% LOWER BOUND = 1.1231

99% UPPER BOUND = 1.1534
99% LOWER BOUND = 1.1169

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THE 11-25-86 THICKNESS OF 1.160" FALLS JUST ABOVE THE 99% UPPER BOUND.

PER ¶ 4.7, THE CORROSION IS CLASSIFIED AS "POSSIBLE".

5.5.5 Bay 9A: 11/25/86 to 12/17/88

The 7-point data set was taken in December 1988 and a single point measurement was taken in November 1986. The data were compared as described in paragraph 2.7. The previous measurement falls below the 99% lower bound of the new 7-point data set. Thus, the corrosion rate is classified as indeterminable. The current mean thickness ± standard error is 1154.6 ±4.8 mils.

10/25/96 14:26:07

GPU Nuclear **Calculation Sheet**

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	C-1302-187-5700-005	Ø	185
Originator: J P Moore, Date: 1-16-89	Reviewed by	Date	

5.5.5. BAY 9A (CONT'D)

```
PROGRAM: OCDWCONF
BAY: 9A

 D8702660
 ********
  1.161
  1.161
  1.163
  1.161
  1.157
  1.152
  1.127

MEAN THICKNESS = 1.1546
STANDARD ERROR OF THE MEAN = .0048001
T(.05/2, 6 )= 2.4469
T(.01/2, 6 )= 3.7074

CONFIDENCE INTERVALS FOR THE MEAN
*********************************

95% UPPER BOUND = 1.1663
95% LOWER BOUND = 1.1428

99% UPPER BOUND = 1.1724
99% LOWER BOUND = 1.1368

January 16, 1989
12:38 PM
```

THE 11-25-86 THICKNESS OF 1.029" FALLS WELL BELOW THE 99% LOWER BOUND.

PER ¶ 4.7, THE CORROSION IS CLASSIFIED AS "INDETERMINABLE".

5.5.6 Bay 13C: 11/25/86 to 12/17/88

The 7-point data set was taken in December 1988 and a single point measurement was taken in November 1986. The data were compared as described in paragraph 2.7. The previous measurement falls within the 95% upper and lower bounds of the new 7-point data set. This implies that significant corrosion has not occurred at this location in the time period covered by the data. The current mean thickness ± standard error is 1147.4 ±3.7 mils.

10/25/06 14:28:07

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PROGRAM: OCDWCONF
BAY: 13C

D8702661
****
1.154
1.156
1.15
1.152
1.15
1.127
1.143

MEAN THICKNESS = 1.1474
STANDARD ERROR OF THE MEAN = .0037407
T(.05/2, 6)= 2.4469
T(.01/2, 6)= 3.7074

CONFIDENCE INTERVALS FOR THE MEAN
****

95% UPPER BOUND = 1.1566
95% LOWER BOUND = 1.1383

99% UPPER BOUND = 1.1613
99% LOWER BOUND = 1.1336

January 16, 1989
12:46 PM

THE 11-25-86 THICKNESS OF 1.141" FALLS WITHIN THE 95% CONFIDENCE INTERVAL.

PER ¶ 4.7, THE CORROSION IS CLASSIFIED AS " NOT SIGNIFICANT"

5.5.7 Bay 13D: 11/25/86 to 12/17/88

The 7-point data set was taken in December 1988 and a single point measurement was taken in November 1986. The data were compared as described in paragraph 2.7. The previous measurement falls within the 95% upper and lower bounds of the new 7-point data set. This implies that significant corrosion has not occurred at this location in the time period covered by the data. The current mean thickness ± standard error is 962.1 ±22.3 mils.

PROGRAM: OCDWCONF
BAY: 13D

D8702667
****
1.03
.985
.898
.871
.949
.995
1.007

MEAN THICKNESS = .96214
STANDARD ERROR OF THE MEAN = .022261
T(.05/2, 6)= 2.4469
T(.01/2, 6)= 3.7074

CONFIDENCE INTERVALS FOR THE MEAN
****

95% UPPER BOUND = 1.0166
95% LOWER BOUND = .90767

99% UPPER BOUND = 1.0447
99% LOWER BOUND = .87961

January 16, 1989
12:47 PM

THE 11-25-86 THICKNESS OF 0.941" FALLS WITHIN THE 95 % CONFIDENCE INTERVAL.

PER ¶ 4.7, THE CORROSION IS CLASSIFIED AS "NOT SIGNIFICANT"

5.5.8 Bay 15A: 11/25/86 to 12/19/88

The 7-point data set was taken in December 1988 and a single point measurement was taken in November 1986. Also, a 6"x6" grid data set was taken on December 2, 1986 at this location. As a best approximation, the first 5 points in the 7-point data set are at the same location as points 38 to 42 of the 6"x6" grid. These five points all fall within the 99% confidence interval of the new 7-point data set. The single measurement falls below the 99% lower bound. This implies that significant corrosion has not occurred at this location in the time period covered by the data. The current mean thickness ± standard error is 1120.0 ±12.6 mils.

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```
PROGRAM: OCDWCONF
BAY: 15A

 D9702662
 ********
  1.138
  1.147
  1.134
  1.123
  1.14
  1.108
  1.05

MEAN THICKNESS = 1.12
STANDARD ERROR OF THE MEAN = .012632
T(.05/2, 6 )= 2.4469
T(.01/2, 6 )= 3.7074

CONFIDENCE INTERVALS FOR THE MEAN
*********************************

95% UPPER BOUND = 1.1509
95% LOWER BOUND = 1.0891

99% UPPER BOUND = 1.1668
99% LOWER BOUND = 1.0732

January 16, 1989
12:47 PM
```

MEAN OF 5 PTS FROM D15A612 = 1.1506
THIS FALLS WITHIN THE 99% CONFIDENCE INTERVAL

THE 11-25-86 THICKNESS OF 0.722"
FALLS BELOW THE 99% LOWER BOUND.
(REF: DATA SHT 86-049-13)

PER ¶ 4.7, THE CORROSION IS CLASSIFIED
AS "NOT SIGNIFICANT".

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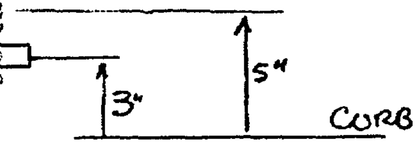
PROGRAM: OCDWCONF
BAY: 15A

DATA SHT: 86-049-25

D15A612

.698	1.163	1.162	1.162	1.167	1.15	1.163
.507	.759	1.168	1.162	1.166	1.15	1.165
.404	.754	1.167	1.169	1.169	1.164	1.166
.648	1.15	.736	1.156	1.15	1.156	1.154
.645	1.15	.73	1.135	1.165	1.143	1.137
.513	1.126	1.151	1.147	1.156	1.154	1.145
1.132	.491	1.117	1.123	1.145	1.123	1.133



MEAN THICKNESS = 1.0337
STANDARD ERROR OF THE MEAN = .032755
T(.05/2, 48)= 2.0106
T(.01/2, 48)= 2.6822

CONFIDENCE INTERVALS FOR THE MEAN
****

95% UPPER BOUND = 1.0995
95% LOWER BOUND = .9678

99% UPPER BOUND = 1.1215
99% LOWER BOUND = .9458

January 20, 1989
10:44 AM

BOX INDICATES APPROX. LOCATION OF READINGS 1-5 ON DATA SHEET 87-026-62

MEAN = 1.1506

6.0 APPENDICES

6.1 SPEAKEZ Programs

6.2 SAS Program

APPENDIX 6.1

```
LISTING OF PROGRAM DWCHISQ
  1.0 PROGRAM
  1.2 $ BY J.P. MOORE, REVISED: 1-18-89
  1.5 JOURNAL ON
  1.6     PRINT "PROGRAM: DWCHISQ"
  2.0 ASK("ENTER NAME OF DATA LIST","HENCEFORTH DATALIST IS ")
  2.2 ASK("ENTER PT NUMBER LIST", "PTNOS= ", "PTNOS=INTS(1,49)")
  2.5 ASK("ENTER NAME OF DATE LIST","HENCEFORTH DATELIST IS ")
  3.0 $GET DATALIST ON OCDAT
  4.0 N = INTS(1,NOELS(DATALIST))
  5.0 TABULATE N,DATALIST
  6.0 ASK("ENTER NO. OF DESIRED DATA", "SELECT = ")
  7.0 J = NOELS(SELECT)
  8.0 P = A1D(: 2.1186E-1, 1.8944E-1, 1.9740E-1, 1.8944E-1, 2.1186E-1)
  9.0 BINS0 = A1D(: -6, -0.8, -0.25, 0.25, 0.8, 6)
 10.0 N = A1D(J:)
 11.0 SD = A1D(J:)
 11.5 STDERR = A1D(J:)
 12.0 MEANTHK = A1D(J:)
 13.0 BIN = A2D(6,J:)
 14.0 OBS = A2D(5,J:)
 15.0 EXP = A2D(5,J:)
 16.0 DFM2 = A1D(J:)
 17.0 CHISQ = A1D(J:)
 18.0 FOR I = 1,J
 19.0       K = SELECT(I)
 20.0       AI = A1D(OBJECT(DATALIST(K)))
 20.2       AI = AI(PTNOS)
 21.0       AI = AI(LOCS(AI.GT.0))
 22.0       N(I) = NOELS(AI)
 23.0       SD(I) = STANDDEV(AI)
 23.5       STDERR(I) = STANDERR(AI)
 24.0       MEANTHK(I) = MEAN(AI)
 25.0       BINS = SD(I)*BINS0 + MEANTHK(I)
 26.0       BIN(,I) = BINS
 27.0      OBS(,I) = BINNED(AI)
 28.0       EXP(,I) = N(I)*P
 29.0       CONF(I) = CHISQUARED(OBS(,I),EXP(,I): DF=DF, CHI=CHI)
 30.0      DFM2(I) = DF - 2
 31.0      CHISQ(I) = CHI
 32.0 NEXT I
 32.2      GMEAN = MEAN(MEANTHK)
 32.3      SEGMEAN = STANDERR(MEANTHK)
 33.0 $ OUTPUT
 33.2      CHI952=A1D(J:) + 5.99
 33.4      CHI992 = A1D(J:) + 9.21
 34.0       TABULATE(DATALIST(SELECT),DATELIST, MEANTHK, SD, STDERR, DFM2
 34.5       TABULATE(CHISQ,CHI952,CHI992)
 35.0       TABULATE(OBS, EXP)
 35.1      SPACE(1)
 35.2      TYPE "GRAND MEAN THICKNESS =" GMEAN
 35.3      TYPE "STANDARD ERROR OF THE GRAND MEAN =" SEGMEAN
 35.4      SPACE(1)
 35.5     DATE;TIME
 36.0      NEWPAGE
 37.0      JOURNAL OFF
 38.0 END
```

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LISTING OF PROGRAM DWCHISQ1

```
 1.0 PROGRAM
 2.0 $ BY J.P.MOORE     1-18-89
 4.0 ASK("ENTER NAME OF DATA SET","HENCEFORTH NAMEX IS ")
 4.5 DATASET = NAMELIST(NAMEX)
 4.7 ASKNAME("BAY NUMBER?","BAY= ")
 5.0 ASK("ENTER PT NUMBER LIST", "PTNOS= ", "PTNOS=INTS(1,49)")
 6.0 ASKNAME("ENTER DATE","DATADATE= ")
12.0 P = A1D(: 2.1186E-1, 1.8944E-1, 1.9740E-1, 1.8944E-1, 2.1186E-1)
13.0 BINS0 = A1D(: -6, -0.8, -0.25, 0.25, 0.8, 6)
17.0 BIN = A1D(6:)
18.0 OBS = A1D(5:)
19.0 EXP = A1D(5:)
24.0 AI = A1D(OBJECT(DATASET))
25.0 AI = AI(PTNOS)
26.0 AI = AI(LOCS(AI.GT.0))
27.0 N = NOELS(AI)
28.0 SD = STANDDEV(AI)
28.5 STDERR = STANDERR(AI)
29.0 MEANTHK = MEAN(AI)
30.0 BINS = SD*BINS0 + MEANTHK
31.0 BIN = BINS
32.0       OBS = BINNED(AI)
33.0 EXP = N*P
34.0 PROB = CHISQUARED(OBS,EXP: DF=DF, CHI=CHI)
35.0       DFM2 = DF - 2
36.0       CHISQ = CHI
38.0 $ OUTPUT
38.2  JOURNAL ON
38.3     TYPE "PROGRAM: DWCHISQ1"
38.4     TYPE "BAY:"BAY
39.0      CHI952 = 5.99
39.5      CHI992 = 9.21
40.0      TABULATE(DATASET,DATADATE,MEANTHK,SD,STDERR,DFM2)
40.5     TABULATE(CHISQ,CHI952,CHI992)
41.0      TABULATE(OBS, EXP)
41.5      TABULATE PTNOS
42.0     DATE;TIME
43.0      NEWPAGE
44.0       JOURNAL OFF
45.0 END
```

LISTING OF PROGRAM OCDWCONF

```
 1.0 PROGRAM
 1.5 $ BY J.P. MOORE. REVISED: 1-16-89
 2.0 ASK("DATASET NAME?","HENCEFORTH DATASET IS ")
 3.0 ASKNAME("BAY NUMBER?","BAY= ")
 4.0 MEANDATA=MEAN(DATASET)
 5.0 STDERR=STANDERR(DATASET)
 6.0 DF = NOELS(DATASET) - 1
 7.0 T95 = ABS(TPROBINVERSE(.975,DF))
 8.0 T99 = ABS(TPROBINVERSE(.995,DF))
 9.0 UB95 = MEANDATA + T95*STDERR
10.0 LB95 = MEANDATA - T95*STDERR
11.0 UB99 = MEANDATA + T99*STDERR
12.0 LB99 = MEANDATA - T99*STDERR
13.0 JOURNAL ON
14.0 TYPE "PROGRAM: OCDWCONF"
15.0 TYPE "BAY:"BAY
16.0 TABULATE DATASET
17.0 TYPE "MEAN THICKNESS =" MEANDATA
18.0 TYPE "STANDARD ERROR OF THE MEAN =" STDERR
19.0 TYPE "T(.05/2," DF ")=" T95
20.0 TYPE "T(.01/2," DF ")=" T99
21.0 SPACE(1)
22.0 TYPE "CONFIDENCE INTERVALS FOR THE MEAN"
23.0 TYPE "*********************************"
24.0 SPACE(1)
25.0 TYPE "95% UPPER BOUND =" UB95
26.0 TYPE "95% LOWER BOUND =" LB95
27.0 SPACE(1)
28.0 TYPE "99% UPPER BOUND =" UB99
29.0 TYPE "99% LOWER BOUND =" LB99
30.0 SPACE(1)
50.0 DATE; TIME
51.0 NEWPAGE
52.0 JOURNAL OFF
53.0 END
```

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LISTING OF PROGRAM T2TAIL

```
 1.0 PROGRAM
 1.5 $ BY J.P. MOORE, REVISED 1-13-89
 2.0 ASKNAME("ENTER BAY NUMBER", "BAY= ")
 3.0 ASK("ENTER NAME OF 1ST DATA SET", "HENCEFORTH DATA1 IS ")
 4.0 ASKNAME("ENTER DATA SHEET NO.", "DATASHT1= ")
 5.0 ASKNAME("ENTER DATE OF 1ST DATA SET", "DATE1= ")
 6.0 ASK("ENTER NAME OF 2ND DATA SET", "HENCEFORTH DATA2 IS ")
 7.0 ASKNAME("ENTER DATA SHEET NO.", "DATASHT2= ")
 8.0 ASKNAME("ENTER DATE OF 2ND DATA SET", "DATE2= ")
 9.0 DATASETS = NAMELIST(DATA1 DATA2)
10.0 DATASHTS = DATASHT1,DATASHT2
11.0 DATADATES = DATE1,DATE2
12.0 D1 = A1D(DATA1)
13.0 D2 = A1D(DATA2)
14.0 D1OK = D1(LOCS(D1.NE.0))
15.0 D2OK = D2(LOCS(D2.NE.0))
16.0 CALC:
17.0   MEANTHK = MEAN(D1OK),MEAN(D2OK)
18.0 FTEST1:
19.0    N1 = NOELS(D1OK)
20.0    N2 = NOELS(D2OK)
21.0    DF1 = N1-1
22.0    DF2 = N2-1
23.0    VAR1 = VARIANCE(D1OK)
24.0    VAR2 = VARIANCE(D2OK)
25.0    IF(VAR2.GT.VAR1) GOTO FTEST2
25.2    DA = D1OK
25.4    DB = D2OK
26.0    NA = N1
27.0    NB = N2
28.0    DFA = DF1
29.0    DFB = DF2
30.0    VARA = VAR1
31.0    VARB = VAR2
32.0    GOTO FTEST3
33.0 FTEST2:
33.2   DA = D2OK
33.4   DB = D1OK
34.0    NA = N2
35.0    NB = N1
36.0    DFA = DF2
37.0    DFB = DF1
38.0    VARA = VAR2
39.0    VARB = VAR1
40.0 FTEST3:
41.0    F = VARA/VARB
42.0    F95 = FPROBINVERSE(0.025,DFA,DFB)
42.5    F99 = FPROBINVERSE(0.005,DFA,DFB)
43.0 TTEST:
44.0    ALPHA = TINDEPT(DA,DB,T,DF)
45.0    T95 = TPROBINVERSE(0.025,DF)
46.0    T99 = TPROBINVERSE(0.005,DF)
47.0 OUTPUT:
48.0 JOURNAL ON
49.0 PRINT "COMPARISON OF MEANS USING TWO-TAILED T-TEST"
50.0 PRINT "*******************************************"
51.0   TABULATE BAY,DATASHTS,DATASETS,DATADATES,MEANTHK
52.0   TABULATE DATA1
53.0   TABULATE DATA2
54.0 PRINT "F TEST FOR EQUAL POPULATION VARIANCES"
55.0 PRINT "*************************************"
56.0 TABULATE VARA,VARB,DFA,DFB
56.2          F
56.4 TYPE "F(.05/2," DFA "," DFB ") =" F95
56.6 TYPE "F(.01/2," DFA "," DFB ") =" F99
57.0 SPACE
58.0 PRINT "TWO-TAILED T-TEST"
59.0 PRINT "*****************"
60.0          DF
61.0          ALPHA
62.0          T
63.0 TYPE  "T(.05/2," DF ") =" T95
64.0 TYPE  "T(.01/2," DF ") =" T99
64.5 DATE,TIME
65.0 JOURNAL OFF
66.0 END
```

```
data dwdata;
input
   @5 dates mmddyy8.
   @15 stddev  3.3;
   retain day0;
   if _n_ = 1 then day0 = dates;
   days = intck('day',day0,dates);
   years = days/365;
cards;
    5/1/87      92.336
    8/1/87     107.370
    9/10/87    109.444
    7/12/88     99.895
    10/3/88     94.979
;;
proc print data=dwdata;
      title1 'LINEAR REGRESSION PLOT';
      title2 'FOR DW WALL THINNING ANALYSIS';
      title3 'OF BAY 11C 3" ABOVE CURB';
      format dates mmddyy8.;
      format day0 mmddyy8.;
proc means data=dwdata n mean std stderr;
      var stddev;
proc reg data=dwdata;
      model stddev = years/ss1 stb clm cli collin;
proc reg data=dwdata;
      model stddev = years/ p r cli clm;
      output out=a p=pred l95=l95 u95=u95 r=residual; clear;
proc plot data=a;
      plot stddev*years='x' pred*years='p' u95*years='u'
           l95*years='l' / overlay
           vaxis=800 to 1250 by 50;
proc plot data=a;
      plot residual*years='r'/
      vaxis = -40 to 40 by 2;
```

GPU Nuclear Technical Data Report	TDR No. 948	Revision No. Ø 1
	Budget Activity No. 315302	Page 1 of 26
Project: OYSTER CREEK	Department/Section 5300	
	Revision Date 2-1-89	

Document Title: STATISTICAL ANALYSIS OF DRYWELL THICKNESS DATA

Originator Signature	Date	Approval(s) Signature	Date
J. P. Moore Jr.	1-23-89	G. Capodanno	1/26/89
[signature]	1-24-89		
		Approval for External Distribution	Date

Does this TDR include recommendation(s)? ___Yes _X_No If yes, TFWR/TR# ____

*	Distribution	Abstract:
	J. D. Abramovici F. P. Barbieri G. R. Capodanno D. W. Covill D. G. Jerko M. W. Laggart L. C. Lanese S. D. Leshnoff J. A. Martin J. P. Moore M. A. Orski S. C. Tumminelli M. O. Sanford D. G. Slear R. W. Keaten	Statement of Problem The design of the carbon steel drywell includes a sand bed which is located around the outside circumference between elevations 8'-11- 1/4" and 12'-3". Leakage was observed from the sand bed drains during the 1980, 1983 and 1986 refueling outages indicating that water had intruded into the annular region between the drywell shell and the concrete shield wall. A long term monitoring program was established in 1986 to take Ultrasonic Thickness (UT) measurements at representative locations on the drywell shell to determine the corrosion rate and monitor it over time. The initial program included six locations in the sand bed region. The program was expanded in 1987 to include measurements at higher elevations. (For Additional Space Use Side 2)

* Abstract Only

A cathodic protection system is being installed in selected regions of the sand bed to minimize corrosion of the drywell. The long term monitoring program was further expanded in 1988 to monitor the effectiveness of the cathodic protection system and to monitor additional sand bed regions not covered by cathodic protection.

A critical part of the long term program is the statistical analysis of the UT measurements to determine the corrosion rate at each location. This report documents the assumptions, methods, and results of the statistical analyses of UT measurements taken through December 31, 1988.

Summary of Key Results

Bay Area	Location	Corrosion Rate**	Mean Thickness***
11A	Sand Bed	Not significant	908.6 ±5.0 mils
11C	Sand Bed	Indeterminable	916.6 ±10.4 mils
17D	Sand Bed	-27.6 ±6.1 mpy	864.8 ±6.8 mils
19A	Sand Bed	-23.7 ±4.3 mpy	837.9 ±4.8 mils
19B	Sand Bed	-29.2 ±0.5 mpy	856.5 ±0.5 mils
19C	Sand Bed	-25.9 ±4.1 mpy	860.9 ±4.0 mils
9D	Sand Bed	Indeterminable*	1021.4 ±9.7 mils
13A	Sand Bed	Not significant*	905.3 ±10.1 mils
15D	Sand Bed	Possible*	1056.0 ±9.1 mils
17A	Sand Bed	Indeterminable*	957.4 ±9.2 mils
5	51' Elev.	-4.3 ±0.03 mpy	750.0 ±0.02 mils
9	87' Elev.	Not significant	620.3 ±1.0 mils
13	87' Elev.	Not significant	635.6 ±0.7 mils
15	87' Elev.	Not significant	634.8 ±0.7 mils
17D	Trench	Not significant*	981.2 ±6.7 mils
17/19	Frame Cutout	Indeterminable*	981.7 ±4.4 mils
1D	Sand Bed	Indeterminable*	1114.7 ±30.6 mils
3D	Sand Bed	Not significant*	1177.7 ±5.6 mils
5D	Sand Bed	Not significant*	1174.0 ±2.2 mils
7D	Sand Bed	Possible*	1135.1 ±4.9 mils
9A	Sand Bed	Indeterminable*	1154.6 ±4.8 mils
13C	Sand Bed	Not significant*	1147.4 ±3.7 mils
13D	Sand Bed	Not significant*	962.1 ±22.3 mils
15A	Sand Bed	Not significant*	1120.0 ±12.6 mils

One data point in Bay 19A and one data point in Bay 5 Elev. 51' fell outside the 99% confidence interval and thus are statistically different from the mean thickness.

*Based on limited data. See text for interpretation.
**Mean corrosion rate in mils per year ± standard error of the mean
***Current mean thickness in mils ± standard error of the mean

GPU Nuclear	DOCUMENT NO. TDR 948

TITLE

STATISTICAL ANALYSIS OF DRYWELL THICKNESS DATA

REV	SUMMARY OF CHANGE	APPROVAL	DATE
1	Corrected outage numbers on pages 3 and 5 (two places). Deleted redundant discussion of Bay 15D on pages 12, 19, 25 and 26.	[signature] Moore G. Capodanno	1-30-89 1/31/89

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Background

The design of the carbon steel drywell includes a sand bed which is located around the outside circumference between elevations 8'-11-1/4" and 12'-3". Leakage was observed from the sand bed drains during the 1980, 1983 and 1986 refueling outages indicating that water had intruded into the annular region between the drywell shell and the concrete shield wall.

The drywell shell was inspected in 1986 during the 11R outage to determine if corrosion was occurring. The inspection methods, results and conclusions are documented in Ref. 3.1, 3.2, and 3.3. As a result of these inspections it was concluded that a long term monitoring program would be established. This program includes repetitive Ultrasonic Thickness (UT) measurements in the sand bed region at a nominal elevation of 11'-3" in bays 11A, 11C, 17D, 19A, 19B, and 19C.

The continued presence of water in the sand bed raised concerns of potential corrosion at higher elevations. Therefore, UT measurements were taken at the 51' and 87' elevations in November 1987 during the 11M outage. As a result of these inspections, repetitive measurements in Bay 5 at elevation 51' and in Bays 9, 13 and 15 at the 87' elevation were added to the long term monitoring program to confirm that corrosion is not occurring at these higher elevations.

A cathodic protection system is being installed in selected regions of the sand bed during the 12R outage to minimize corrosion of the drywell. The long term monitoring program was also expanded during the 12R outage to include measurements in the sand bed region of Bays 1D, 3D, 5D, 7D, 9A, 13A, 13C, 13D, 15A, 15D and 17A which are not covered by the cathodic protection system. It also includes measurements in the sand bed region between Bays 17 and 19 which is covered by the cathodic protection system, but does not have a reference electrode to monitor its effectiveness in this region.

Some measurements in the long term monitoring program are to be taken at each outage of opportunity, while others are taken during each refueling outage. The functional requirements for these inspections are documented in Ref. 3.4. The primary purpose of the UT measurements in the sand bed region is to determine the corrosion rate and monitor it over time. When the cathodic protection system is installed and operating, these data will be used to monitor its effectiveness. The purpose of the measurements at other locations is to confirm that corrosion is not occurring in those regions.

This report documents the assumptions, methods, and results of the statistical analyses used to evaluate the corrosion rate in each of these regions. The complete analyses are documented in Ref. 3.7.

1.2 Statistical Inferences

1.2.1 Statistical Hypotheses

The objective of these statistical analyses is to make statistical decisions or inferences about populations on the basis of sample information. In attempting to reach these decisions, it is useful to make assumptions or guesses about the populations involved. Such assumptions, which may or may not be true, are called statistical hypotheses and in general are statements about the probability distributions of the populations.

In many instances we formulate a statistical hypothesis for the sole purpose of rejecting or nullifying it. For example, in performing a t-test to test the difference between the means of two samples we first hypothesize that there is no difference between the two means. This is referred to as a null hypothesis. Any hypothesis which differs from the null hypothesis is referred to as an alternative hypothesis, eg., the means are not equal, one mean is greater than the other, etc.

1.2.2 Tests of Hypotheses and Significance

If on the supposition that a particular null hypothesis is true we find that results observed in a random sample differ markedly from those expected under the hypothesis on the basis of pure chance, we would say that the observed differences are significant and we would be inclined to reject the hypothesis (or at least not accept it on the basis of the evidence obtained). Procedures which enable us to decide whether to reject or not reject hypotheses are called tests of hypotheses.

1.2.3 Type I and Type II Errors

If we reject a hypothesis when it should not have been rejected, we say that a Type I error has been made. If, on the other hand, we fail to reject a hypothesis when it should have been rejected, we say a Type II error has been made. In either case a wrong decision or error in judgement has occurred.

1.2.4 Level of Significance

In testing a given hypothesis, the maximum probability with which we would be willing to risk a Type I error is called the level of significance of the test. This probability is usually denoted by the Greek letter alpha. In practice a level of significance of 0.05 (5%) or 0.01 (1%) is customary. If 0.05 has been selected, we say that the hypothesis is rejected (or not rejected) at a level of significance of 0.05.

2.0 METHODS

2.1 Selection of Areas to be Monitored

A program was initiated during the 11R outage to characterize the corrosion and to determine its extent. The details of this inspection program are documented in Ref. 3.3. The greatest corrosion was found via UT measurements in the sand bed region at the lowest accessible locations. Where thinning was detected, additional measurements were made in a cross pattern at the thinnest section to determine the extent in the vertical and horizontal directions. Having found the thinnest locations, measurements were made over a 6"-6" grid.

To determine the vertical profile of the thinning, a trench was excavated into the floor in Bay 17 and Bay 5. Bay 17 was selected since the extent of thinning at the floor level was greatest in that area. It was determined that the thinning below the top of the curb was no more severe than above the curb, and became less severe at the lower portions of the sand cushion. Bay 5 was excavated to determine if the thinning line was lower than the floor level in areas where no thinning was detected above the floor. There were no significant indications of thinning in Bay 5.

It was on the basis of these findings that the 6"x6" grids in Bays 11A, 11C, 17D, 19A, 19B and 19C were selected as representative locations for longer term monitoring. The initial measurements at these locations were taken in December 1986 without a template or markings to identify the location of each measurement. Subsequently, the location of the 6"x6" grids were permanently marked on the drywell shell and a template is used in conjunction with these markings to locate the UT probe for successive measurements. Analyses have shown that including the non-template data in the data base creates a significant variability in the thickness data. Therefore, to minimize the effects of probe location, only those data sets taken with the template are included in the analyses.

The presence of water in the sand bed also raised concern of potential corrosion at higher elevations. Therefore, UT measurements were taken at the 51' and 87' elevations in 1987 during the 11M outage. The measurements were taken in a band on 6-inch centers at all accessible regions at these elevations. Where these measurements indicated potential corrosion, the measurements spacing was reduced to 1-inch on centers. If these additional readings indicated potential corrosion, measurements were taken on a 6"x6" grid using the template. It was on the basis of these inspections that the 6"x6" grids in Bay 5 at elevation 51' and in bays 9, 13 and 15 at the 87' elevation were selected as representative locations for long term monitoring.

The long term monitoring program was expanded as follows during the 12R outage:

(1) Measurements on 6"x6" grids in the sand bed region of Bays 9D, 13A, 15D and 17A. The basis for selecting these locations is that they were originally considered for cathodic protection but are not included in the system being installed.

(2) Measurements on 1-inch centers along a 6-inch horizontal strip in the sand bed region of Bays 1D, 3D, 5D, 7D, 9A, 13C, and 15A. These locations were selected on the basis that they are representative of regions which have experienced nominal corrosion and are not within the scope of the cathodic protection system.

(3) A 6"x6" grid in the curb cutout between Bays 17 and 19. The purpose of these measurements is to monitor corrosion in this region which is covered by the cathodic protection system but does not have a reference electrode to monitor its performance.

2.2 UT Measurements

The UT measurements within the scope of the long term monitoring program are performed in accordance with Ref. 3.4. This involves taking UT measurements using a template with 49 holes laid out on a 6"x6" grid with 1" between centers on both axes. The center row is used in those bays where only 7 measurements are made along a 6-inch horizontal strip.

The first set of measurements were made in December 1986 without the use of a template. Ref. 3.4 specifies that for all subsequent readings, QA shall verify that locations of UT measurements performed are within ±1/4" of the location of the 1986 UT measurements. It also specifies that all subsequent measurements are to be within ±1/8" of the designated locations.

2.3 Data at Plug Locations

Seven core samples, each approximately two inches in diameter were removed from the drywell vessel shell. These samples were evaluated in Ref. 3.2. Five of these samples were removed within the 6"x6" grids for Bays 11A, 17D, 19A, 19C and Bay 5 at elevation 51'. These locations were repaired by welding a plug in each hole. Since these plugs are not representative of the drywell shell, UT measurements at these locations on the 6"x6" grid must be dropped from each data set.

The following specific grid points have been deleted:

Bay Area	Points
11A	23. 24, 30, 31
17D	15, 16, 22, 23
19A	24, 25, 31, 32
19C	20, 26, 27, 33,
5	20, 26, 27, 28, 33, 34, 35

2.4 Bases for Statistical Analysis of 6"x6" Grid Data

2.4.1 Assumptions

The statistical evaluation of the UT measurement data to determine the corrosion rate at each location is based on the following assumptions:

(1) Characterization of the scattering of data over each 6"x6" grid is such that the thickness measurements are normally distributed.

(2) Once the distribution of data for each 6"x6" grid is found to be normal, then the mean value of the thickness is the appropriate representation of the average condition.

(3) A decrease in the mean value of the thickness with time is representative of the corrosion occurring within the 6"x6" grid.

(4) If corrosion has ceased, the mean value of the thickness will not vary with time except for random errors in the UT measurements.

(5) If corrosion is continuing at a constant rate, the mean thickness will decrease linearly with time. In this case, linear regression analysis can be used to fit the mean thickness values for a given zone to a straight line as a function of time. The corrosion rate is equal to the slope of the line.

The validity of these assumptions is assured by:

(a) Using more than 30 data points per 6"x6" grid

(b) Testing the data for normality at each 6"x6" grid location.

(c) Testing the regression equation as an appropriate model to describe the corrosion rate.

These tests are discussed in the following section. In cases where one or more of these assumptions proves to be invalid, non-parametric analytical techniques can be used to evaluate the data.

2.4.2 Statistical Approach

The following steps are performed to test and evaluate the UT measurement data for those locations where 6"x6" grid data has been taken at least three times:

(1) Edit each 49 point data set by setting all invalid points to zero. Invalid points are those which are declared invalid by the UT operator or are at a plug location. (The computer programs used in the following steps ignore all zero thickness data points.)

(2) Perform a chi-squared goodness of fit test of each 49 point data set to ensure that the assumption of normality is valid at the 95% and 99% confidence levels.

(3) Calculate the mean thickness of each 49 point data set.

(4) Using the mean thickness values for each 6"x6" grid, perform linear regression analysis over time at each location.

(a) Perform F-test for significance of regression at the 95% confidence level. The result of this test indicates whether or not the regression model is more appropriate than the mean model. In other words, it tests to see if the variation of the regression model is statistically significant over that of a mean model.

(b) Calculate the co-efficient of determination (R^2) to assess how well the regression model explains the percentage of total error and thus how useful the regression line will be as a predictor.

(c) Determine if the residual values for the regression equations are normally distributed.

(d) If the regression model is found to be appropriate, calculate the y-intercept, the slope and their respective standard errors. The y-intercept represents the fitted mean thickness at time zero, the slope represents the corrosion rate, and the standard errors represent the uncertainty or random error of these two parameters.

(5) Use a z score of 2.58 and the standard deviation to establish a 99% confidence interval about the mean thickness values for each 6"x6" grid location to determine whether low thickness measurements or "outliers" are statistically significant. If the data points are greater than the 99% lower confidence limit, then the difference between the value and the mean is deemed to be due to expected random error. However, if the data point is less than the lower 99% confidence limit, this implies that the difference is statistically significant and is probably not due to chance.

2.5 Analysis of Two 6"x6" Grid Data Sets

Regression analysis is inappropriate when data is available at only two points in time. However, the t-Test can be used to determine if the means of the two data sets are statistically different.

2.5.1 Assumptions

This analysis is based upon the following assumptions:

(1) The data in each data set is normally distributed.

(2) The variances of the two data sets are equal.

2.5.2 Statistical Approach

The evaluation takes place in three steps:

(1) Perform a chi-squared test of each data set to ensure that the assumption of normality is valid at the 95% and 99% confidence levels.

(2) Perform an F-test of the two data sets being compared to ensure that the assumption of equal variances is valid at the 95% and 99% confidence levels.

(3) Perform a two-tailed t-Test for two independent samples to determine if the means of the two data sets are statistically different at the 0.05 and 0.01 levels of significance.

A conclusion that the means are <u>not</u> statistically different is interpreted to mean that significant corrosion did not occur over the time period represented by the data. However, if equality of the means is rejected, this implies that the difference is statistically significant and could be due to corrosion.

2.6 Analysis of Single 6"x6" Grid Data Set

In those cases where a 6"x6" data set is taken at a given location for the first time during the current outage, the only other data to which they can be compared are the UT survey measurements taken in 1986 to identify the thinnest regions of the drywell shell in the sand bed region. For the most part, these are single point measurements which were taken in the vicinity of the 49-point data set, but not at the exact location. Therefore, rigorous statistical analysis of these single data sets is impossible. However, by making certain assumptions, they can be compared with the previous data points. If more extensive data is available at the location of the 49-point data set, the t-test can be used to compare the means of the two data sets as described in paragraph 2.5.

When additional measurements are made at these exact locations during future outages, more rigorous statistical analyses can be employed.

2.6.1 Assumptions

The comparison of a single 49-point data sets with previous data from the same vicinity is based on the following assumptions:

(1) Characterization of the scattering of data over the 6"x6" grid is such that the thickness measurements are normally distributed.

(2) Once the distribution of data for the 6"x6" grid is found to be normal, then the mean value of the thickness is the appropriate representation of the average condition.

(3) The prior data is representative of the condition at this location in 1986.

2.6.2 Statistical Approach

The evaluation takes place in four steps:

(1) Perform a chi-squared test of each data set to ensure that the assumption of normality is valid at the 95% and 99% confidence levels.

(2) Calculate the mean and the standard error of the mean of the 49-point data set.

(3) Determine the two-tailed t value from a t distribution table at levels of significance of 0.05 and 0.01 for n-1 degrees of freedom.

(4) Use the t value and the standard error of the mean to calculate the 95% and 99% confidence intervals about the mean of the 49-point data set.

(5) Compare the prior data point(s) with these confidence intervals about the mean of the 49-point data sets.

If the prior data falls within the 95% confidence intervals, it provides some assurance that significant corrosion has not occurred in this region in the period of time covered by the data. If it falls within the 99% confidence limits but not within the 95% confidence limits, this implication is not as strong. In either case, the corrosion rate will be interpreted to be "Not Significant".

If the prior data falls above the upper 99% confidence limit, it could mean either of two things: (1) significant corrosion has occurred over the time period covered by the data, or (2) the prior data point was not representative of the condition of the location of the 49-point data set in 1986. There is no way to differentiate between the two. In this case, the corrosion rate will be interpreted to be "Possible".

If the prior data falls below the lower 99% confidence limit, it means that it is not representative of the condition at this location in 1986. In this case, the corrosion rate will be interpreted to be "Indeterminable".

2.7 Analysis of Single 7-Point Data Set

In those cases where a 7-point data set is taken at a given location for the first time during the current outage, the only other data to which they can be compared are the UT survey measurements taken in 1986 to identify the thinnest regions of the drywell shell in the sand bed region. For the most part, these are single point measurements which were taken in the vicinity of the 7-point data sets, but not at the exact locations. However, by making certain assumptions, they can be compared with the previous data points. If more extensive data is available at the location of the 7-point data set, the t-test can be used to compare the means of the two data sets as described in paragraph 2.5.

When additional measurements are made at these exact locations during future outages, more rigorous statistical analyses can be employed.

2.7.1 Assumptions

The comparison of a single 7-point data sets with previous data from the same vicinity is based on the following assumptions:

(1) The corrosion in the region of each 7-point data set is normally distributed.

(2) The prior data is representative of the condition at this location in 1986.

The validity of these assumptions cannot be verified.

2.7.2. Statistical Approach

The evaluation takes place in four steps:

(1) Calculate the mean and the standard error of the mean of the 7-point data set.

(2) Determine the two-tailed t value using the t distribution tables at levels of significance of 0.05 and 0.01 for n-1 degrees of freedom.

(3) Use the t value and the standard error of the mean to calculate the 95% and 99% confidence intervals about the mean of the 7-point data set.

(4) Compare the prior data point(s) with these confidence intervals about the mean of the 7-point data sets.

If the prior data falls within the 95% confidence intervals, it provides some assurance that significant corrosion has not occurred in this region in the period of time covered by the data. If it falls within the 99% confidence limits but not within the 95% confidence limits, this implication is not as strong. In either case, the corrosion rate will be interpreted to be "Not Significant".

If the prior data falls above the upper 99% confidence interval, it could mean either of two things: (1) significant corrosion has occurred over the time period covered by the data, or (2) the prior data point was not representative of the condition of the location of the 7-point data set in 1986. There is no way to differentiate between the two. In this case, the corrosion rate will be interpreted to be "Possible".

If the prior data falls below the lower 99% confidence limit, it means that it is not representative of the condition at this location in 1986. In this case, the corrosion rate will be interpreted to be "Indeterminable".

2.8 Evaluation of Drywell Mean Thickness

This section defines the methods used to evaluate the drywell thickness at each location within the scope of the long term monitoring program.

2.8.1 Evaluation of Mean Thickness Using Regression Analysis

The following procedure is used to evaluate the drywell mean thickness at those locations where regression analysis has been deemed to be more appropriate than the mean model.

(1) The best estimate of the mean thickness at these locations is the point on the regression line corresponding to the time when the most recent set of measurements was taken. In the SAS Regression Analysis output (Ref. 3.7), this is the last value in the column labeled "PREDICT VALUE".

(2) The best estimate of the standard error of the mean thickness is the standard error of the predicted value used above. In the SAS Regression Analysis output, this is the last value in the column labeled "STD ERR PREDICT".

(3) The two-sided 95% confidence interval about the mean thickness is equal to the mean thickness plus or minus t times the estimated standard error of the mean. This is the interval for which we have 95% confidence that the true mean thickness will fall within. The value of t is obtained from a t distribution table for equal tails at n-2 degrees of freedom and 0.05 level of significance, where n is the number of sets of measurements used in the regression analysis. The degrees of freedom is equal to n-2 because two parameters (the y-intercept and the slope) are calculated in the regression analysis with n mean thicknesses as input.

(4) The one-sided 95% lower limit of the mean thickness is equal to the estimated mean thickness minus t times the estimated standard error of the mean. This is the mean thickness for which we have 95% confidence that the true mean thickness does not fall below. In this case, the value of t is obtained from a t distribution table for one tail at n-2 degrees of freedom and 0.05 level of significance.

2.8.2 Evaluation of Mean Thickness Using Mean Model

The following procedure is used to evaluate the drywell mean thickness at those locations where the mean model is deemed to be more appropriate than the linear regression model. This method is consistent with that used to evaluate the mean thickness using the regression model.

(1) Calculate the mean of each set of UT thickness measurements.

(2) Sum the means of the sets and divide by the number of sets to calculate the grand mean. This is the best estimate of the mean thickness. In the SAS Regression Analysis output (Ref. 3.7), this is the value labelled "DEP MEAN".

(3) Using the means of the sets from (1) as input, calculate the standard error. This is the best estimate of the standard error of the mean thickness.

(4) The two-sided 95% confidence interval about the mean thickness is equal to the mean thickness plus or minus t times the estimated standard error of the mean. This is the interval for which we have 95% confidence that the true mean thickness will fall within. The value of t is obtained from a t distribution table for equal tails at n-1 degrees of freedom and 0.05 level of significance.

(5) The one-sided 95% lower limit of the mean thickness is equal to the estimated mean thickness minus t times the estimated standard error of the mean. This is the mean thickness for which we have 95% confidence that the true mean thickness does not fall below. In this case, the value of t is obtained from a t distribution table for one tail at n-1 degrees of freedom and 0.05 level of significance.

2.8.3 Evaluation of Mean Thickness Using Single Data Set

The following procedure is used to evaluate the drywell thickness at those locations where only one set of measurements is available.

(1) Calculate the mean of the set of UT thickness measurements. This is the best estimate of the mean thickness.

(2) Calculate the standard error of the mean for the set of UT measurements. This is the best estimate of the standard error of the mean thickness.

Confidence intervals about the mean thickness cannot be calculated with only one data set available.

3.0 REFERENCES

3.1 GPUN Safety Evaluation SE-000243-002, Rev. 0, "Drywell Steel Shell Plate Thickness Reduction at the Base Sand Cushion Entrenchment Region"

3.2 GPUN TDR 854, Rev. 0, "Drywell Corrosion Assessment"

3.3 GPUN TDR 851, Rev. 0, "Assessment of Oyster Creek Drywell Shell"

3.4 GPUN Installation Specification IS-328227-004, Rev. 3, "Functional Requirements for Drywell Containment Vessel Thickness Examination"

3.5 Applied Regression Analysis, 2nd Edition, N.R. Draper & H. Smith, John Wiley & Sons, 1981

3.6 Statistical Concepts and Methods G.K. Bhattacharyya & R.A. Johnson, John Wiley & sons, 1977

3.7 GPUN Calculation C-1302-187-5300-005, Statistical Analysis of Drywell Thickness Data Thru 12/31/88.

4.0 EVALUATION OF DATA THROUGH 12/31/88

4.1 Results for 6"x6" Grids in Sand Bed Region at Original Locations

4.1.1 Bay 11A: 5/1/87 to 10/8/88

Six 49-point data sets were available for this bay covering the time period from May 1, 1987 to October 8, 1988. Since a plug lies within this region, four of the points were voided in each data set. The data were analyzed as described in paragraphs 2.4 and 2.8.2.

(1) The data are normally distributed.

(2) The mean model is more appropriate than the regression model.

(3) The current mean thickness ± standard error is 908.6 ±5.0 mils.

(4) There was no significant corrosion from May 1, 1987 to October 8, 1988.

4.1.2 Bay 11C: 5/1/87 to 10/8/88

Five 49-point data sets were available for this bay covering the time period from May 1, 1987 to October 8, 1988. These data were analyzed as described in paragraphs 2.4 and 2.8.2. The initial analysis of this data indicated that the data are not normally distributed. The lack of normality was tentatively attributed to minimal corrosion in the upper half of the 6"x6" grid with more extensive corrosion in the lower half of the grid. To test this hypothesis, each data set was divided into two subsets, with one containing the top three rows and the other containing the bottom four rows.

The top subset was normally distributed but the bottom subset was not. For both subsets, the mean model is more appropriate than the regression model.

Since there is an observable decrease in the mean thickness with time, there appears to be some on-going corrosion at this location. Further analysis is required.

The current mean thickness ± standard error is 916.6 ±10.4 mils for the lower subset and 1057.6 ±16.9 mils for the upper subset.

4.1.3 Bay 17D: 2/17/87 to 10/8/88

Six 49-point data sets were available for this bay covering the time period from February 17, 1987 to October 8, 1988. Since a plug lies within this region, four of the points were voided in each data set. The data were analyzed as described in paragraphs 2.4 and 2.8.1.

(1) The data are normally distributed.

(2) The regression model is appropriate.

(3) The regression model explains 84% of the total variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 864.8 ±6.8 mils.

(6) The corrosion rate ± standard error is -27.6 ±6.1 mils per year.

(7) The measurements below 800 mils were tested and determined not to be statistically different from the mean thickness.

4.1.4 Bay 19A: 2/17/87 to 10/8/88

Six 49-point data sets were available for this bay covering the time period from February 17, 1987 to October 8, 1988. Since a plug lies within this region, four of the points were voided in each data set. The data were analyzed as described in paragraphs 2.4 and 2.8.1.

(1) The data are nearly normally distributed.

(2) The regression model is appropriate

(3) The regression model explains 88% of the total variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 837.9 ±4.8 mils.

(6) The corrosion rate ± standard error is -23.7 ±4.3 mpy.

(7) One data point that was below 800 mils at two different times was tested and determined to be statistically different from the mean thickness. The probability of this occurring is less than 1% at each specific time.

4.1.5 Bay 19B: 5/1/87 to 10/8/88

Five 49-point data sets were available for this bay covering the time period from May 1, 1987 to October 8, 1988. The data were analyzed as described in paragraphs 2.4 and 2.8.1.

(1) The data are normally distributed.

(2) The regression model is appropriate.

(3) The regression model explains 99% of the total variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 856.5 ±0.5 mils.

(6) The corrosion rate ± standard error is -29.2 ±0.5 mpy.

(7) The measurements below 800 mils were tested and determined not to be statistically different from the mean thickness.

4.1.6 Bay 19C: 5/1/87 to 10/8/88

Five 49-point data sets were available for this bay covering the time period from May 1, 1987 to October 8, 1988. Since a plug lies within this region, four of the points were voided in each data set. The data were analyzed as described in paragraphs 2.4 and 2.8.1.

(1) The data are normally distributed.

(2) The regression model is appropriate.

(3) The regression model explains 91% of the total variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 860.9 ±4.0 mils.

(6) The corrosion rate ± standard error is -25.9 ±4.1 mpy.

(7) The measurements below 800 mils were tested and determined not to be statistically different from the mean thickness.

4.2 Results for 6"x6" Grids in Sand Bed Region at New Locations

4.2.1 Bay 9D: 11/25/86 to 12/19/88

The 6"x6" grid data was taken in December 1988 during the 12R outage. This bay was considered for cathodic protection, but is not within the scope of the cathodic protection system being installed. The primary purpose of this data is to establish a base line to monitor corrosion in the future. However, previous measurements were taken in November 1986 in a 10-point 6"x6" cruciform pattern. Measurements were also taken in a 6"x6" grid in December 1986. The new data were compared with both of the previous data sets. These comparisons were made using the chi-squared test, F-test and two-tailed t-test as described in paragraph 2.5. The mean thickness was determined as described in paragraph 2.8.3.

(1) The data are normally distributed.

(2) The variances are equal in both comparisons.

(3) It is appropriate to use the two-tailed t-test in both comparisons.

(4) The difference between the means of the 1988 49-point data set and the 1986 10-point data set is not significant. However, there is a significant difference between the means of the 1988 49-point data set and the 1986 49-point data set. Therefore, significance of the corrosion rate is classified as "Indeterminable".

(5) The current mean thickness ± standard error is 1021.4 ±9.7 mils.

4.2.2 Bay 13A: 11/25/86 to 12/17/88

The 6"x6" grid data was taken for the first time in December 1988 during the 12R outage. This bay was considered for cathodic protection, but is not within the scope of the cathodic protection being installed. The primary purpose of this data is to establish a base line to monitor corrosion in the future. However, previous measurements were taken in November 1986 in abutting 6"x6" cruciform patterns across the entire bay. As a best approximation, 13 of these data points are at the same location as the new 6"x6" grid data set. Therefore, the new data were first compared with these 13 data points, and then with 21 data points which include the 13 plus 8 additional points within one inch on either side. These comparisons were made using the chi-squared test, F-test and two-tailed t-test as described in paragraph 2.5. The mean thickness was determined as described in paragraph 2.8.3.

(1) The data are normally distributed.

(2) The variances are equal in both comparisons.

(3) It is appropriate to use the two-tailed t-test in both comparisons.

(4) The difference between the means of the data sets is not signficant. Therefore, the corrosion is classified as "Not Significant".

(5) The current mean thickness ± standard error is 905.3 ±10.1 mils.

4.2.3 Bay 15D: 11/25/86 to 12/17/88

The 6"x6" grid data was taken for the first time in December 1988 during the 12R outage. This bay was considered for cathodic protection, but is not within the scope of the cathodic protection being installed. The primary purpose of this data is to establish a base line to monitor corrosion in the future. However, a previous 1-point measurement was taken in November 1986. The location of this point may have been somewhat removed from the location of the new 6"x6" grid data set. The previous measurement was compared with the new data set using the methods described in paragraph 2.6. The mean thickness was determined as described in paragraph 2.8.3.

(1) The new data are normally distributed.

(2) The previous measurement falls above the 99% upper bound of the new data.

(3) This implies that the corrosion may have occurred in the time period covered by this data. Therefore, the corrosion is classified as "Possible".

(4) The current mean thickness ± standard error is 1056.0 ±9.1 mils.

4.2.4 Bay 17A: 11/25/86 to 12/17/88

The 6"x6" grid data was taken for the first time in December 1988 during the 12R outage. This bay was considered for cathodic protection, but is not within the scope of the cathodic protection being installed. The primary purpose of this data is to establish a base line to monitor corrosion in the future. However, a previous

1-point measurement was taken in November 1986. The location of this point may have been somewhat removed from the location of the new 6"x6" grid data set. The previous measurement was compared with the new data set using the methods described in paragraph 2.6. The mean thickness was determined as described in paragraph 2.8.3.

(1) The new data are not normally distributed. However, the top three rows and the bottom four rows are each normally distributed.

(2) The previous measurement falls below the 99% confidence interval for the top three rows, and above the 99% confidence interval for the bottom four rows.

(3) The corrosion is classified as "Indeterminable".

(4) The current mean thickness ± standard error is 1133.1 ±6.9 milsfor the top three rows and 957.4 ±9.2 mils for the bottom four rows.

4.3 <u>Results for 6"x6" Grids at Upper Elevations</u>

4.3.1 <u>Bay 5 51' Elevation: 11/01/87 to 10/8/88</u>

Three 49-point data sets were available for this bay covering the time period from November 1, 1987 to October 8, 1988. The data were analyzed as described in paragraphs 2.4 and 2.8.1.

(1) Except for the first data set, the data are normally distributed.

(2) The regression model is appropriate.

(3) The regression model explains 99% of the total variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 750.0 ±0.02 mils.

(6) The corrosion rate ± standard error is -4.3 ±0.03 mpy.

(7) One data point was determined to be statistically different from the mean thickness. The probability of this occurring due to expected random error is less than 1% at each specific time.

4.3.2 Bay 9 87' Elevation: 11/6/87 to 10/8/88

Three 49-point data sets were available for this bay covering the time period from November 6, 1987 to October 8, 1988. The data were analyzed as described in paragraphs 2.4 and 2.8.2.

(1) The data are normally distributed.

(2) The mean model is appropriate than the regression model.

(3) There was no significant corrosion from November 6, 1987 to October 8, 1988.

(4) The current mean thickness ± standard error is 620.3 ±1.0 mils.

4.3.3 Bay 13 87' Elevation: 11/10/87 to 10/8/88

Three 49-point data sets were available for this bay covering the time period from November 10, 1987 to October 8, 1988. The data were analyzed as described in paragraphs 2.4 and 2.8.2.

(1) The data are normally distributed.

(2) The mean model is more appropriate than the regression model.

(3) There was no significant corrosion from November 10, 1987 to October 8, 1988.

(4) The current mean thickness ± standard error is 635.6 ±0.7 mils.

4.3.4 Bay 15 87' Elevation: 11/10/87 to 10/8/88

Three 49-point data sets were available for this bay covering the time period from November 10, 1987 to October 8, 1988. The data were analyzed as described in paragraphs 2.4 and 2.8.2.

(1) The data are normally distributed.

(2) The mean model is more appropriate than the regression model.

(3) There was no significant corrosion from November 10, 1987 to October 8, 1988.

(4) The current mean thickness ± standard error is 634.8 ±0.7 mils.

4.4 Results for Multiple 6"x6" Grids in Trench

4.4.1 Bay 17D Trench: 12/9/86 to 12/23/88

The two sets of measurements in the Bay 17D Trench were taken on December 9, 1986 and December 23, 1988. The 1986 data is a 7 column by 36 row array. The 1988 data is a 7 column by 42 row array. The 1986 data is at the same elevation as the lower 36 rows of the 1988 data, but is centered about 3-/12 inches to the left of the 1988 data. To compare these two data sets, the 1986 data set and the lower 36 rows of the 1988 data set were each subdivided into six 7 column by 6 row subsets. Each pair of subsets was compared as described in paragraphs 2.5 and 2.8.3.

Fourth Subset From The Top:

The chi-squared statistic for the fourth subset from the top from the 1986 data set slightly exceeded the critical value for level of significance of 0.05, but was within the critical value for level of significance of 0.01. Also, the F statistic exceeded the critical value for levels of significance of 0.05 and 0.01. Therefore, it is inappropriate to apply the two-tailed t-test based on equal variances. However, the approximate t-test based on unequal variances can be applied. From the results of this test, it is concluded that the difference between the mean thicknesses is not significant. This implies that corrosion at this location was not significant.

All Other Subsets:

(1) The data are normally distributed.

(2) The variances are equal.

(3) Comparison of the means using the two-tailed t-test is appropriate.

(4) The difference between the means of the subsets was not significant. This implies that there was no significant corrosion in the period from December 9, 1986 to December 23, 1988.

(5) The current mean thickness ± standard error of the top subset is 981.2 ±6.7 mils. This is the thinnest area in the trench.

4.4.2 Bays 17/19 Frame Cutout: December 1988

Two sets of 6"x6" grid measurements were taken in December 1988. The upper one is located 25" below the top of the high curb and the other below the floor. There is no previous data. The upper location has been added to the long term monitoring program. With no prior data, the only possible analysis was to check the data sets for normality using the chi-squared test.

The data at the upper location are not normally distributed. The lack of normality was tentatively attributed to minimal corrosion in the lower half of the 6"x6" grid with more extensive corrosion in the upper half of the grid. To test this hypothesis, each data set was divided into two subsets, with one containing the top three rows and the other containing the bottom four rows. These subsets proved to be normally distributed, thus confirming the hypothesis. The current mean thickness ± standard error is 981.7 ±4.4 mils for the top three rows and 1003.8 ±6.6 mils for the bottom four rows.

The data at the location below the floor is normally distributed. Also, the mean thickness is higher than at the upper location. The mean thickness ± standard error is 1034.1 ±6.8 mils.

4.5 Results for 6" Strips in Sand Bed Region

4.5.1 Bay 1D: 11/25/86 to 12/17/88

The 7-point data set was taken in December 1988 and a single point measurement was taken in November 1986. The data were compared as described in paragraph 2.7. The previous measurement falls below the 99% lower bound of the new 7-point data set. Thus, the corrosion rate is classified as indeterminable. The current mean thickness ± standard error is 1114.7 ±30.6 mils.

4.5.2 Bay 3D: 11/25/86 to 12/17/88

The 7-point data set was taken in December 1988 and a single point measurement was taken in November 1986. The data were compared as described in paragraph 2.7. The previous measurement falls within the 99% upper and lower bounds of the new 7-point data set. This implies that significant corrosion has not occurred at this location in the time period covered by the data. The current mean thickness ± standard error is 1177.7 ±5.6 mils.

4.5.3 Bay 5D: 11/25/86 to 12/17/88

The 7-point data set was taken in December 1988 and a single point measurement was taken in November 1986. The data were compared as described in paragraph 2.7. The previous measurement falls within the 95% upper and lower bounds of the new 7-point data set. This implies that significant corrosion has not occurred at this location in the time period covered by the data. The current mean thickness rate ± standard error is 1174.0 ±2.2 mils.

4.5.4 Bay 7D: 11/25/86 to 12/17/88

The 7-point data set was taken in December 1988 and a single point measurement was taken in November 1986. The data was compared as described in paragraph 2.7. The previous measurement falls just above the 99% upper bound of the new 7-point data set. This implies that corrosion has possibly occurred at this location in the time period covered by the data. The current mean thickness ± standard error is 1135.1 ±4.9 mils.

4.5.5 Bay 9A: 11/25/86 to 12/17/88

The 7-point data set was taken in December 1988 and a single point measurement was taken in November 1986. The data were compared as described in paragraph 2.7. The previous measurement falls below the 99% lower bound of the new 7-point data set. Thus, the corrosion rate is classified as indeterminable. The current mean thickness ± standard error is 1154.6 ±4.8 mils.

4.5.6 Bay 13C: 11/25/86 to 12/17/88

The 7-point data set was taken in December 1988 and a single point measurement was taken in November 1986. The data were compared as described in paragraph 2.7. The previous measurement falls within the 95% upper and lower bounds of the new 7-point data set. This implies that significant corrosion has not occurred at this location in the time period covered by the data. The current mean thickness ± standard error is 1147.4 ±3.7 mils.

4.5.7 Bay 13D: 11/25/86 to 12/17/88

The 7-point data set was taken in December 1988 and a single point measurement was taken in November 1986. The data were compared as described in paragraph 2.7. The previous measurement falls within the 95% upper and lower bounds of the new 7-point data set. This implies that significant corrosion has not occurred at this location in the time period covered by the data. The current mean thickness ± standard error is 962.1 ±22.3 mils.

4.5.8 Bay 15A: 11/25/86 to 12/19/88

The 7-point data set was taken in December 1988 and a single point measurement was taken in November 1986. Also, a 6"x6" grid data set was taken on December 2, 1986 at this location. As a best approximation, the first 5 points in the 7-point data set are at the same location as points 38 to 42 of the 6"x6" grid. These five points all fall within the 99% confidence interval of the new 7-point data set. The single measurement falls below the 99% lower bound. This implies that significant corrosion has not occurred at this location in the time period covered by the data. The current mean thickness ± standard error is 1120.0 ±12.6 mils.

4.6 Summary of Conclusions

Bay & Area	Location	Corrosion Rate**	Mean Thickness***
4.6.1 6"x6" Grids in Sand Bed Region at Original Locations			
11A	Sand Bed	Not significant	908.6 ±5.0 mils
11C	Sand Bed	Indeterminable	916.6 ±10.4 mils
17D	Sand Bed	-27.6 ±6.1 mpy	864.8 ±6.8 mils
19A	Sand Bed	-23.7 ±4.3 mpy	837.9 ±4.8 mils
19B	Sand Bed	-29.2 ±0.5 mpy	856.5 ±0.5 mils
19C	Sand Bed	-25.9 ±4.1 mpy	860.9 ±4.0 mils
4.6.2 6"x6" Grids in Sand Bed Region at New Locations			
9D	Sand Bed	Indeterminable*	1021.4 ±9.7 mils
13A	Sand Bed	Not significant*	905.3 ±10.1 mils
15D	Sand Bed	Possible*	1056.0 ±9.1 mils
17A	Sand Bed	Indeterminable*	957.4 ±9.2 mils
4.6.3 6"x6" Grids at Upper Elevations			
5	51' Elev.	-4.3 ±0.03 mpy	750.0 ±0.02 mils
9	87' Elev.	Not significant	620.3 ±1.0 mils
13	87' Elev.	Not significant	635.6 ±0.7 mils
15	87' Elev.	Not significant	634.8 ±0.7 mils
4.6.4 Multiple 6"x6" Grids in Trench			
17D	Trench	Not significant*	981.2 ±6.7 mils
17/19	Frame Cutout	Indeterminable*	981.7 ±4.4 mils

4.6.5 <u>6" Strips in Sand Bed Region</u>

1D	Sand Bed	Indeterminable*	1114.7 ±30.6 mils
3D	Sand Bed	Not significant*	1177.7 ±5.6 mils
5D	Sand Bed	Not significant*	1174.0 ±2.2 mils
7D	Sand Bed	Possible*	1135.1 ±4.9 mils
9A	Sand Bed	Indeterminable*	1154.6 ±4.8 mils
13C	Sand Bed	Not significant*	1147.4 ±3.7 mils
13D	Sand Bed	Not significant*	962.1 ±22.3 mils
15A	Sand Bed	Not significant*	1120.0 ±12.6 mils

4.6.6 <u>Evaluation of Individual Measurements Below 800 Mils</u>

One data point in Bay 19A and one data point in Bay 5 Elev. 51' fell outside the 99% confidence interval and thus are statistically different from the mean thickness.

*Based on limited data. See text for interpretation.
**Mean corrosion rate in mils per year ± standard error of the mean
***Current mean thickness in mils ± standard error of the mean

GPU Nuclear **Calculation Sheet**

DRF 72566 R1
DRF 82963 R.0

Subject	Calc No.	Rev. No.	Sheet No.
STATISTICAL ANALYSIS OF DRYWELL THICKNESS DATA THRU 4-24-90	C-1302-187-5300-011	0 1	1 of 454
Originator: J P Moore, Date: 6-13-90	Reviewed by		Date: 6/13/90

Verification V-1302-187-005 R2 6/18/90

1.0 PROBLEM STATEMENT

The basic purpose of this calculation is to update the thickness measurement analyses documented in References 3.7, 3.8, and 3.11 by incorporating the measurements taken in March and April 1990.

Specific objectives of this calculation are:

(1) Statistically analyze the thickness measurements in the sand bed region to determine the mean thickness and corrosion rate.

(2) Analyze the data taken since the 12R outage for Bays 11A, 11C, 17D, 19A, 19B, 19C, and the Frame Cutout between Bays 17 and 19 to determine if cathodic protection has reduced the corrosion rate.

(3) Statistically analyze the thickness measurements for Bay 5 at elevation 51' and Bays 9, 13 and 15 at elevation 87' to determine the mean thickness and corrosion rate.

(4) To the extent possible, analyze the data for the new locations at elevation 51' and elevation 52'.

Superseded by Rev 1

2.0 SUMMARY OF RESULTS

Bay & Area	Corrosion Rate **	Mean Thickness ***	F-Ratio
2.1 Sand Bed Region With Cathodic Protection - All Data			
11A	-15.6 ±2.9 mpy	870.4 ± 5.7 mils	5.4
11C Top	-35.2 ±6.8 mpy	977.0 ±12.5 mils	4.6
11C Bottom	-22.4 ±4.3 mpy	865.0 ± 7.8 mils	4.9
17D	-25.0 ±2.0 mpy	829.5 ± 4.0 mils	29.4
19A	-21.4 ±1.5 mpy	807.6 ± 3.0 mils	39.5
19B	-19.0 ±1.7 mpy	836.9 ± 3.2 mils	21.3
19C	-24.3 ±1.3 mpy	825.1 ± 2.3 mils	66.2
2.2 Sand Bed Region With Cathodic Protection - Since October 1988			
11A	Not Significant*	878.0 ± 5.9 mils	
11C Top	Not Significant*	996.6 ± 8.3 mils	
11C Bottom	Not Significant*	878.1 ± 5.6 mils	
17D	-23.7 ±4.6 mpy	830.1 ± 3.8 mils	2.7
19A	-20.6 ±3.9 mpy	808.2 ± 3.2 mils	2.8
19B	-11.8 ±3.9 mpy	841.2 ± 3.3 mils	0.9
19C	-21.5 ±3.5 mpy	826.3 ± 2.9 mils	3.7
2.3 Sand Bed Region Frame Cutout			
17/19 Top	Not Significant*	986.0 ± 4.7 mils	
17/19 Bottom	Not Significant*	1008.4 ± 3.9 mils	
2.4 Sand Bed Region Without Cathodic Protection			
9D	Not Significant*	1021.7 ± 8.9 mils	
13A	-39.1 ± 3.4 mpy	853.1 ± 2.4 mils	16.9
13D	Indeterminate	931.9 ±22.6 mils	
15D	Not Significant*	1056.5 ± 2.3 mils	
17A Top	Not Significant*	1128.3 ± 2.2 mils	
17A Bottom	Not Significant*	745.2 ± 2.1 mils	1.3

* Not statistically significant compared to random variations in measurements
** Mean corrosion rate in mils per year ± standard error of estimate
***Best estimate of current mean thickness in mils ± standard error of the mean

2.0 SUMMARY OF RESULTS

Bay & Area	Corrosion Rate (mpy) Best Estimate*	95% Conf.**	Mean Thickness ***	F-Ratio	N	Yrs	
2.1 Sand Bed Region With Cathodic Protection - All Data							
11A	-15.6 ±2.9 mpy	-21.0	870.4 ± 5.7 mils	5.4	9	3.0	
11C Top	-35.2 ±6.8 mpy	-48.2	977.0 ±12.5 mils	4.6	9	3.0	
11C Bottom	-22.4 ±4.3 mpy	-30.5	865.0 ± 7.8 mils	4.9	9	3.0	
17D	-25.0 ±2.0 mpy	-28.7	829.5 ± 4.0 mils	29.4	10	3.2	
19A	-21.4 ±1.5 mpy	-24.1	807.6 ± 3.0 mils	39.5	10	3.2	
19B	-19.0 ±1.7 mpy	-22.3	836.9 ± 3.2 mils	21.3	9	3.0	
19C	-24.3 ±1.3 mpy	-26.7	825.1 ± 2.3 mils	66.2	9	3.0	
2.2 Sand Bed Region With Cathodic Protection - Since October 1988							
11A	Not Significant****		878.0 ± 5.9 mils		5	1.5	
11C Top	Not Significant****		996.6 ± 8.3 mils		5	1.5	
11C Bottom	Not Significant****		878.1 ± 5.6 mils		5	1.5	
17D	-23.7 ±4.6 mpy	-34.2	830.1 ± 3.8 mils	2.7	5	1.5	
19A	-20.6 ±3.9 mpy	-29.7	808.2 ± 3.2 mils	2.8	5	1.5	
19B	-11.8 ±3.9 mpy	-21.1	841.2 ± 3.3 mils	0.9	5	1.5	
19C	-21.5 ±3.5 mpy	-29.5	826.3 ± 2.9 mils	3.7	5	1.5	
2.3 Sand Bed Region Frame Cutout							
17/19 Top	Not Significant****		986.0 ± 4.7 mils		5	1.3	
17/19 Bottom	Not Significant****		1005.7 ± 5.6 mils		5	1.3	| 1
2.4 Sand Bed Region Without Cathodic Protection							
9D	Not Significant****		1021.7 ± 8.9 mils		5	1.3	
13A	-39.1 ± 3.4 mpy	-46.4	853.1 ± 2.4 mils	16.9	6	1.4	
13D	Indeterminate		931.9 ±22.6 mils		1	0	
15D	Not Significant****		1056.5 ± 2.3 mils		5	1.5	
17A Top	Not Significant****		1128.3 ± 2.2 mils		5	1.4	
17A Bottom	Not Significant****		950.8 ± 5.3 mils		5	1.4	| 1

* Mean corrosion rate in mils per year ± standard error of estimate
** Upper bound of the one-sided 95% confidence interval
*** Best estimate of current mean thickness in mils ± standard error of the mean
****Not statistically significant compared to random variations in measurements

N = Number of data sets
Yrs = Years from first to last data set

GPU Nuclear	DOCUMENT NO. C-1302-187-5300-011

TITLE STATISTICAL ANALYSIS OF DRYWELL THICKNESS THRU 4-24-90

REV	SUMMARY OF CHANGE	APPROVAL	DATE
1	Computed 95% upper bound of the corrosion rate in each bay where regression model is appropriate. Computed maximum potential corrosion rate at 95% confidence for each bay where mean model is appropriate. Deleted Summary of Apparent Corrosion Rates and added Summary of Maximum Potential Corrosion Rates at 95% Confidence. Revised paragraphs 2.0, 4.5.2, and 4.10 to reflect these changes. Corrected typos on Summary Sheets (pg. 2 & 3) & Pgs 4, 21	JP Moore Verification V-1302-187-005 Rev. 4 [signature] [signature]	1-22-91 1/22/91 4/12/91

N0036 (03-90)

Superseded ...

Bay & Area	Corrosion Rate **	Mean Thickness ***	F-Ratio
2.5 Elevation 51'			
5/D-12	- 4.6 ± 1.6	745.2 ± 2.1 mils	1.3
5/5	Indeterminate	745.1 ± 3.2 mils	
13/31	Indeterminate	750.8 ±11.5 mils	
15/23	Indeterminate	751.2 ± 3.8 mils	
2.6 Elevation 52'			
7/25	Indeterminate	715.5 ± 2.9	
13/6	Indeterminate	724.9 ± 2.9	
13/32	Indeterminate	698.3 ± 5.0	
19/13	Indeterminate	712.5 ± 3.1	
2.7 Elevation 87'			
9	Not Significant*	619.9 ± 0.6	
13	Not Significant*	636.5 ± 0.8	
15	Not Significant*	636.2 ± 1.1	

2.5 Apparent Corrosion Rates

These estimates of the corrosion rate are based on a least squares fit of the data. In those cases where the F-Ratio is less than 1.0 they should not be used to make future projections. For bays with cathodic protection, these apparent rates are for the period from October 1988 to April 1990. For the other bays, it is for all data.

Bay	Apparent Corrosion Rate (mpy)	F-Ratio	Bay	Apparent Corrosion Rate (mpy)	F-Ratio
11A	-16.2 ± 8.6	0.2	9D	-21.0 ±18.1	0.1
11C Top	-25.0 ±10.6	0.6	13A	-39.1 ± 3.4	16.9
11C Bottom	-16.7 ± 7.1	0.6	15D	- 4.6 ± 4.8	0.1
17D	-23.7 ± 4.6	2.7	17A Top	- 6.8 ± 3.7	0.3
19A	-20.6 ± 3.9	2.8	17A Bottom	-17.7 ± 7.6	0.01
19B	-11.8 ± 3.9	0.9	5 EL 51'	- 4.6 ± 1.6	1.3
19C	-21.5 ± 3.5	3.7	9 EL 87'	- 0.2 ± 0.9	zero
17/19 Top	- 8.2 ±10.7	0.1	13 EL 87'	zero	
17/19 Bottom	-13.1 ±11.6	0.1	15 EL 87'	zero	

Bay & Area	Corrosion Rate (mpy) Best Estimate*	95% Conf.**	Mean Thickness ***	F-Ratio	N	Yrs
2.5 Elevation 51'						
5/D-12	- 4.6 ± 1.6 mpy	-2.2	745.2 ± 2.1 mils	1.3	8	2.5
5/5	Indeterminate		745.1 ± 3.2 mils		2	1.1
13/31	Indeterminate		750.8 ±11.5 mils		2	1.1
15/23	Indeterminate		751.2 ± 3.8 mils		2	1.1
2.6 Elevation 52'						
7/25	Indeterminate		715.5 ± 2.9 mils		1	0
13/6	Indeterminate		724.9 ± 2.9 mils		1	0
13/32	Indeterminate		698.3 ± 5.0 mils		1	0
19/13	Indeterminate		712.5 ± 3.1 mils		1	0
2.7 Elevation 87'						
9	Not Significant****		619.9 ± 0.6 mils		5	2.4
13	Not Significant****		636.5 ± 0.8 mils		5	2.4
15	Not Significant****		636.2 ± 1.1 mils		5	2.4

2.8 Potential Corrosion Rates at 95% Confidence

For those locations where the corrosion rate is not statistically significant, the possibility does exist that the variability in the data may be masking an actual corrosion rate. The potentially masked corrosion rate at 95% confidence is bounded by the upper bound of the 95% one-sided confidence interval about the slope computed in the regression analysis (see Paragraph 4.10.1).

Bay	Elevation	95% Upper Bound Corrosion Rate (mpy)	N	Yrs
11A (Since 10/88)	Sand Bed	-36.4	5	1.5
11C Top (Since 10/88)	Sand Bed	-49.9	5	1.5
11C Bottom (Since 10/88)	Sand Bed	-33.3	5	1.5
17/19 Top	Frame Cutout	-33.4	5	1.3
17/19 Bottom	Frame Cutout	-40.5	5	1.3
9D	Sand Bed	-63.4	5	1.3
15D	Sand Bed	-16.0	5	1.4
17A Top	Sand Bed	-15.5	5	1.4
17A Bottom	Sand Bed	-35.6	5	1.4
9	87'	-2.2	5	2.4
13	87'	-2.1	5	2.4
15	87'	-0.6	5	2.4

NOTE: The high value for Bay 9D results from one extremely high mean value on 6/26/89. Without this data point, the 95% upper bound is -29.2 mpy.

2.~~8~~ 9 Evaluation of Individual Measurements Exceeding 99%/99% Tolerance Interval

11

One data point in Bay 5 Elev. 51' fell outside the 99%/99% tolerance interval and thus is statistically different from the mean thickness.

Based on a linear regression analysis for this point, it is concluded that the corrosion rate in this pit is essentially the same as the overall grid.

3.0 REFERENCES

3.1 GPUN Safety Evaluation SE-000243-002, Rev. 0, "Drywell Steel Shell Plate Thickness Reduction at the Base Sand Cushion Entrenchment Region"

3.2 GPUN TDR 854, Rev. 0, "Drywell Corrosion Assessment"

3.3 GPUN TDR 851, Rev. 0, "Assessment of Oyster Creek Drywell Shell"

3.4 GPUN Installation Specification IS-328227-004, Rev. 3, "Functional Requirements for Drywell Containment Vessel Thickness Examination"

3.5 Applied Regression Analysis, 2nd Edition, N.R. Draper & H. Smith, John Wiley & Sons, 1981

3.6 Statistical Concepts and Methods, G.K. Bhattacharyya & R.A. Johnson, John Wiley & sons, 1977

3.7 GPUN Calculation C-1302-187-5300-005, Rev. 0, "Statistical Analysis of Drywell Thickness Data Thru 12-31-88"

3.8 GPUN TDR 948, Rev. 1, "Statistical Analysis of Drywell Thickness Data"

3.9 Experimental Statistics, Mary Gibbons Natrella, John Wiley & Sons, 1966 Reprint. (National Bureau of Standards Handbook 91)

3.10 Fundamental Concepts in the Design of Experiments, Charles C. Hicks, Saunders College Publishing, Fort Worth, 1982

3.11 GPUN Calculation C-1302-187-5300-008, Rev. 0, "Statistical Analysis of Drywell Thickness Data thru 2-8-90"

4.0 ASSUMPTIONS & BASIC DATA

4.1 Background

The design of the carbon steel drywell includes a sand bed which is located around the outside circumference between elevations 8'-11-1/4" and 12'-3". Leakage was observed from the sand bed drains during the 1980, 1983 and 1986 refueling outages indicating that water had intruded into the annular region between the drywell shell and the concrete shield wall.

The drywell shell was inspected in 1986 during the 10R outage to determine if corrosion was occurring. The inspection methods, results and conclusions are documented in Ref. 3.1, 3.2, and 3.3. As a result of these inspections it was concluded that a long term monitoring program would be established. This program includes repetitive Ultrasonic Thickness (UT) measurements in the sand bed region at a nominal elevation of 11'-3" in bays 11A, 11C, 17D, 19A, 19B, and 19C.

The continued presence of water in the sand bed raised concerns of potential corrosion at higher elevations. Therefore, UT measurements were taken at the 51' and 87' elevations in November 1987 during the 11R outage. As a result of these inspections, repetitive measurements in Bay 5 at elevation 51' and in Bays 9, 13 and 15 at the 87' elevation were added to the long term monitoring program to confirm that corrosion is not occurring at these higher elevations.

A cathodic protection system was installed in selected regions of the sand bed during the 12R outage to minimize corrosion of the drywell. The cathodic protection system was placed in service on January 31, 1989. The long term monitoring program was also expanded during the 12R outage to include measurements in the sand bed region of Bays 1D, 3D, 5D, 7D, 9A, 13A, 13C, 13D, 15A, 15D and 17A which are not covered by the cathodic protection system. It also includes measurements in the sand bed region between Bays 17 and 19 which is covered by the cathodic protection system, but does not have a reference electrode to monitor its effectiveness in this region.

The high corrosion rate computed for Bay 13A in the sand bed region through February 1990 (Ref. 3.11) raised concerns about the corrosion rate in the sand bed region of Bay 13D. Therefore, the monitoring of this location using a 6"x6" grid was added to the long term monitoring program. In addition, a 2-inch core sample was removed in March 1990 from a location adjacent to the 6"x6" monitored grid in Bay 13A.

Measurements taken in Bay 5 Area D-12 at elevation 51' through March 1990 indicated that corrosion is occurring at his location. Therefore, survey measurements were taken to determine the thinnest locations at elevation 51'. As a result, three new locations were added to the long term monitoring program (Bay 5 Area 5, Bay 13 Area 31, and Bay 15 Area 2/3).

The indication of ongoing corrosion at elevation 51' raised concerns about potential corrosion of the plates immediately above which have a smaller nominal thickness. Therefore, survey measurements were taken in April 1990 at the 52' elevation in all bays to determine the thinnest locations. As a result of this survey, four new locations were added to the long term monitoring plan at elevation 52' (Bay 7 area 25, Bay 13 Area 6, Bay 13 Area 32, and Bay 19 Area 13).

Some measurements in the long term monitoring program are to be taken at each outage of opportunity, while others are taken during each refueling outage. The functional requirements for these inspections are documented in Ref. 3.4. The purpose of the UT measurements is to determine the corrosion rate and monitor it over time, and to monitor the effectiveness of the cathodic protection system.

4.2 Selection of Areas to be Monitored

A program was initiated during the 11R outage to characterize the corrosion and to determine its extent. The details of this inspection program are documented in Ref. 3.3. The greatest corrosion was found via UT measurements in the sand bed region at the lowest accessible locations. Where thinning was detected, additional measurements were made in a cross pattern at the thinnest section to determine the extent in the vertical and horizontal directions. Having found the thinnest locations, measurements were made over a 6"x6" grid.

To determine the vertical profile of the thinning, a trench was excavated into the floor in Bay 17 and Bay 5. Bay 17 was selected since the extent of thinning at the floor level was greatest in that area. It was determined that the thinning below the top of the curb was no more severe than above the curb, and became less severe at the lower portions of the sand cushion. Bay 5 was excavated to determine if the thinning line was lower than the floor level in areas where no thinning was detected above the floor. There were no significant indications of thinning in Bay 5.

It was on the basis of these findings that the 6"x6" grids in Bays 11A, 11C, 17D, 19A, 19B and 19C were selected as representative locations for longer term monitoring. The initial measurements at these locations were taken in December 1986 without a template or markings to identify the location of each measurement. Subsequently, the location of the 6"x6" grids were permanently marked on the drywell shell and a template is used in conjunction with these markings to locate the UT probe for successive measurements. Analyses have shown that including the non-template data in the data base creates a significant variability in the thickness data. Therefore, to minimize the effects of probe location, only those data sets taken with the template are included in the analyses.

The presence of water in the sand bed also raised concern of potential corrosion at higher elevations. Therefore, UT measurements were taken at the 51' and 87' elevations in 1987 during the 11M outage. The measurements were taken in a band on 6-inch centers at all accessible regions at these elevations. Where these measurements indicated potential corrosion, the measurements spacing was reduced to 1-inch on centers. If these additional readings indicated potential corrosion, measurements were taken on a 6"x6" grid using the template. It was on the basis of these inspections that the 6"x6" grids in Bay 5 at elevation 51' and in bays 9, 13 and 15 at the 87' elevation were selected as representative locations for long term monitoring.

A cathodic protection system was installed in the sand bed region of Bays 11A, 11C, 17D, 19A, 19B, 19C, and at the frame between Bays 17 and 19 during the 12R outage. The system was placed in service on January 31, 1989.

The long term monitoring program was expanded as follows during the 12R outage:

(1) Measurements on 6"x6" grids in the sand bed region of Bays 9D, 13A, 15D and 17A. The basis for selecting these locations is that they were originally considered for cathodic protection but are not included in the system being installed.

(2) Measurements on 1-inch centers along a 6-inch horizontal strip in the sand bed region of Bays 1D, 3D, 5D, 7D, 9A, 13C, and 15A. These locations were selected on the basis that they are representative of regions which have experienced nominal corrosion and are not within the scope of the cathodic protection system.

(3) A 6"x6" grid in the curb cutout between Bays 17 and 19. The purpose of these measurements is to monitor corrosion in this region which is covered by the cathodic protection system but does not have a reference electrode to monitor its performance.

The long term monitoring program was expanded in March 1990 as follows:

(1) Measurements in the sand bed region of Bay 13D: This location was added due to the high indicated corrosion rate in the sand bed region of Bay 13A. The measurements taken in March 1990 were taken on a 1"x6" grid. All subsequent measurements are to be taken on a 6"x6" grid.

(2) Measurements on 6"x6" grids at the following locations at elevation 51': Bay 5 Area 5, Bay 13 Area 31, and Bay 15 Area 2/3. These locations were added due to the indication of ongoing corrosion at elevation 51', Bay 5 Area D-1.

The long term monitoring program was expanded in April 1990 by adding the following locations at elevation 52': Bay 7 Area 25, Bay 13 Area 6, Bay 13 Area 32, and Bay 19 Area 13. All measurements are taken on 6"x6" grids. These locations were added due to the indication of ongoing corrosion at elevation 51' and the fact that the nominal plate thickness at elevation 52' is less than at elevation 51'.

4.3 UT Measurements

The UT measurements within the scope of the long term monitoring program are performed in accordance with Ref. 3.4. This involves taking UT measurements using a template with 49 holes laid out on a 6"x6" grid with 1" between centers on both axes. The center row is used in those bays where only 7 measurements are made along a 6-inch horizontal strip.

The first set of measurements were made in December 1986 without the use of a template. Ref. 3.4 specifies that for all subsequent readings, QA shall verify that locations of UT measurements performed are within ± 1/4" of the location of the 1986 UT measurements. It also specifies that all subsequent measurements are to be within ± 1/8" of the designated locations.

4.4 Data at Plug Locations

Seven core samples, each approximately two inches in diameter were removed from the drywell vessel shell. These samples were evaluated in Ref. 3.2. Five of these samples were removed within the 6"x6" grids for Bays 11A, 17D, 19A, 19C and Bay 5 at elevation 51'. These locations were repaired by welding a plug in each hole. Since these plugs are not representative of the drywell shell, UT measurements at these locations on the 6"x6" grid must be dropped from each data set.

The following specific grid points have been deleted:

Bay Area	Points
11A	23, 24, 30, 31
17D	15, 16, 22, 23
19A	24, 25, 31, 32
19C	20, 26, 27, 33,
5 EL 51'	13, 20, 25, 26, 27, 28, 33, 34, 35

The core sample removed in the sand bed region of Bay 13A was not within the monitored 6"x6" grid.

4.5 Bases for Statistical Analysis of 6"x6" Grid Data

4.5.1 Assumptions

The statistical evaluation of the UT measurement data to determine the corrosion rate at each location is based on the following assumptions:

(1) Characterization of the scattering of data over each 6"x6" grid is such that the thickness measurements are normally distributed.

(2) Once the distribution of data for each 6"x6" grid is found to be normal, then the mean value of the thickness is the appropriate representation of the average condition.

(3) A decrease in the mean value of the thickness with time is representative of the corrosion occurring within the 6"x6" grid.

(4) If corrosion has ceased, the mean value of the thickness will not vary with time except for random errors in the UT measurements.

(5) If corrosion is continuing at a constant rate, the mean thickness will decrease linearly with time. In this case, linear regression analysis can be used to fit the mean thickness values for a given zone to a straight line as a function of time. The corrosion rate is equal to the slope of the line.

The validity of these assumptions is assured by:

(a) Using more than 30 data points per 6"x6" grid

(b) Testing the data for normality at each 6"x6" grid location.

(c) Testing the regression equation as an appropriate model to describe the corrosion rate.

These tests are discussed in the following section. In cases where one or more of these assumptions proves to be invalid, non-parametric analytical techniques can be used to evaluate the data.

4.5.2 Statistical Approach

The following steps are performed to test and evaluate the UT measurement data for those locations where 6"x6" grid data has been taken at least three times:

(1) Edit each 49-point data set by setting all invalid points to zero. Invalid points are those which are declared invalid by the UT operator or are at a plug location. (The computer programs used in the following steps ignore all zero thickness data points.)

(2) Perform a Chi-squared goodness of fit test of each 49 point data set to ensure that the assumption of normality is valid at the 5% and 1% level of significance.

(3) Calculate the mean thickness and variance of each 49 point data set.

(4) Perform an Analysis of Variance (ANOVA) F-test to determine if there is a significant difference between the means of the data sets.

(5) Using the mean thickness values for each 6"x6" grid, perform linear regression analysis over time at each location.

(a) Perform F-test for significance of regression at the 5% level of significance. The result of this test indicates whether or not the regression model is more appropriate than the mean model. In other words, it tests to see if the variation of the regression model is statistically significant over that of a mean model.

(b) Calculate the ratio of the observed F value to the critical F value at 5% level of significance. For data sets where the Residual Degress of Freedom in ANOVA is 4 to 9, this F-Ratio should be at least 8 for the regression to be considered ~~"useful"~~ "reliable" ~~as opposed to simply "significant."~~ ~~(Ref. 3.6 pp. 92-93, 129-133)~~ (See Paragraph 10.2)

(c) Calculate the coefficient of determination (R^2) to assess how well the regression model explains the percentage of total error and thus how useful the regression line will be as a predictor.

(d) Determine if the residual values for the regression equations are normally distributed.

(e) If the regression model is found to be appropriate, calculate the y-intercept, the slope and their respective standard errors. The y-intercept represents the fitted mean thickness at time zero, the slope represents the corrosion rate, and the standard errors represent the uncertainty or random error of these two parameters. Calculate the upper bound of the 95% one-sided confidence interval about the computed slope to provide an estimate of the maximum probable corrosion rate at 95% confidence. This is explained in greater detail in paragraph 4.10.2.

(f) If the mean model is found to be more appropriate than the regression model, the corrosion rate is not statistically significant compared to random variations in the mean thickness. Although the mean model is deemed more appropriate than the regression model, the upper bound of the 95% one-sided confidence interval about the slope computed in the regression analysis provides an estimate at 95% confidence of the maximum corrosion rate which could be masked by the random variations. This is explained in greater detail in paragraph 4.10.1.

(6) Use a K factor from Table A-7 of Reference 3.9 and the standard deviation to establish a one-sided 99%/99% tolerance limit about the mean thickness values for each 6"x6" grid location to determine whether low thickness measurements or "outliers" are statistically significant. If the data points are greater than the 99%/99% lower tolerance limit, then the difference between the value and the mean is deemed to be due to expected random error. However, if the data point is less than the lower 99%/99% tolerance limit, this implies that the difference is statistically significant and is probably not due to chance.

4.6 Analysis of Two 6"x6" Grid Data Sets

Regression analysis is inappropriate when data is available at only two points in time. However, the t-test can be used to determine if the means of the two data sets are statistically different.

4.6.1 Assumptions

This analysis is based upon the following assumptions:

(1) The data in each data set is normally distributed.

(2) The variances of the two data sets are equal.

4.6.2 Statistical Approach

The evaluation takes place in three steps:

(1) Perform a chi-squared test of each data set at 5% and 1% levels of significance to ensure that the assumption of normality is valid.

(2) Perform an F-test at 5% and 1% level of significance of the two data sets being compared to ensure that the assumption of equal variances is valid.

(3) Perform a two-tailed t-test for two independent samples at the 5% and 1% levels of significance to determine if the means of the two data sets are statistically different.

A conclusion that the means are not statistically different is interpreted to mean that significant corrosion did not occur over the time period represented by the data. However, if equality of the means is rejected, this implies that the difference is statistically significant and could be due to corrosion.

4.7 Analysis of Single 6"x6" Grid Data Set

In those cases where a 6"x6" data set is taken at a given location for the first time during the current outage, the only other data to which they can be compared are the UT survey measurements taken at an earlier time. For the most part, these are single point measurements which were taken in the vicinity of the 49-point data set, but not at the exact location. Therefore, rigorous statistical analysis of these single data sets is impossible. However, by making certain assumptions, they can be compared with the previous data points. If more extensive data is available at the location of the 49-point data set, the t-test can be used to compare the means of the two data sets as described in paragraph 4.5.

When additional measurements are made at these exact locations during future outages, more rigorous statistical analyses can be employed.

4.7.1 Assumptions

The comparison of a single 49-point data sets with previous data from the same vicinity is based on the following assumptions:

(1) Characterization of the scattering of data over the 6"x6" grid is such that the thickness measurements are normally distributed.

(2) Once the distribution of data for the 6"x6" grid is found to be normal, then the mean value of the thickness is the appropriate representation of the average condition.

(3) The prior data is representative of the condition at this location at the earlier date.

4.7.2 Statistical Approach

The evaluation takes place in four steps:

(1) Perform a chi-squared test of each data set to ensure that the assumption of normality is valid at the 95% and 99% confidence levels.

(2) Calculate the mean and the standard error of the mean of the 49-point data set.

(3) Determine the two-tailed t value from a t distribution table at levels of significance of 0.05 and 0.01 for n-1 degrees of freedom.

(4) Use the t value and the standard error of the mean to calculate the 95% and 99% confidence intervals about the mean of the 49-point data set.

(5) Compare the prior data point(s) with these confidence intervals about the mean of the 49-point data sets.

If the prior data falls within the 95% confidence intervals, it provides some assurance that significant corrosion has not occurred in this region in the period of time covered by the data. If it falls within the 99% confidence limits but not within the 95% confidence limits, this implication is not as strong. In either case, the corrosion rate will be interpreted to be "Not Significant".

If the prior data falls above the upper 99% confidence limit, it could mean either of two things: (1) significant corrosion has occurred over the time period covered by the data, or (2) the prior data point was not representative of the condition of the location of the 49-point data set in 1986. There is no way to differentiate between the two. In this case, the corrosion rate will be interpreted to be "Possible".

If the prior data falls below the lower 99% confidence limit, it means that it is not representative of the condition at this location at the earlier date. In this case, the corrosion rate will be interpreted to be "Indeterminable".

4.8 Analysis of Single 7-Point Data Set

In those cases where a 7-point data set is taken at a given location for the first time during the current outage, the only other data to which they can be compared are the UT survey measurements taken at an earlier time to identify the thinnest regions of the drywell shell in the sand bed region. For the most part, these are single point measurements which were taken in the vicinity of the 7-point data sets, but not at the exact locations. However, by making certain assumptions, they can be compared with the previous data points. If more extensive data is available at the location of the 7-point data set, the t-test can be used to compare the means of the two data sets as described in paragraph 4.5.

When additional measurements are made at these exact locations during future outages, more rigorous statistical analyses can be employed.

4.8.1 Assumptions

The comparison of a single 7-point data sets with previous data from the same vicinity is based on the following assumptions:

(1) The corrosion in the region of each 7-point data set is normally distributed.

(2) The prior data is representative of the condition at this location at the earlier date.

The validity of these assumptions cannot be verified.

4.8.2. Statistical Approach

The evaluation takes place in four steps:

(1) Calculate the mean and the standard error of the mean of the 7-point data set.

(2) Determine the two-tailed t value using the t distribution tables at levels of significance of 0.05 and 0.01 for n-1 degrees of freedom.

(3) Use the t value and the standard error of the mean to calculate the 95% and 99% confidence intervals about the mean of the 7-point data set.

(4) Compare the prior data point(s) with these confidence intervals about the mean of the 7-point data sets.

If the prior data falls within the 95% confidence intervals, it provides some assurance that significant corrosion has not occurred in this region in the period of time covered by the data. If it falls within the 99% confidence limits but not within the 95% confidence limits, this implication is not as strong. In either case, the corrosion rate will be interpreted to be "Not Significant".

If the prior data falls above the upper 99% confidence interval, it could mean either of two things: (1) significant corrosion has occurred over the time period covered by the data, or (2) the prior data point was not representative of the condition of the location of the 7-point data set in 1986. There is no way to differentiate between the two. In this case, the corrosion rate will be interpreted to be "Possible".

If the prior data falls below the lower 99% confidence limit, it means that it is not representative of the condition at this location at the earlier date. In this case, the corrosion rate will be interpreted to be "Indeterminable".

4.9 Evaluation of Drywell Mean Thickness

This section defines the methods used to evaluate the drywell thickness at each location within the scope of the long term monitoring program.

4.9.1 <u>Evaluation of Mean Thickness Using Regression Analysis</u>

The following procedure is used to evaluate the drywell mean thickness at those locations where regression analysis has been deemed to be more appropriate than the mean model.

(1) The best estimate of the mean thickness at these locations is the point on the regression line corresponding to the time when the most recent set of measurements was taken. In the SAS Regression Analysis output (App. 6.2), this is the last value in the column labeled "PREDICT VALUE".

(2) The best estimate of the standard error of the mean thickness is the standard error of the predicted value used above. In the SAS Regression Analysis output, this is the last value in the column labeled "STD ERR PREDICT".

(3) The two-sided 95% confidence interval about the mean thickness is equal to the mean thickness plus or minus t times the estimated standard error of the mean. This is the interval for which we have 95% confidence that the true mean thickness will fall within. The value of t is obtained from a t distribution table for <u>equal tails</u> at n-2 degrees of freedom and 0.05 level of significance, where n is the number of sets of measurements used in the regression analysis. The degrees of freedom is equal to n-2 because two parameters (the y-intercept and the slope) are calculated in the regression analysis with n mean thicknesses as input.

(4) The one-sided 95% lower limit of the mean thickness is equal to the estimated mean thickness minus t times the estimated standard error of the mean. This is the mean thickness for which we have 95% confidence that the true mean thickness does not fall below. In this case, the value of t is obtained from a t distribution table for <u>one tail</u> at n-2 degrees of freedom and 0.05 level of significance.

4.9.2 <u>Evaluation of Mean Thickness Using Mean Model</u>

The following procedure is used to evaluate the drywell mean thickness at those locations where the mean model is deemed to be more appropriate than the linear regression model. This method is consistent with that used to evaluate the mean thickness using the regression model.

(1) Calculate the mean of each set of UT thickness measurements.

(2) Sum the means of the sets and divide by the number of sets to calculate the grand mean. This is the best estimate of the mean thickness. In the SAS Regression Analysis output, this is the value labelled "DEP MEAN".

(3) Using the means of the sets from (1) as input, calculate the standard error about the mean. This is the best estimate of the standard error of the mean thickness.

(4) The two-sided 95% confidence interval about the mean thickness is equal to the mean thickness plus or minus t times the estimated standard error of the mean. This is the interval for which we have 95% confidence that the true mean thickness will fall within. The value of t is obtained from a t distribution table for equal tails at n-1 degrees of freedom and 0.05 level of significance.

(5) The one-sided 95% lower limit of the mean thickness is equal to the estimated mean thickness minus t times the estimated standard error of the mean. This is the mean thickness for which we have 95% confidence that the true mean thickness does not fall below. In this case, the value of t is obtained from a t distribution table for one tail at n-1 degrees of freedom and 0.05 level of significance.

4.9.3 Evaluation of Mean Thickness Using Single Data Set

The following procedure is used to evaluate the drywell thickness at those locations where only one set of measurements is available.

(1) Calculate the mean of the set of UT thickness measurements. This is the best estimate of the mean thickness.

(2) Calculate the standard error of the mean for the set of UT measurements. This is the best estimate of the standard error of the mean thickness.

Confidence intervals about the mean thickness cannot be calculated with only one data set available.

1

4.19 The possibility does exist that the variability in the data may be masking an actual corrosion rate. Although the mean model is deemed more appropriate than the regression model, the results of the regression analysis can be used to estimate the potentially masked corrosion rate. We can state with 95% confidence that the potential corrosion rate cannot exceed the upper bound of the 95% one-sided confidence interval of the slope computed in the regression analysis. The 95% upper bound is equal to the computed slope plus the one-sided t-table value times the standard error of the slope. The value of t is determined for n-2 degrees of freedom.

4.10 Evaluation of Drywell Corrosion Rate

4.10.1 Mean Model

If the ratio of the observed F value to the critical F value is less than 1 for the F-test for the significance of regression, it indicates that the mean model is more appropriate than the regression model at the 5% level of significance. In other words, the variation in mean thickness with time can be explained solely by the random variations in the measurements. This means that the corrosion rate is not significant compared to the random variations.

In this case, an F-test is performed to compare the variability of the data set means between data sets with the variability of individual measurements within the data sets. If the observed F value is less than the critical F value, it confirms that the mean model is appropriate.

Supersided

If the F-test indicates that the variability of the means is significant, the Least Significant Difference (LSD) is computed. This is the maximum difference between data set mean thicknesses that can be attributed to random variation in the measurements. If the difference between the means of data sets exceeds LSD, it indicates that difference is significant. The difference between means is subtracted from LSD and the result is divided by the time between measurements to estimate the "Significant Corrosion Rate" in mils per year (mpy). If the difference between the means does not exceed LSD, then it is concluded that no significant corrosion occurred during that period of time. 1

4.10.2 Regression Model

If the ratio of the observed F value to the critical F value is 1 or greater, it indicates that the regression model is more appropriate than the mean model at the 5% level of significance. In other words, the variation in mean thickness with time cannot be explained solely by the random variations in the measurements. This means that the corrosion rate is significant compared to the random variations.

Although a ratio of 1 or greater indicates that regression is significant, it does not mean that the slope of the regression line is an accurate prediction of the corrosion rate. The ratio should be at least 4 or 5 to consider the slope to be a useful predictor of the corrosion rate (Ref.

3.5, pp. 93, 129-133). A ratio of 4 or 5 means that the variation from the mean due to regression is approximately twice the standard deviation of the residuals of the regression.

To have a high degree of confidence in the predicted corrosion rate, the ratio should be at least 8 or 9 (Ref. 3.5, pp. 129-133).

4.10.3 ~~Best Estimate of Recent Corrosion Rate~~

In most instances, four sets of measurements over a period of about one year do not provide a significant regression model which can be used to predict future thicknesses. However, a least squares fit of the four data points does provide a reasonable estimate of the recent corrosion rate. This information is particularly valuable for assessing the effectiveness of cathodic protection and the draining of the sand bed region. Since a linear regression analysis performs a linear least squares fit of the data, the best estimate of the recent corrosion rate is the slope from the regression analysis for the period of interest.

These values are tabulated as the "Apparent Corrosion Rate" in paragraph 2.5.

Superseded

The upper bound of the 95% one-sided confidence interval about the computed slope is an estimate of the maximum probable corrosion rate at 95% confidence. The 95% upper bound is equal to the computed slope plus the one-sided t-table value times the standard error of the slope. The value of t is determined for n-2 degrees of freedom.

1

5.0 CALCULATIONS

5.1 6"x6" Grids in Sand Bed Region With Cathodic Protection

5.1.1 Bay 11A

5.1.1.1 Bay 11A: 5/1/87 to ~~2/8/90~~ 4/24/90

1

Nine 49-point data sets were available for this bay covering 4/24/90 period. Since a plug lies within this region, four of the points were voided in each data set. The data were analyzed as described in paragraphs 4.4, 4.5.1 and 4.6.1.

(1) The data are normally distributed.

(2) The regression model is appropriate.

(3) The regression model explains 78.3% of the variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 870.4 ± 5.7 mils.

(6) The corrosion rate ± standard error is -15.6 ± 2.9 mils per year.

(7) F/F critical = 5.4.

(8) The measurement below 800 mils was tested and determined not to be statistically different from the mean thickness.

5.1.1.2 Bay 11A: 10/8/88 to 4/24/90

Five 49-point data sets were available for this bay covering this period.

(1) The data are normally distributed.

(2) The mean model is more appropriate than the regression model.

(3) The F-test for the significant of the difference between the means shows that the difference between the mean thickness are not significant.

(4) The t-test of the last two data sets shows that the difference between the mean thickness is not significant.

(5) The current thickness based on the mean model is 878.9 ± 5.9 mils.

(6) These analyses indicate that the corrosion rate with cathodic protection is not significant compared to random variations in the measurements.

(7) The best estimate of the corrosion rate during the period based on a least squares fit is -16.2 ± 8.6 mils per year.

5.1.2 Bay 11C

5.1.2.1 Bay 11C: 5/1/87 to 4/24/90

Nine 49-point data sets were available for this bay covering this period. The initial analysis of this data indicated that the data are not normally distributed. The lack of normality was tentatively attributed to minimal corrosion in the upper half of the 6"x6" grid with more extensive corrosion in the lower half of the grid. To test this hypothesis, each data set was divided into two subsets, with one containing the top three rows and the other containing the bottom four rows.

Top 3 Rows

(1) The data are normally distributed.

(2) The regression model is appropriate.

(3) The regression model explains 79% of the total variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 977.0 ± 12.5 mils.

(6) The corrosion rate is -35.2 ± 6.8 mils per year.

(7) F/F critical = 4.6.

Bottom 4 Rows

(1) Seven of the nine data sets are normally distributed. The other two are skewed toward the thinner side of the mean. The Chi-square test shows that they are close to being normally distributed at the 1% level of significance.

(2) The regression model is appropriate.

(3) The regression model explains 80% of the total variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 865.0 ± 7.8 mils.

(6) The corrosion rate ± standard error is -22.4 ± 4.3 mils per year.

(7) F/F critical = 4.9

5.1.2.2 Bay 11C: 10/8/88 to 4/24/90

Five 49-point data sets were available for this period. These data were divided into two subsets as described above.

Top 3 Rows

(1) The data are normally distributed.

(2) The mean model is more appropriate than the regression model.

(3) The F-test for the significance of the difference between the means shows that the differences between the mean thicknesses are not significant.

(4) The t-test of the last two data sets shows that there is no statistical difference between their means.

(5) These analyses indicate that the current corrosion rate with cathodic protection is not significant compared to random variations in the measurements.

(6) Based on the mean model, the current thickness ± standard error is 996.6 ± 8.3 mils.

(7) The best estimate of corrosion rate during this period based on a least squares fit is -25.0 ± 10.6 mils per year.

Bottom 4 Rows

(1) Four of the five data sets are normally distributed. (See 5.1.2.1 above).

(2) The mean model is more appropriate than the regression model.

(3) The F-test for the significance of the difference between the means shows that the differences between the mean thicknesses are significant.

(4) The t-test of the last two data sets shows that there is no significant statistical difference between their means.

(5) Based on the mean model, the current thickness ± standard error is 878.1 ± 5.6 mils.

(6) Based upon examination of the distribution of the five data set mean values, it is concluded that the current corrosion rate is not significant compared to random variations in the measurements. The measurements alternated as follows: 897, 877, 891, 869, 863. Therefore the difference must be due to variations other than corrosion.

(7) The best estimate of the corrosion rate during this period based on a least squares fit is -16.7 ± 7.1 mils per year.

5.1.3 Bay 17D

5.1.3.1 Bay 17D: 2/17/87 to 4/24/90

Ten 49-point data sets were available for this period. Since a plug lies within this region, four of the points were voided in each data set. Point 24 in the 2/8/90 data was voided since it is characteristic of the plug thickness.

(1) The data are normally distributed.

(2) The regression model is appropriate.

(3) The regression model explains 95% of the total variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 829.5 ± 4.0 mils.

(6) The corrosion rate ± standard error is -25.0 ± 2.0 mils per year.

(7) F/F critical = 29.4

(8) The measurements below 800 mils were tested and determined not to be statistically different from the mean thickness.

5.1.3.2 Bay 17D: 10/8/88 to 4/24/90

Five 49-point data sets were available for this period.

(1) The data are normally distributed.

(2) The regression model is more appropriate than the mean model.

(3) The regression model explains 90% of the variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 830.1 ± 3.8 mils.

(6) The corrosion rate ± standard error is -23.7 ± 4.6 mpy.

(7) F/F critical = 2.7

5.1.4 Bay 19A

5.1.4.1 Bay 19A: 2/17/87 to 4/24/90

Ten 49-point data sets were available for this period. Since a plug lies within this region, four of the points were voided in each data set.

(1) The data are normally distributed at the 1% level of significance.

(2) The regression model is appropriate

(3) The regression model explains 96% of the total variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 807.6 ± 3.0 mils.

(6) The corrosion rate ± standard error is -21.4 ± 1.5 mpy.

(7) F/F critical = 39.5

(8) The data points that were below 800 mils were tested and determined not to be statistically different from the mean thickness.

5.1.4.2 Bay 19A: 10/8/88 to 4/24/90

Five 49-point data sets were available for this period.

(1) The data are normally distributed.

(2) The regression model is more appropriate than the mean model.

(3) The regression model explains 90% of the variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 808.2 ± 3.2 mils.

(6) The corrosion rate ± standard error is -20.6 ± 3.9 mpy.

(7) F/F critical = 2.8

5.1.5 Bay 19B

5.1.5.1 Bay 19B: 5/1/87 to 4/24/90

Nine 49-point data sets were available for this period.

(1) The data are normally distributed.

(2) The regression model is appropriate.

(3) The regression model explains 94% of the total variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 836.9 ± 3.2 mils.

(6) The corrosion rate ± standard error is -19.0 ± 1.7 mpy.

(7) F/F critical = 21.3

(8) The measurements below 800 mils were tested and determined not to be statistically different from the mean thickness.

5.1.5.2 Bay 19B: 10/8/88 to 4/24/90

Five 49-point data sets were available for this period.

(1) The data are normally distributed.

(2) The regression model is more appropriate than the mean model.

(3) The regression model explains 75% of the variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 841.2 ± 3.3 mils.

(6) The corrosion rate ± standard error is -11.8 ± 3.9 mpy.

(7) F/F critical = 0.9

5.1.6 Bay 19C

5.1.6.1 Bay 19C: 5/1/87 to 4/24/90

Nine 49-point data sets were available for this period. Since a plug lies within this region, four of the points were voided in each data set.

(1) The data are normally distributed at the 1% level of significance, but appears to be developing two peaks.

(2) The regression model is appropriate.

(3) The regression model explains 98% of the total variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 825.1 ± 2.3 mils.

(6) The corrosion rate ± standard error is -24.3 ± 1.3 mpy.

(7) F/F critical = 66.2

(8) The measurements below 800 mils were tested and determined not to be statistically different from the mean thickness.

5.1.6.2 Bay 19C: 10/8/88 to 4/24/90

Five 49-point data sets were available for this period.

(1) The data are normally distributed at the 1% level of significance.

(2) The F-test for significance of regression indicates that the regression model is appropriate.

(3) The regression model explains 93% of the total variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 826.3 ± 2.9 mils.

(6) The corrosion rate ± standard error is -21.5 ± 3.5 mpy.

(6) F/F critical = 3.7.

5.1.7 Bays 17/19 Frame Cutout: 12/30/88 to 4/24/90

Two sets of 6"x6" grid measurements were taken in December 1988. The upper one is located 25" below the top of the high curb and the other below the floor. There is no previous data. The upper location was added to the long term monitoring program.

Five 49-point data sets were available for this period. These data were analyzed as described in 4.4, 4.5.2 and 4.6.1. The initial analysis of this data indicated that the first and last data sets are not normally distributed. The lack of normality was tentatively attributed to more extensive corrosion in the upper half of the grid than the bottom half. To test this hypothesis, each data set was divided into two subsets, with one containing the top three rows and the other containing the bottom four rows.

Top 3 Rows

(1) Four of the five subsets are normally distributed at the 1% level of significance but one is not.

(2) The mean model is appropriate.

(3) The F-test for the significance of the difference between the means shows that the differences between the mean thicknesses are not significant at 1% level of significance.

(4) These analyses indicate that the corrosion rate is not significant compared to the random variations in the measurements.

(5) Based on the mean model, the current thickness ± standard error is 986.0 ± 4.7 mils.

(6) The best estimate of the corrosion rate during this period based on a least squares fit is -8.2 ± 10.7 mils per year.

Bottom 4 Rows

(1) Four of the five subsets are normally distributed at the 5% level of significance, and one at the 1% level of significance.

(2) The mean model is appropriate.

(3) The F-test for the significance of the difference between the means shows that the differences between the mean thicknesses are not significant at 1% level of significance.

(4) These analyses indicate that the corrosion rate is not significant compared to the random variations i the measurements.

(5) Based on the mean model, the current thickness ± standard error is 1005.7 ± 5.6 mils.

(6) The best estimate of the corrosion rate during this period based on a least squares fit is -13.1 ± 11.6 mils per year.

5.2 6"x6" Grids in Sand Bed Region Without Cathodic Protection

5.2.1 Bay 9D: 12/19/88 to 4/24/90

Five 49-point data sets were available for this period.

(1) The data are normally distributed.

(2) The mean model is more appropriate than the regression model.

(3) The current mean thickness is 1021.7 ± 8.9 mils.

(4) The F-test for the significance of the difference between the mean thicknesses indicates that the differences between the means are significant. The LSD analysis shows that this is due to the second measurement on 6/26/89 which is 33 to 52.3 mils higher than the other four.

(5) The t-test of the last two data sets shows that the difference between the mean thicknesses is not significant.

(6) The overall analysis indicates that there was no significant corrosion from December 19, 1988 to April 24, 1990.

(7) The best estimate of the corrosion rate during this period based on a least squares fit is -21.0 ± 18.1 mils per year.

5.2.2 Bay 13A: 12/17/88 to 4/24/90

Seven 49-point data sets were available for this period.

(1) The data are normally distributed.

(2) The regression model is appropriate.

(3) The regression model explains 97% of the total variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 853.1 ± 2.4 mils.

(6) The indicated corrosion rate ± standard error is -39.1 ± 3.4 mils per year.

(7) F/F critical = 16.9

(8) The measurements below 800 mils were tested and determined not to be statistically different from the mean thickness.

5.2.3 Bay 13D: 3/28/90 to 4/25/90

One 7-point data set and one 49-point data set are available for this bay covering this period.

(1) The 7-point data set is normally distributed at 5% level of significance. The 49-point data set is normally distributed at 1% level of significance. However, there is a diagonal line of demarcation separating a zone of minimal corrosion at the top from a corroded zone at the bottom. Thus, corrosion has occurred at this location.

(2) The mean of the 7-point data set is not significantly different from the mean of the corresponding 7 points in the 49-point data set.

(3) The current means thickness is 931.9 ± 22.6 mils.

It is concluded that corrosion has occurred at this location. However, with minimal data over a one-month period, it is impossible to determine the current corrosion rate.

5.2.4 Bay 15D: 12/17/88 to 4/24/90

Five 49-point data sets were available for this period.

(1) The data are normally distributed.

(2) The mean model is more appropriate than the regression model.

(3) The current mean thickness ± standard error is 1056.5 ± 2.3 mils.

(4) The F-test for the significance of the difference between the mean thicknesses indicates that the differences between the means are not significant.

(5) The t-test of the last two data sets shows that the difference between the mean thicknesses is not significant.

(6) There was no significant corrosion from December 17, 1988 to April 24, 1990.

(7) The best estimate of the corrosion rate during this period based on a least squares fit is -4.6 mils per year.

5.2.5 Bay 17A: 12/17/88 to 4/24/90

Five 49-point data sets were available for this period.

The initial analysis of this data indicated that the data are not normally distributed. The lack of normality was tentatively attributed to minimal corrosion in the upper half of the 6"x6" grid with more extensive corrosion in the lower half of the grid. To test this hypothesis, each data set was divided into two subsets, with one containing the top three rows and the other containing the bottom four rows.

Top 3 Rows

(1) The data are normally distributed.

(2) The mean model is more appropriate than the regression model.

(3) The current mean thickness ± standard error is 1128.3 ± 2.2 mils.

(4) The F-test for the significance of the difference between the mean thicknesses indicates the differences between the means are not significant.

(5) The t-test of the last two data sets indicates that the difference between the mean thicknesses is not significant.

(6) There was no significant corrosion during this period.

(7) The best estimate of the corrosion rate during this period based on a least squares fit is -6.8 ± 3.7 mils per year.

Bottom 4 Rows

(1) The data are normally distributed.

(2) The mean model is more appropriate than the regression model.

(3) The current mean thickness ± standard error 950.83 ± 5.3 mils.

(4) The F-test for the significance of the difference between the mean thicknesses indicates that the differences between the means are not significant.

(5) The t-test of the last two data sets indicates that the difference between the mean thicknesses is not significant.

(6) There was no significant corrosion during this period.

(7) The best estimate of the corrosion rate during this period based on a least squares fit is -17.7 ± 7.6 mils per year.

5.3 6"x6" Grids at 51' Elevation

5.3.1 Bay 5 Area D-1 2 51' Elevation: 11/1/87 to 4/24/90

Eight 49-point data sets were available for this period.

The initial analysis of this data indicated that the data are not normally distributed. These data sets names start with E. The following adjustments were made to the data:

(1) Point 29 in the 9/13/89 data is much greater than the preceding or succeeding measurements. Therefore, this reading was dropped from the analysis.

(2) Point 9 is a significant pit. Therefore, it was dropped from the overall analysis and is evaluated separately.

(3) Points 13 and 25 are extremely variable and are located adjacent to the plug which was removed from this grid. They were also dropped from the analysis.

(4) Point 43 in the 11/01/87 data is much less than any succeeding measurement. Therefore, this reading was dropped from the analysis.

With these adjustments, the first and last data sets are normally distributed at the 1% level of significance and the other five at 5%. These data set names start with F.

It was noted that the D-Meter calibration at 0.750" yielded readings which ranged from -1 mil for one set of measurements to + 4 mils for another. The data was adjusted to eliminate these biases. These data set names start with G. The final analyses are based on these adjusted data sets.

(1) The data are normally distributed.

(2) The regression model is appropriate.

(3) The regression model explains 57% of the total variation about the mean.

(4) The residuals are normally distributed.

(5) The current mean thickness ± standard error is 745.2 ± 2.1 mils.

(6) The indicated corrosion rate ± standard error is -4.6 ± 1.6 mils per year.

(7) F/F critical = 1.3. Thus, the regression is just barely significant.

(8) The F-test for significance of the difference between the mean thickness indicates that the differences are significant.

(9) The t-test of the last two data sets shows that the difference between the mean thickness is not significant.

(10) The measurements of the pit at point 9 were 706, 746, 696, 694, 700, 688, 699 and 689 mils. The mean value of these measurements is 702.3 ± 6.5 mils. A least squares fit shows that the best estimate of the corrosion rate during this period is -11.5 mils per year with R^2=31%. The second measurement is much higher than the others. Dropping this point, the mean of the remaining measurements is 696.0 ± 2.4 mils, and the best estimate of the corrosion rate is -4.9 mils per year with R^2 = 49%. Recognizing that the variability of single measurements will be about 6 times the variability of the mean of 40 measurements, it is concluded that the corrosion rate in the pit is essentially the same as the overall grid.

5.3.2 Bay 5 Area 51-5 at 51' Elevation: 3/31/90 to 4/25/90

Two 49-point data sets are available for this time period.

(1) The data are not normally distributed. This is due to a large corroded patch near the center of the grid, and several small patches on the periphery.

When the data less than the grand mean were segregated, it was found that these subsets are normally distributed.

(2) The t-tests of the two complete data sets and the two subsets indicate that the difference between the mean thicknesses are not significant.

(3) The current mean thickness ± standard error is 745.1 ± 3.2 mils.

It is concluded that corrosion has occurred at this location. However, with minimal data over such a brief period, it is impossible to determine the current corrosion rate.

5.3.3 Bay 13 Area 31 Elevation 51': 3/31/90 to 4/25/90

Two 49-point data sets are available for this time period.

(1) The data are to normally distributed. This is due to a large corroded patch at the left edge of the grid.

When the data less than the grand mean were segregated, it was found that these subsets are normally distributed.

(2) The t-test of the two complete data sets indicate that the difference between the means is statistically significant. However, the difference between the means of the two subsets is not statistically significant.

(3) The current mean thickness is ± standard error is 750.8 ± 11.5 mils.

It is concluded that corrosion has occurred at this location. However, with minimal data over such a brief period, it is impossible to determine the current corrosion rate.

5.3.4 Bay 15 Area 23 Elevation 51': 3/31/90 to 4/25/90

Two 49-point data sets are available for this time period.

(1) The data are not normally distributed. This is due to a large corroded patch.

When the data less than the grand mean were segregated, it was found that these two subsets are normally distributed.

(2) The t-tests of the two complete data sets and the two subsets indicate that the differences between the mean thicknesses are not significant.

(3) The current mean thickness ± standard error is 751.2 ± 3.8 mils.

It is concluded that corrosion has occurred at this location. However, with minimal data over such a brief period, it is impossible to determine the current corrosion rate.

5.4 6" x 6" Grids at 52' Elevation

5.4.1 Bay 7 Area 25 Elevation 52': 4/26/90

One 49-point data set is available.

(1) The data are not normally distributed.

The subset of the data less than the mean thickness is not normally distributed.

When four points below 700 mils were dropped from the data set, the remaining data was found to be normally distributed. Therefore, the lack of normality of the complete data set is attributed to these thinner points. Three of these could be considered to be pits (626, 657 and 676 mils) since they deviate from the mean by more than 3 sigma.

(2) The current mean thickness ± standard is 715.5 ± 2.9 mils.

It is concluded that corrosion has occurred at this location.

5.4.2 Bay 13 Area 6 Elevation 52': 4/26/90

One 49-point data set is available.

(1) The data are not normally distributed.

The subset of the data less than the mean thickness is normally distributed. Thus, the lack of normality of the complete data set is attributed to a large corroded patch at the left side of the grid.

(2) The current mean thickness ± standard error is 724.9 ± 2.9 mils.

(3) It is concluded that corrosion has occurred at this location.

5.4.3 Bay 13 Area 32 Elevation 52': 4/26/90

One 49-point data set is available.

(1) The data are not normally distributed.

The subset of the data less than the mean thickness is normally distributed. Thus, the lack of normality of the complete data set is attributed to these corrosion patches.

(2) The current mean thickness ± standard error is 698.3 ± 5.0 mils.

It is concluded that corrosion has occurred at this location.

5.4.4 Bay 19 Area 13 Elevation 52': 4/26/90

One 49-point data set is available.

(1) The data are normally distributed. However, two adjacent points differ from the mean by 3 sigma and 5 sigma. Thus, there is a pit.

(2) The current means thickness ± standard error is 712.5 ± 3.1 mils.

It is concluded that some corrosion has occurred at this location.

5.5 6" x 6" Grids at 87' Elevation

5.5.1 Bay 9 87' Elevation: 11/6/87 to 3/28/90

Five 49-point data sets were available for this period.

(1) The data are normally distributed.

(2) The mean model is more appropriate than the regression model.

(3) There was no significant corrosion during this period.

(4) The current mean thickness ± standard error is 619.9 ± 0.6 mils.

(5) The best estimate of the corrosion rate during this period based on a least squares fit is -0.2 ± 0.9 mils per year.

5.5.2 Bay 13 87' Elevation: 11/10/87 to 3/28/90

Five 49-point data sets were available for this period.

(1) The data are normally distributed.

(2) The mean model is more appropriate than the regression model.

(3) There was no significant corrosion during this period.

(4) The current mean thickness ± standard error is 636.5 ± 0.8 mils.

(5) The best estimate of the corrosion rate during this period based on a least squares fit is zero mils per year.

5.5.3 Bay 15 87' Elevation: 11/10/87 to 3/28/90

Five 49-point data sets were available for this period.

(1) The data are normally distributed.

(2) The mean model is more appropriate than the regression model.

(3) There was no significant corrosion during this period.

(4) The current mean thickness ± standard error is 636.2 ± 1.1 mils.

(5) The best estimate of the corrosion rate during this period based on a least squares fit is zero mils per year.