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February 6, 1986

Sheldon J. Wolfe, Chairman
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In the Matter of
METROPOLITAN EDISON COMPANY, et al.
(Three Mile Island Nuclear Station, Unit No. 1)
Docket No. 50-289 SP

Dear Administative Judges:

With reference to my letter to you of February 3, 1986, I am enclosing for your information copies of Technical Specification Change Request No. 153 which Licensee submitted to the NRC Staff on February 4. The requested change to the Technical Specifications would be applicable only for the

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March 1986 eddy current testing outage, and is not a part of the pending Change Request No. 148.

Sincerely,

Bruce W. Churchill
Counsel for Licensee

Enclosure

cc: Service List Attached

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

Atomic Safety and Licensing Board Panel

In the Matter of)
)
METROPOLITAN EDISON COMPANY, *et al.*) Docket No. 50-289
)
(Three Mile Island Nuclear Station,)
Unit No. 1))

SERVICE LIST

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Office of Nuclear Reactor Regulation
Attn: J. F. Stolz, Director
PWR Projects Directorate No. 6
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Dear Mr. Stolz:

Three Mile Island Nuclear Station Unit 1 (TMI-1)
Operating License No. DPR-50
Docket No. 50-289
Technical Specification Change Request No. 153

Enclosed are three originals of Technical Specification Change Request No. 153, which reflects a revision for an interim period to the repair limit for the Three Mile Island Unit 1 Once Through Steam Generator Tubes. Forty conformed copies are being sent separately.

Pursuant to 10CFR50.91 (a) (1) we enclose our analyses, using the standards of 10CFR50.92 for significant hazards considerations.

Pursuant to 10CFR50.91 (b)(1) of the regulations, we have provided a copy of this letter, the proposed change in Technical Specifications, and our analyses of significant safety hazards considerations to Thomas Gerusky of the Bureau of Radiation Protection, the designated representative of the Commonwealth of Pennsylvania. Also enclosed are signed copies of the Certificate of Service for this request to the chief executives of the township and county in which the facility is located, as well as to the Bureau of Radiation Protection.

Pursuant to the provisions of 10CFR170.21, a check for $150.00 in payment of the fee associated with Technical Specification Change Request No. 153 Rev. 0 is being forwarded by separate correspondence.

The next TMI-1 Eddy Current Outage is scheduled for March, 1986. In order for us to implement the revised repair limit at that time, we request that NRC review and approve Technical Specification Change Request expeditiously.

Sincerely,

RJ Toole for
H. D. Hukill
Director, TMI-1

SK:HDH:2852f

cc: J. Thoma
R. Conte

Enclosures: 1) Technical Specification Change Request No. 153

2) Certificate of Service for Technical Specification Change Request No. 153

RELATED CORRESPONDENCE

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METROPOLITAN EDISON COMPANY

JERSEY CENTRAL POWER & LIGHT COMPANY

AND

PENNSYLVANIA ELECTRIC COMPANY

THREE MILE ISLAND NUCLEAR STATION, UNIT 1

Operating License No. DPR-50
Docket No. 50-289
Technical Specification Change Request No. 153

This Technical Specification Change Request is submitted in support of Licensee's request to change Appendix A to Operating License No. DPR-50 for Three Mile Island Nuclear Station, Unit 1. As a part of this request, proposed replacement pages for Appendix A are also included.

GPU NUCLEAR CORPORATION

BY RJ Toole for
Director, TMI-1

Sworn and Subscribed
to before me this 4th
day of February, 1986.

Sharon P. Brown
Notary Public

SHARON P. BROWN, NOTARY PUBLIC
MIDDLETOWN BORO, DAUPHIN COUNTY
MY COMMISSION EXPIRES JUNE 12, 1989
Member, Pennsylvania Association of Notaries

UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

IN THE MATTER OF

DOCKET NO. 50-289
LICENSE NO. DPR-50

GPU NUCLEAR CORPORATION

This is to certify that a copy of Technical Specification Change Request No. 153 to Appendix A of the Operating License for Three Mile Island Nuclear Station Unit 1, has, on the date given below, been filed with executives of Londonderry Township, Dauphin County, Pennsylvania; Dauphin County, Pennsylvania; and the Pennsylvania Department of Environmental Resources, Bureau of Radiation Protection, by deposit in the United States mail, addressed as follows:

Mr. Jay H. Kopp, Chairman
Board of Supervisors of
Londonderry Township
R. D. #1, Geyers Church Road
Middletown, PA 17057

Mr. Norman P. Hetrick, Chairman
Board of County Commissioners
of Dauphin County
Dauphin County Courthouse
Harrisburg, PA 17120

Mr. Thomas Gerusky, Director
PA. Dept. of Environmental Resources
Bureau of Radiation Protection
P.O. Box 2063
Harrisburg, PA 17120

GPU NUCLEAR CORPORATION

BY H G Toole for
Director, TMI-1

DATE: February 4, 1986

I. TECHNICAL SPECIFICATION CHANGE REQUEST (TSCR) NO. 153

GPUN requests that the attached revised pages (Attachment 1) replace pages 4-80 and 4-82, and add page 4-80a in the TMI-1 Technical Specifications.

II. REASON FOR CHANGE

GPUN in the past has repaired OTSG tubes based on a general 40% throughwall repair limit. This repair limit defines as acceptable a tube with an imperfection extending up to 40% of the tube wall thickness. The imperfection may be up to 360° in circumferential extent. GPUN recently has developed an analytical basis to demonstrate that an equivalent margin to safety can be provided by a tube with an imperfection of greater than 40% of the tube wall thickness and a given continuous length (specifically, 50% of the tube wall thickness with a continuous length of 0.55 inches on the interior wall of the tube). Eddy current technology has evolved such that it is possible to characterize continuous imperfections in terms of volumetric degradation, more specifically circumferential or axial extent, as well as throughwall penetration.

Implicit in the application of the general 40% throughwall repair limit have been an allowance of 10% on the throughwall extent for inaccuracies associated with the eddy current detection capability, and an allowance of 10% for corrosion. GPUN has demonstrated eddy current capability to characterize imperfections with inaccuracy of less than 10% of nominal throughwall. Also, GPUN has demonstrated to the satisfaction of the NRC staff, as well as the Atomic Safety and Licensing Board, that corrosion is not an ongoing phenomenon in the primary side of the TMI-1 Once Through Steam Generators.

Also, application of the proposed criteria would result in a reduction in occupational radiation doses. During the most recent TMI-1 eddy current outage beginning in November 1984, GPUN removed from service 328 tubes by plugging, 118 of which would have been dispositioned to remain in service in accordance with the repair limit proposed herein. The occupational exposure rate inside the OTSG's during the 1984 plugging activity was approximately 700mR/hr. which resulted in an average exposure of approximately 120mR per tube. GPUN cannot make a projection at this time as to the number of tubes which will require removal from service, if any, during the next eddy current outage; however, based on recent history of plant operation, an exposure rate of 2-10R/hr within the steam generators is anticipated. Thus, a significant reduction in occupational exposure could be expected with application of the proposed repair limit.

III. SAFETY EVALUATION JUSTIFYING CHANGE

The existing steam generator tube repair limit defines as acceptable a tube with a imperfection extending up to 40% of the tube wall thickness and up to 360° in circumferential extent and unlimited axial extent. This is based on analyses and state of the art eddy current technology typical of the mid 1970's. With today's eddy current technology, imperfections can be better characterized in terms of volumetric degradation, more specifically circumferential, as well as throughwall penetration. Recent analyses have demonstrated the acceptability of tubes based on the extent of both depth and length of the imperfection. These analyses show that many imperfections exceeding 40% throughwall are acceptable because they would not be of a size or configuration, either at the time of ECT detection or during the interval between inspections, to adversely affect the degree of required tube integrity. Hence, the proposed criteria are based on the total cross section of unimpaired tube remaining in the tube freespan, rather than a consideration of throughwall depth alone.

The following paragraphs discuss the analytical basis for the proposed repair limit based on extent of volumetric degradation, the characterization of defects previously discovered in the TMI-1 OTSG tubes, the capabilities of the eddy current program in place at TMI-1, and compliance with NRC General Design Criteria 14, "Reactor Coolant Pressure Boundary," 15, "Reactor Coolant System Design," and 31, "Fracture Prevention of Reactor Coolant Pressure Boundary." Also provided, as Appendix A, is TDR-758, "Assessment of 50% TW Repair Limit with Respect to Reg. Guide 1.121 Guidelines" which presents a detailed demonstration that the proposed criteria are in accordance with the guidelines presented in Regulatory Guide 1.121.

GPUN has demonstrated that a imperfection extending greater than 0.55 inches in continuous length with a throughwall penetration of 50% can withstand loads associated with normal operation and faulted conditions (i.e., main steam line break), with margins to safety as suggested in Reg. Guide 1.121, assuming a 10% allowance on nominal throughwall for eddy current inaccuracy. The error associated with the eddy current process at TMI-1 has been shown to be within this allowance.

The proposed criteria apply to primary side (internal diameter, ID) imperfections only. Areas of reduced eddy current sensitivity on the primary side (namely, the upper and lower tubesheet secondary faces and tube support plate entry and exist locations) are excluded; the repair limit for indications in these areas remains 40% of the nominal tube wall thickness.

The proposed criteria address imperfections both predominantly circumferential in orientation and predominantly axial in orientation. The analytical basis was derived for both axial and circumferential imperfections; however, no axial imperfections have been found in the ID tube freespan, either during previous eddy current examinations or metallographic examinations. The TMI-1 Eddy Current Inspection Progam can discriminate between axial and circumferential imperfections.

ANALYTICAL BASIS

The bases for plugging criteria based on extent of volumetric degradation were developed from several existing analyses of the serviceability of flawed tubes under normal, transient or accident conditions. These analyses included ASME Section III (Ref. 1) and Section XI (Ref. 2) fatigue evaluations, and a solid mechanics single accident load (Main Steam Line Break Accident, MSLB) analysis conducted as part of GPU Nuclear's response to the 1981 tube cracking experience, as presented in TR-008 (Reference 3). These analyses have been previously reviewed and endorsed by the NRC staff.

GPUN's approach to determining a minimum required tube wall thickness was twofold: (a) to establish by fatigue analysis that tubes inservice would not develop cracks under normal operating conditions, even in areas of suspected degradation and (b) to demonstrate that existing cracks, should they go undetected, would not propagate throughwall under normal operating or postulated accident loading conditions. GPUN's evaluation combines the methodology of both ASME Sections III and XI in order to assess the reduction in fatigue resistance caused by identified or hypothetical ECT indications. ASME Section III provides guidance for designing nuclear pressure components against failure; ASME Section XI provides guidance for evaluating the impact of suspected flaws in pressure retaining components in service.

1. ASME Section III Fatigue Analysis

The Section III fatigue failure analysis uses crack initiation as the criterion for loss of fatigue resistance of the material; therefore design using this approach assumes only a degraded material condition and not outright structural failure. The approach used to enter the ASME III design fatigue curve was originally discussed in TDR-421 (Ref. 4) and is summarized in TR-008 (Ref. 3), which formed a basis for NRC conclusions in NUREG-1019 (Ref. 5).

2. Non-Propagation of a Hypothetical Crack

In ASME Section XI, the methods of linear elastic fracture mechanics (LEFM) are recommended. In this approach the presumed crack is analytically interacted with the local stress field in order to predict enlargement and propagation as service loads (both mechanical and thermal) are cycled in the anticipated manner. As discussed previously in TDR-388 (Ref. 6) and TR-008, a particular fracture mechanics solution was used by GPUN in order to properly model the response of a thin tube to the presence of an ID circumferential crack under applied axial load, internal pressure, and bending stress due to flow induced vibration.

The aim of this analysis was to demonstrate the adequacy of the threshold of ECT detection sensitivity; however, the results of that analysis also satisfy the Section XI flaw acceptance criteria when combined with the results of the main steam line break analysis.

The rupture strength of a flawed tube to the maximum axial load, applied one time only, was evaluated under the faulted condition of a main steam line break (MSLB). The tube response was analyzed by methods of solid mechanics, capturing the increased flexibility of the tube at the elevation of the flaw and utilizing the flow stress as the limited material condition.

Based on these discussions in TR-008, the NRC staff reached the following relevant conclusions on page 12 of NUREG-1019 (Ref. 5):

1. Cracks which are large enough, i.e, critical size, to propagate due to flow-induced vibration are readily detectable by ECT;
2. Cracks which are below the threshold of ECT detectability will not propagate under combined cyclic, flow-induced and thermal loadings;
3. The maximum crack size which will remain stable during a MSLB has been determined;
4. Throughwall defects which may propagate during operation can be detected well below the threshold size that could fail during a MSLB.

3. Conclusion

The analytical results of the ASME Section III fatigue evaluation, the Section XI LEFM results, and the MSLB solid mechanics evaluation were developed in terms of allowable tube wall degradation. The proposed revision to the plugging criteria (i.e, a repair limit based on degradation less than 50% throughwall penetration with a length of no greater than 0.55 inches, or 40% throughwall penetration for lengths greater than 0.55 inches) bounds the Section III fatigue evaluation, the Section XI LEFM results, and the MSLB solid mechanics analysis. In addition, the margin separating the ASME Section III fatigue analysis results and the proposed plugging criteria of 50% throughwall with a length no greater than 0.55 inches is twenty percentage points (20% on nominal throughwall). The margins separating the ASME Section XI analysis and the solid mechanics single accident load analysis are even greater (See TR-008 Figure IX-2).

CHARACTERIZATION OF TMI-1 OTSG DEFECTS

In order to identify the cause of eddy current indications detected during the TMI-1 OTSG tube examination beginning in November, 1984, GPUN performed an in-depth review of the eddy current results and plant chemistry history since the OTSG's were first filled after the kinetic expansion repairs. The results of this analysis were initially presented to the NRC in TDR-638 "Evaluation of Eddy Current Indications Detected During the 1984 Tech. Spec. Inspection" Rev. 0 (Reference 7), and subsequently in TDR-638 Rev. 1 (Appendix B). TDR-638 discusses the two possible causes evaluated for the 1984 eddy current indications: corrosion, either continuing or newly initiated, and enhanced eddy current detectability of existing intergranular attack (IGA) or intergranular stress assisted cracking (IGSAC), and concludes that the most likely reason for having eddy current indications at this time was enhanced detectability of preexisting areas of IGA/IGSAC.

TDR-652 "Evaluation of the 1984 Required Technical Specification Examination of the TMI-1 OTSG" (Appendix C) provides an in-depth evaluation of the results of the 1984 eddy current examination, and concludes that the 1984 examination identified indications that were already present in the tubes in 1982 but because of their weak signal amplitude were masked by background noise. TDR-652 also concludes that the mechanical, thermal and hydraulic loads imposed on the OTSG since the 1982 examination may have enhanced the eddy current detection of small indications by increasing the signal amplitude but without evidence of increase to percent throughwall. The review of the 1984, 1983 and 1982 examination results revealed that the percent through wall determination showed no trend of continued throughwall growth, and provided no evidence of an active mechanism occurring during the period of observation.

Recently, additional investigations were performed in an attempt to further characterize the intergranular attack (IGA) that existed in the OTSG's as a result of thiosulfate intrusion into the RCS in 1981 as well as to help clarify the sensitivity and accuracy of eddy current examination for IGA/IGSAC, as summarized in TDR 686, "Characterization of IGA in TMI-1 OTSG Samples," Rev. 1 (Appendix D). Existing reports were reviewed and reported IGA areas were characterized. Tubes that had been previously removed and stored were eddy current and fiberoptic inspected. Two tube sections were also cut and examined by metallography. TDR-686 concludes that the metallographically determined sizes of IGA patches were below the established level of eddy current sensitivity for IGSAC.

CAPABILITY OF TMI-1 EDDY CURRENT TECHNIQUE

During eddy current examination of the TMI-1 OTSG's the percent throughwall penetration of a discontinuity is determined by measuring the signal's phase angle and using a conversion curve to determine the percent throughwall. The traditional curves used for this purpose are designed for outside diameter discontinuities. For inside diameter discontinuities the percent throughwall determinations are obtained by extrapolation from the outside diameter curve. This traditional extrapolation tends to overcall small volume inner diameter discontinuities. The presence of inner diameter initiated, intergranular stress assisted cracks in the TMI-1 OTSG's has required GPUN to develop a more accurate means of assigning the percent throughwall values.

In TDR-642, "Qualification of Conversion Curve for Inner Diameter Discontinuities", (Appendix E), GPU Nuclear Corporation developed a conversion curve which more accurately represents small volume, inner diameter initiated discontinuities, by enhancing the traditional inner diameter conversion curve with supplemental data from EDM notches with various known depths. The accuracy of the enhanced curve was verified through metallurgical correlations using actual IGSAC.

The ECT accuracy may be demonstrated using six data points (eddy current calls) from these metallurgical samples. The mean of these six data points represents an overcall of 13.4%. A statistical evaluation resulted in a standard deviation of + 16.7%. Thus, within one standard deviation, an undercall of up to 3.3% was observed which is well within the allowance for eddy current error. As discussed under ANALYTICAL BASIS, above, the minimum margin separating the fatigue analysis results from the new plugging criteria of 50% throughwall penetration with a length no greater than 0.55 inches is twenty percentage points (20% on nominal throughwall thickness).

COMPLIANCE WITH GENERAL DESIGN CRITERIA 14, 15 and 31

Use of the proposed repair limit would not reduce or alter the extent of TMI-1 compliance with General Design Criteria 14, 15, and 31.

1. General Design Criterion 14 - Reactor Coolant Pressure Boundary

GDC 14 specifies that the reactor coolant pressure boundary shall be designed, fabricated, erected and tested so as to have an extremely low probability of abnormal leakage, of rapidly propagating failure, and of gross rupture.

The proposed change does not involve any change to the reactor coolant pressure boundary design, fabrication and erection.

The OTSG tubes have an extremely low probability of abnormal leakage or of rapidly propagating failure as demonstrated, by the margin (greater than 30% of nominal throughwall) between the proposed plugging criterion and the LEFM Section XI analytical results. In addition, the TMI-1 Operating License includes the exceedingly restrictive condition that if primary to secondary system leakage exceeds the baseline leakage rate by more than 0.1 gpm, the facility is to be shutdown and the leaking tube(s) removed from service.

Also, the probability of gross rupture is extremely low, as demonstrated by the margin (greater than 40% of nominal throughwall) to the results for loadings associated with the Main Steam Line Break analysis. Independent analysis in TDR-758 (Appendix A) has demonstrated adequacy of the proposed plugging criteria for loads associated with faulted conditions, with a margin to safety of 1.428, as prescribed by Reg. Guide 1.121.

2. General Design Criterion 15-Reactor Coolant System Design

GDC 15 specifies that the reactor coolant system and associated auxiliary, control and protection systems shall be designed with sufficient margin to assure that the design conditions of the reactor coolant pressure boundary are not exceeded during any condition of normal operation, including anticipated operational occurrences.

As discussed under ANALYTICAL BASIS, above, GPUN has verified that sufficient margin exists with the proposed plugging criteria such that design conditions of the OTSG tubes are not exceeded during any condition of normal operation, including anticipated operational occurrences.

3. General Design Criterion 31-Fracture Prevention of Reactor Coolant Pressure Boundary

GDC 31 specifies that the reactor coolant pressure boundary shall be designed with sufficient margin to assure that when stressed under operating, maintenance, testing and postulated accident conditions (1) the boundary behaves in a nonbrittle manner and (2) the probability of rapidly propagating fracture is minimized. The design shall reflect consideration of service temperatures and other conditions of the boundary material under operating, maintenance, testing and postulated accident conditions and the uncertainties in determining (1) material properties, (2) the effects of irradiation on material properties, (3) residual, steady state and transient stresses, and (4) size of flaws.

The use of the proposed criteria would not alter the boundary material and hence would not affect the nonbrittle behavior of the boundary material.

As discussed under GDC 14, above, sufficient margin is provided to minimize the probability of rapidly propagating fracture.

The analysis presented herein includes consideration of service conditions associated with operating and postulated accident conditions. Loads associated with maintenance and testing conditions are small by comparison, and are enveloped by the loads assumed in the analyses.

The analytical results include a margin of twenty percentage points or greater on throughwall for the proposed plugging criteria of 50% throughwall with a length no greater than 0.55 inches to account for uncertainties in determining flaw size.

4. Conclusion

Use of the proposed criteria would not reduce the extent of compliance with General Design Criteria 14, 15 and 31.

REFERENCES

1. ASME Boiler and Pressure Vessel Code Section III 1977 Edition and Addenda through Summer 1978.
2. ASME Boiler and Pressure Vessel Code Section XI 1977 Edition and Addenda through Summer 1978.
3. TR-008, "Assessment of TMI-1 Plant Safety for Return to Service After Steam Generator Repair," Rev. 3, August 1983.
4. TDR-421, "Steam Generator Adequacy of Tube Plugging and Stabilizing Repair Criteria." Rev. 0, March 1983.
5. NUREG-1019, "Safety Evaluation Report Related to Steam Generator Tube Repair and Return to Operation - Three Mile Island Nuclear Station Unit No. 1."
6. TDR-388, "Mechanical Integrity Analysis of TMI-1 OTSG Unplugged Tubes," Rev. 3, May 1983
7. TDR-638, "Evaluation of Eddy Current Indications Detected During the 1984 Tech. Spec. Inspection," Rev. 0, January 1985.

IV. NO SIGNIFICANT HAZARDS CONSIDERATIONS

Application of the revised OTSG tube repair limits would not involve significant hazards considerations for reasons as follows:

1. Use of the proposed criteria would not involve a significant increase in the probability of occurrence or consequences of an accident previously evaluated.

   The proposed criteria provide assurance of OTSG tube wall integrity under normal operating conditions. In accordance with the recommendations of Reg. Guide 1.121, a margin of safety against ductile failure equal to 3.0x normal loads has been verified. Thus, use of the proposed criteria does not involve a significant increase in the probability of occurrence of a steam generator tube rupture event.

The proposed criteria also provide assurance that the OTSG tube wall integrity will be maintained under faulted conditions, specifically under loads associated with the main steam line break accident. In accordance with the recommendations of Reg. Guide 1.121, a margin of safety against ductile failure equal to 1.428x upset loads has been verified. Thus, use of the proposed criteria does not involve a significant increase in the consequences of an accident previously evaluated.

2. Use of the proposed criteria would not create the possibility of a new or different kind of accident from any accident previously evaluated.

   Use of the proposed criteria has no bearing on any accident other than the steam generator tube rupture or main steam line break, discussed above.

3. Use of the proposed criteria would not involve a significant reduction in a margin of safety.

   The margin of safety for the proposed revised criteria is no less than the licensing basis for the existing repair limit. The limiting margin of safety previously approved by NRC is not affected or reduced. The margin separating the proposed revised criteria from the analytical results for normal operating and faulted conditions is in accordance with the guidelines of Regulatory Guide 1.121.

Thus, the use of the proposed criteria involves no significant hazards considerations.

V. IMPLEMENTATION

It is requested that the amendment authorizing this change become effective immediately after receipt.

VI. AMENDMENT FEE (10CFR 170.21)

Pursuant to the provisions of 10CFR 170.21, a check for $150.00 is being forwarded by separate correspondence as payment of the fee associated with this TSCR.

2. A seismic occurrence greater than the Operating Basis Earthquake.

3. A loss of coolant accident requiring actuation of the engineering safeguards, or

4. A major main steam line or feedwater line break.

4.19.4 Acceptance Criteria

a. As used in this Specification:

   1. Imperfection means an exception to the dimensions, finish or contour of a tube from that required by fabrication drawing or specifications. Eddy current testing indications below 20% of the nominal tube wall thickness, if detectable, may be considered as imperfections.

   2. Degradation means a service-induced cracking, wastage, wear or general corrosion occurring on either inside or outside of a tube.

   3. Degraded Tube means a tube containing imperfections 20% of the nominal wall thickness caused by degradation.

   4. % Degradation means the percentage of the tube wall thickness affected or removed by degradation.

   5. Defect means an imperfection of such severity that it exceeds the repair limit. A tube containing a defect is defective.

   6. Repair Limit means the extent of degradation at or beyond which the tube shall be repaired or removed from service because it may become unserviceable prior to the next inspection.

      This limit is equal to 40% of the nominal tube wall thickness, except for the primary side tube freespan.

      For the primary side tube freespan, the repair limit is either:

      a. 50% of the nominal tube wall thickness and defect length of 0.55 inches or less; or

b. 40% of the nominal tube wall thickness and defect length greater than 0.55 inches; or

c. 40% of the nominal tube wall thickness in areas of reduced eddy current sensitivity (upper and lower tubesheet secondary faces and support plate entry and exit locations).

This primary side repair limit applies until Refueling Outage 6R, at which time the repair limit for the primary tube freespan will be such a limit as has been approved by the NRC.

7. Unserviceable describes the condition of a tube if it leaks or contains a defect large enough to affect its structural integrity in the event of an Operating Basis Earthquake, a loss of coolant accident, or a steam line or feedwater line break as specified in 4.19.3.c, above.

8. Tube Inspection means an inspection of the steam generator tube from the bottom of the upper tubesheet completely to the top of the lower tubesheet, except as permitted by 4.19.2.b.2, above.

The program for inservice inspection of steam generator tubes is based on a modification of Regulatory Guide 1.83, Revision 1. Inservice inspection of steam generator tubing is essential in order to maintain surveillance of the conditions of the tubes in the event that there is evidence of mechanical damage or progressive degradation due to design, manufacturing errors, or inservice conditions. Inservice inspection of steam generator tubing also provides a means of characterizing the nature and cause of any tube degradation so that corrective measures can be taken.

The Unit is expected to be operated in a manner such that the primary and secondary coolant will be maintained within those chemistry limits found to result in negligible corrosion of the steam generator tubes. If the primary or secondary coolant chemistry is not maintained within these chemistry limits, localized corrosion may likely result.

The extent of steam generator tube leakage due to cracking would be limited by the secondary coolant activity Specification 3.1.6.3.

The extent of cracking during plant operation would be limited by the limitation of total steam generator tube leakage between the primary coolant system and the secondary coolant system (primary-to-secondary leakage = 1 gpm). Leakage in excess of this limit will require plant shutdown and an unscheduled inspection, during which the leaking tubes will be located and repaired and removed from service.

Wastage-type defects are unlikely with proper chemistry treatment of the primary or secondary coolant. However, even if a defect would develop in service, it will be found during scheduled inservice steam generator tube examinations. Steam generator tube inspections of operating plants have demonstrated the capability to reliably detect degradation that has penetrated 20% of the original tube wall thickness.

Plugging or repair will be required for degradation equal to or in excess of 40% of the tube nominal wall thickness, except for the primary tube freespan.

For the primary side tube freespan, plugging or repair is required for degradation either (a) equal to or greater than 50% of the tube nominal wall thickness if the defect length is less than or equal to 0.55 inches; or (b) equal to or greater than 40% of the tube nominal wall thickness if the defect length is greater than 0.55 inches; or (c) equal to or greater than 40% of the tube nominal wall thickness if the defect is located in an area of reduced eddy current sensitivity (upper and lower tubesheet secondary faces and tube support plate entry and exit locations). The above plugging criteria for the primary side tube freespan apply only until Refueling Outage 6R, at which time the repair limit will be such a limit as has been approved by the NRC.

Where experience in similar plants with similar water chemistry, as documented by USNRC Bulletins/Notices, indicate critical areas to be inspected, at least 50% of the tubes inspected should be from these critical areas. First sample inspections sample size may be modified subject to NRC review and approval.

Nuclear

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717 944-7621
TELEX 84-2386
Writer's Direct Dial Number

February 4, 1986
5211-86-2013

Mr. Thomas A. Gerusky, Director
Pa. Dept. of Environmental Resources
Bureau of Radiation Protection
P.O. Box 2063
Harrisburg, PA 17120

Dear Mr. Gerusky:

Three Mile Island Nuclear Station, Unit I (TMI-1)
Operating License No. DPR-50
Docket No. 50-289
Technical Specification Change Request No. 153

Enclosed please find one copy of Technical Specification Change Request No. 153 to Appendix A of the Operating License for Three Mile Island Nuclear Station, Unit 1.

This request was filed with the U.S. Nuclear Regulatory Commission on the above date.

Sincerely,

RJ Toole for
H. D. Hukill
Director, TMI-1

HDH/SMO/spb

Enclosure

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TELEX 84-2386
Writer's Direct Dial Number

February 4, 1986
5211-86-2013

Mr. Norman P. Hetrick, Chairman
Board of County Commissioners of Dauphin County
Dauphin County Courthouse
Harrisburg, PA 17120

Dear Mr. Hetrick:

Enclosed please find one copy of Technical Specification Change Request No. 153 to Appendix A of the Operating License for Three Mile Island Nuclear Station, Unit 1.

This request was filed with the U. S. Nuclear Regulatory Commission on the above date.

Sincerely,

RJ Toole for
H. D. Hukill
Director, TMI-1

HDH/SMO/spb

Enclosure

GPU Nuclear Corporation is a subsidiary of the General Public Utilities Corporation

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February 4, 1986
5211-86-2013

Mr. Jay H. Kopp, Chairman
Board of Supervisors of Londonderry Township
R. D. #1, Geyers Church Road
Middletown, PA 17057

Dear Mr. Kopp:

Enclosed please find one copy of Technical Specification Change Request No. 153 to Appendix A of the Operating License for Three Mile Island Nuclear Station, Unit 1.

This request was filed with the U. S. Nuclear Regulatory Commission on the above date.

Sincerely,

RJ Toole for
H. D. Hukill
Director, TMI-1

HDH/SMO/spb

Enclosure

APPENDIX A

GPU Nuclear

TECHNICAL DATA REPORT

TDR NO. 750	**REVISION NO.** 0	
BUDGET ACTIVITY NO. 123125	**PAGE** 1 **OF** 11	
PROJECT: OTSG Tube Plugging	**DEPARTMENT/SECTION**	
	RELEASE DATE	**REVISION DATE**

DOCUMENT TITLE: Assessment of 50% TW Repair Limit with respect to Reg. Guide 1.121 Guidelines.

ORIGINATOR SIGNATURE	DATE	APPROVAL(S) SIGNATURE	DATE
S. D. Leshnoff		D. K. Croneberger	2-3-86
S.D. Leshnoff	1/31/86	N. C. Kazanas NCKazanas	1/31/86
		APPROVAL FOR EXTERNAL DISTRIBUTION	**DATE**
		R. F. Wilson	2/4/86

Does this TDR include recommendation(s)? ☐ Yes ☐ No **If yes, TFWR/TR #**

*	DISTRIBUTION
	R. F. Wilson D. K. Croneberger H. D. Hukill J. J. Colitz R. J. Toole R. O. Barley G. R. Capodanno J. D. Abramovic R. J. McGoey N. C. Kazanas F. S. Giacobbe R. L. Miller J. Jandovitz S. Kowkabany D. D. Bowman

ABSTRACT:

PURPOSE
Analytical results, provided by several different methods, show that tubes with deep local flaws need not be treated the same as tubes with shallower but more extensive flaws. A comprehensive plugging criteria should disposition tubes based on ECT characterization of both depth and circumferential extent for circumferential defects and depth and length for axial defects.

A comprehensive tube plugging criteria is developed here which meets or exceeds NRC guidelines on structural margin, as per the guidelines of Reg. Guide 1.121, addresses ECT accuracy, and provides a basis that an additional thickness degradation allowance is not necessary.

METHODS:
Structural
Analytical results, some described in earlier reports, were compared against guidelines for establishing a steam generator tube plugging criteria contained in Reg. Guide 1.121. These guidelines addressed, among other things, providing a margin of 3.0 on normal loads and 1.428 on upset to prevent ductile failure (circumferential defect) or burst (axial).

*COVER PAGE ONLY

METHODS: Cont'd

Margin against plastic collapse was met by using a non-linear strain analysis and exceeded by an elastic plastic fracture mechanics analysis. The margin to burst was shown to be exceeded by net section collapse methods and by actual test data.

ECT Accuracy

ECT accuracy was demonstrated with metallurgical samples. The recently qualified conversion curve was used in conjunction with the .540 SD probe.

RESULTS:

The following results were derived:

Defect size

A defect of 50% TW with a continuous length of 0.55" is acceptable.

ECT Accuracy

The proposed tube plugging criteria contains a margin of ten percentage points on throughwall extent out of recognition of possible ECT error. For a 50% throughwall defect, this represents a 20% margin for error.

Using the mean and standard deviation obtained from metallurgical samples the percent error due to undercall is 3.3%.

Additional thickness degradation allowance

An additional thickness degradation allowance, as suggested in Reg. Guide 1.121, has not been included because, first, the mechanism for continued chemical attack from the inner surface has been arrested and, second, the TMI-1 OTSG's do not have a history of either significant tube problems because of wear on the outer surface at the elevations of the lateral support plates or secondary side chemical attack. Both the NRC staff and the Atomic Safety and Licensing Board have concurred that primary side corrosive attack is not ongoing.

CONCLUSIONS:

1. Comparison of the present results with the results from previous analysis, albeit that methods differed, shows that they are nearly the same.

   This comparison allows the conclusion that fatigue, plastic collapse and burst concerns are all satisfied. Plastic collapse and burst are addressed for the first time herein.

2. The proposed tube plugging criteria contains margins to failure equal to or greater than those recommended in Reg. Guide 1.121.

3. The percent error due to undercall is less than that previously assumed.

4. The tube plugging criteria developed here is applicable to flaws on the inner surface of the tube only. In addition, it is applicable to the free span portion of the tube only, away from entrance effects associated with support plates.

   Tubes with defects on the OD surface will be dispositioned at 40% TW. Tubes with indication of nearby OD and ID flaws will be dispositioned on a case-by-case basis in a conservative manner consistent with the nature of the degradations involved and the uncertainties of the ECT call.

PURPOSE

The proposed GPUN OTSG tube plugging criteria provides for the structural integrity of tubes with defects against fatigue failure mechanisms and against failure in single application of large loads.

The latter condition, based in ASME Code practice, is recommended in Reg. Guide 1.121, Basis for Plugging Degraded PWR Steam Generator Tubes (Ref. 2). This source recommends a margin of safety against ductile failure equal to 3.0 x normal loads and 1.428 x upset loads. In addition, identification of error associated with ECT is also necessary as is a discussion of an additional thickness degradation allowance.

Reg. Guide 1.121 does not recognize the demonstrated capability of ECT in characterizing both depth and extent of circumferential defects nor does it make a distinction between circumferential and axial defects. A comprehensive plugging criteria should disposition tubes based on ECT characterization of both depth and circumferential extent for circumferential defects and depth and length of axial defects.

A comprehensive tube plugging criteria is developed here which meets or exceeds NRC guidelines on structural margin, identifies a probability of ECT error, and provides basis that an additional thickness degradation allowance is not necessary.

METHODS

The approach used to demonstrate structural margin, as recommended in Reg. Guide 1.121, is described first. The approaches to address ECT error and additional thickness degradation allowance will follow.

1. Structural Margin

Structural margin is demonstrated in "Evaluation of GPUN proposed OTSG Tube Plugging Criteria" (Ref. 3) prepared by Structural Integrity Associates.

Conceptual Overview
Loads

A factor of 3x normal loads (ASME Code, Sect. III). and 1.428 x upset loads (ASME Code, Sect. III, App. F) is recommended by Reg. Guide 1.121. The basic loads originate in a B&W generic document on tube plugging (Ref. 4). That report not only provides identification of loads under anticipated design basis conditions, it also provides the thermal/hydraulic methodology for deriving those service loads. The dominant component in the tube axial load is thermally induced, as would occur when the OTSG shell is hotter than the tubes. The resulting load is due to thermal growth difference, or, in other words, displacement control. If displacements of interacting members are reduced, reactions are reduced. This is in opposition to load control where reactions are independent of displacement.

Non-linear Strain Analysis

Applying large factors to relatively large loads produces stresses in the region of the material stress-strain curve where displacement and load are no longer linearly related. Resistance to displacement decreases as material response becomes non-linear. Reaction loads decrease as the more flexible tubes are stretched, or displaced, to conform to the growth of the OTSG vessel shell. Loads less than what are predicted by linear proportionality are actually generated. Invoking the tube material actual stress-strain response shows that lower internal reactions should be used in the evaluation. The loads that are actually developed on the OTSG tubes are identified. This is discussed in Ref. 3, Sec. 2-1; please see Fig. 2-1, specifically.

This effect is particularly important when considering circumferential defects. No such benefit exits for axial defects, however, because large strains are only possible in the longitudinal tube direction.

Failure Criteria: Net Section Collapse, Tearing Instability, and Burst.

Net section collapse (NSC) has been used by EPRI to gauge the structural integrity of pipes with circumferential defects (Ref. 5). A defect is unacceptably large where a point on the cross-section reaches the material flow stress. This condition is equated to ductile failure. The flow stress condition represents the departure from uniform material elongation and the on-set of neck-down deformation prior to reaching the ultimate tensile strength. The analysis of NSC proceeds from principles of solid mechanics.

The analysis for tearing instability, however, proceeds from principles of elastic plastic fracture mechanics (EPFM). A crack in a structure may propagate a small distance and then arrest or it may tear through the material without arresting if the combination of load and crack size is sufficiently damaging. EPFM predicts the onset of the latter condition, i.e., tearing instability. The tearing modulus and applied J are computed for this purpose. See Sect. 4.1 of Ref. 3. Burst is the failure mode for tubes with axial defects. No benefit can be taken here for actual material response to reduce reaction loads because burst is load, not displacement, controlled. Analytically, flow stress is taken to govern prediction of burst. A comparison of predicted burst behavior with experimental data shows that analysis contains inherent conservatism. See Sect. 5.3 of Ref. 3.

Failure by Fatigue Mechanisms and the MSLB

Analyses demonstrating the serviceability of flawed tubes against fatigue failure mechanisms have been previously reviewed and endorsed by the NRC staff. These analyses included ASME Section III and Section XI fatigue evaluations, and a solid mechanics single accident load (Main Steam Line Break, MSLB) analysis conducted as part of GPU Nuclear's response to the 1981 tube cracking experience, as presented in TR-008 (Ref. 1).

GPUN can now take credit for that previous work in identifying minimum required tube wall thickness. Inherent in the previous work was the capability to establish that a) by fatigue analysis that inservice tubes would not develop cracks under normal operating conditions, even in areas of suspected degradation and b) that existing cracks, should they go undetected, would not propagate throughwall under normal operating conditions.

GPUN's evaluation combines the methodology of both ASME Sections III and XI in order to assess the reduction in fatigue resistance caused by identified or hypothetical ECT indications. ASME Section III provides guidance for designing nuclear pressure components against failure; ASME Section XI provides guidance for evaluating the impact of suspected flaws in pressure retaining components inservice.

The Section III fatigue failure analysis uses crack initiation as the criterion for loss of fatigue resistance of the material; therefore, design using this approach assumes only a degraded material condition and not outright structural failure. The approach used to enter the ASME III design fatigue curve was originally discussed in TDR-421 (Ref. 11) and is summarized in TR-008 (Ref. 1), which formed a basis for NRC conclusions in NUREG-1019.

In ASME Section XI, the methods of linear elastic fracture mechanics (LEFM) are recommended. In this approach the presumed crack is analytically interacted with the local stress field in order to predict enlargement and propagation as service loads (both mechanical and thermal) are cycled in the anticipated manner. As discussed previously in TDR-388 (Ref. 10) and TR-008 (Ref. 1), a particular fracture mechanics solution was used by GPUN in order to properly model the response of a thin tube to the presence of an ID circumferential crack under applied axial load, internal pressure, and bending stress due to flow induced vibration. The aim of this analysis originally was to demonstrate the adequacy of the threshold of ECT detection sensitivity.

The rupture strength of a flawed tube to the maximum axial load, applied one time only, was evaluated under the faulted condition of a main steam line break (MSLB). The tube response was analyzed by methods of solid mechanics, capturing the increased flexibility of the tube at the elevation of the flaw and utilizing the flow stress as the limiting material condition.

2. ECT Accuracy

ECT accuracy was demonstrated with metallurgical samples. The recently qualified conversion curve was used in conjunction with the .540 SD probe to generate 6 data points for defects.

The approach taken here utilizes percent error of the ECT call with respect to actual flaw size, as shown by metallurgical examination, to establish relative error. This approach allows conclusions concerning ECT overcall or undercall.

The margin separating the fatigue analysis results and the proposed plugging criteria is at least ten percentage points (10%) on throughwall out of recognition of possible ECT error.

3. Additional Thickness Degradation Allowance

Additional material allowance out of recognition of both a primary side attack combined, at the same elevation, with mechanical wear from the outer surface, as at the elevation of the upper lateral support plate, is addressed in two ways. First, primary side chemical attack was arrested by chemical cleaning and is prevented from reoccurring by plant chemistry procedures involving pH and lithium addition (Ref. 8).

Second, plant engineering records of the tube plugging on account of wear on the outer surface (Ref. 7) indicate that cross-flow patterns for the generators at TMI-1 do not promote this mode of degradation. Six lane tubes were plugged on account of wear at the 15th lateral support plate as a precautionary measure. ECT techniques now in place will be employed to examine these areas.

RESULTS

1. Structural Margin

The results of the non-linear strain analysis are shown in Figure 1. Tube load versus displacement, assuming linearity, is shown as the bold straight line. The parallel dashed line is the 0.2% offset yield line. The curved dashed lines are the actual material temperature dependent engineering stress-strain curves. As the material strains, the predominately thermal loads are reduced. Dropping down from the pseudo-elastic response to the actual non-linear material response (intersection at circles) gives the true tube load by reading back to that axis. The applied axial loads are shown multiplied by the factors of safety recommended by Reg. Guide 1.121.

The results of the NSC and EPFM structural analyses for circumferential defects in tubes are shown in Fig. 2. The analytical results are shown with respect to a piece-wise linear expression of the proposed plugging criteria. The two NSC curves (dotted) reflect the two conditions of flawed tube structural response; that the tube is flexible (triangle) and that it is inflexible. The EPFM result is indicated as: J-T, 42 KSI. The 42 KSI follows from the industry practice for 360°, 40% TW defects.

In the area of the proposed plugging criteria, both NSC models produce results well removed from the 10% TW zone. The EPFM results are in a region well removed from the proposed plugging criteria. These results are nowhere within 10% TW of the criteria. The NSC results for a flexible tube model (triangles), where the centroids of the defective and non-defective cross-sections tend to line-up under load reducing the internal moment reactions, come within 10% TW of the plugging criteria only for defects of very large circumferential extent. Results for an inflexible tube (squares) come within 10% TW over a broader region of circumferential extent. Inflexible tube response is less likely than flexible response.

The results shown in Fig. 2 are all within the proposed plugging criteria.

Figures 3 and 4 show NSC results for tubes with axial defects. The normal and upset loads are multiplied by the factors of safety recommended by Reg. Guide 1.121. The figures indicate that the proposed plugging criteria bounds the analytical results. Figures 5 and 6 compare actual burst tests results for INCO 600 with analytical prediction. The latter are always conservative when compared to burst test results.

Except for a small region, these results are not within 10% TW of the plugging criteria. Where there is a small discrepancy there is margin in the analysis methods to compensate. For example, using Figures 5 and 6 and equations 5-4 and 5-5 in Ref. 3, the actual burst pressure by test, is about 22.5% greater than predicted burst pressure.

The results of the previous fatigue and MSLB analyses are provided in (Ref. 1) TR-008. The proposed plugging criteria bounds the results of these analyses. In the area of the proposed plugging criteria, there is at least a margin of 20% TW or greater. (The margin increases with decreasing length.) Margin of this magnitude occurs when stable crack growth and not fatigue resistance are governing.

ECT Accuracy

ECT accuracy was demonstrated with metallurgical samples using the recently qualified conversion curve (6). The mean of six data points (Ref. 6) was 13.4% overcall. The standard deviation was ± 16.7%. On this basis, a 3.3% undercall was observed. This is less than the 20% undercall, on a 50% throughwall indication, already included in the proposed criteria.

Previously, (Ref. 6), a statistical presentation was made regarding differences between ECT sizing and metallurgical results. The approach taken here utilizes percent error of theECT call with respect to actual flaw size as shown by metallurgical examination. The approach allows conclusions concerning ECT overcall or undercall. Previous work discusses accuracy in terms of per cent throughwall units. That approach gauges error against the total throughwall dimension. The previous work does not include an assessment of relative error, as presented above.

In the region of the proposed plugging criteria, the margin against ECT is at least 10% on throughwall as seen by inspection of Figure 2 and TR-008 (Ref. 1). These analyses represent distinctly different solutions but allow the same conservative conclusions with regard to margin against ECT error.

DISCUSSION

Application of Plugging Criteria

In a strict sense, the structural model used here was that for a ID surface flaw. The applicability of the results will be limited to that geometry only. Defects on the OD surface will be dispositioned in accordance with the existing Tech Spec repair criterion.

The ECT sizing accuracy is established for defects on the ID surface in the free span. Applicability of these structural results will be limited to these regions.

The structural problem of OD and ID surface flaws at the same elevation has not been solved here. Tubes having this type of defect combination will be dispositioned on a case-by-case basis in a conservative manner consistent with the nature of the degradations involved.

IGA/IGSAC

Previous work (Ref. 8) provided an explanation of the November, 1984, tube defects. What was proposed was, essentially, that previously existing IGA/IGSAC was mechanically exercised into ECT detectability. Additionally (Ref. 9), it was found from pulled tube specimens that IGA could exist apart from IGSAC.

The structural results discussed above apply to defects whose origination is from either mechanism. Inability to call IGA defects would impact only the statistics associated with ECT. If necessary, the issue of ECT margin will be revisited should there be a deficiency in ECT with regard to detection and sizing of IGA alone.

CONCLUSIONS:

1. Comparison of the present results with the results from previous analysis, albeit that methods differed, shows that they are nearly the same.

   This comparison allows the conclusion that fatigue, plastic collapse and burst concerns are all satisfied. Plastic collapse and burst are addressed for the first time herein.

2. The previous tube plugging criteria contains margins to failure equal to or greater than those recommended in

   Reg. Guide 1.121.

3. The percent error due to undercall based on an assessment of metallurgical data is less than that assumed in GPUN structural analyses.

4. The tube plugging criteria developed here is applicable to flaws on the inner surface of the tube only. In addition, it is applicable to the free span portion of the tube only, away from entrance effects associated tube support plates.

   Tubes with defects on the OD surface will be dispositioned at 40% TW. Tubes with indication of nearby OD and ID flaws will be dispositioned on a case-by-case basis in a conservative manner consistent with the nature of the degradations involved.

References

1. TDR 008 Assessment of TMI-1 Plant Safety for Return to Service after OTSG Repair, Rev. 3, 8/83.

2. Regulatory Guide 1.121, Basis for Plugging Degraded PWR Steam Generator Tubes, 8/70.

3. J.F. Copeland and T.L. Gerber, Evaluation of GPUN Proposed OTSG Tube Plugging Criteria, S.I. Report No.: SIR-85-017, May, 1985.

4. BAW 10146, Determination of Minimum Required Tube Wall Thickness for 177-FA Once Through Steam Generators.

5. B.J.L. Darlaston, Some Aspects of Leak-Before-Break; Their Quantification and Application, Nuclear Eng'g & Design 84 (1985) 225-232, North-Holland, Amsterdam.

6. TDR 642, Qualification of Conversion Curve for Inner Diameter Discontinuities, Evaluation of Eddy Current Indicators During the 1984 Tech., Rev. 2.

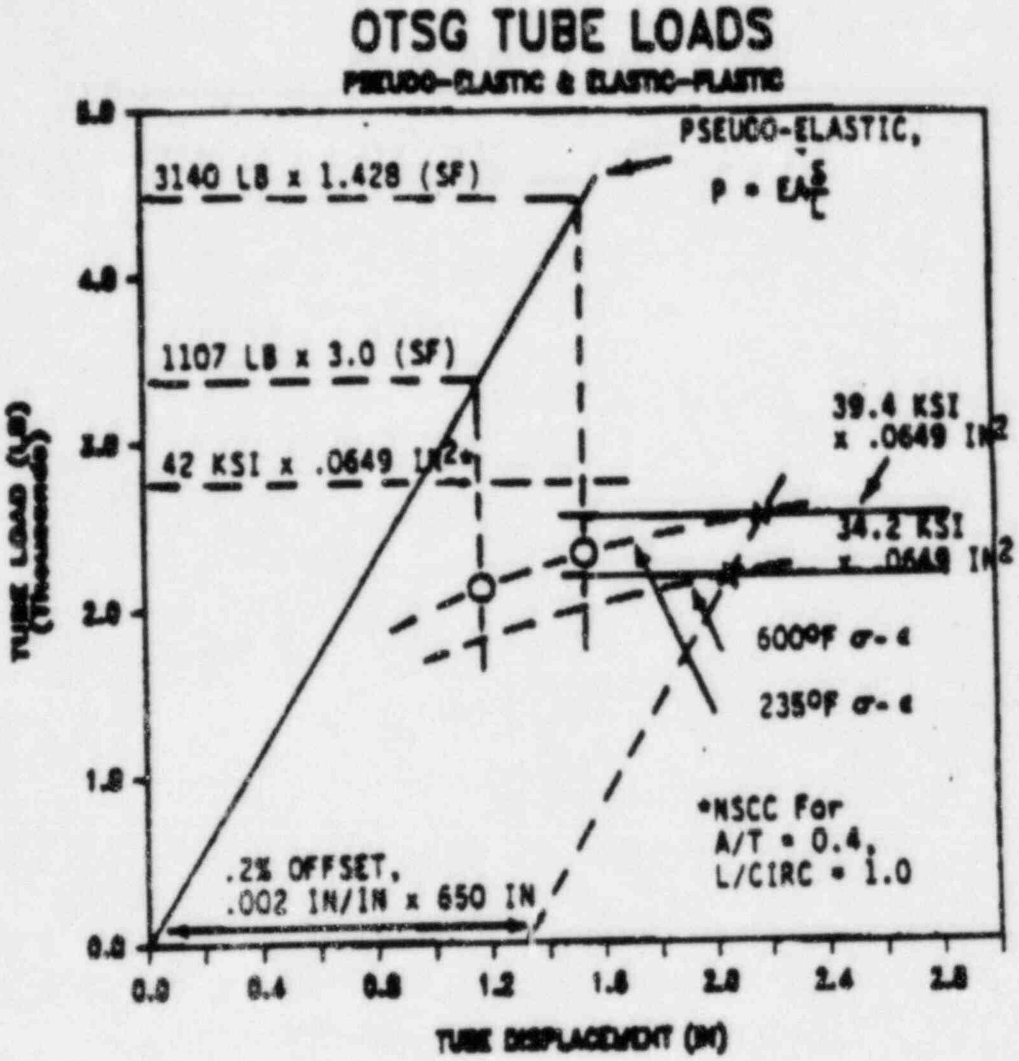
7. Record of Telephone Conversation, R. O. Barley to S. D. Leshnoff, OTSG Tubes Plugged Because of Wear on the O.D. Surface, 5/7/85.

8. TDR 638, Rev. 0 Evaluation of Eddy Current Indications Detected During the 1984 Tech. Spec. Inspection.

9. TDR 686, Rev. 1, Characterization of IGA in TMI-1 OTSG Tube Samples.

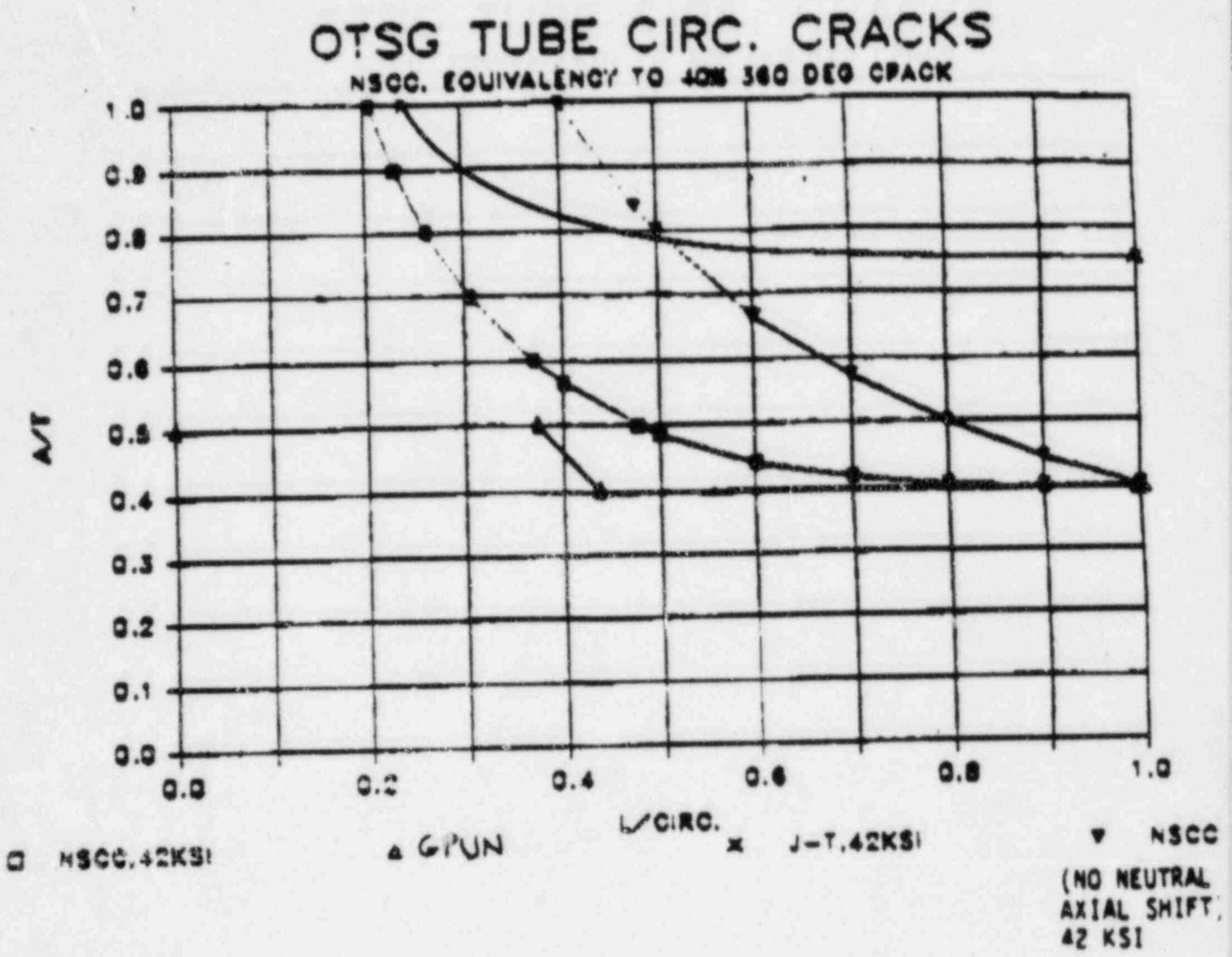
10. TDR 388, Rev. 3, Mechanical Integrity Analysis of TMI-1 OTSG Unplugged Tubes.

11. TDR 421, Rev. 0, Steam Generator Adequacy of Tube Plugging and Stabilizing Criteria.



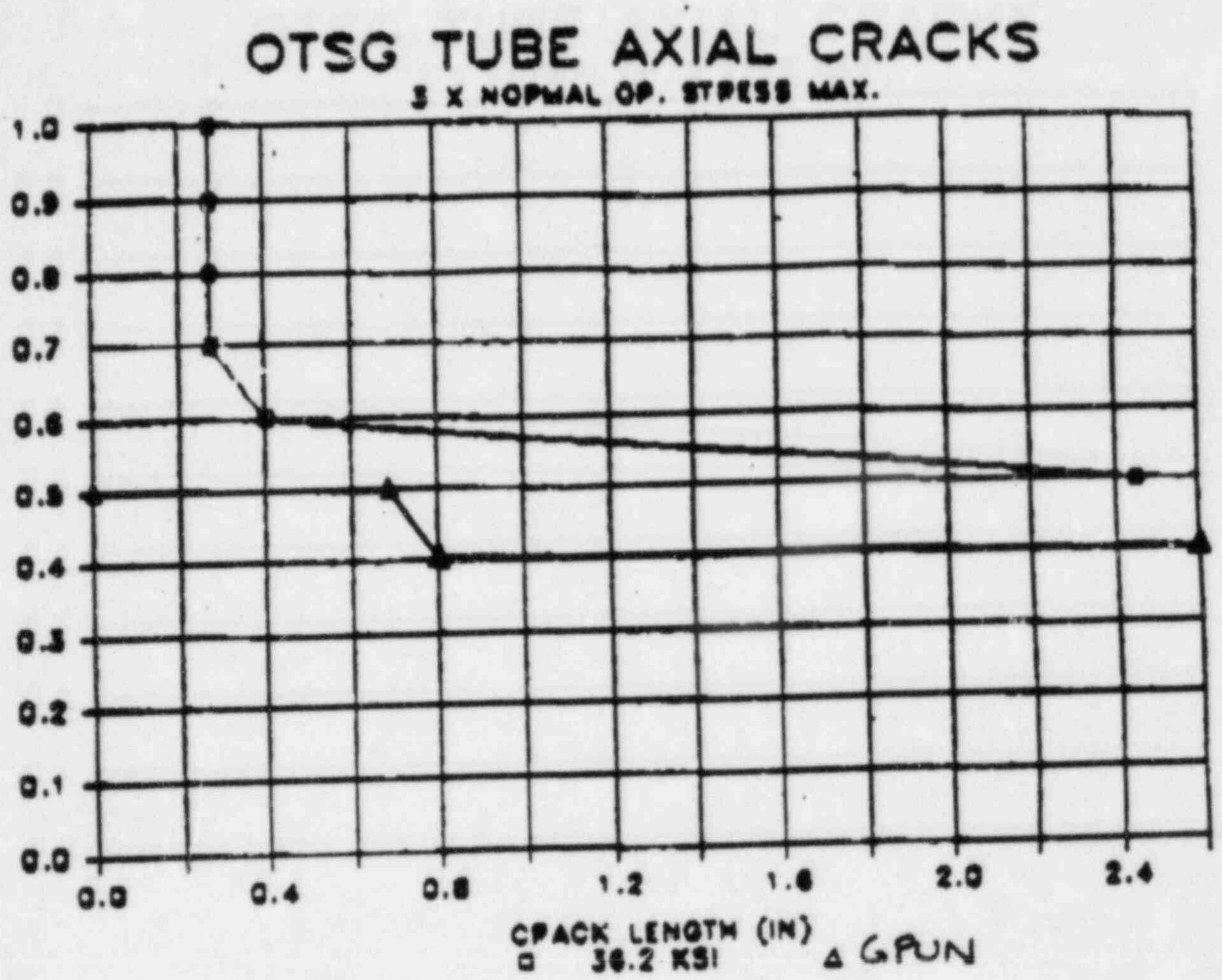
OTSG Tubing Elasticity Calculated and Expected Load Displacement Behavior

FIG 1



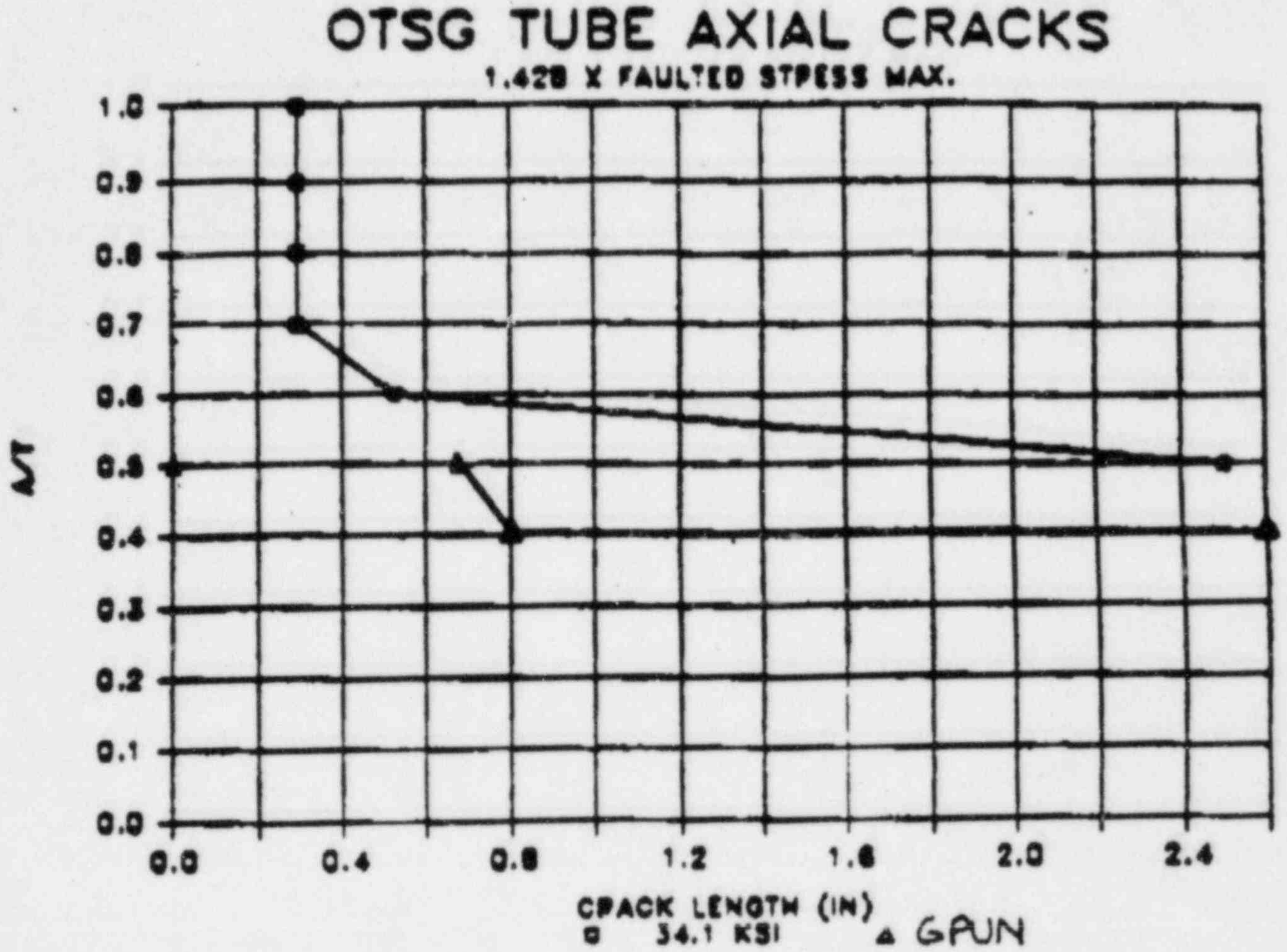
Net Section Collapse Criterion and J-T Instability Results for Circumferential Cracks in Tubes with an Axial Stress of 42.0 Ksi which Permits a 360°, 40% Through the Tube Wall Crack

FIG 2



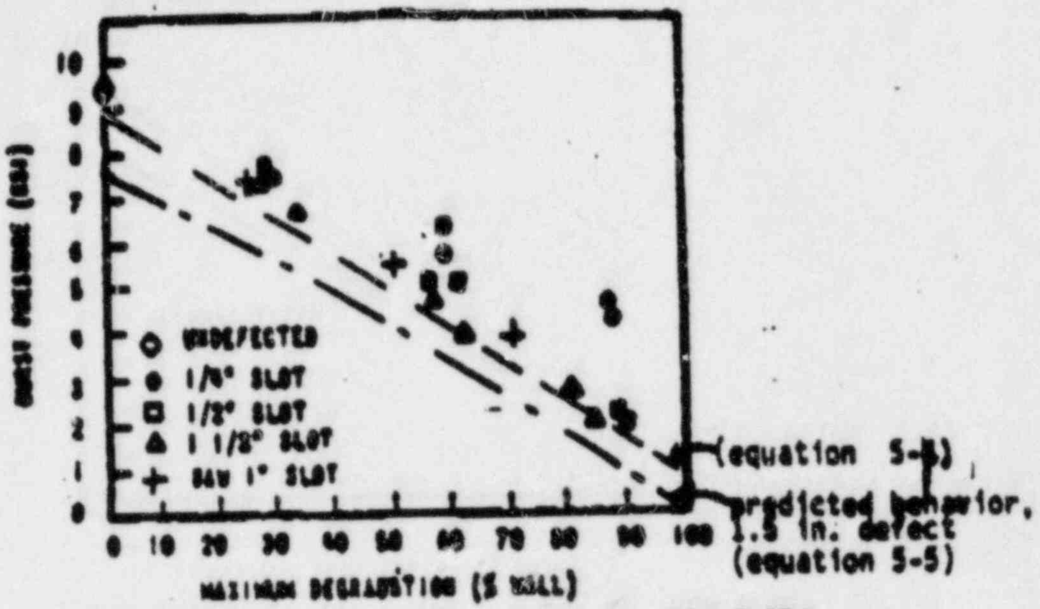
Net Section Collapse Criterion Results for Axial Cracks in Tubes at Three Times Normal Operating Stress (36.161 Ksi)

FIG 3

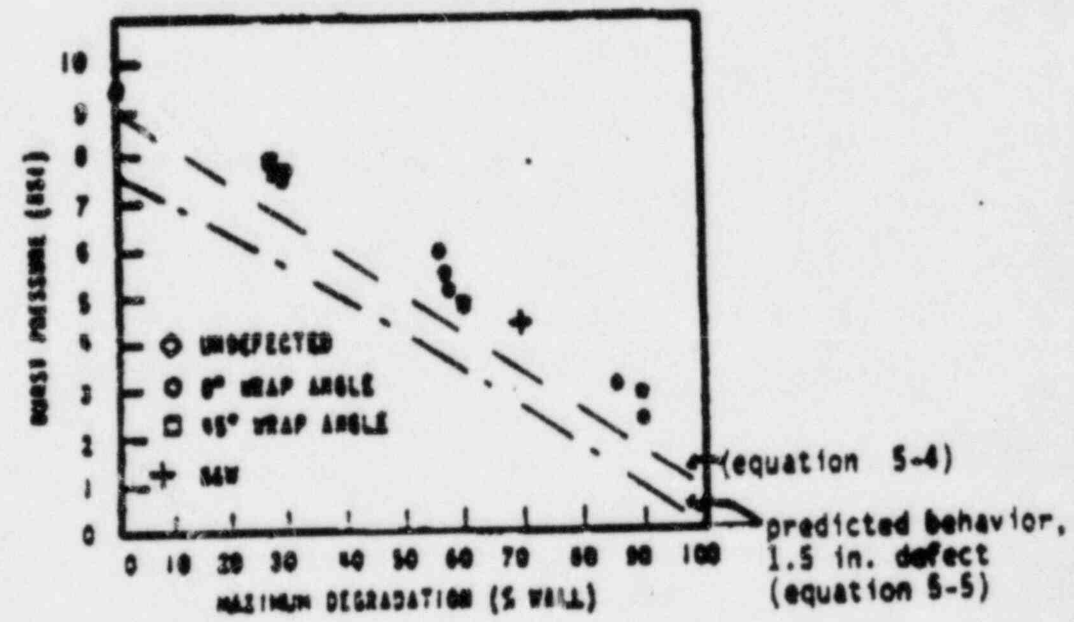


Net Section Collapse Criterion Results for Axial Cracks in Tubes at 1.428 Times Faulted Stress (34.068 Ksi)

FIG. 4



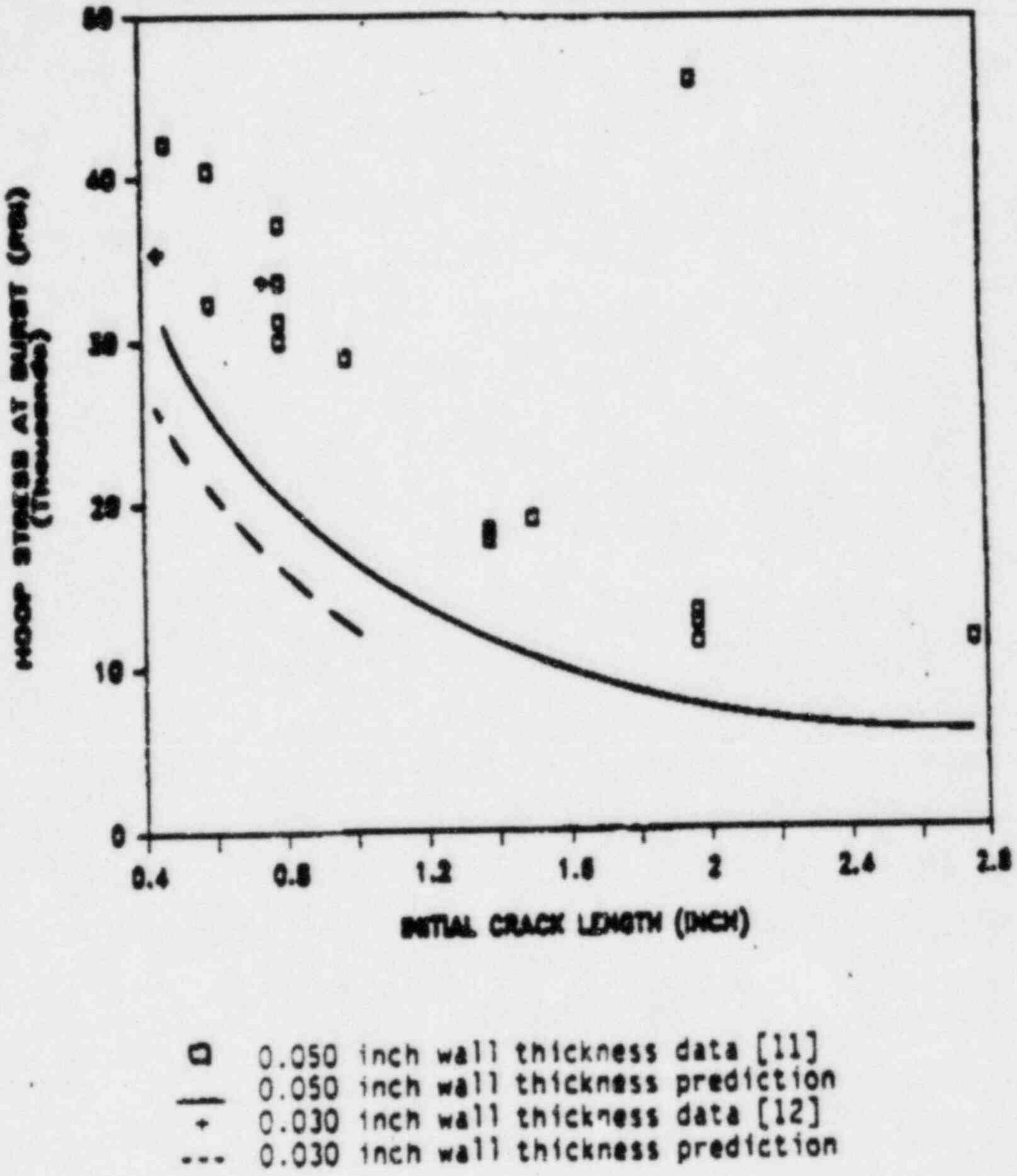
BURST PRESSURES FOR 0.625 x 0.034 IN. EDM SLOTS



BURST PRESSURES FOR 0.625 x 0.034 IN. ELLIPTICAL WASTAGE

Burst Test Results (3) and Predictions for Tubes with Part Through-Wall Defects

FIG. 5



Comparison of Thru-Wall Crack Burst Test Data with Predicted Behavior

FIG. 6

APPENDIX B

GPU Nuclear
TECHNICAL DATA REPORT

TDR NO. 638	**REVISION NO.** 1	
BUDGET ACTIVITY NO. 123125	**PAGE** 1 **OF** 50	
PROJECT: TMI-1 OTSG REPAIRS	**DEPARTMENT/SECTION** Engineering & Design Materials Engrg/Failure Anal.	
	RELEASE DATE 10/21/85	**REVISION DATE**

DOCUMENT TITLE: Evaluation of Eddy Current Indications Detected During the 1984 Tech. Spec. Inspection

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ABSTRACT:

In order to identify the cause of the eddy current indications detected during the TMI-1 OTSG tube examination beginning in November 1984, Materials Engineering/Failure Analysis performed an in-depth review of the eddy current results and plant operating/chemistry history since the OTSG's were first filled after the kinetic expansion repairs.

Two possible causes for the eddy current indications were evaluated: corrosion, either continuing or newly initiated, and enhanced eddy current detectability of existing intergranular attack (IGA or intergranular stress assisted cracks (IGSAC). During unit layup, GPUN Layup specifications were followed. Some out of specification periods did occur; however. they were promptly corrected and were not of sufficient magnitude to have caused corrosion. Additional corrosion-preventive conditions were also maintained during layup.

During hot operations, system chemistry conditions were maintained within specifications that industry experience and TMI-1 tube testing have shown are non-corrosive.

The most likely reason for having eddy current indications at this time was enhanced detectability of pre-existing areas of IGA/IGSAC. As a result of thermally induced strains and hydraulic forces during hot functional testing, grains could fall out or grain boundaries could separate within pre-existing IGA, resulting in greater local disturbance of the eddy currents and a correspondingly higher signal to noise ratio.

Additional plant data from leak rate observations and the fiberscope examination of a sample of tubes also support the mechanical damage scenario. No leaks have been identified in the tube free span since 1983. In the region of 1984 eddy current indications, patch-like indications suggestive of IGA were seen by the fiberscope examination.

●COVER PAGE ONLY

GPU Nuclear

DOCUMENT NO. TDR 638

TITLE Evaluation of Eddy Current Indications Detected During the 1984 Tech. Spec. Inspection

REV	SUMMARY OF CHANGE	APPROVAL	DATE
1	Abstract: Changed IGA to IGA/IGSAC Changed larger eddy current signal to higher signal to noise ratio		10/21/85
1	Page 7: Changed IGA to IGSAC		10/21/85
1	Page 23: Deleted Para. 4		10/21/85
1	Page 23: Added under item 1: ... in the LTCT LTCT (Ref. 8). This could produce a crack like indication, etc.		10/21/85
1	Page 25: Revisions made to entire page		10/21/85
1	Page 27: Added Table 7		10/21/85 10-30-85

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Introduction

In accordance with the requirements of Technical Specification 4.19, eddy current testing of the OTSG tubing at TMI-1 was begun in November 1984. Initial testing with the 0.540" high gain standard differential probe method revealed previously unreported indications in the unexpanded portions of the OTSG tubes between the tube sheets.

Two possible causes for the eddy current indications were identified and evaluated; first, whether corrosion of the OTSG tubes caused either new defects or growth of existing defects and second, whether straining of existing defects caused them to become more detectable by eddy current. Since the original 100% baseline inspection of the OTSG tubes in 1982, the tubes have been subjected to mechanical loading during the kinetic expansion and thermal and hydraulic loads during the two hot functional tests.

In order to attempt to determine the cause of these indications, the Materials Engineering/Failure Analysis group reviewed 1) the historical eddy current data and 2) plant operational and chemistry data since the OTSG's were filled after the kinetic expansion repair of the tubes.

Based on the results of this review, the cause of the indications is discussed. Data supporting the conclusion are also included.

Background

As defined by Technical Specification 4.19, GPUN conducted eddy current examinations of both steam generators at TMI Unit 1. Performance of this examination ultimately resulted in 100% of the tubes in A-OTSG and all tubes in the outer 16 tube periphery of the B-OTSG being examined.

The B-OTSG had only a limited number of indications with an indicated through-wall extent greater than 40%. Due to the limited number of B-OTSG indications, statistically-based analysis is not feasible. All these indications, however, are located near the outer periphery of the B-OTSG.

The following generalizations about the EC indications can be drawn from the A-OTSG results:

1. They are primarily located in the upper tube sheet and 16th tube span area.
2. They are concentrated in the outer periphery, but some indications occur across the entire OTSG.
3. Approximately 78% of the indications are less than 50% through wall.
4. They generally exhibit voltages in the 0.5-2 v. range.
5. Except for two indications, the number of 8 X 1 absolute eddy current coils producing a signal from a defect is 2 or less, indicating a small circumferential extent.

Evaluation of Eddy Current Results

Note: This section uses the eddy current data base as of Jan. 3, 1985.

GPUN conducted a qualified full-length, eddy current examination program on all tubes from both generators during July to November 1982. The purpose of this program was to screen out all relevant indications and establish a 6" qualified length in the kinetically expanded zone immediately above the new transition zone which was essentially indication free. It was further established that small defects below the threshold of detection could exist. Reference 1 identifies the maximum size of these small defects which could possibly go undetected.

Prior to the expansion, a 100-tube sample of tubes in each generator was eddy current tested periodically to check for indication changes. These tests were performed on seven occasions over a 7 month period. No growth was observed.

Post-Baseline Growth Studies

In-Process Testing

During and following the kinetic expansion repair, a total of 437 tubes were inspected in both the A and B generators (Ref 2, 3). A total of 15 tubes (3.5%) with indications were found that had not been detected by our ECT inspection program prior to the repair. An evaluation was performed on why these indications were not identified previously (Ref. 3). It was concluded that:

1) The recent indications were not initiated by the kinetic expansion process nor was there any evidence of ductile propagation of existing indications.

2) The defects were small (threshold) type indications that had been either masked by the high background noise levels in the upper tube regions or were sufficiently tight that the volume of lost metal was not detectable. Kinetic expansion may have altered these areas of IGA/IGSAC to make them more detectable by causing additional grain boundary separation.

Confirmation on the small size of the indications was established by the visual examination using fiber-optics. Some of the indications appeared to be small pits.

Additional confirmation was obtained that kinetic expansion would not cause ductile tearing by using test mock-ups and metallurgical examination (Ref. 2). Small intergranular stress assisted (IGSAC) cracks were examined using eddy current techniques before and after kinetic expansions. Expansion caused the cracks to become non-detectable by .540" S.D. techniques. However, the cracks remained visible to the 8 X 1 absolute technique with essentially no change in signal. These specimen tubes were subsequently removed from the test block and metallurgical examination did not reveal ductile tearing or generation of new indications.

ISI Indications

During OTSG repairs, a subset of tubes (28 in A-OTSG, 56 in B-OTSG) was identified as having eddy current indications that did not require plugging. That is, the indications were less than 40% through wall, not in the lane/lane wedge area, and below the 15th tube support plate. This group of tubes (designated as "ISI" tubes by GPUN) was fully characterized and listed for eddy current inspection in the future as a distinct subset.

The "ISI" tubes were re-examined in April/May 1983. No growth of the existing indications was detected.

As part of the eddy current campaign which started in October 1984, all 84 of the "ISI" tubes have been retested. No growth in the ISI subset was detected. (Growth is identified as a substantial increase in the through wall percentage, combined with an increase in voltage and/or circumferential extent.)

June 1984 Testing

During June 1984, 67 tubes in B-OTSG and 3 tubes in A-OTSG were eddy current tested. This set of tubes was retested in November 1984 - no new indications were detected for the two retests performed.

100 Tube Sample November 1984

Since discovery of the additional indications in November 1984, a second 100 tube sample with indications has been re-examined at approximate two week intervals. As of December 18, 1984, no growth and no new indications have been detected for the two retests performed.

1984 Technical Specification Required Testing

In November 1984, eddy current testing required by TMI-1 Technical Specification 4.19 was conducted as specified. 3% of the tubes in each generator were initially examined. This examination included tubes randomly selected across the entire generator plus a concentrated examination in the periphery of each generator. The more extensive examination in the periphery was performed because this was the region of highest previous (1981) damage .

As a result of this initial examination, OTSG A was classified as category "C-3" per technical specification and OTSG B was classified as category "C-2". Subsequently the entire A-OTSG was inspected while the B-OTSG inspection was complete after the entire 16-tube periphery, approximately 6500 tubes, had been examined.

The number of indications is much higher in A-OTSG than B-OTSG. In A-OTSG, 2.0% of the tubes (299 out of approximately 14589) have indications greater than 40% through wall, while in B-OTSG, 0.5% (33 out of approximately 6576) have such indications.

Spatial Distribution

The indications with greater than 40% through wall depth are concentrated toward the outer periphery and top of A-OTSG. In the outer periphery, the percentage of tubes with greater than 40% through wall indications is higher than the 2.0% average, while inside the outer support rods the percentage of indications is below 1%. 71% of the indications are located above the 15th tube support plate (TSP).

Characterization of Indications

To understand the nature of the defects better, we characterized the indications reported back in the 1981-1982 time frame and compared them to the indications discovered today.

The axial and radial locations of indications in A-OTSG are essentially the same in 1984 as in 1982, if one does not consider the 1982 indications in the kinetically expanded region in the 1984 evaluation.

Table 1 characterizes the 1982 and 1984 eddy current signals. The 1984 eddy current indications exhibit a similar type of signal response as the previous test program. Details of the differences in responses are noted below:

1) Reported voltages are essentially the same. This indicates that the 1984 indications present a similar volume for the eddy current probe to detect as the 1982 IGSAC.

2) Both through wall penetration and number of coils is significantly lower in 1984. Thus, the 1984 indications extend a shorter distance both into and around the OTSG tube.

Statistical analysis of the eddy current data reveals that 78% of the observed indications are less than 50% through wall and 90% are .194" or less in circumferential extent.

Degraded Tubes

Per GPUN procedure, tubes with indications reported between 20 and 40% through wall were not required to be plugged if the tubes were not in the lane or lane wedge and the indication was below the 15th tube support plate. At the completion of the 1982 kinetic expansion repairs, a total of 15 A-OTSG tubes and 51 B-OTSG tubes were classified as "degraded" and were included in the ISI group. As of January 4, 1985, 347 additional A-OTSG tubes and 98 additional B-OTSG tubes are classed as degraded.

Table 1

Comparison of 1982 and 1984 Eddy Current Data

a) Reported Voltage - % of indications reported

	A-OTSG		B-OTSG	
Voltage	1982	1984	1982	1984
< 1	34	40	24	27
1	44	35	30	21
2	16	20	25	29
3	4	4	10	12
> 3	2	1	11	11

b) Reported through wall penetration - % of indications

	A-OTSG		B-OTSG	
% T.W.	1982	1984	1982	1984
< 20	< 1	< 1	12	
20-40	3	61	28	75
40-60	21	25	24	18
60-80	17	10	15	5
> 80	59	4	21	2

c) Number of coils on 8 x 1 examination - % of calls

	A-OTSG		B-OTSG	
Coils	1982	1984	1982	1984
1	20	90	18	80
2	26	10	24	20
3	16	< 1	15	< 1
> 3	38	< 1	43	< 1

NOTE: 1982 data includes inspection of original tube roll transition area. The 1984 data does not include inspection from the top of tube sheet to the bottom of the kinetically expanded region. See TDR 652 for complete summary of eddy current indications (Ref. 17).

Chemistry Specifications

Corrosion Experience with Inconel 600

Three types of primary-side initiated attack have been identified in Inconel 600. In recirculating steam generators using mill-annealed tubes that have not been stress-relieved after U-bending, stress corrosion cracking (SCC) has initiated from the primary side in the highly stressed bend areas. Also in mill-annealed tubes in recirculating steam generators, SCC has been found to initiate from the primary side at highly stressed transition areas in the lower tubesheet. Laboratory studies have shown that the stress relieved Inconel tubing used in OTSG's is significantly more resistant to SCC than the mill annealed type.

The other primary side attack of Inconel 600 that has occurred in steam generators is the intergranular stress assisted cracking (IGSAC) caused by reduced sulfur species on sensitized OTSG tubing. This is the mechanism which caused the TMI-1 OTSG leakage in 1981. This mechanism requires sensitized tubing, low temperatures, oxygen, and significant levels of reduced sulfur species.

Corrosion Test Results

As part of the overall program to evaluate the most recent eddy current testing results, we have reviewed the results of corrosion tests performed as part of the original failure analysis and OTSG requalification programs. These data provided a partial basis upon which we could evaluate the layup and test conditions to which the steam generators had been subjected.

Long Term Corrosion Test (LTCT)

The primary purpose of the long term corrosion tests was to verify that the proposed operating chemistry specifications are satisfactory to prevent corrosive attack of the OTSG tubes. To this end, chemistry conditions for the testing were established at the maximum allowable values consistent with the upgraded TMI-1 operating specification (Ref. 4). The LTCT was conducted using actual TMI-1 tubing. Temperatures, tube loads, and heatup and cooldown rates were representative of actual plant operating conditions.

In addition, as the LTCT was actually performed, specific factors which parallel actual plant layup conditions were experienced. The tubes were held in a cold, aerated condition for several days after the completion of each operating cycle. Aeration was done after cooldown. Before heatups, or while waiting for other autoclaves in the test program to be ready for operation, the test loops were operated in a cold, deaerated, circulating mode. Because eddy current examinations were done after each test cycle, the tubes had to be removed from the autoclaves and drained. Thus, drained aerated layup conditions were also included.

Table 2 summarizes LTCT operational times in each mode. All loops spent significant time under drained, cold deaerated, and aerated conditions.

Review of the chemistry history of the LTCT's revealed that the conditions were comparable to the plant's experience. The LTCT specification (Ref 5) for sulfate and chlorides was 0.100 ppm ± .050 ppm. Actual analysis results (Ref. 6, 7, 8) revealed that the concentrations of these species were maintained at or slightly above the .150 ppm upper limit. The actual values measured in these tests bound any of the contaminant "spikes" reported in the Chemistry and Operational History Review.

C-ring tube samples from archive tubing (tubing never installed in the TMI-1 OTSG's, which was included as a control sample) showed no evidence of cracking, pitting or general corrosion both before and after the LTCT.

Data presented from the LTCT show, that of a total of 54 "C" ring samples tested and evaluated, 46 had no visible defects, 3 had very short circumferential cracks when strained severely, 3 had IGA patches greater than 20% but less than 40% through wall (Table 7) and 2 had IGA patches less than 20% through wall.

Five full tube samples were examined after the LTCT. In addition to previously reported defects, four samples exhibited scattered, shallow cracking or IGA which were not sized metallographically and therefore a determination could not be made as to their detectability by eddy current testing.

IGA which was metallographically evaluated was consistent in size and shape with IGA that had been seen during the failure analysis (Ref. 9). Therefore, the observed IGA on these four tubes was judged to have been present at the start of the LTCT. And as stated above, the control samples showed no IGA/IGSAC.

Results of metallographic examination of the LTCT samples (Ref. 8) confirmed that normal operations would not cause corrosion of TMI-1 OTSG tubing.

Short Term Test Results

Several sets of tests were previously run on Inconel 600 tubing to establish corrosion resistance under various conditions representative of TMI-1 service. Those results which apply to the period of this review are summarized below:

1) Screening work on actual TMI-1 removed tubes and archive tubes (Ref. 10) identified that at oxidizing potentials, 1 ppm of thiosulfate was required to cause IGSAC. Sulfate levels as high as 10 ppm did not cause IGSAC.

2) Simulation of hot functional testing and cooldown (Ref. 11) utilizing thiosulfate contamination and actual operating temperatures and times revealed that 1 ppm of thiosulfate caused IGSAC.

These short term tests thus confirmed that in the absence of thiosulfate contamination, no short term attack of OTSG tubes is expected.

Bulk vs. Surface Effects

The above corrosion tests were performed using actual TMI-1 OTSG tubing. The surface film condition was therefore representative of that in the plant. Chemistry control in both corrosion testing and actual operation is done by the measurement and control of species of interest in the bulk fluid.

Since both surface conditions and chemistry control were identical between the laboratory tests and plant operations, the results of the corrosion tests can be directly applied to the plant environment, and, conversely, plant bulk chemistry data can be used to evaluate the propensity for corrosion.

TMI-1 Chemistry Guidelines

Hot Operations

After sulfur was identified as the causative agent of the 1981 IGSAC, hot operational guidelines (Ref. 4) were reviewed to ensure that adequate corrosion protection was maintained. As a result of this review, two changes were made to provide increased margins against corrosive attack.

First, a requirement was added that primary system sulfate be maintained below 0.100 ppm. Sulfate at this level does not cause corrosive attack of Inconel 600 in primary coolant, and maintaining sulfate below this level provided assurance that intermediate sulfur species could not exist at harmful concentrations.

Second, the lower limit on lithium concentration was increased to 1.0 ppm, to take advantages of lithium's inhibiting effect on sulfur-induced IGSAC in Inconel 600 (Ref. 12).

The net result of these changes is to ensure that total sulfur species concentrations are a factor of 10 below the level at which corrosive attack might occur. At the same time, the minimum Li/S ratio will be 30 (or Li/SO4 of 10), which is a factor of 3 over the recommended (Ref. 12) ratio of 10 for inhibition of IGSAC initiation.

Layup

For cold layup conditions, guidelines have been established to maintain as many protective conditions as feasible. The individual protective conditions that are feasible for the TMI-1 RCS are:

1) Elevated pH - during layup, pH has been elevated, using ammonia, to at least 7.2. The normal pH without ammonia is 5.6 - 6.5.

2) Control of contaminants - The primary water contaminants of concern are chlorides and sulfates. Chlorides have traditionally been limited to less than 0.100 ppm during operation; we have maintained this level as a general guideline during layup. The sulfate level of less than 0.100 ppm used during hot operation also applies to layup.

3) Control of oxygen level - When the system is filled and able to be pressurized, the oxygen level is to be maintained below 0.1 ppm. For cases where the primary system is open and oxygen cannot be excluded, air saturated conditions are specified as this is more protective than some intermediate oxygen level.

4) Control of OTSG level - One of the contributing factors to the 1981 IGSAC incident was the existence of a water line on the primary side of the OTSG tubes. For layup of the OTSG's, wherever possible, no static waterline shall be allowed to exist in the OTSG tubes. Either the water level should be above the upper tubesheet or the OTSG primary side should be fully drained.

5) Inventory Turnover - Periodic replenishing of the OTSG contents will assure that local buildup of contaminants will not occur. Layup guidelines have included provisions for periodically turning over the water inventory on the OTSG primary side to meet this objective.

TABLE 2

Summary of Operations for Long Term Corrosion Tests

	Operating Days				
		Cold Circulating		Drained	
Loop	Hot	Deaerated	Aerated	Layup (Note 1)	Comments
1	348	52	28	132	
2	308	69	27	157	Thiosulfate loop
3	241	42	23	58	
4	242	40	22	61	

Notes

1. Does not include drained layup between completion of operational cycles and start of metallographic examination.

Chemistry and Operating History Review

Data Base

The chemistry and operating history data were obtained from two sources. First, the on-site Plant Analysis group reviewed operational records to identify plant conditions during this time period (Ref. 13). Then, we retrieved the primary plant chemistry parameters of interest from the GPUN computerized chemistry data base.

The major plant activities that occurred between May 1983 and October 1984 are listed in Table 3. Within each of these periods, we identified different plant conditions of RCS level, temperature, pressure, circulation, and pH. Then, we reviewed the chemistry data for each time period.

Chemistry data selected to be of interest with respect to corrosion were pH, oxygen, lithium, sulfate and chloride. As an additional check on the effectiveness of chemistry controls, we calculated the lithium to sulfur ratio for each operating period. In cases where simultaneous analyses for lithium and sulfate exist, we calculated the Li/S ratio for each data point.

The data from the operational and chemistry investigations are plotted as a function of time in Appendix A.

Results of Operational/Chemistry Review

During both hot shutdown and cold layup conditions, TMI-1 has maintained conditions within chemistry guidelines for about 95% of the time. For short time periods, some deviations have occurred which are discussed in the balance of this section.

Chloride and Sulfate

There have been short time periods where chlorides and/or sulfates have exceeded specified limits. In all instances chemistry data reflect that corrective actions were appropriately and promptly taken to return the concentrations of these species to specified levels. Collectively, these out-of-specification periods can best be described as normal chemistry "spikes".

Oxygen

In preparation for both the September 1983 and May 1984 hot functional tests, it was necessary for the RCS to be taken from a layup to an operating mode. During this transition, oxygen levels were higher than desired for optimum protection, but other factors made it very unlikely that corrosion occurred. First, chloride and sulfate concentrations were controlled to acceptably low levels. Second, the lithium level was maintained such that the minimum lithium to sulfur ratio was 66; the recommended minimum value for protection against IGSAC is 10 (Ref. 12). Chemistry control during these periods is summarized in Table 4.

Other Operational Considerations

During the Integrated Leak Rate Test (ILRT) in April 1984, the primary side water level was maintained at about the 12th tube support plate for 8 days. This condition was both preceded and followed by drained layup with elevated pH, aerated water. Both sulfate and chloride levels remained within specification. Therefore, no OTSG tube corrosion was expected.

In August 1983 and May 1984 oxygenated water was injected into deoxygenated RCS during HPI testing. Most of these tests were conducted prior to the high temperature portion of the hot functional tests, and the oxygen introduced would have been consumed by hydrazine and/or hydrogen added for that purpose. One test was conducted on May 26, 1984, at the end of HFT and may be postulated to have injected 5000-6000 gallons of oxygen-saturated water. During this time period, however, the lithium to sulfur ratio was greater than 30 which was more than adequate to inhibit corrosion during this test.

TABLE 3

Major Plant Evolutions, 5/83 to 10/24

Event	Duration
Fill & Bubble Test	June 1983
Peroxide Clean	July 1983
Hot Functional Test	Aug - Oct 1983
Circulating Wet Layup	Oct - Nov 1983
DH-V1 Repair	Nov 1983
Circulating Wet Layup	Nov 1983 - Jan 1984
RC-P1B Repair	Feb - April 1984
Integrated Leak Rate Test	April 1984
Hot Functional Test	May 1984
Non-Circulating Wet Layup	May - June 1984
Tube Plug Rerolling and Bubble Testing	June - Oct 1984

TABLE 4

Chemistry Summary Before Hot Functional Testing

Period	Days	Oxygen, ppm	Li, ppm	SO_4, ppm	Cl ppm	Li/S Ratio
8/83	29	0.3	.82-1.96	.047-.079	.05-.156	66-123
5/84	19	.075-2.2	1.06-2.17	.02-.047	.05-.110	127-240

In-Plant Observations

Leak Testing

Since completion of the kinetic expansion repairs, several leak tests have been performed to measure primary-to-secondary leakrates and identify individual leaking tubes. These tests are summarized in Table 5.

No pattern of tube leakage can be seen. After the cooldown tests included in hot functional testing some increase in leakage was seen. Further investigation showed that this leakage was the result of leaks through a small number of tubes. These leaks were located in the expanded region within the upper tube sheet and were repaired by mechanically rolling a portion of the expanded area.

Of greatest significance is that since 1983 no tube which is in service has had a leak in an unexpanded portion of the tube. All leaks have either been due to bypass leaks in the expanded area or leaking plugs.

Fiberscope Inspection of Selected Tubes

A fiberscope inspection was performed (Ref. 14) of six A-OTSG tubes which exhibited typical eddy current indications. During the inspection features were observed on 4 out of 6 tubes at the same elevation as the eddy current indications.

The visual features were "patchlike" rounded areas having an outer ring which was darker than the general tube surface and slightly reflective components in the interior. The patches were between 0.020 and 0.060" in diameter.

The patches appeared similar to surface deposits seen during the initial tube failure analysis. These earlier deposits were found to be associated with partial through wall intergranular attack.

TABLE 5

Leak Tests in OTSG's Since 5/01/83

Month/Year	Test Type	Reason For Test	Results	Repairs
May 1983	Drip	Test of Kinetic Expansion	2 Leaking Tubes, 8 Leaking Rolled Plugs 10 Leaking Explosive Plugs	Plugs Installed/Rerolled
June 1983	Bubble/Drip	Final Test of Kinetic Expansion	Small Number of Slightly Leaking Tubes and Plugs in A OTSG - 1 Leaking welded plug	Repaired welded plug
Sept 1983	Kr-85 Tracer	Establish Baseline Leak Rate	Baseline Leak Rate 1 gph	None Required
May 1984		Measure Baseline Leak Rate	Slight Increase in Leak Rate	None Required
June 1984	Bubble/Drip	Identify Leaking Tube(s)	4-5 Leaking Tubes in B-OTSG	Plug 3 tubes w/welded plugs
			6 Rolled Plugs Missing	Reroll all W plugs Replugged tubes.
Oct. 1984	Bubble/Drip	Test Rolled Repairs	Small Number of Leaking Tubes, one welded plug	Roll 8 Tubes Reweld Plug

Note: No leaks seen in final October 1984 Bubble Test, after tube rolling.

Discussion

General

Removal of sodium thiosulfate from the TMI-1 site and tighter operational chemistry controls implemented since 1981 have made it highly unlikely that the conditions to cause sulfur-induced IGA/IGSAC could be recreated. The steam generator layup guidelines are specifically designed to protect the steam generators from additional corrosion and are more stringent than B&W's generic recommendations, particularly in the areas of contaminant control and the use of elevated pH during cold layup. Industry experience on B&W PWR's also does not reveal any other primary-side initiated attack mechanisms on Inconel OTSG tubing.

TMI-1 compliance with operating and layup specifications has been excellent. Transient out-of-specification conditions, which were identified during plant operation, have been infrequent and corrected promptly by the plant operators. Plant conditions have always been bounded by those which were evaluated during corrosion testing and found to be satisfactory.

The only period of possible vulnerability to corrosion would have existed during the time when the OTSG's were drained for the kinetic expansion repair. During this period sulfur would have remained in the oxide film on the tube surfaces as peroxide cleaning had not yet been performed. During this time, however, eddy current testing done on the 100 tube surveillance sample did not reveal any growth of existing indications or any new indications. Thus, while the oxide film may have contained sulfur during this time, there is no evidence that corrosion continued.

Under mechanical loadings induced by kinetic expansion or cooldown, areas of IGA/IGSAC could become more detectable by eddy current through several mechanisms:

1) creation of a linear grain boundary separation within the IGA islands as was seen in the LTCT (Ref. 8). This could produce a crack-like indication, or increase the overall grain boundary volume of the IGA patch. In addition, mechanical working can also produce increased grain boundary separation of IGSAC.

2) disconnected grains dropping out and leaving pits.

Two additional pieces of data from Ref. 16 lend support to the mechanical scenario. First, peripheral tubes consistently see higher loads than core tubes. Therefore, in the periphery, the highest stresses would also act on this IGA/IGSAC. Second, the A-OTSG cooled down more quickly than the B unit. The peak load during the most rapid cooldown (Ref. 16) was 200 lb. in the A-OTSG, 12% higher than in B-OTSG. Figure 1 is a representation of how the A-OTSG would have had significantly more tubes carrying loads high enough to cause IGA/IGSAC to become more detectable.

A previous study (Ref. 15) on crack opening displacement of archive tubes with approximately .5" long through-wall cracks found that loads between 1500 and 2000 lbs. would induce permanent displacements in the vicinity of the cracks. Loads less than this would induce only elastic displacements with a load of 1000 lbs. producing an elastic displacement of approximately .002". Although tubes with cracks of this size are no longer in-service with the steam generators, this study does point out that one can expect local straining in the vicinity of smaller defects, but that it would be of proportionately lesser magnitude.

During the 1983 HFT, the most rapid cooldown was calculated to have induced loads in the tubing of between 1600 and 1700 lbs. (Ref. 16). It is such loads acting on the regions of IGA/IGSAC which we believe leads to grain dropping or grain boundary separation.

Detectability of Indications by Eddy Current

It should be noted that the primary defects of concern for OTSG tube integrity (i.e. tube rupture) are circumferential cracks. The production of 0.540" standard differential eddy current technique is optimized and qualified for this type of defect. However, it can also be used for detecting different defect geometries as discussed below.

The 1984 tube ID indications as detected by eddy current and as seen during the fiberscope inspection had significantly different characteristics than the IGSAC responsible for the 1981 tube leakage. The 1981 IGSAC consisted of tight, circumferential cracks that penetrated completely through the wall. The 1984 IGA as observed by fiberscopic examination appears rounded and does not completely penetrate the tube wall.

The different geometry will have a direct effect on detectability. The current .540" S.D. eddy current technique was optimized for the IGSAC geometry; therefore, a different geometry will have a different detectability. The balance of this section of this report will discuss changes in sensitivity due to changes in indication geometry.

Figure 2 (Figure 2 from Reference 2) shows the measured sensitivity of the .540" S.D. technique in the range of short circumferentially oriented defects. The shaded region in Fig. 2 identifies the range based on eddy current indication sizing in which 90% of the 1984 indications fall. It can be seen that the eddy current calls span the 0.3 volt detectability limit. (NOTE: Circumferential length is based on the number of 8X1 coils giving a signal and not an actual defect measurement.) Thus only slight changes in indication geometry could cause a particular indication to become detectable assuming the defects lie close to the detectability line.

In Figure 3a and 3b, we have taken the eddy current data and visual observations from the fiberscope inspection (shown in Table 6) and indicated where the indications would be in relationship to the calibration curves. The tubes for fibrescope inspection were chosen to be representative of the types of indications being found in 1984. All of the below-UTS indications (Figure 3b) are close to the 0.3 v detectability limits; the within-UTS indications (Figure 3a) do not fall into the detectable range. Therefore, it is reasonable that before mechanical loading these indications may not have been detectable. Mechanical loading, as discussed in the previous section, can alter IGA/IGSAC geometry.

The large increase in the number of degraded tubes in A-OTSG and B-OTSG is also consistent with the scenario of pre-existing IGA/IGSAC becoming more detectable. IGA/IGSAC of 20-40% through wall extent could be estimated to have a length of about .015-.030 inches; this is below the 300 mV sensitivity for free-span detection (Figure 2). The inability to detect these small regions of IGA/IGSAC below the level of detectability was further confirmed by evaluations which took place during the Long Term Corrosion Test Program. This program identified four patches of IGA which also were not detected (Table 7) by eddy current examination.

Table 6 - Comparison of Preliminary Eddy Current Data and Fiberscope Results

"A" - OTSG			EC Results				
			.540 S.D.		8 X 1		
Row	**Tube**	**Elevation**	**% T.W.**	**Volts**	**Volts**	**Coils**	**Visual Observations**
89	124	US+5.4	98	1.6	1.6	2	
		US+4					Rounded indications - possible IGA
		US+5.8					Axial alignment of 3 rounded indications
76	119	US+2.4	97	2.1	0.8	2	
		US+5.5					Small dark spot when scanning w/90° head
66	129	15+27.6	62	2.8	1.3	2	
		15+24.5					Rounded indications - possible IGA
61	123	15+21.6	59	2.3	1.1	2	
		15+26					Small dark spot - no detail visible
		15+24.7	28	1.7	0.5	1	
57	128	US-2.6	92	1.3	0.3	1-2	
		US-1.5					Axially oriented rounded indications
60	126	15-14.2/15-6.5	20/31	1/1.0	NDD		Small single rounded indication

TABLE 7

IGA 20% T.W. in Samples Removed From the LTCT Not Detected by Eddy Current

Tube	Section	IGA Location With Respect to Top of Upper Tubesheet	IGA Size		Type Sample
			Circum.	Depth	
A-24-94	25 7/16" - 30 13/16"	28"	.030"	.010"	C-ring (1)
A-24-94	19 5/16" - 25 7/16"	26"	.035"	.009"	C-ring (1)
A-24-94	19 5/16" - 25 7/16"	27"	.006"	.008"	C-ring (2)
A-13-63	11" - 18 15/16"	12.5"	.020"	.013"	Tube (1)

Note (1): These samples were exposed to thiosulfate contaminant during the LTCT.

(2): This sample was exposed to sulfate contaminant during the LTCT.

Figure 1 - TMI-1 OTSG Testing 3rd Cooldown (10-2-83)

Tube Load Distribution as a Function of Tube Location at the Peak Applied Load for "A" and "B" OTSGs

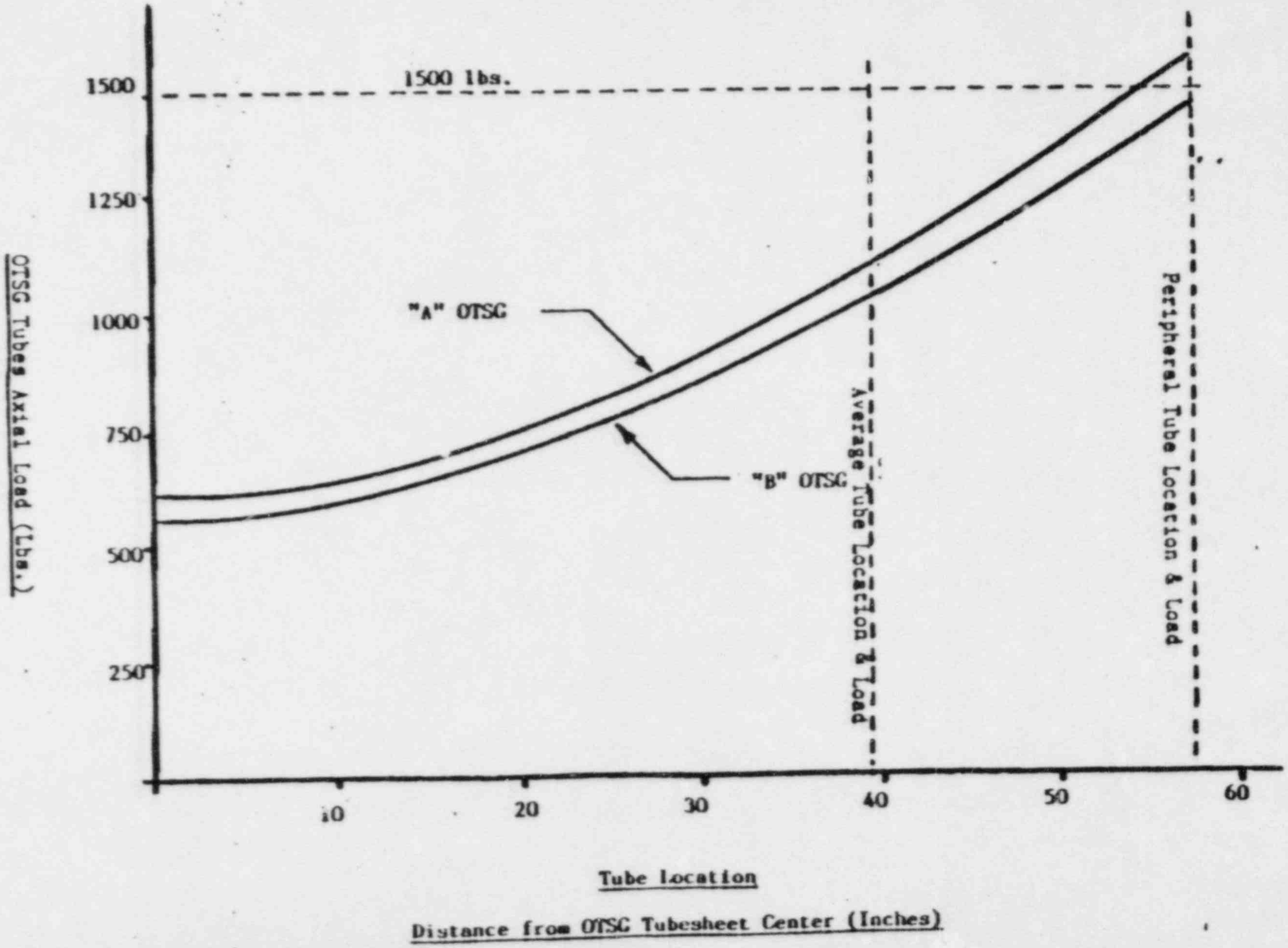


Figure 2 - 1984 Eddy Current Data

Compared to Detectaability Limits

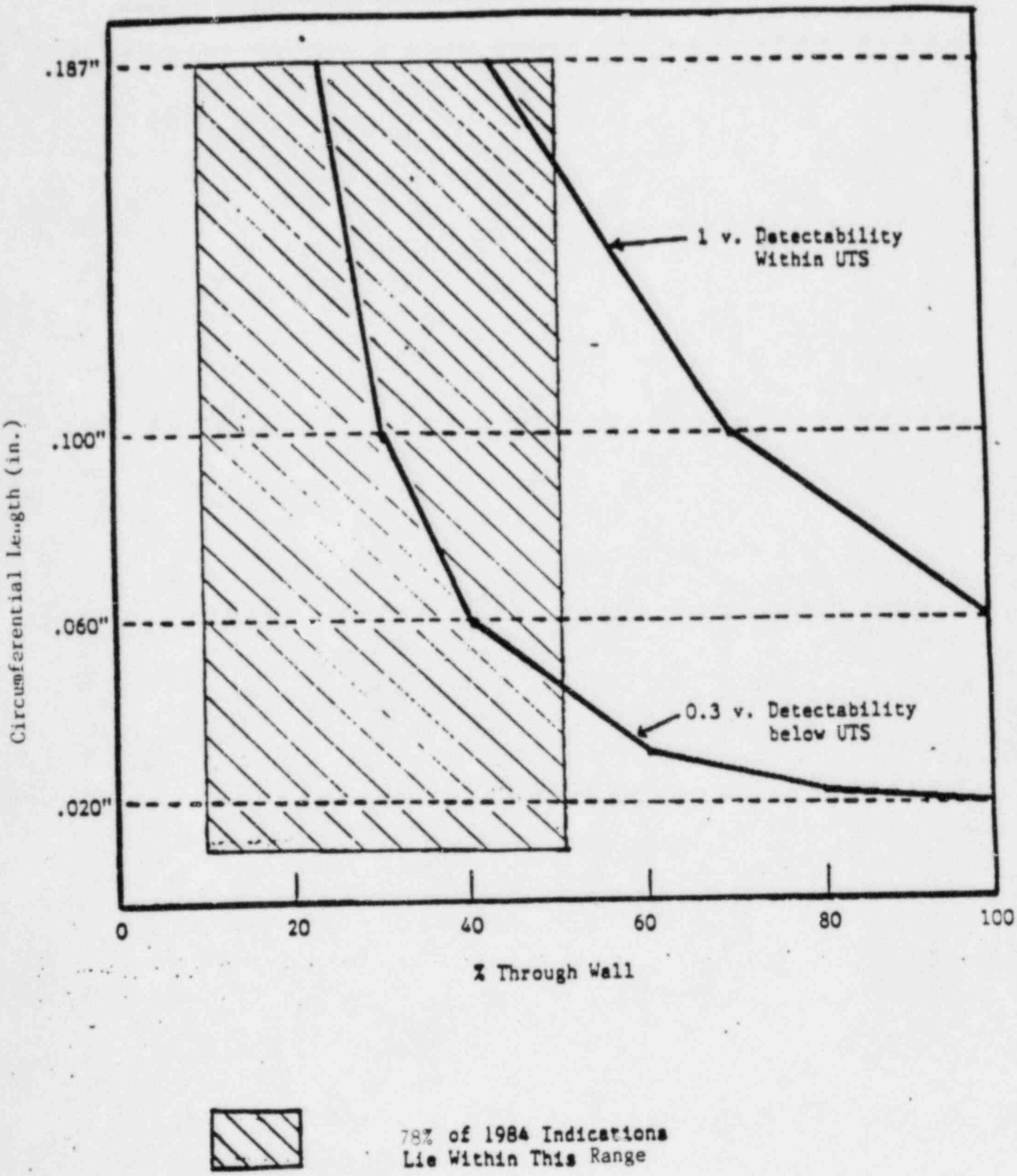
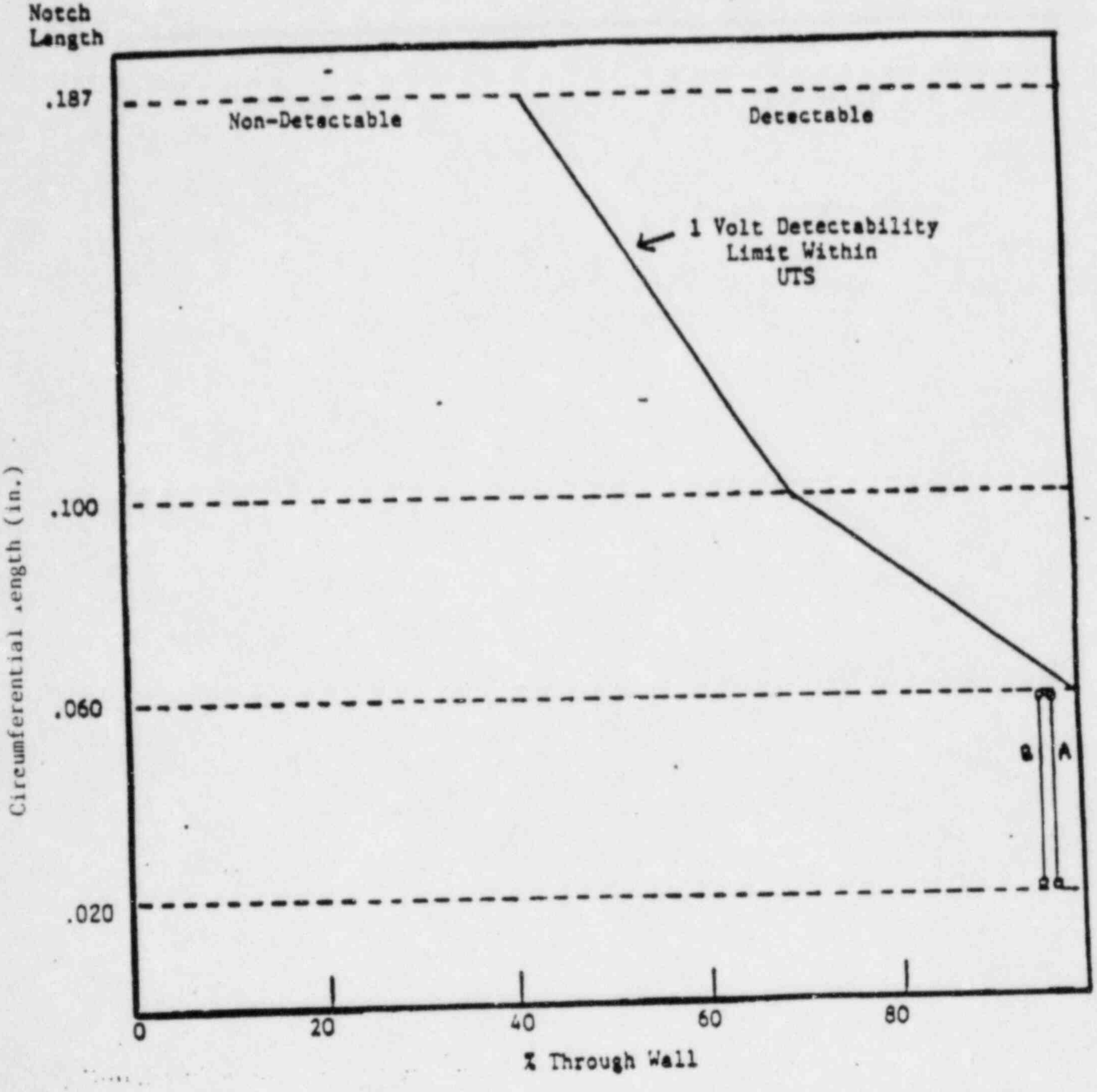


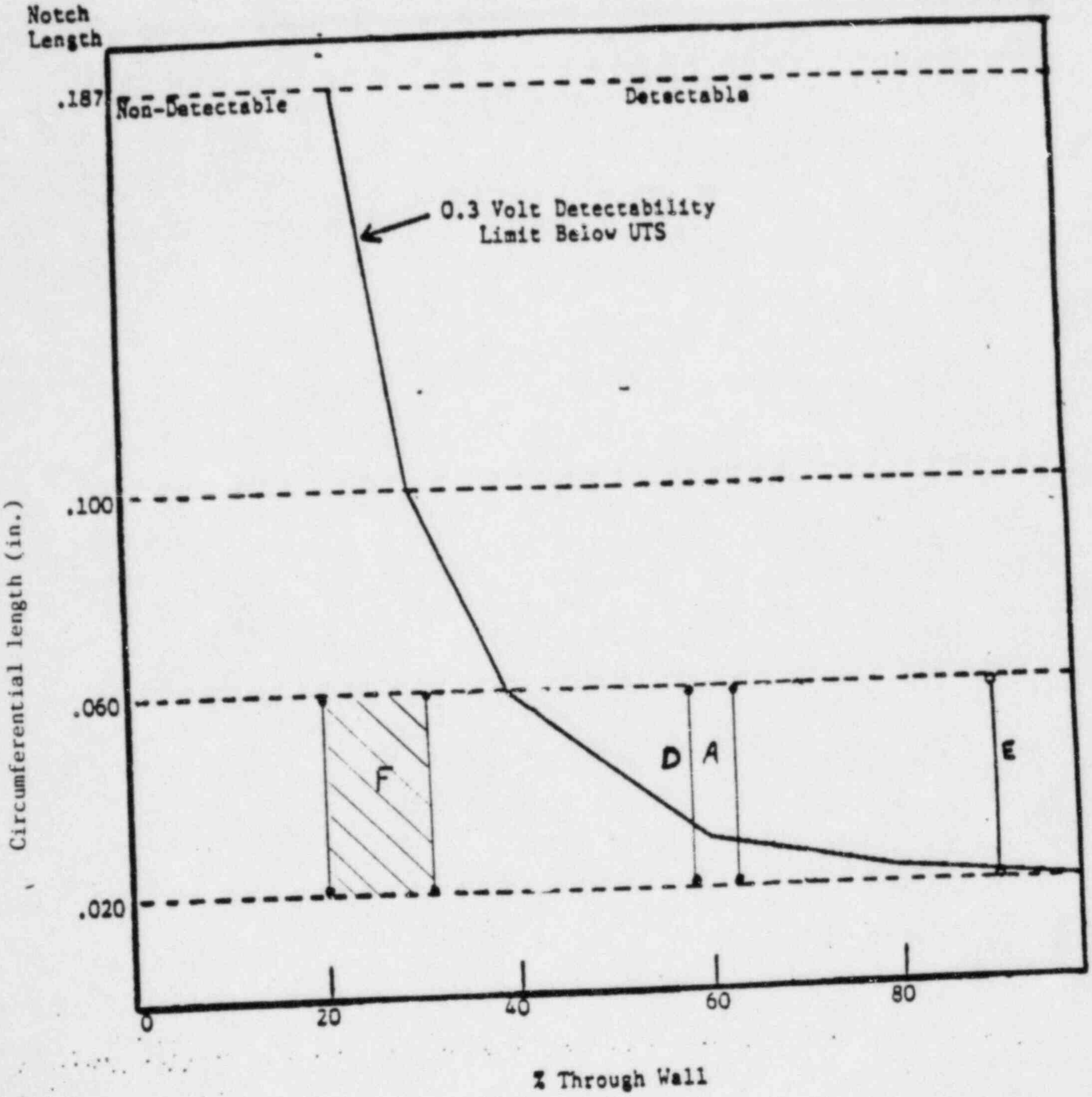
Figure 3a - Within - Tubesheet
Fiberscope Indications
Compared to Detectability Limit



Tube Identification

A	A-89-124
B	A-76-119

Figure 3b - Below - Tubesheet Fiberscope Indications Compared to Detectability Limit



Tube Identification

C	A-66-129
D	A-61-123
E	A-57-128
F	A-60-126

Conclusions

1. The TMI-1 layup guidelines are adequate to prevent any identified mechanisms for primary side initiated corrosion of Inconel 600 OTSG tubes.

2. The TMI-1 layup guidelines have been adhered to since completion of the kinetic expansion repair. Minor deviations have been corrected promptly.

3. Vulnerability to corrosion may have existed during the period when the OTSG's were drained for repair prior to peroxide cleaning. However, eddy current data and the absence of OTSG leakage during this time period do not show evidence of corrosion of OTSG tubes.

4. Results of both GPUN-sponsored and industry corrosion test programs confirm that corrosion would not be expected during TMI-1 operations since May 1983.

5. Results of eddy current tests since 1982 do not indicate any trends of indication growth of pre-existing indications.

6. Leak rate testing and OTSG bubble testing do not indicate any increases in leakage or new leaks in the tube free span.

7. The eddy current data and visual observations are consistent with a mechanism where previously existing areas of IGA/IGSAC are made more detectable by mechanical loading during kinetic expansion and thermal and hydraulic loading during cooldown from HFT.

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13. J. R. Kasper, "TMI-1 Primary Plant Status from 5/01/83 to 11/27/84," GPUN IOM PA-TMI-84-47, Nov. 27, 1984.

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APPENDIX A

TMI-1 CHEMISTRY DATA

MAY 1, 1983 to OCTOBER 26, 1984

Contents

Table A1

CHEMISTRY GUIDELINES APPLIED TO TMI-1

5/1/83 to 10/26/84

Operating Mode	Wet Layup	Drained Layup	Hot Shutdown (Hot Functional Testing)	Peroxide Cleaning
OTSG Primary Level	Full	Drained	Full	Full
Maximum Chloride, ppm	0.1	0.1	0.1	0.2
Maximum Sulfate, ppm	0.1	0.1	0.1	Note 2
Maximum Oxygen, ppm	0.1	N/A	0.1	Note 2
pH	greater than 7.2	4.6-8.5	4.6-8.5	8.0-8.5
Li,ppm	1.0-2.0	1.0-2.0	1.0-2.0	1.8-2.5
Minimum Li/S ratio	10	10	10	N/A

Notes:
1. Limits are for bulk RCS - no water in OTSG's at this time.
2. Sulfate and oxygen were monitored but no limit was applied.

CHEMISTRY DATA
FILL AND BUBBLE TEST PERIOD
May - July 1983

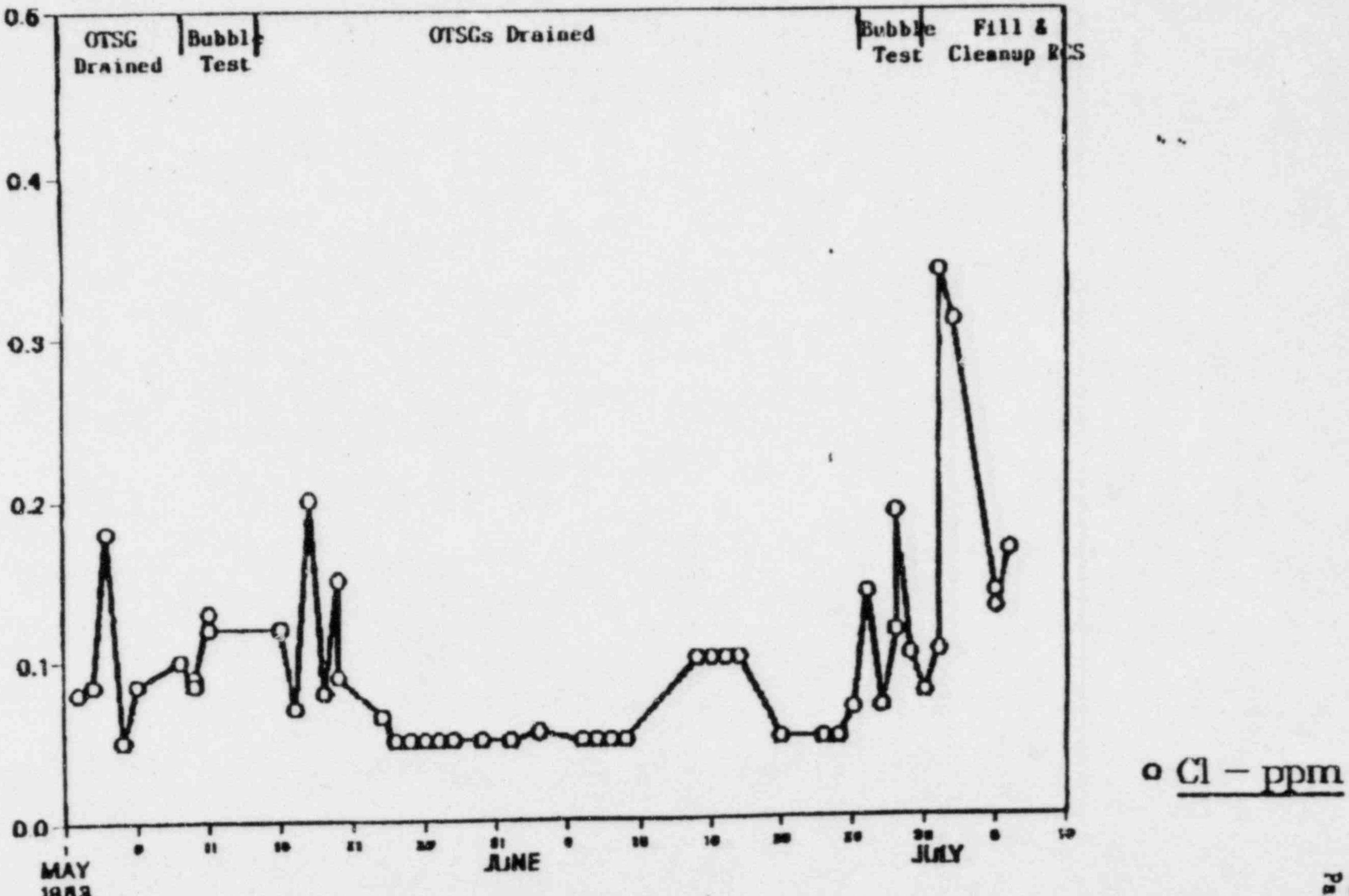

Figure A1-1a

CHEMISTRY DATA
FILL AND BUBBLE TEST PERIOD
May – July 1983

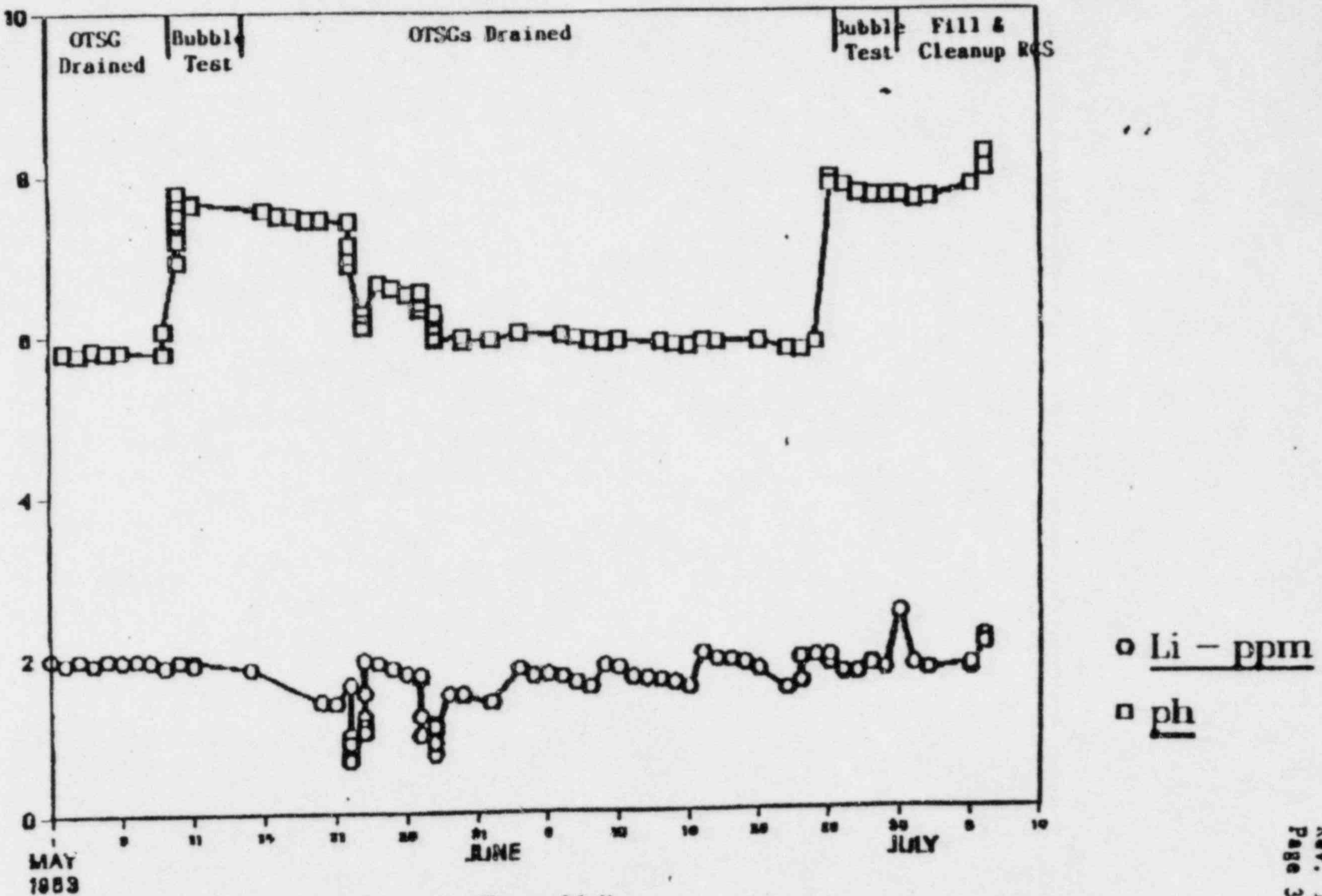

Figure A1-1b

CHEMISTRY DATA
PEROXIDE CLEANING AND PREPARATIONS FOR HFT
July – August 1983

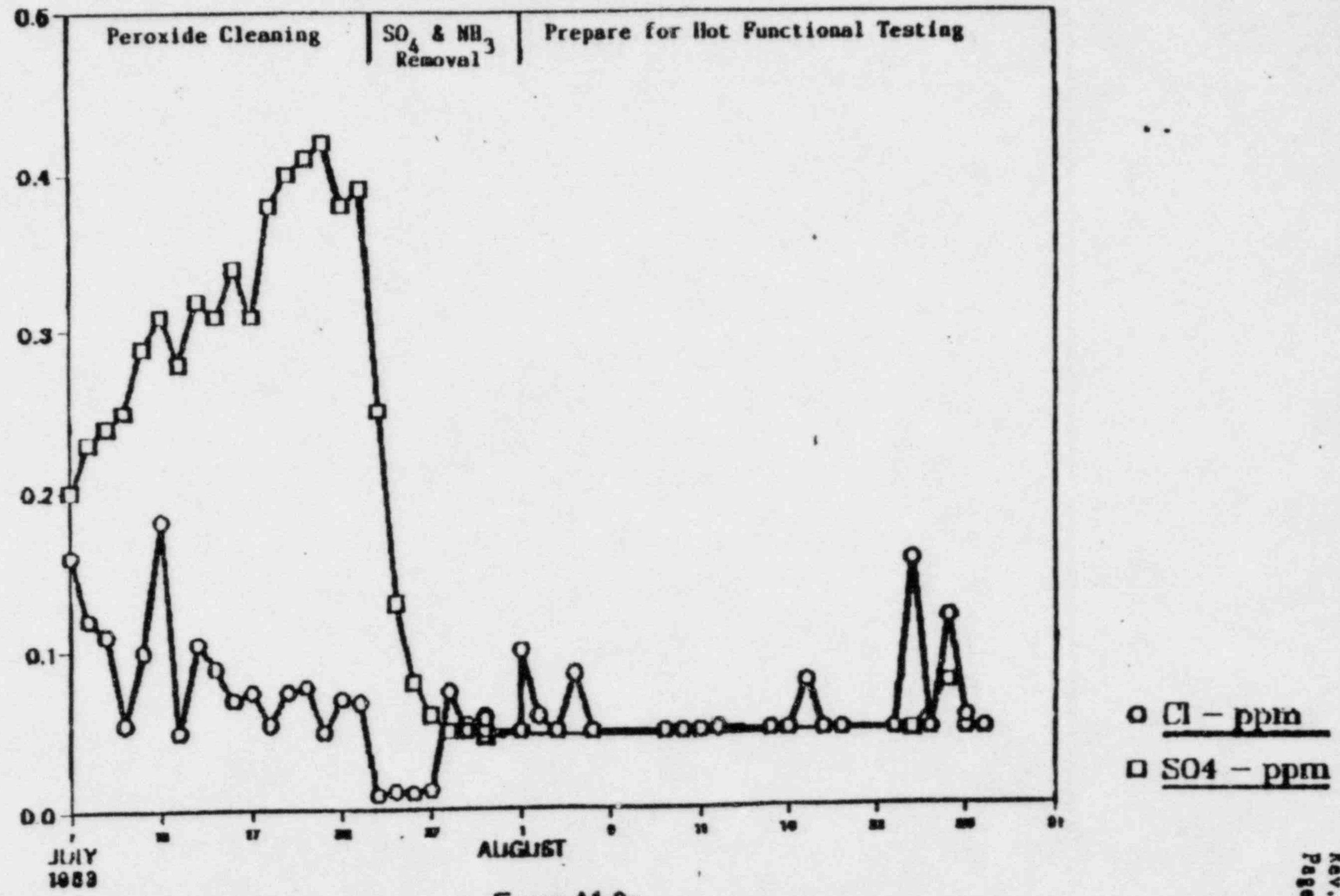

Figure A1-2a

CHEMISTRY DATA
PEROXIDE CLEANING AND PREPARATIONS FOR HFT
July - August 1983

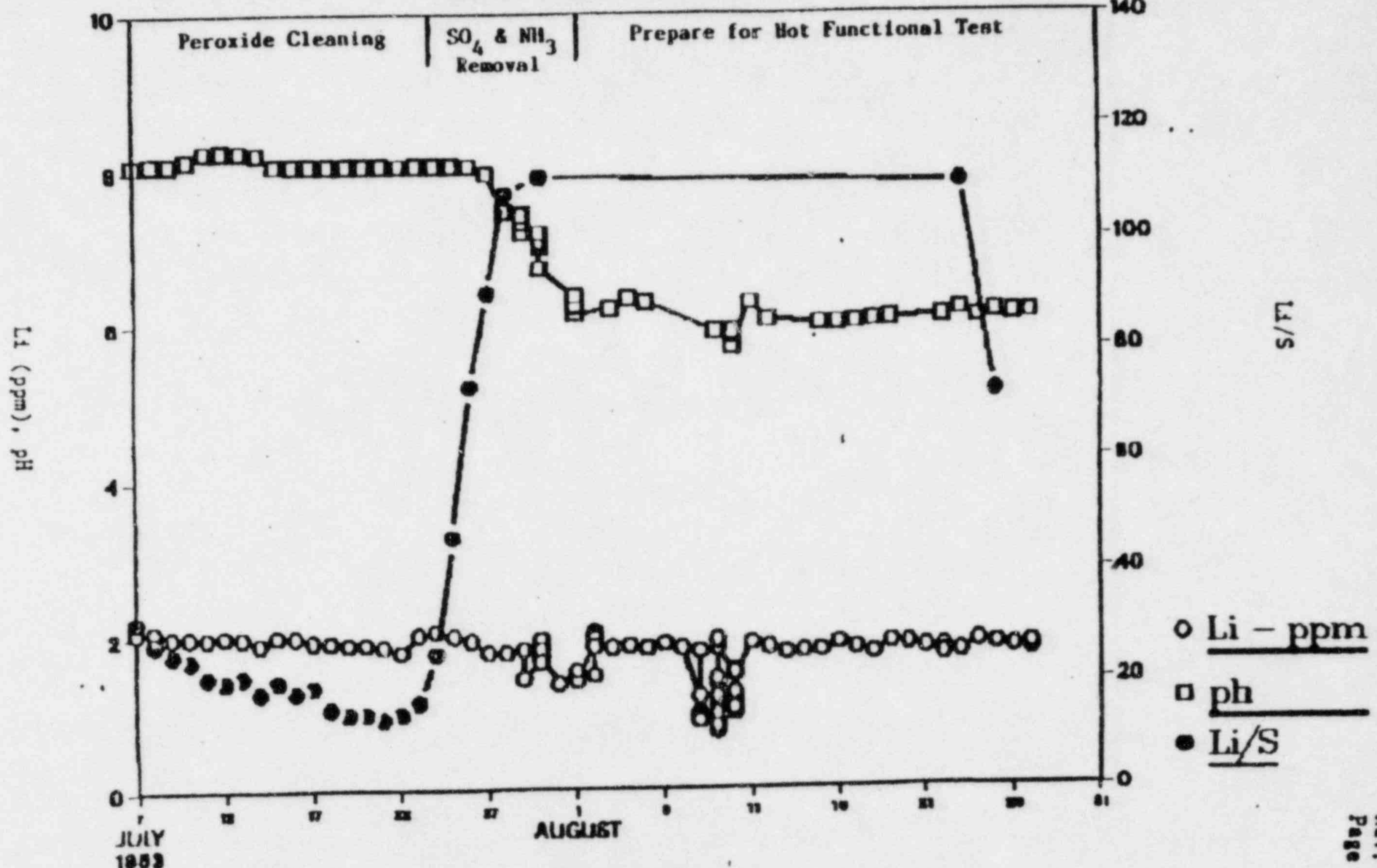

Figure A1-2b

CHEMISTRY DATA
HOT FUNCTIONAL TESTING AND WET LAYUP
August - November 1983

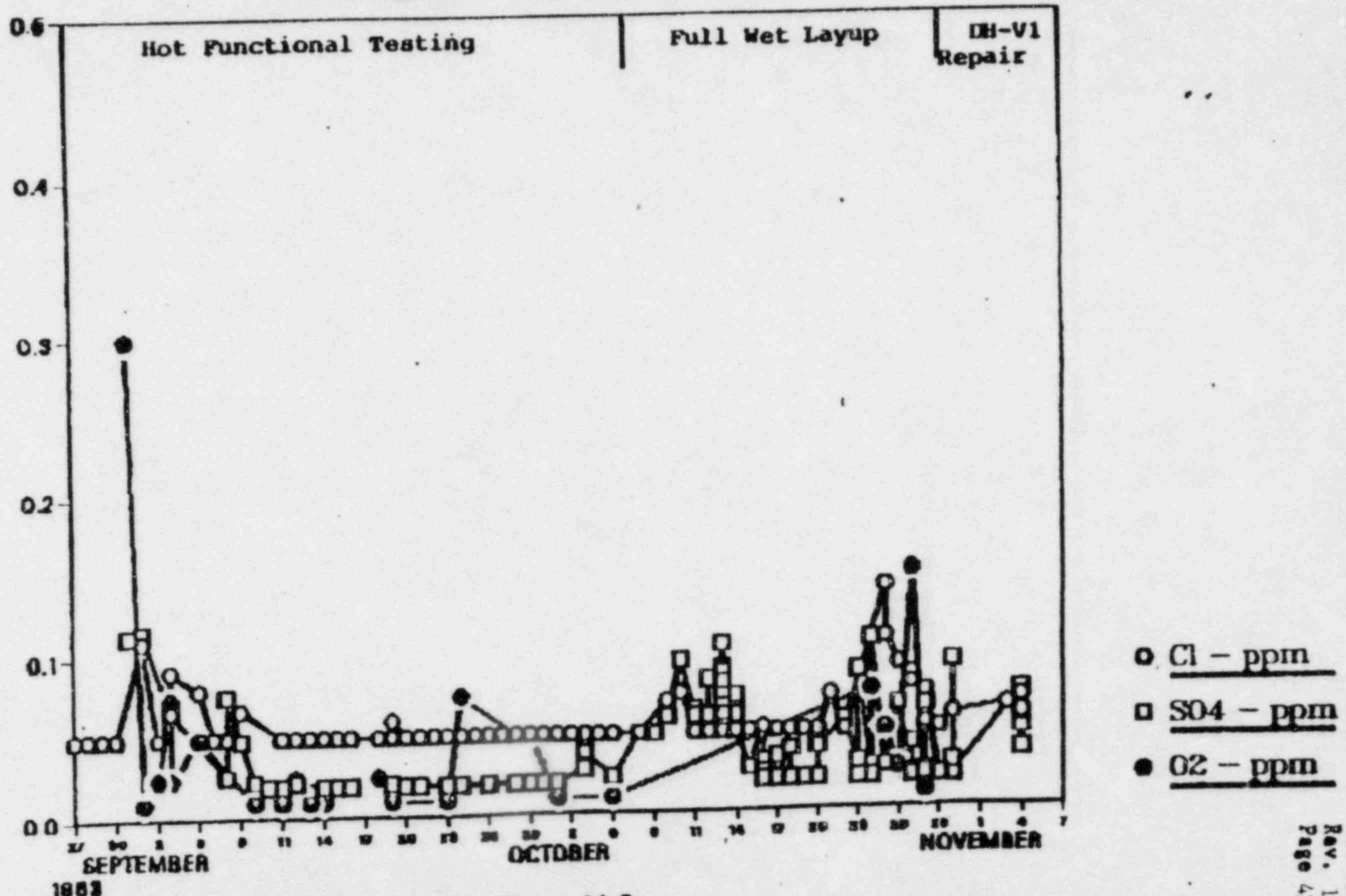

Figure A1-3a

CHEMISTRY DATA
HOT FUNCTIONAL TESTING AND WET LAYUP
August - November 1983

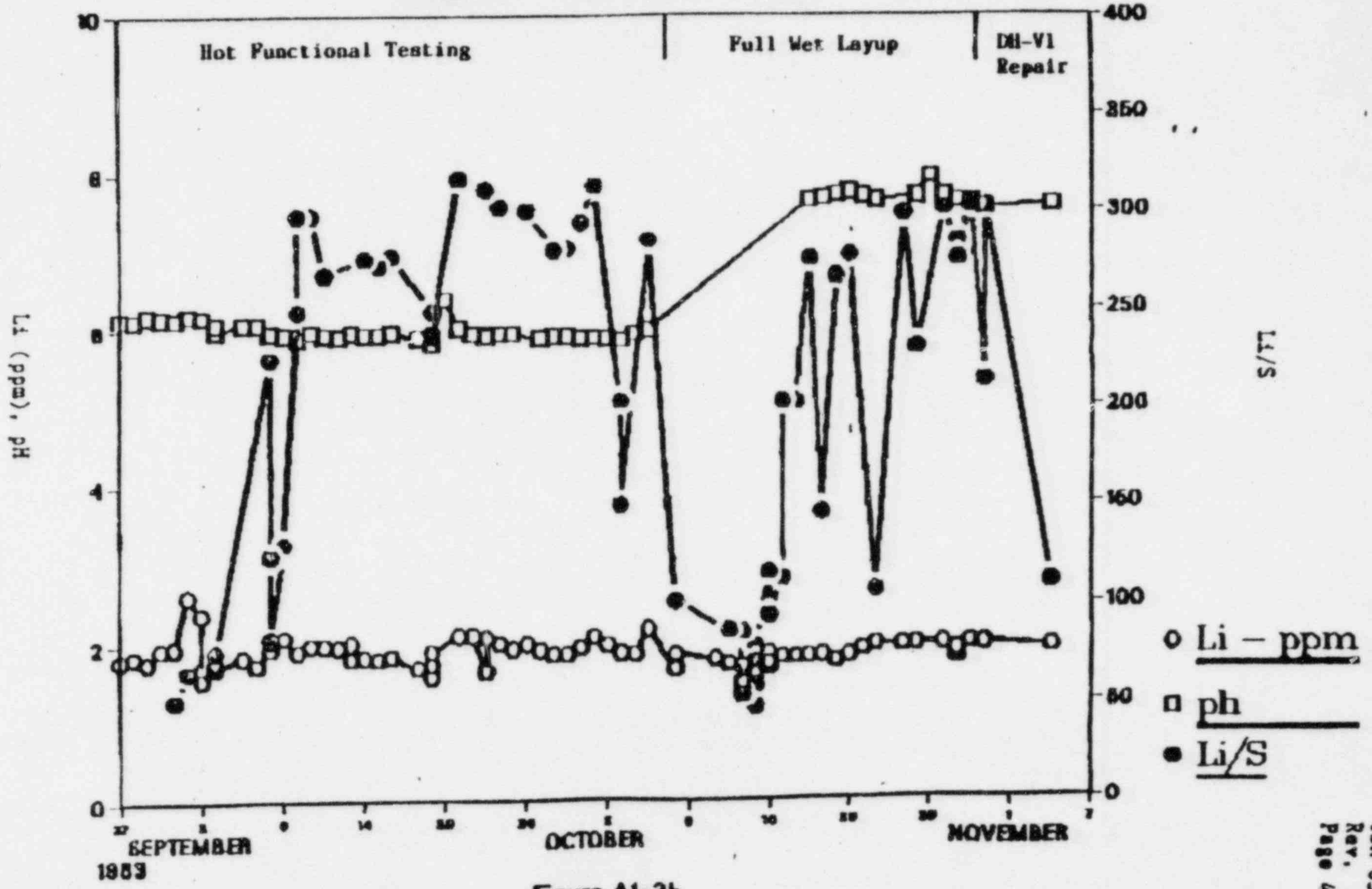

Figure A1-3b

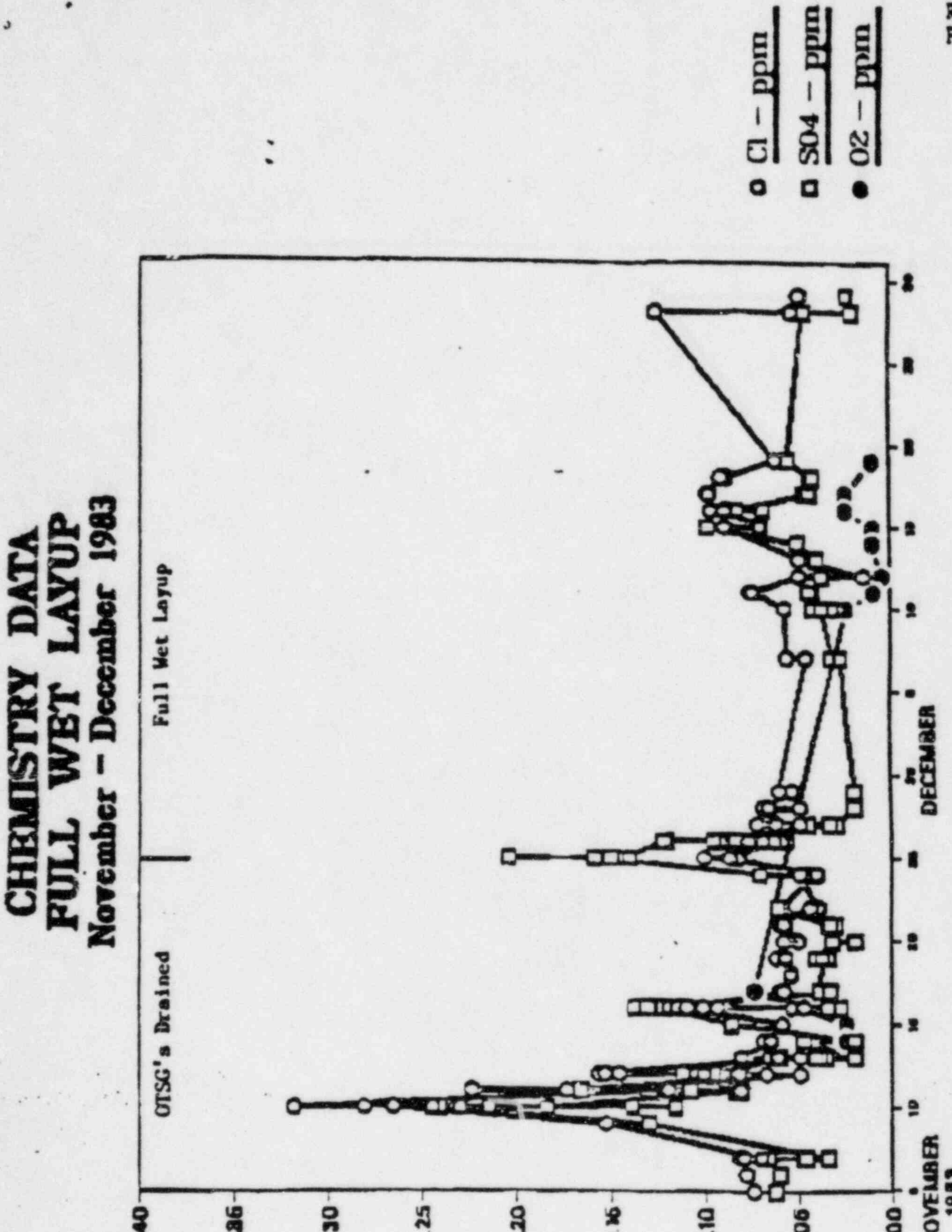
CHEMISTRY DATA
FULL WET LAYUP
November - December 1983
OTSG's Drained
Full Wet Layup
○ Cl – ppm
□ SO4 – ppm
● O2 – ppm
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
NOVEMBER 1983
DECEMBER
O2
O2

Figure A1-4a

CHEMISTRY DATA
FULL WET LAYUP
November - December 1983

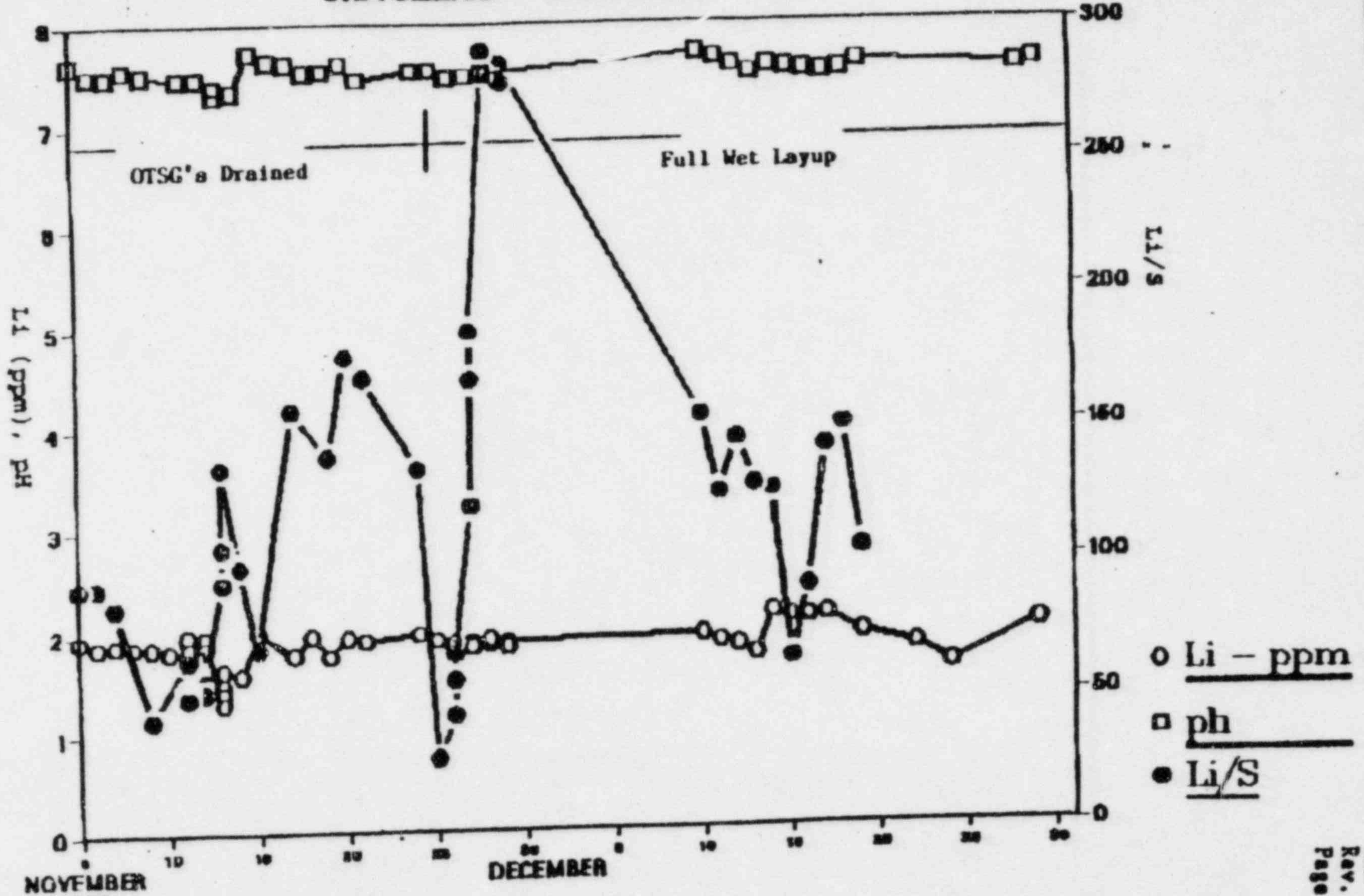

Figure A1-4b

CHEMISTRY DATA
FULL WET LAYUP AND RC-P1B TESTING
January - April 1984

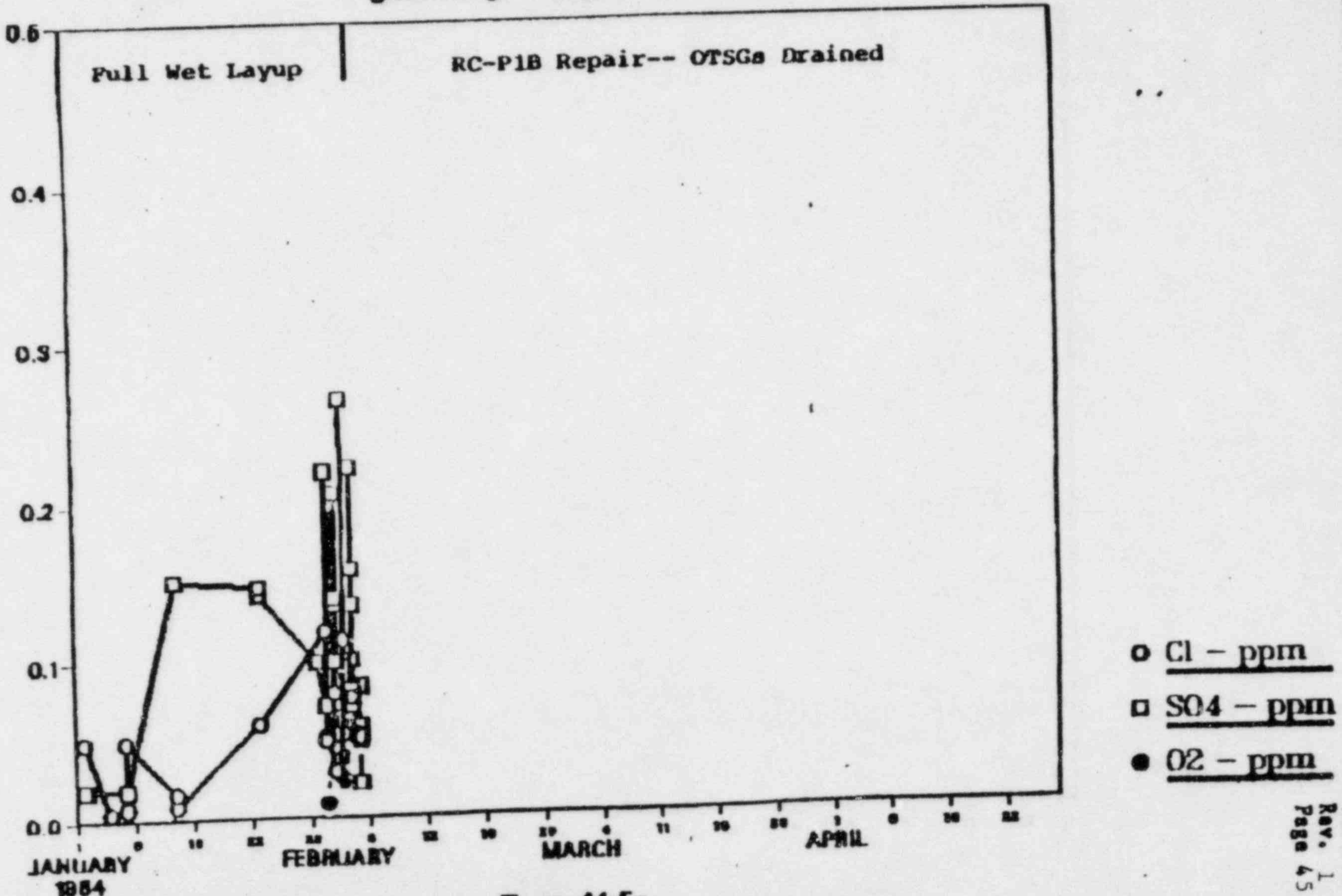

Figure A1-5a

CHEMISTRY DATA
FULL WET LAYUP AND RC-P1B REPAIR
January - April 1984

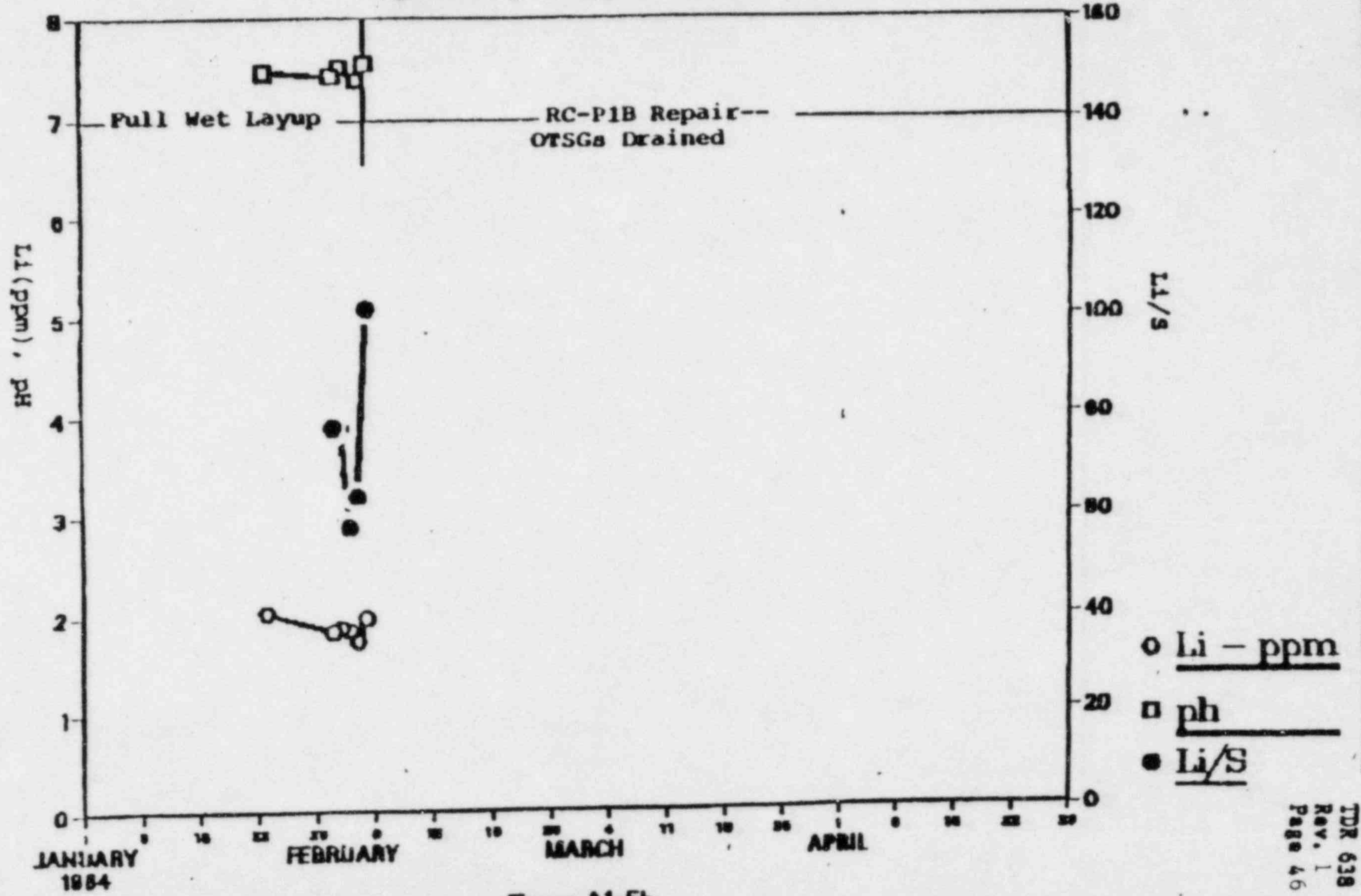

Figure A1-6b

CHEMISTRY DATA
HOT FUNCTIONAL TESTING AND WET LAYUP
April – June 1984

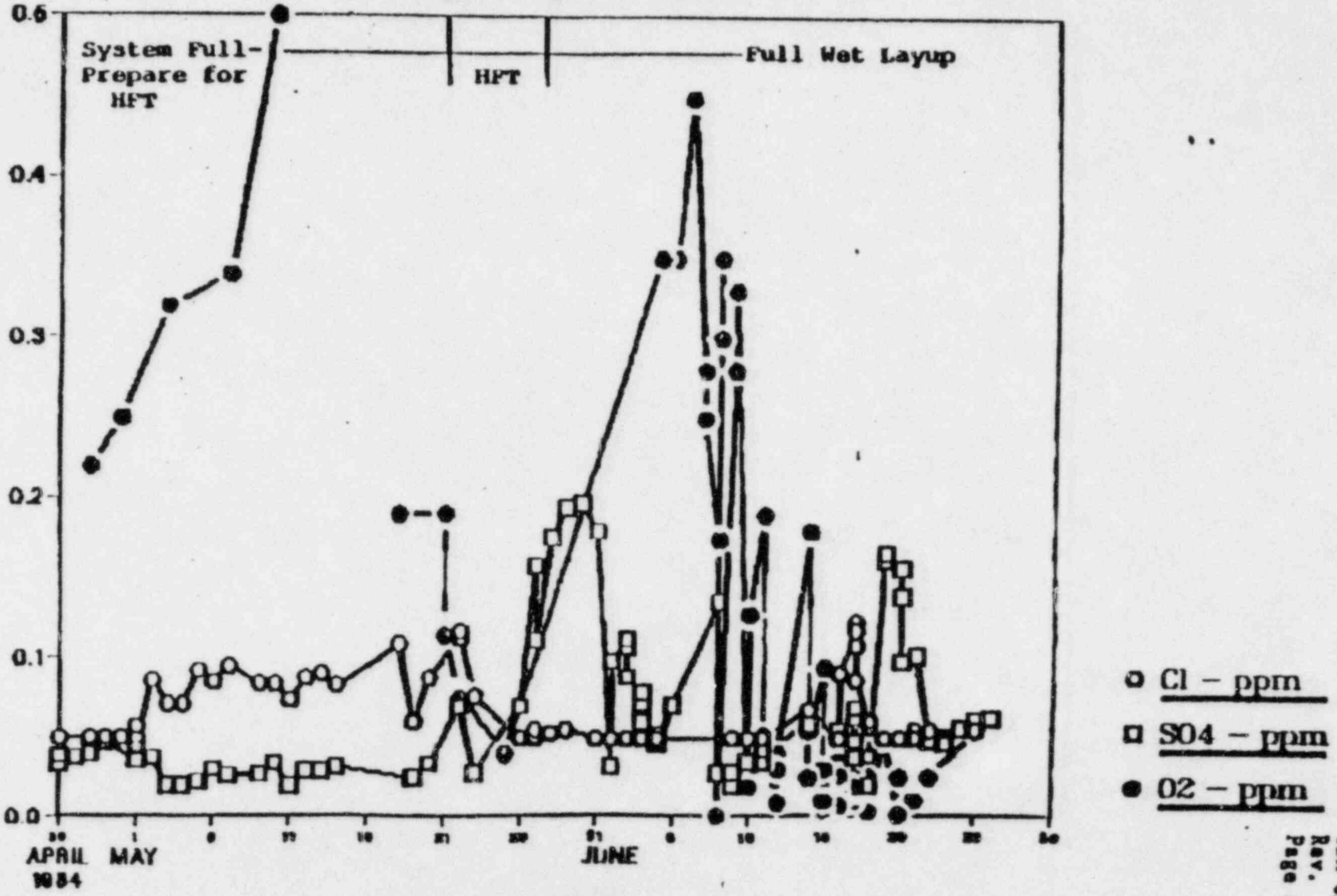

Figure A1-6a

CHEMISTRY DATA
HOT FUNCTIONAL TESTING AND WET LAYUP
April - June 1984

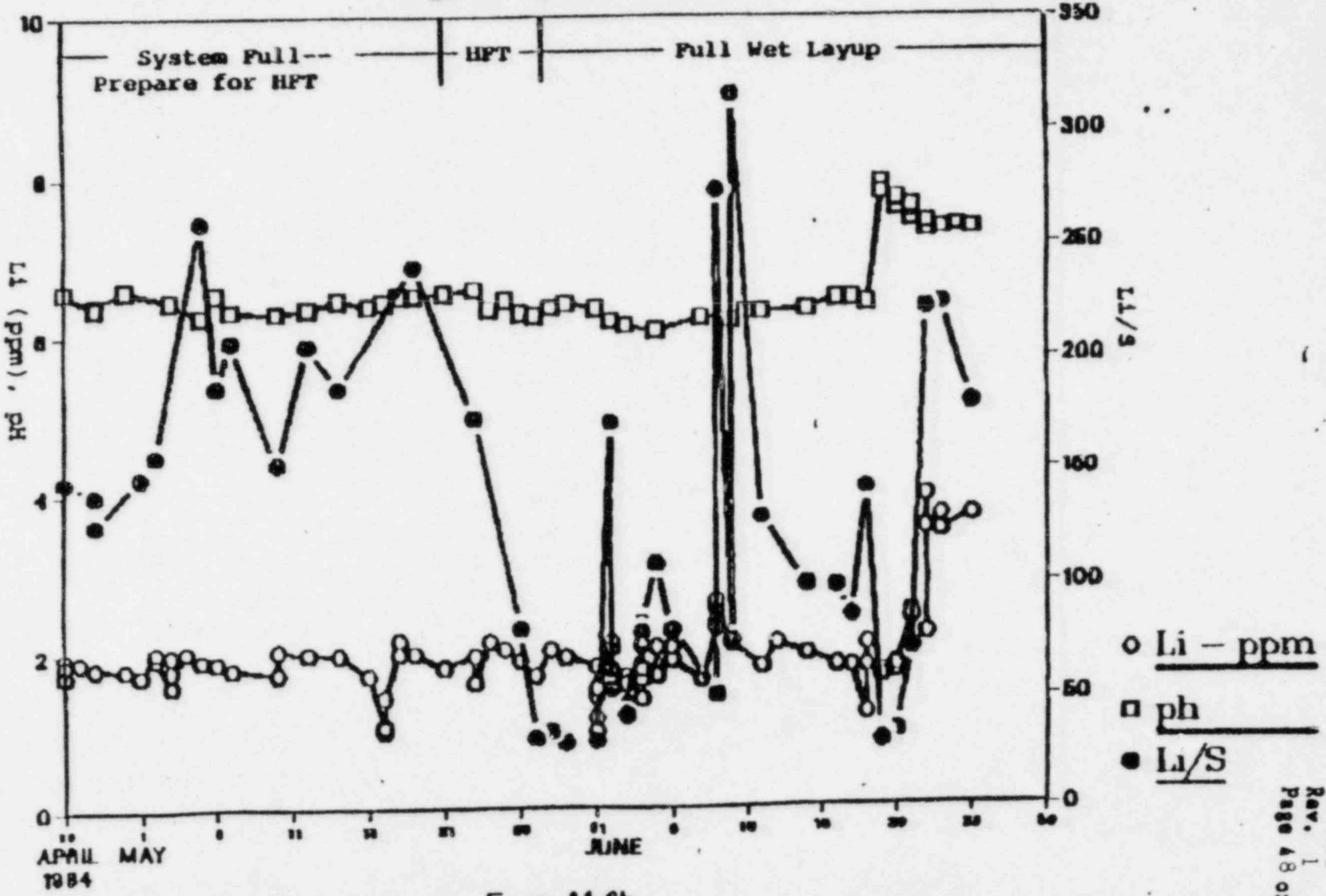

Figure A1-6b

CHEMISTRY DATA
PLUG REROLLING AND BUBBLE TESTING
June – October 1984

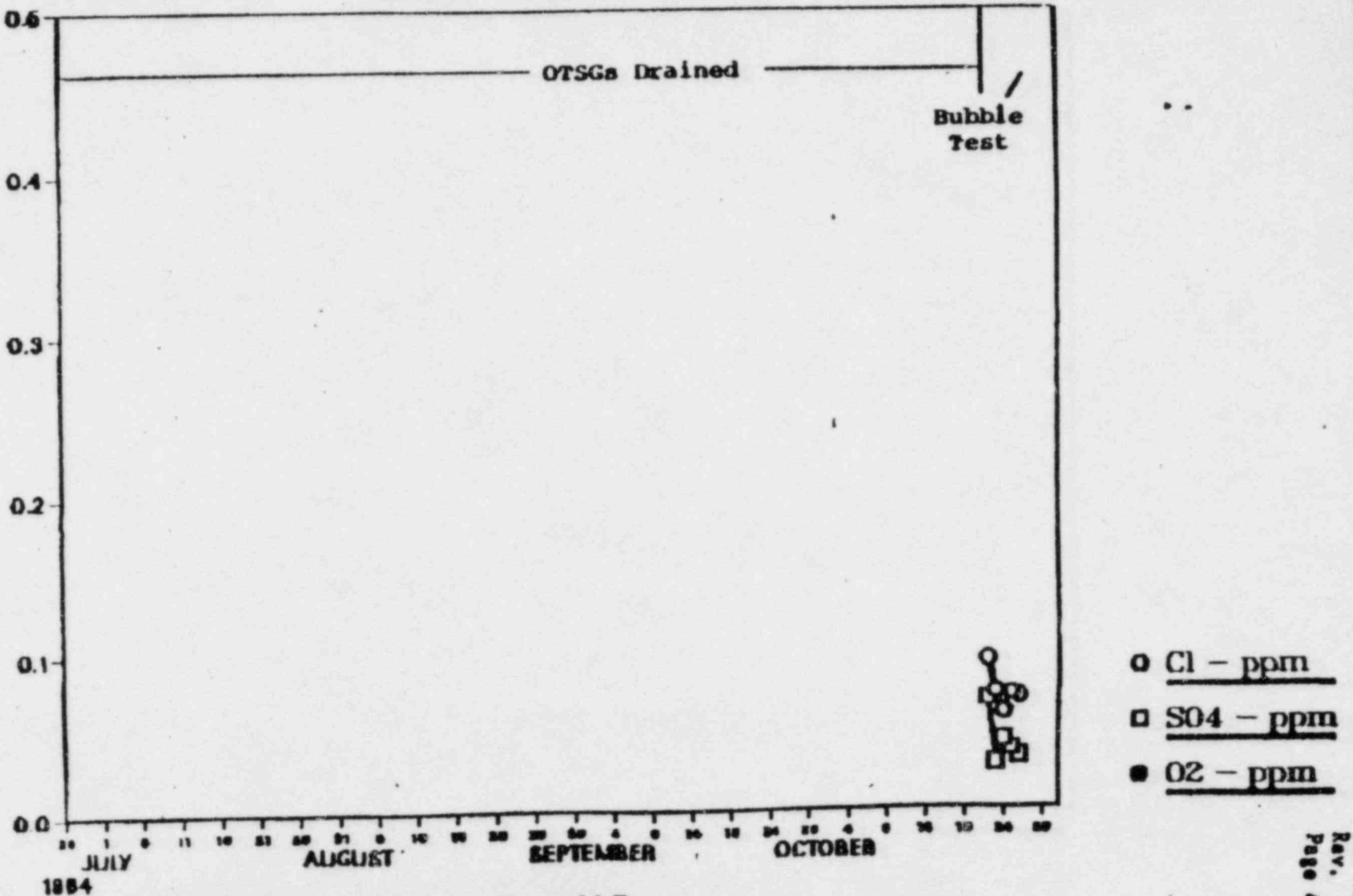

Figure A1-7a

CHEMISTRY DATA
PLUG REROLLING AND BUBBLE TESTING
June – October 1984

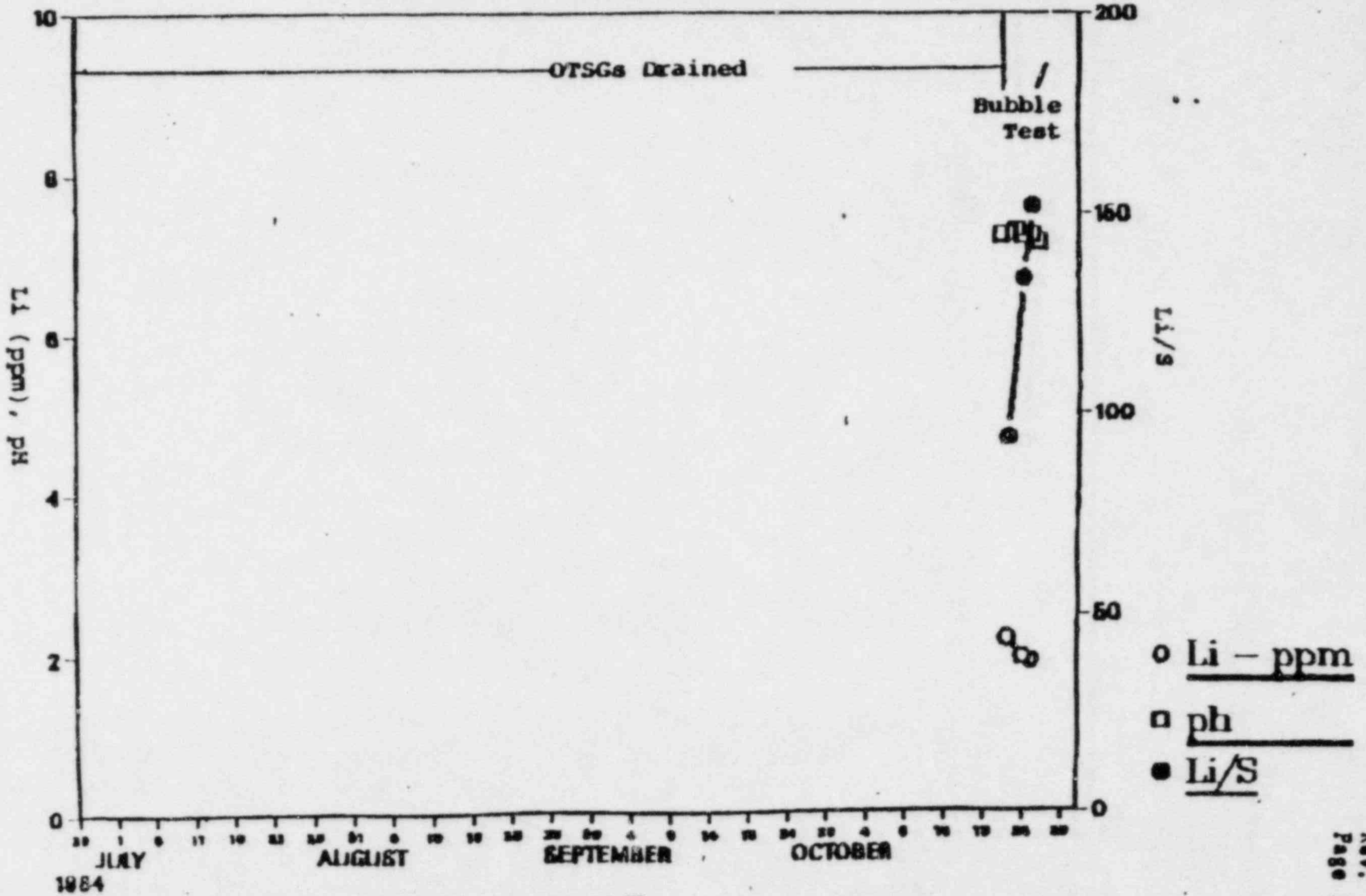

Figure A1-7b

APPENDIX C

GPU Nuclear **TECHNICAL DATA REPORT**	**TDR NO.** 652 **BUDGET ACTIVITY NO.** 123125	**REVISION NO.** 2 **PAGE** 1 **OF** 80
PROJECT: TMI Unit 1 OTSG Eddy Current Program	**DEPARTMENT/SECTION** Quality Assurance/Special Processes & Programs **RELEASE DATE**	**REVISION DATE**

DOCUMENT TITLE: Evaluation of the 1984 Required Technical Specification Examination for the TMI-1 OTSG

ORIGINATOR SIGNATURE	**DATE**	**APPROVAL(S) SIGNATURE**	**DATE**
G. E. Rhedrick See Rev. 0		R. O. Barley	11/22/85
M. T. Torborg	11-22-85	T. J. Patterson	11/22/85
D. L. Langan See Rev. 0		N. C. Kazanas N C Kazanas	11/22/85
		APPROVAL FOR EXTERNAL DISTRIBUTION	**DATE**
			12/2/85

Does this TDR include recommendation(s)? ☐ **Yes** ☒ **No** **If yes, TFWR/TR #**

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DRF 029572

ABSTRACT: Statement of Problem

The results of the 1984 eddy current examination performed on the TMI-1 steam generator tubing had identified 328 tubes with confirmed indications of ≥ 40% through wall penetration. These indications were not identified in previous eddy current examinations performed prior to mechanical thermal and hydraulic loading evolutions which took place in the steam generators.

Technical Approach

Knowing the locations of the 1984 confirmed indications, a review of the 1983 and 1982 examinations has confirmed the earlier presence for a majority of these indications. A characterization of the 1984 indications by defect location, signal amplitude, percent through wall and circumferential extent was performed and compared to the 1982 examination results. A growth sample study on a random selection of tubes was performed after the detection of the 1984 indications in order to determine if evidence of an active mechanism was occurring.

Findings

It was observed that the 1984 indications were located in the same affected axial and radial areas previously identified during the 1982 examination. The 1984 indications were predominately shorter in circumferential extent. The review of 1984, 1983 and 1982 examination results revealed that the percent through wall determination showed no trend of continued through wall growth. 90% of the new indications were of size at or near the threshold of GPUN standard differential technique sensitivit of detection. The results of the growth sample study showed no evidence of an active mechanism occurring during the period of observation.

Conclusion

The 1984 examination identified indications that were already present in the tubes in 1982 but because of their weak signal amplitude were masked by background noise. The mechanical, thermal and hydraulic loads imposed on the OTSG since 1982 examination may have enhanced the eddy currrent detection of small indications by increasing the signal amplitude but without evidence of increase to percent through wall.

•COVER PAGE ONLY

A0000030 4-83

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DOCUMENT NO.
TDR-652 Page 1A

TITLE Evaluation of the 1984 Required Technical Specification Examination for the TMI-1 OTSG

REV	SUMMARY OF CHANGE	APPROVAL	DATE
2	Page 1: Replaced Revision 0 cover page to permit signatures of different originators and approvers for Revision 2.		11-22-85
	Page 1: Changed wording in abstract to reflect conclusions of Section VI.		11-22-85
	Page 2: Revised Table of Contents to incorporate new Section VI.	TRBailey	11/22/85
	Page 4: Revised conclusion number two (2).	NCKazanas	11/22/85
	Pages 6, 10, 12, 13, 18, 19: Revised numbers of tubes to reflect final disposition of tubes.		
	Page 11: Added reference to Section VI.		
	Page 14: Added Note to Table 1.		
	Page 29: Added reference to Section VI.		
	Pages 34, 35: Corrected typos 20-40.		
	Page 35: Clarified first sentence.		
	Page 37: Added statement on accuracy of ECT at broached support locations.		
	Page 39: Added reference to Section VI.		
	Page 43: Added note to Table 5.		
	Page 43: Corrected typo 28-31.		

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DOCUMENT NO. TDR 652 Page 1B

TITLE Evaluation of the 1984 Required Technical Specification Examination for the TMI-1 OTSG

REV	SUMMARY OF CHANGE	APPROVAL	DATE
2	Pages 44-63: Added Section VI. Evaluation of Changes In The Eddy Current Signals From 1982 to 1984.		11-22-85
	Page 64: Renumbered Section.		11-22-85
	Page 66: Renumbered Section.		11/22/85
	Page 68: Added reference 6.		11/22/85
	Page 68: Renumbered Section.		
	Page 77: Corrected typo 3-coils.		
	Figures: Added Figure 7.		

GPU Nuclear

DOCUMENT NO.	TDR-652
TITLE	Evaluation of the 1984 Required Technical Specification Examination for the TMI-1 OTSG

REV	SUMMARY OF CHANGE	APPROVAL	DATE
1	The number of confirmed indications ≥ 40% thru wall in "A" Once Through Steam Generator has changed to 298 tubes from 297 tubes. The total number of tubes with indications ≥ 40% for both "A" & "B" has increased by one to 320. Pg. 12 add subtitle "Status of ISI Tubes." Revised Table 1, % T.W. & Volts 1983 & 1984. Revised Table 2, quantity of tubes in "A" OTSG with indications ≥ 40% to 22 from 20 and to 298 from 297. Revised Table 3, add column to report ISI tubes that were preventively plugged. Revised Table 4, revised quantity of tubes examined and tubes NR I to be in agreement with revision made to Table 3. Revised Table 5, % T.W. & Volts - 1983 & 1984.	3/26/85 TOB 3/26/85 RCK 3/27/85	

GPU Nuclear

DOCUMENT NO	TDR-652
TITLE	Evaluation of the 1984 Required Technical Specification Examination for the TMI-1 OTSG

REV	SUMMARY OF CHANGE	APPROVAL	DATE
1	The number of confirmed indications ≥ 40% thru wall in "A" Once Through Steam Generator has changed to 293 tubes from 297 tubes. The total number of tubes with indications ≥ 40% for both "A" & "B" has increased by one to 328. Pg. 12 add subtitle "Status of ISI Tubes." Revised Table 1, % T.W. & Volts 1983 & 1984. Revised Table 2, quantity of tubes in "A" OTSG with indications ≥ 40% to 22 from 20 and to 298 from 297. Revised Table 3, add column to report ISI tubes that were preventively plugged. Revised Table 4, revised quantity of tubes examined and tubes NR I to be in agreement with revision made to Table 3. Revised Table 5, % T.W. & Volts - 1983 & 1984.	G.E. Rhedrick/s/ R.O. Barley/s/ N.C. Kazanas/s/	3/26/85 3/26/85 3/27/85

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APPENDIX

SUMMARY

During the 1984 Technical Specification required eddy current examination, performed on the once through steam generator tubing at TMI Unit 1, a number of new relevant indications were detected in the "A" and "B" steam generator tubes. These new indications were not detected back in November 1982 when a full length eddy current examination was conducted on all the inservice "A" and "B" steam generator tubes. During both inspection periods the same eddy current examination technique was employed.

Since the 1982 eddy current examination both steam generators had undergone mechanical loading due to kinetic expansion tube repair and thermal/hydraulic loading due to two hot functional tests.

GPUN first determined that a new corrosion mechanism was not active. This was determined through repeat eddy current examinations on a controlled group of tubes in 1984 after initial detection of the new indications. This revealed that no growth or change in given eddy current signals occurred for the time period studied.

The 1984 indications were characterized as to size, location, depth and then compared to the 1982 examination results. GPUN concluded that the 1984 indications are a smaller additional subset of those detected in 1982 examination. The percent through wall and circumferential extent for 90% of the

1984 indications are of a size that approximates the threshold of detection for the measured sensitivity curve using the GPUN qualified standard differential eddy current examination process.

Detailed analysis of the new 1984 indications reveal, that by knowing the specific location of the indication, the majority can be found in the 1982 eddy current tapes. The indications that could be measured in the 1982 tapes including the in service inspection tubes reveal that:

(1) No new indications were detected in the ISI subset (one exception explained)

(2) The percent through wall assignments, as determined by phase angle measurement, did not show continued through wall degradation from 1982 to 1984.

(3) For indications not previously identified in 1982, the amplitude of the eddy current signal has substantially increased in the 1984 tapes which would result from some increase in the discontinuity volume. Presumably the latter is a reflection of the mechanical/thermal working of the tubing.

(4) For indications not previously identified in 1982 the increase in the amplitude of the indications in 1984 contributed to our ability to detect the small indications which now revealed themselves above the surrounding background noise. The latter combined with the low amplitudes associated with the signals from the indications prevented earlier detection.

Implicit within this fact, is that the earlier undetected indications were in fact very small. This is substantiated by the characterization studies for the 1984 indications which show them to be smaller percent through wall and circumferential extent than the 1982 indications. Additionally, the 1984 indications are located in areas which identify closely to intergranular stress assisted corrosion cracking revealed earlier in the 1981-1982 examinations.

I. INTRODUCTION

In November of 1984, eddy current examination was performed on the TMI - Unit 1, once through steam generator (OTSG) tubing in accordance with Technical Specification, 4.19. The examination ultimately included 14,615 tubes in the "A" OTSG and approximately 6,500 tubes in the "B" OTSG. This examination was concluded with a total count of 328 tubes with confirmed indications having tube wall degradation measuring 40 percent through wall or greater. This is a criterion that requires engineering disposition. There were another 309 tubes that had confirmed indications with a measured through wall degradation less than 40 percent. Those tubes with 20-40% through wall indication are classified "degraded" tubes and are required to be monitored for change at future examinations. In addition, those tubes which contain indications of 40% through wall or greater but do not meet the approved plugging criteria will also be monitored.

Since the last complete eddy current examination (1982 baseline) performed on the OTSG in 1982, the OTSG tubes have been subjected to mechanical loading due to kinetic expansion repairs and thermal and hydraulic loadings due to the two hot functional tests. The eddy current examinations performed subsequent to these loadings have resulted in the detection of indications not seen previously.

The analysis performed herein has the following purposes:

1. To characterize and report the indications identified during the 1984 examination and compare these characteristics with indications reported during the 1982 baseline examination. The purpose of this comparison is to evaluate the pattern of defect distribution and to determine if the affected areas correspond to the previously affected areas.

2. Determine the correlation of the kinetic expansion and subsequent hot functional test to the detection of indications not detected prior to these loading events. And, evaluate the impact from a chronological perspective.

3. Review the data from the 1984 Growth Program and evaluate the results to determine if evidence of continued tube degradation existed.

II. METHOD OF EXAMINATION

The eddy current examinations performed in November of 1984 utilized both standard differential and absolute eddy current examination techniques. This dual examination method was developed by GPUN to specifically detect and confirm small volume but predominately circumferentially oriented inner diameter defects. (See Appendix A)

The dual examination method involved first examining the tubing with a high gain standard differential technique using a .540" diameter eddy current probe. If no indications are detected the examination is complete and the tube is considered acceptable. Tubes found to have standard differential indications were examined a second time using the absolute 8x1 technique which used a probe having 8 independent coils. The absolute 8x1 examination determines the circumferential extent of the defect and also determines if the indications are relevant or non-relevant. A relevant indication is a flaw that has been confirmed by absolute 8x1 examination.

This dual examination method is the same method GPUN qualified and used for the 1982 baseline eddy current examination of the TMI-1 OTSG tubing (Ref. 1)

III. SCOPE OF EXAMINATION

The initial set of tubes for the 1984 eddy current examinations was a 3% sample selected in accordance with the requirements of Technical Specification 4.19. As required by 4.19, this set included all tubes remaining in service which were classified "degraded tubes." These tubes had previously reported indications of 20-40% through wall and are referred to as the ISI tubes. Approximately 50% of the 3% sample was from the high defect area (outer periphery) with the remaining 50% being located randomly throughout the generators.

The examination of the initial sample identified some discontinuities which exceeded the 40% through wall technical specification limit. As a result of these discontinuities, the examination scope was increased to include 100% of the tubes in the affected area of both OTSGs. This increased scope included 100% of the tubes in OTSG "A" and 100% of the tubes in the outer periphery of OTSG "B". This outer periphery is defined as the area outside the outer tie rod circle and includes approximately 6500 tubes.

The November 1984 examination was not continued into the center of the "B" generator because no confirmed indications ≥40% through wall were found in this area during the random examination. The indications reported in the "B" generator were at a significantly lower frequency than reported in the "A" generator. And their distribution declined sharply with distance from the outer perimeter and was bounded by the outer tie rod circle.

As part of the expanded scope, a selected 100 tube sample, designated the "A" Growth Program, was monitored in order to determine if there was an active mechanism initiating the 1984 eddy current indications. This sample was also comparatively evaluated against the eddy current tapes from the 1982 examination.

Examinations discussed within this report included the full length of the unexpanded region of the tubes. Expanded portions of the tubes cannot be effectively examined and evaluated with the standard differential technique and are therefore not included in the tubing examinations.

IV. RESULTS OF 1984 EXAMINATIONS

A. INDICATIONS REPORT

As a result of expanding the scope of the examinations, 14,615 tubes in OTSG "A" and approximately 6500 tubes in OTSG "B" were examined. Of these tubes, 298 in OTSG "A" and 30 in OTSG B were identified as having relevant indications 40% through wall or greater. In addition, 265 tubes in OTSG "A" and 44 tubes in OTSG "B" were identified as having confirmed indications from 20-40% through wall and are classified as "degraded tubes". These tubes and any tubes with confirmed indications 40% through wall or greater which do not meet the approved plugging criteria will be monitored during future examinations as "ISI tubes".

B. ISI TUBES

The subset of ISI tubes included 28 tubes in OTSG A and 56 tubes in OTSG B which had indications of 20-40% through wall penetration identified and recorded during previous examinations.

These ISI tubes were examined as a subset and an in depth evaluation and comparison of the 1984 data to the previous data was performed. The purpose of this evaluation and comparison was to determine if the previously identified indications had "grown".

The criteria used to establish growth addressed significant changes in percent through wall determinations, changes in signal voltage or changes in arc length of the monitored indication. When performing evaluations of this type, it must be noted that changes of about 10% through wall can be caused by a change of only 3 degrees in the phase angle measurement of the standard differential response signal. When addressing small voltage signals, measurement errors of this type can be expected. For the absolute 8x1, the orientation of the coils to the defect may change the number of coils an indication appears on by 1 additional coil during repeat examinations. The evaluations must therefore factor in these limitations on repeatability.

An indepth analysis of the phase angles of the indications from 1982, 1983 and 1984 was performed and is addressed in section VI of this TDR.

<u>ISI Tubes in the "A" Generator</u>

From the "A" generator 28 of the 28 ISI tubes showed no evidence of growth for any of the previously identified indications.

Two tubes, A-2-9 and A-88-128, had indications previously identified as being <40% through wall which were subsequently reported as ≥40% through wall in 1984. These indications were compared by the data analyst on a one-to-one basis to the previous data and it was determined that the change in the percent through wall determinations were caused by variations in the repeatability of the overall eddy current process and not by the physical changes in the tube. (See Table 1).

ISI Tubes in the "B" Generator

In OTSG "B" there was no indication of "growth" for 56 of the 56 tubes. One tube B-98-5 did have an indication reported as greater than 40% through wall and required further evaluation. The details for this tube are shown in Table 1.

The 1984 and previous data for this tube was re-evaluated by the data analyst to compare the eddy current signal's shape. The analyst determined the variation in the percent through wall determinations was attributed to distortion of eddy current signals caused by multiple indications and was not a result of physical changes in the tube.

Status of ISI Tubes

A number of tubes previously placed in the ISI category during the 1982 baseline examination were determined to have non-relevant indications as a result of the 1984 absolute 8x1 examination.

These tubes had non-relevant indications as determined by absolute 8x1 in 1982 but were placed on the ISI list for monitoring purposes in order to verify the precision of the absolute 8x1 confirmation exams during future dual examination exercises. With the completion of the 1984 examination and the consistency of reporting the same standard differential indication as non-relevant, these tubes were removed from the ISI list.

The number of ISI tubes (Degraded Tubes) has increased as 254 tubes in OTSG A and 20 tubes in OTSG B had confirmed indications from 20-40% through wall in 1984 which were not previously identified. This puts the present population of ISI tubes between 20-40% through wall at 265 tubes in "A" and 44 tubes in "B".

Table 1

ISI Confirmed Indications Greater Than 40% Through Wall in 1984

Gen	Row Tube	Indication Elevation	Origin	April 1983 Post KE Data		Nov. 1984 Post HFT Data	
				% T.W.	Volts	%	Volts
A	2 - 9	US+06*	ID	40%	1.7	45%	1.6
A	88 - 128	12+05	ID	<20%	0.9	31%	1.4
		13-09	ID	<20%	0.6	<20%	0.6
		US-11	ID	23%	1.9	41%	2.5
B	99 - 5	US+07*	ID	37%	2.3	48%	4.0
		US+01	ID	<20%	1.9	<20%	2.0
		US+04	ID	<20%	2.3	21%	3.5

*immediately below expanded area

Note: These tubes were removed from service in 1985.

C. CHARACTERIZATION OF INDICATIONS

The indications detected during the 1984 examinations were characterized by the location and extent of degradation based on the eddy current response signal. Details, listing the data in support of this section are included in Appendix B.

The characterization is further defined by comparing the 1984 indications with those reported in 1982. For this comparison GPUN used the 1984 data described previously and the 1982 standard differential high gain data base. The 1982 data base included all tubes examined using the GPUN dual examination method prior to 1984. This data base was previously used to disposition the OTSG tubes for the kinetic expansion process and subsequent tube plugging. This data base contains the 1982 baseline results which are summarized in TDR 442. (See Ref. 2).

Both the standard differential and absolute techniques are used to furnish these characterization as described below.

Standard differential response signal offers the following:

a. Amplitude (this relates to the defects geometry and volume, and is reported as a voltage reading).
b. Percent through wall (this relates to the response signal's phase angle and is measured in degrees).

c. Axial locations are reported by distance from the tube support plates that are spaced at known elevations in the generators.

Absolute 8x1 signal offers the following:

a. Number of coils (this relates to the defect's circumferential extent). The maximum circumferential extent is 8 coils and represents a defect circumferential arc length that could be as much as 360 degrees.

NOTE: Amplitude, phase and axial location are also recorded on the absolute 8x1 results; however, these results are used only to confirm the standard differential indications.

1. RADIAL DISTRIBUTION

The indications detected during the 1984 examination were located in essentially the same areas of the OTSGs as those discovered in 1982. The indications were located predominately towards the outer periphery of both OTSG A and B. In addition to the indications located in the periphery there was also a smaller number of indications present in the center of OTSG A. No indications greater than or equal to 40% through wall were reported in the center of OTSG B. (See Figures 1a and 1b).

2. AXIAL DISTRIBUTION

The axial location of the 1984 indications can be characterized as being towards the top of the OTSGs. For OTSG A, 79 percent of the indications during the 1984 examination are located in or above the 15th span with 57 percent of the indications in OTSG B located in this region. This corresponds with 82 percent in "A" generator and 74 percent in "B" generator for the 1982 examination.

In order to compare the 1982 and 1984 axial distributions, it must be noted that the majority of the indications detected during 1982 were within the upper tube sheet area and were captured by the kinetic expansion process. As a result of the expansion process and the coining of the tube wall against the tube sheet an examination of the coined area was not possible using the standard differential probe. Only the area of the tube below the expansion zone could be examined using the standard differential technique.

With the exception of the upper tube sheet region, the overall distribution of the indications in 1984 closely resembles the 1982 distribution. This distribution shows the indications are concentrated towards the uppermost regions of the OTSGs and the frequency of occurrence decreases sharply at the lower regions (See Figures 2a and 2b).

3. SIGNAL AMPLITUDE

The majority of the discontinuities detected in 1984 were small volume as indicated by the amplitude of the standard differential signal. In OTSG A, 93 percent of the 1984 indications detected were 2 volts or less in amplitude, while in OTSG B 74 percent of the indications were in this category.

This voltage distribution corresponds to approximately 93 percent of the 1982 indications in OTSG A and 78 percent of the indications in OTSG B as being 2 volts or less. (See Figures 3a and 3b).

To establish a reference volume for the discontinuities in this range, a comparison can be made to the responses from the calibration standard. This standard has a 100% through wall 0.052" diameter drilled hole which produces a 15 volt response signal for calibration purposes. This indicates that the discontinuities present in the OTSGs are of a significantly smaller volume than the calibration standard.

4. PERCENT THROUGH WALL

The 1984 eddy current examination results have shown that a considerable number of the reported indications measured less than 40% through wall penetration. The 1984 examination reported 563 tubes in "A" and 74 tubes in "B" with confirmed indications. In the "A" generator the indications in 47% of the 563 tubes were less than 40% through wall and in the "B" generator the indications in 59% of the 74 tubes were less than 40% through wall.

For the 1982 examination, the results indicated higher percent through wall degradation. In the "A" generator, 50% of the indications reported were 90% through wall penetration or greater while 3% of the reported indications were less than 40% through wall. In the "B" generator, 16% of the indications reported were 90% through wall penetration or greater and 40% of the reported indications were less than 40% through wall. (See figures 4a and 4b).

The contrast between the 1982 and 1984 examination results for percent through wall comparison must consider that most of the tubing within the upper tubesheet region could not be examined in 1984. This region accounted for 63% in "A" and 61% in "B" of the reported indications in the 1982 examination. This comparison serves as an approximation only, since an improved inner diameter conversion curve was used for the November 1984 examinations (Ref. 3).

5. CIRCUMFERENTIAL EXTENT

To confirm the relevancy of the reported standard differential indication an absolute 8x1 examination is performed. The number of coils that respond to a relevant indication provides an estimate of the indication's circumferential extent. The 1984 examination results showed that the confirmed indications ranged from 1 to 3 coils. The circumferential extent for a one coil indication is from the threshold of detection to 0.194". A two coil indication is from 0.024" to 0.413" whereas a three coil indication is from 0.219" to 0.632". (Ref. 4). For the "A" generator approximately 90% of the confirmed indications were 1 coil, approximately 10% were 2 coils, and only 2 indications were 3 coils of which one was outer diameter. For the "B" generator 79% of the confirmed indications were 1 coil, 20% were 2 coils, and only one was 3 coils.

For the 1982 examination the results showed that the confirmed indications ranged from 1 to 8 coils. For the "A" generator 56% of the confirmed indications were 1 coil, and for the "B" generator 50% of the confirmed indications were 1 coil. A greater number of 2 coil and greater indications were confirmed by absolute 8x1 during the 1982 examination than in the 1984 examination. (See figures 5a and 5b).

D. SUMMARY OF INDICATION CHARACTERIZATION

The eddy current examinations performed in 1982 and 1984, both utilized the GPUN qualified examination program using a combination of standard differential high gain .540" probe and absolute 8x1 probe. This dual examination method was developed to detect intergranular stress assisted cracking, predominately circumferentially oriented and initiated on the tube's inner diameter wall.

The 1982 eddy current examinations prior to the kinetic expansion repair were full length examinations performed on all in service tubes in both "A" and "B" generators. The 1984 examination were also full length however the kinetic expanded area could not be examined.

Some tubes could not be examined with the S.D. .540" probe below the center of the lower tubesheet due to ligament distortion from adjacent explosive plugs.

The comparison of the 1982 to 1984 data showed both similarities and differences in the characterization of the indications reported. The characterization of the axial and radial distribution showed the indications occurred in the same regions of the OTSGs in both 1982 and 1984. The amplitudes of the indications also appears to be similar in 1982 and 1984. The differences between the two sets of data appear in the percent through walls, which are significantly lower in 1984 than in 1982 and in the circumferential extent which is also smaller in 1984 than in 1982.

This characterization and comparison would suggest the 1984 indications are a smaller additional subset of those detected during the 1982 examination.

To determine how the size of the new 1984 indications reflect on the given sensitivity curve established in TDR 401 and 423, the maximum size of the new indications detected was established and compared to the above. It was determined that approximately 90% of the indications are a maximum of one coil. (Note: a one coil indication if not preferentially oriented could give a two coil response). Additionally, approximately 90% of the new indications were determined to be between 20-60% through wall. Using this data against the sensitivity curve shown in TDR 423, the new indications appear to predominately reveal themselves at or near the threshold of detection of the given sensitivity curves.

It was determined that approximately 10% was from a population that had ≥60% through wall determination. For indications ≥60% through wall all were 1 or 2 coils with the exception of one indication in tube B-97-5. The indication (76% through wall, 3 coils) was located at the upper tube sheet lower face region. It is expected that the sensitivity for detection is suppressed during the eddy current probe passage into and out of (0.5" distance) this region. (Ref. 1).

The two other 3 coil indications in tubes A-84-131 and A-79-1 had <20% and 52% through wall determinations respectively.

The three, 3 coil circumferential extent indications, and the ≥60% through wall indications are of dimension below those analyzed to withstand the main steam line brake loadings (See Figure 6).

The following is the breakdown of the 1982 and 1984 characterization:

		1982	1984
1.	Radial Distribution	Predominately in the outer periphery of both "A" & "B" (significantly fewer in "B")	Predominately in the outer periphery of both "A" & "B" (significantly fewer in "B")
2.	Axial Distribution	Predominately in the UTS Region ≅63%, and 16th span ≅14%	Most in UTS Region ≅50%. Some in 16th span ≅19%
3.	Amplitude (Voltage)	76% less than 2 volts in "A" and 51% less than 2 volts in "B"	75% less than 2 volts in "A" and 47% less than 2 volts in "B"
4.	Percent Through Wall	50% greater than 90% T.W. and 96% greater than 40% T.W. in "A". 16% greater than 90% T.W. and 60% greater than 40% T.W. in "B"	2% greater than 90% T.W. and 40% greater than 40% T.W. in "A". 1% greater than 90% T.W. and 27% greater than 40% T.W. in "B"

	1982	1984
5. Circumferential Extent	The indications ranged from 1 to 8 coils in both "A" and "B". For "A" more than 90% of the indications were 1 and 2 coils (66% - 1 coil and 30% - 2 coils). For "B" more than 90% of the indictations were 1, 2, 3 coils (50% -1, 34% -2 coils and 8% - 3 coils)	The indications ranged from 1 to 3 coils in both "A" and "B". For "A" 90% of the indications were 1 coil. For "B" more than 90% of the indications were 1 and 2 coils (79% - 1 coil and 20% - 2 coils). There was a total of 3 indications with 3 coils 2 were inner diameter and 1 was outer diameter

V. REVIEW OF PRE KINETIC, POST KINETIC & POST HOT FUNCTIONAL EXAMINATION DATA

A. OVERVIEW

GPUN performed a 100% Examination of the OTSG tubes in 1982. This examination is referred to as the 1982 baseline.

Since performing this examination GPUN has reexamined a select number of the OTSG tubes to monitor the effects of the kinetic expansion repair (KE) and the subsequent hot functional testing (HFT).

These examinations revealed the presence of indications which were not previously identified during the 1982 baseline examinations. To more fully understand the appearance of these indications GPUN performed detailed evaluations of the available eddy current data to determine if the indications had been present but could not be detected on previous examinations or if the indications were in previously unaffected areas of tubing.

Included in these evaluations were data sets of:

1982 In Process Examinations for Kinetic Expansion (October, 1982)

Purpose: Determine the effects of kinetically expanding the OTSG tubes.

This data set consisted of examining 437 tubes in OTSG A and B after the tubes were expanded. The data was then compared to the 1982 baseline.

1983 Post KE Examinations (April, 1983)

Purpose: Determine the effects of the complete kinetic expansion process on the OTSG tubes.

This data set consisted of examining 477 tubes in OTSG A & B after the kinetic expansion repair was completed. The data was then compared to the 1982 baseline. This data set includes the ISI tubes.

1984 Post HFT Examinations (November, 1984)

Purpose: Determine the cumulative effects of the kinetic expansion repair and subsequent HFT on the condition of the OTSG tubes.

A data set of 375 tubes was identified from the November 1984 population which remained in service for which GPUN had 1983 post kinetic expansion data. This data set includes the ISI tubes. This data was then compared to the 1983 post kinetic expansion and the 1982 baseline data.

Also included in the review were 45 tubes with indications identified as >40% through wall, during the 1984 examinations. These tubes were selected from tubes included in the 1984 flaw growth program. Since no 1983 post KE data was available, the evaluation results were compared to the 1982 baseline.

B. METHOD OF EVALUATION

During the evaluations, the data analyst reviewed the magnetic tapes of the previous eddy current data for tubes with newly detected indications. This review was accomplished by isolating the specific area of interest and performing a detailed review of the eddy current signals. By isolating the known area of interest, the data analyst was able to perform an intense analysis of the eddy current signals at a higher level of sensitivity than allowed by production analysis techniques. This intense focus permitted the data analyst to identify the possible presence of low level eddy current signals which may be masked by background noise during production analysis.

Once the signal was identified and isolated, the analyst then measured and recorded the signals amplitude, which indicates the volume of the discontinuity, and the phase angle, which indicates the depth of the discontinuity.

The amplitudes and phase angles of the signals were then characterized to determine the relative size of the discontinuities. The evaluations from the successive examinations were then compared to establish when the signals were first detectable by eddy current. This also characterized any changes which made the signal detectable by production eddy current techniques.

C. RESULTS OF EVALUATIONS

As a result of the evaluations performed on these data sets GPUN concluded that:

1. Knowing the exact location of a reported indication, most of the indications could be identified in previous examination data. This indicated the discontinuities were previously present but not detectable due to their low amplitude.

2. As a result of the kinetic expansion and the hot functional testing the amplitude of previously unidentified signals increased making the signal response more detectable. This was typically a 100-200% increase in amplitude which brought the signals above the threshold of detection. This can be attributed to an increase in the volume of the discontinuity.

   Example: 1984 data shows 1.5 volt signal in 0.5 volt noise.
   re-review of 1982 data shows 0.5 volt signal in 0.5 volt noise at the same location.

3. Although the amplitude of the signals increased, the phase angle of the signals did not show a corresponding increase for the indications first detected in 1984. This would indicate that, although the volume of the discontinuity changed, the percent through wall penetration remained constant. This is discussed in greater detail in Section VI of this TDR.

4. The new (1984) indications which were reviewed are located at the upper elevations of the OTSGs. This corresponds to the previously affected areas of the OTSGs identified during the 1982 examinations.

D. DETAILS OF EVALUATIONS PERFORMED

The following is a brief description of the evaluations performed and the details of the data sets utilized. The data sets are presented in chronological order to demonstrate the cumulative effects of the various OTSG activities upon the tubes since the 1982 baseline. This chronology is also contained in Table 2.

1982 In Process Examinations for Kinetic Expansion (October, 1982)

Purpose: Determine the effects of kinetically expanding the OTSG tubes.

In order to monitor the effects of the kinetic expansions GPUN examined 437 tubes. The tubes selected for these examinations were the first tubes to be expanded, located in rows 1-8, in both OTSGs.

This examination identified discontinuities which were not previously recorded in 15 of the 437 tubes examined (3.5%). An evaluation was performed at that time to determine why the indications were not identified previously.

This evaluation is documented in TDR 401 (Ref. 4) and TR-008 (p. 44-45) (Ref. 5) and concluded that:

1. The indications were not initiated by the kinetic expansion process nor was there any evidence of detectable propagation of existing indications.

2. The defects were small (threshold) type indications that had either been masked by the high background noise levels in the upper tube sheet regions or were sufficiently tight that significant metal removal was not present to permit detection. Kinetic expansion may have altered these areas to make them more detectable.

1983 Post Kinetic Expansion Examinations (April, 1983)

Purpose: Determine the effects of the Kinetic Expansion Repair and associated Tube Plugging Activities

GPUN examined a sample of 477 tubes in OTSGs A and B using the dual examination method. This sample was selected to determine if the kinetic expansion process had significantly altered the condition of the OTSG tubes.

The sample was based on the requirements of GPUN specification SP-1101-22-014 which is summarized in TR-008 Appendix A (p. 109-113). The sample requirements are summarized below:

(a) All tubes with <40% through wall indications which remained in-service. (ISI Tubes)

(b) All tubes adjacent to 10 selected simply plugged tubes with defects in the 15th, 10th and 1st spans. (10 tubes each OTSG).

(c) All tubes adjacent to 10 selected simply plugged tubes, in the periphery of each OTSG.

(d) 50 tubes in high plugging density areas in each OTSG.

(e) All tubes adjacent to 5 plugged tubes in each OTSG with >3 volt signals in the lower part of the OTSGs.

(f) In addition to (a) through (e) above, all tubes identified as leaking during the post repair drip and or bubble tests were included.

The examination of the above sample of tubes provided an evaluation of the "worst case" areas of the OTSGs. The examination resulted in the identification of indications ≥40% through wall which were not previously recorded in 35 tubes (7.5%). In addition, 1 of the indications previously identified as being <40% through wall in OTSG A appeared as ≥40% and required further dispositioning. The comparison of the tube status prior to and after the kinetic expansion process is summarized in Table 3 and in TR-008, Appendix A (p. 109-113).

In its 1983 evaluation GPUN reviewed the 1982 baseline to establish the cause of the newly detected indications. This review concluded that:

1. The majority of the indications could be detected during detailed reviews of specific areas of the 1982 baseline data. These reviews showed the indications had typically been present at low amplitudes and signal to noise ratios of 1 to 1 or less.

2. The kinetic expansion process apparently caused the amplitude and corresponding signal to noise ratio of the indications to increase thereby making them more detectable.

3. The indications were located near the top of the OTSG. Twenty eight (28) of the 35 (80%) of the indications ≥40% through wall which had not previously been detected were located within the upper tube sheet. This would be the area most affected by the kinetic expansion process.

4. The phase angles of the indications reported in 1983 did not show a relevant increase in the percent through wall when compared to the 1982 baseline data.

GPUN also reviewed the 1982 baseline and 1983 post KE data to determine if the indication (ISI tube in 1982) previously identified as being <40% through wall in 1982, and then reported as greater than 40% through wall in 1983, indicated a change in the status of the tube. A detailed review of this tube and prior associated indications revealed that they were outside diameter originated and are therefore not part of this evaluation for primary side attack. Its disposition was covered by the TMI Unit 1 technical specifications requirements and the tube was removed from service.

1984 Post Hot Functional Testing Examinations (November, 1984)

Purpose: Determine the cumulative effects of the kinetic expansion repair and subsequent hot functional testing on the condition of the OTSG tubes.

Following the hot functional testing (HFT) performed after the kinetic expansion repairs (KE) GPUN performed the 1984 examinations of the TMI OTSGs. These examinations provided a basis for determining the cumulative effects of the kinetic expansion repair and subsequent hot functional testing of the OTSG tubes. These examinations identified indications not recorded in previous examinations. To characterize the newly recorded indications and determine when they could first be detected, GPUN performed extensive reviews of the historical data for 2 data sets. These data sets are discussed in (A) and (B) below.

(A) The first data set selected for evaluation from the November, 1984 data set was 375 tubes for which post kinetic expansion data was available. This data set included:

(1) All tubes remaining in service in OTSG A which were previously examined during the 1983 post KE examination. This consisted of 163 tubes with no previously recorded indications and 28 tubes previously identified as having 20-40% through wall indications (ISI Tubes).

(2) All tubes in the outer periphery of OTSG B which had been examined in 1983 and remained in service following the 1983 post KE examinations. This consisted of 128 tubes with no previous indications and 56 tubes previously identified as having 20-40% through wall indications (ISI Tubes).

As a result of these examinations, 14 of the 291 (5%) tubes with no previous indications were identified as having indications ≥40% through wall. Of the 84 previous ISI tubes, 3 tubes had indications reported in 1984 which had not been previously identified in 1983. These 14 tubes with no previous indications and the 3 ISI tubes are discussed separately below. The results of the examinations are summarized in Tables 4 and 5.

Tubes With No Previous Indications

For the 14 tubes with indications ≥40% through wall which were not previously recorded, a complete evaluation of the historical data was performed. The review characterized the indications and determined if they had been present during the previous examinations. This evaluation concluded that:

1. During the review of the 1983 post KE data, 14 of the 14 indications were detectable but were low amplitude signals within the noise. During the review of the 1982 baseline

data, 9 of the 14 indications could be identified. This would suggest that both the kinetic expansion and hot functional testing increased the detectability of the indications.

2. The amplitude of the indications increased from the 1983 post KE examination to the 1984 post HFT examinations making them more detectable from the surrounding noise.

3. The indications recorded during the 1984 Post HFT examinations have a small circumferential extent as shown by the 8x1 absolute probe. Of the 14 indications having ≥40% through wall penetrations, 13 appear as 1 coil and 1 appears as a 2 coil indication. A 360° indication would appear as an 8 coil indication.

ISI Tubes

For the three previous ISI tubes which have indications ≥40% through wall, which were not previously identified and reported in 1983, the evaluations are as follows:

One tube A-120-106 showed an additional indication which was identified as being 95% through wall and 4.0 volts and was located at the edge of the 15th support plate.

Upon a re-review of the 1983 Post Kinetic Expansion Data it was determined that the indication was present at approximately 55% through wall and 2.1 volts but the signal was masked by the signal from the tube support plate. The effects of the support plate signal also distorts the phase angle of the eddy current signal making an accurate percent through wall determination impractical.

This particular tube support is a drilled support and cannot be "mixed out" using the multifrequency eddy current techniques used to examine the broached supports located throughout the remainder of the OTSGs. This creates a zone of reduced sensitivity (approximately .5" above and below the edges of the support plate) at the drilled support locations. The 1983 signal at 2.1 volts is below the 3.3 volt threshold of detection for the drilled support plate as established in TDR 423.

This zone of reduced sensitivity applies to the edges of both the upper and lower tubesheets and the drilled hole in the 15th support plate. The drilled holes are located only in the extreme outer periphery of the 15th support plate. The remainder of the 15th support plate and the other 14 support plates are the "broach" design and although they reduce the accuracy for sizing indications in this area, they do not have this zone of reduced sensitivity for detection of indications.

The other two tubes, A-3-31 and A-149-14, had indications greater than 40% through wall reported in 1984 which had not been previously identified. In the re-review of the 1983 data at the specified location, the indications were identified and compared to the 1984 data. This comparison showed the indications were low amplitude signals masked by noise in the 1983 data. (See Table 5).

(B) The second data set selected for evaluation from the November 1984 data set was 46 tubes with indications first identified during the 1984 examinations. This data set included:

(1) 12 tubes with indications less than 40% through wall and 34 tubes with indications greater than 40% through wall. The tubes selected for this evaluation were previously included in the 1984 Growth Program. The tubes were located in the outer periphery of the OTSG A.

The indications were characterized and compared to the 1982 baseline data. The results of the evaluation conclude that:

1. Knowing the exact location of the 1984 indications, the corresponding indications could be identified during a review of the 1982 baseline data for 32 (70%) of the tubes. This would indicate the areas had been affected prior to the 1982 baseline examinations.

2. A comparison of the 1982 to 1984 data shows the average amplitude increased from 0.6 volts in 1982 to 1.5 volts in 1984. This demonstrates the amplitude of the indications increased during this time period making them more detectable.

3. The comparison of the 1982 to 1984 percent through wall determinations showed a slight downward trend of approximately 11 percent through wall (equivalent to 3° phase angle change). Based on this phase angle evaluation, no significant trend of through wall growth can be established. This trend is further discussed in Section VI of this TDR.

Table 2

Chronology of Steam Generator Evolutions and Corresponding Eddy Current Examination

Steam Generator		Eddy Current Examination		
Event	Duration	Data Sets	Results > 40% T.W.	
			A	B
Start-up & Test - 131 tubes leak	Oct-Nov 1981	July-Sept 1982 (1982 baseline)	885	273
Kinetic Expansion Repair	Oct-Dec 1982	Oct-Nov 1982 (in process)	9	6
		April-May 1983 (Post)	22	14
Hot Functional Test	Aug-Oct 1983 May 1984		- -	- -
Leak Test	June 1984	July 1984	0	1
Dry Lay up	June-Nov 1984		-	-
Tech Spec 4.19	Nov-Dec 1984	Nov-Jan 1984	298	30

Table 3

Results of 1983 Post Kinetic Expansion Examinations

Status Prior to Kinetic Expansion (1982 Baseline)

OTSG	Tubes Examined	Tubes NRI	Tubes <40% (ISI Tubes)	Tubes ≥40%	** ISI Tu Prevent Plug
A	215	200	14	0	
B	263	212	51	0	_
TOTALS	478	412	65	0	

Status After Kinetic Expansion (1983 Examinations)

OTSG	Tubes Examined	Tubes NRI	Tubes <40%	(ISI Tubes)	Tubes ≥40%		** ISI T Preven Plug
A	214	163	28	(12 previous ISI) (16 previous NRI)	22	(1* previous ISI) (21 previous NRI)	
B	263	193	56	(51 Previous ISI) (5 Previous NRI)	14	(0 previous ISI) (14 Previous NRI)	_
TOTALS	477	356	84		36		

NRI - No Relevant Indications

NOTES: * In 1 tubes, indications reported as <40% through wall in 1982 were reported as ≥40% through wall in 1983. These indications are outside diameter initiated and are not considered relevant to the present evaluations.

** These ISI tubes were preventively plugged in accordance with engineering dispositioning based on location (axial and/or radial) of <40% thru wall indications.

Table 4

Results of Post Hot Functional Testing Examinations

Status of Tubes Prior to H.F.T.

OTSG	Tubes Examined	Tubes NRI	Tubes <40% (ISI Tubes)	Tubes ≥40%
A	191	1[illegible]	28	0
B	184	1[illegible]	56	0
Total	375	291	84	0

Status of Tubes After H.F.T.

OTSG	Tubes Examined	Tubes NRI	Tubes <40% (ISI Tubes)	Tubes ≥40%
A	191	133	39 (23 previous ISI) (16 previous NRI)	19 (5 previous ISI) (14 previous NRI)
B	184	127	56 (55 previous ISI) (1 previous NRI)	1 (1 previous ISI) (0 previous NRI)
Total	375	260	95	20

NRI = No Relevant Indications

Table 5

ISI Confirmed Indications

Greater Than 40% Through Wall in 1984

				April		Nov.	
		Indication		1983 Post KE Data		1984 Post HFT Data	
Gen	Row Tube	Elevation	Origin	% T.W.	Volts	%	Volts
A	3 - 31	13+0	ID	33%*	1.1	33%	1.5
		13+04	ID	27%**	0.8	<20%	1.3
		13+05	ID	33%**	1.3	36%	3.3
		13+08	ID	40%**	0.6	45%	1.5
		13+15	ID	30%**	0.3	28-31%	0.8
A	149 - 14	14-06	ID	86%**	0.4	76%	0.6
		15-16	ID	80%**	0.5	69%	0.7
		US+04	ID	20%	1.0	Not Detected	
A	120 - 106	12+09	ID	40%**	0.5	41%	1.4
		13-08/15-08	ID	50%**	0.4	48%	0.7
		15-0	ID	55%**	2.1	95%	4.0
		US+02	ID	20%	1.1	20%	1.2

* Represents re-evaluation of 1983 data.

** Indications not previously identified during production examinations, indications first identified during 1984 review of 1983 data.

Note: These tubes were removed from service in 1985.

VI. EVALUATION OF CHANGES IN THE EDDY CURRENT SIGNALS FROM 1982 to 1984

A. OVERVIEW

GPUN's evaluation of the historical data (1982, 1983) for indications first detected in 1984 revealed changes in the eddy current signals from 1982 to 1984. These changes are characterized as an increase in the amplitude (voltage) of the signal with a corresponding decrease in the phase angle of the eddy current signal. This phase angle change has resulted in an apparent decrease in the depths of the indications observed from 1982 to 1984. This phenomenon was first identified in 1984 during a review of the historical data for the tubes included in the OTSG A growth program discussed in Section VII of this report. To better understand the cause and impact of these changes in the ECT signals, GPUN evaluated additional sets of available data considered most applicable. These data sets included tubes previously identified as ISI tubes (Degraded Tubes), tubes previously removed from the OTSGs, tubes subjected to Long Term Corrosion Testing (LTCT) and tubes with synthetic defects (EDM Notches) previously used as qualification standards for the GPUN examination techniques.

The purpose of these evaluations was to:

1) Investigate the cause of the changes in the ECT signals
2) Determine the impact of the changes in the ECT signals on the GPUN ECT program.
3) Quantify the degree of change in terms of percent through wall.

4) Identify the areas in the OTSGs in which the ECT signals were affected.

5) Determine the effect of the changes on future ECT examinations.

The evaluations performed by GPUN to address these areas are discussed in the body of this section.

B. CONCLUSIONS

Through the evaluations of the available eddy current data from 1982, 1983 and 1984, GPUN was able to characterize and further define the "phase shift" (decrease in phase angle) previously identified in Revision 0 of this TDR. These evaluations have demonstrated that the present GPUN ECT techniques, used to disposition the 1984 examination data, are acceptable as presently qualified and are not affected by the observed changes in the ECT signals. Although GPUN was unable to determine the root cause of the "phase shift", the following conclusions can be drawn from the technical evaluation of the available data.

- The review of the ECT process variables shows the reported "phase shift" is <u>not</u> a result of changes in the ECT techniques
- The metallurgical data indicates the GPUN ECT program is acceptable for dispositioning ECT signals which have been affected by the observed changes.

- The "phase shift" initially identified as -11% through wall included both changes in the ECT signals and variability in the ECT data evaluation process. This phase shift was redefined as -6.9% through a reevaluation of the data.

- The "phase shift" which was initially identified in the OTSG "A" Growth Sample from 1982 to 1984 has also been identified in the OTSG "A" ISI tube samples from 1982 to 1983.

- The shift in phase angles appears to have occurred at all axial and radial locations in the OTSG where inner diameter indications were observed.

- The OTSG A ISI Tubes (Degraded Tubes) demonstrate that once the discontinuities become detectable during production examinations, the phase angle of the ECT signal remains constant (within expected repeatability) during subsequent examinations.

- The percent through wall penetrations of ECT indications of one (1) volt or greater are shown to be accurately evaluated using the qualified GPUN ECT Program. Indications of less than one (1) volt have been shown to result in the assignment of overly conservative percent through wall values. At a minimum these indications will be evaluated and monitored during successive inspections.

C. ECT PROCESS REVIEW

Prior to evaluating the changes in the ECT signals, GPUN reviewed the variables involved in the overall ECT process to verify the validity of the data sets. The variables reviewed included both the ECT data collection process and the subsequent data evaluation process. The review of the data collection process included the ECT equipment, probes, calibration standards and calibration techniques used during the 1982, 1983 and 1984 examinations. The data evaluation techniques were also reviewed to determine if changes in the method of analysis from 1982 to 1984 or variations between the data analysts could be identified.

The review of the process variables was performed using certified data analysts from two separate NDE contractors. This review concluded that the ECT techniques used in 1982, 1983 and 1984 were consistent and the changes identified in the ECT signals were not the result of changes in the process variables. The results of this review are documented separately.

During the review of the evaluation techniques, GPUN and their ECT contractors determined the inherent variability of the ECT evaluation process was introducing additional data scatter into the data evaluation process and biased the initial comparisons of the 1982 and 1984 data. After identifying this variability GPUN was able to account for this bias in subsequent evaluations.

D. DISCUSSION OF SIGNAL CHANGES

To further define the extent of the identified phase angle changes GPUN characterized both the signal to noise ratios (S/N Ratios) of the ECT signals and the shapes of the ECT signals. This characterization was performed for both the 1982 and 1984 ECT signals and showed a definite change in the signals during this time period.

This characterization showed the 1982 signals were predominantly very tight looped, straight signals, with very poor signal to noise ratios (typically less than 1 to 1). By contrast, the 1984 signals exhibited broader loops with complex signal formations. The signal to noise ratio of the 1984 signals was also greatly improved over the 1982 signals. Typical changes in the signals from 1982 to 1984 are shown in Figure 7.

E. METHOD OF REVIEW

To address the questions raised by the change in the ECT signals from 1982 to 1984, GPUN performed evaluations of various sets of data. This section details the methods of evaluation and the data sets utilized to resolve these questions.

1) Investigate the Cause of the Changes in the ECT Signals

The review of the EDM notch standards showed the characteristic shape of the ECT signal from the inner diameter notches changed in relationship to the signal amplitude. The characteristic shape of the signals from the notches was similar to the signals observed in the OTSGs in that the low amplitude signals from the smaller volume EDM notches have the same basic shape as the small amplitude 1982 signals. The higher amplitude signals from the larger volume notches have the same basic shape as the 1984 ECT signals.

As the shape and the amplitudes of the ECT signals changed from 1982 to 1984, the phase angle of the signals also changed. This change in the phase angle (percent through wall) can be associated with changes in the volume of the discontinuities. Research performed in the industry (Reference 6) has shown a strong dependence of the phase angle of the ECT signal on the size of the discontinuity, where the geometric shape and the depth of the discontinuity remained constant while the volume was varied. For this reason it is important that the methods used for evaluating the phase angles of the ECT signals be based on geometries and volumes representative of the discontinuities.

Based on the above information the changes in the shape and phase angle of the ECT signals appears to be a function of changes in the volume of the inner diameter defects. These factors have been addressed in the qualification of the GPUN ECT techniques.

2) Determine the Impact of the Changes in the ECT Signals on the GPUN ECT Program

To determine the impact of the signal changes on the previously qualified GPUN ECT techniques, GPUN evaluated data resulting from the ECT examinations of synthetic defects (EDM Notches) and the results of metallurgical examinations performed on tubes removed from the TMI OTSGs in 1981 and 1982.

The ECT data from the EDM Notches was reanalyzed to verify that the method of interpretation of the notch depth was consistent with the methods used for interpretation of the insitu ECT data. Other analysis techniques such as measuring the steepest angle of the ECT signal and analyzing the auxiliary frequencies (i.e., 200KH$_z$, 800KH$_z$) were also evaluated. These evaluations showed the present method of analysis to be consistent with those used to qualify the techniques and the most applicable for the TMI OTSGs.

To further define the impact of the observed changes on the accuracy of the GPUN ECT techniques, additional correlations of the existing metallurgical data were performed. The data set used for this sample included all identified part through wall IGSAC. This data set includes 6 data points which were previously used in the metallurgical correlations in TDR 642. The data set also includes 2 additional data points previously excluded from TDR 642 because of poor signal to noise ratios

These data points are included in this set because they are representative of the signal to noise ratios of the indications observed during the review of the 1982 data. The ECT data for these examinations consists of both .510 S.D. and .540 H.G.S.D. which was performed using the insitu ECT procedures and is considered representative of the insitu data.

The data set of 8 points for which metallurgical data was available was statistically evaluated both as a complete set and as 2 additional subsets. These subsets were the 4 indications with signal amplitudes of 1 volt or greater which are typical of the 1984 indications and the 4 indications with less than 1 volt signals which are typical of the indications identified during the review of the 1982 data. The statistical evaluations are as follows:

Statistical Evaluation of Part-Through Wall IGSAC

Data Set: All available part-through wall IGSAC. Includes 6 data points from TDR 642 and 2 additional data points.

Indications In Sample	Stat.	% T.W. Met	% T.W. E.C.T.	% Diff. Met/E.C.T
8	$\bar{X}$	45.9	63.4	+ 17.5
	σ	21.8	27.7	25.9

Data Set: Data points from above set with signal amplitudes less than 1 volt. (Typical of indications identified during review of 1982 data.)

Indications In Sample	Stat.	% T.W. Met	% T.W. E.C.T.	% Diff. Met/E.C.T
4	$\bar{X}$	46.3	77.5	+ 31.3
	σ	25.4	25.4	31.9

Data Set: Data points from above set with signal amplitudes 1 volt or greater. (Typical of indications identified during the 1984 examinations.)

Indications In Sample	Stat.	% T.W. Met	% T.W. E.C.T.	% Diff. Met/E.C.T
4	$\bar{X}$	45.5	49.3	+ 3.8
	σ	21.4	24.7	6.2

$\bar{X}$ = Mean Value

σ = 1 Standard Deviation (Sample)

The statistical evaluation of this sample can be used to show a general trend in the accuracy of the percent through wall calls. When all 8 data points are included the mean overcall is 17.5%. When only the 4 signals of one volt or less are considered the mean overcall is 31.3%. By contrast the 4 signals with amplitudes of 1 volt or greater showed a mean overcall of 3.8%.

This data set is limited and the indications included have not experienced the mechanical and thermal stresses applied to the insitu tubes and therefore cannot be used to define exact margins of overcall for part through wall IGSAC. However, the data indicates a consistent trend of overcalling the percent through wall of the small, poor signal to noise ratio indications typical of those identified during the review of the 1982 data. The data from the larger, 1 volt or greater, signals typical of the 1984 data, implies a degree of accuracy more consistent with the GPUN qualified techniques (Reference 3) than observed for the lower amplitude signals.

Since the 1984 ECT signals may be the result of IGA, IGSAC, or both, GPUN reviewed available data to determine the accuracy of sizing IGA with IGSAC protruding from the bottom. The data available was limited to only one data point. This data point had a 35% through wall IGA pit with an IGSA crack extending completely through wall. The data reviewed for this defect was .510 S.D. insitu data which showed the indication to be greater than 100% through wall (recorded as 95%). The indication did not appear to be affected by the IGA and would have been properly dispositioned.

3) Quantify the Degree of Change in Terms of Percent Through Wall

GPUN evaluated data from 3 data sets to quantify the degree of changes in the ECT signals in terms of percent through wall. These various data sets include the OTSG A Growth Program and the OTSG A&B Degraded Tubes (ISI Tubes). The review of a 4th data set, the LTCT data from examinations performed by Westinghouse indicated the ECT process was not consistent with the TMI ECT program and therefore the data was not included.

OTSG A Growth Program (100 Tubes)

The primary data set used to quantify the changes in the ECT signals was the 39 indications identified in the OTSG A Growth Program. This data set did not include any indications previously identified during the 1982 examinations and was further limited to those indications 20% through wall or greater.

Prior to performing a statistical evaluation of the 1982 and 1984 data, the data was re-evaluated by a single data analyst. The re-evaluation was performed to account for the variability previously identified during the review of the ECT process.

This variability applied primarily to the larger amplitude 1984 ECT signals and therefore biased the initial 1982 to 1984 data comparisons. This re-evaluation does not impact the previous disposition of the 1984 data as the majority of the tubes which were included in this sample were removed from service based on the original 1984 evaluations. For the tubes which remain inservice, the percent through wall values assigned during the re-evaluation process did not exceed 46%. Inherent in the plugging criteria (40% T.W.) is a tolerance (± 10% based on industry standards) for ECT accuracy. None of the indications remaining in service exceed this tolerance (50% T.W.). The statistical evaluations performed herein are considered to more accurately reflect the changes in the ECT signals and supercede previously reported values.

The statistical evaluation of the data was performed using the complete data set of 39 points and a subset of 16 points. The subset of 16 points included indications which had signal amplitudes of .6 volts or greater in both 1982 and 1984. This subset represents a 2:1 <u>nominal</u> signal to noise ratio for the indications. The results of these evaluations are as follows.

Statistical Evaluation of OTSG "A" Growth Program

Data Set: All indications $\geq$ 20% T.W. (I.D.) which were confirmed by 8 x 1. Includes only tubes $\geq$ 20% T.W. in both 1982 and 1984.

Indications		1982		1984		1982-1984	
In Sample	Stat.	%	V	%	V	Δ%	ΔV
39	$\bar{X}$	55.3	.6	48.4	1.6	-6.9	+1.0
	σ	18.9	.4	17.4	1.2	10.7	1.0

Data Set: All indications $\geq$ 20% T.W. (I.D.) which were confirmed by 8 x 1. Includes only tubes $\geq$ 20% and $\geq$ .6V in 82 and 84.

Indications		1982		1984		1982-1984	
In Sample	Stat.	%	V	%	V	Δ%	ΔV
16	$\bar{X}$	50.3	.9	46.0	2.1	-4.3	+1.2
	σ	18.9	.5	19.5	1.8	7.6	1.3

$\bar{X}$ = Mean Value

σ = 1 Standard Deviation (Sample)

The statistical evaluation of this population showed a trend of increased signal voltage and a decrease in the reported percent through wall from 1982 to 1984. The mean decrease in reported percent through wall for the initial data set (39 Pts) was -6.9% while the mean decrease for the second data set (16 Pts) was -4.3%. The evaluations of the signal amplitudes also showed a consistent trend for both data sets with the initial data set showing a mean increase in voltage from .6 volts to 1.6 volts for a mean increase of 167%. The same trend was observed in the second data set as the mean voltage increased from .9 volts to 2.1 volts for a mean increase of 144% from 1982 to 1984.

Although these data sets showed similar trends in the changes to the ECT signals, the difference in the magnitude of the phase shift (-6.9% versus -4.3%) indicates the noise associated with the 1982 data may be a factor.

OTSG A&B Degraded Tubes (ISI Tubes)

The evaluation of the 100 tube growth program represented indications which were below the threshold of detectability in 1982 and became detectable in 1984. By contrast the OTSG A and B Degraded Tubes (ISI Tubes) provide a population of tubes which were detectable in both 1982 and 1984. These populations represent better signal to noise ratio indications in 1982 and 1983 and are typical of the indications to remain inservice as degraded tubes.

The total population of ISI tubes with inner diameter indications was 15 tubes in OTSG A and 14 tubes in OTSG B. (Indications at support plates which are considered areas of reduced accuracy are excluded from this evaluation.) (Reference 1)

The data sets were statistically evaluated, by OTSG, as a total population for 1982, 1983 and 1984 and as a subset of indications for OTSG A. For the statistical evaluation of the total population the indications identified as 20% T.W. or less were all treated as 20% T.W. For the evaluation of the OTSG A subset, all indications less than 20% T.W. in 1982, 1983 or 1984 were excluded. The results of these evaluations are as shown on Table 6.

The statistical evaluation of these populations shows significant differences between OTSG A & B. Because of these differences the data sets will be discussed separately by OTSG.

The statistical evaluation of the OTSG A $\geq$ 20% subset from 1982 to 1983 showed a mean increase in the signal amplitude of .5 volts (83%) with a mean decrease in the reported percent through wall of -16.6%. From 1983 to 1984 the mean voltage increased by .9 volts (82%) however, the percent through wall remained more constant with a 2.9% increase. This same trend was also observed in the data set containing all indications.

By contrast the evaluation of the OTSG B data set showed no significant changes from either 1982 to 1983 or from 1983 to 1984. In OTSG B the limited number of data points (2) with ≥ 20% T.W. evaluations in 1982, 1983 and 1984 prevented using this criteria for subset. The evaluations were therefore performed using the complete data set in which the mean percent through wall for 1982 was 22.8% while 1983 was 22.0% and 1984 was 22.0%. The signal amplitudes for the examinations also remained constant with a mean voltage of 1.6 volts in both 1982 and 1983 and 1.5 volts in 1984.

GPUN further evaluated the ISI data sets from OTSGS A & B to determine the cause of the significant differences in the statistical results. This evaluation included a subjective review of the signals by a Level III data analyst and determined the OTSG B indications <u>may not</u> be indications of IGA or IGSAC but may be caused by other surface anomalies.

The review of the above data sets would indicate the change in the phase angles of the ECT signals has occurred at various times in the OTSGs and is not associated with a specific thermal or mechanical cycle. The changes identified in the OTSG A ISI tubes from 1982 to 1983 were similar to those identified in the OTSG A Growth Program from 1983 to 1984.

The data from the OTSG A Growth Program was evaluated using stricter controls than the production data sets and therefore represents the best available data for additional analysis.

4) Characterize the Locations in the OTSGs where Changes in the ECT Signals Occurred

The previously described data sets were reviewed to characterize the axial and radial locations of the OTSGs in which changes in the ECT signals occurred. The available data indicates the changes in the signals occurred at all locations where inner diameter indications were present. This includes axial locations from the 5th T.S.P. to the kinetically expanded area. The radial locations of the indications was limited to the outer periphery of the OTSG. in this periphery all locations appeared to be affected equally.

5) Determine the Effect of the Observed Changes in the ECT Signals on Future Examinations

The changes identified in the shape and phase angles of the ECT signals have been identified in data from examinations performed at various times since the 1982 baseline. The change in the ECT signals can first be identified when comparing the 1982 baseline data to the 1983 post repair ECT. The changes observed during this time period are very similar to the changes observed between the 1982 and the 1984 data.

During the 1982 examinations the strict plugging criteria applied to the OTSGs required most of the tubes with indications to be removed from service. The only available data base of indications detected during 2 or more production examinations is therefore the comparison of 1983 and 1984 Degraded Tubes (ISI tubes). This data set includes 7 indications in OTSG A and 2 indications in OTSG B which were greater than or equal to 20% T.W. and can be used for analysis. The remainder of the data sets discussed in this section therefore represent the comparison of indications which were below the threshold of detection on the first exam- ination and have increased in amplitude to become detectable during the second examination.

The comparison of these two types of data (previously detected and not previously detected) shows significant differences in the repeatability of the examination results. A review of the statistical data in Table 6 shows that when an indication is first detectable during production evaluations and then compared to the previous examinations, a definite shift in the phase angles of the indications can be observed. This shift occurs as the signal amplitude and the signal to noise ratio change to make the indication detectable. In the OTSG A Growth Program, which represents this type of data, the mean change in signal amplitudes was +1.0 volts from 1982 to 1984 while the reported percent through wall decreased by a mean of -6.9%.

By contrast, where indications were of sufficient amplitude to be detected during the 1983 production examinations, phase shifts of this magnitude have not been observed in the 1984 data. The comparison of the 1983 to 1984 data for this population of tubes (OTSG A Degraded Tube) shows a mean increase in the amplitude of the indications of .9 volts while the mean change in percent through wall was +2.9%.

Based on this ECT data the phase angles of indications which have become detectable in 1984 and have experienced the phase shift since 1982 would be expected to stabilize during future examinations. For indications which increase in amplitude and are first detected during future outages, phase shifts similar to those observed from 1982 to 1984 would be expected.

The results of the metallurgical correlations show the low amplitude indications of less than 1 volt are not being accurately evaluated and result in an overly conservative disposition of the tubes. To minimize the impact of the inaccuracies associted with these small amplitude signals, GPUN can implement guidelines to provide a voltage threshold for evaluating indications. The evaluation of the OTSG A Growth Program and the Degraded Tubes (ISI Tubes) indicate a 1 volt threshold for evaluating indications would improve accuracy of determining the percent through wall penetration of discontinuities. Tubes with indications below this threshold can be further evaluated using additional data such as 8 x 1 absolute to determine if the tube should be removed from service or monitored during future examinations.

TABLE 6
SUMMARY OF STATISTICAL EVALUATION OF 1982, 1983 AND 1984 ECT DATA

	# Pts.	Stat.	1982			1983			1984		82-83		83-84		82-84	
			%	V		%	V		%	V	$\Delta_\%$	Δ_V	$\Delta_\%$	Δ_V	$\Delta_\%$	Δ_V
1984 Growth All Inds. ≥20% ≥ .6V in 1982	16	$\bar{X}$ =	50.3	.9					46.0	2.1					-4.3	1.2
		σ =	18.9	.5					19.5	1.8					7.6	1.3
Subset: Sample - All Inds. ≥20%	39	$\bar{X}$ =	55.3	.6					48.4	1.6					-6.9	1.0
		σ =	18.9	.4					17.4	1.2					10.7	1.0
OTSG A ISI All Inds.	Varies By Yr.	$\bar{X}$ = (20	38.8	.7	(23	25.8	1.2	(23	27.3	1.7	-13.0	+.5	+1.5	+.5	-11.5	1.0
		σ = Pts)	16.5	.6	Pts)	7.3	.7	Pts)	9.3	.8		.5		.5		.7
Subset: Inds. ≥20%	7	$\bar{X}$ =	49.2	.6		32.7	1.1		35.6	2.0	-16.6	+.5	+2.9	.9	-13.7	1.3
		σ =	16.3	.5		7.7	.6		10.7	.7	18.5	.4	8.5	.6	20.6	.6
OTSG B ISI All Inds.	Varies By Yr.	$\bar{X}$ = (24	22.8	2.8	(25	22.0	3.0	(25	22.0	3.1	-.8	+.3	0	.0	+.3	-.8
		σ = Pts)	7.4	1.6	Pts)	6.4	1.6	Pts)	6.5	1.5		.8		.7	1.1	
Subset: Ind. ≥20%	2	$\bar{X}$ =	43.0	1.8		42.5	1.8		43.0	2.6	-.5	0	+.5	+.8	0	+.8
		σ =	9.9	0		7.8	.7		7.1	2.1	17.7	.7	14.8	1.3	2.8	2.1

$\bar{X}$ = Mean Value

σ = 1 Standard Deviation (Sample)

VII. GROWTH PROGRAM

GPUN initiated a growth program during the examinations in November 1984 to determine if a growth mechanism was active during the current (July-Nov 1984) period of extended dry layup of the TMI-1 OTSGs. This sample included a population of 100 tubes in 'A' and 50 tubes in 'B'. The tubes for both generators were selected from high defect areas of the generators and were examined full length using the GPUN dual examination method.

OTSG A GROWTH PROGRAM

The growth program in the 'A' OTSG consisted of examining a population of 100 tubes 3 times at approximately 2 week intervals. Initially, these tubes were examined as part of the production eddy current program in Mid-November 1984. The tubes were subsequently examined a second time in late November 1984 and a third time in Mid-December 1984. Results of the 3 examinations of each tube were then compared for changes in the number of indications and for changes in signal response voltage or percent through wall determinations.

The 100 tubes in the 'A' Growth Program included 55 tubes with confirmed indications and 45 with no relevant indications. The comparisons of the repeat examinations were performed by evaluating the signal amplitudes and percent through wall determinations. These evaluations revealed essentially no change in the voltage or percent through wall determinations. These results indicate that there was no continued degradation during the three examinations from November to December, 1984.

OTSG B GROWTH PROGRAM

The Growth Program in 'B' consisted of a Mid-November 1984 examination of 50 tubes which were previously examined in July 1984. These 50 tubes were selected from the high defect area for full length examination in July 1984 during a limited scope examination performed when primary to secondary leakage was detected.

The July and November 1984 Eddy Current results were then compared and no previously undetected indications were found to exist in the November 1984 results. There was no evidence of continued degradation in these tubes between July and November 1984.

GROWTH PROGRAM CONCLUSIONS

The Growth Program evaluations indicate there was no significant change in the condition of the tubes from July to November 1984 in the 'B' OTSG or from Mid-November to Mid-December in 1984 for the 'A' OTSG. This information does not indicate any correlation between extended dry lay-up and identification of previously undetected indications.

VIII. CONCLUSIONS

Based on the characterization of the 1984 indications, a review of the 1982, 1983 and the growth program data, GPUN was able to draw the following conclusions for the 1984 examination results.

1. The characterization of the 1984 indications by axial and radial locations, and their correlation to the indications reported in the 1982 baseline, suggest that the 1984 indications are an additional subset of the 1982 indications.

2. The re-evaluation of previous data suggests that the indications identified in 1984 were already present during the 1982 examination but were within the background noise.

   The kinetic expansion repair and hot functional testing may have increased the amplitude of these previously existing indications and made them detectable during production examinations. There was no trend of through wall growth associated with this amplitude increase.

3. Based on the evaluation of the Growth Program, there is no evidence of continuing tube degradation since the OTSGs were placed in dry layup in July 1984.

4. The characterization of the 1984 indications shows that approximately 90% of the indications are 20-60 percent through wall and 1 coil. These indications are at or near the threshold of detection for the previously established sensitivity curve.

5. Approximately 10% of the indications are higher percent through wall (≥60%) with a circumferential extent of 1 or 2 coils. There is a total of three 3- coil circumferential extent indications. All of these indications are between the threshold for detection and the most conservative curve for critical crack size. (Main Steam Line Break).

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6. Sagar, Amrit, "Multifrequency Eddy Current Method and the Separation of Test System Variables," Eddy Current Characterization of Materials and Structures, ASTM STP 722, George Birnbaum and George Free, Eds., American Society for Testing and Materials, 1981, pp. 269-297.

APPENDIX A

ABSTRACT ON THE DEVELOPMENT OF THE DUAL INSPECTION TECHNIQUE AND PERCENT THROUGH WALL CALIBRATION CURVE

Prior to the 1982 OTSG tubing inspection, GPU Nuclear had always performed its OTSG tubing examinations with the standard differential eddy current technique for detecting indications that normally originated on the outer diameter of the tube wall. The eddy current inspection system was operated at normal gain and the probes used for these inspections measured 0.510" diameter. These parameters traditionally were considered acceptable for inspecting the OTSG tubing which has a nominal inner diameter of 0.557".

After 131 tubes leaked upon start-up and test in November 1981, eddy current examinations were immediately performed with the standard differential (S.D.) .510" technique and some of the leaking indications were not detected. A subsequent examination was performed with a multi-coil absolute eddy current technique and indications were identified in the roll transition of the leaking tubes. In addition, other indications which had not been detected by the previous S.D. .510" examination were identified. The defects discovered in the OTSG tubing were metallurgically evaluated as inner diameter initiated, very tight, and orientated around the circumference of the tubes. It was then recognized that the S.D. .510" technique was not sensitive enough for detecting all of the new inner diameter discontinuities.

GPU Nuclear modified and improved the sensitivity of its standard differential technique by increasing the probe's diameter to 0.540", and increasing the operating gain. This modification improved the standard differential's sensitivity for detection of predominately circumferential, I.D. initiated indications by approximately 175% over the older technique. The disadvantage of using the high gain and improved fill factor is that the standard differential examination becomes overly sensitive to surface anomalies.

The absolute technique used to confirm the standard differential inspection results was also modified and improved. The development of the 8X1 Absolute probe with eight pancake shape coils placed around the probe body provided 360 degrees coverage on the circumference of the tube wall. This design permitted a single pass of the probe in the tube during an examination as compared to multiple passes when fewer coils are used. The eight coils also provided a fair estimate of the arc length of an indication because the response signal from each coil represents its proximity to the indication.

Using the improved S.D. .540" high gain and absolute 8x1 techniques, GPU Nuclear developed a dual method eddy current inspection technique. The initial examination was performed by the S.D. .540" high gain technique. If the examination by S.D. .540" showed no evidence of a defect, its examination became the final inspection of record.

If the S.D. .540" examination reported an indication, a second examination was performed using the absolute 8x1 technique. The absolute 8x1 examination determined if the reported indication was relevant or non-relevant. For those indications determined to be relevant, the absolute 8x1 result was used to estimate the arc length and also confirm the origin (I.D./O.D.) and axial location of the indication.

During a standard differential eddy current examination the percent through wall penetration of a flaw is determined by measuring the response signal's phase angle and converting that measurement to the percent through wall. A calibration for this conversion is established by setting up the standard differential equipment and testing a known standard. The phase angle for the eddy current response signal is adjusted to a specified measurement which generally is 40 degrees for a 100 percent through wall by .052" diameter hole standard. This calibration is done in accordance with the ASME Section XI code. The traditional conversion curve for phase angle measurement to inner diameter initiated percent through wall is determined by the values that are extrapolated from the 40 degree phase angle-100 percent through wall (given by the .052" diameter hole standard) to zero degree phase angle--zero percent through wall.

The estimated percent through wall that is extrapolated from the conversion curve tends to overcall the actual percent through wall of a small volume flaw. This over calling is considered conservative eddy current evaluation and was instituted in the 1982 dual inspection technique.

It had always been acknowledged that this traditional curve overcalled small volume inner diameter discontinuities. The presence of smaller inner diameter initiated cracks in the TMI-1 OTSG's had required GPUN to develop a more accurate means of assigning the percent through wall penetration. Therefore, the traditional inner diameter conversion curve was enhanced by using supplemental data from EDM with various known depths. This data was used to develop a conversion curve which more accurately represented small volume, inner diameter initiated discontinuities and this accuracy was verified through metallurgical correlations using actual intergranular stress assisted crack samples.

APPENDIX B

1982, 1984 EDDY CURRENT STATISTICS

TMI STEAM GENERATOR A AXIAL LOCATIONS OF CONFIRMED INDICATIONS 0-100% THROUGH WALL
PERCENT VS SPAN
1982 VS 1984

	1982		1984	
Support	Frequency	%	Frequency	%
LP-1	6	.19	1	.090
1-2	23	.717	2	.181
2-3	8	.249	8	.726
3-4	8	.249	19	1.725
4-5	17	.53	7	.635
5-6	58	1.808	19	1.725
6-7	34	1.714	26	2.361
7-8	55	1.060	5	.458
8-9	34	1.714	12	1.1
9-10	11	.343	4	.367
10-11	24	.748	8	.726
11-12	54	1.683	13	1.181
12-13	63	1.964	54	4.900
13-14	146	4.551	57	5.177
14-15	97	3.024	78	7.084
15-US	530	16.521	217	19.70
US-UP	2040	63.591	571	51.861
TOTAL	3208		1101	

Note: (1) 1984 data includes the length of tubing below the kinetically expanded zone. (Approximately US+7 and below).

(2) 1982 data includes the length of tubing from US+15 and below.

(3) Data taken from 1982 and 1984 data bases as of 2/15/85.

TMI STEAM GENERATOR B AXIAL LOCATION OF CONFIRMED INDICATIONS 0-100% THROUGH WALL
PERCENT VS SPAN
1982 VS 1984

	1982		1984	
Support	Frequency	%	Frequency	%
LS	6	.468	6	3.109
1-2	3	.234	2	1.036
2-3	4	.312	1	.518
3-4	20	1.561	3	1.554
4-5	9	.703	6	3.109
5-6	9	.703	4	2.072
6-7	24	1.874	8	4.145
7-8	12	.937	7	3.627
8-9	19	1.483	4	2.072
9-10	20	1.561	9	4.663
10-11	15	1.171	2	1.036
11-12	34	2.654	12	6.218
12-13	34	2.654	12	6.218
13-14	106	8.275	7	3.627
14-15	81	6.323	7	3.627
15-US	98	7.650	25	12.953
US	787	61.144	78	40.414
TOTAL	1281		193	

Note: (1) 1984 data includes the length of tubing below the kinetically expanded zone. (Approximately US+7 and below).

(2) 1982 data includes the length of tubing from US+15 and below.

(3) Data taken from 1982 and 1984 data bases as of 2/15/85.

TMI STEAM GENERATOR A VOLTAGE DISTRIBUTION FOR CONFIRMED INDICATIONS 0-100% THROUGH WALL
PERCENT VS VOLTS
1982 VS 1984

1982		1984	
Volts	Percent	Volts	Percent
0	31.807	0	34.968
1	44.653	1	35.15
2	16.595	2	23.615
3	4.702	3	4.814
4	1.537	4	.636
5	.338	5	.363
6	.184	6	.091
7	.061	7	.182
8	.092	8	.182
9	0	9	0
10	.031	10	0

Note: (1) 1984 data includes the length of tubing below the kinetically expanded zone. (Approximately US+7 and below).

(2) 1982 data includes the length of tubing from US+15 and below.

(3) Data taken from 1982 and 1984 data bases as of 2/15/85.

TMI STEAM GENERATOR B VOLTAGE DISTRIBUTION FOR CONFIRMED INDICATIONS 0-100% THROUGH WALL
PERCENT VS VOLTS
1982 VS 1984

1982		1984	
Volts	Percent	Volts	Percent
0	23.878	0	26.425
1	28.897	1	20.207
2	25.019	2	27.979
3	9.810	3	11.917
4	6.844	4	5.699
5	1.901	5	3.109
6	1.597	6	1.036
7	.608	7	1.554
8	1.217	8	1.554
9	0	9	0
10	.076	10	.518
11	.152	11	0

Note: (1) 1984 data includes the length of tubing below the kinetically expanded zone. (Approximately US+7 and below).

(2) 1982 data includes the length of tubing from US+15 and below.

(3) Data taken from 1982 and 1984 data bases as of 2/15/85.

TMI STEAM GENERATOR A CONFIRMED PERCENT THROUGH WALL DISTRIBUTION FOR CONFIRMED INDICATIONS 0-100% THROUGH WALL PERCENT VS PERCENT THROUGH WALL
1982 VS 1984

1982		1984	
% Thru-Wall	%	% Thru-Wall	%
0-19	.281	0-19	0
20-29	1.434	20-29	39.055
30-39	1.309	30-39	21.163
40-49	6.827	40-49	17.802
50-59	13.685	50-59	7.629
60-69	9.757	60-69	5.904
70-79	7.512	70-79	2.186
80-89	8.635	80-89	1.907
90-100	50.561	90-100	3.724

Note: (1) 1984 data includes the length of tubing below the kinetically expanded zone. (Approximately US+7 and below).

(2) 1982 data includes the length of tubing from US+15 and below.

(3) Data taken from 1982 and 1984 data bases as of 2/15/85.

TMI STEAM GENERATOR B CONFIRMED PERCENT THROUGH WALL DISTRIBUTION FOR CONFIRMED INDICATIONS 0-100% THROUGH WALL PERCENT VS PERCENT THROUGH WALL 1982 VS 1984

1982 % Thru-Wall	%	1984 % Thru-Wall	%
0-19	11.788	0-19	0
20-29	11.866	20-29	63.212
30-39	16.472	30-39	13.99
40-49	10.617	40-49	11.917
50-59	13.349	50-59	4.663
60-69	8.041	60-69	3.109
70-79	6.401	70-79	2.073
80-89	5.699	80-89	0
90-100	15.769	90-100	1.036

Note: (1) 1984 data includes the length of tubing below the kinetically expanded zone. (Approximately US+7 and below).

(2) 1982 data includes the length of tubing from US+15 and below.

(3) Data taken from 1982 and 1984 data bases as of 2/15/85.

CIRCUMFERENTIAL EXTENT FOR CONFIRMED INDICATIONS

GENERATOR A

Coils	1982 Frequency	%	Coils	1984 Frequency	%
0	270 (N/A)		0	321 (N/A)	
1	655	66.973	1	1111	89.959
2	301	30.777	2	122	9.878
3	18	1.840	3	2	0.162
4	1	0.102	4	0	0
5	1	0.102	5	0	0
6	0	0	6	0	0
7	1	0.102	7	0	0
8	1	0.102	8	0	0
TOTAL	978			1235	

GENERATOR B

Coils	1982 Frequency	%	Coils	1984 Frequency	%
0	361 (N/A)		0	321 (N/A)	
1	147	50.000	1	102	79.069
2	102	34.694	2	26	20.155
3	26	8.843	3	1	.775
4	7	2.381	4	0	0
5	4	1.360	5	0	0
6	0	0	7	0	0
7	0	0	8	0	0
8	8	2.721	9	0	0
TOTAL	294			129	

Note: (1) 1984 data includes the length of tubing below the kinetically expanded zone. (Approximately US+7 and below).

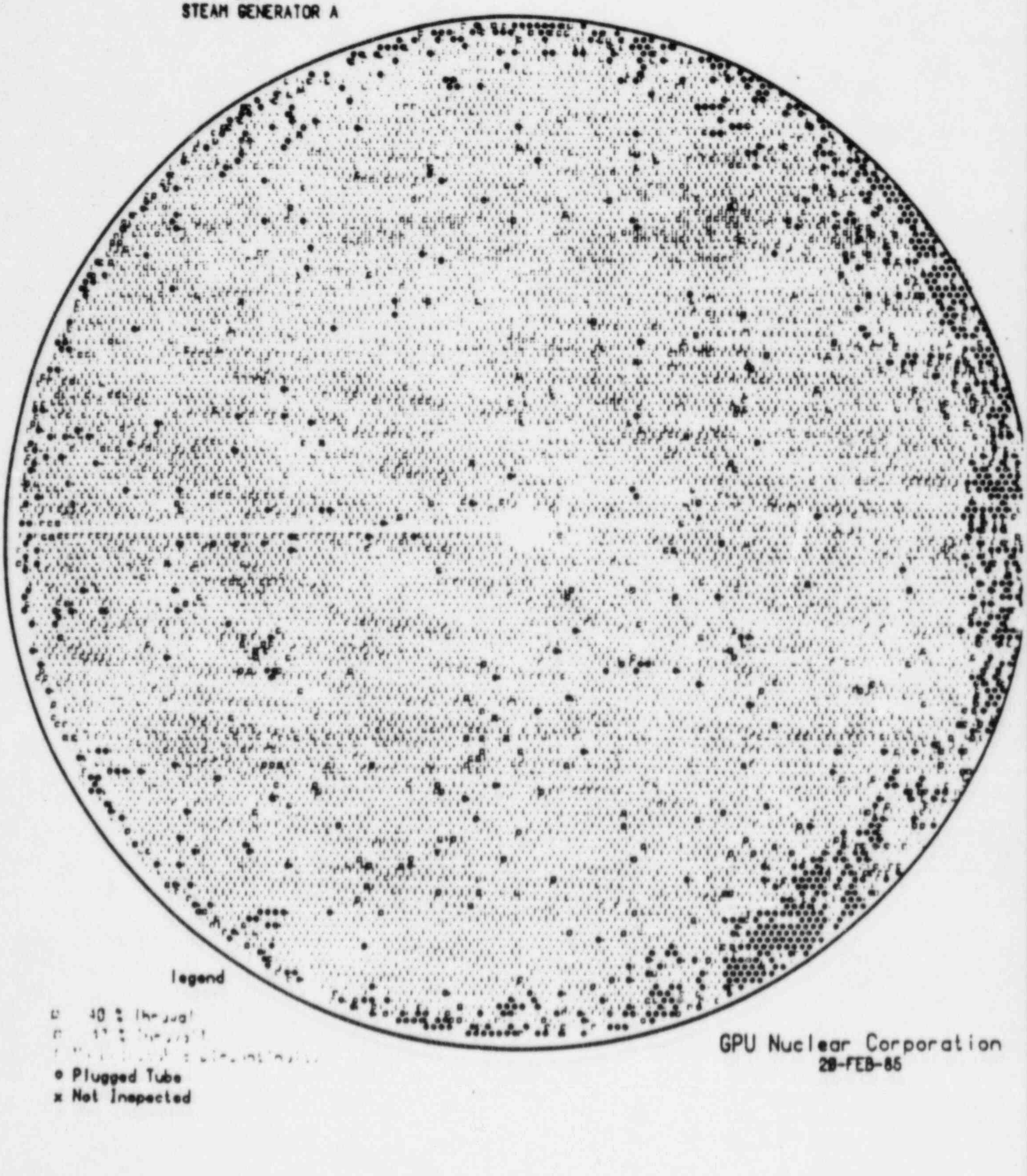
(2) 1982 data includes the length of tubing from US+15 and below.

(3) Data taken from 1982 and 1984 data bases as of 2/15/85.

FIG. 1A

THREE MILE ISLAND NUCLEAR GENERATING STATION

UNIT 1
STEAM GENERATOR A

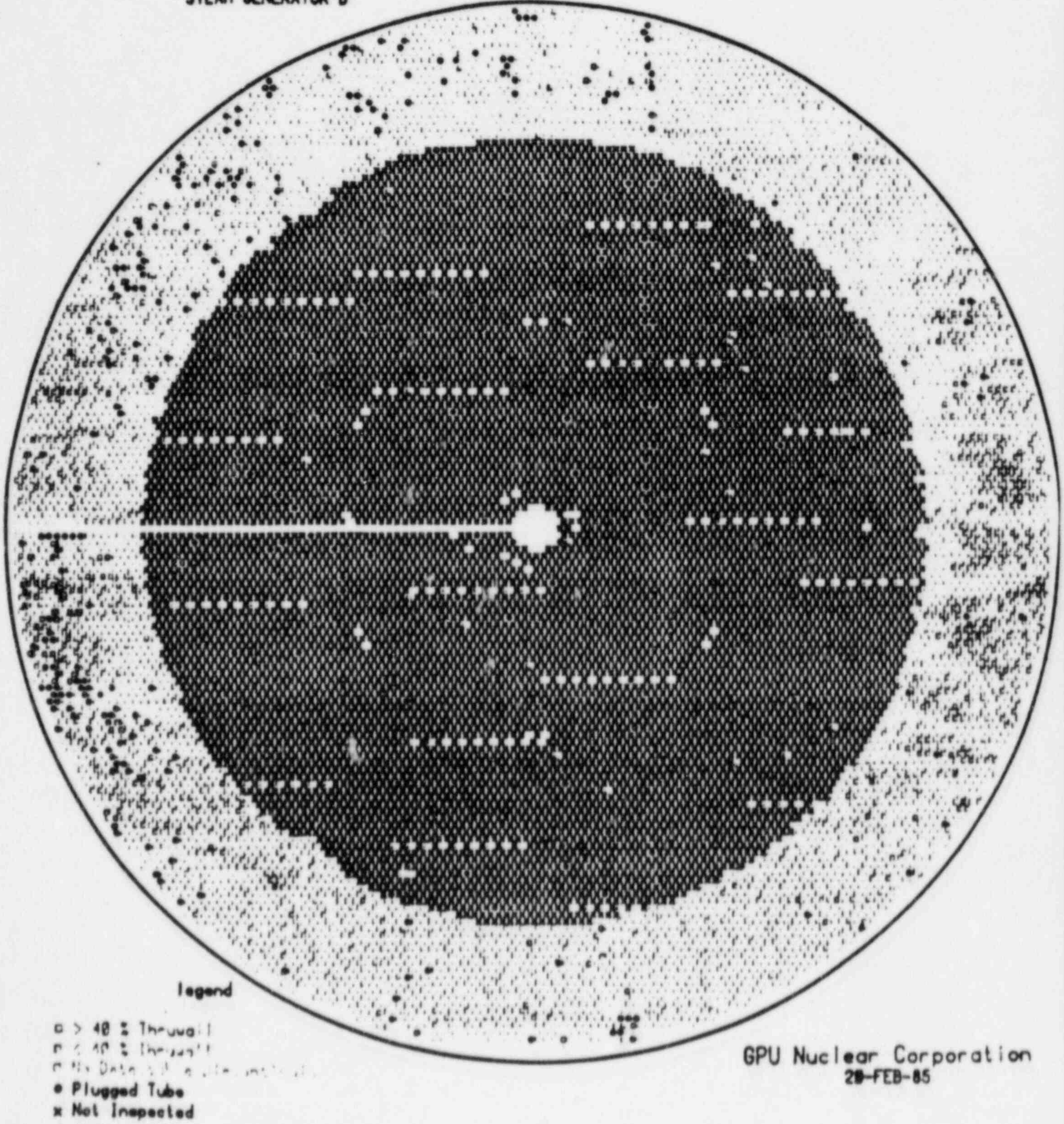


GPU Nuclear Corporation
20-FEB-85

FIG. 1B

THREE MILE ISLAND NUCLEAR GENERATING STATION

UNIT 1
STEAM GENERATOR B



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28-FEB-85

FIGURE 2A

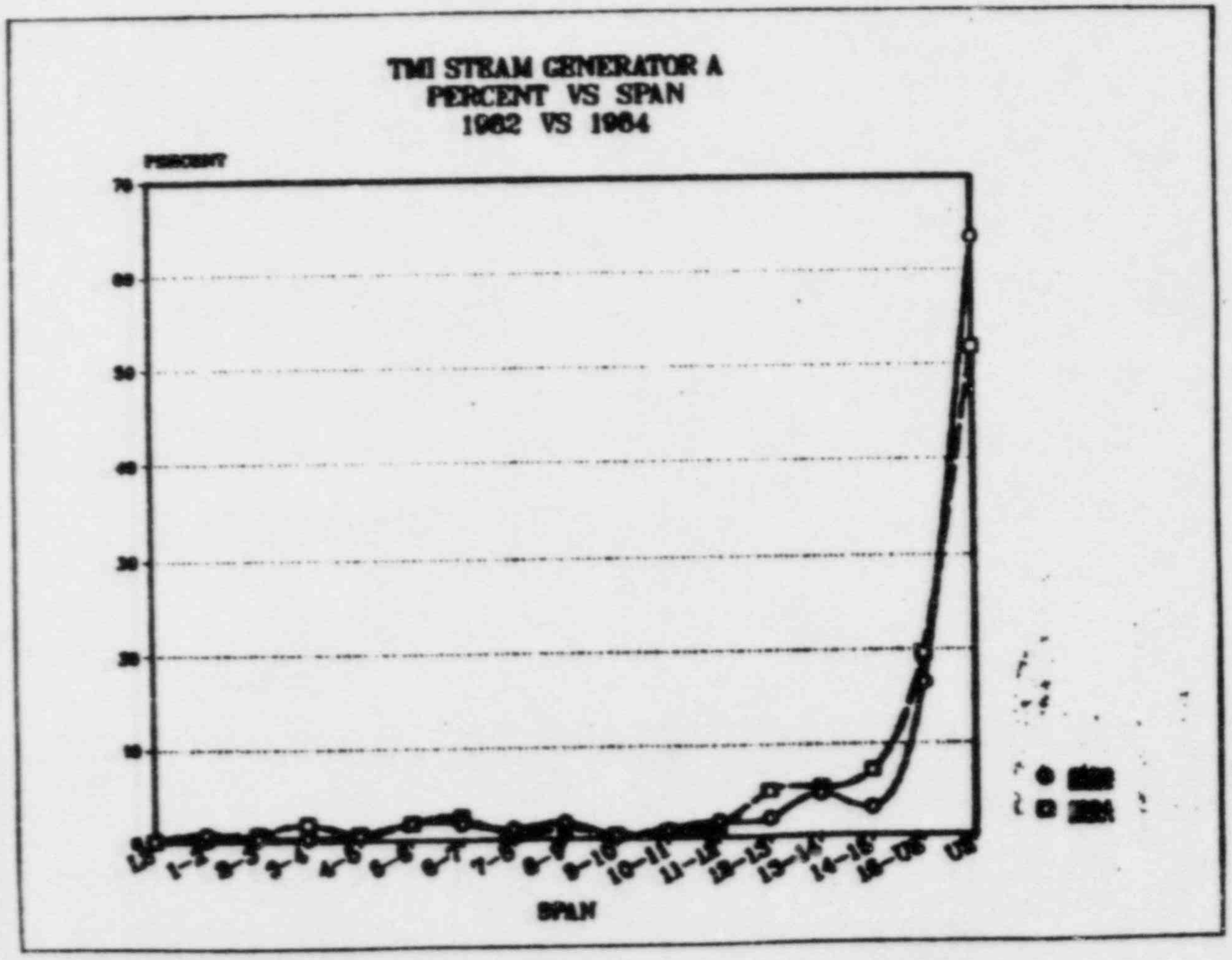

TMI STEAM GENERATOR A
PERCENT VS SPAN
1982 VS 1984
PERCENT
70
60
50
40
30
20
10
0
LTS
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
10-11
11-12
12-13
13-14
14-15
15-UTS
UTS
SPAN
1982
1984

FIGURE 2B

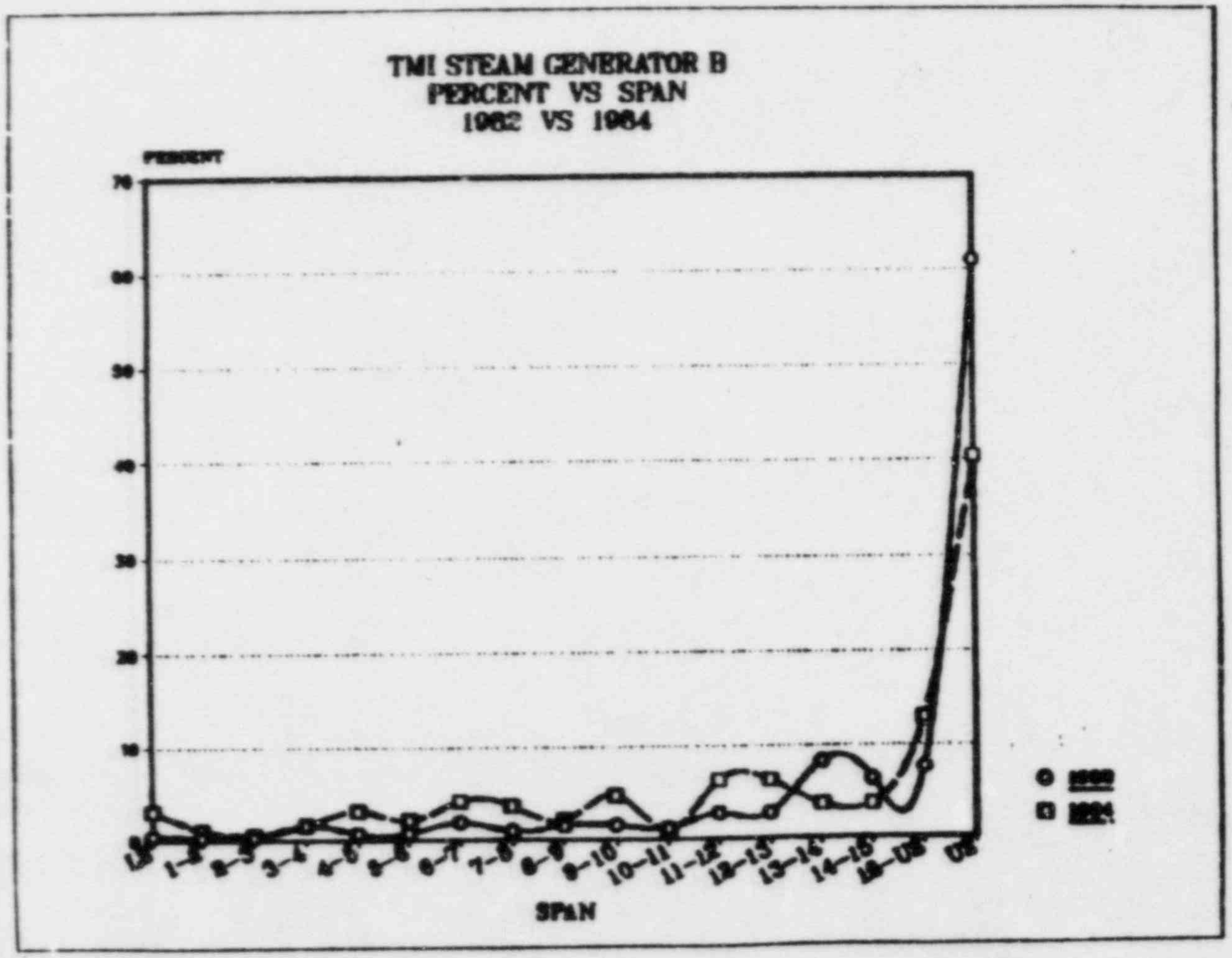

TMI STEAM GENERATOR B
PERCENT VS SPAN
1982 VS 1984
PERCENT
70
60
50
40
30
20
10
0
LTS-1
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
10-11
11-12
12-13
13-14
14-15
15-UTS
UTS
SPAN
○ 1982
□ 1984

FIGURE 3A

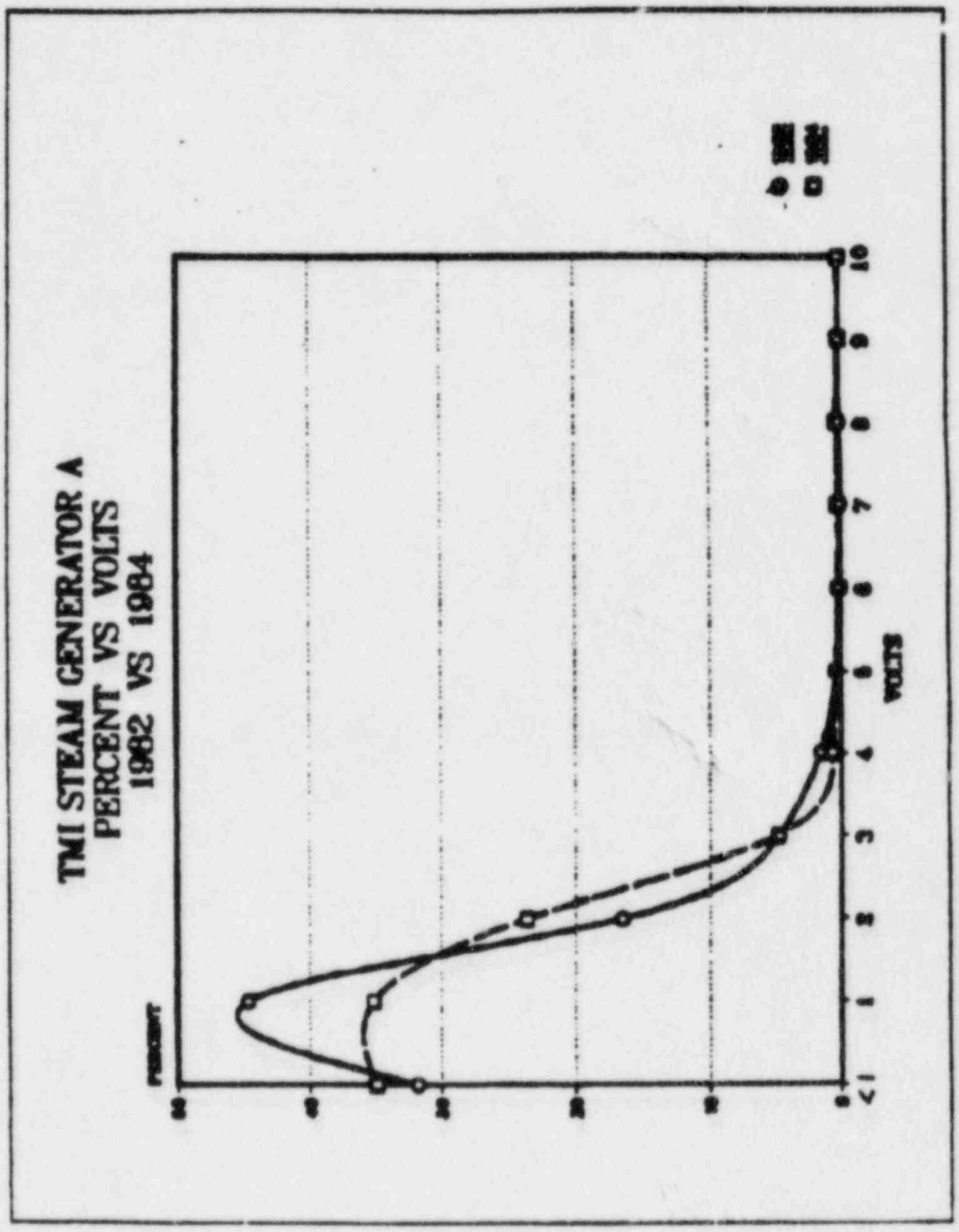

TMI STEAM GENERATOR A
PERCENT VS VOLTS
1982 VS 1984
PERCENT
50
40
30
20
10
0
<1
1
2
3
4
5
6
7
8
9
10
VOLTS
1982
1984

FIGURE 3B

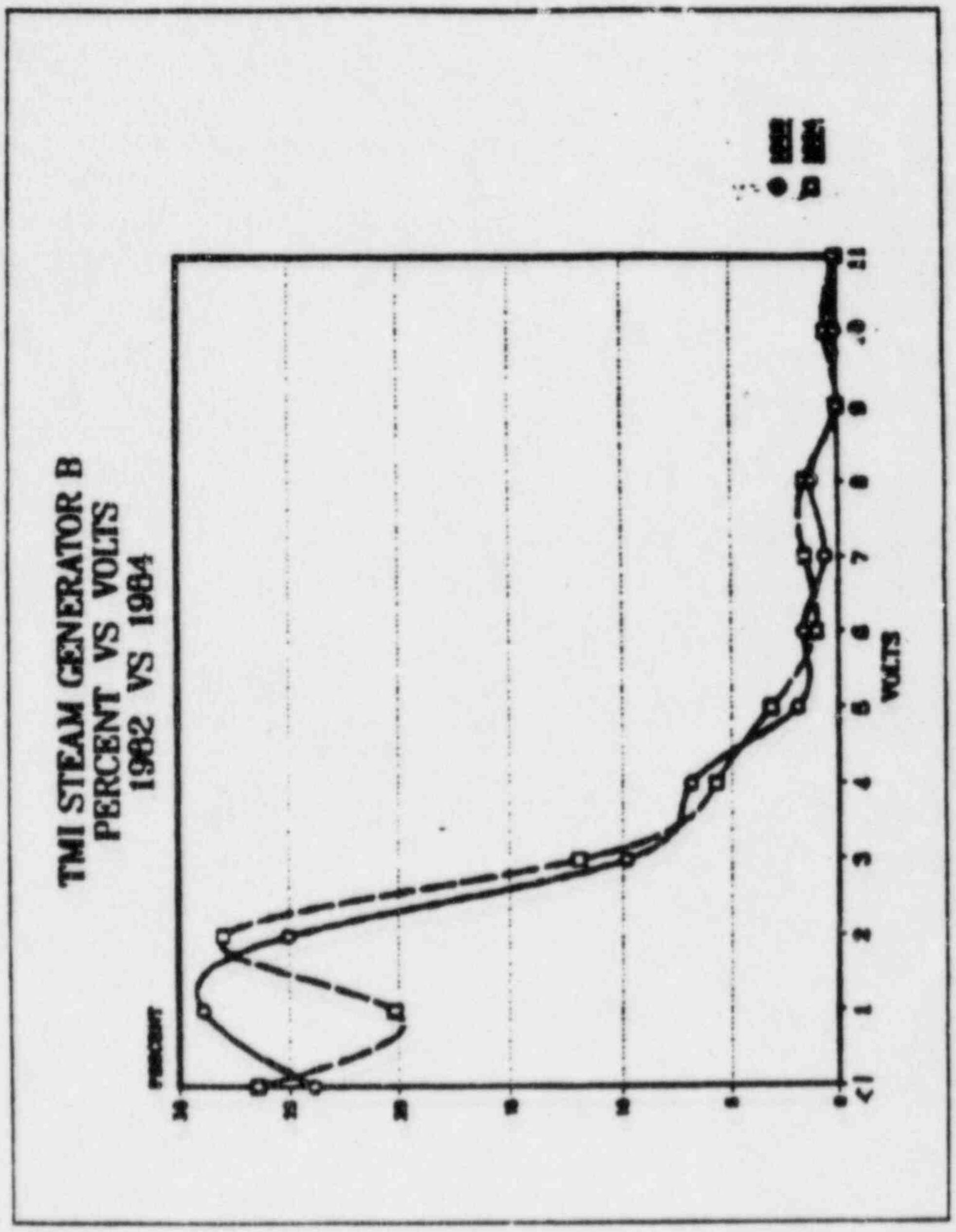

TMI STEAM GENERATOR B
PERCENT VS VOLTS
1982 VS 1984
PERCENT
30
25
20
15
10
5
0
<1
1
2
3
4
5
6
7
8
9
10
11
VOLTS

FIGURE 4A

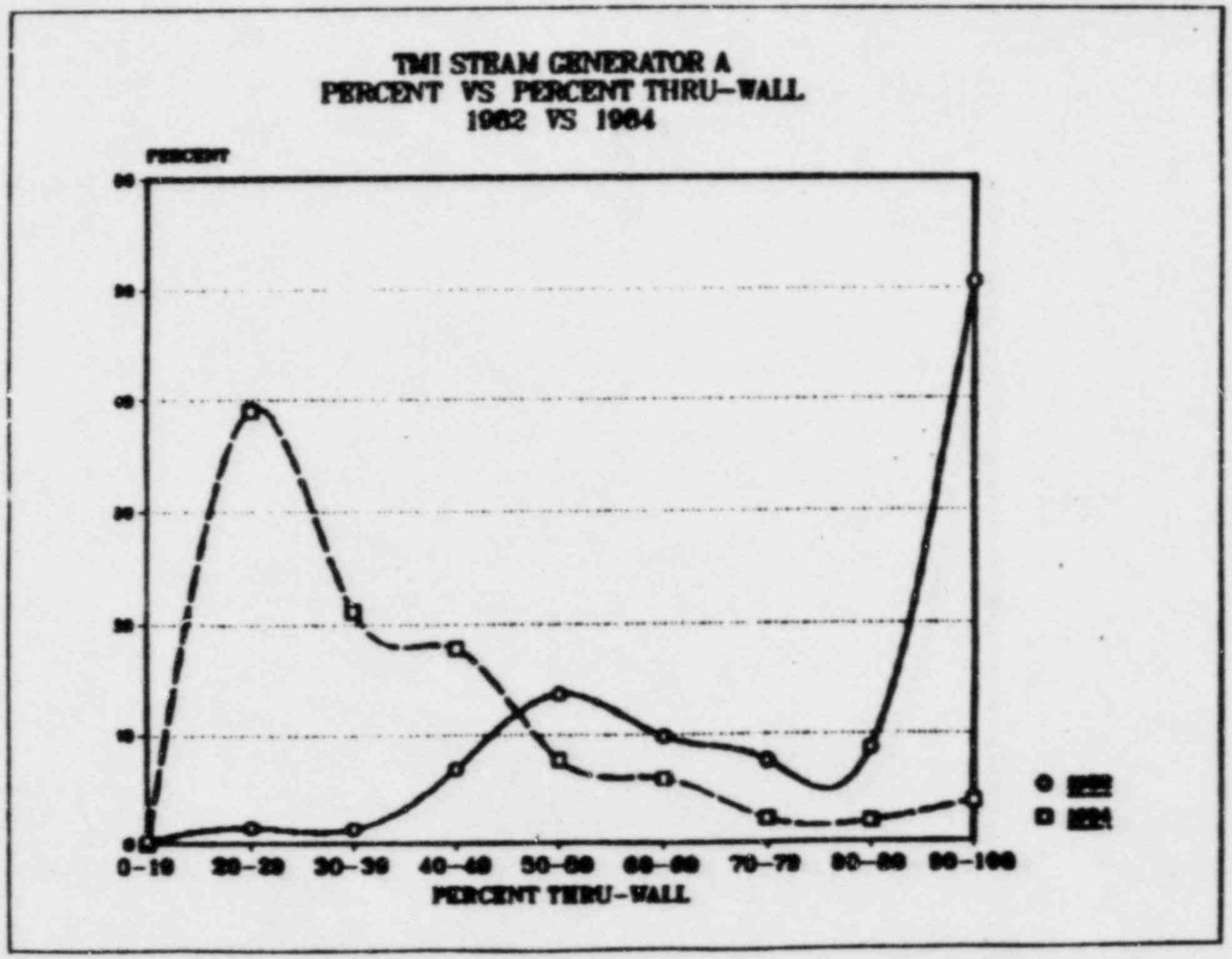

TMI STEAM GENERATOR A
PERCENT VS PERCENT THRU-WALL
1982 VS 1984
PERCENT
60
50
40
30
20
10
0
0-19
20-29
30-39
40-49
50-59
60-69
70-79
80-89
90-100
PERCENT THRU-WALL
○ 1982
☐ 1984

FIGURE 5A

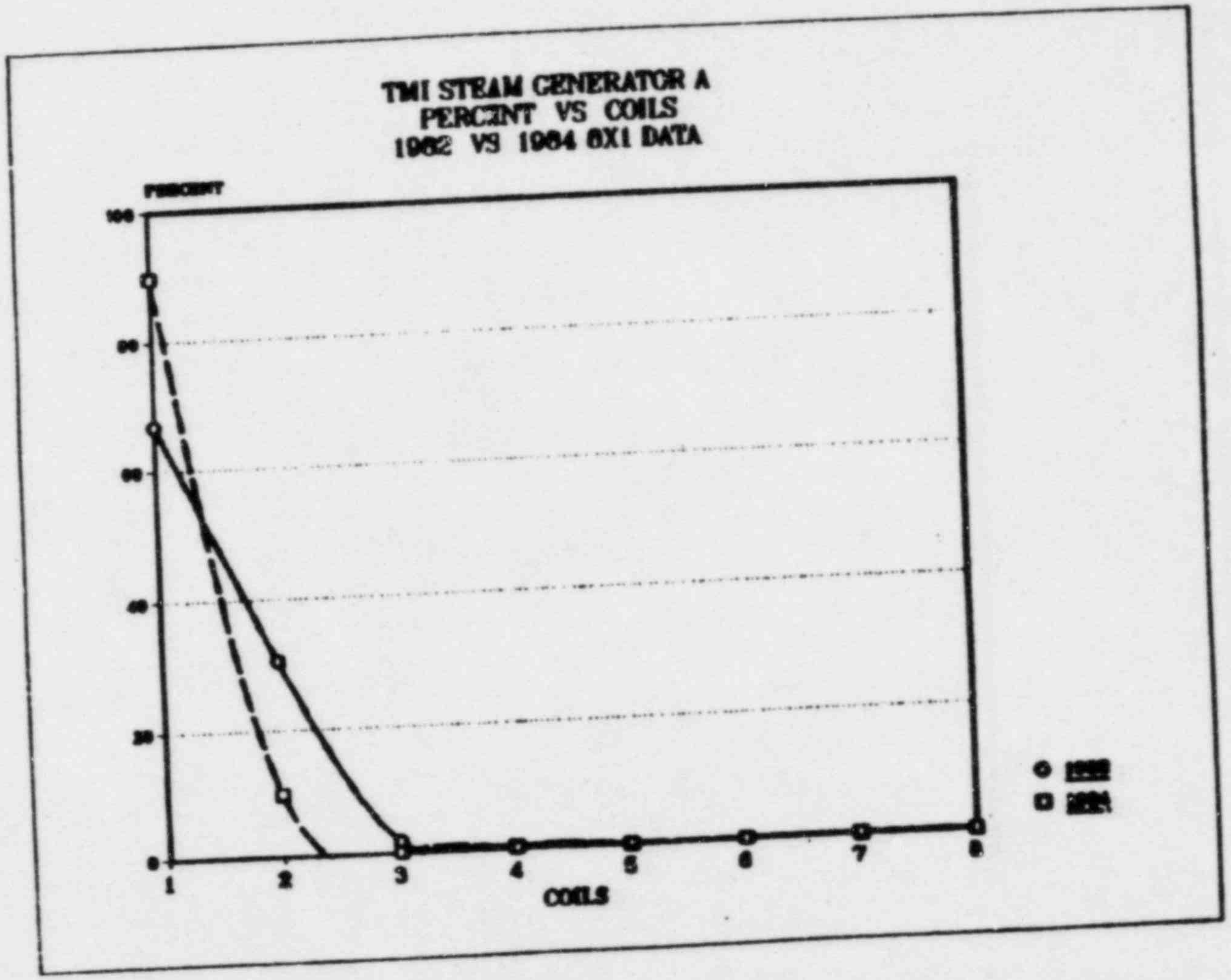

TMI STEAM GENERATOR A
PERCENT VS COILS
1982 VS 1984 8X1 DATA
PERCENT
100
80
60
40
20
0
1
2
3
4
5
6
7
8
COILS

FIGURE 5B

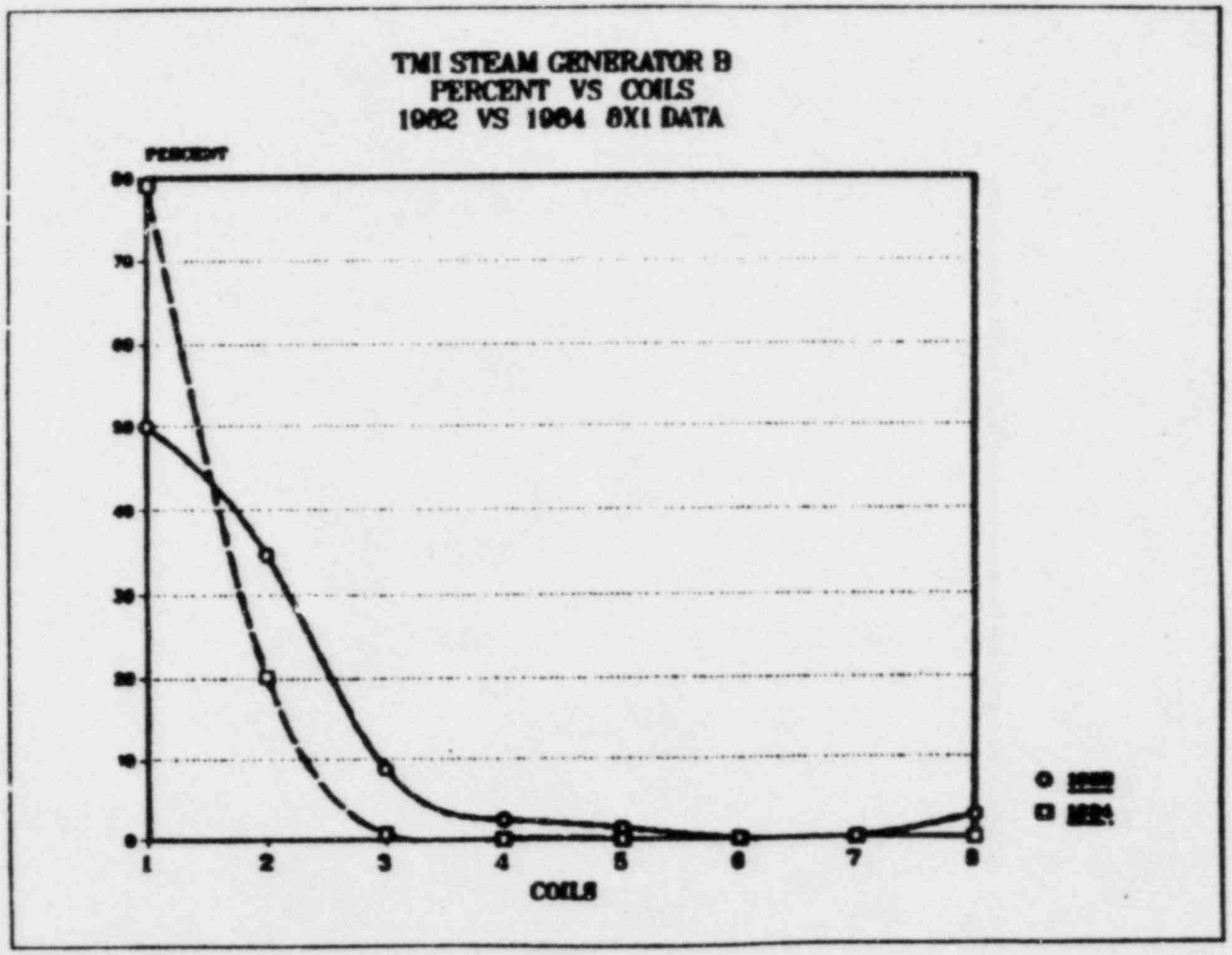

TMI STEAM GENERATOR B
PERCENT VS COILS
1982 VS 1984 8X1 DATA
PERCENT
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
COILS

FIGURE 6

ESTABLISHED MINIMUM SENSITIVITY FOR THE HIGH GAIN .540 S.D. EXAMINATIONS BELOW UPPER TUBESHEET (300 MV) WITHIN UPPER TUBESHEET (1 VOLT) AND TUBESHEET ENTRY (3.3 VOLTS)

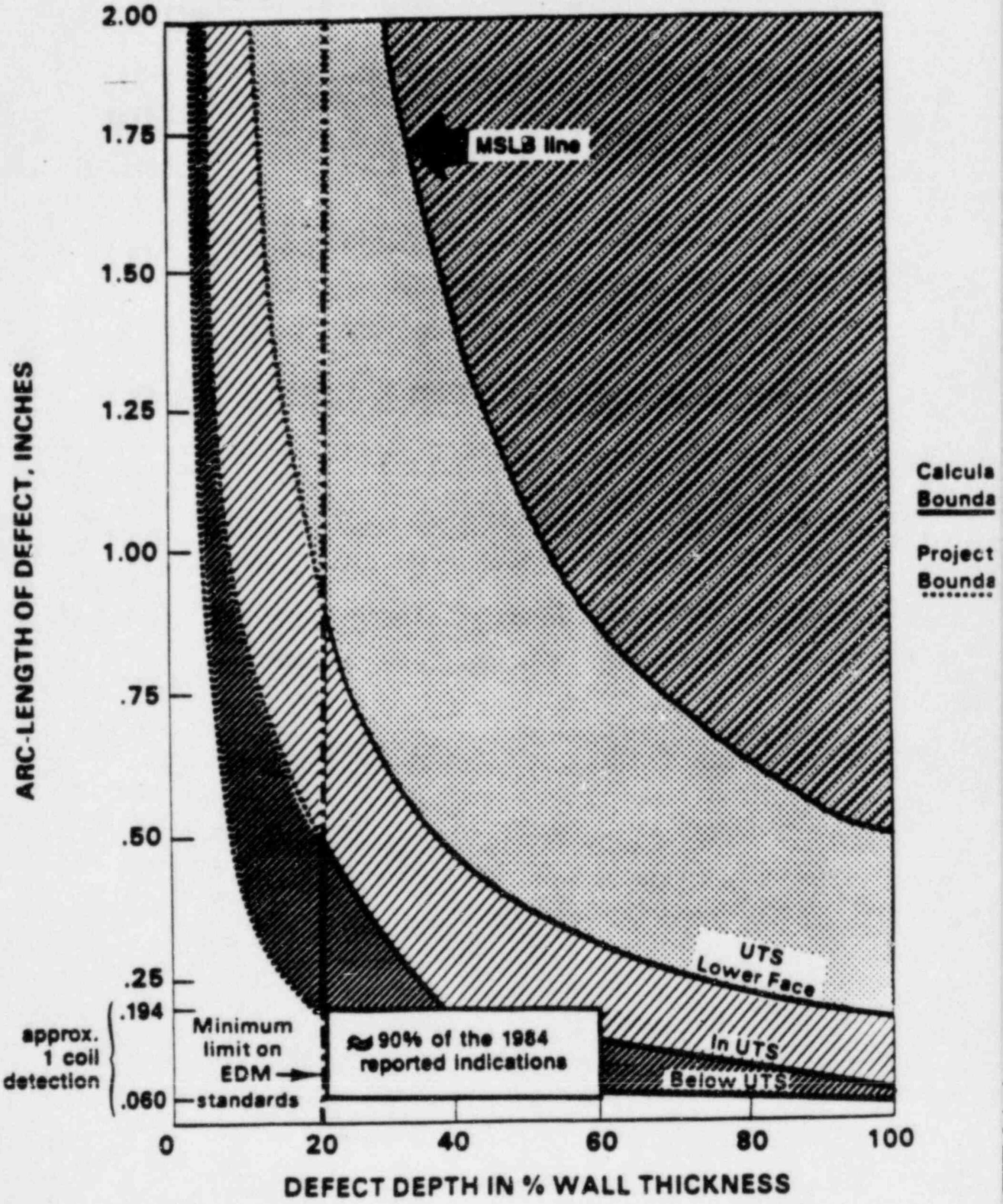
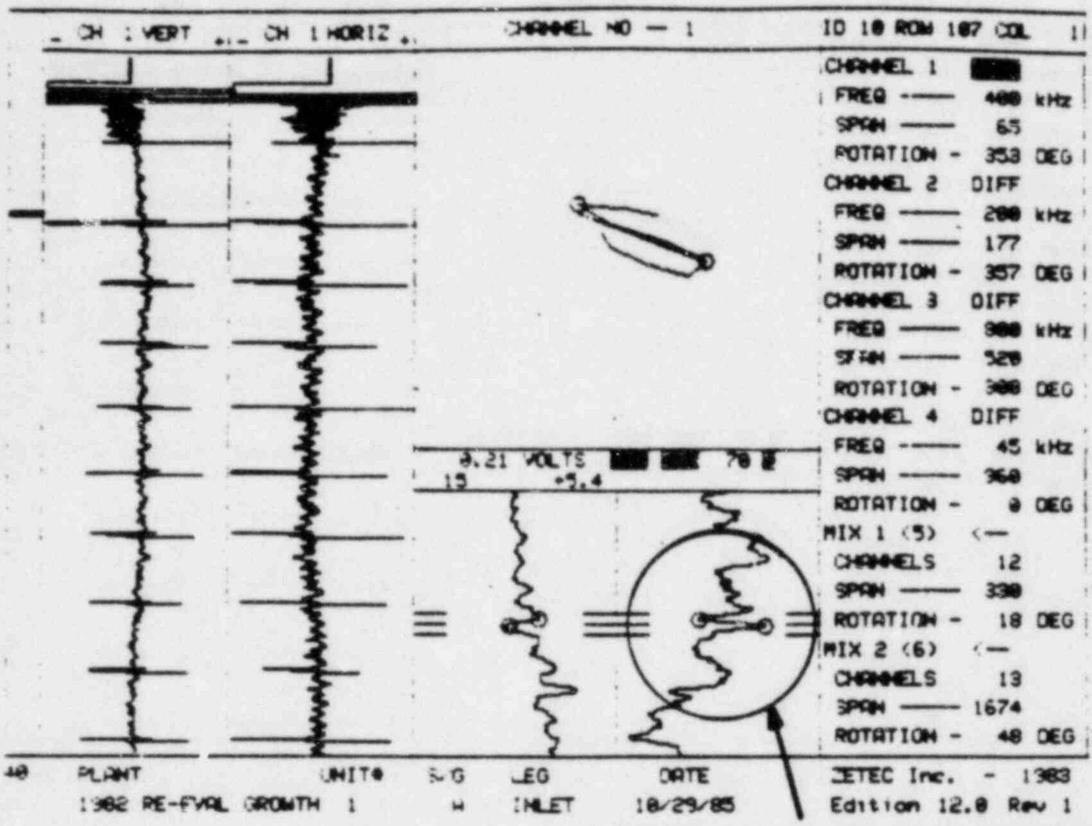


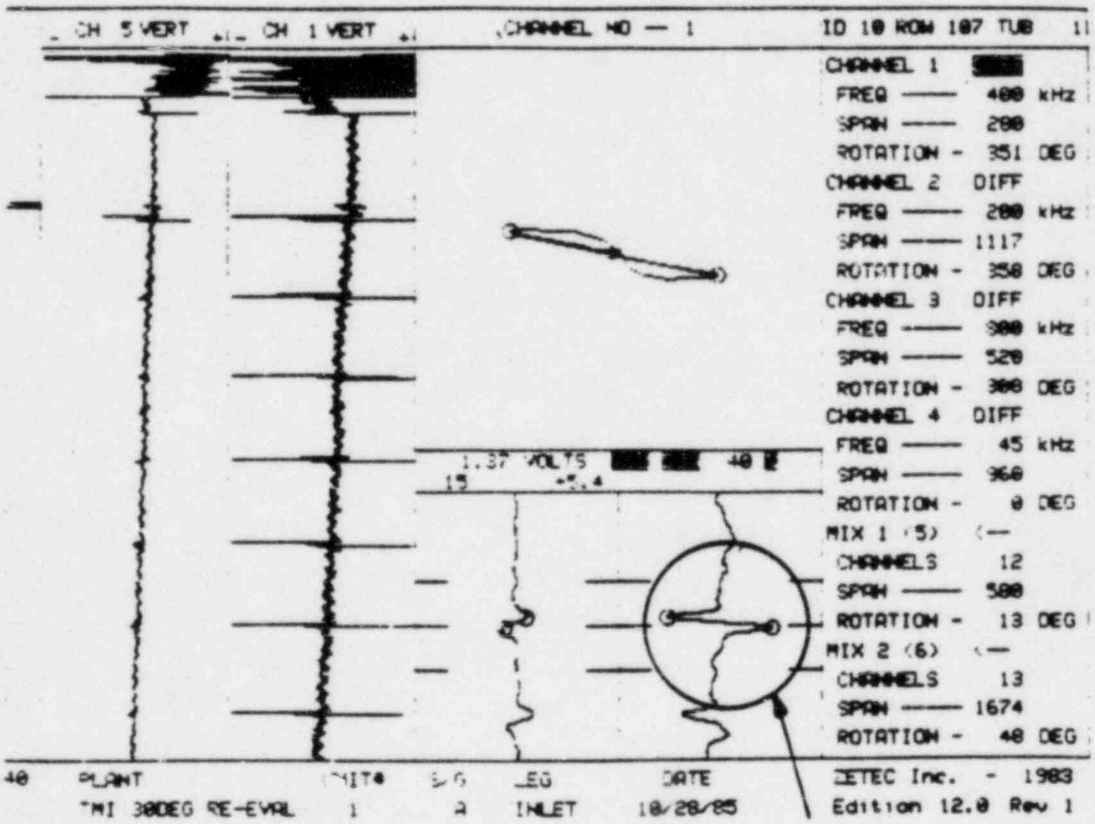
FIGURE 7



```
_ CH 1 VERT +._ CH 1 HORIZ +.      CHANNEL NO — 1          ID 10 ROW 107 COL    11
                                                           CHANNEL 1
                                                            FREQ ----  400 kHz
                                                            SPAN ----   65
                                                            ROTATION - 353 DEG
                                                           CHANNEL 2   DIFF
                                                            FREQ ----  200 kHz
                                                            SPAN ----  177
                                                            ROTATION - 357 DEG
                                                           CHANNEL 3   DIFF
                                                            FREQ ----  900 kHz
                                                            SPAN ----  520
                                                            ROTATION - 300 DEG
                                                           CHANNEL 4   DIFF
                                   0.21 VOLTS        70     FREQ ----   45 kHz
                                   15      +5.4             SPAN ----  360
                                                            ROTATION -   0 DEG
                                                           MIX 1 (5)   <—
                                                            CHANNELS    12
                                                            SPAN ----  330
                                                            ROTATION -  18 DEG
                                                           MIX 2 (6)   <—
                                                            CHANNELS    13
                                                            SPAN ---- 1674
                                                            ROTATION -  40 DEG
40   PLANT                 UNIT#   S/G   LEG     DATE      ZETEC Inc.  -  1983
     1982 RE-EVAL GROWTH   1       H     INLET   10/29/85  Edition 12.0 Rev 1
```

Small Amplitude 1982 Indication

Illustration of ECT Signal (Between Dots) and Surrounding Noise



```
_ CH 5 VERT +._ CH 1 VERT +.       CHANNEL NO — 1          ID 10 ROW 107 TUB    11
                                                           CHANNEL 1
                                                            FREQ ----  400 kHz
                                                            SPAN ----  200
                                                            ROTATION - 351 DEG
                                                           CHANNEL 2   DIFF
                                                            FREQ ----  200 kHz
                                                            SPAN ---- 1117
                                                            ROTATION - 358 DEG
                                                           CHANNEL 3   DIFF
                                                            FREQ ----  900 kHz
                                                            SPAN ----  520
                                                            ROTATION - 300 DEG
                                                           CHANNEL 4   DIFF
                                   1.37 VOLTS        40     FREQ ----   45 kHz
                                   15      +5.4             SPAN ----  360
                                                            ROTATION -   0 DEG
                                                           MIX 1 (5)   <—
                                                            CHANNELS    12
                                                            SPAN ----  500
                                                            ROTATION -  13 DEG
                                                           MIX 2 (6)   <—
                                                            CHANNELS    13
                                                            SPAN ---- 1674
                                                            ROTATION -  40 DEG
40   PLANT                 UNIT#   S/G   LEG     DATE      ZETEC Inc.  -  1983
     TMI 300DEG RE-EVAL    1       A     INLET   10/28/85  Edition 12.0 Rev 1
```

Same Indication As Above In 1984

Illustration of ECT Signal (Between Dots) and Surrounding Noise

APPENDIX C

GPU Nuclear

TECHNICAL DATA REPORT

TDR NO. 686	REVISION NO. 1	
BUDGET ACTIVITY NO. 123125	PAGE 1 OF 23	
PROJECT: TMI-I OTSG Recovery	DEPARTMENT/SECTION E&D/Mat Eng/Failure Analysis	
	RELEASE DATE	REVISION DATE 10/03/85

DOCUMENT TITLE:

Characterization of IGA in TMI-1 OTSG Tube Samples

ORIGINATOR SIGNATURE	DATE	APPROVAL(S) SIGNATURE	DATE
J. A. Janiszewski	10/8/85	F. S. Giacobbe	10/8/85
		D. K. Croneberger	10-30-85
		APPROVAL FOR EXTERNAL DISTRIBUTION	DATE
			10/31/85

Does this TDR include recommendation(s)? ☐ Yes ☒ No If yes, TFWR/TR #

•	DISTRIBUTION
	D. K. Croneberger R. J. McGoey S. D. Leshnoff J. J. Colitz G. E. Von Nieda R. F. Wilson

ABSTRACT:

This report describes the additional investigations to further characterize the intergranular attack (IGA) that existed in the OTSG's as a result of the thiosulfate intrusion into the RCS in 1981 as well as help clarify the sensitivity and accuracy of eddy current examination for IGA/IGSAC. Unfortunately, this investigation was unable to produce any data or conclusions regarding the detectability of IGA by eddy current testing.

Existing reports were reviewed and reported IGA areas were characterized. Tubes that had been previously removed and stored were eddy current and fiber optic inspected. Two tube sections were also cut and examined by metallography.

IGA in areas away from identified intergranular stress-assisted cracks (IGSAC) and away from stained areas were found which were approximately hemispherical and penetrating less than 40% through wall. Visible pitting was found to be less than 0.005" deep and .005" in diameter.

Stains present on the tube I.D. do not describe the geometric shape of underlying IGA. Large areas of staining exist without significant IGA. These stained areas, however, may contain discrete, randomly distributed patches of IGA. IGA surrounding visible pits may exist but is not deeper than the pits and extends no further than twice the diameter of the pit.

No evidence of axial cracking was detected in the OTSG below the upper tubesheet.

•COVER PAGE ONLY

GPU Nuclear

DOCUMENT NO.
TDR 686

TITLE
CHARACTERIZATION OF IGA IN TMI-1 OTSG TUBE SAMPLES

REV	SUMMARY OF CHANGE	APPROVAL	DATE
1	Abstract: Abstract has been completely rewritten. Ref. to grain disturbance has been deleted.		10/5/85
1	Pg. 3: Introduction has been completely rewritten.		
1	Pg. 8, Table 2: Deleted "none" under stain description.		
1	Pg. 11: Paragraphs 2, 3 & 4 rewritten for better clarity.		
1	Pg. 14: Deleted statement regarding 2:1 extent to depth relationship.		
1	Pg. 16: Table 6: Deleted column labeled "Percent of IGA in this Group"		
1	Pg. 17: Deleted para. on <u>Grain Boundary Separations</u>.		
1	Pg. 18: (Rev. 0) Deleted Figs. 6a & 6b.		
1	Pg. 18: Conclusions #1&6 deleted		
1	Pg. 19: References #2, 4, 11 deleted		10/5/85 10-30-85

TABLE OF CONTENTS

INTRODUCTION

Indications of greater than 40% TW penetration identified during the 1984-85 EC examinations indicate that IGA/IGSAC of this depth did exist which were previously below the eddy current voltage response required for dispositioning of a defect. As a result of mechanical loadings on the actual OTSG's, these pre-existing IGA/IGSAC areas have probably been disturbed producing local grain boundary separations or loss of grains which enhanced their voltage response permitting a signal disposition (Ref. 1).

In order to attempt to describe and quantify pre-existing IGA, GPUN initiated a laboratory investigation at B&W's Lynchburg Research Center (Ref. 2). This investigation used actual OTSG tubing that had been removed from the OTSG's in late 1981 and early 1982.

The results from the LRC effort were then analyzed in conjunction with previous analyses of IGA/IGSAC in order to describe IGA/IGSAC that might exist in the OTSG's at the time of the 1984-5 EC inspections and its relationship to stains and eddy current indications.

METHODS AND SOURCES OF DATA

The principal source of data used in this analysis was the investigation done by B&W's Lynchburg Research Center (LRC) from February to April, 1985 (Ref. 2). As a supplement to the above analysis we used the results of additional eddy current testing done by Nuclear Energy Services (Conam) on the same group of OTSG tubes.

To increase the database on intergranular attack, we reviewed previous reports (Ref. 3-7) on failure analysis and long term corrosion testing of TMI-1 OTSG tubes.

For the 1985 B&W investigation, we selected OTSG tubes that were from the periphery of the A-OTSG. These tubes were removed between late 1981 and mid-1982 for use in the TMI-1 OTSG failure analysis. They were stored at LRC since that time.

In order to make eddy current testing meaningful, the tubes had to be at least six inches long. The final set of tubes (Table 1) consisted of fourteen tube sections.

B&W metallographically examined samples cut from two of the tube sections. Details of specimen selection and preparation are contained in Reference 3.

RESULTS AND DISCUSSION

I.D. Oxide Stains

We examined the oxide films both directly and indirectly. Indirect examination was done on all tubes using fiberscopes as previously described. Direct examinations using a stereo microscope were done on tubes A-111-13, piece 1 and A-112-5, piece 1, after the pieces had been longitudinally sectioned. The direct examinations were more sensitive.

We identified three types of stains during the direct examinations. Type 1 stains (Figure 1) consist of small (approximately .010" diameter) darkened areas that resemble oil spots. They do not have any visible internal structure and are not associated with any underlying tube defects.

Figure 1
Type 1 stains resembling oil spots in A-112-5, piece 1, approx. 5 in. from top. 8.6X.

Type II stains are from approximately 0.25" to over 1" long and are irregularly shaped (Figure 2). Their internal color is a dark brown, and there is a distinct border between the stained area and the balance of the tube oxide film.

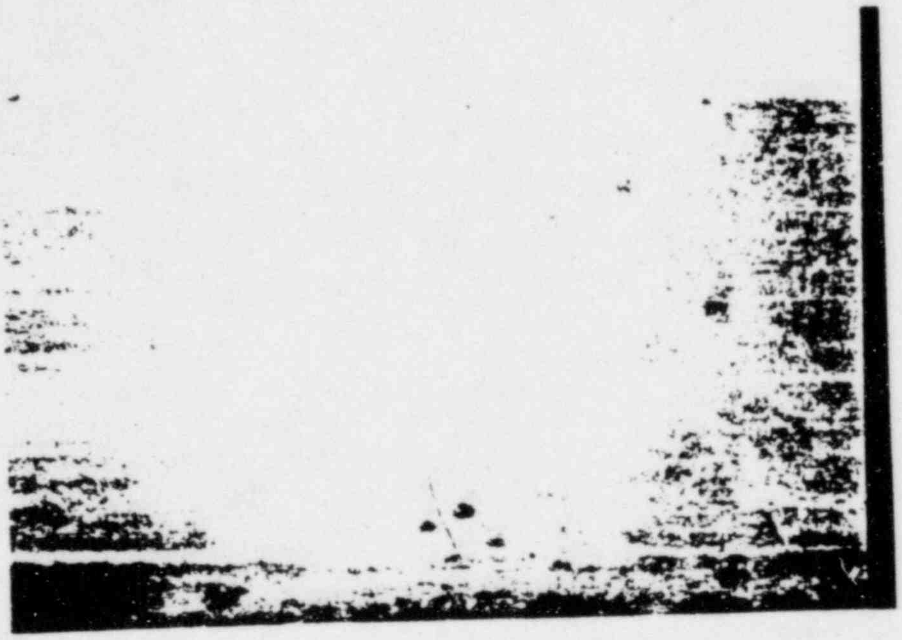


Figure 2
Type II stain near a crack in tube A-112-5, piece 2, 5.4 inches from top. 8.6X.

Type III stains are similar to Type II in extent, overall color, and in the presence of a border. However, within a Type III stain there are one or more areas which appear grey in color and are usually accompanied by grain loss which appears as small pits. (Figure 3). The pits are on the order of 0.010" in diameter.

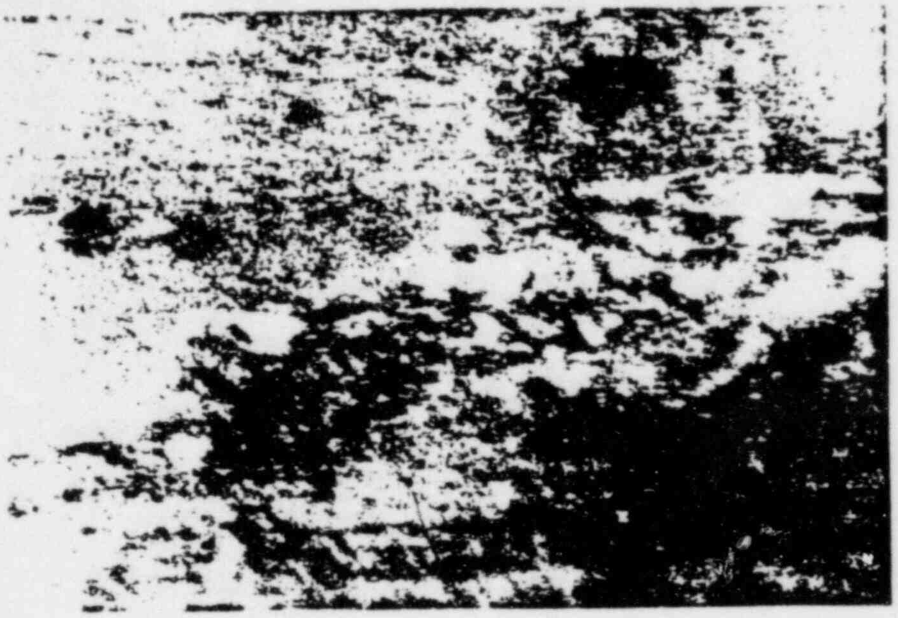


Figure 3
Type III stain - tube A-112-5, piece 1,
4 inches from top.

The fiberoptics examination was not sensitive enough to detect Type I stains. We did identify several areas which could be identified as either Type II or III stains.

Table 2 compares the fiberscope observed locations of stains to the locations of eddy current indications in the tube samples. Tube A-112-5 is listed separately because of the large number of eddy current indications in it (see next section).

TABLE 2 - Correlation of Eddy Current Indications With Stains Detected by Fiberscope

Stain Description	EC Indication at Stain Location?	Tube Sections Other than A-112-5[1]
Type II	No	6
	Yes	0
Type III	No	0
	Yes	5

Note 1 - Tube A-112-5 not listed because of large number of eddy current indications.

For tube sections other than A-112-5, Type II stains did not correlate with eddy current indications, and Type III did. In tube A-112-5, some Type II stains appeared at eddy current indications. However, with the combined imprecision of both eddy current and fiberscope measurements with respect to axial location (elevation), the stain - indications match is suspect for this tube.

Eddy Current Inspections

Table 3 presents a summary of the results of both the Conam and B&W eddy current evaluations. B&W's evaluation (Ref. 2) concluded that there was no significant change in the eddy current results between 1981-82 and 1985. Conam reported all indications that were visible above background, regardless of voltage level.

Table 3 - Summary of Eddy Current Inspections

			B&W Evaluation					Conam Evaluation				
			1985									
					ITW/Voltage				ITW/Voltage		8 X 1 Result	
OT-SG	Tube ID	Piece #	Location in. from top of OTSG	Location in. from top of piece	0.500	0.540	Comments	Location in. from top of piece	.500	.540	# Coils	Max. Volt.
A	13-63	3	31-38		NDD	NDD	Multiple Dents		NDD	NDD	NDD	
A	112-9	1	4.3-12.3	4.8	86% 2.2v	84% 3.2v	Indications on O.D. Plane	4.1	100% 1.50	100% 3.10	2	5.44
A	24-94	3	13.3-19.8	2.5	62% 1.6v	78% 2.4v	Indications on I.D. Plane	2.2	56% 1.64	76% 2.16	2	.99
		8	41.8-48.9		NDD	NDD	Multiple Dents		NDD	NDD	NDD	
		9	48.9-55.8		NDD	NDD			NDD	NDD	NDD	
		10	55.8-67.8		NDD	NDD	3 Bulges		NDD	NDD	NDD	
A	111-13	1	2-24.6	At Top		89% .8v	I.D. Plane Possible Defect	1.2		23% 1.57	2	.45
								1.5	50% .45	96% .79	2	1.04
								2.1	70% .36	46% .63	2	.59
		3	50.7-57.5		NDD	NDD			NDD	NDD		
		4	76.3-89.0		NDD	NDD			NDD	NT		
		7	151.3-176.4		NDD	NDD			NDD	NT		
		8	176.4-201.6		NDD	NDD	Small Ding		NDD	NDD	NDD	
		9	201.6-213.8		NDD	NDD	2 Dents		NDD	NDD	NDD	
A	23-93	1	2-12		NDD	NDD	Possible Indication at End of Tube	1.0	100% .44	100% 1.55	2	.48
A	112-5	1	2-12					0.3		100% 1.64		
								0.7			3	2.45
								0.9		100% 1.32		
							Indications on O.D. Plane. Multiple Indications on All Exams, Not All Indications Recorded	1.0			2	1.42
								1.1		70% .69		
								1.2			1	.29
								1.4	100% 1.01	100% .87		
								1.5			1	.95
								1.8			2	2.81
				2.0	92% 1.1v	89% 2.7v		2.0	100% .35			
								2.1			1	.24
								2.2			2	.32
								2.3	100% .40		2	.44
								2.4		100% .87		
								2.6			2	1.48
								2.7	100% .46			
								2.9		100% 1.09		
								3.0			3	6.98
								3.2		100% 1.22	1	2.90
								3.4	100% 1.77			
								3.5			1	3.47
				3.8	85% 1.8v	87% 5.1v		3.8	100% .66		2	10.00
								4.0			2	1.01
								4.1		100% 4.95		
								4.2	100% .23			
								4.7		100% 1.76		
								4.9		96% .71	1	.09
								5.7			3	4.32
								5.8	100% .99	100% 2.55		
				6.2	62% .7v	79% 2.8v						

NDD - No Detectable Discontinuities
NT - Not tested - Probe would not fit due to tube distortion

The results of the eddy current inspections were consistent with both previous inspections and each other. Of the fourteen tube sections, nine had no detectable defect indications, either reported previously or by the current inspection as evaluated by Conam. Three more had previously reported indications that were confirmed by the present tests.

The two remaining tubes had previously identified indications which B&W confirmed had not changed since the previous examinations. During the Conam reevaluation of these tubes, additional indications were identified. In tube A-112-5, piece 1, Conam was able to individually evaluate signals previously identified as "multiples". In tube A-111-13 Conam reported two additional indications in an area where B&W had previously reported a possible defect. The reported indications were low level, less than 1 volt and their detection may be attributed to improvements in analysis equipment and techniques from 1981 to 1985.

The indications in these two tubes were further characterized by metallography. The results of this characterization are described in the metallography section of this report.

Metallography

We selected tubes A-111-13, piece 1 and A-112-5, piece 1, for metallography. We had two objectives in the metallography: First, to determine the presence and severity of intergranular attack (IGA) under stains and second, to determine if IGA was detectable by eddy current testing. We felt that these two tubes were the most likely to provide useful data, since they both contained low voltage eddy current indications (below normal reporting level).

The first part of the investigation consisted of sectioning both tube sections longitudinally. Tube A-112-5, section 1 had 15 visible circumferential cracks in it. It also had a large number of stains of all three types.

We selected two areas from this tube for metallographic examination. The first was an area from 1.125 to 1.802 inches from the top of this section. This area contained a large Type III stain.

We made four transverse cuts through the stain and characterized any IGA and pitting.

We found only superficial IGA (less than 0.001") under the stains. We ground into three areas of pitting; the deepest pit was 0.005", while the other two were less than 0.002" deep.

We took another transverse section through a longitudinal stain that contained a longitudinal line of pits at about 2.75 inches from the top of tube A-112-5. Again, only superficial IGA appeared under the stains, and pit depths were less than 0.002".

Tube A-111-13 had considerably fewer stains on the I.D. surface. No cracks were visible, but we observed individual or clustered pits near the reported eddy current locations. In order to characterize the pits and check for circumferential cracking, we took three longitudinal specimens at locations corresponding to eddy current indications. After completion of several successive grinding/polishing steps, we broke the tube sections out of their mounts and bent them slightly with the ID in tension. We also bent the unmounted sections of the tube. We found circumferential cracks at all three eddy current indications in tube A-111-13.

The results of the metallography indicate that staining is not indicative of areas of general IGA.

Both direct visual observation and metallographic examination suggest that the pits are formed by the drop out of a small number of grains in a limited area of IGA. The deepest pit examined was 0.005" deep, or approximately 14% through the wall. Most of the pits were less than 0.002" deep.

Finally, this metallography was not successful in determining the detectability of IGA by eddy current. Table 4 attempts to correlate eddy current indications, visual and metallographic results, however, due to the close proximity of indications to each other and the imprecision of location measurement these correlations can only be considered approximate.

TABLE 4 - Correlations of Eddy Current Indications and IGSAC

	EC ANALYSIS						CRACK CHARACTERIZATION		
	Location(1) In. From Top of Piece		.540" Result(11)		8 X 1 Result				
Tube ID	.540	8 X 1	% T.W.	Volts	# of Coils	Volts(2)	Location(3) In. From Top of Piece	% T.W.(10)	Length in.
Tube A-112-5	0.3	0.55(4)	100	1.55	3	2.45	.549	100	.31
	0.9	0.85(4)	100	1.32	2	1.42	.754	100	.14-.12(1
	1.1	1.05(4)	70	.69	1	0.29	1.095	100	.09-.15(1
	1.4	1.35(4)	91	2.58	1	0.95	1.357	100	.26
		1.65(4)			2	2.81	1.631(5)	100	.15
							1.701(5)	100	.09
							1.759(5)	100	.1
		1.95(4)			1	0.24	1.930	100	.25
		2.05(4)			2(6)	0.32	2.053	100	.19-.24(
	2.4	2.3	83	.87	2	0.44	2.301	100	.2
		2.6			2	1.48	2.556	100	.23-.29(
	2.9	3.0	85	1.09	3	6.98	3.195	100	.32
		3.2	83	1.22	1	2.90	Note 7		
		3.5			1	3.47	Note 7		
		3.8			2	10.0	3.640	100	.26

TABLE 4 - Correlations of Eddy Current Indications and IGSAC
(continued)

	EC ANALYSIS						CRACK CHARACTERIZATION		
	Location(1) In. From Top of Piece		.540" Result		8 X 1 Result		Location(3) In. From Top of Piece	% T.W.(10)	Length in.
Tube ID	.540	8 X 1	% T.W.	Volts	# of Coils	Volts(2)			
Tube 112-5	4.1	4.0	87	4.95	2	1.01	4.025	100	.31
	4.7		84	1.71					
	4.9	4.9	96	0.71	1	.09	4.80	Note 8	
	5.8	5.7	80	2.55	3	4.32	5.380	100	.31
Tube A-111-13	1.2	1.2	23	1.57	2	.45	1.0	20	0.25
	1.5	1.5	96(13)	.79	2	1.04	1.5	20	.175
	2.1	2.1	46	.63	2	.59	2.8	29	.037 (9

Notes:

1 - Based on interpretation of tapes w/assumed constant pull speed.
2 - Maximum coil voltage
3 - Based on in-laboratory measurement
4 - Locations less than 2.3 inches from top have had 0.15 inches subtracted from Conam reported locations to account for apparent non-uniform probe motion.
5 - Cracks too close to resolve by eddy current
6 - Coils were not adjacent
7 - Heavy pitting but no cracks observed. Specimen was not examined by bending
8 - No cracking - cutting tool damage to I.D.
9 - Up to .148" may have been lost during cutting and mounting for metallography.
10 - Approximations only.
11 - Crack depths over 80% are administratively treated as 100%.
12 - Crack only visible running to cut edge of one half. Length range base on measured sawblade width of 0.055 in.
13 - EC signal was significantly distorted

Figure 4 compares the observed length of cracks with predicted ranges for the number of coils reported by the 8 X 1 probe. The data show that in general the observed crack lengths are consistent with the reported number of coils, except for two one-coil defects which were longer than predicted. These defects were probably either misaligned such that a second coil would pick them up at a level too low to be reported, or manufacturing tolerances in the 8 X 1 probe caused one-coil coverage to be larger than predicted. By GPUN plugging criteria, these indications would have been combined with adjacent indications and the tube dispositioned conservatively.

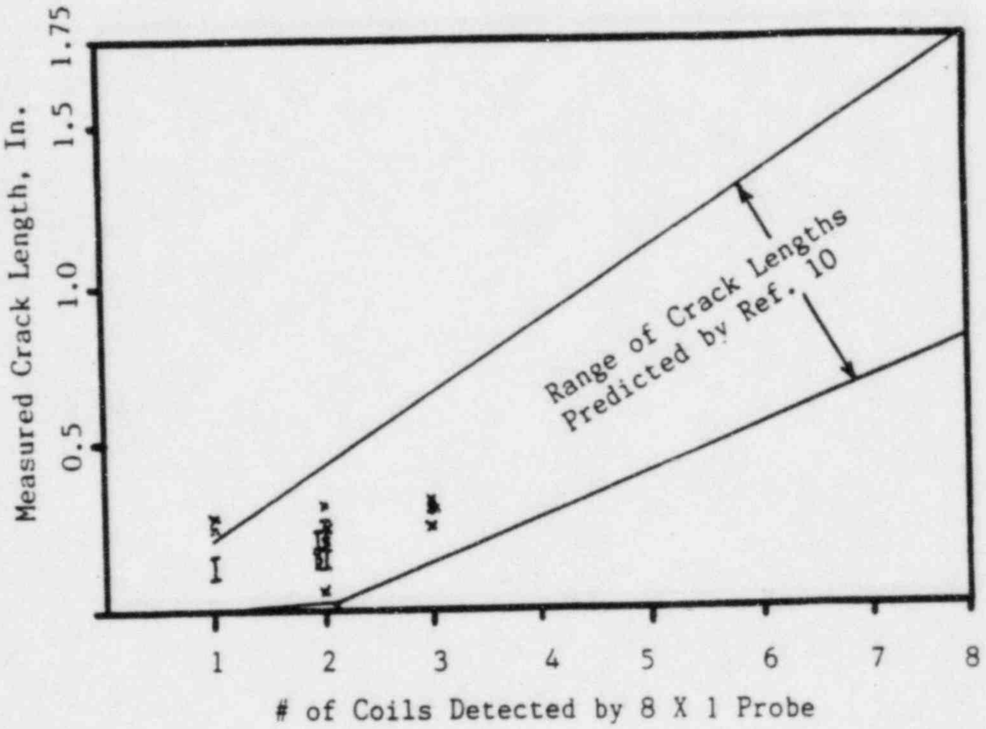


Figure 4
Measured IGSAC length vs. number of coils by 8 X 1 probe.

Distribution and Characterization of IGA

Data Base

Data on the size, shape and frequency of occurrence of IGA have been generated from several previous investigations as well as the 1985 program at LRC. As part of the present data analysis effort, we compiled available data from metallography samples reported in the following investigations:

1) First and second round failure analysis at B&W and Battelle - References 3 and 4.

2) Third round failure analyses at B&W and Battelle - References 5 and 6.

3) Long term corrosion test at Westinghouse - Reference 7.

We have reviewed each of these references and extracted reported data on the amount of tube surface metallographically examined and any IGA detected. Relevant data from each reference are contained in Appendix A.

Characterization of IGA

A total of twenty areas of IGA have been detected (Table A-1). Nine of these areas were within 0.5 inches of an identified IGSAC, while eleven were more than 0.5 inches away. The bulk of this discussion is based on IGA away from IGSAC, since this should be representative of the IGA which could potentially have remained in service in the OTSG's.

The IGA areas away from IGSAC generally appear bowl-shaped. Figure 5 shows the extent (axial or circumferential length) to depth ratios for the IGA. The IGA areas near IGSAC tend to be deeper for the same axial length.

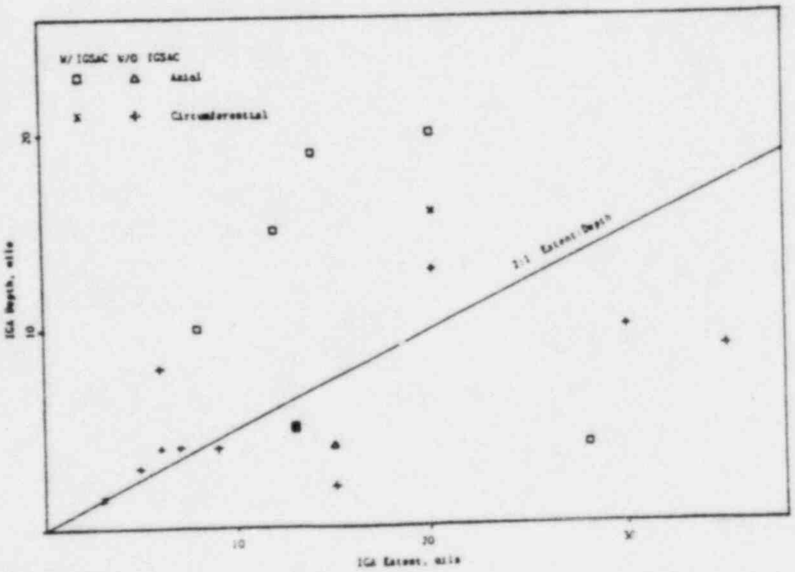


Figure 5
Depth vs. Extent of IGA in OTSG tubes.

The maximum depth of IGA detected away from IGSAC was 0.013 inches, or 38% of minimum wall. The mean depth was 0.0061 inches, with a standard deviation of 0.0036 inches. The mean depth of this IGA was 0.011 inches, standard deviation was 0.039, and maximum depth was 0.020 inches.

The mean axial and circumferential lengths of IGA away from IGSAC are the same: 014 in. This is approximately twice the mean depth of 0.0061 in. This confirms the bowl-type geometry of the IGA away from IGSAC.

Frequency of Occurrence of IGA

In Table 5, we have summarized the frequency of occurrence of IGA. The frequency figures are based on the total length of examined surfaces.

TABLE 5 - Occurrence of IGA in Metallography Samples

	Longitudinal Samples	Circumferential Samples
Total Met. Sample Length,		
Within 0.5" of IGSAC	3.053 in.	4.347 in.
Away from IGSAC	1.278 in.	81.508 in.
Total	4.331 in.	85.855 in.
Length of IGA Areas,		
Within 0.5" of IGSAC	0.106 in.	0.048 in.
Away from IGSAC	0.019 in.	0.150 in.
Total	0.125 in.	0.198 in.
Percent of Sample Length Occupied by IGA		
Within 0.5" of IGSAC	3.4 %	1.1 %
Away from IGSAC	1.5 %	0.2 %
Average - all samples	2.8 %	0.2 %

Both overall and in the specimens more than 0.5 inches away from identified IGSAC, approximately 0.2% of the transverse specimens' surface contained IGA. Near IGSAC, the IGA-occupied length increased to 0.9%. For longitudinal specimens, the % of IGA was approximately 3% overall, 3.6% near IGSAC and 1.5% away from IGSAC.

The logic for sampling the transverse and longitudinal specimens was different. Most longitudinal specimens were selected based on mounting a surface feature of interest, such as an IGSAC, stain, or pit. The vast majority of the transverse specimens, on the other hand, were C-ring specimens from the long term corrosion test. As such, they were selected to represent a sample of tubes, heats, and elevations, and thus should constitute a more representative sample of actual tube conditions. The transverse specimens also constitute a larger sample than the longitudinal ones; approximately 20 times more tube surface was examined in transverse mounts.

In Table 6, we present the analysis of IGA distribution by height. The percentage of sample length exhibiting IGA ranges only from 0 to 0.6% - this is a relatively narrow range. Therefore, within the limited data base the frequency of IGA does not appear to be strongly dependent on axial height. It should be noted, however, that we have removed no tubes below the 9th tube support plate.

TABLE 6 - Distribution of IGA by Height
in Transverse Samples

Distance From Primary Face of UTS, In.	Percent of Total Met. Sample Length	Percent of Sample Exhibiting IGA
0-11	36.9	0.2
11-16	3.1	0.6
16-24	15.4	0.0
24-70	44.5	0.3
70+	0.1	0.0

The C-ring samples examined in the long term corrosion test form a subset of particular interest. These samples were selected to represent a variety of tubes, heats, and elevations, away from IGSAC. As a consequence of the post-test examinations (Ref. 7), these tube sections were thoroughly examined for IGA and IGSAC.

Table 7 summarizes the results from tubes used for C-ring samples. Except for tube A-24-94, all IGA was found in the upper tubesheet area in tubes which also contained rejectable eddy current defects.

Table 7 - C-Ring Sample Examinations from Long Term Corrosion Test

Tube	Examination Elevation, In. from Primary Face of UTS	No. of C-Rings Examined	No. of C-Rings Containing IGA	% of Transverse Length Occupied by IGA(2)
A-62-8	5-8	5	1	0.05
A-37-29	49.5-52.5	5	0	0.0
A-88-7	10-13	3	0	0.0
A-24-94	25.5-29	5	4	0.8
A-13-63	20-21	2	0	0.3(1)
B-16-22	60-63	3	0	0.0
A-16-69	2-3.5, 9	4	1	0.2
B-94-27	18.5-21.5	2	0	0.0
B34-19	6.5-7.5	2	0	0.0
Total		31	6	

(1) Includes 1 area of IGA found on full tube specimen taken from tube next to C-rings.

(2) IGA occupied 0.2% of the total C-ring length examined.

Tube A-24-94 has been previously recognized as a tube with an inordinately large amount of both IGA and IGSAC (Ref. 9). No reason has been identified why this tube should be the worst of the 29 tubes removed from the OTSG's. It should be noted, however, that this tube would have been removed from service because it contained IGSAC of greater than 40% thru wall penetration.

CONCLUSIONS

1. ID tube stains do not represent areas of significant IGA. IGA observed under stains is typically less than .001". Some IGA exists near visible pits, but it is usually less than 0.005 in. deep.

2. Visible pitting is small, less than 0.005 inches deep and wide. Pits of this size are below the expected detectability for eddy current testing. They are visible by fiberscope inspection.

3. IGA areas occupy, on the average, 0.2% of the examined sample length. Within the limited sample examined, there appears to be a uniform axial distribution of the localized IGA.

4. No conclusion can be drawn from the available data presented in this report regarding the E.C. detectability of IGA not associated with IGSAC.

5. No axial cracks have been detected below the upper tubesheet region.

6. Measured circumferential length of IGSAC correlates well with the number of 8 X 1 coils on which the signal appears.

REFERENCES

1 - J. A. Janiszewski, "Evaluation of Eddy Current Indications Detected During the 1984 Tech. Spec. Inspection," GPUN Technical Data Report 638, Rev. 0, Jan. 11, 1985.

2 - S. C. Inman, "Investigation of IGA in TMI-1 OTSG Tubes," B&W Report RDD: 85:5046-03:01, June 1985. (Attached)

3 - M. A. Rigdon and E. B. S. Pardue, "Evaluation of Tube Samples from TMI-1," B&W Report No. 77-1135317, July 7, 1982.

4 - A. K. Agrawal, W. N. Stiegelmeyer, and W. E. Berry, "Final Report on Failure Analysis of Inconel 600 Tubes From OTSG A and B of Three Mile Island Unit 1," Battelle Columbus Laboratories, June 30, 1982.

5 - S. C. Inman, "Examination of OTSG Tubes from TMI-1 Third Pulling Sequence," B&W Report RDD: 83: 5068-03-03, December 1982.

6 - A. K. Agrawal, W. N. Steigelmeyer, and W. E. Berry, "Final Report on Failure Analysis of Inconel 600 Tubes from OTSG A and B of Three Mile Island Unit 1, Battelle Columbus Laboratories, "June 30, 1982.

7 - "Long Term Corrosion Test Program of Nuclear Steam Generator Tubing Samples from Three Mile Island Unit 1 - Final Report," Westinghouse Electric Corp., May, 1985.

8 - G. E. Rhedrick, "Task IV Report on Eddy Current Indications Found Subsequent to Kinetic Expansion of TMI-1 Steam Generator Tubes," GPUN Technical Data Report No. 401, Rev. 0, April 8, 1983.

Appendix A

Summary of
Metallographic Samples
From Laboratory Investigations

TABLE A1 - IGA Detected During Metallographic Examinations

OTSG	Tube	Specimen Elevation In. From Top	Type of Specimen(1)	Length of Sample Examined, In.	IGA Extent, mils Length Axial	IGA Extent, mils Length Circum	IGA Extent, mils Depth	Elevation of Nearest IGSAC	Documentation Ref.	Documentation Page/Figure	Note
B	8-25	1.25	L	.041	.014		.019	1.21	4	F 17	
B	11-23	1.25	L	-	.012		.015	1.25	4	F 24	(2)
A	146-6	10.5	SEM	.027 X .036	.011	.025		10.5	4	F 37	(3)
		10.5	L	.035	.020		.020	10.5	4	F 38	(4)
A	146-8	7.0	SEM	.008 X .006		.004	.004	3.75	4	F 49	(3)
		8.5	L	.035	.015		.004	3.75	4	F 50	
A	24-94	5.5	T	.016		.003	.0014	5.5	5	F2-32	(3)
B	16-22	.125	L	.105	.028		.004	Top	5	F2-44	
A	24-94	28	T	2.63		.030	.010	32	7	F7-59	
						.007	.004				
						.015	.002				
		28	T	1.46		.005	.003	32	7	F7-59	
		26	T	2.63		.035	.009	32	7	F7-67	
		29	T	2.63		.009	.004	32	7	F7-69	
		27	T	2.63		.006	.008	32	7	F7-78	
A	62-8	8	T	2.63		.006	.004	4	7	F7-84	
A	16-69	9	T	1.46		.020	.016	9	7	F7-105	
A	13-63	11-20	T	.87		.020	.013	16	7	F7-120	
A	111-13	3.6	L	1.0	.013	.013	.005	3.6	2	P 15	
		4.8	L	1.0	.008		.010	4.8	2	P 15	

Notes:

1 - L - Longitudinal, T - Transverse, SEM - SEM exam. of surface

2 - IGA at end of IGSAC

3 - Measurement taken on surface pit with IGA morphology

TABLE A2 - Metallography Samples Not Containing IGA

OTSG	Tube	Specimen Elevation In. From Top	Type of Specimen	Length of Surface Examined, In. Axial	Length of Surface Examined, In. Circumferential	Elevation of Nearest IGSAC	Documentation Ref.	Documentation Page/Figure
A	12-62	8 3/16	L	.085		8 3/16	3	P63
	13-63	1	T, L	.060	.080	1.125	3	P64, 65
B	33-30	8 5/8	T, L	.075	.060	8 5/8	3	P66, 67
A	13-63	26 5/16	T, L	.055	.060	27	3	FG1-6
	62-8	11 7/8	T, L	.060	.060	NDD	3	FG7
	133-74	1	T, L	.060	.060	9/16, 1 1/2	3	FG8
		10 5/16	T, L	.060	.060	10 11/16	3	FG9
		23 5/16	T, L	.060	.060	23 5/16	3	FG10-12
		32 3/4	T, L	.060	.060	33	3	FG13
		35 3/4	L	.060	.060	33	3	FG14, 15
B	33-30	32 1/4	L, T	.060	.060	8 5/8	3	FG19
A	71-126	53.5	L	.020		3	4	F30
		54	L	.015		3	4	F31
A	146-6	8.5	L	.130		8.5	4	F35
A	146-9	1.0	L	.008		3.75	4	F42b
		4.0	L	.040		3.75	4	F47
		0.5	L	.012		3.75	4	F51
		0.25	T		.038	3.75	4	F52
A	37-29	110	T, T		.028	112	5	F2-31
B	34-19	Top	T		.160	Top	5	F2-37
B	16-22	.140	T		.075	.140	5	F2-42
		.110	T		.192	Top	5	F2-43a
		.110	T		.128	Top	5	F2-43b
		.125	L	.105		Top	5	F2-47
B	16-22	Top	L	.055		Top	5	F2-45
A	62-8	5	T		2.63	3	7	F7-24
A	37-29	49.5	T		2.63	112	7	F7-25
A	88-7	10.5	T		2.63	6	7	F7-26
	24-94	25.5	T		2.63	34	7	F7-27
	13-63	21	T		2.63	16	7	F7-28
B	16-22	60	T		2.63	NDD	7	F7-29
		62	T		2.63	NDD	7	F7-30
A	16-69	3	T		2.63	4	7	F7-32
A	88-7	13	T		2.63	6	7	F7-38
B	94-27	18.5	T		2.63	14	7	F7-40
A	37-29	50	T		2.63	112	7	F7-42
		51	T		2.63	112	7	F7-44
B	34-19	6.5	T		2.63	NDD	7	F7-46
		7	T		2.63	NDD	7	F7-48
	94-27	21.5	T		2.63	14	7	F7-50
A	62-8	6	T		2.63	3	7	F7-52
		7	T		2.63	3	7	F7-54
B	16-22	61	T		2.63	NDD	7	F7-56
A	37-29	52	T		2.63	112	7	F7-57
	16-69	2	T		2.63	4	7	F7-58
	88-7	10	T		2.63	6	7	F7-65
	13-63	20.5	T		2.63	16	7	F7-71
	16-69	2	T		2.63	4	7	F7-73
	62-8	8	T		2.63	3	7	F7-86
	37-29	52.5	T		2.63	112	7	F7-88
A	112-5	4.75	T		0.090	4.6	7	P14
		3.2	T		1.75	3.1, 3.35	2	P14
A	111-13	3.3	L	1.0		3.3	2	P14

RC 254

Babcock & Wilcox
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Research and Development Division
Lynchburg Research Center
Lynchburg, Virginia 24506-1165

To J. F. CUVELIER - SPIS	
From S.C. Inman S.C. INMAN - NUCLEAR MATERIALS, LRC	
Cust. GPUN	File No. or Ref. RDD:86:5046-04:01
Subj. TMI-1 OTSG TUBE RETEST	Date MAY 7, 1985

This letter to cover one customer and one subject only.

SUMMARY

Eddy current defect indications were recently observed in the unexpanded portion of a number of OTSG tubes at TMI-1. As part of an investigation to determine their origin, fourteen sections of removed TMI-1 tubing in storage at the LRC were retrieved, eddy current tested, and inspected on the inner surface using fiber optics. The inner surfaces of two tube sections were further examined using photography and metallography. Scattered darkened areas appearing as stains were visually observed on the surface. Metallographic inspections showed some of these stained areas to contain patches of shallow intergranular attack (~0.008-inch maximum depth) and isolated pits (~0.005-inch maximum depth).

Results showed no significant difference between eddy current signals observed during previous testing and those observed during this work. It could not be determined from this investigation whether the mechanism which caused damage to the tubes in situ at TMI-1 was active or inactive during the storage period.

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2.0 METHODS AND RESULTS

2.1 Eddy Current Testing

Personnel from both B&W and GPUN participated in an inspection using the same equipment and similar test parameters as that used during inspections performed in June 1982 at the LRC and in situ at TMI-1. A total of fourteen (14) sections of six (6) different peripheral tubes from the A-OTSG were examined using two (2) different probes. The 0.500-inch diameter annular differential probe (manufactured by B&W) was used at frequencies of 200, 400, 600, and 800 kHz. The 0.540-inch diameter annular differential probe (manufactured by Zetec) was used at 200, 400, and 800 kHz frequencies (all differential) and 200 kHz absolute. The Zetec MIZ-12 system was used to drive the probes at the selected frequencies. The frequencies, phase angle, and gain settings used duplicated those used in the 1982 inspections and in situ at TMI-1.

Prior to inspecting the tube sections, the techniques were calibrated using the same standard as was used in 1982. The standard was rotated at four 90° increments, giving a total of four scans for each method. Using the 0.540-inch probe, the amplitude of the signal response to the 0.052-inch diameter through-wall hole in the calibration standard was set at 15 volts peak-to-peak (400 kHz). During calibration, the maximum amplitude variation was 15.3 to 14.6 volts using the 0.540-inch probe and 10 to 4.2 volts with the 0.500-inch probe. Since the standard was not rotated during the 1982 inspections and amplitude will vary depending on relative circumferential location of the defect, direct comparisons between voltage responses from one inspection to another should be avoided.

The inspection data were recorded on magnetic tape and later analyzed using the digital data analysis system (DDA-4). Table 1 lists results of the 1985 and 1982 inspections performed at B&W. Two tube sections, A112-5 Piece 1 and A23-93 Piece 1, were not inspected at B&W in 1982. Therefore, results of

1.0 INTRODUCTION

In late 1984 and early 1985, in situ eddy current testing of the Three Mile Island Unit 1 (TMI-1) once-through steam generators (OTSGs) revealed new defect indications in the unexpanded region of many tubes. These indications had not been observed during previous inspections performed immediately after the tube expansion operation.

This project was initiated to investigate possible origins of these new indications. Sections of tubes which had been removed from the OTSGs and were in storage at the Babcock and Wilcox Lynchburg Research Center (LRC) were retrieved for re-examination. Laboratory eddy current testing, fiber optics and visual inspections of the tube inner surfaces, and metallography were utilized in this examination, results of which are presented in this report.

inspections performed by Battelle and Conam in 1981 are listed for comparison. No indications were observed in the 1985 inspection which were not observed previously. Slight differences in the axial location of indications exist between the two inspections and are attributed to different means of measuring location on the tube at which the indication was observed.

2.2 Fiber Optics Inspection

Each tube section exhibiting eddy current indication(s) was inspected on the inner surface using an 8 mm Olympus Fiberscope with a 90° head. The tube was rotated to permit inspection of the entire surface. Results were recorded on videotape while monitoring them on a high resolution CRT. A summary of observations made during the inspection is listed in Table 2. Results showed that an anomaly of some type, i.e. pits, stains, and/or cutter tool damage, was present at each location where an eddy current indication was observed.

2.3 Visual Inspections and Photography

Two tube sections were selected for destructive examinations based on results of the nondestructive inspections. Piece 1 of tube A112-5 was selected since it contained multiple eddy current defect indications over a small length of the tube. Piece 1 of tube A111-13 was selected to investigate a small voltage indication. The sections were split longitudinally in half along pre-determined axes using both a diamond saw and jeweler's saw. The appearance of the inner surfaces was documented at various magnifications between approximately 7x and 30x using the stereomicroscpoe and 35 mm color photography, while landmark areas were noted. Photomontages were assembled to reconstruct the tube sample appearance. Comments made during the visual inspections and from the photographs are listed in Tables 3 and 4. Selected photographs of the tube samples are shown in Figures 1 through 4. The following is a description of the samples.

Tube A112-5 Piece 1

This 10-inch tube section was transversely cut at 7 inches and both pieces then split along the 120-300° axes. As noted in Table 3, the upper 6 inches of the sample contained numerous pits, cracks, and stains. Except for darker brown stained regions, the color of the inner surface was typical of that observed during the previous examinations (1,2). In many cases, cracks and scattered pits were associated with the darker brown stained regions, but many stains were observed without defects. The stains were observed in a variety of shapes, from single spots to large "patches" with branches in many directions. All cracks were circumferentially oriented and longitudinal sectioning had intersected nearly each one, so the crack lengths listed are approximate. The pits were approximately 0.005-inch or less in diameter.

Tube A111-13 Piece 1

The upper 4 inches of this 22.6-inch long tube section was longitudinally split in half along the 0-180° axes. Table 4 lists the observations made from the A111-13 samples. The inner surfaces were relatively clean when compared to the A112-5 samples, i.e. very few stained regions and scattered pits. When pits were observed, they were also very small (0.005-inch maximum diameter) and located within stained regions. No cracks were visible in the A111-13 tube samples. Figures 3 and 4 are typical photographs showing some of the minor anomalies present.

The inner surface of both sample halves from tube A111-13 was placed in tension in the hoop direction by placing the samples concave side down on a flat surface and applying a 185-pound load to the tube outer surface. This was done to determine whether any non-visible anomalies on the inner surface would open and become visible. The photographs of the samples after stressing showed no visible change in the appearance of the tube surface.

2.4 Metallography

Tables 5 and 6 contain details of the metallography performed during this investigation. Figures 5 and 10 are the cutting diagrams for the samples from tubes A112-5 and A111-13, respectively, which indicate specimen origination. The specimens are described below according to tube number.

Tube A112-5 Samples

Four small half-ring specimens were sectioned from the region of the 300-120° sample containing a "tree-like" stained and pitted region on the inner surface at 1 to 1.5 inches from the top of the piece. All four specimens were mounted together so that transverse edges could be examined. Three individual grind increments of approximately 0.005, 0.010 and 0.015-inch were taken into the specimens, with inspection and photography at each increment. Results showed that stained regions of each specimen corresponded to areas of superficial intergranular attack (IGA) of ≤0.001-inch in depth. In fact, this corrosion was barely distinguishable from the as-manufactured pickling corrosion on the inner surface. Typical photomicrographs of this observation are shown in Figure 6. A number of shallow pits and depressed areas were observed, examples of which are shown in Figures 7 and 8. Maximum observed depth of these regions was scaled to be 0.005-inch, or approximately 13 percent of the tube wall thickness. Maximum observed surface opening or mouth of a pit was approximately 0.010-inch. One pit (shown in Figure 8) had intergranular penetrations extending from its base. In all cases, the anomalies observed on these four specimens were adjacent to or within regions of superficial IGA.

A 0.145-inch long half-ring specimen was sectioned from an axially oriented stain containing pits in the 120-300° sample. Incremental grinding steps were also taken through this specimen, with inspection of the transverse edge at each increment. Again, the stained region corresponded to superficial IGA ≤0.001-inch in depth on the inner surface. A depressed region, possibly several overlapping pits, was observed at the location where a pit was observed during the visual inspections. Maximum observed depth of this defect was 0.002-inch. Selected photomicrographs of this specimen showing the depressed region and the superficial IGA are shown in Figure 9.

Tube A111-13

Two strip specimens were sectioned from 1 to 2 inches from the top and mounted longitudinally in attempt to intersect the single pits at 1.2 and 1.6 inches. These specimens are shown in Figure 10 as specimens "A" and "B", respectively. Successive grind increments were taken into both specimens as indicated in Table 6.

Nothing anomalous was observed on the inner surface of specimen "A". Figure 11 is a typical photomicrograph of the inner surface and reveals the as-manufactured pickling corrosion observed.

Figure 12 contains photomicrographs which reveal the "patch" of IGA observed on the third and fourth grind increment of specimen "B". Maximum depth of the IGA was determined to be 0.005-inch, with a mouth of 0.013-inch. Also on the fourth increment, an area of shallow surface corrosion (≤0.001-inch deep) was observed at a location 0.040-inch down the tube from the IGA. A final grind increment of 0.013-inch revealed the typical tube inner surface appearance, with no anomalies.

Longitudinal specimens "A" and "B" were then removed from the metallographic mounts and reverse bent about a plane normal to the tube axis (inner surface in tension) to open any cracks present. Inspection of each specimen under the stereomicroscope revealed no cracks in specimen "A", while a circumferential crack did open at approximately 1.6 inches in specimen "B". The crack was approximately 0.135-inch long and intersected a cut edge (approximately the 70° axis). While the crack was not 100 percent through-wall, maximum depth was not determined. Figure 13 contains photographs of this crack.

Specimen "C" shown in Figure 10 was sectioned from 2.5 to 3.25 inches and mounted so that a longitudinal edge could be viewed in the regions of pitting at 2.8 inches from the top. The first and second grind increments revealed a circumferentially oriented intergranular crack penetrating a maximum of 0.010-inch into the tubewall. Photomicrographs in Figure 14 show this crack and the "cap" of material on the tube inner surface protuding inward toward the tube center. A single pit just above an area of superficial corrosion was observed on the third increment. The pit was approximately 0.002-inch deep on this plane of polish, which did not intersect the mouth of the pit. This indicates the pit was somewhat spherical in shape with an overall diameter greater than it's mouth diameter. Photomicrographs of the specimen on the third and forth grind increments are shown in Figure 15. The fourth grinding increment revealed only very shallow superficial corrosion (≤0.001-inch deep), indicating the pit was less than 0.014-inch in diameter (most likely well less).

Strip specimens "D" and "E" shown in Figure 10 were reverse bent in the same fashion as were specimens "A" and "B". A circumferential crack opened at 1 inch from the top of specimen "D" and extended from the 180° cut edge approximately 0.240-inch toward the 270° axis. The photographs of this crack shown in Figure 16 indicate it was less than 100 percent through-wall in depth, however maximum depth was not determined. No cracks were observed in specimen "E" after bending.

3.0 DISCUSSION

Fourteen tube sections were re-eddy current inspected using similar parameters and the 0.500 and 0.540-inch probes during this project. As seen in Table 1 amazingly small differences exist between the depth estimated and voltages of the indications detected during the present and previous eddy current inspections. These differences are well within those expected due to process variation and are deemed insignificant. With the differences between location of indication due to method of measurement, it must be concluded that no change occurred to the eddy current indications as a result of the tubes being in dry storage in plastic bags for several years.

Subsequent additional eddy current testing was performed at the LRC which utilized the more sensitive 8x1 probe. In addition to the crack indications detected in piece 1 of tubes A112-5 and A111-13 using the differential probe the 8x1 inspection detected more defect indications (results reported in a GPUN document). Destructive examination of these tube sections during this project confirmed that the crack-like indications were caused by circumferential cracks and/or patches of IGA. Since these tube sections were not destructively examined during the previous tube examinations (1,2), it could not be determined whether the dry storage conditions played any role in forming the currently observed defects. It seems doubtful however, that any growth or propagation had occurred since no change occurred to the eddy current indications.

In addition to the cracks, many isolated and clustered pits were present within stained areas in tube A112-5. These pits were very shallow (≤0.005-inch in depth) and insignificant when compared to the severe pitting corrosion which has been observed in steam generator tubing removed from other nuclear plants.(3)

Due to the small volume of material removed, it is doubtful that the pits present in the TMI-1 tubes would be observed as defects using conventional eddy current testing methods. Determining the origin of the pits and stains in the TMI-1 tubes was not within the scope of this project.

4.0 CONCLUSIONS

The following have been concluded based on the results of this examination of TMI-1 OTSG tube sections:

- Using the 0.500 and 0.540-inch differential probes, no increase in size of the existing eddy current defect indications in the TMI-1 A-OTSG peripheral tubes was observed as a result of being in dry storage for several years. Also, no defect indications were observed which had not been observed during the 1982 inspections.

- Crack-like defect indications were caused by the presence of circumferential cracks and/or patches of IGA on the tube inner surface.

5.0 REFERENCES

1. M.A. Rigdon and E.B.S. Pardue. "Evaluation of Tube Samples from TMI-1." Babcock and Wilcox Document Number 77-1135317, 1981.

2. S.C. Inman. "Examination Of OTSG Tubes from TMI-1 Third Pulling Sequence - Final Report." Babcock and Wilcox RDD:83:5068-03:03, December 1982.

3. S.C. Inman. "Examination of Steam Generator Tube Sections from the Millstone Point Unit 2 Nuclear Power Plant." Project S304-6, Electric Power Research Institute, Palo Alto, California (to be published).

TABLE 1
EDDY CURRENT TESTING RESULTS [1]

				1982				1985				
					Probe				Probe			
OTSG	Tube ID	Piece #	Axial Location [2]	Location of Indication [3]	0.500" Depth/Voltage (%/V)	0.540" Depth/Voltage (%/V)	Comments	Location of Indication [3]	0.500" Depth/Voltage (%/V)	0.540" Depth/Voltage (%/V)	Comments	82 - 85 Comparison
A	13-63	3	31 - 38	1.5	(Comments)	-	Large Dent		NDD	NDD	Multiple Dents	No Change
A	112-9	1	4.3 - 12.3	4.1	90-100/1.5	-	ID Defect	4.8	86/2.2	84/3.2	Indication on OD Plane	No Change
A	24-94	3	13.3 - 19.8	3.0	90-100/1.4	90-100/2.3	ID Defect	2.5	62/1.6	78/2.4	Indication on OD Plane	No Change
		8	41.8 - 48.9		NDD	-			NDD	NDD	Multiple Dents	No Change
		9	48.9 - 55.8		NDD	-			NDD	NDD		No Change
		10	55.8 - 67.8		NDD	-			NDD	NDD	3 Bulges	No Change
A	111-13	1	2 - 24.6	1.0	-/0.5	-	Initially identified using OD pencil probe	(near top)	NDD	89/0.8	Possible Defect, ID Plane	No Change
		3	50.7 - 57.5		NDD	-			NDD	NDD		No Change
		4	76.3 - 89.0		NDD	-			NDD	NDD		No Change
		7	151.3 - 176.4		NDD	-			NDD	NDD		No Change
		8	176.4 - 201.6		NDD	-			NDD	NDD	Small Ding	No Change
		9	201.6 - 213.8		NDD	-			NDD	NDD	2 Dents	No Change
A	112-5 [4]	1	2 - 12	1.8	95/1	-		2.0	92/1.1	81/2.7	Indications on OD Plane, Multiple Small Indications Not Reported	No Change
				3.7	95/2	-		3.8	85/1.8	87/5.1		No Change
				5.8	95/1	-		6.2	62/0.7	79/2.8		No Change
A	23-93 [5]	1	2 -12	0.6	80/ [6]	-			(Comments)	NDD	Possible Indication Near Top of Tube	No Change

[1] Hyphen indicates not inspected using that technique
NDD - No Detectable Discontinuites
[2] Inches from OTSG UTS Primary Face
[3] Inches from top of tube piece
[4] 1982 results from Conam inspection
[5] 1982 results from Battelle inspection
[6] Voltage not available

TABLE 2
FIBER OPTICS INSPECTION SUMMARY

Tube	Piece	Orientation	Axial Location[1]	Remarks
A13-63	3	0°	6	Stained area
		180°	1.5	Scattered pits, cutter tool damage
			2-2.5	Scattered pits
			3-3.5	Possible pits
				(Scattered pits along length of section)
		240°	1.5-2	Possible pits, cutter tool damage
			4.5	Scattered pits
				(Scattered pits along length of section)
		300°	4-4.5	Possible pits
A112-9	1	0°	6.5-7	Possible pits
		180°	4	Stained areas
		270°	4	Axially oriented staining
A24-94	3	180°	2.25	Possible raised area
			2.75	Pits
			3	Stained areas
		270°	0.5-1	Pits
			2-2.5	Pits
			2.25	Possible raised area
			2.75	Pits
A111-13	1	90°	1.75	Single pit
		180°	1	Possible pits, stains
		270°	1	Pits, stains
		340°	1	Pits, stains
A112-5	1	30°	2	Possible pits, stains
			4-4.5	Pits and stains
		90°	2.5	Pits
			4-4.5	Pits and stains
		190°	5.75-6	Stains
		260-360°	4.5	Cutter tool damage
		270°	8-8.5	Pits and spots
		350°	3.75	Pits
A23-93	1	0°	0.75	Pits
		200-270°	0.5-0.75	Pits
		250°	5.5	Stains

---

[1] Inches from top of piece

TABLE 3
VISUAL INSPECTION RESULTS FOR TUBE SAMPLE A112-5

Axial Location, in. from top of tube section	Comments
0.05-0.6	Axial lines of stain containing pits
0-0.2	Tube removal damage
0-0.8	Serpentine stains
0.35-0.9	Patch of stain
0.55	Circumferential crack, 0.258-inch (1)
0.64	Pits within stains
0.75	Circumferential crack, 0.144-inch (2)
1.0-1.6	Tree-like stain containing pits
1.1	Circumferential crack, 0.092-inch (3)
1.4	Circumferential crack, 0.210-inch (1)
1.5	Pits within stains
1.6	Circumferential crack, 0.123-inch (3)
1.7	Circumferential crack, 0.060-inch (2), pits within stains
1.8	Circumferential crack, 0.072-inch (3)
1.9	Circumferential crack, 0.196-inch (1)
2.0	Circumferential crack, 0.185-inch (3)
2.2-3.6	Axial line of stain containing numerous single pits
2.3	Circumferential crack, 0.143-inch (1)
2.6	Circumferential crack, 0.205-inch (1)
3.2	Circumferential crack, 0.263-inch (1)
3.6	Circumferential crack, 0.232-inch (3)
4.0	Circumferential crack, 0.252-inch (1)
4.3	Pits within stains
4.6-5.9	Pits within stains
4.9	Patch of stain
5.4	Circumferential crack, 0.255-inch (1)
5.4-[illegible].9	Pits within stains
7.4-9.3	Tube removal damage
8.0-8.5	Pits within stains

(1) Crack observed on both halves after sectioning; crack length obtained by adding dimensions from both halves.

(2) Crack observed on 120-300° half.

(3) Crack observed on 300-120° half.

TABLE 4
VISUAL INSPECTION RESULTS FOR TUBE SAMPLE A111-13

Axial Location, in. from top of tube section	Comments
0-1.0	Tube removal mandrel marks
0.84	Isolated pits
1.0	Isolated pits
1.29	Isolated pits
1.6	Stains containing pits
2.88	Stains containing pits
3.5-3.8	Scattered single pits

TABLE 5
METALLOGRAPHY RESULTS FOR TUBE A112-5

Half, cw	Specimen Axial Location[1]	Designation-Type[2]	Grind Increment[3]	Observations
300-120°	1-1.2	A1-T	~ 0.005	Surface IGA in stains, <0.001" max. depth
			~ 0.010	Surface IGA in stains, <0.001" max. depth
			~ 0.015	Surface IGA in stains, <0.001" max. depth
	1.2-1.3	A2-T	~ 0.005	Surface IGA in stains, <0.001" max. depth; intersected crack at 1.2"
			~ 0.010	Surface IGA in stains, <0.001" max. depth
			~ 0.015	Two single pits, 0.002" max. depth; surface IGA adjacent to pits, <0.001" max. depth
	1.3-1.4	A3-T	~ 0.005	Two adjacent pits, 0.001" max. depth; surface IGA adjacent to pits, <0.001" max. depth
			~ 0.010	Surface IGA in stains, <0.001" max. depth
			~ 0.015	Single pit, 0.005" max. depth, IGA at base of pit; surface IGA adjacent to pit
	1.4-1.5	A4-T	~ 0.005	Surface IGA in stains, <0.001" max. depth
			~ 0.010	Surface IGA in stains, <0.001" max. depth
			~ 0.015	Surface general corrosion, 0.002" max. depth; two single pits, 0.002" max. depth

---

[1] Measured from top of piece

[2] T: Transverse views

[3] Incremental amount of material removed, in inches

TABLE 5, cont'd.
METALLOGRAPHY RESULTS FOR TUBE A112-5

Half, cw	Specimen Axial Location[1]	Designation-Type[2]	Grind Increment[3]	Observations
120°-300°	2 7/16-2 3/4	B-T	0.035	Surface IGA in stain, <0.001" max. depth
			0.005	Several overlapping pits, 0.002" max. depth; surface IGA in stain adjacent to pits, <0.001" max. depth
			0.002	Surface IGA in stain, <0.001" max. depth
			0.014	Surface IGA in stain, <0.001" max. depth
			0.012	Surface IGA in stain, <0.001" max. depth; intersected crack at 2.3"

---

[1] Measured from top of piece
[2] T: Transverse views
[3] Incremental amount of material removed, in inches

TABLE 6
METALLOGRAPHY RESULTS FOR TUBE A111-13

Half, cw	Specimen Axial Location[1]	Designation Type[2]	Grind Increment[3]	Observations
0-180°	1-2	A-L (1.2")	0.019"	Typical ID surface appearance
			0.023"	Typical ID surface appearance
			0.015"	Typical ID surface appearance
	1-2	B-L (1.6")	0.073"	Typical ID surface appearance
			0.014"	Typical ID surface appearance
			0.011"	"Patch" of IGA, 0.005" max. depth, 0.013" mouth
			0.005"	"Patch" of IGA, 0.005" max. depth, 0.010 mouth; surface corrosion 0.040" below IGA, <0.001-inch deep
			0.013"	Typical ID surface appearance
	2 1/2 - 3 1/4	C-L (2.8")	0.093	IG Crack, 0.010" max. depth; surface IGA adjacent to crack, <0.001" max. depth
			0.023"	"Patch" of IGA, 0.008" max. depth, 0.005" mouth; surface IGA adjacent to crack, 0.002" max. depth
			0.014"	Single pit, 0.002" max. depth, 0.002" mouth; surface corrosion 0.030" below pit, 0.002" max. depth; surface IGA between pit and general corrosion, 0.003" max. depth
			0.013"	Surface general corrosion, 0.002" max. depth

---

[1] Measured from top of piece

[2] L: Longitudinal views

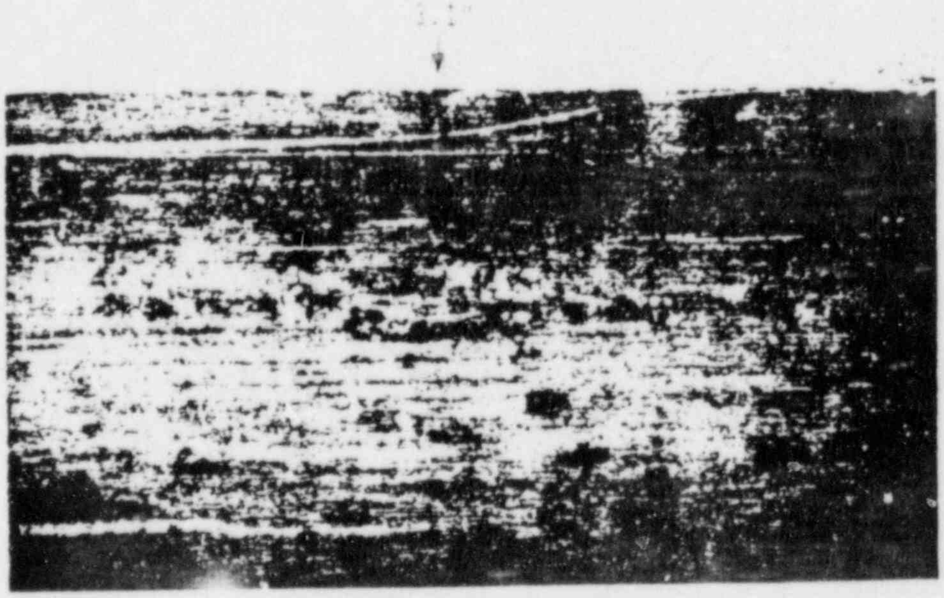
[3] Incremental amount of material removed, in inches

300°-120° Half

Pits Within Stain

Top of Tube

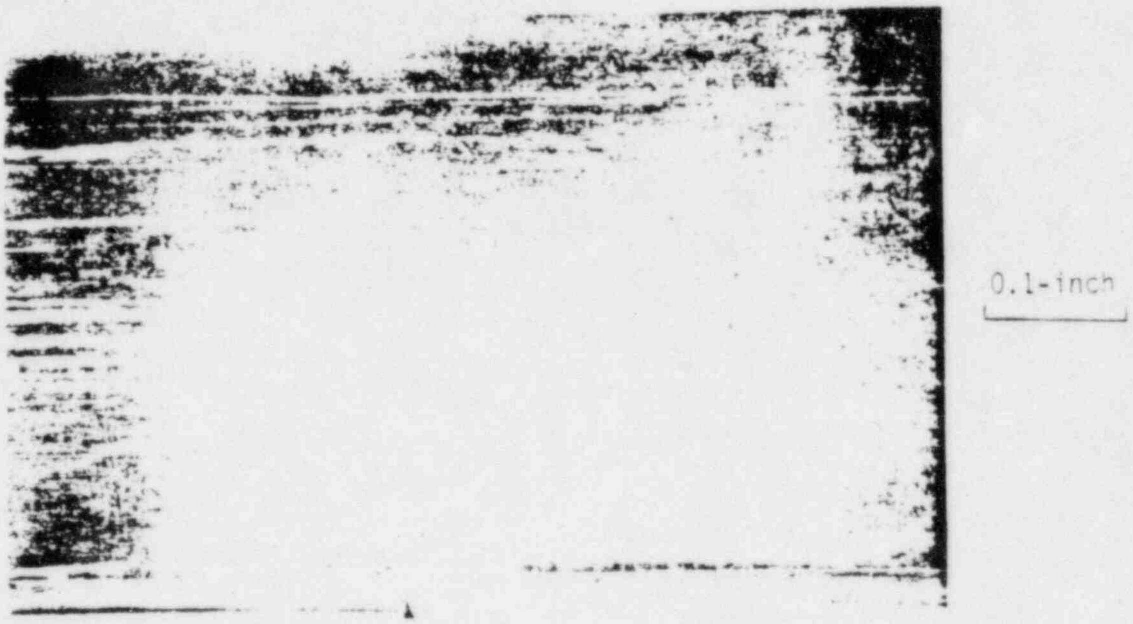
0.1-inch



300°-120° Half

Circumferential Crack
and Pits within Stain

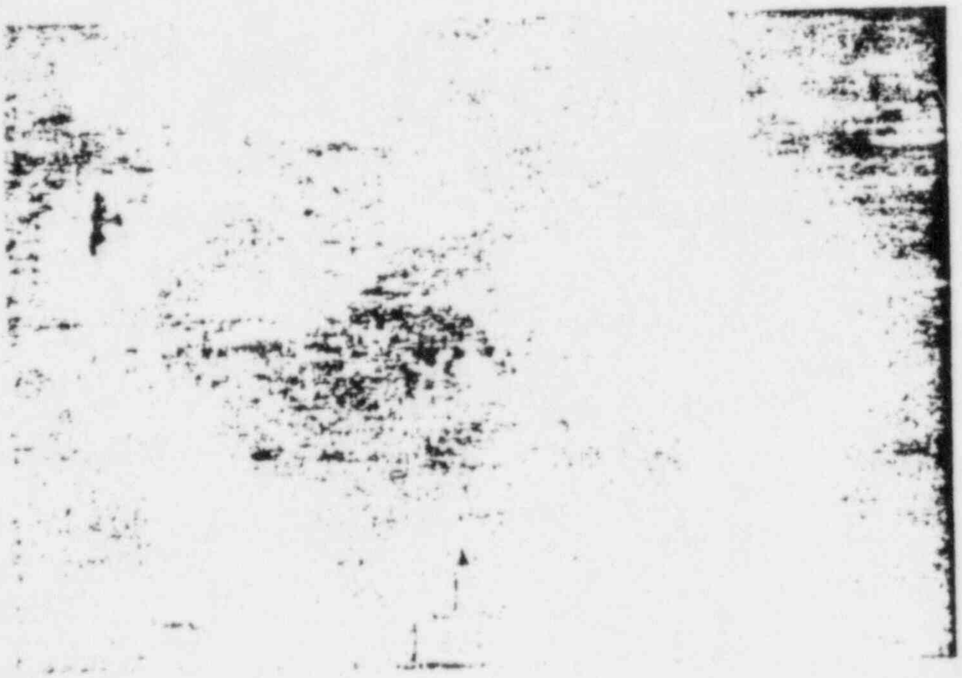
Figure 1. Photographs of Tube 112-6 Sample



120°-300° Half

Circumferential Crack and Pits Within Stain

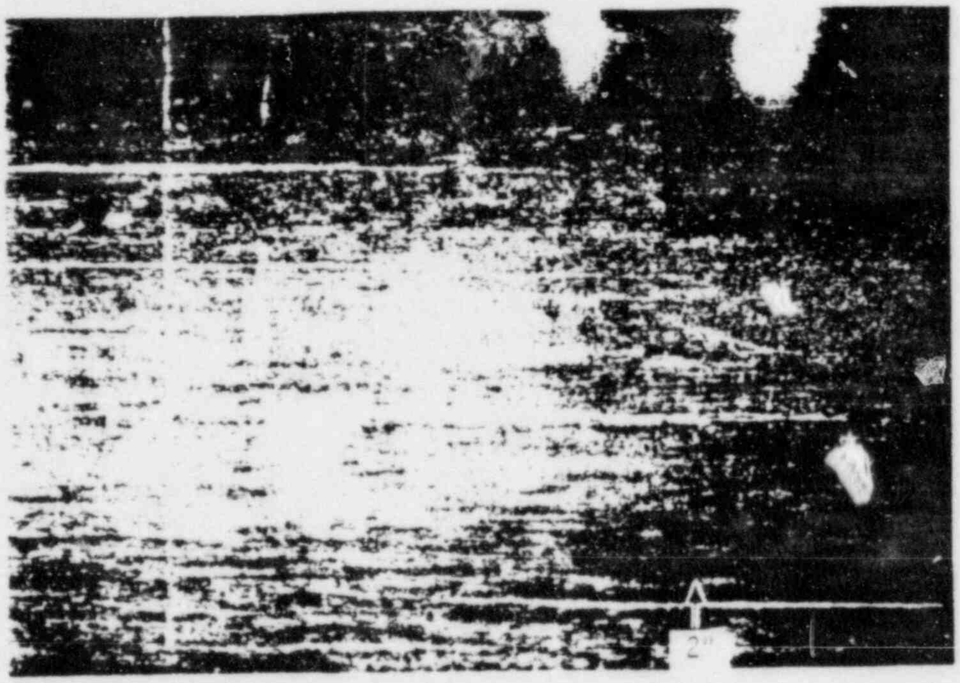
← Top of Tube



300°-120° Half

Pits Within Stain

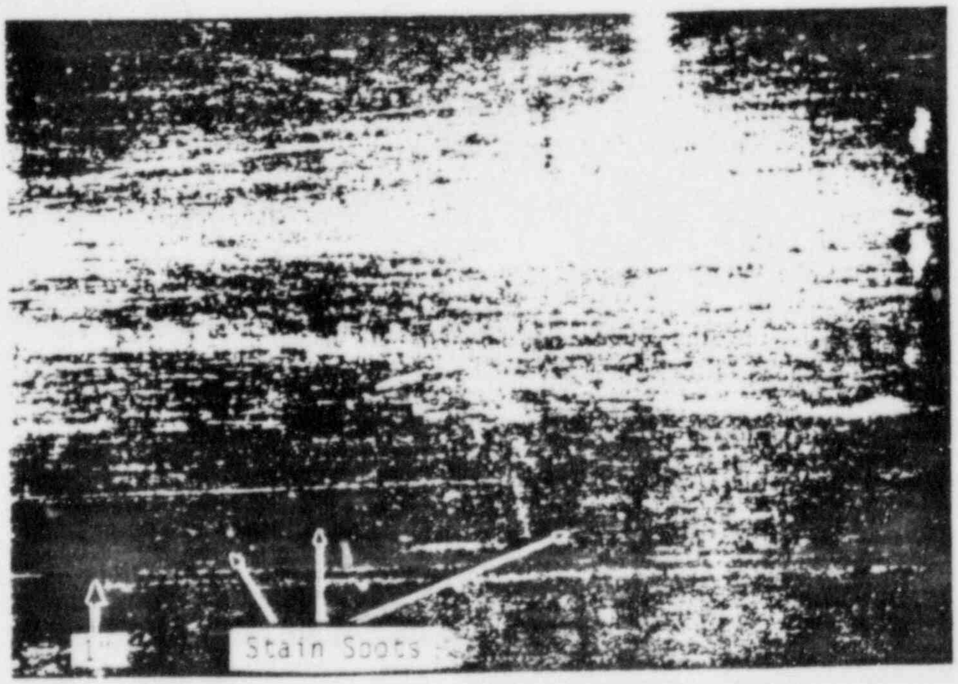
Figure [illegible] Photographs of [illegible]



180°-360° Half

0.1-inch

← Top of Tube



0°-180° Half

After Stressing

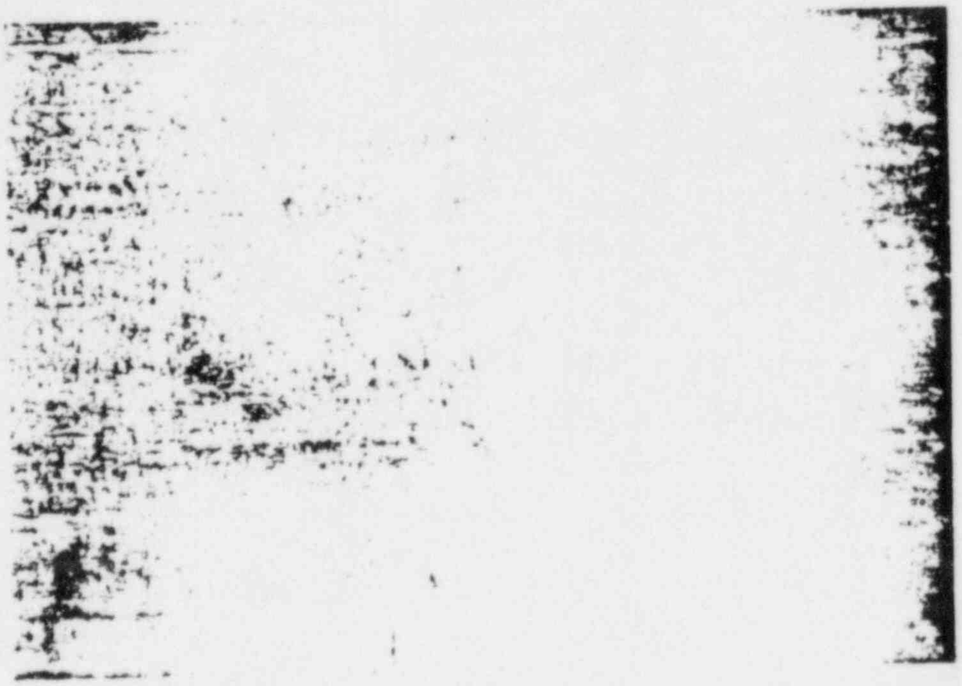
Figure 3. Photographs of Tube 111-13 Sample

0°-180° Half

Single Pit Within Stain

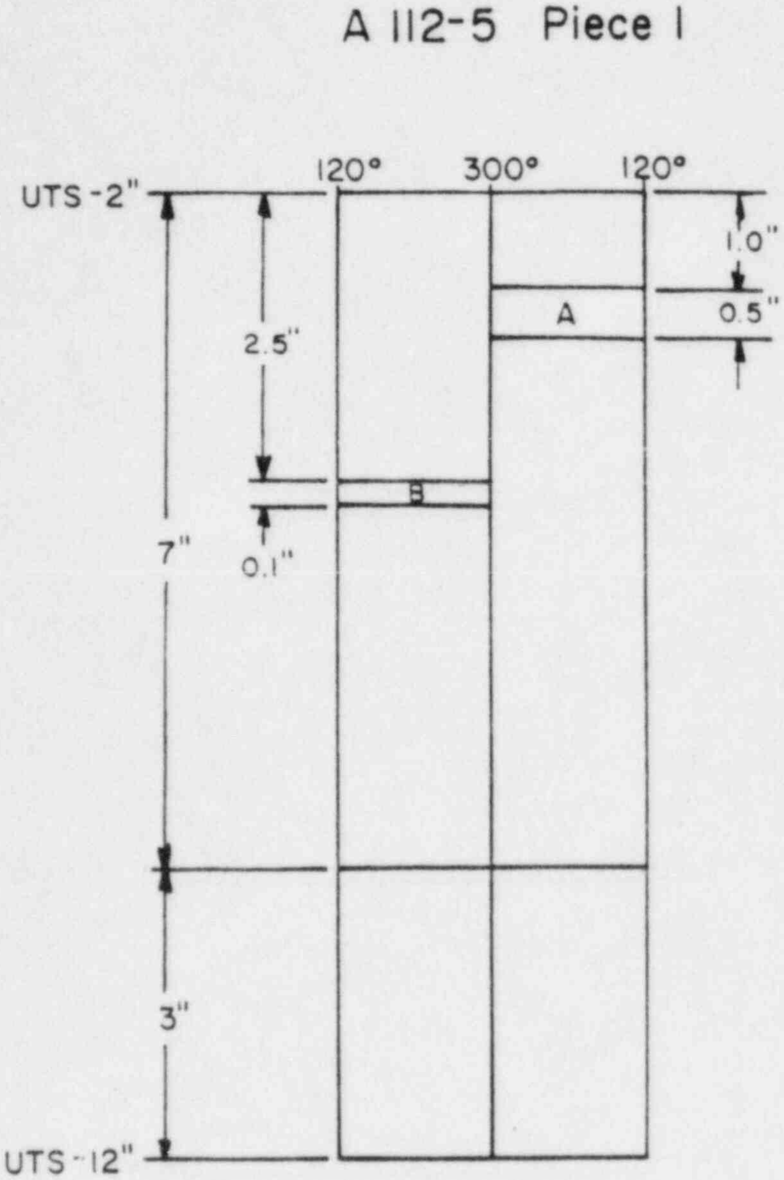
0.05-inch

← Top of Tube



0°-180° Half

[illegible] Within Stain



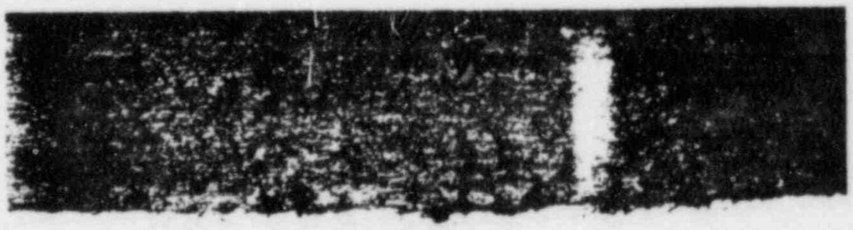
Specimen List

A: 4 Transverse specimens through tree-like stain and pits

B: Transverse specimen through pit string

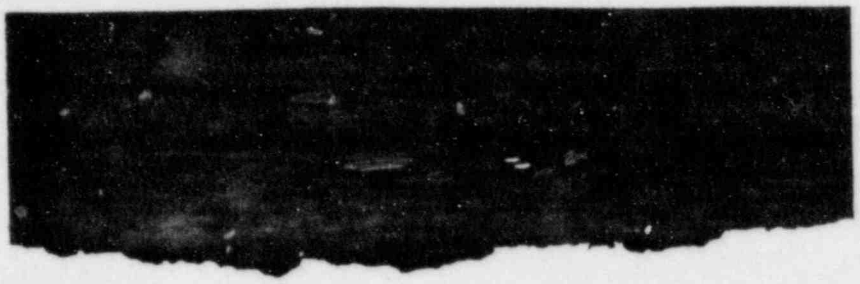
Figure 5. Section Diagram for Tube 112-5 Sample

Specimen A3 - Grind 1 Typical ID



Specimen A1 - Grind I Shallow IGA

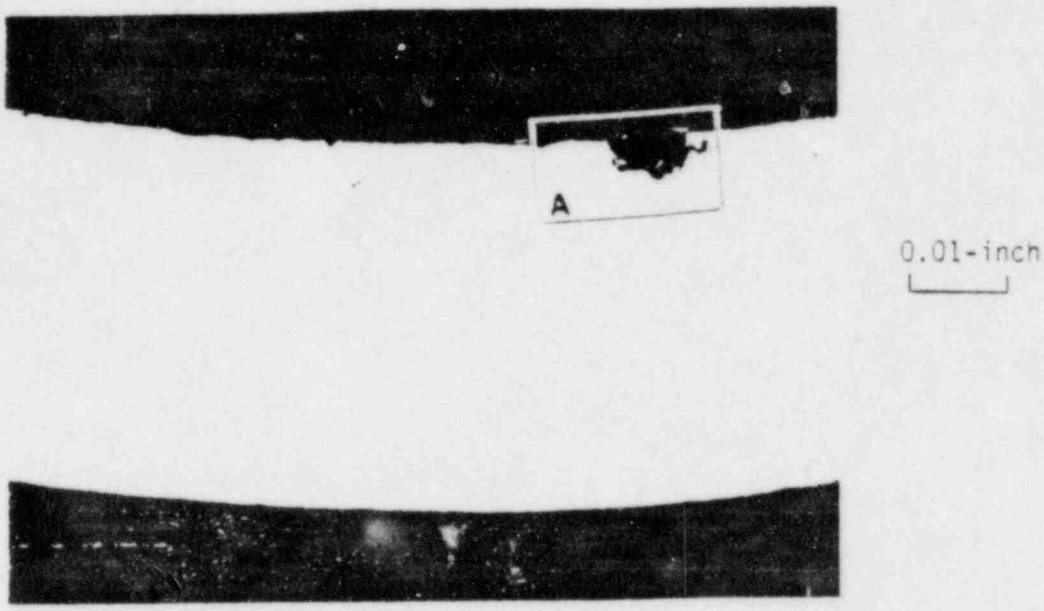
Figure 6. Transverse Photomicrographs Through Tree-like St
in Tube 112-5 Specimens



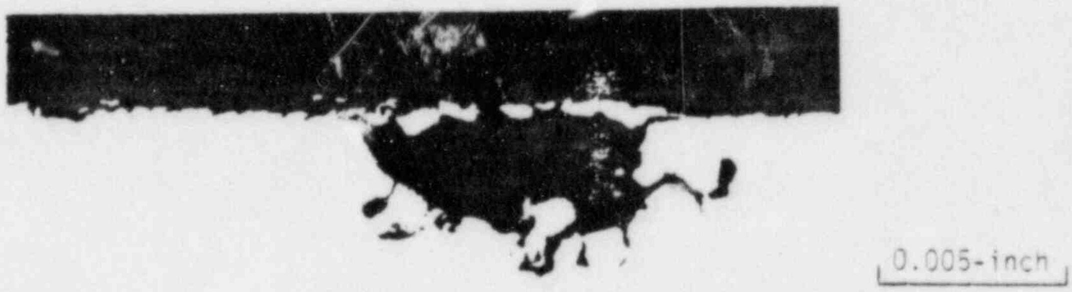
Specimen A4 - Grind 3 General Corrosion

Specimen A3 - Grind 1 Shallow Pits

Figure 7. Transverse Photomicrographs through Tree-like Stain in Tube 112-5 Specimens



Specimen A3 - Grind 3 Single Pit



Region A

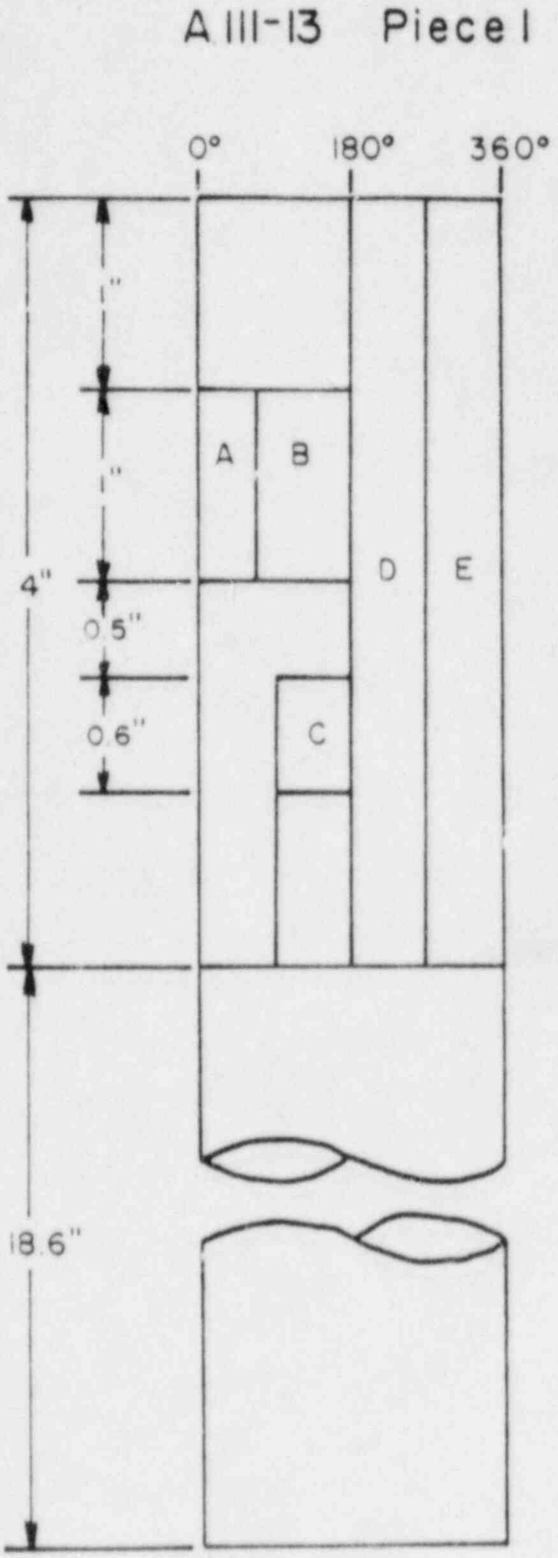
Figure 8. Transverse Photomicrographs Through Tree-like Stain in Tube 112-5 Specimens

Grind 1 Shallow IGA on ID

0.005-inc

Grind 2 General Corrosion

Figure 9. Transverse Photomicrographs Through Pit String in Tube 112-5 Specimen B



Specimen List

A: Longitudinal Specimen to examine pit at 1.2", reverse bend

B: Longitudinal specimen to examine pit at 1.6", reverse bend

C: Longitudinal specimen to examine pits at 2.8"

D&E: Reverse bend specimens

Figure 10. Section Diagram for Tube 111-13 Sample

Grind 1

Typical ID

0.010-inch

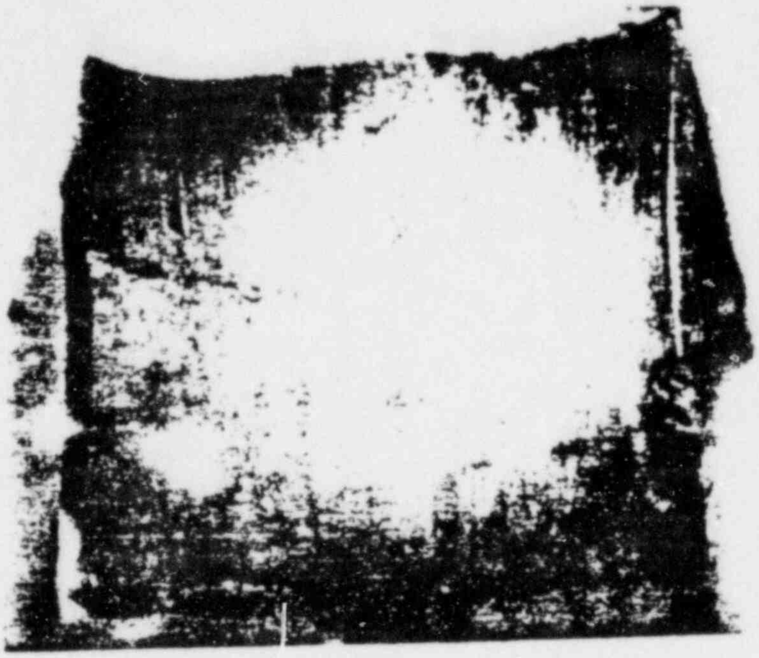
Figure 11. Longitudinal Photomicrographs of Tube 111-13
Specimen A (0.2")

Grind 3 Patch of IGA

Grind 4 Patch of IGA

Grind 4 General Corro

Figure 12. Longitudinal Photomicrographs of Tube 111-13
Specimen B (1.6")



Partial-wall Circumferential Crack at 1.6"

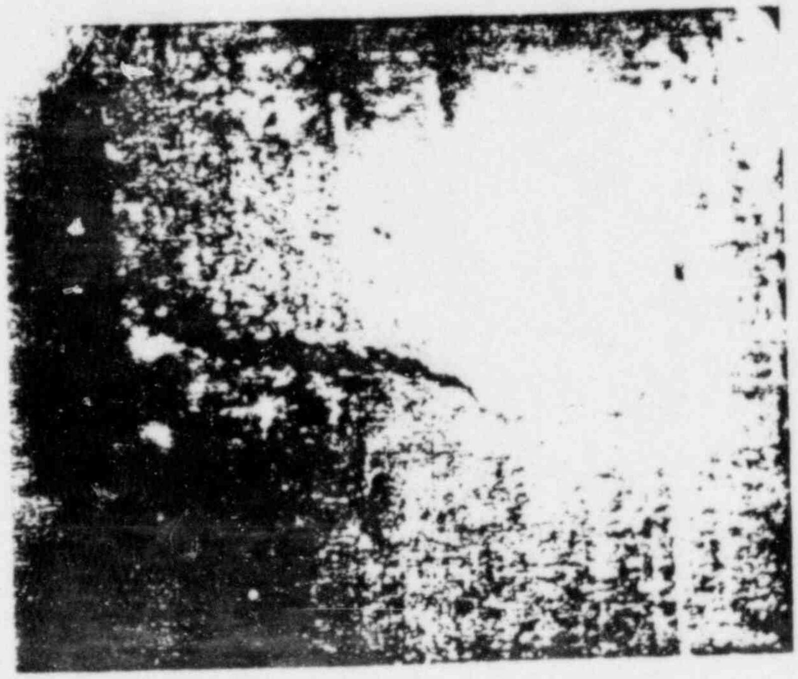
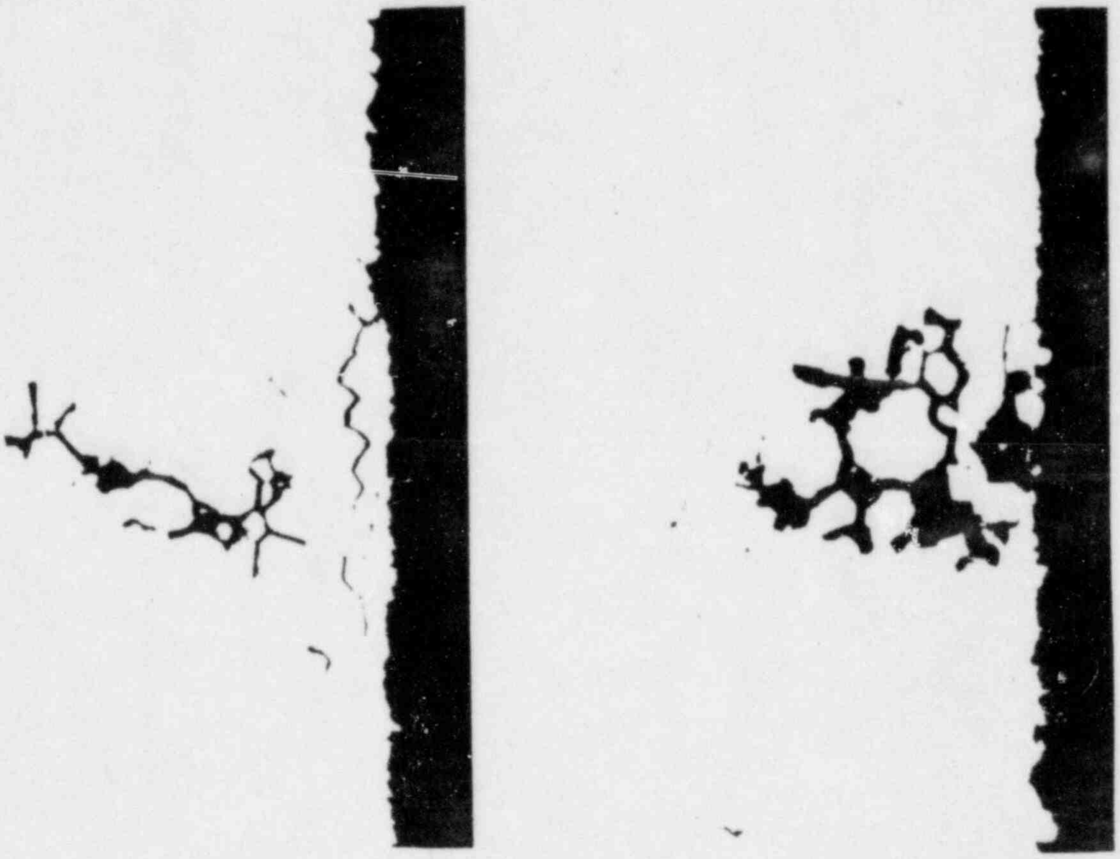


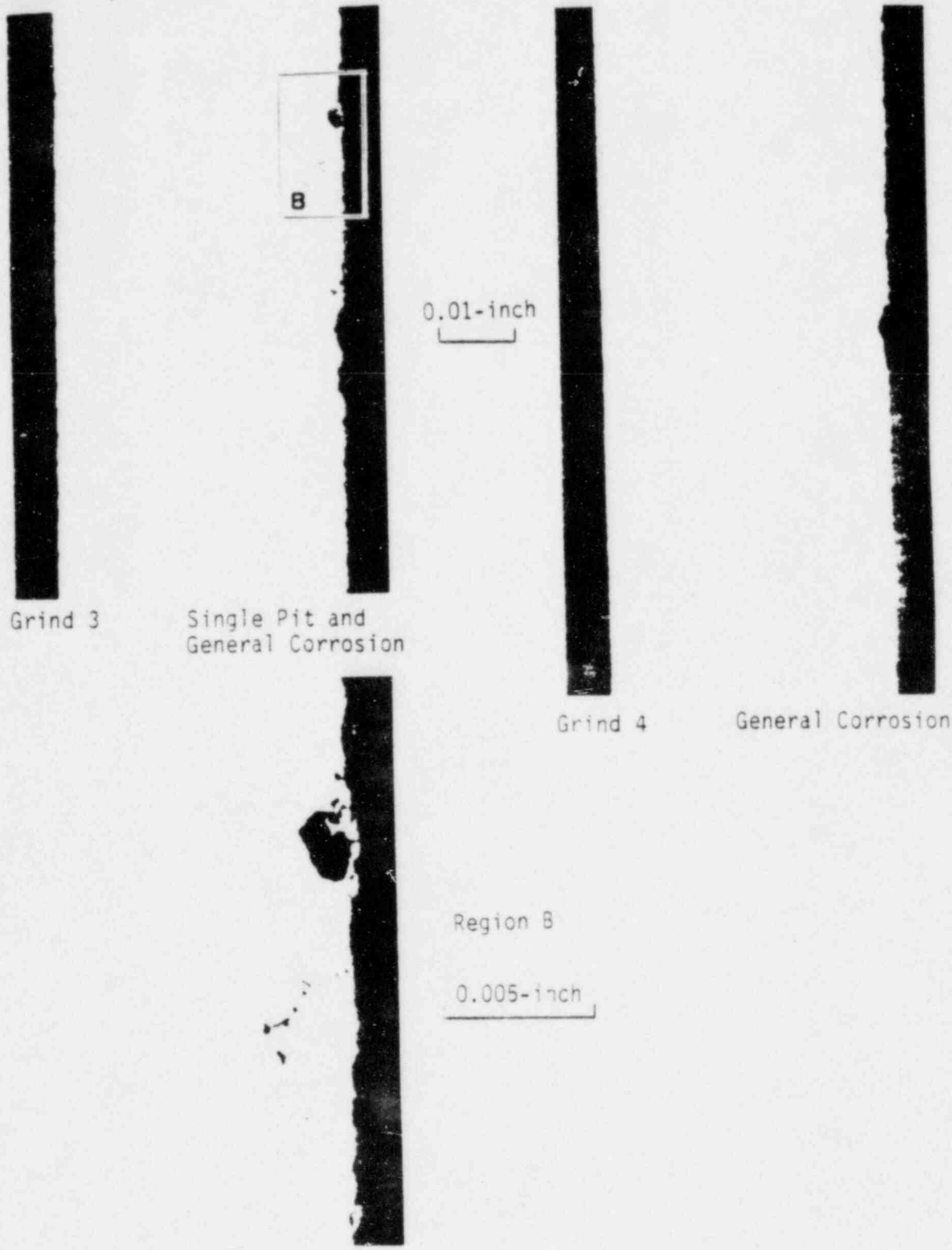
Figure 13. Photographs of Tube 111-13 Specimen B - After Bend



Grind 1 Grind 2

Patch of IGA and
Shallow IGA on ID

Figure 14. Longitudinal Photomicrographs of Tube 111-13 Specimen C



Grind 3

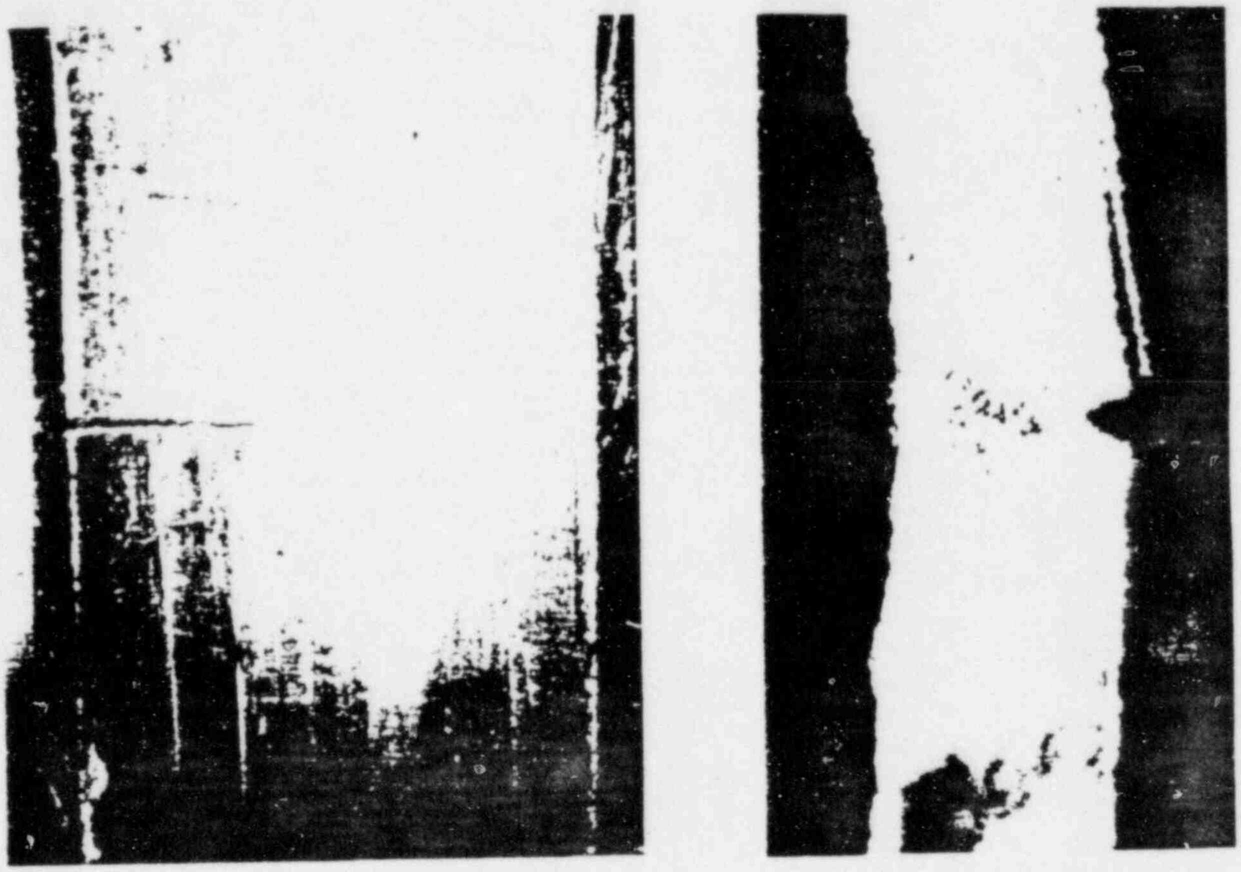
Single Pit and General Corrosion

Grind 4

General Corrosion

Region B

Figure 15. Longitudinal Photomicrographs of Tube 111-13 Specimen C



Partial-wall Circumferential Crack at 1"

0.1-inch

Longitudinal Edge

0.01-inch

Top of Tube

Figure 16. Photographs of Tube 111-13 Specimen D - After Bend

APPENDIX E

GPU Nuclear

TECHNICAL DATA REPORT

TDR NO. 642	**REVISION NO.** 2
BUDGET ACTIVITY NO. 123125	**PAGE** 1 **OF** 15
PROJECT: TMI - UNIT 1 OTSG EDDY CURRENT PROGRAM	**DEPARTMENT/SECTION** Quality Assurance **RELEASE DATE** ______ **REVISION DATE** ______

DOCUMENT TITLE: Qualification of Conversion Curve for Inner Diameter Discontinuities

ORIGINATOR SIGNATURE	**DATE**	**APPROVAL(S) SIGNATURE**	**DATE**
M.T. Torborg	1-24-85	R.O. Barley	1/25/85
G.E. Rhedrick GE Rhedrick	1-24-85	N.C. Kazanas N C Kazanas	1/29/85
		APPROVAL FOR EXTERNAL DISTRIBUTION	**DATE**
		R F Wilson	10/31/85

Does this TDR include recommendation(s)? ☐ **Yes** ☒ **No** **If yes, TFWR/TR #** ______

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ABSTRACT:

STATEMENT OF PROBLEM

During eddy current examinations of the TMI-1 OTSGs the percent thru wall penetration of a discontinuity is determined by measuring the signals phase angle and using a conversion curve to determine the percent thru wall. The traditional curves used for this purpose are designed for outside diameter discontinuities. For inside diameter discontinuities the percent thru wall determinations are obtained by extrapolation from the outside diameter curve. This traditional extrapolation tends to overcall small volume inner diameter discontinuities. The presence of inner diameter initiated, intergranular stress assisted cracks (IGSAC) in the TMI-1 OTSGs has required GPUN to develop a more accurate means of assigning the percent thru wall volumes.

METHOD

The traditional inner diameter conversion curve was enhanced using supplemental data from EDM notches with various known depths. This data was used to develop a conversion curve which more accurately represents small volume, inner diameter initiated discontinuities. The accuracy of the enhanced curve was verified through metallurgical correlations using actual IGSAC samples.

THIRD PARTY REVIEW

In order to confirm the technical adequacy of the methodology used in establishing the GPUN inner diameter curve, an independent third party review was performed. This review was performed by a Level III certified individual and concluded the methodology utilized was accurate and satisfactory for GPUN's application. A copy of this report is included as attachment 1 to this TDR.

CONCLUSION

The traditional eddy current conversion curves overcall the percent thru wall of small volume inner diameter initiated defects such as the IGSAC present in the TMI-1 OTSGs. The use of the enhanced inner diameter conversion curve permits GPUN to more accurately determine the percent thru wall of the IGSAC which is detected during eddy current examinations.

•COVER PAGE ONLY

A0000030 4-83

GPU Nuclear

DOCUMENT NO.
TDR-642

TITLE: Qualification of Conversion Curve for Discontinuities for Inner Diameter

REV	SUMMARY OF CHANGE	APPROVAL	DATE
1	"Report of Third Party Review of GPUN Report #642" has been furnished as Attachment 1.	A. Rheisick	4/22/85
		N.C. Kazanas N.C. Kazanas	4/22/85
2	Revised TDR to incorporate additional data from TDR 686 and to provide statistical evaluations. Page 5,6, Added paragraph to describe outer diameter discontinuities. Page 6, Clarified wording for paragraph 2. Page 10, Added references to Appendix E and Figure 3a. Appendix C, Page 1, Added reference to TDR 686 and clarified wording; Appendix C, Page 2, Added data from TDR 686. Added Appendix E Metallurgical Versus Eddy Current Examination Statistical Evaluation. Appendix D, Page 15, Corrected typo. Page 14 and 15 updated figures.	Mark Torborg Mark Torborg W. C. Gung NC Kazanas	10-24-8 10-28-8. 10-22-

TABLE OF CONTENTS

INTRODUCTION

GPU Nuclear utilizes a standard differential eddy current technique to examine the tubing in the TMI Once Through Steam Generators (OTSGs). Discontinuities present in the tube wall distort the eddy current field and produce signals which are analyzed to characterize the extent of tube wall degradation.

The analysis of the eddy current signals is performed by evaluating the amplitude and orientation of the signal. The amplitude of the signal indicates the volume of the discontinuity and is measured in volts. The orientation of the signal is measured as a phase angle and indicates the origin (inner diameter or outer diameter) and percent through wall penetration of the discontinuity. This method of analyzing the eddy current signals is called Phase Analysis. In this process, a certified data analyst measures the phase angle of the eddy current signal in degrees. The phase angle measurement is then applied to a conversion curve and the origin and percent through wall penetration of the discontinuity are determined.

The basis of the traditional conversion curve has been the ASME code. The ASME code delineates the parameters for establishing a curve for discontinuities originating on the outside diameter of the tubing. Industry practice has been to extrapolate this outside diameter curve to provide a linear curve for discontinuities of 0-100 percent through wall originating on the inside diameter of the tube wall (See Figure 1).

The discontinuities present in the TMI OTSGs are very tight, intergranular stress assisted cracks (IGSAC) originating on the inner diameter of the tube wall and are therefore not well represented by the traditional curve which tends to over call small volume inner diameter discontinuities.

In order to establish a more accurate conversion curve for the specific discontinuities present in the TMI OTSGs, the traditional curve was enhanced through the use of supplemental reference points. These supplemental reference points were based on the eddy current responses from synthetic defects (EDM notches) placed on the inner diameter of inconel tubing representative of the actual OTSG tubing. The analysis of the eddy current responses from the EDM notches provided known and measured intermediate points for defining the inner diameter conversion curve. This data provides intermediate reference points of 20, 40, 60, and 80% through wall (nominal) permitting the development of a multipoint curve representing inner diameter originated discontinuities.

The use of this enhanced conversion curve enables GPUN to more accurately determine the percent through wall penetration of inner diameter discontinuities which ensures indications of 40% through wall or greater are properly dispositioned. In addition, discontinuities of less than 40% through wall can be monitored for future change.

As part of this analysis, the accuracy of the curve was verified using actual IGSAC samples. This verification was made by correlating the actual percent through wall, as determined by metallography, with the assigned eddy current percent through wall, as determined from the phase angle measurement.

METHOD OF CURVE DEVELOPMENT

Using phase analysis techniques for eddy current analysis, the depth of penetration (percent through wall) and origin (inner diameter or outer diameter) of a discontinuity can be determined. This determination is made by analyzing the phase angle (orientation) of the eddy current signal and converting the phase angle into a percent through wall determination.

During the examination of OTSG tubing, inner diameter originated discontinuities produce eddy current response signals with phase angles which occur over a 30 degree range. This range of phase angles is bounded by a 100% through wall hole which is set for 40 degrees and represents the upper limit. The lower limit is bounded by probe motion and non-relevant tube noise which represents the inside surface of the tube. This probe motion and tube noise has been measured at approximately 10 degrees.

By contrast, discontinuities which originate on the outer diameter of the tube result in eddy current responses with phase angles from the 100% through wall hole at 40 degrees to approximately 110 degrees for a 20%

through wall discontinuity. This phase relationship allows the data analyst to determine the origin of part through wall discontinuities up to approximately 80% through wall. Above this point, the influence of other factors such as discontinuity shape and volume prohibit making accurate determinations of the discontinuities origin. GPUN therefore administratively dispositions discontinuities above 80% through wall as 100% through wall.

The narrow phase spread for the inner diameter discontinuities is relatively constant and no significant improvement was noted during a review of the existing 200, 400 and 800 KHz data. The inherent limitations of this narrow phase spread require the use of conversion curves and evaluation techniques capable of providing the highest degree of accuracy and repeatability which can be obtained.

The development of a conversion curve capable of providing accurate percent through wall determinations requires using standards which accurately represent the actual discontinuities. The discontinuities previously identified in the TMI OTSGs are characterized as being very tight, intergranular stress assisted cracks (IGSAC) originating on the inner diameter of the tube and propagating in a circumferential manner (See TDR 341).

Utilizing the EDM notch standards which were originally used to qualify the eddy current test program presently being implemented at TMI (See TDR 423), a conversion curve representing small volume inner diameter originated discontinuities was developed. (See Figure 2). This initial curve was developed by plotting the "Least Squares Fit" of the eddy current signal phase angles from EDM notches of 20, 40, 60, and 80% through wall (nominal) with arc lengths ranging from .060 to 1.00 inches. (See Appendix A).

This EDM notch curve revealed that the traditional conversion curve for inner diameter originated discontinuities was overly conservative and did not provide accurate percent through wall determinations. The EDM notch conversion curve offered a substantial increase in the accuracy of percent through wall determination, however, the hyperbolic shape of the curve prevented using the existing automated data evaluation system.

The existing data evaluation system, the Zetec DDA-4, offers computerized phase analysis of eddy current signals and provides a mechanism for accurately and efficiently determining percent through wall values. However, the DDA-4 is limited to a linear inner diameter conversion curve and, therefore, could not readily utilize the EDM notch conversion curve. (See Appendix B).

The benefits of utilizing the DDA-4 warranted further investigation to develop a conversion curve which could combine the accuracy of the EDM notch curve with the data analysis capabilities of the DDA-4. In order to provide a means of implementing an accurate inner diameter curve using the DDA-4, a linear approximation of the EDM notch curve was developed. This approximation was developed as a linear function using the 100% through wall hole in the ASME calibration standard to bound the upper limit at 40 degrees. The lower limit was established using the signals from probe motion and tube noise which occur at approximately 10 degrees. (See Figure 2).

In addition to providing a means of utilizing the DDA-4, the linear approximation also provides an additional level of conservatism over the EDM notch curve for indications 40% through wall or greater. This additional conservatism accounts for variations in sizing actual discontinuities versus sizing uniform geometry synthetic defects and assures discontinuities from 40 to 100% through wall will be properly dispositioned.

For discontinuities which are identified as being less than 40% through wall, no further disposition is required. Tubes with discontinuities in this range are categorized as "degraded" tubes and are monitored during subsequent examinations.

The assigned percent through wall values for this subset tend to be lower than the actual percent through wall penetration, however, the assigned values are utilized for data base management only. Although the assigned percent through wall values are lower than the actual values, the assigned values can be used to effectively monitor indications for changes in phase angles.

METHOD OF CURVE VERIFICATION

The accuracy and repeatability of the GPUN inner diameter conversion curve was verified using two different types of data. These verifications were based on data obtained from metallurgical correlations and from the previously identified EDM notches.

The accuracy of the GPUN inner diameter conversion curve for the specific discontinuities in the TMI OTSGs was verified through metallurgical correlations of actual IGSAC samples. These metallurgical correlations were performed by comparing the actual IGSAC percent through wall, as determined by metallography, with the assigned eddy current percent through wall, as determined by the GPUN inner diameter conversion curve.

The correlation included actual IGSAC samples which were previously removed from the OTSGs and laboratory induced IGSAC samples. The sample of removed tubes included all available samples from below the upper tube sheets, all available part through wall samples and additional 100% through wall samples from within the upper tube sheet. In addition, to these removed samples, two samples of TMI archive tubing with laboratory induced part through wall IGSAC were included. (See Appendices C and E).

To graphically illustrate this correlation, the eddy current assigned percent through walls were plotted against the actual percent through walls, as determined by metallography as shown in Figures 3 and 3a. These plots verify the GPUN inner diameter curve provides a more accurate means of determining percent through wall for actual IGSAC samples than traditional conversion curves. Appendix E has been added to provide the statistical evaluation of this correlation.

The GPUN inner diameter curve was further analyzed using the previously mentioned EDM notch standards to verify the reliability and repeatability of the overall examination techniques. The analysis was performed by examining the same EDM notch standards used to develop the "EDM Notch" curve.

The examinations consisted of scanning each of the standards four times, rotating the standard 90° between each scan. This method of scanning subjected each notch to "best case" and "worst case" probe orientation to simulate the effects of probe passage during in-situ examinations. The examinations were then repeated using a different probe to account for variations in probes. The probes were designated B and C and the data collected was identified as Data Sets B and C. Data set A was used for the initial screening as described in Appendix A.

The eddy current percent through wall determinations were then plotted against the actual percent through walls to determine the repeatability of the examinations. The resulting data plots showed an average overcall for indications 40% through wall or greater. This average overcall indicates the conservatism GPUN added by using the linear approximation can be maintained during repeat examinations. (See Figures 4 & 5 and Appendix D)

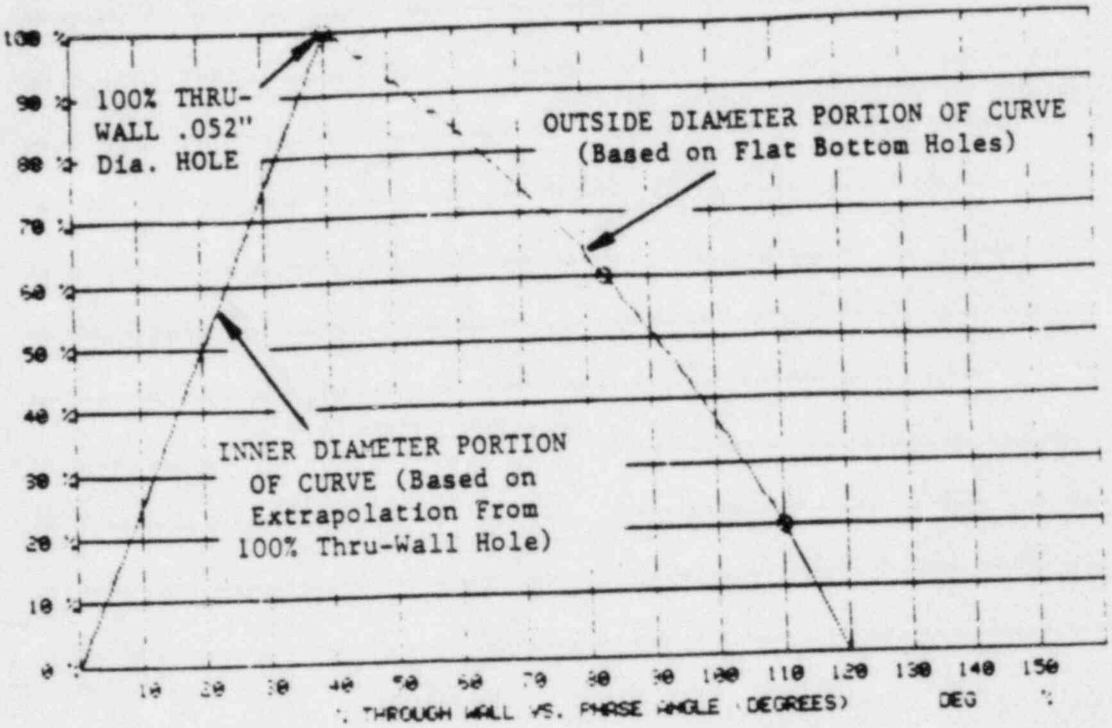
CONCLUSIONS

The inner diameter conversion curve qualified herein provides a more accurate means of dispositioning inner diameter initiated, intergranular stress assisted cracks (IGSAC) than traditional conversion curves. The implementation of this curve will enhance GPUN's eddy current capacilities and ensure the IGSAC indications identified during OTSG eddy current examinations will be properly dispositioned.

In addition to providing the ability to properly disposition discontinuities, the conversion curve can be implemented using the existing data analysis techniques. Maintaining this continuity in analysis techniques, enables GPUN to monitor tubes with indications (degraded tubes) during subsequent examinations.

FIGURE 1

TYPICAL EDDY CURRENT CONVERSION CURVE



DEG	%	DEG	%	DEG	%	DEG	%	DEG	%	DEG	%	DEG	%	DEG	%
000	00	020	50	040	99	060	84	080	64	100	37	120	00	140	00	160	00
001	03	021	53	041	99	061	83	081	62	101	35	121	00	141	00	161	00
002	05	022	55	042	99	062	82	082	61	102	34	122	00	142	00	162	00
003	08	023	57	043	98	063	81	083	60	103	32	123	00	143	00	163	00
004	10	024	60	044	97	064	80	084	59	104	30	124	00	144	00	164	00
005	13	025	63	045	96	065	79	085	58	105	29	125	00	145	00	165	00
006	15	026	65	046	96	066	78	086	56	106	27	126	00	146	00	166	00
007	18	027	68	047	95	067	77	087	55	107	25	127	00	147	00	167	00
008	20	028	70	048	94	068	76	088	54	108	24	128	00	148	00	168	00
009	23	029	73	049	93	069	75	089	52	109	22	129	00	149	00	169	00
010	25	030	75	050	92	070	74	090	51	110	20	130	00	150	00	170	00
011	28	031	78	051	92	071	73	091	50	111	18	131	00	151	00	171	00
012	30	032	80	052	91	072	72	092	48	112	16	132	00	152	00	172	00
013	33	033	83	053	90	073	71	093	47	113	14	133	00	153	00	173	00
014	35	034	85	054	89	074	70	094	46	114	12	134	00	154	00	174	00
015	38	035	88	055	88	075	69	095	44	115	10	135	00	155	00	175	00
016	40	036	90	056	87	076	68	096	43	116	08	136	00	156	00	176	00
017	43	037	93	057	87	077	67	097	41	117	06	137	00	157	00	177	00
018	45	038	95	058	86	078	66	098	40	118	04	138	00	158	00	178	00
019	48	039	98	059	85	079	65	099	38	119	02	139	00	159	00	179	00

FIGURE 2

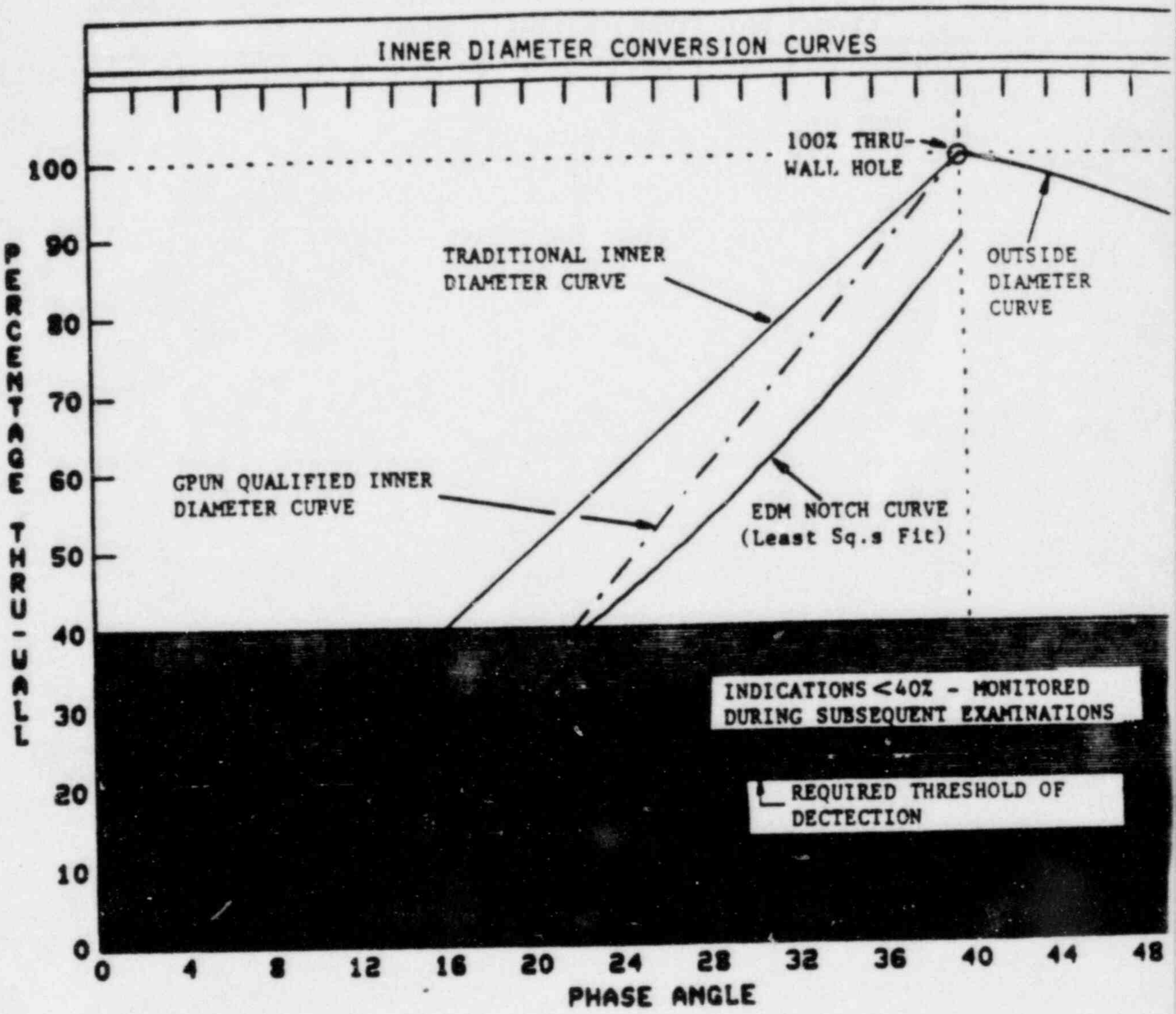
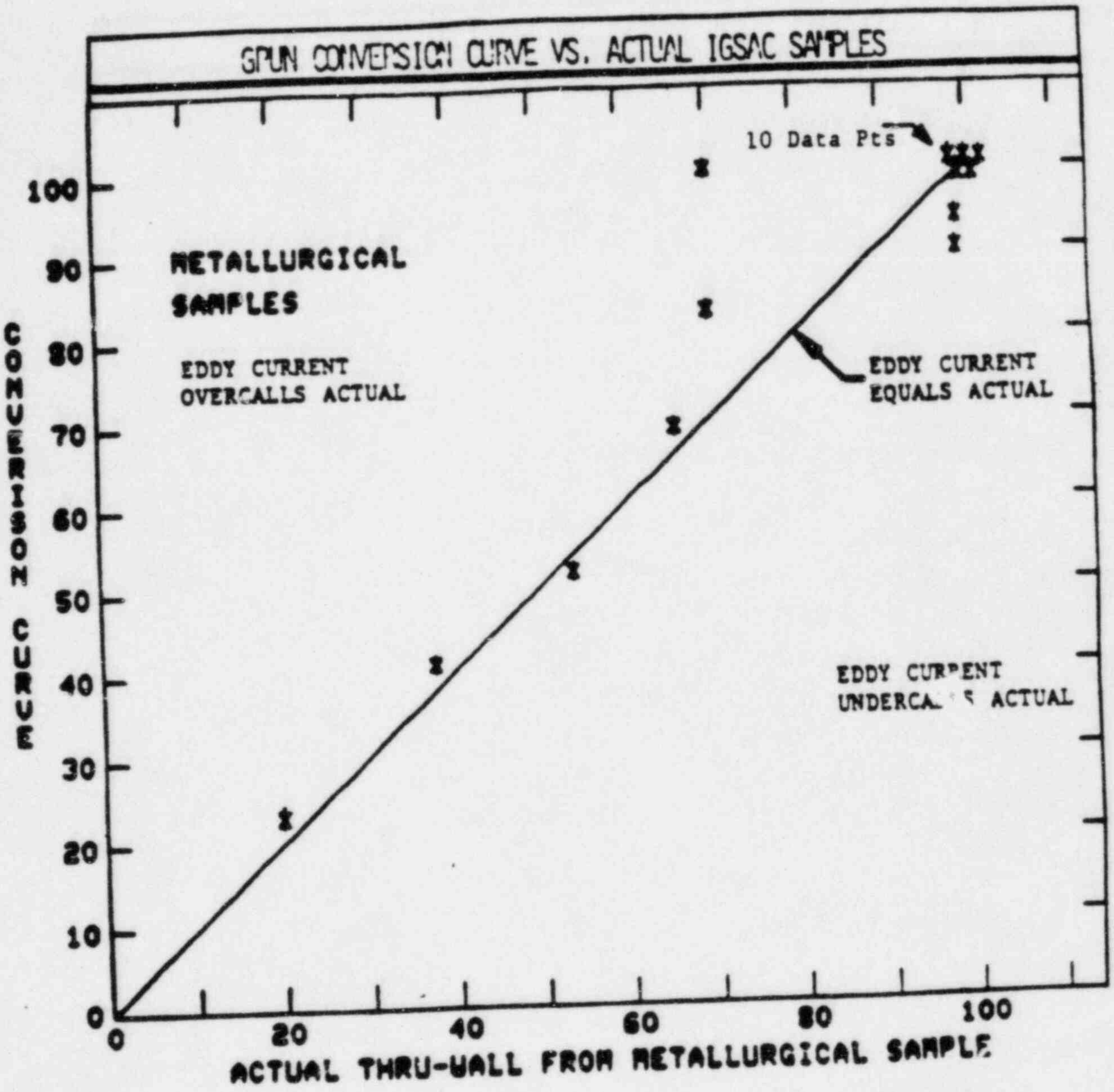
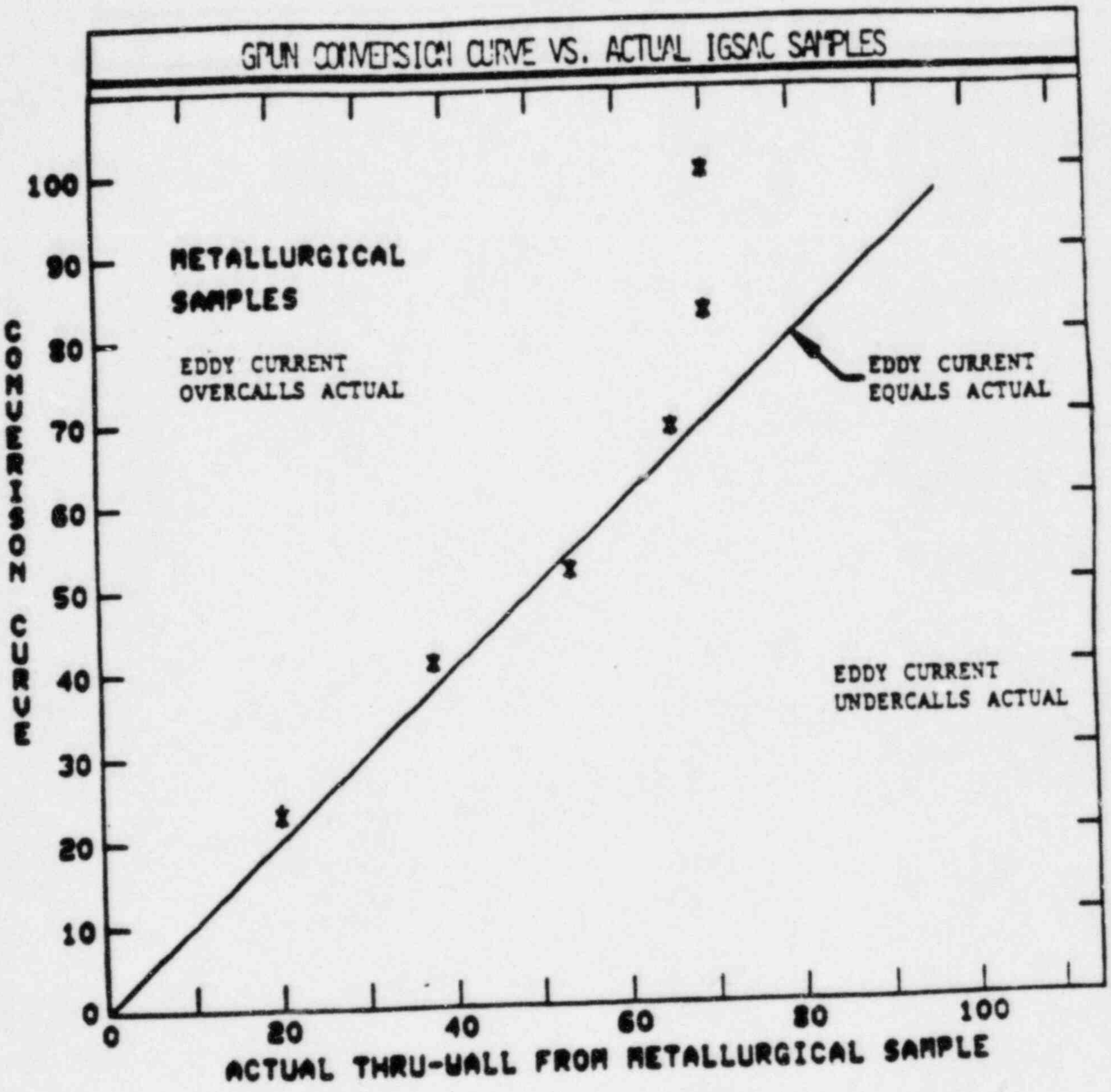

INNER DIAMETER CONVERSION CURVES
100% THRU-WALL HOLE
TRADITIONAL INNER DIAMETER CURVE
OUTSIDE DIAMETER CURVE
GPUN QUALIFIED INNER DIAMETER CURVE
EDM NOTCH CURVE (Least Sq.s Fit)
INDICATIONS <40% - MONITORED DURING SUBSEQUENT EXAMINATIONS
REQUIRED THRESHOLD OF DECTECTION
PERCENTAGE THRU-WALL
0
10
20
30
40
50
60
70
80
90
100
PHASE ANGLE
0
4
8
12
16
20
24
28
32
36
40
44
48

FIGURE 3



DATA SET "R", APPENDIX E ALL IGSAC SAMPLES (18 POINTS)

FIGURE 3a



DATA SET I APPENDIX E 20 - 70% TW IGSAC SAMPLES (6 POINTS)

FIGURE 4

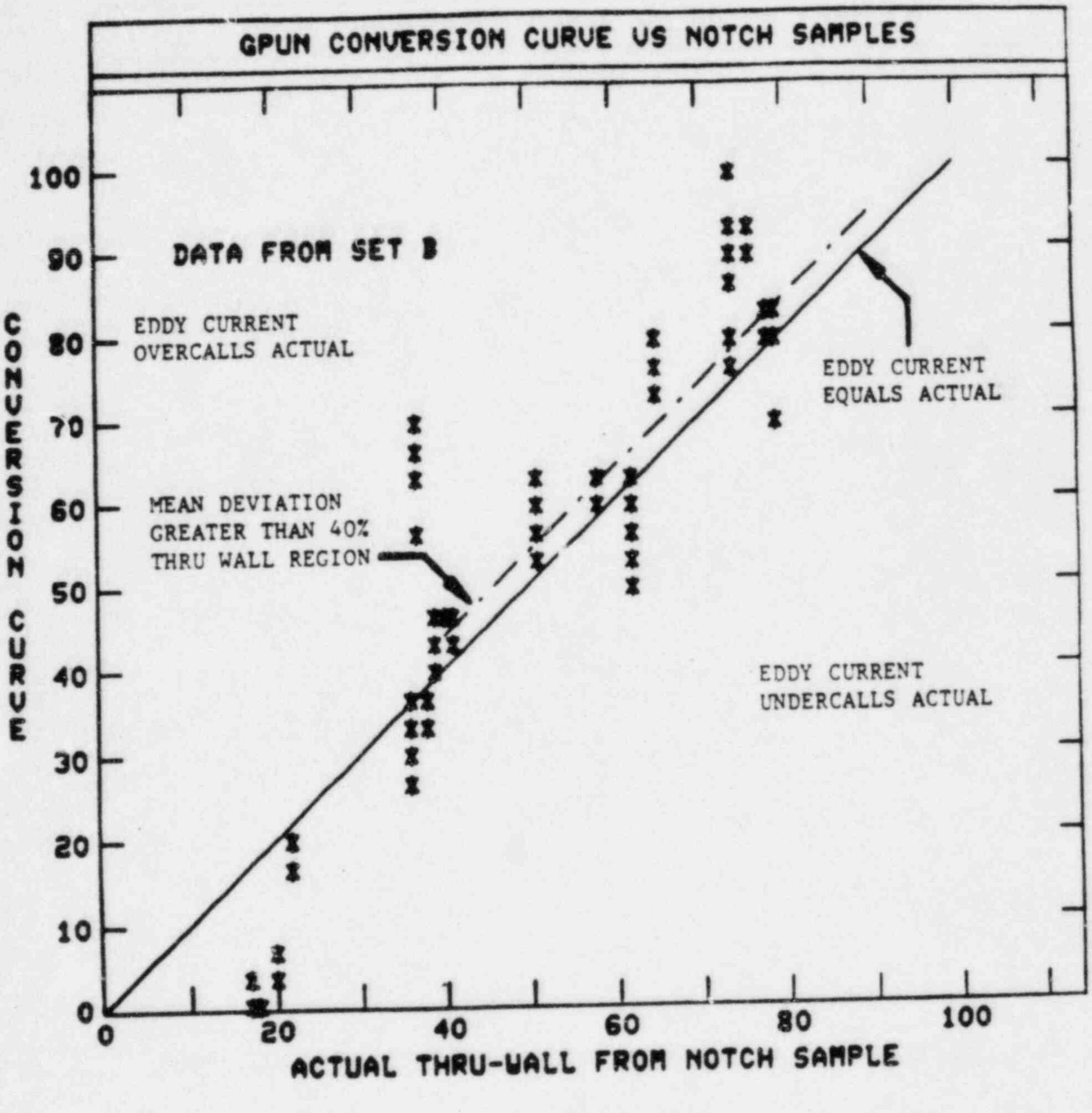
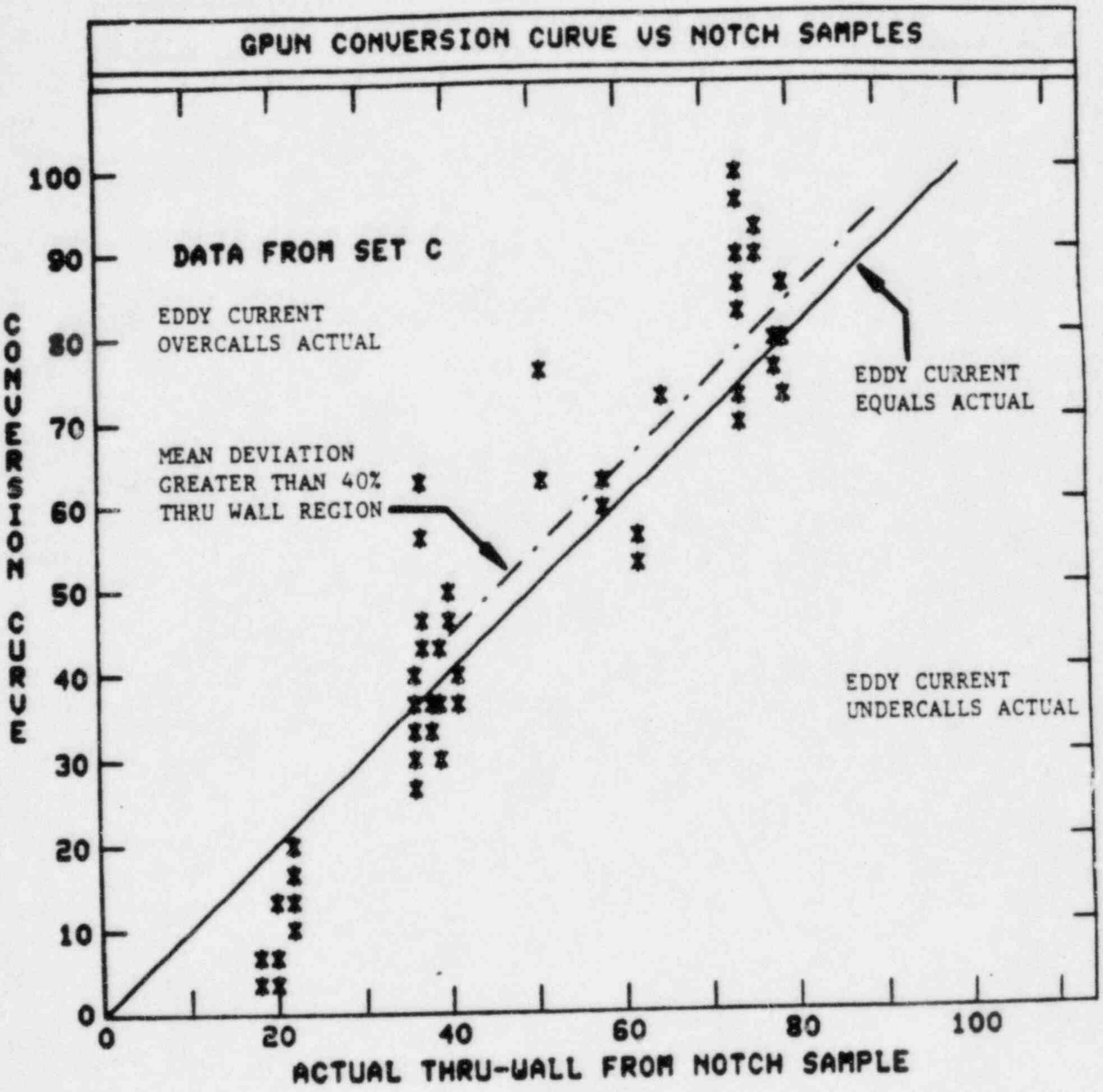

GPUN CONVERSION CURVE VS NOTCH SAMPLES
DATA FROM SET B
EDDY CURRENT OVERCALLS ACTUAL
EDDY CURRENT EQUALS ACTUAL
MEAN DEVIATION GREATER THAN 40% THRU WALL REGION
EDDY CURRENT UNDERCALLS ACTUAL
CONVERSION CURVE
ACTUAL THRU-WALL FROM NOTCH SAMPLE
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100

FIGURE 5


GPUN CONVERSION CURVE VS NOTCH SAMPLES
DATA FROM SET C
EDDY CURRENT
OVERCALLS ACTUAL
MEAN DEVIATION
GREATER THAN 40%
THRU WALL REGION
EDDY CURRENT
EQUALS ACTUAL
EDDY CURRENT
UNDERCALLS ACTUAL
CONVERSION CURVE
ACTUAL THRU-WALL FROM NOTCH SAMPLE
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100

APPENDIX A

EDDY CURRENT STANDARDS AND EQUIPMENT USED FOR QUALIFICATION

EDDY CURRENT STANDARDS AND EQUIPMENT USED FOR QUALIFICATION

The standard differential examination technique used to examine the TMI-1 OTSG tubing utilizies a Zetec MIZ-12 test system operated at a base frequency of 400 KHZ. The eddy current probes can be either a .510" or .540" diameter operating at normal or high gain.

To reduce the number of examinations required to qualify the inner diameter conversion curve for use with the different probes and gain settings, the techniques were compared using both an A.S.M.E. standard and a E.D.M. notch standard. The results as shown on Figure A-1 confirm that the phase angle of the eddy current signal is not affected by varying gains or probe diameters.

As a result of this comparison, the remainder of the qualification was performed using the applicable portions of the existing .540" High Gain examination procedure (1300-4B/42-EC-068).

The qualification program used nine standards having electro-discharged machined (EDM) notches. The depth of the notches varied between 17% to 100% through wall penetration with a nominal width of .005". The notches were circumferentially orientated with arc lengths from .060" to 1.000". In addition, one standard (TMI-ET-110) contained .060" longitudinal notches. (See Figure A-2)

Prior to using the fabricated tube standards for establishing a qualification program, it was necessary to review the eddy current responses to ensure the eddy current signal was not being influenced by tube abnormalities. This review was conducted on each of the 31 notches. As a result of this review the following notches were deleted.

1. E.T. Std. No. - TMI-ET-112 - .100 x 56%
   .100 x 79%
2. E.T. Std. No. - TMI-ET-111 - .060 x 17%
3. E.T. Std. No. - TMI-ET-113 - .187 x 57%

The above notches were deleted due to signal distortion caused by tube noise, manufacturing, and/or handling. Figures A-3, A-4, A-5 are photos of the eddy current presentation.

Figure A-1

PHASE ANGLE COMPARISON AT 400KHZ

STANDARD	EDDY CURRENT PHASE ANGLE (Measured in Degrees)		
ASME Standard (O.D.) S/N 92311 Flat Bottom Holes	.510 Normal Gain	.510 High Gain	.540 High Gain
100% T.W.	40	40	40
80% T.W.	75	75	75
60% T.W.	92	92	92
40% T.W.	113	113	113
20% T.W.	121	122	121

E.D.M. Notch Standard (I.D.) S/N TMI-ET-114 Circumerential Notches	.510 Normal Gain	.510 High Gain	.540 High Gain
80% T.W.	38	38	38
60% T.W.	30	30	30
40% T.W.	26	27	27
20% T.W.	9	9	9

Figure A-2

LIST OF TUBE STANDARDS

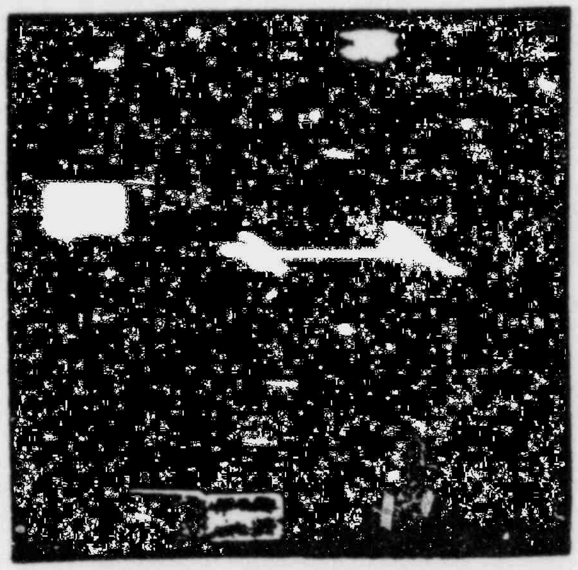
STANDARDS	NOTCH LENGTH	NOTCH DEPTH	COMMENTS
TMI-ET-101	.250 C	39% O.D.	4 Notches 90° Apart
	.250 C	38% I.D.	4 Notches 90° Apart
TMI-ET-110	.060 L	20% I.D.	
	.060 L	36% I.D.	
	.060 L	62% I.D.	
	.060 L	79% I.D.	
TMI-ET-111	.060 C	17% I.D.	Delete
	.060 C	37% I.D.	
	.060 C	51% I.D.	
	.060 C	74% I.D.	
TMI-ET-112	.100 C	18% I.D.	
	.100 C	39% I.D.	
	.100 C	56% I.D.	Delete
	.100 C	79% I.D.	Delete
TMI-ET-113	.187 C	17% I.D.	
	.187 C	36% I.D.	
	.187 C	57% I.D.	Delete
	.187 C	74% I.D.	
TMI-ET-114	.250 C	18% I.D.	
	.250 C	40% I.D.	
	.250 C	58% I.D.	
	.250 C	79% I.D.	
	.250 C	100%	
TMI-ET-115	.520 C	65% I.D.	
	.520 C	76% I.D.	
	.520 C	100%	
TMI-ET-116	.750 C	41% I.D.	
	.750 C	62% I.D.	
	.750 C	78% I.D.	
TMI-ET-117	1.000 C	22% I.D.	
	1.000 C	38% I.D.	

C - Circumferential
L - Longitudinal

Eddy Current Standard Certification packages are on file at the TMI Site

Figure A-3

Eddy Current Tube Sample S/N TMI-ET-112



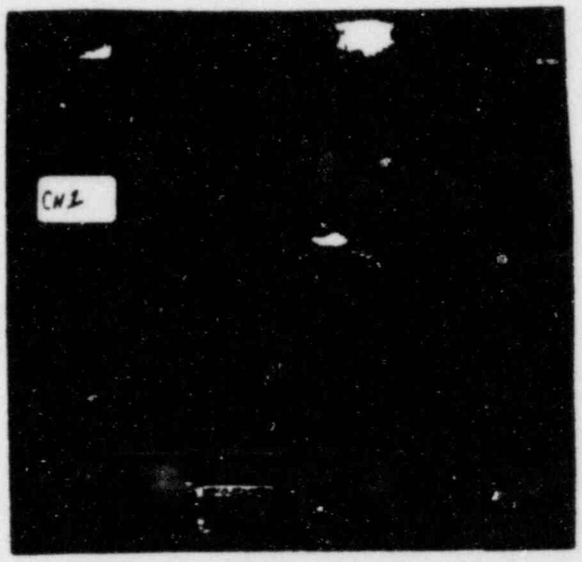
Notch .100" x 56% ID

Notch .100" x 79% ID

The above flaw lissajous patterns are distorted by interfering signals. The trace does not cross over at the zero point and also forms in reverse on the trailing lobe.

Figure A-4

Eddy Current Tube Sample S/N TMI-ET-111

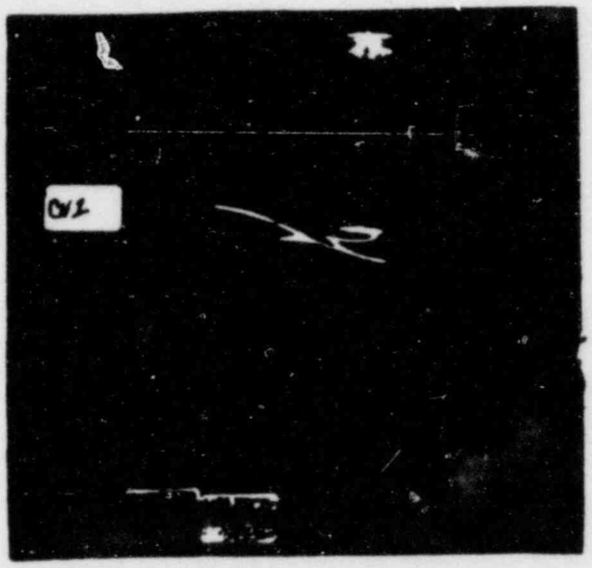


Notch .060" x 17% ID

The above 17% notch is below the qualified threshold of detection and cannot be isolated from the tube noise.

Figure A-5

Eddy Current Tube Sample S/N TMI-ET-113



Notch .187" x 57% ID

The above flaw lissajous pattern is being distorted due to interference from a dent.

APPENDIX B

DATA INTERPRETATION USING THE DDA-4

Introduction

The eddy current data collected during TMI OTSG tubing examination is recorded on magnetic tape and analyzed "off line" by a certified Data Analyst.

The data analysis process is carried out using both the conventional Zetec Miz 12 analog system and the Zetec DDA-4 digital system. In this process, the data analyst reviews the eddy current data on an oscilloscope and identifies potential defect signals.

Once a potential defect is identified, the portion of the data containing the signal is entered into the DDA-4 analysis system for further evaluation.

The purpose of using this two step method of data analysis is to maintain the sensitivity of the analog oscilloscope for identification of potential defects while providing the additional analysis capabilities of the DDA-4.

Method

Prior to starting the review of the eddy current data, the data analyst reviews the calibration standard which is recorded at the start of each magnetic tape. The analyst enters the phase angles from the calibration standard into the DDA-4 and the phase angle versus percent through wall conversion curve for outside diameter discontinuities is automatically developed. The development of this conversion curve is preprogrammed and it based on the outside diameter flat bottom holes contained in the "ASME" standard. The inner diameter portion of the curve is automatically extrapolated from the 100% through wall hole to zero. By shifting the location of the through wall, phase spread of the extrapolated portion can be varied.

The proper orientation of the through wall hole is determined by the angle of the probe motion, which should occur horizontally. During examination of the TMI OTSGs, the separation of the probe motion and the 100% through wall hole is 30° and therefore inner diameter discontinuities will have phase angles in this range. (Figure B-1 shows a typical conversion curve for the TMI OTSGs.)

With the calibration standard information entered into the DDA-4, the conversion of phase angles to percent through wall can be accomplished automatically using the preprogrammed vector analyzer.

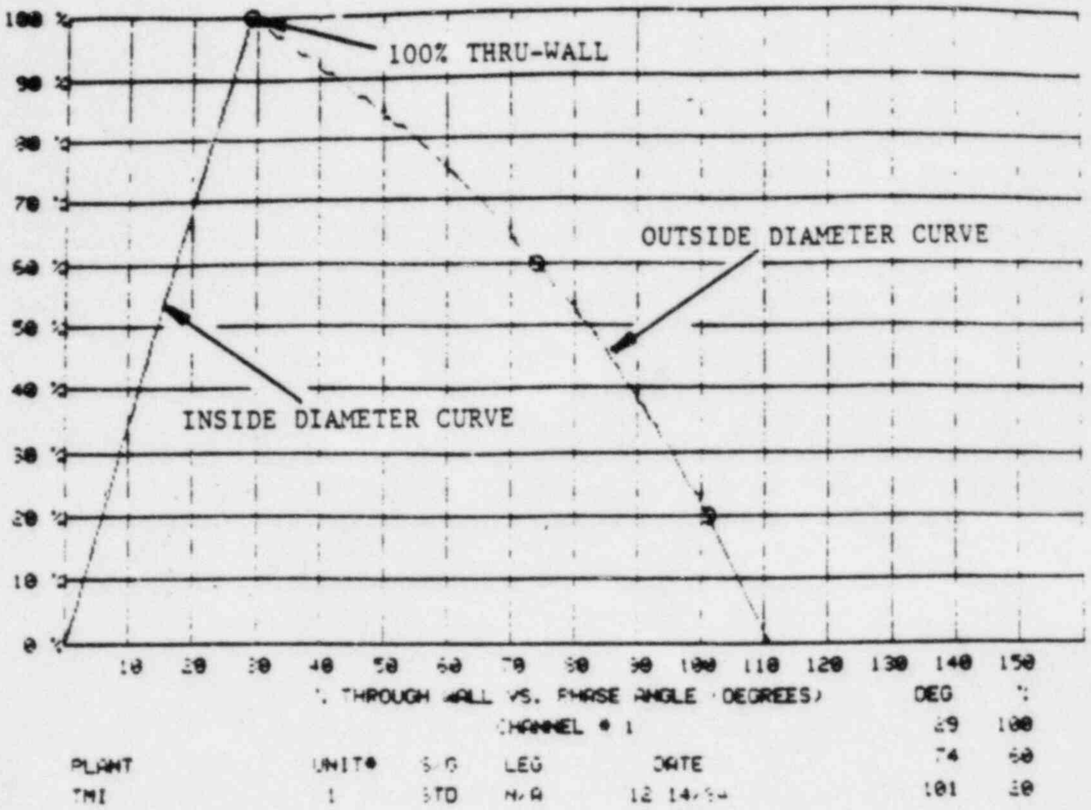
In order to determine the percent through wall of a discontinuity, the data analyst isolates the eddy current signal on the screen. The signal can then be expanded to permit the analyst to more accurately select the appropriate points for signal measurements.

Once the appropriate points are selected, the phase angle measurement, signal amplitude and percent through wall are displayed. The eddy current signal and all pertinent information can then be printed as a hard copy or the information, including the eddy current signal can also be recorded on a data diskette. (Figures B-2, B-3, and B-4 show typical eddy current signals as analyzed using the DDA-4.)

At present the eddy current signals and evaluations are being maintained using data sheets and are supplemented by the hard copy printouts. The data is then manually input into the TMI Eddy Current Data Base System.

Should GPUN decide to utilize a direct input data base in the future the DDA-4 generated diskettes can provide the direct input mechanism.

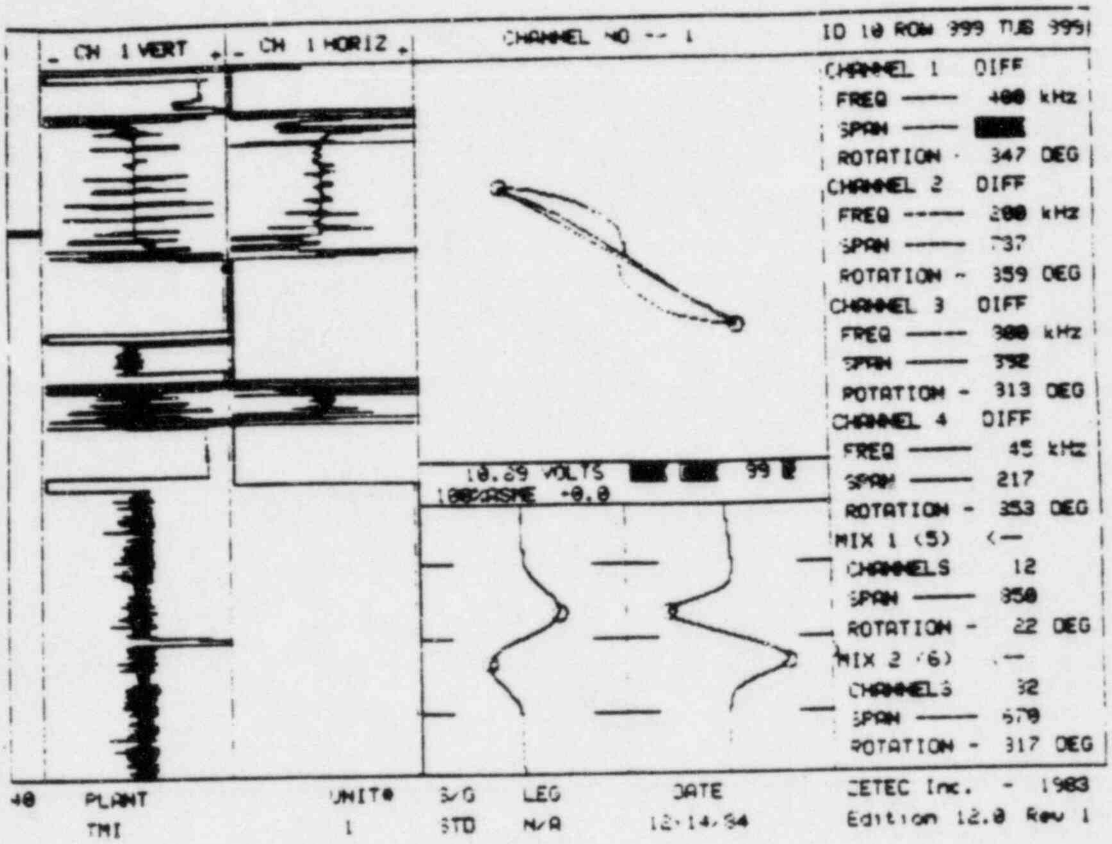
Figure B-1



DEG	%	DEG	%	DEG	%	DEG	%	DEG	%	DEG	%	DEG	%	DEG	%	DEG	%
000	00	020	69	040	92	060	75	080	53	100	22	120	00	140	00	160	00
001	03	021	72	041	91	061	74	081	51	101	20	121	00	141	00	161	00
002	07	022	76	042	91	062	73	082	50	102	18	122	00	142	00	162	00
003	10	023	79	043	90	063	72	083	49	103	16	123	00	143	00	163	00
004	14	024	83	044	89	064	71	084	47	104	14	124	00	144	00	164	00
005	17	025	86	045	88	065	70	085	46	105	12	125	00	145	00	165	00
006	21	026	90	046	87	066	69	086	44	106	10	126	00	146	00	166	00
007	24	027	93	047	87	067	68	087	43	107	08	127	00	147	00	167	00
008	28	028	97	048	86	068	67	088	41	108	06	128	00	148	00	168	00
009	31	029	99	049	85	069	66	089	40	109	04	129	00	149	00	169	00
010	34	030	99	050	84	070	65	090	38	110	02	130	00	150	00	170	00
011	38	031	99	051	83	071	63	091	37	111	00	131	00	151	00	171	00
012	41	032	98	052	82	072	62	092	35	112	00	132	00	152	00	172	00
013	45	033	97	053	82	073	61	093	34	113	00	133	00	153	00	173	00
014	48	034	97	054	81	074	60	094	32	114	00	134	00	154	00	174	00
015	52	035	96	055	80	075	59	095	31	115	00	135	00	155	00	175	00
016	55	036	95	056	79	076	58	096	29	116	00	136	00	156	00	176	00
017	59	037	94	057	78	077	56	097	27	117	00	137	00	157	00	177	00
018	62	038	94	058	77	078	55	098	25	118	00	138	00	158	00	178	00
019	66	039	93	059	76	079	54	099	24	119	00	139	00	159	00	179	00

Typical DDA-4 Conversion Curve. Curve was plotted after rotating phase to place probe motion horizontal which cuts 100% Hole at 30°.

Figure B-2

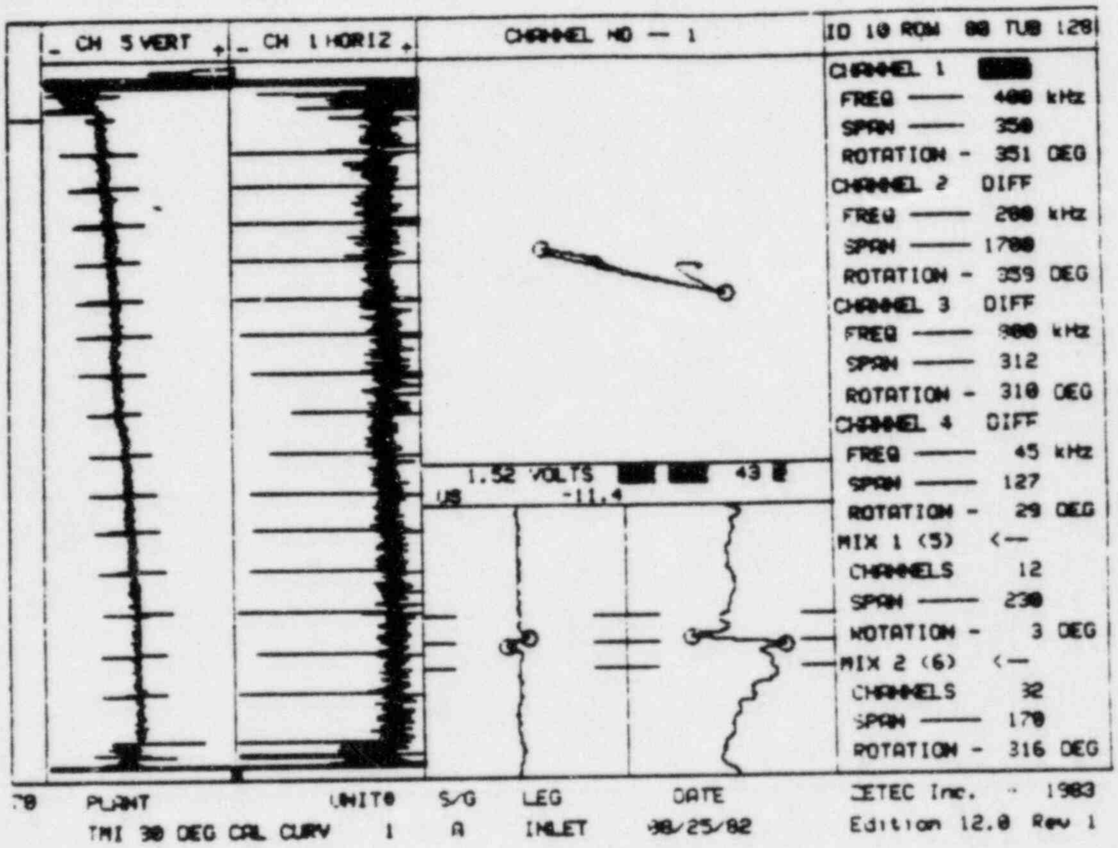


```
ID 10 ROW 999 TUB 9991
CHANNEL 1   DIFF
 FREQ ----   400 kHz
 SPAN ----   [illegible]
 ROTATION -  347 DEG
CHANNEL 2   DIFF
 FREQ ----   200 kHz
 SPAN ----   737
 ROTATION -  359 DEG
CHANNEL 3   DIFF
 FREQ ----   300 kHz
 SPAN ----   392
 ROTATION -  313 DEG
CHANNEL 4   DIFF
 FREQ ----    45 kHz
 SPAN ----   217
 ROTATION -  353 DEG
MIX 1 (5)   <-
 CHANNELS     12
 SPAN ----   850
 ROTATION -   22 DEG
MIX 2 (6)   <-
 CHANNELS     32
 SPAN ----   679
 ROTATION -  317 DEG
```

```
40   PLANT   UNIT#   S/G   LEG   DATE       ZETEC Inc.  - 1983
     TMI     1       STD   N/A   12-14-84   Edition 12.0 Rev 1
```

Typical ODA-4 Printout showing 100% thru-wall hole in ASME calibration standard. Hole is set at 30° as would occur during production examinations.

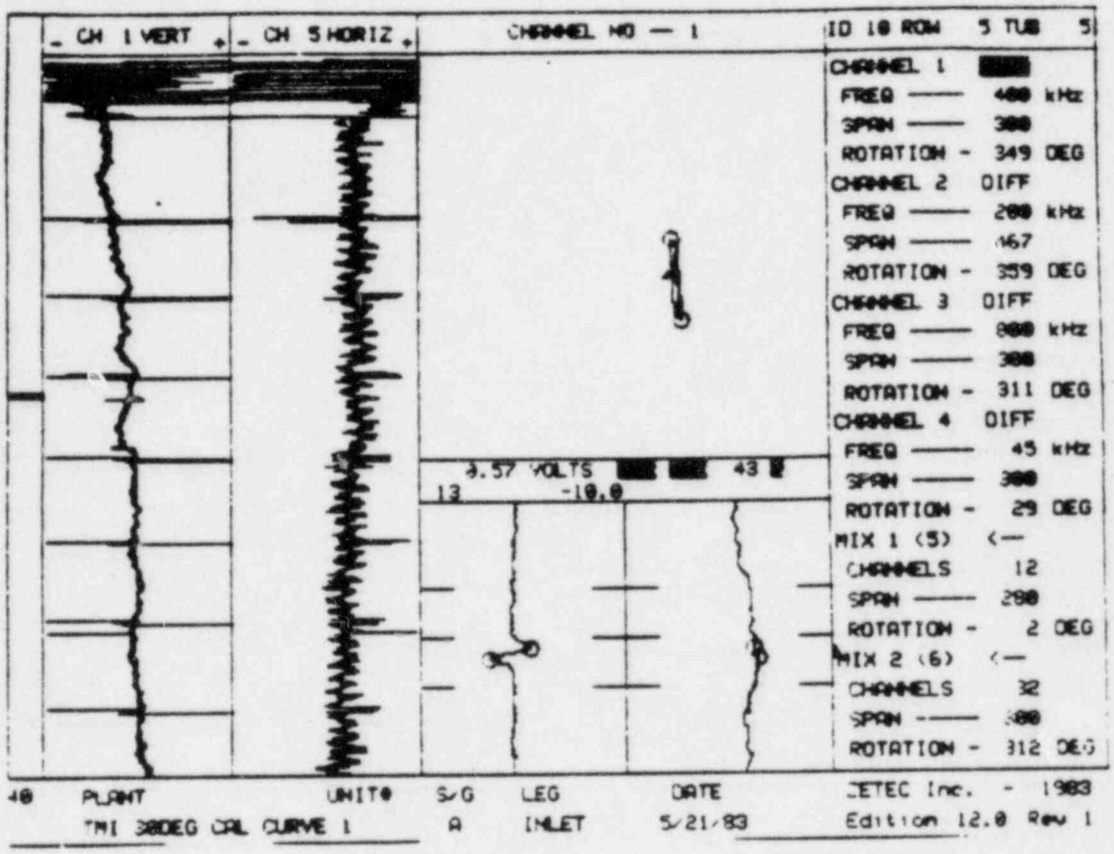
Figure B-3



```
ID 10 ROW 00 TUB 128
CHANNEL 1
 FREQ ——— 400 kHz
 SPAN ——— 350
 ROTATION - 351 DEG
CHANNEL 2  DIFF
 FREQ ——— 200 kHz
 SPAN ——— 1700
 ROTATION - 359 DEG
CHANNEL 3  DIFF
 FREQ ——— 900 kHz
 SPAN ——— 312
 ROTATION - 310 DEG
CHANNEL 4  DIFF
 FREQ ———  45 kHz
 SPAN ——— 127
 ROTATION -  29 DEG
MIX 1 (5)  <—
 CHANNELS   12
 SPAN ——— 230
 ROTATION -   3 DEG
MIX 2 (6)  <—
 CHANNELS   32
 SPAN ——— 170
 ROTATION - 316 DEG

78  PLANT                 UNIT0  S/G  LEG     DATE        ZETEC Inc.  -  1983
    TMI 30 DEG CAL CURV   1      A    INLET   08/25/82    Edition 12.0 Rev 1
```

Typical DDA-4 Printout showing a 43% thru-wall (ID), 1.52 volts eddy current signal. The corresponding discontinuity is located 11.4" below the upper tubesheet.

Figure B-4



```
ID 10 ROW    5 TUB    5
CHANNEL 1
 FREQ ——      400 kHz
 SPAN ——      300
 ROTATION -  349 DEG
CHANNEL 2   DIFF
 FREQ ——      200 kHz
 SPAN ——      467
 ROTATION -  359 DEG
CHANNEL 3   DIFF
 FREQ ——      800 kHz
 SPAN ——      300
 ROTATION -  311 DEG
CHANNEL 4   DIFF
 FREQ ——       45 kHz
 SPAN ——      300
 ROTATION -   29 DEG
MIX 1 (5)   <—
 CHANNELS      12
 SPAN ——      200
 ROTATION -    2 DEG
MIX 2 (6)   <—
 CHANNELS      32
 SPAN ——      300
 ROTATION -  312 DEG
```

```
40   PLANT                  UNIT0   S/G   LEG      DATE      ZETEC Inc.  -  1983
     TMI 380DEG CAL CURVE 1         A     INLET    5/21/83   Edition 12.0 Rev 1
```

Typical DDA-4 Printout showing a 43% thru-wall (OD), .57 volt eddy current signal. The corresponding discontinuity is located 10.0" below the 13th tube support plate.

APPENDIX C

METALLURGICAL CORRELATIONS

Metallurgical Correlations

GPUN utilized metallurgical correlations to verify the accuracy of the enhanced inner diameter conversion curve. The metallurgical data used for these correlations was extracted from TDR 423, Appendix A and TDR 686. The eddy current percent through wall determinations were made by re-analyzing existing eddy current data using the present data analysis techniques and the GPUN inner diameter conversion curve.

The eddy current analysis was completed using the techniques described in Appendix B. In using these techniques the data was recorded on a curve which extends from 0-30°. The data was then normalized by adding 10° to permit correlations with data which was recorded on a curve from 10-40°. This normalization maintains consistency with the remainder of the analysis which was recorded on a 10-40° curve as shown on Figure #2 in the body of this report.

The IGSAC samples utilized for the correlations consisted of laboratory induced IGSAC samples and tubes which were previously removed from the TMI-1 OTSG's. The IGSAC was characterized in TDR 341 as being very tight, inner diameter initiated and propagating in a circumferential manner.

Figure C-1 is a summary of the eddy current versus metallurgical correlation. Figures C-2 through C-13 are examples of hard copy printouts detailing the eddy current signal analysis as performed using the Zetec DDA-4.

Figure C-1

Correlation of Eddy Current Percent Throughwall Versus Actual Percent Throughwall

Data from TDR 423

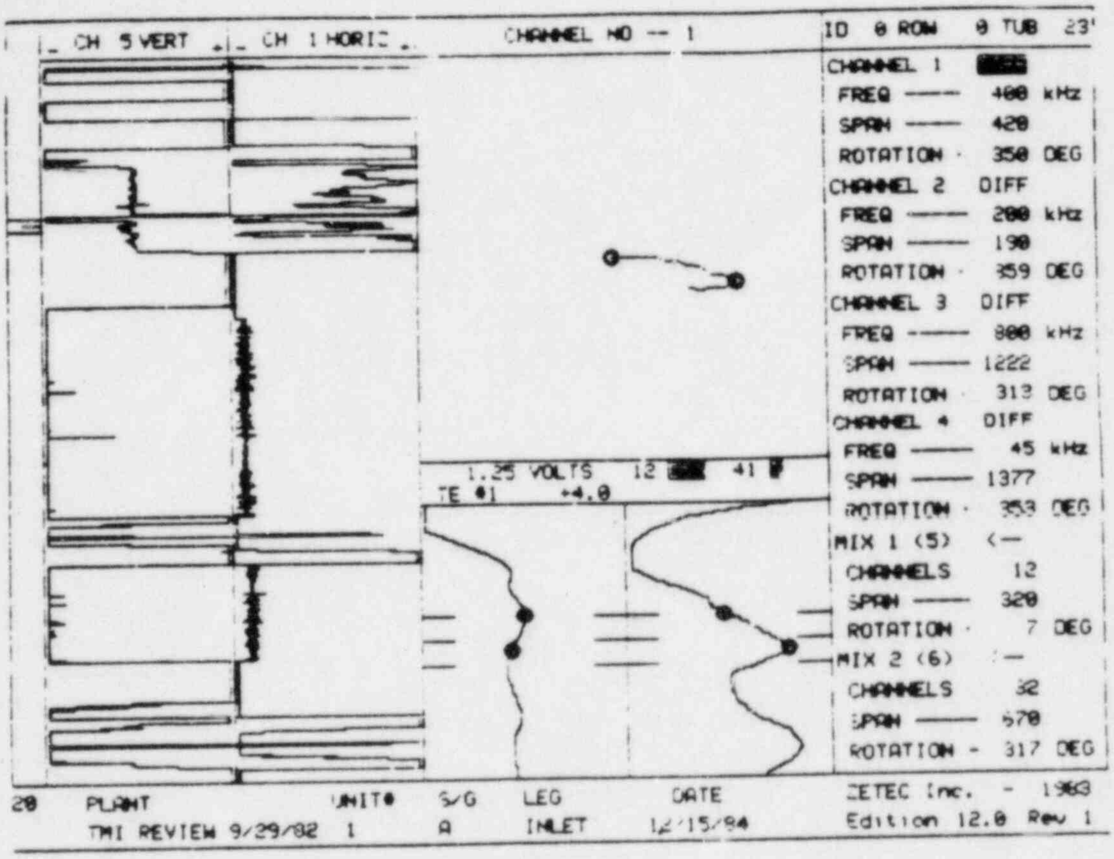
Obs	Tube Number	Location From Top (inches)	Metallurgical Depth	Eddy Current Depth (Normalized)	Eddy Current Phase Angle
			Laboratory Induced IGSAC		
1	Sample 23	4.0	38%	41%	22°
2	Sample 24	4.8	54%	51%	25°
			OTSG Pulled Tubes		
3	A-112-7	10.7	66%	68%	30°
4	A-146-8	4.0	70%	82%	34°
5	A-24-94	12.8	70%	100%	39°
6	A-24-94	34.0	100%	100%*	46°
7	A-133-74	32.0	100%	90%	37°
8	A-133-74	33.0	100%	100%*	51°
9	A-11-66	11.6	100%	100%*	44° (mix)
10	A-146-6	8.5	100%	100%*	62°
11	A-13-63	26.8	100%	100%*	58°
12	A-10-29	7.6	100%	93%	38°

Data from TDR 686

Obs	Tube Number	Location From Top (inches)	Metallurgical Depth	Eddy Current Depth	Eddy Current Phase Angle (Normalized)
13	A-111-13	1.2	20%	23%	17°
14	A-112-05	1.4	100%	100%*	53°
15	A-112-05	2.4	100%	100%*	68°
16	A-112-05	2.9	100%	100%*	[illegible]
17	A-112-05	4.1	100%	100%*	58°
18	A-112-05	5.8	100%	100%*	[illegible]

* The measured phase angles identify these signals as being outer diameter 83 to 97% through wall discontinuities. GPUN administratively considers indications greater than 80% through wall, inner diameter or outer diameter, to be at or near 100% through wall.

Figure C-2



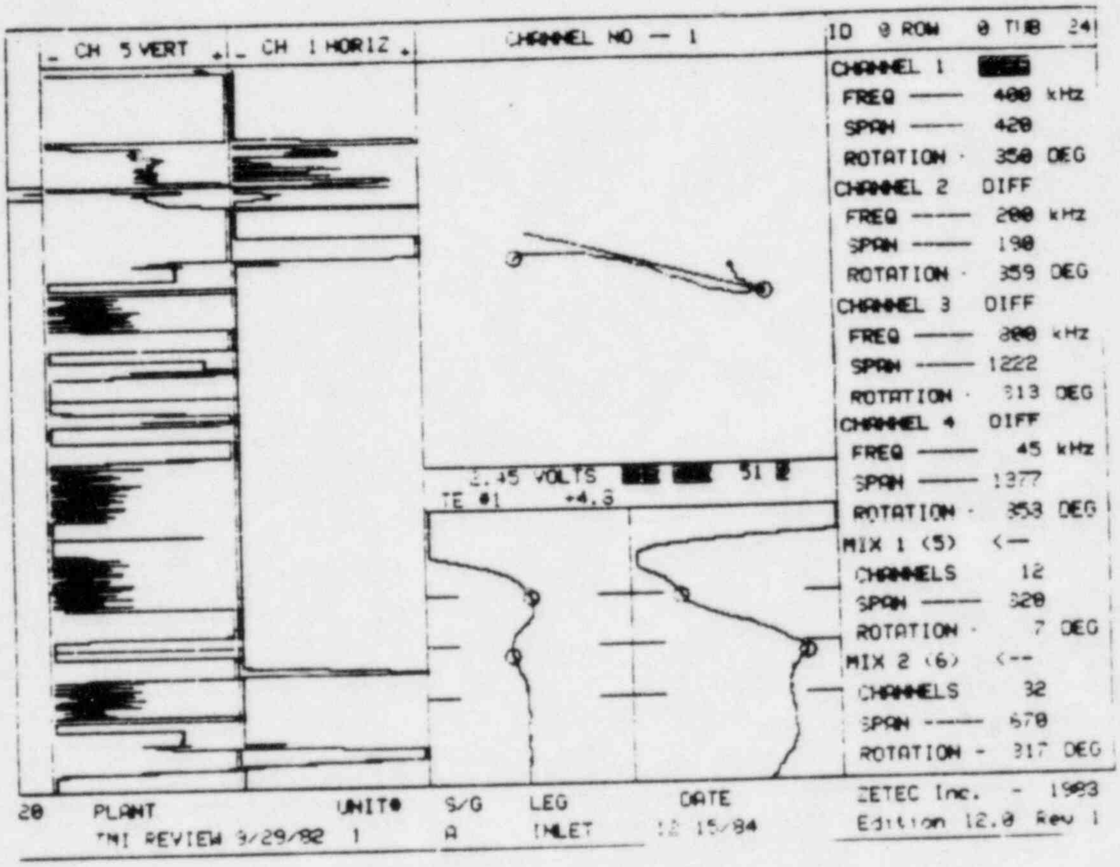
```
| _ CH 5 VERT .|_ CH 1 HORIZ .     CHANNEL NO -- 1          ID 0 ROW   0 TUB  23'
                                                          CHANNEL 1
                                                           FREQ ----    400 kHz
                                                           SPAN ----    420
                                                           ROTATION ·   350 DEG
                                                          CHANNEL 2   DIFF
                                                           FREQ ----    200 kHz
                                                           SPAN ----    190
                                                           ROTATION ·   359 DEG
                                                          CHANNEL 3   DIFF
                                                           FREQ ----    800 kHz
                                                           SPAN ----   1222
                                                           ROTATION ·   313 DEG
                                                          CHANNEL 4   DIFF
                                   1.25 VOLTS   12    41   FREQ ----     45 kHz
                                  TE #1     +4.0           SPAN ----   1377
                                                           ROTATION ·   353 DEG
                                                          MIX 1 (5)   <-
                                                           CHANNELS      12
                                                           SPAN ----    320
                                                           ROTATION ·     7 DEG
                                                          MIX 2 (6)   <-
                                                           CHANNELS      32
                                                           SPAN ----    570
                                                           ROTATION -   317 DEG
20   PLANT                 UNIT#   S/G   LEG     DATE       ZETEC Inc. - 1983
     TMI REVIEW 9/29/82    1       A     INLET   12/15/84   Edition 12.0 Rev 1
```

Sample 23 - Location 4.0

Eddy Current Signal Analysis

41% Through Wall (ID) 1.25 Volts

Figure C-3



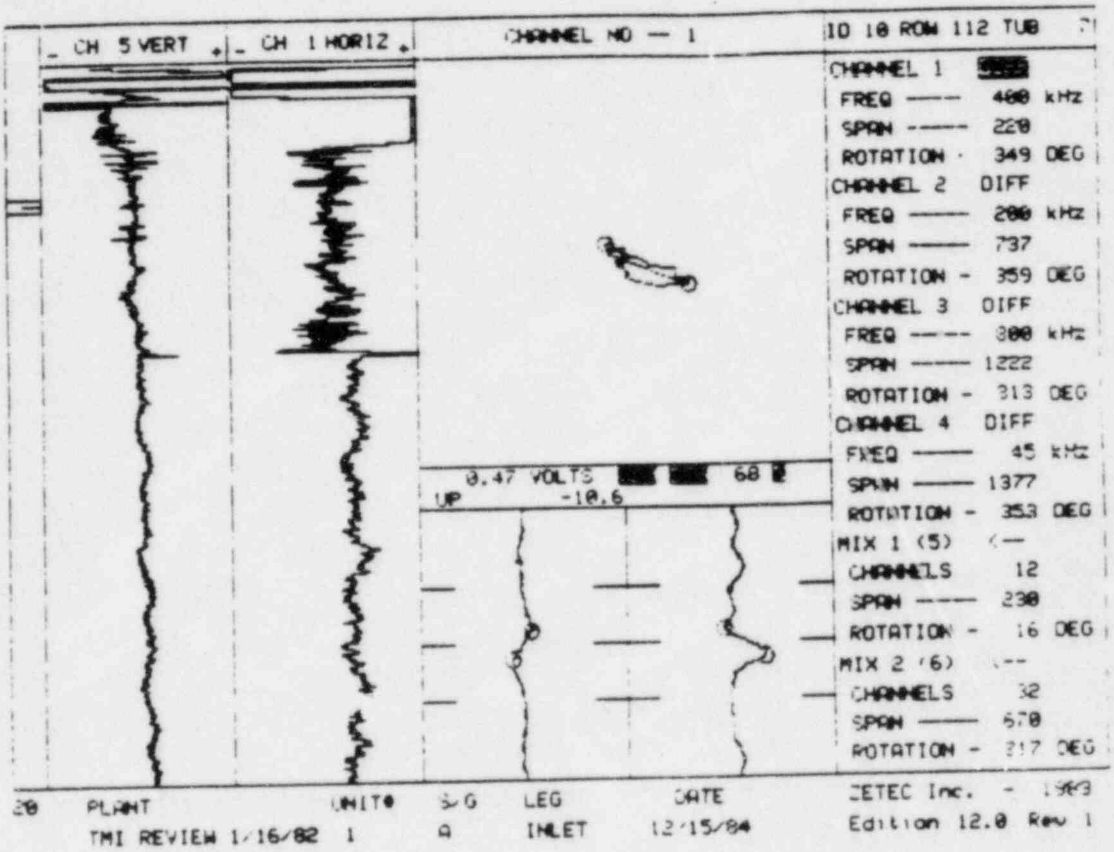
```
ID  0 ROW    0 TUB  24
CHANNEL 1
 FREQ ———      400 kHz
 SPAN ———      420
 ROTATION ·    350 DEG
CHANNEL 2   DIFF
 FREQ ————     200 kHz
 SPAN ————     190
 ROTATION ·    359 DEG
CHANNEL 3   DIFF
 FREQ ————     800 kHz
 SPAN ———— 1222
 ROTATION ·    313 DEG
CHANNEL 4   DIFF
 FREQ ————      45 kHz
 SPAN ———— 1377
 ROTATION ·    353 DEG
MIX 1 (5)   <—
 CHANNELS       12
 SPAN ————     320
 ROTATION ·      7 DEG
MIX 2 (6)   <--
 CHANNELS       32
 SPAN ————     670
 ROTATION -    317 DEG

20  PLANT                UNIT#  S/G  LEG    DATE
    TMI REVIEW 9/29/82   1      A    INLET  12 15/84

ZETEC Inc.  -  1983
Edition 12.0  Rev 1
```

Sample 24 - Location 4.8

Eddy Current Signal Analysis

51% Through wall (ID) 2.45 Volts

Figure C-4



```
10 10 ROW 112 TUB
CHANNEL 1
 FREQ ----    400 kHz
 SPAN -----   220
 ROTATION ·   349 DEG
CHANNEL 2   DIFF
 FREQ -----   200 kHz
 SPAN -----   737
 ROTATION -   359 DEG
CHANNEL 3   DIFF
 FREQ ----    300 kHz
 SPAN ----- 1222
 ROTATION -   313 DEG
CHANNEL 4   DIFF
 FREQ -----    45 kHz
 SPAN ----- 1377
 ROTATION -   353 DEG
MIX 1 (5)   <—
 CHANNELS      12
 SPAN ----    230
 ROTATION -    16 DEG
MIX 2 (6)   <--
 CHANNELS      32
 SPAN -----   670
 ROTATION -   317 DEG

20  PLANT               UNIT#  S/G  LEG    DATE       ZETEC Inc. - 1983
    TMI REVIEW 1/16/82  1      A    INLET  12/15/84   Edition 12.0 Rev 1
```

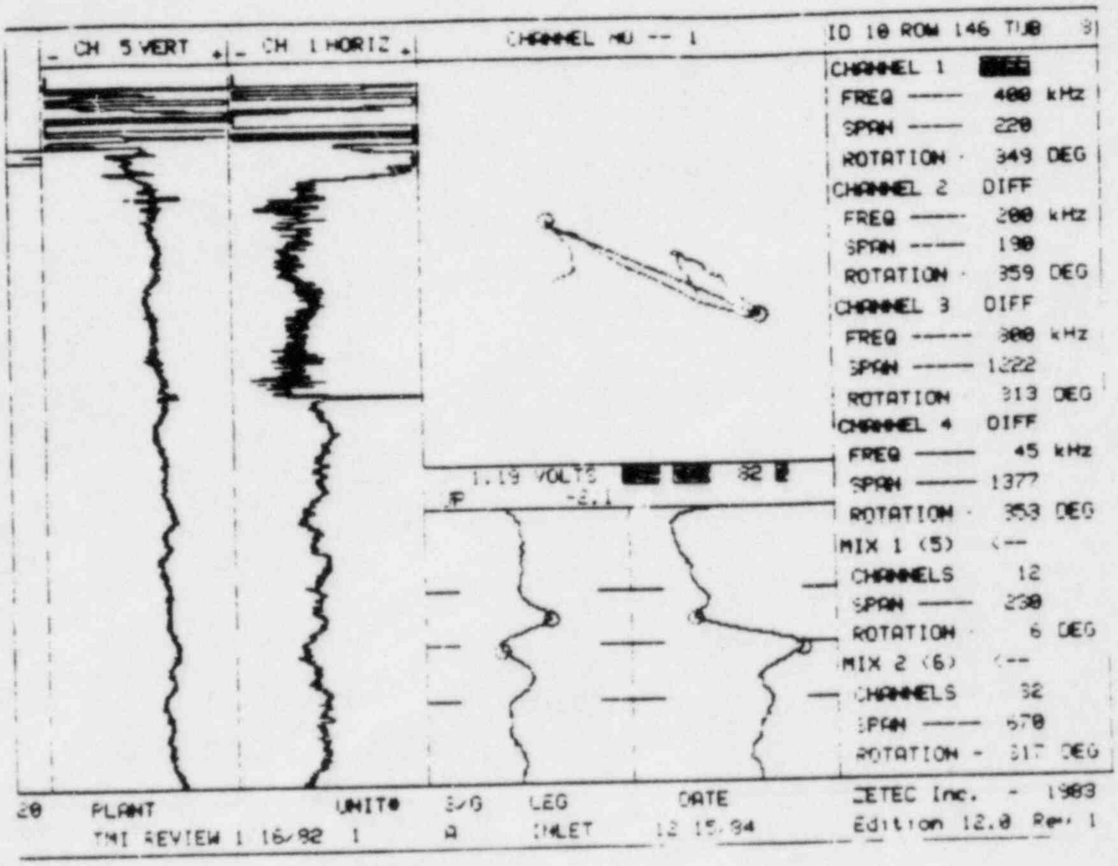
Tube A-112-7 - Location 10.6

Eddy Current Location: UP-10.7 - This area correlates to 10.6 identified in TDR 423

Eddy Current Signal Analysis

68% Through Wall (ID) .47 Volts

Figure C-5



```
ID 10 ROW 146 TUB    8
CHANNEL 1
 FREQ ----     400 kHz
 SPAN ----     220
 ROTATION ·    349 DEG
CHANNEL 2   DIFF
 FREQ ----     200 kHz
 SPAN ----     190
 ROTATION ·    359 DEG
CHANNEL 3   DIFF
 FREQ -----    300 kHz
 SPAN -----   1222
 ROTATION      313 DEG
CHANNEL 4   DIFF
 FREQ ----      45 kHz
 SPAN -----   1377
 ROTATION ·    353 DEG
MIX 1 (5)   <--
 CHANNELS       12
 SPAN ----     230
 ROTATION        6 DEG
MIX 2 (6)   <--
 CHANNELS       32
 SPAN ----     570
 ROTATION -    317 DEG

20  PLANT                  UNIT#  S/G  LEG    DATE       ZETEC Inc.  -  1983
    TMI REVIEW 1 16/82     1      A    INLET  12 15 84   Edition 12.0 Rev 1
```

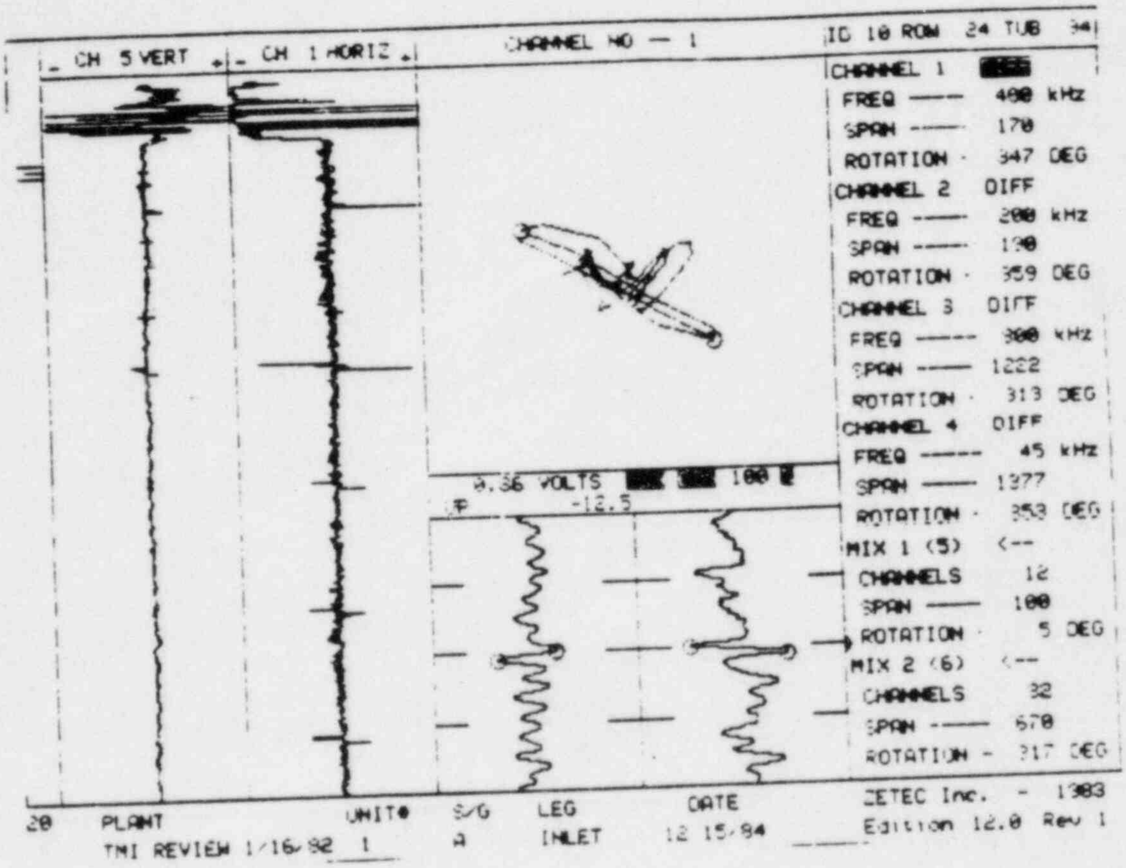
Tube Number : A-146-8 (4.0)

Eddy Current Location: UP-2.1 - This area correlates to 4.0 identified in TDR 403

Eddy Current Signal Analysis

82% Through wall (ID) 1.19 Volts

Figure C-6



```
ID 10 ROW 24 TUB 94
CHANNEL 1
 FREQ ----  400 kHz
 SPAN -----  170
 ROTATION ·  347 DEG
CHANNEL 2   DIFF
 FREQ -----  200 kHz
 SPAN -----  130
 ROTATION ·  359 DEG
CHANNEL 3   DIFF
 FREQ -----  300 kHz
 SPAN ----- 1222
 ROTATION ·  313 DEG
CHANNEL 4   DIFF
 FREQ -----   45 kHz
 SPAN ----- 1377
 ROTATION ·  353 DEG
MIX 1 (5)   <--
 CHANNELS     12
 SPAN -----  100
 ROTATION ·    5 DEG
MIX 2 (6)   <--
 CHANNELS     32
 SPAN -----  670
 ROTATION -  317 DEG
ZETEC Inc.  -  1983
Edition 12.0  Rev 1

20  PLANT                 UNIT#  S/G  LEG    DATE
    TMI REVIEW 1/16/82    1      A    INLET  12 15/84
```

Tube Number: A-24-94 (12.8)

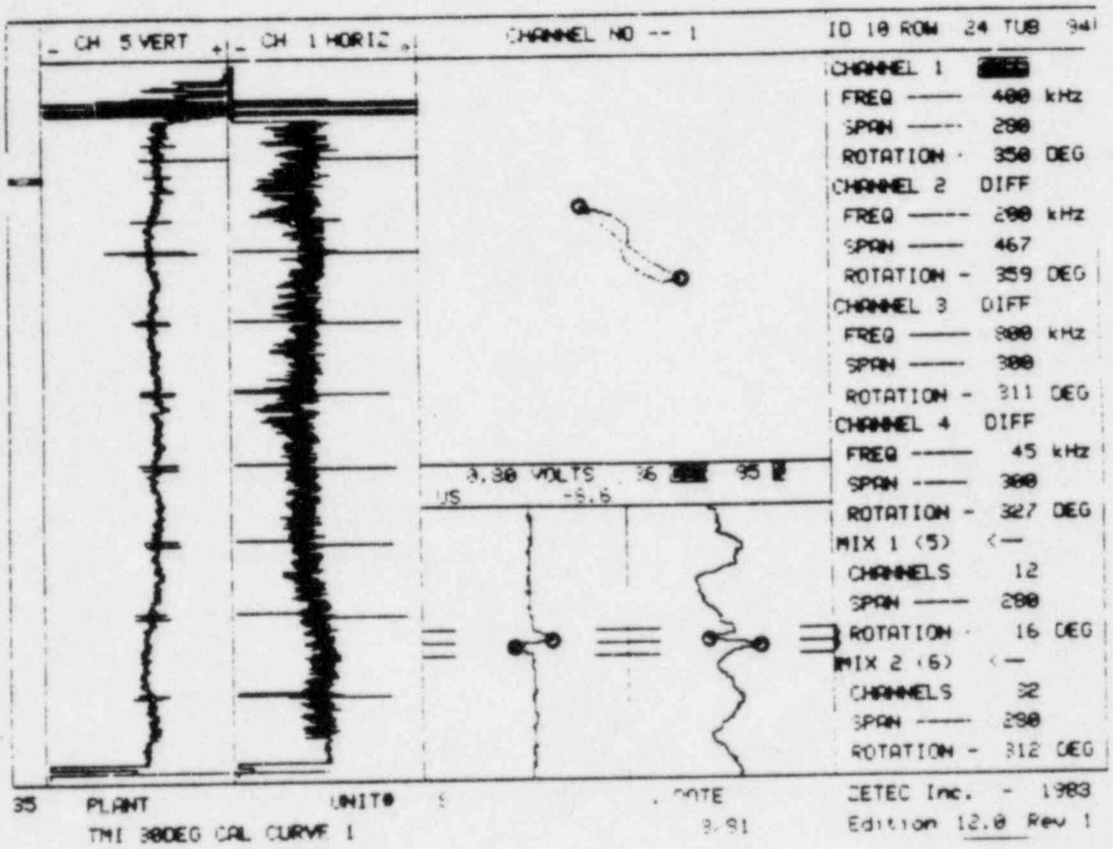
Flaw Location: UP-12.5 - This area correlates to 12.8

identified in TDR 423

Eddy Current Signal Analysis

100% Through Wall .36 Volts

Figure C-7



ID 10 ROW 24 TUB 94

CHANNEL 1
FREQ —— 400 kHz
SPAN —— 280
ROTATION - 350 DEG
CHANNEL 2 DIFF
FREQ —— 200 kHz
SPAN —— 467
ROTATION - 359 DEG
CHANNEL 3 DIFF
FREQ —— 800 kHz
SPAN —— 300
ROTATION - 311 DEG
CHANNEL 4 DIFF
FREQ —— 45 kHz
SPAN —— 300
ROTATION - 327 DEG
MIX 1 (5) <—
CHANNELS 12
SPAN —— 280
ROTATION - 16 DEG
MIX 2 (6) <—
CHANNELS 32
SPAN —— 290
ROTATION - 312 DEG

35 PLANT UNIT# DATE
TMI 300DEG CAL CURVE 1 9/91

CETEC Inc. - 1983
Edition 12.0 Rev 1

Tube Number: A-24-94 (34.0)

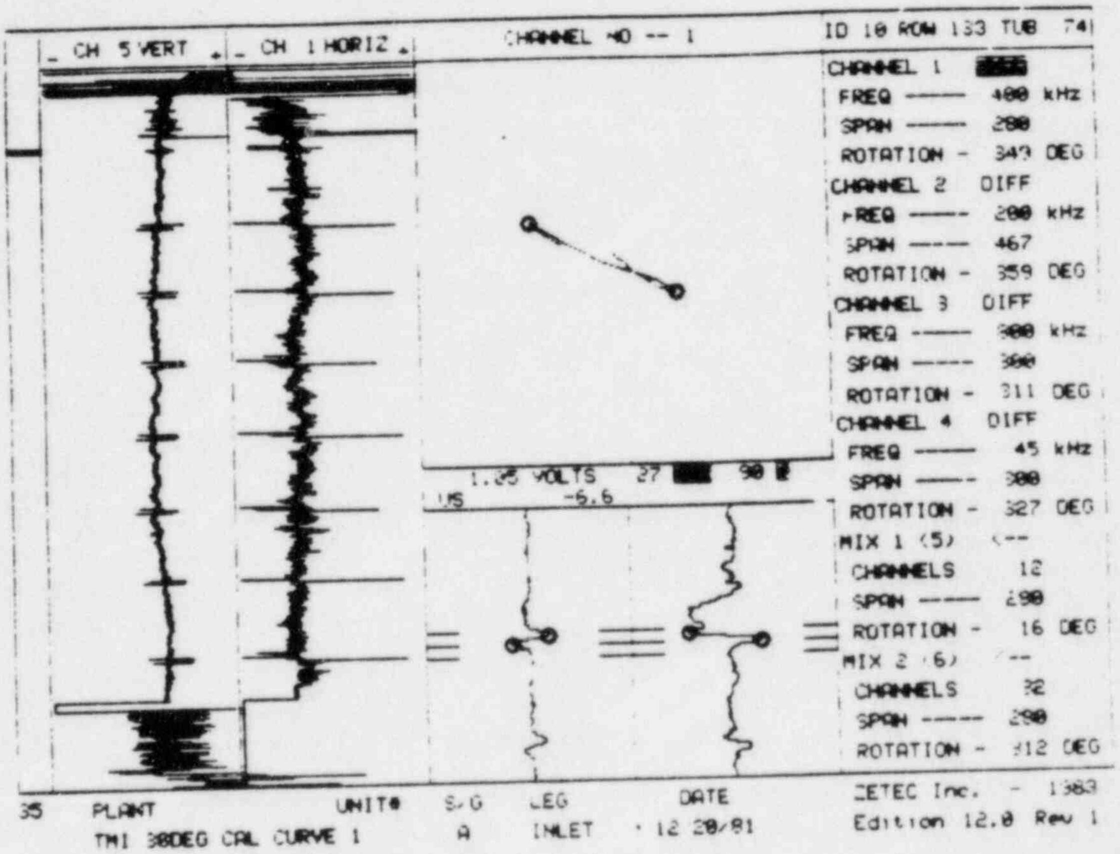
Flaw Location: US-8.6 - This area correlates to 34.0

Identified in TDR [illegible]

Eddy Current Signal Analysis

95% Through wall (OD) .80 Volts

Figure C-8



```
_ CH 5 VERT +|_ CH 1 HORIZ +     CHANNEL NO -- 1          ID 10 ROW 133 TUB 74
                                                          CHANNEL 1
                                                           FREQ ------ 400 kHz
                                                           SPAN ------ 200
                                                           ROTATION -  343 DEG
                                                          CHANNEL 2  DIFF
                                                           FREQ ------ 200 kHz
                                                           SPAN ----   467
                                                           ROTATION -  359 DEG
                                                          CHANNEL 3  DIFF
                                                           FREQ ------ 900 kHz
                                                           SPAN -----  300
                                                           ROTATION -  311 DEG
                                                          CHANNEL 4  DIFF
                                  1.05 VOLTS   27    90    FREQ ------  45 kHz
                                  US       -6.6            SPAN -----  300
                                                           ROTATION -  327 DEG
                                                           MIX 1 (5)  <--
                                                            CHANNELS    12
                                                            SPAN ----- 290
                                                            ROTATION -  16 DEG
                                                           MIX 2 (6)  <--
                                                            CHANNELS    32
                                                            SPAN ----- 290
                                                            ROTATION - 312 DEG
35  PLANT                   UNIT#  S/G   LEG      DATE     CETEC Inc.  -  1983
    TMI 30DEG CAL CURVE 1          A     INLET  · 12 20/81  Edition 12.0  Rev 1
```

Tube Number: A-133-74 (32.0)

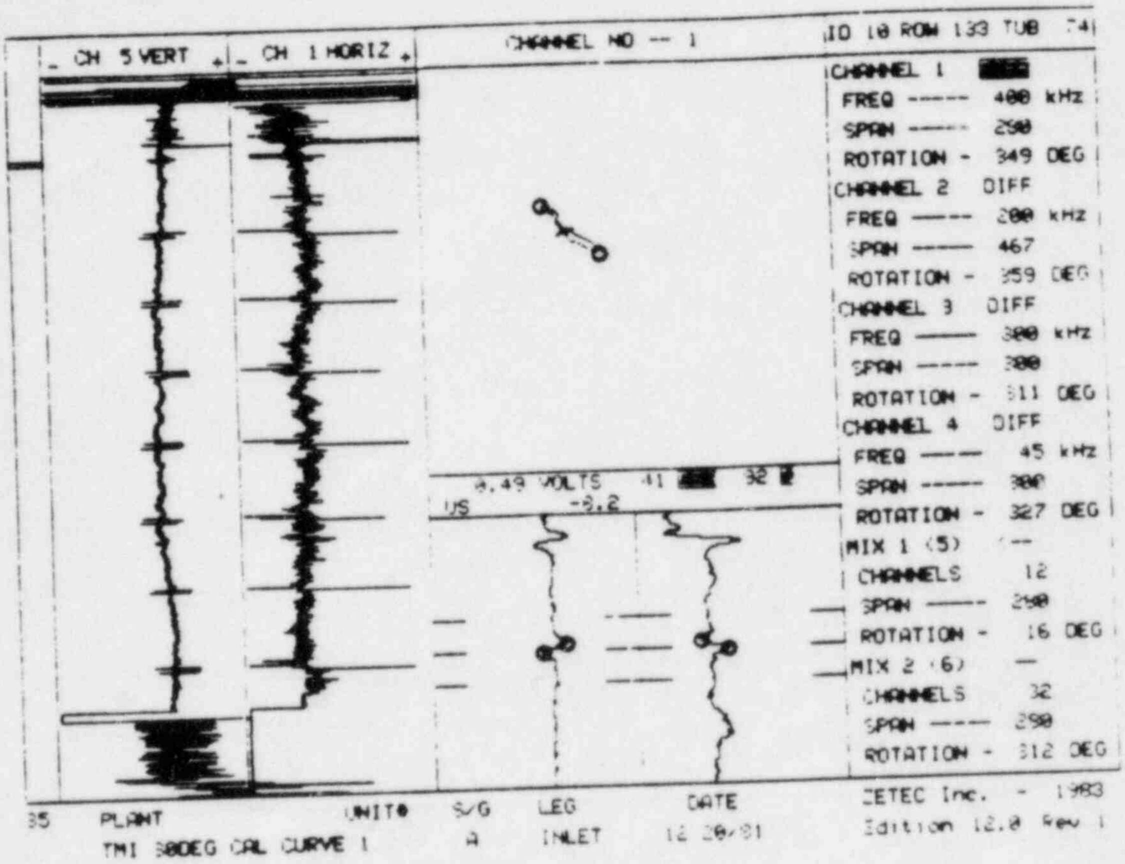
Flaw Location: US-6.6 - This area correlates to 32.0

identified in TDR 423

Eddy Current Signal Analysis

90% Through wall (ID) 1.05 Volts

Figure C-9



```
_ CH 5 VERT +|_ CH 1 HORIZ +     CHANNEL NO -- 1         ID 10 ROW 133 TUB  74
                                                         CHANNEL 1   [illegible]
                                                          FREQ ------  400 kHz
                                                          SPAN ------  290
                                                          ROTATION -  349 DEG
                                                         CHANNEL 2   DIFF
                                                          FREQ ----   200 kHz
                                                          SPAN -----  467
                                                          ROTATION -  359 DEG
                                                         CHANNEL 3   DIFF
                                                          FREQ -----  300 kHz
                                                          SPAN -----  300
                                                          ROTATION -  311 DEG
                                                         CHANNEL 4   DIFF
                                                          FREQ ---     45 kHz
                                  0.49 VOLTS   41 [illegible]  32 [illegible]     SPAN -----  300
                                 US      -8.2             ROTATION -  327 DEG
                                                         MIX 1 (5)    --
                                                          CHANNELS     12
                                                          SPAN -----  290
                                                          ROTATION -   16 DEG
                                                         MIX 2 (6)    --
                                                          CHANNELS     32
                                                          SPAN ----   290
                                                          ROTATION -  312 DEG
35   PLANT                UNIT#   S/G   LEG      DATE       ZETEC Inc.  -  1983
     TMI 380DEG CAL CURVE 1       A     INLET    12 20/81   Edition 12.0 Rev 1
```

Tube Number: A-133-74 (33.0)

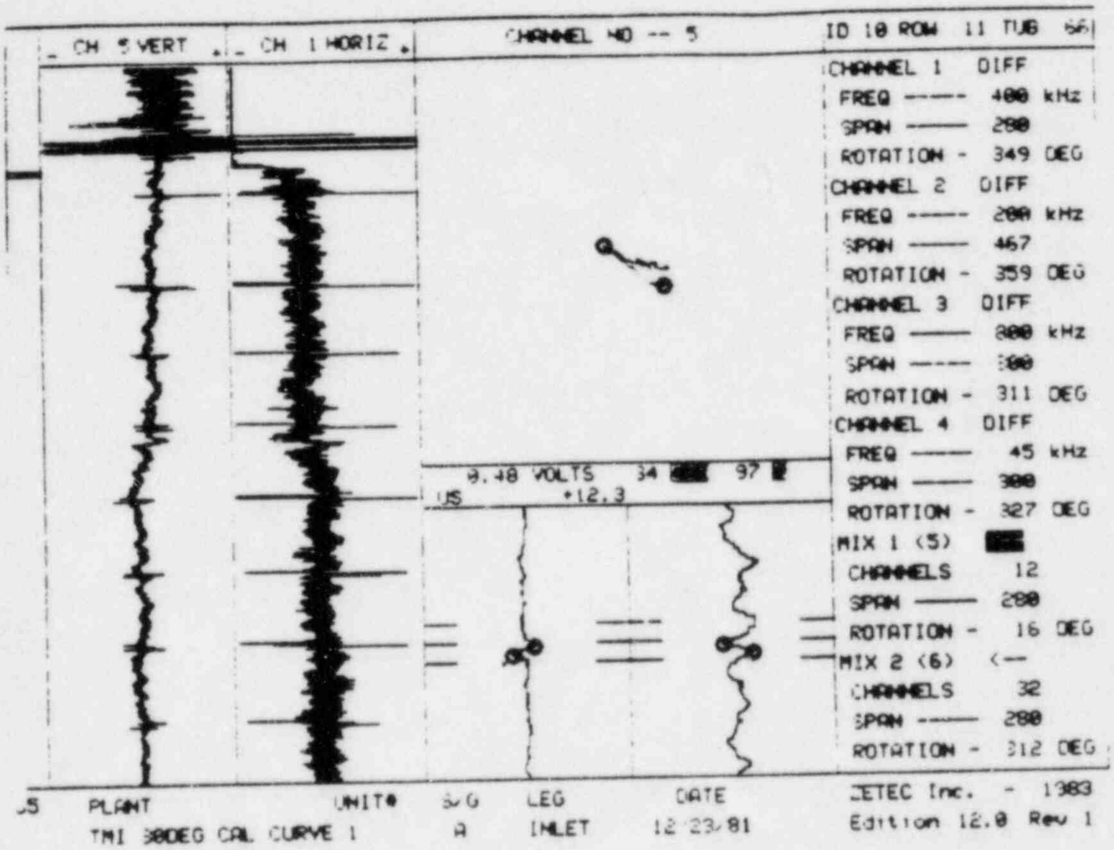
Flaw Location: US-8.2 - This area correlates to 33.0

identified in TDR 423

Eddy Current Signal Analysis

92% Through Wall (OD) .49 Volts

Figure C-10



```
_ CH 5 VERT  + _ CH 1 HORIZ +     CHANNEL NO -- 5        ID 10 ROW  11 TUB  66
                                                         CHANNEL 1   DIFF
                                                          FREQ -----  400 kHz
                                                          SPAN ------ 280
                                                          ROTATION -  349 DEG
                                                         CHANNEL 2   DIFF
                                                          FREQ -----  200 kHz
                                                          SPAN ------ 467
                                                          ROTATION -  359 DEG
                                                         CHANNEL 3   DIFF
                                                          FREQ ------ 800 kHz
                                                          SPAN -----  300
                                                          ROTATION -  311 DEG
                                                         CHANNEL 4   DIFF
                                                          FREQ ------  45 kHz
                                   0.48 VOLTS   34    97  SPAN ------ 300
                                  US      +12.3           ROTATION -  327 DEG
                                                         MIX 1 (5)
                                                          CHANNELS     12
                                                          SPAN ------ 280
                                                          ROTATION -   16 DEG
                                                         MIX 2 (6)   <--
                                                          CHANNELS     32
                                                          SPAN ------ 280
                                                          ROTATION -  312 DEG
.5  PLANT                  UNIT#   S/G   LEG     DATE    ZETEC Inc.  -  1983
    TMI 300EG CAL CURVE 1           A    INLET   12/23/81  Edition 12.0  Rev 1
```

Tube Number: A-11-66 (11.6)

Flaw Location: US+12.3 - This area correlates to 11.6

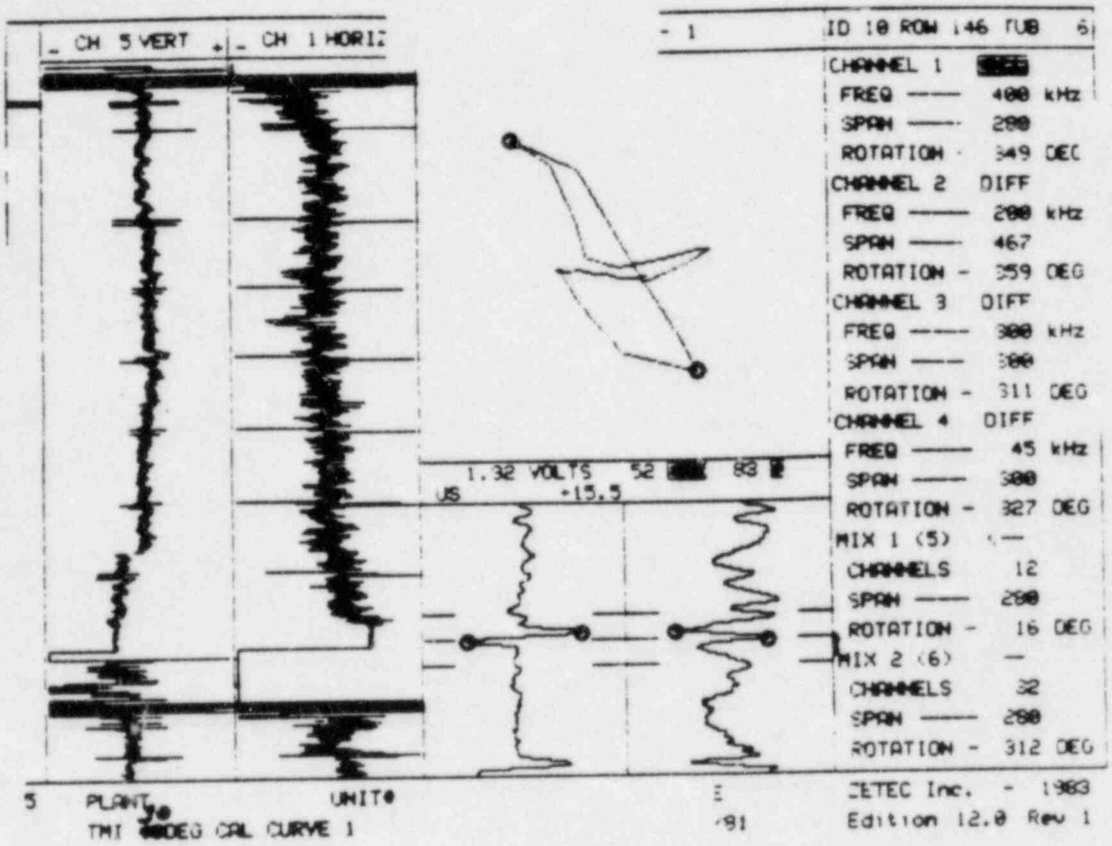
identified in TDR 423

Eddy Current Signal Analysis

97% Through Wall (OD) .48 Volts

NOTE: This indication was being influenced by interfering signals within the tube sheet, there the evaluation was supplemented using the upper mix.

Figure C-11



ID 10 ROW 146 TUB 6

CHANNEL 1 [illegible]
FREQ ---- 400 kHz
SPAN ---- 200
ROTATION - 349 DEG
CHANNEL 2 DIFF
FREQ ---- 200 kHz
SPAN ---- 467
ROTATION - 359 DEG
CHANNEL 3 DIFF
FREQ ---- 300 kHz
SPAN ---- 300
ROTATION - 311 DEG
CHANNEL 4 DIFF
FREQ ---- 45 kHz
SPAN ---- 300
ROTATION - 327 DEG
MIX 1 (5) —
CHANNELS 12
SPAN ---- 200
ROTATION - 16 DEG
MIX 2 (6) —
CHANNELS 32
SPAN ---- 200
ROTATION - 312 DEG

ZETEC Inc. - 1983
Edition 12.0 Rev 1

Tube Number: A-146-6 (8.5)

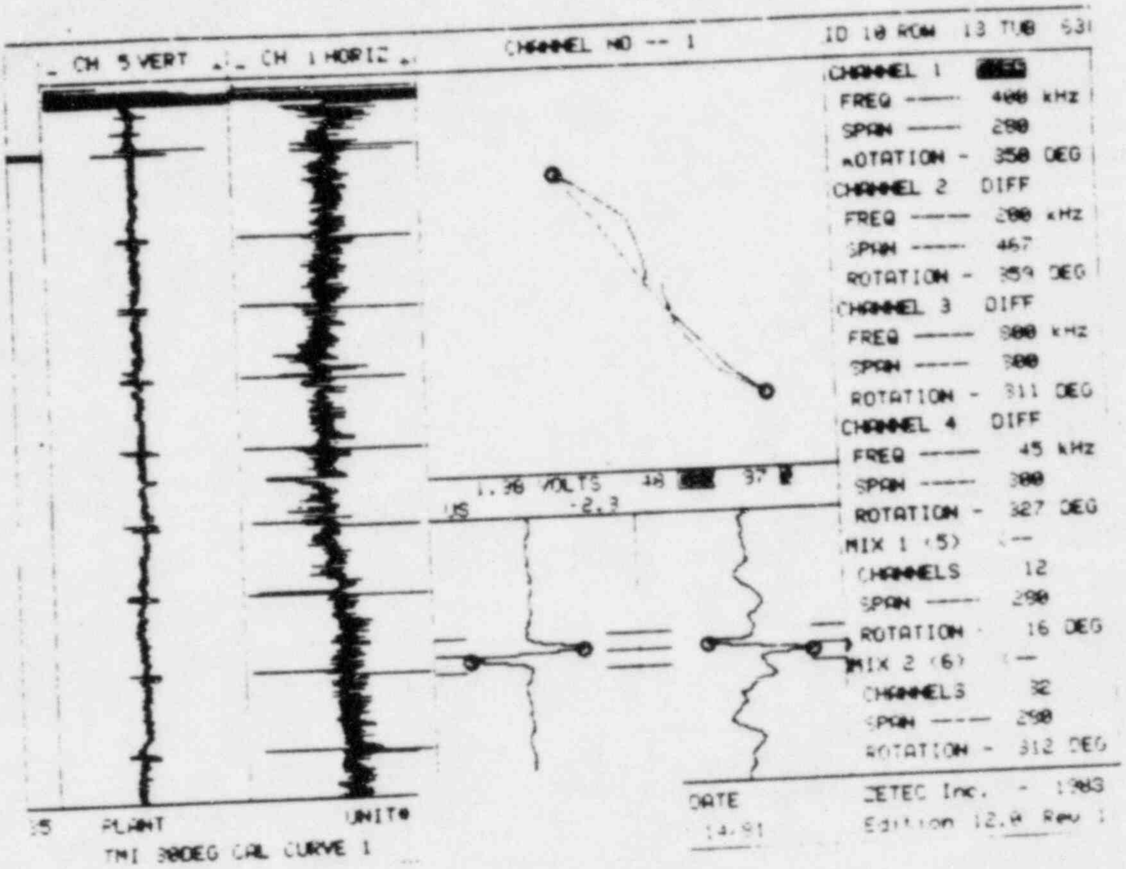
Flaw Location: US+15.5 - This area correlates to 8.5

identified in TDR 423

Eddy Current Signal Analysis

83% Through Wall (OD) 1.32 Volts

Figure C-12



```
ID 10 ROW  13 TUB  631
CHANNEL 1
 FREQ -----    400 kHz
 SPAN -----    290
 ROTATION -    350 DEG
CHANNEL 2   DIFF
 FREQ -----    200 kHz
 SPAN -----    467
 ROTATION -    359 DEG
CHANNEL 3   DIFF
 FREQ -----    900 kHz
 SPAN -----    300
 ROTATION -    311 DEG
CHANNEL 4   DIFF
 FREQ -----     45 kHz
 SPAN -----    300
 ROTATION -    327 DEG
MIX 1 (5)   <--
 CHANNELS       12
 SPAN -----    290
 ROTATION -     16 DEG
MIX 2 (6)   <--
 CHANNELS       32
 SPAN -----    290
 ROTATION -    312 DEG
ZETEC Inc.  -  1983
Edition 12.0 Rev 1
```

Tube Number: A-13-63 (26.3)

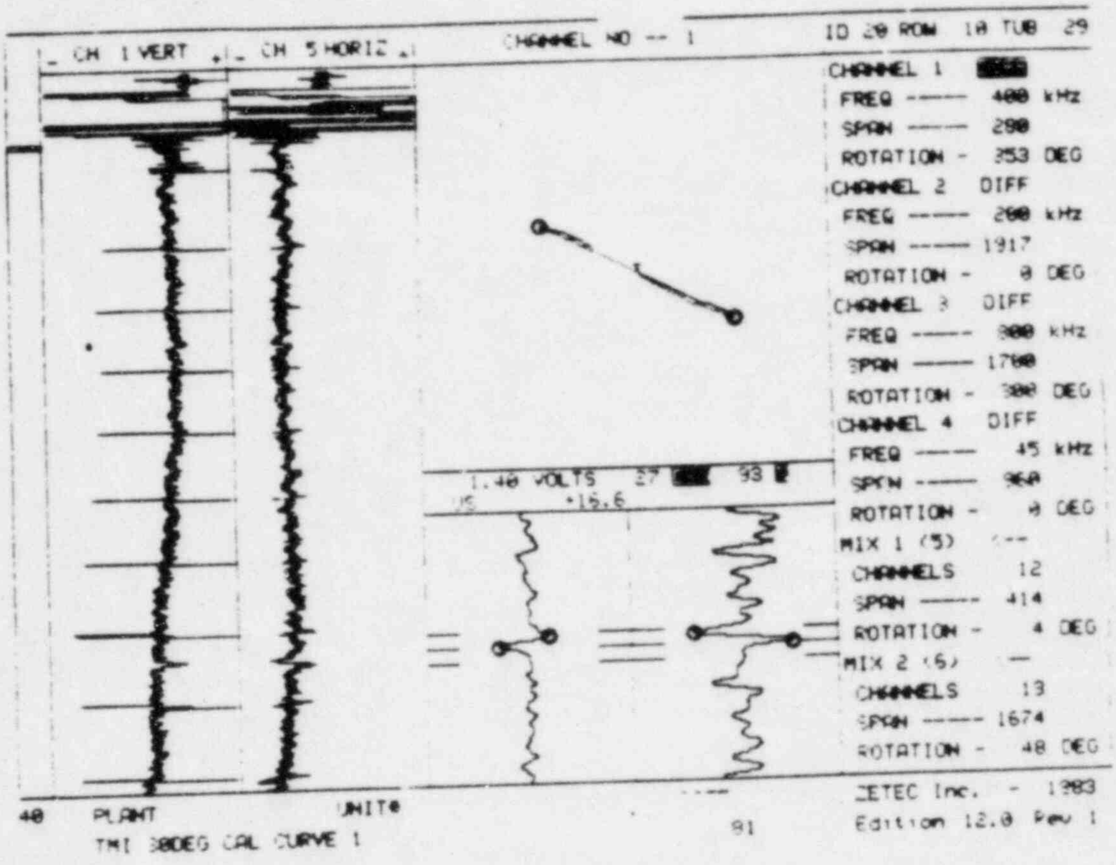
Flaw Location: US-2.3 - This area correlates to 26.8

identified in TDR 413

Eddy Current Signal Analysis

37% Through wall (OD) 1.38 volts

Figure C-13



ID 20 ROW 10 TUB 29

CHANNEL 1
FREQ ----- 400 kHz
SPAN ----- 290
ROTATION - 353 DEG
CHANNEL 2 DIFF
FREQ ----- 200 kHz
SPAN ----- 1917
ROTATION - 0 DEG
CHANNEL 3 DIFF
FREQ ----- 900 kHz
SPAN ----- 1700
ROTATION - 300 DEG
CHANNEL 4 DIFF
FREQ ----- 45 kHz
SPAN ----- 960
ROTATION - 0 DEG
MIX 1 (5) <--
CHANNELS 12
SPAN ----- 414
ROTATION - 4 DEG
MIX 2 (6) —
CHANNELS 13
SPAN ----- 1674
ROTATION - 48 DEG

Tube Number: A-10-29 (7.6)

Flaw Location: US+16.6 - This area correlates to 7.6

identified in TDR 403

Eddy Current Signal Analysis

93% Through Wall (ID) 1.40 Volts

APPENDIX D

METHOD OF DATA ANALYSIS

G. E. Rhedrick

Method of Data Analysis - Introduction

In performing Eddy Current Examinations on tubing similar to what is installed in the Three Mile Island Unit 1 Once Through Steam Generators (OTSGs) the analysis of the standard differential eddy current response signal indicates the magnitude of a flaw that may be present in the base material. The eddy current signal analysis is quantified by recording the signals amplitude in voltage and the phase angle measurement in degrees.

The voltage is related to the flaw's total volume and the phase angle is related to the flaw's penetration in the base material. It is the depth of the flaw that ultimately determines the disposition to remove steam generator tubing from operating service.

The Engineers at GPUN have recognized that the traditional formula used to determine the flaw's penetration, derived from the phase angle measurement, consistently overcalls the depth of small volume inner diameter flaws. In order to understand the degree of overcall that has been reported during Eddy Current Examinations using the traditional phase angle to percent through wall conversion process, a control test was performed to correlate the actual values of small volume inner diameter flaws and the corresponding Eddy Current phase angles.

This data from EDM Notches was used to understand the true relationship between phase angle and percent through wall penetration for steam generator tubes and to modify the process that determines flaw depth during the standard differential Eddy Current Examinations on the TMI-1 OTSGs. This report discusses the method of data analysis that was used in the qualification of the modified conversion curve.

Data Sets

The data recorded for EDM notches, percent through walls and the corresponding phase angles, was collected in two data sets labelled B and C. These sets were run independent of each other while the control of the process for the two sets was identical. (See Table D-1)

The data recorded for the metallurgical samples was obtained by reanalyzing prior data and was labelled data set D.

A scattered plot showing the relationship between percent through wall and the standard differential phase angle was prepared from data in sets B and C.

The data values for the 100% through wall notches were eliminated from the plot because the notches were machined from the tube's outer diameter. The phase angle response from outer diameter machined notches was influenced by the resulting geometry and biased the data set.

By eliminating the 100% through wall notch data, the plots provided a graphical illustration of the function that relates inner diameter percent through walls at various depths to corresponding signal phase angles. The pattern of the scattered plots for set B and C formed a hyperbolic shape (See Figures D-1 & D-2)

Line of Best Fit

For each percent through wall less than 100% the average phase angle value was calculated. The method of least squares for a nonlinear relationship was applied in order to determine and plot the line of best fit to the data represented by the percent through wall vs average phase angle values.

The line of best fit served as a reference curve to the predicted values. The two lines of best fit for data set B and C exhibited close agreement in the equations that satisfy the lines

data set B $\quad y = 7.778 + .6442(x) + .034925(x)^2$

data set C $\quad y = 8.0516 + .72137(x) + .032784(x)^2$

A linear relationship was developed by virtue of the 40 degree, 100% through wall requirements on the upper bound and the 10 degree, eddy current probe motion as the lower bound. This linear function was compared to the reference curve for best fit in order to establish the degree of certainty of maintaining coverage. (See Figures D-1 & D-2.)

Correlation

To show the variant in the agreement between percent through wall determination made from the proposed linear line and the eddy current assigned percent through wall from the EDM notches, a correlation was established. For phase angle measurements recorded during the eddy current analysis of data sets B and C, the corresponding percent through wall from the linear line was determined. Shown in Table D-2, "phase" represents the measured phase angle from the inspection of EDM Notches from data sets B&C. "TW1" represents the corresponding percent through wall calculated from the GPUN conversion curve by using the measured phase angle. "TWB" and "TWC" represent the actutal percent through walls from data sets B and C, respectively. A plot of the GPUN conversion curve assigned through wall values vs the actual percent through wall is shown in Figures D-3 and D-4. The 45° line represents 100% correlation.

For GPUN to demonstrate the proposed conversion curve is conservative, the conversion curve must overcall the actual percent through wall values. The average overcall for indications 40% through wall or greater was 3.9 and 4.3 for data sets B and C respectively.

The above average values were determined by calculating the mean for the differences between the actual and GPUN conversion curve assigned values. (See Figures D-5 and D-6)

Note Because percent through walls less than 20 are considered nonrelevant indications during production examinations, the data for less than 20% was deleted.

FIGURE D-1

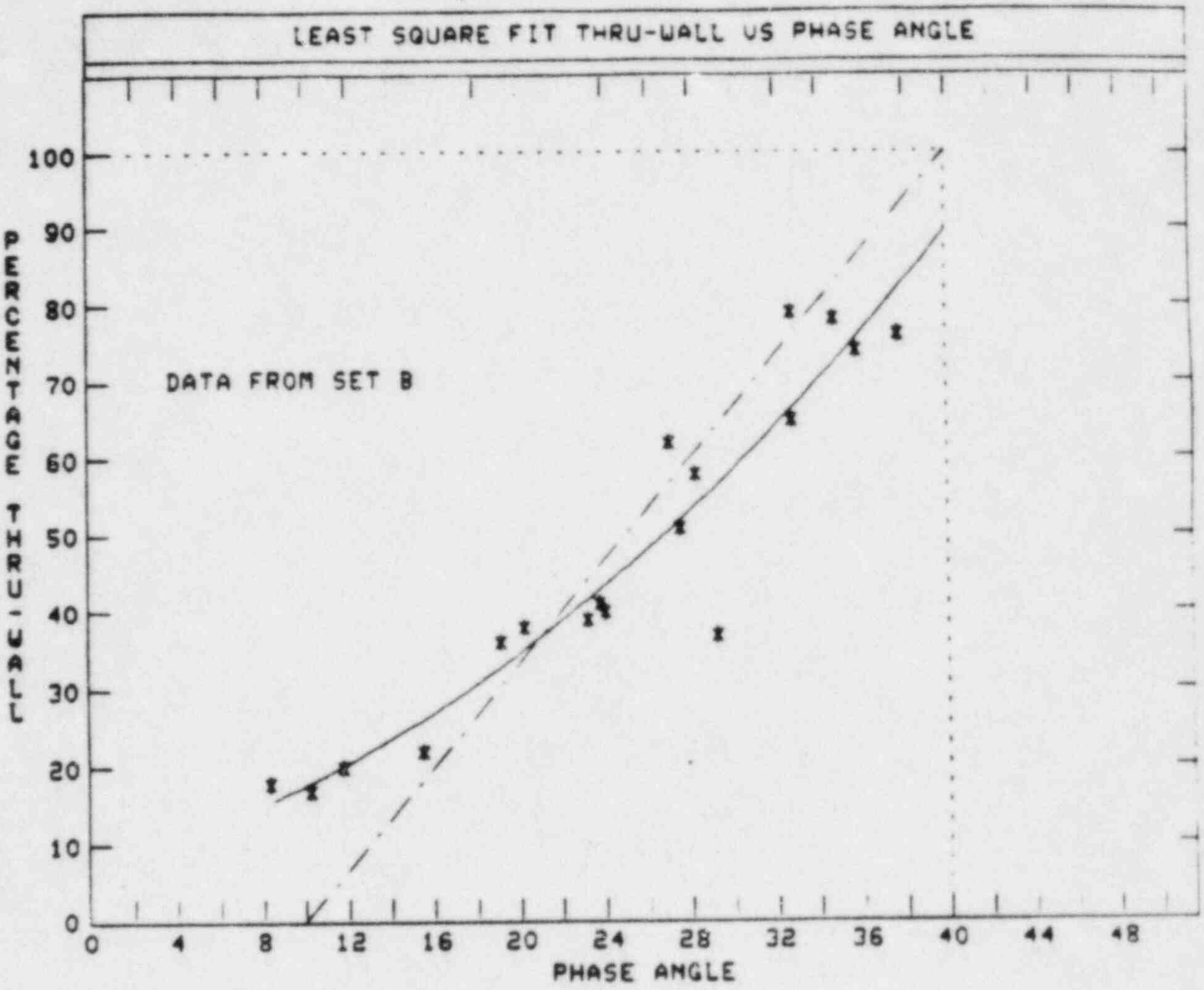

LEAST SQUARE FIT THRU-WALL VS PHASE ANGLE
PERCENTAGE THRU-WALL
0
10
20
30
40
50
60
70
80
90
100
DATA FROM SET B
0
4
8
12
16
20
24
28
32
36
40
44
48
PHASE ANGLE

FIGURE D-2

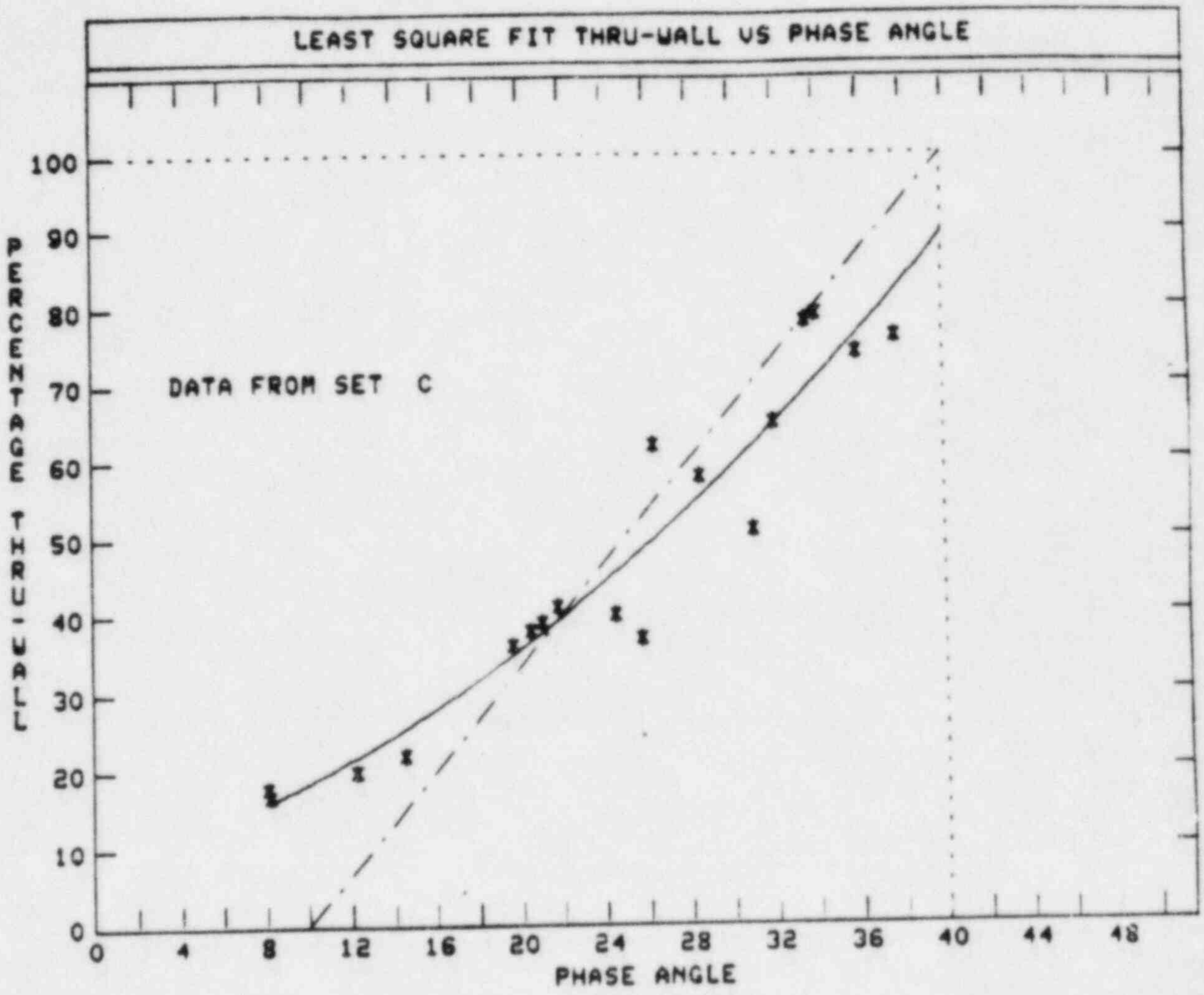

LEAST SQUARE FIT THRU-WALL VS PHASE ANGLE
PERCENTAGE THRU-WALL
100
90
80
70
60
50
40
30
20
10
0
DATA FROM SET C
0
4
8
12
16
20
24
28
32
36
40
44
48
PHASE ANGLE

FIGURE D-3

COMPARISON OF GPUN CURVE VS EDDY CURRENT RESULTS ON EDM NOTCH SAMPLES

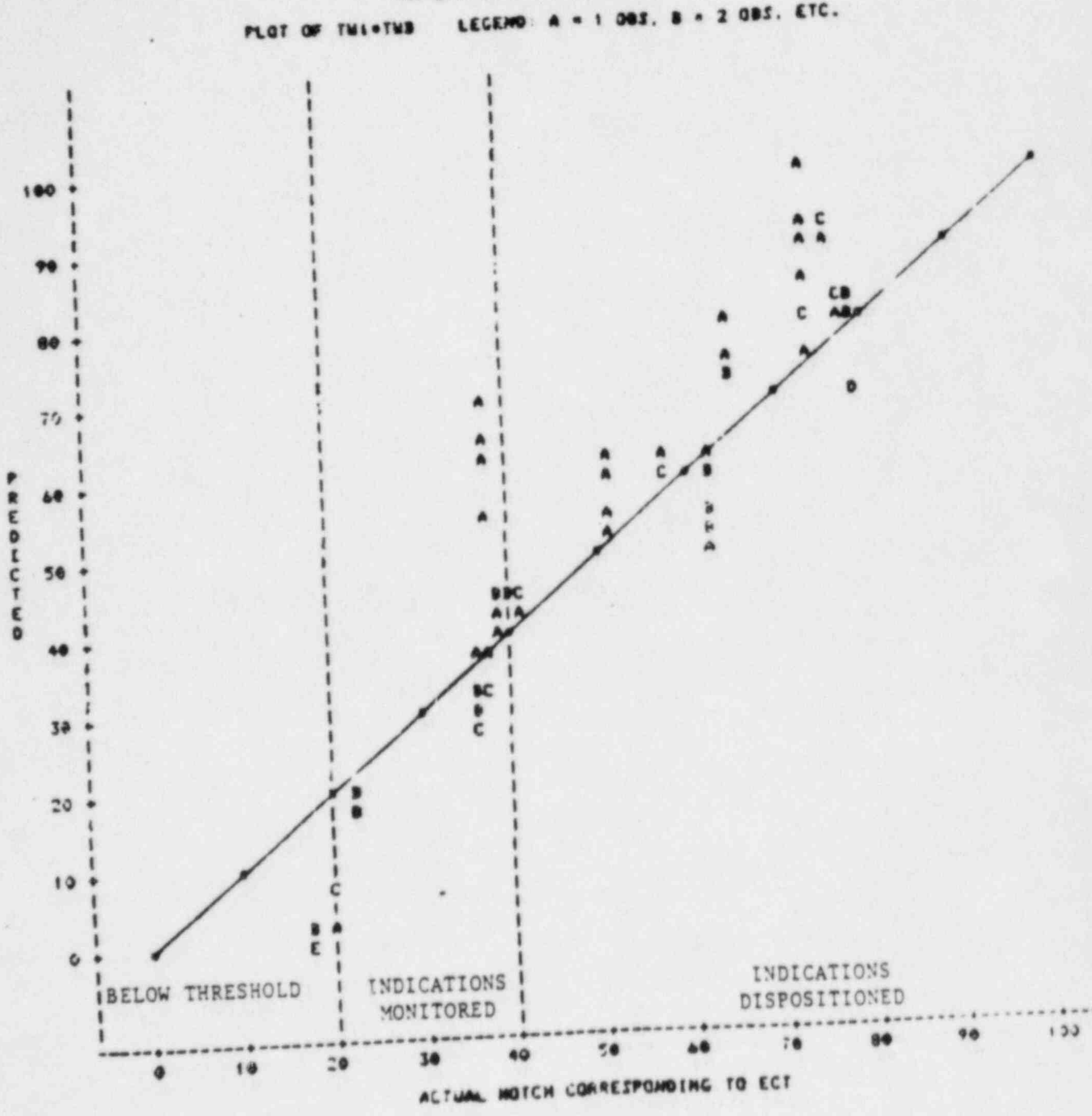


FIGURE D-4

COMPARISON OF GPUN CURVE VS EDDY CURRENT RESULTS
ON EDM NOTCH SAMPLES

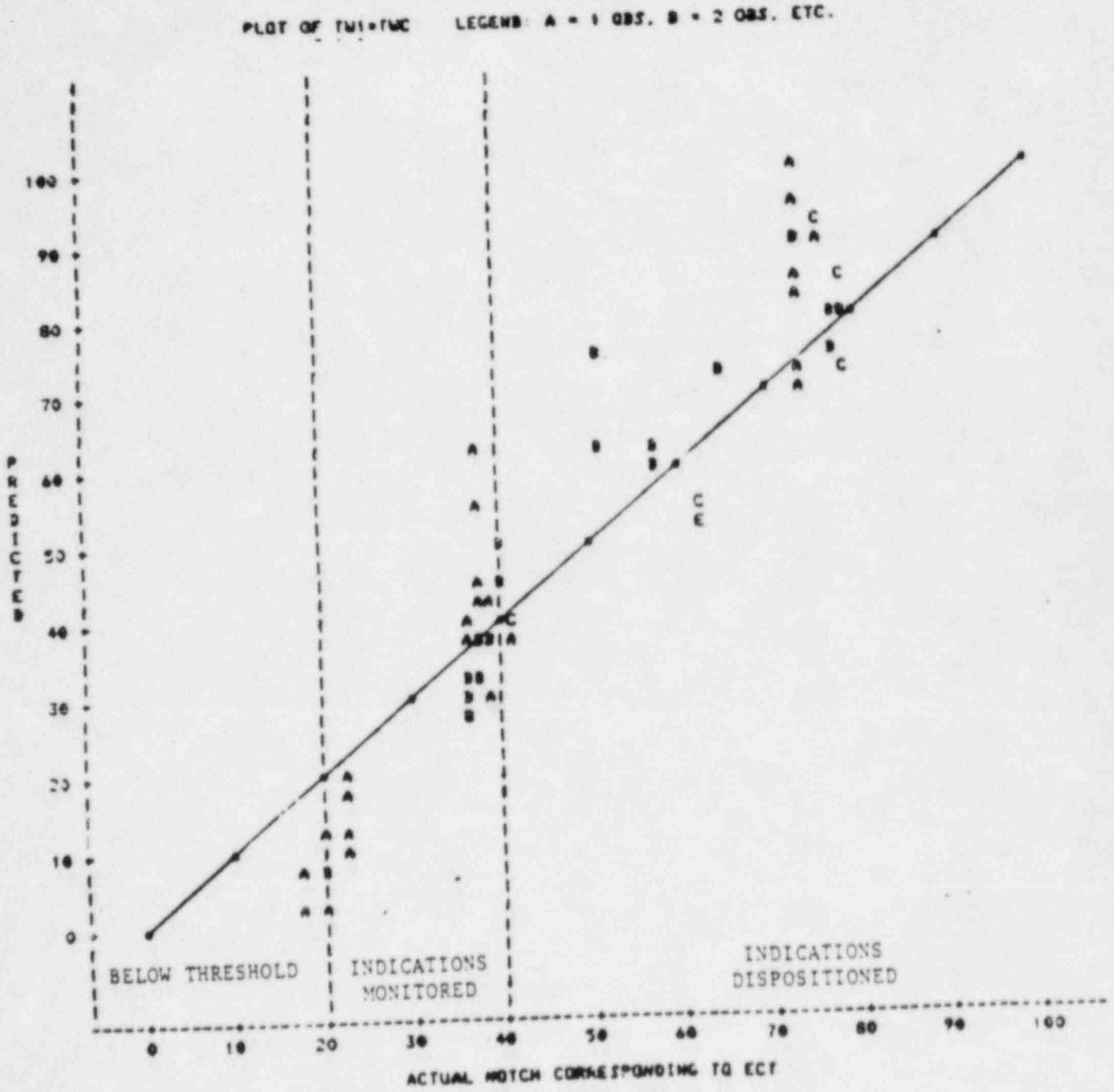


FIGURE D-5

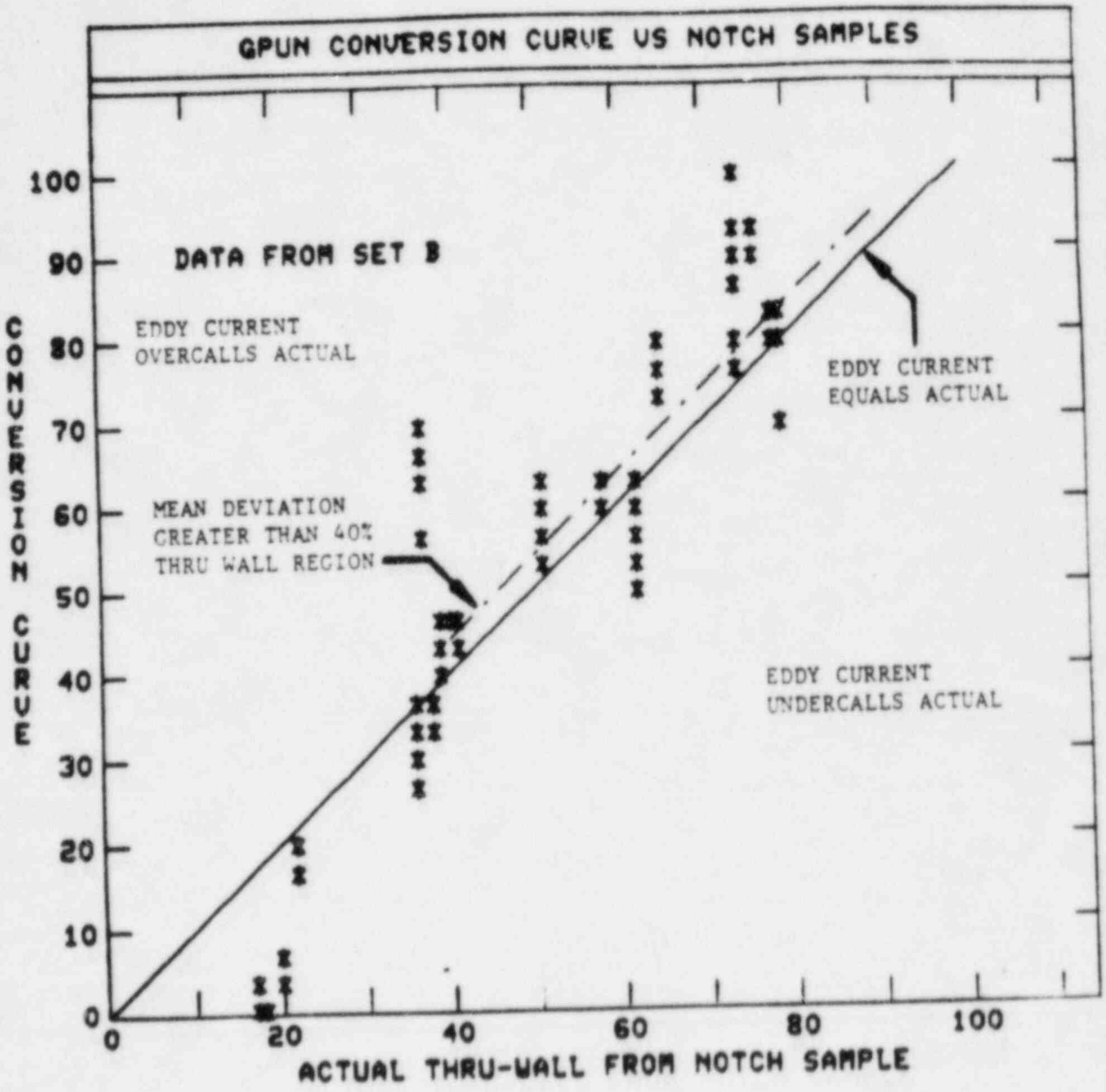

GPUN CONVERSION CURVE VS NOTCH SAMPLES
DATA FROM SET B
EDDY CURRENT
OVERCALLS ACTUAL
MEAN DEVIATION
GREATER THAN 40%
THRU WALL REGION
EDDY CURRENT
EQUALS ACTUAL
EDDY CURRENT
UNDERCALLS ACTUAL
CONVERSION CURVE
0
10
20
30
40
50
60
70
80
90
100
ACTUAL THRU-WALL FROM NOTCH SAMPLE
0
20
40
60
80
100

FIGURE D-6

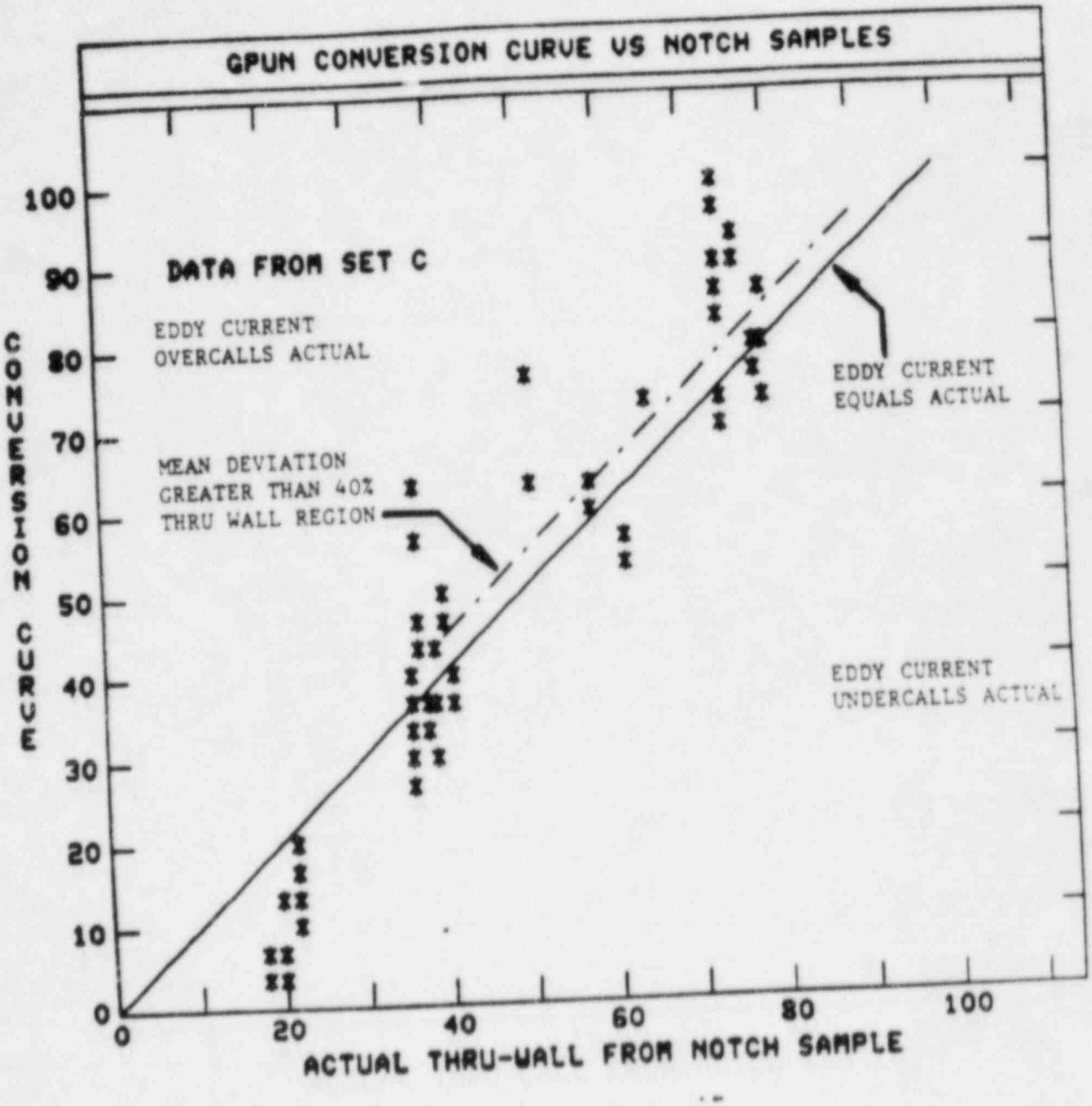

GPUN CONVERSION CURVE VS NOTCH SAMPLES
DATA FROM SET C
EDDY CURRENT OVERCALLS ACTUAL
MEAN DEVIATION GREATER THAN 40% THRU WALL REGION
EDDY CURRENT EQUALS ACTUAL
EDDY CURRENT UNDERCALLS ACTUAL
CONVERSION CURVE
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100
ACTUAL THRU-WALL FROM NOTCH SAMPLE

TABLE D-1

SHEET 1 of 5

COMPLETE B DATA SET

OBS	SET	STD	TEST	TWD	PHASE	VLT400
1	B	ET 110	1	20	11	0.99
2	B	ET 110	1	36	18	2.40
3	B	ET 110	1	62	27	3.92
4	B	ET 110	1	79	31	5.66
5	B	ET 110	2	20	12	0.99
6	B	ET 110	2	36	18	2.44
7	B	ET 110	2	62	26	3.94
8	B	ET 110	2	79	31	5.65
9	B	ET 110	3	20	12	1.00
10	B	ET 110	3	36	18	2.35
11	B	ET 110	3	62	26	3.93
12	B	ET 110	3	79	31	5.70
13	B	ET 110	4	20	12	1.01
14	B	ET 110	4	36	19	2.37
15	B	ET 110	4	62	25	3.95
16	B	ET 110	4	79	31	5.62
17	B	ET 111	1	37	29	0.40
18	B	ET 111	1	51	29	0.65
19	B	ET 111	1	74	34	0.76
20	B	ET 111	2	51	28	0.64
21	B	ET 111	2	37	31	0.39
22	B	ET 111	2	74	33	0.75
23	B	ET 111	3	51	26	0.65
24	B	ET 111	3	37	27	0.40
25	B	ET 111	3	74	34	0.74
26	B	ET 111	4	51	27	0.62
27	B	ET 111	4	37	30	0.42
28	B	ET 111	4	74	34	0.72
29	B	ET 112	1	18	10	0.49
30	B	ET 112	1	39	22	0.78
31	B	ET 112	2	18	10	0.49
32	B	ET 112	2	39	24	0.78
33	B	ET 112	3	18	10	0.50
34	B	ET 112	3	39	23	0.76
35	B	ET 112	4	18	10	0.53
36	B	ET 112	4	39	24	0.75
37	B	ET 113	1	17	9	0.72
38	B	ET 113	1	36	20	1.41
39	B	ET 113	1	74	40	1.92
40	B	ET 113	2	17	10	0.74
41	B	ET 113	2	36	21	1.39
42	B	ET 113	2	74	38	2.22
43	B	ET 113	3	17	11	0.72
44	B	ET 113	3	36	20	1.41
45	B	ET 113	3	74	37	2.26
46	B	ET 113	4	17	11	0.75
47	B	ET 113	4	36	19	1.38
48	B	ET 113	4	74	35	2.35
49	B	ET 114	1	18	8	1.00
50	B	ET 114	1	40	24	1.87
51	B	ET 114	1	58	28	2.55
52	B	ET 114	1	79	34	3.04
53	B	ET 114	2	18	6	1.01
54	B	ET 114	2	40	24	1.84

TABLE D-1

SHEET 2 of 5

COMPLETE B DATA SET

OBS	SET	STD	TEST	TWB	PHASE	VLT400
57	B	ET 114	3	18	6	1.02
58	B	ET 114	3	40	24	1.92
59	B	ET 114	3	58	28	2.52
60	B	ET 114	3	79	34	3.04
61	B	ET 114	4	18	7	1.02
62	B	ET 114	4	40	24	1.90
63	B	ET 114	4	58	29	2.50
64	B	ET 114	4	79	35	3.01
65	B	ET 115	1	65	32	5.28
66	B	ET 115	1	76	38	5.55
67	B	ET 115	2	65	34	5.23
68	B	ET 115	2	76	30	5.64
69	B	ET 115	3	65	33	5.25
70	B	ET 115	3	76	37	5.57
71	B	ET 115	4	65	32	5.25
72	B	ET 115	4	76	38	5.55
73	B	ET 116	1	41	24	5.66
74	B	ET 116	1	62	27	8.12
75	B	ET 116	1	78	35	8.79
76	B	ET 116	2	41	24	5.85
77	B	ET 116	2	62	29	8.00
78	B	ET 116	2	78	35	8.71
79	B	ET 116	3	41	23	5.82
80	B	ET 116	3	62	28	8.24
81	B	ET 116	3	78	34	8.90
82	B	ET 116	4	41	24	5.76
83	B	ET 116	4	62	28	8.23
84	B	ET 116	4	78	35	8.88
85	B	ET 117	1	22	15	5.10
86	B	ET 117	1	38	20	10.90
87	B	ET 117	2	22	16	5.12
88	B	ET 117	2	38	20	10.77
89	B	ET 117	3	22	16	5.19
90	B	ET 117	3	38	20	10.80
91	B	ET 117	4	22	15	5.20
92	B	ET 117	4	38	21	10.76

TABLE D-1

SHEET 3 of 5

COMPLETE C DATA SETS

OBS	SET	STD	TEST	TUC	PHASE	VLT400
1	C	ET 110	1	20	14	0.87
2	C	ET 110	1	36	18	2.17
3	C	ET 110	1	62	26	3.59
4	C	ET 110	1	79	34	4.54
5	C	ET 110	2	20	11	.
6	C	ET 110	2	36	19	.
7	C	ET 110	2	62	26	.
8	C	ET 110	2	79	32	.
9	C	ET 110	3	20	12	0.86
10	C	ET 110	3	36	20	2.17
11	C	ET 110	3	62	26	3.64
12	C	ET 110	3	79	32	5.14
13	C	ET 110	4	20	12	0.84
14	C	ET 110	4	36	17	2.20
15	C	ET 110	4	62	26	3.66
16	C	ET 110	4	79	32	4.97
17	C	ET 111	1	37	24	0.47
18	C	ET 111	1	51	29	0.60
19	C	ET 111	1	74	39	0.68
20	C	ET 111	2	37	23	0.44
21	C	ET 111	2	51	29	0.60
22	C	ET 111	2	74	37	0.66
23	C	ET 111	3	37	29	0.40
24	C	ET 111	3	74	32	0.75
25	C	ET 111	3	51	33	0.55
26	C	ET 111	4	37	27	0.42
27	C	ET 111	4	74	31	0.69
28	C	ET 111	4	51	33	0.56
29	C	ET 112	1	18	12	0.48
30	C	ET 112	1	39	21	0.80
31	C	ET 112	2	18	9	0.54
32	C	ET 112	2	39	21	0.54
33	C	ET 112	3	18	8	0.49
34	C	ET 112	3	39	23	0.40
35	C	ET 112	4	18	11	0.50
36	C	ET 112	4	39	19	0.31
37	C	ET 113	1	17	8	0.66
38	C	ET 113	1	36	21	1.27
39	C	ET 113	1	74	37	2.14
40	C	ET 113	2	17	8	0.64
41	C	ET 113	2	36	22	1.27
42	C	ET 113	2	74	40	2.11
43	C	ET 113	3	17	9	0.75
44	C	ET 113	3	36	18	1.46
45	C	ET 113	3	74	36	.40
46	C	ET 113	4	17	8	0.78
47	C	ET 113	4	36	20	1.46
48	C	ET 113	4	74	35	2.43
49	C	ET 114	1	18	5	0.80
50	C	ET 114	1	40	25	1.77
51	C	ET 114	1	58	29	2.33
52	C	ET 114	1	79	36	2.74
53	C	ET 114	2	18	7	0.80
54	C	ET 114	2	40	24	1.79
55	C	ET 114	2	58	28	2.26
[illegible]	[illegible]	[illegible]			[illegible]	2.43

TABLE D-1

SHEET 4 of 5

COMPLETE C DATA SETS

OBS	SET	STD	TEST	TWC	PHASE	VLT400
57	C	ET 114	3	18	7	0.91
58	C	ET 114	3	40	24	1.79
59	C	ET 114	3	58	29	2.33
60	C	ET 114	3	79	34	2.75
61	C	ET 114	4	18	6	0.98
62	C	ET 114	4	40	25	1.79
63	C	ET 114	4	58	28	2.39
64	C	ET 114	4	79	36	2.74
65	C	ET 115	1	65	32	5.57
66	C	ET 115	1	76	37	5.80
67	C	ET 115	2	65	32	5.38
68	C	ET 115	2	76	38	5.65
69	C	ET 115	3	65	32	5.31
70	C	ET 115	3	76	33	5.71
71	C	ET 115	4	65	32	5.29
72	C	ET 115	4	76	38	5.74
73	C	ET 115	4	100	40	7.36
74	C	ET 116	1	41	22	6.18
75	C	ET 116	1	62	27	8.64
76	C	ET 116	1	78	33	9.47
77	C	ET 116	2	41	22	6.24
78	C	ET 116	2	62	26	8.68
79	C	ET 116	2	78	33	9.47
80	C	ET 116	3	41	21	6.05
81	C	ET 116	3	62	27	8.24
82	C	ET 116	3	78	34	9.13
83	C	ET 116	4	41	22	6.13
84	C	ET 116	4	62	27	8.45
85	C	ET 116	4	78	34	9.35
86	C	ET 117	1	22	13	5.30
87	C	ET 117	1	38	21	11.13
88	C	ET 117	2	22	14	5.29
89	C	ET 117	2	28	20	10.68
90	C	ET 117	3	22	16	4.93
91	C	ET 117	3	18	20	10.31
92	C	ET 117	4	22	15	5.04
93	C	ET 117	4	38	21	10.16

TABLE D-1

SHEET 5 of 5

COMPLETE MCTLAB DATA SETS

OBS	SET	STD	TWE	TEST	PHASE	ETDPT
1	D	A-011-66	100	1	24	89
[illegible]	D	A-013-63	100	1	48	87
3	D	A-024-94	70	1	[illegible]	100
4	D	A-024-94	100	2	[illegible]	95
5	D	A-112-77	56	1	20	69
6	D	A-132-74	100	1	26	96
7	D	A-133-74	69	2	41	92
8	D	A-142-06	100	1	[illegible]	83
9	D	A-146-78	70	1	[illegible]	83
10	D	[illegible]	100	1	[illegible]	93
11	D	SAMPL	30	1	12	41
12	D	SAMPLE24	54	1	15	~~44~~ 51

TABLE D-2

SHEET 1 of 3

CORRELATING FRECENT THRU-WALL FROM
SLTS B AND C TO THE CONVERISON CURVE
FOR THE ASSOCIATED PHASE ANGLES

OBS	PHASE	TWI	TWB	TWC	STD	TEST
1	5	-16.5	.	18	ET 114	1
2	6	-13.2	18	.	ET 114	2
3	6	-13.2	18	.	ET 114	3
4	6	-13.2	.	18	ET 114	4
5	7	-9.9	.	18	ET 114	2
6	7	-9.9	.	18	ET 114	3
7	7	-9.9	18	.	ET 114	4
8	8	-6.6	.	18	ET 112	3
9	8	-6.6	.	17	ET 113	1
10	8	-6.6	.	17	ET 113	2
11	8	-6.6	.	17	ET 113	4
12	8	-6.6	18	.	ET 114	1
13	9	-3.3	.	18	ET 112	2
14	9	-3.3	17	.	ET 113	1
15	9	-3.3	.	17	ET 113	3
16	10	0.0	18	.	ET 112	1
17	10	0.0	18	.	ET 112	2
18	10	0.0	18	.	ET 112	3
19	10	0.0	18	.	ET 112	4
20	10	0.0	17	.	ET 113	2
21	11	3.3	20	.	ET 110	1
22	11	3.3	.	20	ET 110	2
23	11	3.3	.	18	ET 112	4
24	11	3.3	17	.	ET 113	3
25	11	3.3	17	.	ET 113	4
26	12	6.6	20	.	ET 110	2
27	12	6.6	20	20	ET 110	3
28	12	6.6	20	20	ET 110	4
29	12	6.6	.	18	ET 112	1
30	13	9.9	.	22	ET 117	1
31	14	13.2	.	20	ET 110	1
32	14	13.2	.	22	ET 117	2
33	15	16.5	22	.	ET 117	1
34	15	16.5	22	22	ET 117	4
35	16	19.8	22	.	ET 117	2
36	16	19.8	22	22	ET 117	3
37	18	26.4	36	36	ET 110	1
38	18	26.4	36	.	ET 110	2
39	18	26.4	36	.	ET 110	3
40	18	26.4	.	36	ET 113	3
41	19	29.7	.	36	ET 110	2
42	19	29.7	36	36	ET 110	4
43	19	29.7	.	39	ET 112	4
44	19	29.7	36	.	ET 113	4
45	20	33.0	.	36	ET 110	3
46	20	33.0	36	.	ET 113	1
47	20	33.0	36	.	ET 113	3
48	20	33.0	.	36	ET 113	4
49	20	33.0	38	.	ET 117	1
50	20	33.0	38	38	ET 117	2
51	20	33.0	38	38	ET 117	3
52	21	36.3	.	39	ET 112	1
53					[illegible]	[illegible]
5[illegible]						

TABLE D-2

SHEET 2 of 3

CORRELATING PRECENT THRU-WALL FROM SETS B AND C TO THE CONVERISON CURVE FOR THE ASSOCIATED PHASE ANGLES

OBS	PHASE	TWI	TWB	TWC	STD	TEST
55	21	36.3	36	.	ET 113	2
56	21	36.3	.	41	ET 116	3
57	21	36.3	.	38	ET 117	1
58	21	36.3	38	38	ET 117	4
59	22	39.6	39	.	ET 112	1
60	22	39.6	.	36	ET 113	2
61	22	39.6	.	41	ET 116	1
62	22	39.6	.	41	ET 116	2
63	22	39.6	.	41	ET 116	4
64	23	42.9	.	37	ET 111	2
65	23	42.9	39	39	ET 112	3
66	23	42.9	41	.	ET 116	3
67	24	46.2	.	37	ET 111	1
68	24	46.2	39	.	ET 112	2
69	24	46.2	39	.	ET 112	4
70	24	46.2	40	.	ET 114	1
71	24	46.2	40	40	ET 114	2
72	24	46.2	40	40	ET 114	3
73	24	46.2	40	.	ET 114	4
74	24	46.2	41	.	ET 116	1
75	24	46.2	41	.	ET 116	2
76	24	46.2	41	.	ET 116	4
77	25	49.5	62	.	ET 110	4
78	25	49.5	.	40	ET 114	1
79	25	49.5	.	40	ET 114	4
80	26	52.8	.	62	ET 110	1
81	26	52.8	62	62	ET 110	2
82	26	52.8	62	62	ET 110	3
83	26	52.8	.	62	ET 110	4
84	26	52.8	51	.	ET 111	3
85	26	52.8	.	62	ET 116	2
86	27	56.1	62	.	ET 110	1
87	27	56.1	37	.	ET 111	3
88	27	56.1	51	37	ET 111	4
89	27	56.1	62	62	ET 116	1
90	27	56.1	.	62	ET 116	3
91	27	56.1	.	62	ET 116	4
92	28	59.4	51	.	ET 111	2
93	28	59.4	58	.	ET 114	1
94	28	59.4	58	58	ET 114	2
95	28	59.4	58	.	ET 114	3
96	28	59.4	.	58	ET 114	4
97	28	59.4	62	.	ET 116	3
98	28	59.4	62	.	ET 116	4
99	29	62.7	37	51	ET 111	1
100	29	62.7	51	51	ET 111	1
101	29	62.7	.	51	ET 111	2
102	29	62.7	.	37	ET 111	3
103	29	62.7	.	58	ET 114	1
104	29	62.7	.	58	ET 114	3
105	29	62.7	58	.	ET 114	4
106	29	62.7	62	.	ET 116	2

TABLE D-2

SHEET 3 of 3

CORRELATING PERCENT THRU-WALL FROM SETS B AND C TO THE CONVERSION CURVE FOR THE ASSOCIATED PHASE ANGLES

OBS	PHASE	TWA	TWB	TWC	STD	TEST
109	31	69.3	79	.	ET 110	2
110	31	69.3	79	.	ET 110	3
111	31	[illegible]	79	.	ET 110	4
112	31	[illegible]	37	.	ET 111	2
113	31	69.3	.	74	ET 111	4
114	32	72.6	.	79	ET 110	2
115	32	72.6	.	79	ET 110	3
116	32	72.6	.	79	ET 110	4
117	32	72.6	.	74	ET 111	3
118	32	72.6	65	65	ET 115	1
119	32	72.6	.	65	ET 115	2
120	32	72.6	.	65	ET 115	3
121	32	72.6	65	65	ET 115	4
122	33	75.9	74	.	ET 111	2
123	33	75.9	.	51	ET 111	3
124	33	75.9	.	51	ET 111	4
125	33	75.9	65	.	ET 115	3
126	33	75.9	.	78	ET 116	1
127	33	75.9	.	78	ET 116	2
128	34	79.2	.	79	ET 110	1
129	34	79.2	74	.	ET 111	1
130	34	79.2	74	.	ET 111	3
131	34	79.2	74	.	ET 111	4
132	34	79.2	79	.	ET 114	1
133	34	79.2	79	79	ET 114	3
134	34	79.2	65	.	ET 115	2
135	34	79.2	78	78	ET 116	3
136	34	79.2	.	78	ET 116	4
137	35	82.5	.	74	ET 113	4
138	35	82.5	79	.	ET 114	2
139	35	82.5	79	.	ET 114	4
140	35	82.5	78	.	ET 116	1
141	35	82.5	78	.	ET 116	2
142	35	82.5	78	.	ET 116	4
143	36	85.8	.	74	ET 113	1
144	36	85.8	74	.	ET 113	4
145	36	85.8	.	79	ET 114	1
146	36	85.8	.	79	ET 114	2
147	36	85.8	.	79	ET 114	4
148	37	89.1	.	74	ET 111	2
149	37	89.1	.	74	ET 113	1
150	37	89.1	74	.	ET 113	3
151	37	89.1	.	76	ET 115	1
152	37	89.1	76	.	ET 115	3
153	38	92.4	74	.	ET 113	2
154	38	92.4	76	.	ET 115	1
155	38	92.4	76	76	ET 115	2
156	38	92.4	.	76	ET 115	3
157	38	92.4	76	76	ET 115	4
158	[illegible]	95.7	.	74	ET 111	1
159	[illegible]	99.0	74	.	ET 113	1
160	[illegible]	99.0	.	74	ET 113	2

TABLE D-3

SHEET 2 of 3

TABULATING THE DELTA VALUES

PHASE	PHASE	TWI	TWB	DELTB	TWC	DELTC
24	24	46.2	40	5.2	.	.
24	24	46.2	40	5.2	.	.
24	24	46.2	41	5.2	.	.
24	24	46.2	41	5.2	.	.
24	24	46.2	41	5.2	.	.
24	24	46.2	.	.	37	9.2
24	24	46.2	.	.	40	6.2
24	24	46.2	.	.	40	6.2
25	25	49.5	62	-12.5	.	.
25	25	49.5	.	.	40	9.5
25	25	49.5	.	.	40	9.5
26	26	52.8	62	-9.2	.	.
26	26	52.8	62	-9.2	.	.
26	26	52.8	51	1.8	.	.
26	26	52.8	.	.	62	-9.2
26	26	52.8	.	.	62	-9.2
26	26	52.8	.	.	62	-9.2
26	26	52.8	.	.	62	-9.2
26	26	52.8	.	.	62	-9.2
27	27	56.1	62	-5.9	.	.
27	27	56.1	37	19.1	.	.
27	27	56.1	51	5.1	.	.
27	27	56.1	62	-5.9	.	.
27	27	56.1	.	.	37	19.1
27	27	56.1	.	.	62	-5.9
27	27	56.1	.	.	62	-5.9
27	27	56.1	.	.	62	-5.9
28	28	59.4	51	8.4	.	.
28	28	59.4	58	1.4	.	.
28	28	59.4	58	1.4	.	.
28	28	59.4	58	1.4	.	.
28	28	59.4	62	-2.6	.	.
28	28	59.4	62	-2.6	.	.
28	28	59.4	.	.	58	1.4
28	28	59.4	.	.	58	1.4
29	29	62.7	37	25.7	.	.
29	29	62.7	51	11.7	.	.
29	29	62.7	58	4.7	.	.
29	29	62.7	62	0.7	.	.
29	29	62.7	.	.	51	11.7
29	29	62.7	.	.	51	11.7
29	29	62.7	.	.	37	25.7
29	29	62.7	.	.	58	4.7
29	29	62.7	.	.	58	4.7
30	30	66.0	37	29.0	.	.
31	31	69.3	79	-9.7	.	.
31	31	69.3	79	-9.7	.	.
31	31	69.3	79	-9.7	.	.
31	31	69.3	79	-9.7	.	.
31	31	69.3	37	32.3	.	.
31	31	69.3	.	.	74	-4.7
32	32	72.6	65	7.6	.	.
32	32	72.6	65	7.6	.	.
32	32	72.6	.	.	79	-6.4
32	32	72.6	.	.	79	-6.4
[illegible]	[illegible]	[illegible]			[illegible]	[illegible]

TABLE D-3

SHEET 1 of 3

TABULATING THE DELTA VALUES

PHASE	PHASE	TWI	TWB	DELTB	TWC	DELTC
11	11	3.3	20	-16.7	.	.
11	11	3.3	.	.	20	-16.7
12	12	6.6	20	-13.4	.	.
12	12	6.6	20	-13.4	.	.
12	12	6.6	20	-13.4	.	.
12	12	6.6	.	.	20	-13.4
12	12	6.6	.	.	20	-13.4
13	13	9.9	.	.	22	-12.1
14	14	13.2	.	.	20	-6.8
14	14	13.2	.	.	20	-6.8
15	15	16.5	22	-5.5	.	.
15	15	16.5	22	-5.5	.	.
15	15	16.5	.	.	22	-5.5
16	16	19.8	22	-2.2	.	.
16	16	19.8	22	-2.2	.	.
16	16	19.8	.	.	22	-2.2
18	18	26.4	36	-9.6	.	.
18	18	26.4	36	-9.6	.	.
18	18	26.4	36	-9.6	.	.
18	18	26.4	.	.	36	-9.6
18	18	26.4	.	.	36	-9.6
19	19	29.7	36	-6.3	.	.
19	19	29.7	36	-6.3	.	.
19	19	29.7	.	.	36	-6.3
19	19	29.7	.	.	36	-6.3
19	19	29.7	.	.	36	-6.3
20	20	33.0	36	-3.0	.	.
20	20	33.0	36	-3.0	.	.
20	20	33.0	38	-5.0	.	.
20	20	33.0	38	-5.0	.	.
20	20	33.0	38	-5.0	.	.
20	20	33.0	.	.	36	-3.0
20	20	33.0	.	.	36	-3.0
20	20	33.0	.	.	38	-5.0
20	20	33.0	.	.	38	-5.0
21	21	36.3	36	.3	.	.
21	21	36.3	38	-1.7	.	.
21	21	36.3	.	.	39	-2.7
21	21	36.3	.	.	39	-2.7
21	21	36.3	.	.	36	0.3
21	21	36.3	.	.	41	-4.7
21	21	36.3	.	.	38	-1.7
21	21	36.3	.	.	38	-1.7
22	22	39.6	39	0.6	.	.
22	22	39.6	.	.	36	3.6
22	22	39.6	.	.	41	-1.4
22	22	39.6	.	.	41	-1.4
22	22	39.6	.	.	41	-1.4
23	23	42.9	39	3.9	.	.
23	23	42.9	41	1.9	.	.
23	23	42.9	.	.	37	5.9
23	23	42.9	.	.	37	5.9
24	24	46.2	39	7.2	.	.
24	24	46.2	39	7.2	.	.

TABLE D-3

SHEET 3 of 3

TABULATING THE DELTA VALUES

PHASE	PHASE	TWI	TWB	DELTB	TWC	DELTC
32	32	72.6	.	.	74	-1.4
32	32	72.6	.	.	65	7.6
32	32	72.6	.	.	65	7.6
32	32	72.6	.	.	65	7.6
32	32	72.6	.	.	65	7.6
33	33	75.9	74	1.9	.	.
33	33	75.9	65	10.9	.	.
33	33	75.9	.	.	51	24.9
33	33	75.9	.	.	51	24.9
33	33	75.9	.	.	78	-2.1
33	33	75.9	.	.	78	-2.1
34	34	79.2	74	5.2	.	.
34	34	79.2	74	5.2	.	.
34	34	79.2	74	5.2	.	.
34	34	79.2	79	0.2	.	.
34	34	79.2	79	0.2	.	.
34	34	79.2	65	14.2	.	.
34	34	79.2	78	1.2	.	.
34	34	79.2	.	.	79	0.2
34	34	79.2	.	.	79	0.2
34	34	79.2	.	.	78	1.2
34	34	79.2	.	.	78	1.2
35	35	82.5	79	3.5	.	.
35	35	82.5	79	3.5	.	.
35	35	82.5	78	4.5	.	.
35	35	82.5	78	4.5	.	.
35	35	82.5	78	4.5	.	.
35	35	82.5	.	.	74	8.5
36	36	85.8	74	11.8	.	.
36	36	85.8	.	.	74	11.8
36	36	85.8	.	.	79	6.8
36	36	85.8	.	.	79	6.8
36	36	85.8	.	.	79	6.8
37	37	89.1	74	15.1	.	.
37	37	89.1	76	13.1	.	.
37	37	89.1	.	.	74	15.1
37	37	89.1	.	.	74	15.1
37	37	89.1	.	.	76	13.1
38	38	92.4	74	18.4	.	.
38	38	92.4	76	16.4	.	.
38	38	92.4	76	16.4	.	.
38	38	92.4	76	16.4	.	.
38	38	92.4	.	.	76	16.4
38	38	92.4	.	.	76	16.4
38	38	92.4	.	.	76	16.4
39	39	95.7	.	.	74	21.7
40	40	99.0	74	25.0	.	.
40	40	99.0	.	.	74	25.0

TABLE D-4

Analysis of Correlation Differences

For thru walls greater than or equal to 20%

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE
DELTB	80	2.42000000	10.12914581	-16.70000000	32.30000000	1.13247293	193.60000000	102.59959494
DELTC	80	1.88375000	10.01019030	-16.70000000	25.70000000	1.11917330	150.70000000	100.20390981

For thru walls greater than or equal to 40%

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE
DELTB	52	3.9365	8.164	-12.5	25.0	1.132	204.7	66.6596
DELTC	52	4.3807	9.545	-9.2	25.0	1.323	227.8	91.1235

For thru wall less than or equal to 30%

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE
DELTB	8	-9.03750000	5.78592813	-16.70000000	-2.20000000	2.04563451	-72.30000000	33.47696429
DELTC	8	-9.86250000	4.85561163	-16.70000000	-2.20000000	1.71671295	-78.90000000	23.57696429

For thru walls greater than 30% or less than or equal to 70%

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE
DELTB	48	2.76041667	9.74484566	-12.50000000	32.30000000	1.40654732	132.50000000	94.96201684
DELTC	48	1.59166667	9.33521891	-9.60000000	25.70000000	1.34742279	76.40000000	87.14631206

For thru walls greater than 70%

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE
DELTB	24	5.55833333	9.59097397	-9.70000000	25.0000000	1.95774120	133.40000000	91.98601449
DELTC	24	6.38333333	9.46709021	-6.40000000	25.0000000	1.93246170	153.20000000	89.62579710

APPENDIX E

METALLURGICAL VERSUS EDDY CURRENT EXAMINATION, STATISTICAL EVALUATION

Metallurgical Versus Eddy Current Examination, Statistical Evaluation

Included in this appendix are the statistical results for the comparison of the actual depths of IGSAC as determined by metallography, to the eddy current assigned depths as determined by phase analysis. This statistical evaluation, which includes a total of eighteen (18) data points is intended to confirm the accuracy of the GPUN inner diameter conversion curve for sizing inner diameter initiated IGSAC.

The 18 data points are evaluated in 2 data sets identified as "R" and "I". Data set "R" includes all the data points contained in Appendix C, Figure C-1. Data set "I" is a subset of "R" which contains the samples which were reported by metallography to be 20% to 70% through wall. This subset represents the greatest area of interest for dispositioning the OTSG tubes.

The analysis was performed to quantify the difference between the actual percent through wall values (Actual Depth) and the eddy current assigned percent through wall values (ECT Depth). The analysis was performed using the values shown in tables E-1 and E-2 for data sets "R" and "I" respectively.

The analysis includes a determination of the 'Mean' difference and the standard deviation. These values are summarized below along with a comparison of the same values which were extracted from Appendix D for EDM notches.

Comparison of Statistics for
20-100% Through Wall Discontinuities

	EDM Notches Extracted from App. D			Actual IGSAC Samples Data Set R		
Data Set	No. DPTS	Mean Difference (Percent)	One Standard Diviation	No. DPTS	Mean Difference (Percent)	One Standard Diviation
Delt B	80	2.4	10.13	18	+ 1.67	8.31
Delt C	80	+ 1.8	10.010			

Comparison of Statistics for
20-70% Through Wall Discontinuities

	EDM Notches Extracted from App. D			Actual IGSAC Samples Data Set I		
Data Set	No. DPTS	Mean Difference (Percent)	One Standard Diviation	No. DPTS	Mean Difference (Percent)	One Standard Diviation
Delt B	48	+ 2.76	9.74	6	7.83	11.89
Delt C	48	+ 1.59	9.34			

Note: A positive mean indicates the Eddy Current overcalls the actual depth. A negative mean would indicate an undercall by Eddy Current.

The result of this comparison demonstrate the GPUN I.D. conversion overcalls the depth of both EDM notches and actual IGSAC. The comparison further demonstrates additional conservatism is included for the 20-70% through wall region as is indicated by a 7.8% mean overcall for the 6 data points in data set "I".

Figure E-1

Comparison of Metallurgical Results

To the Eddy Current Predicted

Data Set R
Includes All Data Points
From Figure C-1

OBS	SAMPLE ID	LOCATION	ACTUAL DEPTH	ECT DEPTH	DIFF.
1	Sample 23	4.0	38%	41%	+ 3%
2	Sample 24	4.8	54%	51%	- 3%
3	A-112-7	10.7	66%	68%	+ 2%
4	A-146-8	4.0	70%	82%	+12%
5	A-24-94	12.8	70%	100%	+30%
6	A-24-94	34.0	100%	100%	0%
7	A-133-74	32.0	100%	90%	-10%
8	A-133-74	33.0	100%	100%	0%
9	A-11-66	11.6	100%	100%	0%
10	A-146-6	8.5	100%	100%	0%
11	A-13-63	26.8	100%	100%	0%
12	A-10-29	7.6	100%	93%	-7%
13	A-111-13	1.2	20%	23%	+3%
14	A-112-05	1.4	100%	100%	0%
15	A-112-05	2.4	100%	100%	0%
16	A-112-05	2.9	100%	100%	0%
17	A-112-05	4.1	100%	100%	0%
18	A-112-05	5.8	100%	100%	0%

Mean of Difference $\mathrm{Diff}_{mean} = \frac{\sum \mathrm{Diff}_i}{n} = 1.67$ n = no. of observations

Standard Deviation of Sample $\sigma \text{ Sample} = \sqrt{\frac{\sum \mathrm{Diff}_i - \mathrm{Diff}_{mean}}{n-1}} = 8.31$

Figure E-2
Comparison of Metallurgical Results
To the Eddy Current Predicted

Data Set I
Includes Data Points With Metallurgical
Depths GE 20% and LE 70%

OBS	SAMPLE ID	LOCATION	ACTUAL DEPTH	ECT DEPTH	DIFF.
1	Sample 23	4.0	38%	41%	+ 3%
2	Sample 24	4.8	54%	51%	- 3%
3	A-112-7	10.7	66%	68%	+ 2%
4	A-146-8	4.0	70%	82%	+12%
5	A-24-94	12.8	70%	100%	+30%
6	A-111-13	1.2	20%	23%	+3%

Mean of Difference $\text{Diff}_{mean} = \frac{\Sigma \text{Diff}_i}{n} = \frac{47}{6} = +7.83$ n = no. of observations

Standard Deviation of Sample $\sigma \text{ Sample} = \sqrt{\frac{\Sigma \text{Diff}_i - \text{Diff}_{mean}}{n-1}} = 11.89$