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SUBJECT: Forwards analysis for TS change to allow Unit 1 SG tube interim plugging criteria of 1.0 volt for Cycle 14,per NRC request that portions of draft NUREG-1477 be incorporated in 930310 LAR.Affected TS pages & Westinghouse rept also encl.

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Donald C. Cook Nuclear Plant Unit 1
Docket No. 50-315
License No. DPR-58
TECHNICAL SPECIFICATIONS CHANGES TO ALLOW UNIT 1
STEAM GENERATOR TUBE INTERIM PLUGGING CRITERIA OF
1.0 VOLT FOR CYCLE 14

U. S. Nuclear Regulatory Commission
Document Control Desk
Washington, D.C. 20555

Attn: T. E. Murley

December 15, 1993

Dear Dr. Murley:

The purpose of this letter is to supersede the Donald C. Cook Nuclear Plant, Unit 1, interim plugging criteria (IPC) submitted by AEP:NRC:1166G dated March 10, 1993. This submittal is required because your staff requested us to incorporate portions of draft NUREG-1477 and recent industry data and information which resulted in reducing the criteria limit from 4.0 to 3.1 volts on technical specification (T/S) page 3/4 4-11.

The March 10, 1993, license amendment request assesses tube integrity based on standard bobbin coil signal amplitude for dispositioning flaw-like indications. Eddy current inspection results during the 1994 refueling outage relative to numbers of indications and maximum voltage levels are anticipated to be comparable to the 1992 results. The standard bobbin probe will continue to be the main probe utilized for tube plugging determination during the 1994 refueling outage at Cook Nuclear Plant Unit 1.

Attachment 1 provides the latest analysis and includes the following: steamline break (SLB) leakage calculations as described in draft NUREG-1477, tube degradation characterization, the basis for no additional tube pulls, steam generator tube integrity discussion, eddy current guidelines, and an assessment of IPC methodology. We believe this is sufficient justification for the interim plugging criteria and the T/S changes requested in this submittal.

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Our significant hazard consideration is contained in Attachment 2. For your convenience all the affected T/S pages are included, although only one page, 3/4 4-11, is added by this letter. Attachment 3 contains the marked-up copies of the existing T/S pages. Attachment 4 contains the proposed revised T/S pages.

Attachment 5 contains the Westinghouse Report NSD-TAP-3052, "Supplemental Information for Cook Nuclear Plant Unit 1 IPC." Appendix A "NDE Data Acquisition and Analyses Guidelines" is contained in Attachment 6.

We believe that the proposed changes will not result in (1) a significant change in the type of effluents or a significant increase in the amount of any effluents that may be released offsite, or (2) a significant increase in individual or cumulative occupational radiation exposure.

These proposed changes have been reviewed by the Plant Nuclear Safety Review Committee and the corporate Nuclear Safety and Design Review Committee.

In compliance with the requirements of 10 CFR 50.91(b)(1), copies of this letter and its attachments have been transmitted to Mr. J. R. Padgett of the Michigan Public Service Commission and to the Michigan Department of Public Health.

Please contact us if you have any questions concerning this license amendment request.

This letter is submitted pursuant to 10 CFR 50.30(b) and, as such, an oath statement is attached.

Sincerely,

E. E. Fitzpatrick
Vice President

dr

Attachments

cc: A. A. Blind
G. Charnoff
J. B. Martin - Region III
NFEM Section Chief
NRC Resident Inspector
J. R. Padgett

bc: S. J. Brewer
D. H. Malin/K. J. Toth
J. D. Benes/J. R. Jensen
M. L. Horvath - Bridgman (w/o attachments)
J. B. Shinnock (w/o attachments)
W. G. Smith, Jr./S. H. Steinhart
J. B. Hickman, NRC - Washington, D.C.
AEP:NRC:1166H
DC-N-6015.1 (w/o attachments)

STATE OF OHIO)
COUNTY OF FRANKLIN)

E. E. Fitzpatrick, being duly sworn, deposes and says that he is the Vice President of licensee Indiana Michigan Power Company, that he has read the forgoing TECHNICAL SPECIFICATIONS CHANGE TO ALLOW UNIT 1 STEAM GENERATOR TUBE INTERIM PLUGGING CRITERIA OF 1.0 VOLT FOR CYCLE 14 SUPPLEMENTAL INFORMATION and knows the contents thereof; and that said contents are true to the best of his knowledge and belief.

E E Fitzpatrick

Subscribed and sworn to before me this 15th

day of December, 19 93.

NOTARY PUBLIC
Commission expires 3-9-96

ATTACHMENT 1 TO AEP:NRC:1166H

TECHNICAL SUMMARY OF THE RECENT STEAM GENERATOR TUBE INTERIM PLUGGING CRITERIA (IPC)

DESCRIPTION OF THE AMENDMENT REQUEST

As required by 10 CFR 50.91 (a)(1), an analysis is provided to demonstrate that the proposed license amendment to implement an interim tube plugging criteria for the tube support plate (TSP) elevation outer diameter stress corrosion cracking (ODSCC) occurring in the Donald C. Cook Nuclear Plant Unit 1 steam generators involves a no significant hazards consideration. The existing plugging criteria utilizes correlations between eddy current bobbin probe signal amplitude (voltage) and tube burst and leakage capability. The plugging criteria is based on testing of laboratory induced ODSCC specimens, extensive examination of pulled tubes from operating steam generators (industry wide - including 3 tubes representing 6 intersections from the Cook Nuclear Plant Unit 1 steam generators utilized in the burst and leak rate database), and field experience from leakage due to indications at the TSPs resulting from axial ODSCC (identified in European plants only).

The interim plugging criteria (IPC) can be summarized as follows:

> "Flaw indications with a bobbin coil voltage less than or equal to 1.0 volt can remain in service without further action. For flaw indications in excess of 1.0 volt but less than 3.1 volts, the tube can remain in service provided a rotating pancake coil (RPC) inspection of the indication does not detect ODSCC or any other degradation mode. Crack indications above 3.1 volts will be repaired following RPC characterization."

Potential leakage following a postulated steam line break (SLB) event at the end of cycle (EOC) conditions shall be less than 1.0 gpm for the most limiting steam generator. This leakage limit is consistent with the assumptions presented in the Cook Nuclear Plant Unit 1 FSAR. In support of the original license amendment request addressing the alternate plugging criteria program for Cook Unit 1, an offsite dose evaluation was performed according to Standard Review Plan methodology (with the exception that Iodine spiking was not included) to establish the amount of leakage which would result in offsite dose equal to 10% of the 10 CFR 100 guidelines in the event of a main SLB event (outside of containment but upstream of the main steam isolation valve). This evaluation determined that primary to secondary leakage of 120 gpm would satisfy the licensing requirements. This evaluation is considered more conservative than the original FSAR dose evaluation due primarily to the use of an Iodine partition coefficient of 1.0, compared to an Iodine partition coefficient of 0.1 for the FSAR evaluation. The evaluation assumed 1% fuel defects (4.6 microcuries per gram of dose-equivalent I-131). The current reactor coolant dose-equivalent Iodine-131 levels at Cook Nuclear Plant Unit 1 are approximately 200 times less than the technical specification (T/S) value of 1.0 microcuries per gram.

As prescribed in draft NUREG-1477, an evaluation of primary to secondary leakage (and subsequently offsite dose) is required for all plants implementing the IPC. Per draft NUREG-1477, all bobbin indications are included in the SLB leakage analyses along with the consideration of probability of detection (POD). If the projected leakage exceeds 1.0 gpm in the faulted loop during a postulated SLB event, the number of indications in which the IPC are applied below the 1.0 volt limit is reduced through tube repair until the primary to secondary leakage limits are satisfied. In lieu of tube repair, the T/S reactor coolant dose-equivalent Iodine-131 levels can be reduced, effectively increasing the allowable leakage limit while remaining within the licensing basis.

The proposed amendment for re-application of the steam generator tube IPC retains modification to T/Ss 3/4.4.5, "Steam Generators" and 3/4.4.6, "Reactor Coolant System Leakage" and the associated Bases from that which was implemented during Cycle 13 operation.

The T/Ss associated with the repair limits are changed to reflect the impact of the following:

a. The addition of tube pull burst and leakage data to the EPRI 7/8 inch data base and its effect on the tube structural limit and tube SLB leakage consideration.

b. The completion of main steam line leakage calculations consistent with draft NUREG-1477.

This amendment is only applicable for Cycle 14 operation of Cook Nuclear Plant Unit 1.

The only numerical changes to the T/Ss for the plugging criteria during Cycle 14 operation is a reduction in bobbin probe threshold voltage from 4.0 to 3.1 volts (due to a change in the methodology used for reduction of the voltage/burst data) above which tube repair by plugging will be required regardless of RPC confirmation of the indication. This change is addressed in the evaluation section below.

EVALUATION

Tube Degradation Characterization

In general, the degradation morphology occurring at the TSP intersections at plants in the U.S. can be described as axial ODSCC. Axially oriented macrocracks can occur at one or more azimuthal locations around the circumference of the tube. The macrocracks are comprised of short, nearly collinear microcracks separated by ligaments of material. Typical microcrack length is less than 0.2 inch. The corresponding microcrack can be as long as the support plate thickness.

Minor to moderate intergranular attack (IGA) can occur in addition to the axial ODSCC. For Cook Nuclear Plant Unit 1, three tubes with six intersections were pulled in 1992 in direct support of the IPC program (only 5 intersections were burst tested). The corrosion morphology of the Cook Nuclear Plant Unit 1 pulled tubes is consistent with the TSP degradation morphology experienced in other plants.

For the tubes pulled in 1992, the examined support plate crevice regions showed that the degradation is predominantly axially oriented intergranular stress corrosion cracking (IGSCC) and can exist with patches of axial and obliquely oriented cracks which tend to form a patch or cell-like structure. Corrosion within the patches was dominated by short, axial cracks. The degradation was entirely confined within the TSP crevice region.

Room temperature burst pressures ranged from 9,100 psi to 11,200 psi. The intersection with the largest bobbin voltage (2.02 volts), R18C21, first TSP region, exhibited a burst pressure of 10,200 psi. Maximum crack depth for this indication was 56% and average crack depth was determined to be 42%. Virgin tubing is expected to burst at 11,500 to 12,000 psi. All burst specimens had axial burst openings. The deepest areas of degradation were located within the burst fracture faces. Field bobbin depth predictions ranged from 19% to 66% through-wall. Degradation greater than 40% through-wall was readily detectable by both the bobbin and RPC probes. All cases of degradation of an extent which influenced the burst capability of the intersections was readily detectable. One intersection with a maximum depth of corrosion penetration of 38% through-wall was not detected by either the bobbin or RPC probe in the field. This intersection burst at 11,200 psi. No leakage was detected at either normal operating or SLB conditions, as was expected since no through-wall degradation was detected.

Basis for No Tube Pull at Cook Nuclear Plant Unit 1

Draft NUREG-1477 states that removing tubes during each outage for examination and testing is important to enhance and validate the empirical burst and leakage correlations, to confirm that axial ODSCC continues to be the dominant degradation method at the TSP intersections, and to provide additional data for assessing the reliability of the inspection methods.

It is currently not planned to pull any tubes for sample analysis at the next scheduled refueling outage in February 1994. Over the years numerous tube samples have been pulled from Cook Nuclear Plant Unit 1 and the "old" Cook Nuclear Plant Unit 2 steam generators before their replacement. The latest sample examinations were conducted during the past refueling outage in Cook Nuclear Plant Unit 1 as part of the alternate plugging criteria program. The results confirmed that the dominant degradation mechanism for the Cook Nuclear Plant Unit 1 indications at the TSP remains as axial ODSCC. Leak and burst testing of selected samples also provided extremely conservative data in regard to confirming the structural integrity of tubes

at low voltages. The data indicated no leakage and burst tests results ranging from 9,100 psig to 11,200 psig.

No tube pulls are required to support the very conservative IPC of 1.0 volt and only tube pulls with high voltage indications might be beneficial to support the burst and leakage correlations for full alternate repair criteria implementation. The higher voltage data would be most influential in establishing the slope and magnitude of the burst correlation at the structural limits and the probability of burst at accident condition loadings.

Tube pulls for non-dented intersections (such as is the case at Cook Nuclear Plant Unit 1) are no longer needed to show that the dominant mode of degradation is ODSCC. Over 138 non-dented tube intersections have been pulled world wide (not all have burst/leakage measurements) and all have shown axial ODSCC with modest variation in IGA and cellular corrosion environment. Most of the associated voltages are less than approximately 2 volts for domestic data and up to 40 volts for French data. Even with variations in cellular morphologies, such as circumferential bands, the burst data fall at upper uncertainty levels. No new information on morphology can be expected, particularly at low voltages.

There is no additional need for tube pulls to support the reliability of inspection methods. The 138 intersections currently available provide an adequate database to support inspection methods and define POD with adequate accuracy. Pulling tubes for refining POD would have an extremely high cost/benefit ratio as shown by the large number of no detectable degradation (NDD) intersections pulled from Ringhals 3 and 4.

Industry wide, the crack morphology of ODSCC cracks at TSP intersections is best described as short, tight, axially oriented microcracks separated by ligaments of non-degraded material. As noted above, destructive examination of the pulled tubes from the Cook Nuclear Plant Unit 1 steam generators indicates that this same morphology is present.

Steam Generator Tube Integrity Discussion

The purpose of the T/S tube repair limit is to ensure that tubes accepted for continued service will retain adequate structural and leakage integrity during normal operating, transient, and postulated accident conditions.

In the development of an IPC for Cook Nuclear Plant Unit 1, Regulatory Guide 1.121, "Bases for Plugging Degraded PWR Steam Generator Tubes" and R.G. 1.83 "Inservice Inspection of PWR Steam Generator Tubes" are used as the bases for determining that steam generator tube integrity considerations are maintained within acceptable limits. RG 1.121 describes a method acceptable to the NRC staff for meeting General Design Criteria 14, 15, 31, and 32 by reducing the probability and consequences of steam generator tube rupture

through determining the limiting safe conditions of tube wall degradation beyond which tubes with unacceptable cracking, as established by inservice inspection, should be removed from service by plugging. This regulatory guide uses safety factors on loads for tube burst that are consistent with the requirements of Section III of the ASME Code. For the TSP elevation degradation occurring in the Cook Unit 1 steam generators, tube burst criteria are inherently satisfied during normal operating conditions by the presence of the TSP. The presence of the TSP enhances the integrity of the degraded tubes in that region by precluding tube deformation beyond the diameter of the drilled hole, thus, precluding tube burst. Conservatively, no credit is taken in the development of the plugging criteria for the presence of the TSP during normal operating and accident conditions. Based on the existing database for 7/8" tubing, burst testing shows that the safety requirements for tube burst margins during both normal and accident condition loadings can be satisfied with EOC bobbin coil signal amplitudes less than 4.9 volts, regardless of the depth of tube wall penetration of the cracking.

Upon implementation of the plugging criteria, tube leakage considerations must also be addressed. It must be determined that the cracks will not leak excessively during all plant conditions. For the IPC criteria developed for the Cook Nuclear Plant Unit 1 steam generator tubes, no leakage is anticipated during normal operating conditions even with the presence of potentially through-wall cracks. No leakage during normal operating conditions has been observed in the field for crack indications with signal amplitudes up to 7.7 volts (3/4" tubes). No primary to secondary leakage at the TSPs has been detected in U.S. plants. Relative to the expected leakage during accident condition loadings, the limiting event with respect to differential pressure experienced across the SG tubes is a postulated SLB event. Steam line break primary to secondary leakage will be calculated as prescribed in Section 3.3 of draft NUREG-1477 (using a primary-to-secondary pressure differential of 2560 psid) once EOC 13 eddy current data is reduced. This calculated leakage must be shown to be less than 1.0 gpm in the faulted loop.

Eddy Current Guidelines

The inspection guidelines contained in Appendix A to WCAP-13187, Revision 0 was attached to our submittal AEP:NRC:1166. The WCAP-13187 Appendix A, "NDE Data Acquisition and Analysis Guidelines" (Attachment 6) has been updated to include recent industry data and incorporated as part of the IPC program. The updated eddy current guidelines will be used with this IPC. It defines probe specifications, calibration requirements, specific acquisition and analysis criteria, and flaw recording guidelines to be used for the inspection of the steam generators.

Assessment of IPC Methodology

An assessment of the methodology described in WCAP-13187, Revision 0 will be conducted for the IPC. It will address discrepancies between predicted and actual EOC voltage distributions. The assessment will include:

a. EOC 12 voltage distribution - indications found during the inspection regardless of motorized rotating pancake coil (MRPC) confirmation.

b. Cycle 12 growth rate (i.e. from beginning of cycle (BOC) 12 to EOC 12).

c. EOC 12 repaired indications voltage distribution - distribution of indications presented in (a) above that were repaired (if plugged or sleeved).

d. Voltage distribution for indications left in service at the BOC 13 regardless of MRPC confirmation - obtained from (a) and (c) above.

e. Voltage distribution for indications left in service at the BOC 13 that were confirmed by MRPC to be crack-like or not MRPC inspected.

f. Non-destructive examination uncertainty distribution used in predicting the EOC 13 voltage distribution.

g. Projected EOC 13 voltage distribution using the methodology in WCAP-13187, Revision 0.

h. Actual EOC 13 voltage distribution - indications found during the inspection regardless of MRPC confirmation.

i. Cycle 13 growth rate (i.e. from BOC 13 to EOC 13).

j. EOC 13 repaired indications voltage distribution - distribution of indications presented in (h) above that were repaired (i.e. plugged or sleeved).

k. Voltage distribution for indications left in service at the BOC 14 regardless of MRPC confirmation - obtained from (h) and (j) above.

l. Voltage distribution for indications left in service at the BOC 14 that were confirmed by MRPC to be crack-like or not MRPC inspected.

m. Nondestructive examination uncertainty distribution used in predicting the EOC 14 voltage distribution.

n. Projected EOC 14 voltage distribution using the methodology in WCAP-13187, Revision 0.

The total assessment, (a) through (n) will be submitted approximately 10 weeks from completion of steam generator inspections. However, per technical specification requirements the leak rate and burst probability, growth rate for EOC 13, and projected EOC 14 growth rate will be provided prior to start-up.

Additional Considerations

The proposed amendment would preclude occupational radiation exposure that would otherwise be incurred by personnel involved in tube plugging or repair operations. By reducing non-essential tube plugging, the proposed amendment would minimize the loss of margin in the reactor coolant flow through the steam generator in LOCA analyses. The proposed amendment would avoid loss of margin in reactor coolant system flow and, therefore, assist in demonstrating that minimum flow rates are maintained in excess of that required for operation at full power. Reduction in the amount of tube repair required can reduce the length of plant outages and reduce the time that the steam generator is open to the containment environment during an outage.

The 100% eddy current bobbin probe inspection associated with implementation of the IPC will help to identify new areas of concern which may arise by providing a level of inservice inspection which is far in excess of the Technical Specification requirements utilizing the 40% depth-based plugging limit for acceptable tube wall degradation.

The eddy current inspection, reporting, and leakage requirements as previously stated in the T/Ss for fuel Cycle 13, will be maintained for fuel Cycle 14.

ATTACHMENT 2 TO AEP:NRC:1166H

STEAM GENERATOR TUBE PLUGGING CRITERIA FOR ODSCC

DONALD C. COOK NUCLEAR PLANT UNIT 1

CYCLE 14

10 CFR 50.92 ANALYSIS

In accordance with the three factor test of 10 CFR 50.92(c), implementation of the proposed license amendment is analyzed using the following standards and found not to 1) involve a significant increase in the probability or consequences of an accident previously evaluated; or 2) create the possibility of a new or different kind of accident from any accident previously evaluated; or 3) involve a significant reduction in margin of safety.

Conformance of the proposed amendment to the standards for a determination of no significant hazard as defined in 10 CFR 50.92 (three factor test) is shown in the following:

1) Operation of Donald C. Cook Nuclear Plant Unit 1 in accordance with the proposed license amendment does not involve a significant increase in the probability or consequences of an accident previously evaluated.

Testing of model boiler specimens for free span tubing (no TSP restraint) at room temperature conditions shows burst pressures in excess of 5000 psi for indications of ODSCC with voltage measurements as high as 19 volts. Burst testing performed on pulled tubes from Cook Nuclear Plant Unit 1 with up to a 2.02 volt indication shows measured burst pressure in excess of 10,000 psi at room temperature. Correcting for the effects of temperature on material properties and minimum strength levels (as the burst testing was done at room temperature), tube burst capability significantly exceeds the RG 1.121 criterion requiring the maintenance of a margin of 3 times normal operating pressure differential on tube burst. The 3 times normal operating pressure differential for the Cook Nuclear Plant Unit 1 steam generators corresponds to 4275 psi. Based on the existing data base, this criterion is satisfied with 7/8" diameter tubing with bobbin coil indications with signal amplitudes less than 4.9 volts, regardless of the indicated depth measurement. A 1.0 volt plugging criteria compares favorably with the structural limit considering the previously calculated growth rates for ODSCC within the Cook Nuclear Plant Unit 1 steam generators. Considering a voltage increase of 0.4 volts, and adding a 20% NDE uncertainty of 0.20 volts (90% Cumulative Probability) to the IPC of 1.0 volts results in an EOC voltage of approximately 1.6 volts for Cycle 14 operation. A 3.3 volt safety margin is implied (4.9 structural limit - 1.6 volt EOC = 3.3 volt margin). This EOC voltage compares favorably with the Structural Limit of 4.9 volts.

For the voltage/burst correlation, the EOC structural limit is supported by a voltage of 4.9 volts. A 3.1 volt BOC repair limit confirms the structural limit when 40% growth and 20% uncertainty are applied to the repair limit. This repair limit will be applied for Cycle 14 IPC implementation to repair bobbin indications greater than 3.1 volts independent of RPC confirmation of the indication.

The conservatism of this repair limit is shown by the EOC 12 (Summer 1992) eddy current data. The overall average voltage growth was determined to be only 2.2%, with a 12% average voltage growth for indications less than 0.75 volt BOC and a 1% average voltage growth for indications >0.75 volt at the BOC. In addition, the Cycle 12 maximum observed voltage increase was found to be 0.49 volts, and occurred in a tube initially <1.0 BOC. In accordance with the technical specification requirements, the applicability of Cycle 13 growth rates for Cycle 14 operation will be confirmed prior to return to power of Cook Nuclear Plant Unit 1. Similar large structural margins are anticipated.

As stated previously, TSP proximity to the tubes will prevent tube burst during all plant conditions. Test data indicates that tube burst cannot occur within the TSP, even for tubes which have 100% through-wall EDM notches, 0.75 inch long, provided that the TSP is adjacent to the notched area. Therefore, a more realistic assessment of tube operability should be performed against the RG 1.121 loading requirements during accident SLB conditions, since the TSP has the potential to deflect during blowdown following a main SLB, thereby uncovering the intersection. At the ASME Code recommended faulted condition loading of 3657 psi (2560 psi/0.7) structural integrity is provided for bobbin voltage indications of a minimum of 9.6 volts. The repair limit based on the structural limit at conservative SLB conditions would be 6.0 volts (compared to a 3.1 volt repair limit for a structural limit based on the 3ΔP burst capability voltage).

Only three indications of ODSCC have been reported to have operating leakage, and all three have been in European plants. No field leakage has been reported at other plants from tubes with indications of a voltage level of under 7.7 volts (from 3/4" tubing). Relative to the expected leakage during accident condition loadings, it has been previously established that a postulated main SLB outside of containment but upstream of the MSIV represents the most limiting radiological condition relative to the IPC. In support of implementation of the IPC, it will be determined whether the distribution of cracking indications at the TSP intersections at the EOC 14 are projected to be such that primary to secondary leakage would result in site boundary doses within a small fraction of the 10 CFR 100 guidelines. The SLB leakage rate calculation methodology prescribed in Section 3.3 of draft NUREG-1477 will be used to calculate EOC 14 leakage. Due to the relatively low voltage growth rates at Cook Nuclear Plant Unit 1 and the relatively small number of indications affected by the IPC, SLB leakage prediction per draft NUREG-1477 is expected to be less than the acceptance limit of 1.0 gpm in the faulted loop and far below the conservatively calculated SRP based allowable value of 120 gpm in the faulted loop. The NRC leakage rate calculation methodology applies a 98% confidence limit on leakage that is independent of voltage. This method for calculating SLB leakage is conservative as it assumes no correlation exists between SLB leakage and bobbin probe voltage. Tube pull results from Cook Nuclear Plant Unit 1 indicate that tube wall degradation of greater than 40% through-wall was detectable either by the bobbin or RPC probe. The tube with maximum

through-wall penetration of 56% (42% average) had a voltage of 2.02 volts. This indication also was the largest recorded bobbin voltage from the EOC 12 eddy current data. All burst tested tube intersections had degradation depths of 40% to 56% (actual) deep and all were detected by both probes, with all bobbin voltages greater than or equal to 1.0. Since the criteria requires the plugging of >1.0 volt bobbin indications with confirmed RPC calls, using the Cook Nuclear Plant Unit 1 pulled tube destructive examination results, it is reasonable that no indications of degradation greater than 40% to 56% deep with an ability to influence tube burst capability were left in service. Since the majority of the EOC 14 indications at Cook Nuclear Plant Unit 1 are expected to be below this level, the inclusion of all IPC intersections into the leakage calculation is exceptionally conservative.

Therefore, as re-implementation of the 1.0 volt IPC during Cycle 14 does not adversely affect steam generator tube integrity and results in acceptable dose consequences, the proposed amendment does not result in any increase in the probability or consequences of an accident previously evaluated within the Cook Nuclear Plant Unit 1 FSAR.

2) The proposed license amendment does not create the possibility of a new or different kind of accident from any accident previously evaluated.

Implementation of the proposed steam generator tube IPC does not introduce any significant changes to the plant design basis. Use of the criteria does not provide a mechanism which could result in a tube rupture outside of the region of the TSP elevations; no ODSCC is occurring outside the thickness of the TSPs. Neither a single or multiple tube rupture event would be expected in a steam generator in which the plugging criteria has been applied (during all plant conditions).

Specifically, Cook Nuclear Plant will continue to implement a maximum leakage rate limit of 150 gpd (0.1 gpm) per steam generator to help preclude the potential for excessive leakage during all plant conditions. The Cycle 14 Technical Specification limits on primary to secondary leakage at operating conditions is a maximum of 0.4 gpm (600 gpd) for all steam generators, or, a maximum of 150 gpd for any one steam generator. The RG 1.121 criterion for establishing operational leakage rate limits that require plant shutdown are based upon leak-before-break considerations to detect a free span crack before potential tube rupture. The 150 gpd limit should provide for leakage detection and plant shutdown in the event of the occurrence of an unexpected single crack resulting in leakage that is associated with the longest permissible crack length. RG 1.121 acceptance criteria for establishing operating leakage limits are based on leak-before-break considerations such that plant shutdown is initiated if the leakage associated with the longest permissible crack is exceeded. The longest permissible crack is the length that provides a safety factor of 3 against bursting at normal operating pressure differential. A voltage

amplitude of 4.9 volts for typical ODSCC corresponds to meeting this tube burst requirement at a lower 95% prediction limit on the burst correlation coupled with 95/95 LTL material properties. Alternate crack morphologies can correspond to 4.9 volts so that a unique crack length is not defined by the burst pressure versus voltage correlation. Consequently, typical burst pressure versus through-wall crack length correlations are used below to define the "longest permissible crack" for evaluating operating leakage limits.

At current plant conditions, the single through-wall crack lengths that result in tube burst at 3 times normal operating pressure differential and SLB conditions are 0:44 inch and 0.84 inch, respectively. A leak rate of 150 gpd will provide for detection of 0.42 inch long cracks at nominal leak rates and 0.61 inch long cracks at the lower 95% confidence level leak rates. Since tube burst is precluded during normal operation due to the proximity of the TSP to the tube and the potential exists for the crevice to become uncovered during SLB conditions, the leakage from the maximum permissible crack must preclude tube burst at SLB conditions. Thus, the 150 gpd limit provides for plant shutdown prior to reaching critical crack lengths for SLB conditions.

3) The proposed license amendment does not involve a significant reduction in margin of safety.

The use of the voltage based bobbin probe interim TSP elevation plugging criteria at Cook Nuclear Plant Unit 1 is demonstrated to maintain steam generator tube integrity commensurate with the criteria of Regulatory Guide 1.121. RG 1.121 describes a method acceptable to the NRC staff for meeting GDCs 14, 15, 31, and 32 by reducing the probability or the consequences of steam generator tube rupture. This is accomplished by determining the limiting conditions of degradation of steam generator tubing, as established by inservice inspection, for which tubes with unacceptable cracking should be removed from service. Upon implementation of the criteria, even under the worst case conditions, the occurrence of ODSCC at the TSP elevations is not expected to lead to a steam generator tube rupture event during normal or faulted plant conditions. The EOC 14 distribution of crack indications at the TSP elevations will be confirmed to result in acceptable primary to secondary leakage during all plant conditions and that radiological consequences are not adversely impacted.

In addressing the combined effects of LOCA + SSE on the steam generator component (as required by GDC 2), it has been determined that tube collapse may occur in the steam generators at some plants. This is the case as the TSPs may become deformed as a result of lateral loads at the wedge supports at the periphery of the plate due to the combined effects of the LOCA rarefaction wave and SSE loadings. Then, the resulting pressure differential on the deformed tubes may cause some of the tubes to collapse.

There are two issues associated with steam generator tube collapse. First, the collapse of steam generator tubing reduces the RCS flow area through the tubes. The reduction in flow area increases the resistance to flow of steam from the core during a LOCA which, in turn, may potentially increase peak clad temperature (PCT). Second, there is a potential that partial through-wall cracks in tubes could progress to through-wall cracks during tube deformation or collapse.

Consequently, since the leak-before-break methodology is applicable to the Cook Nuclear Plant Unit 1 reactor coolant loop piping, the probability of breaks in the primary loop piping is sufficiently low that they need not be considered in the structural design of the plant. The limiting LOCA event becomes either the accumulator line break or the pressurizer surge line break. LOCA loads for the primary pipe breaks were used to bound the Cook Nuclear Plant Unit 1 smaller breaks. The results of the analysis using the larger break inputs show that the LOCA loads were found to be of insufficient magnitude to result in steam generator tube collapse or significant deformation.

Addressing RG 1.83 considerations, implementation of the bobbin probe voltage based interim tube plugging criteria of 1.0 volt is supplemented by the following: enhanced eddy current inspection guidelines to provide consistency in voltage normalization, a 100% eddy current inspection sample size at the TSP elevations, and RPC inspection requirements as outlined in the technical specifications and Appendix A "NDE Data Acquisition and Analysis Guidelines" (Attachment 6).

As noted previously, implementation of the TSP elevation plugging criteria will decrease the number of tubes which must be repaired. The installation of steam generator tube plugs reduce the RCS flow margin. Thus, implementation of the alternate plugging criteria will maintain the margin of flow that would otherwise be reduced in the event of increased tube plugging.

Based on the above, it is concluded that the proposed license amendment request does not result in a significant reduction in margin with respect to plant safety as defined in the Final Safety Analysis Report or any of the plant Technical Specifications.

CONCLUSION

Based on the preceding analysis, it is concluded that using the TSP elevation bobbin coil probe voltage-based interim steam generator tube plugging criteria for repairing or removing tubes from service at Donald C. Cook Nuclear Plant Unit 1 is acceptable and the proposed license amendment involves a no significant hazards consideration as defined in 10 CFR 50.92.

ATTACHMENT 5 TO AEP:NRC:1166H

WESTINGHOUSE REPORT NSD-TAP-3052

SUPPLEMENTAL INFORMATION FOR COOK NUCLEAR PLANT UNIT 1 IPC

NSD-TAP-3052

SUPPLEMENTAL INFORMATION FOR THE D. C. COOK-1 IPC

December 9, 1993

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Supplemental Information for the D. C. Cook-1 IPC

1.0 Introduction

This report provides supplemental information to update the APC criteria for D.C. Cook-1 developed in WCAP-13187. Although not included in this report, the Appendix A eddy current analysis guidelines of WCAP-13187 has also been updated to the latest information currently being implemented in support of IPC implementation. The data of this report and the revised Appendix A provide supporting data for implementation of an IPC or APC for Cycle 14 beginning in the spring of 1994. The latest APC database is given in EPRI Report NP-7480-L, Volume 1, Revision 1, September, 1993. This database is used to develop the APC repair limits in this report. Recent destructive examination data from Plant F is also utilized in this report.

An assessment of the 1992 D.C. Cook-1 pulled tube data for incorporation in the APC burst pressure versus bobbin voltage correlation is given in Section 2.0. Voltage growth data are summarized in Section 3.0. The equivalent APC repair limit, above which bobbin voltage indications require repair independent of RPC confirmation, is developed in Section 4.0. For current IPC applications, the NRC has required that potential EOC SLB leak rates be calculated using the methodology described in draft NUREG-1477. This methodology is summarized in Section 5.0.

2.0 Assessment of D.C. Cook-1 Pulled Tube Data for Inclusion in Burst Correlation

In EPRI Report NP-7480-l, Volume 1, Revision 1, Sections 2.5, 4.6 and C.5, the influence of crack morphology on bobbin voltage response is described. Based on the considerations given in this report, it was concluded by the EPRI ARC Committee that the D.C. Cook-1 1992 pulled tube results should not be included in the burst correlation. This discussion (particularly that of Appendix C, Section C.5) is given below and supplemented by destructive exam data from Plant F which became available since Appendix C of the EPRI report was prepared. The EPRI report conclusions are further extended to define morphologies that should be excluded from the burst correlation due to atypical, high voltages (and high burst pressures in the correlation) for relatively minor degradation. It is conservative to apply the IPC/APC repair criteria to these atypical indications which is the D.C. Cook-1 application. The burst morphologies for exclusion from the database are provided in response to the NRC request given to Westinghouse in a NRC, Duke Power, Westinghouse telecon of December 7, 1993.

As discussed in the EPRI report, the dominant causes for low and high "outlier" data points in the burst pressure versus voltage correlation can be explained by the crack morphologies of the limiting burst cracks. In particular, the presence of relatively large ligament areas within deep indications, which lower the voltage response, are typical of low outliers in the burst correlation. The absence of any ligaments or the presence of a very small, uncorroded ligament area results in higher than normal or expected voltage response and high outlier behavior in the burst correlation. Only the high burst pressure outliers are considered for exclusion from the burst correlation (D.C. Cook-1 pulled tubes, for example) and are further discussed in the following.

Table 1 (Table C-2 of EPRI report with Plants F and W added) shows the number and total width of uncorroded ligaments for pulled tubes in which the ligaments were sized as part of the destructive

exam. The burst capability, high or low relative to the 95% confidence bands, is also noted for the associated indications. It is readily seen that the high outliers have the following burst crack morphology features: 0 to 3 uncorroded ligaments with small (≤ 0.020 inch) ligament widths (except D.C. Cook-1, R11C60 - TSP 1) and maximum depths < 60%. These indications are atypical in that shallow cracks more commonly have relatively large numbers of ligaments. As crack depths approach 100%, it is common for the ligaments to corrode and, if they do not corrode, the indications tend toward low outliers on the burst correlation. D.C. Cook-1, R11C60, TSP 1 is a case of a high outlier with a relatively large (0.071 inch) ligament width. For this indication, the largest ligament is near the center of the crack as a ledge between two shorter cracks. The ledge may not have functioned as an effective electrical conductor in comparison to that found for other indications. However, the morphology cause for the high voltage on this indication is not as apparent as for the other high outlier indications.

The influence of loss of ligaments on voltage response of shallow indications is even more dramatically seen for the Plant F data which became available after Appendix C of the EPRI report was prepared. These indications have maximum depths < 30% and voltages as high as 1.81 volts which result from the total loss of ligaments in the shallow indications. For this plant, maximum crack depths as small as 18% have been readily detected by bobbin and RPC inspections which is judged to be due to the loss of ligaments.

The high outlier behavior appears to be associated with low growth rates in that D.C. Cook-1 and Plant F have growth rates among the lowest found for all plants evaluated for IPC/APC applications. It is probable that these low growth rates may be more associated with voltage increases from loss of ligaments than increases in crack depth. It would then be expected that the high outlier behavior trend would become more common as corrosion rates become increasingly lower with further improvements in secondary chemistry. However, this effect of loss of ligaments increasing the voltage response would be expected only for small indications (< 2 to 3 volts) as deeper indications generally have fewer ligaments independent of growth rate.

Based on the above discussion, the cause for high outliers in the burst correlation is the loss of ligaments in shallow (< 60%) cracks resulting in atypical or higher than expected voltages for the associated crack depths. The two plants having pulled tube high outliers have low growth rates which may increase the corrosion of ligaments compared to growth in depth. In total contrast, the general cause for low outliers in the burst correlation is a relatively large number of ligaments (or a single large throughwall ligament) which reduce the voltage but do not contribute significantly to burst capability. Since the causative factors for high and low burst outliers are distinctly different, the high outlier data should not be applied in the burst correlation to strongly influence the low outlier tail of the distribution which is of interest for APC applications. Therefore, it is appropriate to not include high outliers in the burst correlation when the outlier behavior is due to atypical crack morphologies having few ligaments and shallow cracks.

The data of Table 1 permit a definition of atypical morphologies for not including high outliers in the burst correlation. The high outliers are only D.C. Cook-1 and Plant F data. A definition of high outliers for exclusion from the burst correlation of ≤ 2 uncorroded ligaments and < 60% depth encompasses all Cook-1 and Plant F outliers except R11C60, TSP 1. The latter indication has 3 ligaments and a relatively large total ligament width such that it does not readily meet the criterion for exclusion of shallow indications and this indication could optionally be kept in the burst correlation.

No other pulled tube data in either 7/8 or 3/4 inch tube diameters satisfy the above criterion for exclusion of data from the burst correlation. All Plant L tubes except R29C70 of Table 1 have 5 or more ligaments. No comparable high outliers have been found for 3/4 inch diameter tubing. Similarly, no model boiler specimens satisfy the above criterion for exclusion from the burst database. All model boiler specimens destructively examined have maximum crack depths > 60%.

In summary, the D.C. Cook-1 burst data (except possibly R11C60, TSP 1) and all Plant F data should not be included in the burst correlation. The R11C60 indication could optionally be included in the correlation. The criteria for excluding data from the correlation are ≤ 2 uncorroded ligaments and maximum crack depths < 60%.

Based on the burst correlation of the EPRI report, which does not include the D.C. Cook-1 and Plant F data in the correlation, the structural limit for burst at $1.43x\Delta P_{SLB}$ is 9.6 volts and for burst at $3x\Delta P_{NO}$ is 4.9 volts. If the R11C60, TSP 1 indication is retained in the correlation, the latter structural limits are 8.8 and 4.5 volts, respectively. The impact of this one indication on the structural limits, which are evaluated at the lower 95% prediction bound and adjusted for temperature and lower tolerance material properties, is significant because the indication lies well above the upper 95% prediction bound and increases the standard deviation for the burst correlation. It does not appear appropriate to reduce the structural limit based on high burst pressure test results with effectively the same impact on structural limits as a low burst pressure result.

The D.C. Cook-1 and Plant F burst results are much higher than that applied to develop the APC repair limits. If sufficient data were available, it is probable that a burst correlation developed from these data would yield significantly higher repair limits than obtained from the APC database. Therefore, even though the D.C. Cook-1 data are excluded from the APC burst correlation due to their high "outlier" trend, it is conservative to apply the APC repair limits at D.C. Cook-1. Also, since the D.C. Cook-1 burst data exceed the upper 95% confidence band of the APC burst correlation and that these tubes were pulled at the last outage, there is no need for additional tube pulls at the next outage to support IPC or APC implementation.

3.0 Voltage Growth for D.C. Cook-1

Voltage growth rates for D.C. Cook-1 have been developed for the last three operating cycles and the average growth rates are given in Table 3. For the first two cycles, the average growth rates were 42%. In the 1989 time frame, reductions in T-hot and primary pressure were implemented at D.C. Cook-1. While this operating condition change to reduce corrosion growth may not have been strongly effective in the 1989 to 1990 cycle, the impact is evident by the small 2.2% average growth rate found over the last cycle. This growth rate was developed for the largest 202 indications out of a total of 467 indications found at the last inspection. The use of only the largest indications results in a more conservative growth estimate than if all indications are included in the growth distribution. In addition, the larger average BOC voltage for the last cycle of 1.0 volt compared to ≤ 0.45 volts for the prior cycle data of Table 3 is also due to utilizing only the largest indications in the growth evaluation.

In developing the D.C. Cook-1 APC repair limit in WCAP-13187, an allowance for growth of 50% was utilized based on the data of Table 3 up to the 1990 outage. The low growth found in the last cycle permits a reduction in the growth allowance for the APC repair limit. A conservative allowance of 40% growth is applied in this report to develop the equivalent APC repair limit in Section 4.0. If

the current operating cycle continues to demonstrate the low growth rate found over the last cycle, the growth rate allowance in the repair limit could be further reduced.

4.0 Equivalent APC Repair Limit

For IPC applications the equivalent or full APC repair limit is applied to define the upper voltage limit above which indications are to be repaired independent of confirmation of a flaw by RPC inspection. The equivalent APC repair limit is developed by reducing the voltage structural limit by allowances for growth and NDE uncertainties. Per R.G. Guide 1.121, the structural limit is the more limiting of three times normal operating pressure differential ($3x\Delta P_{NO}$) or $1.43x\Delta P_{SLB}$. For ODSCC at TSPs, burst at normal operating conditions is prevented by the constraint of the drilled TSP hole. Consequently, the normal operating structural limit is inherently satisfied essentially independent of voltage and the margin against burst under SLB conditions is the limiting structural criteria. In the D.C. Cook-1 APC WCAP-13187, the normal operating pressure margin was conservatively applied to obtain an APC repair limit of 4.0 volts. In this section, voltage repair limits are developed for both structural limits based on the latest APC database of EPRI Report NP-7480-L, Volume 1, Revision 1. It is recommended that the structural limit based on margin against burst at SLB conditions be applied for APC repair limits.

The allowance for NDE uncertainty applied in WCAP-13187 was 20%. Although new data is available to define the NDE uncertainties as given in the EPRI report, the net NDE uncertainty allowance of 20% for the repair limit remains applicable. As discussed in Section 3, a conservative allowance for voltage growth is 40% based on the low growth found in the last cycle which averaged only 2.2%. Based on the burst pressure versus voltage correlation given in the EPRI report, which does not include the 1992 D.C. Cook-1 pulled tube data in the burst correlation, the voltage structural limit for $1.43x\Delta P_{SLB}$ is 9.6 volts and for $3x\Delta P_{NO}$ is 4.9 volts. In developing the repair limit, the percentage allowances for NDE uncertainties and growth are applied to the repair limit.

Table 2 summarizes the development of the repair limit. The equivalent APC repair limit for margin against SLB would be 6.0 volts and for margins at normal operation (not required due to TSP constraint preventing burst) would be 3.1 volts. The current D.C. Cook-1 Technical Specification has 4.0 volts for the equivalent APC repair limit above which tube repair is required independent of RPC confirmation. The 4.0 volt limit could be retained for the next cycle as a conservative value compared to the 6.0 volts structural limit for margin against burst at SLB conditions.

As described in Section 2.0, the D.C. Cook-1 pulled tube indication R11C60, TSP 1 could optionally be included in the burst correlation since the crack morphology for this tube does not fully meet the criteria developed in this section for excluding shallow indications from the burst correlation. If this indication were included in the correlation, the structural limit for $1.43x\Delta P_{SLB}$ would become 8.8 volts and the equivalent APC repair limit would be 5.5 volts. The application of the 4.0 volt APC repair limit, as given in the Tech. Spec., provides margin against even this 5.5 volt repair limit.

5.0 NRC Leak Rate Methodology

The NRC methodology of draft NUREG-1477 obtains the number of indications as:

$$N = N_d + N_{nd} - N_r = N_d + [(1-POD)/POD]*N_d - N_r = N_d/POD - N_r$$

where, N_d = number of detected bobbin indications
N_r = number of repaired indications
N_{nd} = number of indications not detected by the bobbin inspection
POD = probability of detection (0.6 for NRC methodology)

The above adjustments for POD are incorporated in the BOC voltage distribution used to project the EOC voltage distribution for SLB leakage and burst probability analyses. The POD adjusted BOC voltage distribution is applied to project the EOC distribution by Monte Carlo methods utilizing distributions for NDE uncertainty and voltage growth allowances. The Monte Carlo methods have been described in WCAP-13187 and have been accepted by the NRC for EOC projections and tube burst probability analyses. Section 3.3 of draft NUREG-1477 states that the total leak rate, LR, should be determined as:

$$LR = \mu P + Z \sqrt{[\sigma^2 P + \mu^2 P - \mu^2 \Sigma_i (N_i P_i^2)]}$$

where, μ = mean of the leak rate data independent of voltage
σ = standard deviation of the leak rate data independent of voltage
P_i = probability that a tube leaks for the i-th voltage bin
N_i = number of indications (after POD adjustment) in the i-th voltage bin
$P = \Sigma_i(N_i P_i)$ = expected number of indications that leak summed over all voltage bins
Z = standard normal distribution deviate (establishes level of confidence on leakage)

For the total leakage, the first term of the above equation represents a mean expected leak rate while the square root term is an effective standard deviation for the total leakage. Draft NUREG-1477 recommends that Z be applied as 2 which corresponds to a level of confidence of 98%. Leakage data for the above equation are obtained from EPRI Report NP-7480, Volume 1, Revision 1. These data include the probability of leakage correlation, μ = 14.85 liter/hour and σ = 21.65 liter/hour. As a first order approximation for Z =2 at 98% confidence, the leak rate per indication that leaks is 58.15 liters/hr or 0.26 gpm per leaking indication. Thus P (the number of leaking tubes) would be about 3.8 for 1 gpm leakage which would very roughly correspond to about 60 to 80 indications between 2 and 3 volts at EOC.

Table 1

Pulled Tubes with Measured Ligament Widths

Macrocrack

Plant	Tube	TSP	Length	Max. Depth	No. Ductile Ligaments	Total Width of Ligaments	Volts	Burst Capability [2]
L	R29C70	1	0.29	74%	0	0.0	0.64	
		2	0.62	75%	11	0.074	0.28	Low
		3	0.45	70%	6	0.031	0.59	
	R30C64	1	0.73	55%	11	0.108	0.67	
		2	0.61	62%	7	0.038	1.26	
		3	0.45	49%	5	0.019	1.08	
	R8C69	1	0.86	98%	9	0.063	0.99	Low
		2	<0.75	83%	17	0.059	0.93	Low
		3	0.49	68%	10	0.062	1.04	
P-1	R16C60	2	0.74	68%	10	0.029	0.9	
W	R6C58	1	0.45	91%	0	0.0	1.93	Low
		2	0.31	65%	0	0.0	0.67	
A-1	R14C80	2	0.68	85%	1	0.013	3.3	
	R19C41	1	0.61	71%	2	0.022	3.2	
A-2	R4C73	1	0.42	100%	0	0.0	2.81	
	R38C46	1	0.37	78%	0	0.0	1.44	
Cook-1	R11C60	1	0.75	54%	3	0.071	1.38	High
		2	0.53	52%	1	0.020	1.27	High
	R18C16	1	0.70	48%	1	0.008	1.48	High
	R18C21	1	0.75	56%	1	0.012	2.01	High
F	R13C42	1C	0.40	24%	0	0.0	1.16	High
		2C	0.27	21%	0	0.0	0.52	High
	R16C29	1C	0.38	29%	0	0.0	1.81	High
	R16C42	1C	0.42	29%	0	0.0	1.18	High
		2C	0.36	18%	0	0.0	0.93	High
R-1	R7C71	2	0.35	77%	4	0.053	0.83	
		3	0.44	79%	4	0.021	1.96	
	R9C76	2	0.38	98%	2	0.011	1.30	
		3	0.43	88%	3	0.009	1.50	
	R9C91	3	0.46	82%	2	0.046	1.13	
		2	0.46	100%	4	0.014	3.54	

Notes:

1. Does not include ligaments near (~0.05") edges of crack which have insignificant influence on voltage.

2. Burst capability low or high compared to 95% prediction interval on burst vs. voltage correlation.

Table 2

Tube Repair Limits to Satisfy Structural Requirements

Item	Volts Burst At 3 x ΔP	Volts Burst at 1.43 x ΔP SLB
Maximum Voltage to Satisfy Tube Burst Structural Requirement	4.9	9.6
Allowance for NDE Uncertainty - 20%	0.6	1.2
Allowance for Crack Growth Between Inspections - 40%	1.2	2.4
Equivalent APC Repair Limit •Acceptable Limit to meet Structural Requirement	3.1	6.0

Table 3

Average Voltage Growth Per Cycle for D. C. Cook Unit 1

Cycle	Number Indications	Average V_{Boc}	Average ΔV	Average % ΔV
1987 to 1989 (FC 10)				
Entire Voltage Range	234	0.32	0.13	42%
$V_{BOC} < 0.75$ Volt	230	0.31	0.13	43%
$V_{BOC} \geq 0.75$ Volt	4	0.91	0.10	11%
1989 to 1990 (FC 11)				
Entire Voltage Range	249	0.45	0.19	42%
$V_{BOC} < 0.75$ Volt	225	0.39	0.18	46%
$V_{BOC} \geq 0.75$ Volt	24	0.95	0.08	8%
1990 to 1992 (FC 12)				
Entire Voltage Range	202	1.00	0.022	2.2%
$V_{BOC} < 0.75$ Volt	31	0.67	0.08	12%
$V_{BOC} \geq 0.75$ Volt	171	1.07	0.01	1%

FC = Fuel Cycle

ATTACHMENT 6 TO AEP:NRC:1166H

APPENDIX A

NDE DATA ACQUISITION AND ANALYSIS GUIDELINES

APPENDIX A
NDE DATA ACQUISITION AND ANALYSIS GUIDELINES

A.1 INTRODUCTION

This appendix contains guidelines which provide direction in applying the ODSCC alternate repair limits described in this report. The procedures for eddy current testing using bobbin coil and rotating pancake coil (RPC) techniques are summarized. The procedures given apply to the bobbin coil inspection, except as explicitly noted for RPC inspection. The methods and techniques detailed in this appendix are requisite for the Cook 1 implementation of the alternate repair limit and are to be incorporated in the applicable inspection and analysis procedures. The following sections define specific acquisition and analysis parameters and methods to be used for the inspection of the steam generator tubing.

A.2 DATA ACQUISITION

The Cook 1 steam generators utilize 7/8" OD x 0.050" wall, Alloy 600 mill-annealed tubing. The carbon steel support plates are designed with drilled holes.

A.2.1 Probes

Bobbin Coil Probes

Eddy current equipment used shall be the ERDAU (Echoram Tester), Zetec MIZ-18 or other equipment with similar specifications. To maximize consistency with laboratory data, differential bobbin probes with the following parameters shall be used:

The bobbin probe diameter shall be optimized to provide the largest practical fill factor for the tubes inspected:

Nominal Tube ID: 0.775"
Primary Probe Size: 0.720"
Probe Sizes: 0.640" - 0.740"
Fill Factor: 56% - 86%

The primary probe size should be used whenever the tube can be inspected with the 0.720" diameter probe. Alternate probe sizes can be used when specific tubes cannot be fully inspected with the 0.720" probe such as tubes with sleeves at TSP intersections and small radius tubes sleeved in the tubesheet region. Larger probe diameters than 0.720" are generally acceptable but, for data consistency, should only be used when it has been demonstrated that the larger probe diameter improves the inspection at other regions of the S/Gs than TSP intersections. For all probe diameters, the centering devices must provide stable positioning within the nominal tube I.D. to minimize the variability of the probe response as measured with the four hole wear standard. Alternate probes must have voltage normalization at the 20% ASME holes in the same manner as the 0.720" probe and must meet the acceptance criteria utilizing the probe wear standard (see Section A.2.2 to A.2.5).

Figure A-1 illustrates the equivalence of responses obtained with bobbin probes of various sizes relative to those obtained with the reference 0.720" bobbin. It has been found that the use of bobbin probes smaller in diameter than the reference 0.720" probe, but calibrated to the APC amplitude for 20% holes on an ASME standard, results in conservative signal responses. Plant L data taken with 560 mil or 580 mil bobbin probes as well as with the reference 720 mil probe yielded the following correlation for 46 data points:

[560/580 voltage = 0.47 + 1.07 x (720 voltage)].

Similarly 21 support plate indications tested in Plant A with 640 mil probes calibrated to the APC voltages also yielded a conservative result: 640 voltage = 1.20V (720 voltage).

Each probe shall employ two bobbin coils, each 60 mils long with 60 mils between the coils (center to center spacing equal to 120 mils). Either magnetically biased or non-biased coils may be employed. Table A-1 presents the behavior of 0.720" bobbin probes for an ASME standard, a tube support plate simulation, the 4 hole wear standard and an EDM (electron discharge machined) notch standard for both coil configurations. There is no significant difference in the amplitudes of the responses from non-biased or magnetically biased probes for any of the discontinuities tested. Similar results were reported on pulled tube specimens from Plant R as shown as Table A-2.

Rotating Pancake Coil Probes

The pancake coil diameter shall be ≤0.125". While any number coil (i.e., 1, 2 or 3-coil) probe can be utilized, it is recommended that if a 3-coil probe is used, any voltage measurements should be made with the probe's pancake coil rather than its circumferential or axial coil. The maximum probe pulling speed shall be ≈0.2 in./sec for the 1-coil or 3-coil probe, or 0.4 in./sec for the 2-coil probe. The maximum rotation speed shall be ≈300 rpm; this would result in a pitch of ≈40 mils for the 3 coil probe.

A.2.2 Calibration Standards

Bobbin Coil Standards

To provide IPC implementation at Cook 1 consistent with the development and analyses of the supporting database report and with prior NRC-approved IPC applications, a probe wear standard to guide probe replacement and ASME standards calibrated against the reference laboratory standard are to be utilized.

The bobbin coil calibration standard shall contain:

- Four 0.033" diameter through wall holes, 90° apart in a single plane around the tube circumference. The hole diameter tolerance shall be ±0.001".
- One 0.109" diameter flat bottom hole, 60% through from OD.
- One 0.187" diameter flat bottom hole, 40% through from the OD.
- Four 0.187" diameter flat bottom holes, 20% through from the OD, spaced 90° apart in a single plane around the tube circumference. The tolerance on hole diameter and depth shall be ±0.001".
- A simulated support ring, 0.75" thick, comprised of SA-285 Grade C carbon steel or equivalent.
- This calibration standard will have been calibrated against the reference standard used for the APC laboratory work. Voltages reported for IPC/APC

REACTOR COOLANT SYSTEM

OPERATIONAL LEAKAGE

LIMITING CONDITION FOR OPERATION

3.4.6.2 Reactor Coolant System leakage shall be limited to:

a. No PRESSURE BOUNDARY LEAKAGE,

b. 1 GPM UNIDENTIFIED LEAKAGE,

c. 600 gallons per day total primary-to-secondary leakage through all steam generators and 150 gallons per day through any one steam generator for Fuel Cycle 14.

d. 10 GPM IDENTIFIED LEAKAGE from the Reactor Coolant System,

e. Seal line resistance greater than or equal to 2.27E-1 ft/gpm^2 and,

f. 1 GPM leakage from any reactor coolant system pressure isolation valve specified in Table 3.4-0.

APPLICABILITY: MODES 1, 2, 3 and 4.**

ACTION:

a. With any PRESSURE BOUNDARY LEAKAGE, be in at least HOT STANDBY within 6 hours and in COLD SHUTDOWN within the following 30 hours.

b. With any Reactor Coolant System leakage greater than any one of the above limits, excluding PRESSURE BOUNDARY LEAKAGE, reduce the leakage rate to within limits within 4 hours or be in at least HOT STANDBY within the next 6 hours and in COLD SHUTDOWN within the following 30 hours.

c. With any reactor coolant system pressure isolation valve(s) leakage greater than the above limit, except when:

   1. The leakage is less than or equal to 5.0 gpm, and

   2. The most recent measured leakage does not exceed the previous measured leakage* by an amount that reduces the

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* To satisfy ALARA requirements, measured leakage may be measured indirectly (as from the performance of pressure indicators) if accomplished in accordance with approved procedures and supported by computations showing that the method is capable of demonstrating valve compliance with the leakage criteria.

** Specification 3.4.6.2.e is applicable with average pressure within 20 psi of the nominal full pressure value.

applications shall include the cross calibration differences between the field and laboratory standard.

- A probe wear standard for monitoring the degradation of probe centering devices leading to off-center coil positioning and potential variations in flaw amplitude responses. This standard shall include four through wall holes, 0.067" in diameter, spaced 90° apart around the tube circumference with an axial spacing such that signals can be clearly distinguished from one another (see Section A.2.3).

<u>RPC Standard</u>

The RPC standard shall contain:

- Two axial EDM notches, located at the same axial position but 180° apart circumferentially, each 0.006" wide and 0.5" long, one 80% and one 100% through wall from the OD.

- Two axial EDM notches, located at the same axial position but 180° apart circumferentially, each 0.006" wide and 0.5" long, one 60% and one 40% through wall from the OD.

- Two circumferential EDM notches, one 50% throughwall from the OD with a 75° (0.57") arc length, and one 100% throughwall with a 26° (0.20") arc length, with both notches 0.006" wide.

- A simulated support segment, 270° in circumferential extent, 0.75" thick, comprised of SA-285 Grade C carbon steel or equivalent.

The center to center distance between the support plate simulation and the nearest slot shall be at least 1.25". The center to center distance between the EDM notches shall be at least 1.0". The tolerance for the widths and depths of the notches shall be $\pm$0.001". The tolerance for the slot lengths shall be $\pm$0.010".

A.2.3 Application of Bobbin Coil Probe Wear Standard

A calibration standard has been designed to monitor bobbin coil probe wear (see Figure A-2). During steam generator examination, the bobbin coil probe is inserted into the wear monitoring standard; the initial (new probe) amplitude response from each of the four holes is determined and compared on an individual basis with subsequent measurements. Signal amplitudes or voltages from the individual holes must remain within 15% of their initial amplitudes for an acceptable probe wear condition. If this condition is not satisfied for all four holes, then the probe must be replaced. If any of the last probe wear standard signal amplitudes prior to probe replacement exceed the +/- 15% limit, say by a value of X%, then any indications measured since the last acceptable probe wear measurement that are within x% of the plugging limit must be reinspected with the new probe. For example, if any of the last probe wear signal amplitudes prior to probe replacement were 17% above or below the initial amplitude, then indications that are within 2% (17% - 15%) of the plugging limit must be reinspected with the new probe. Alternatively, the voltage criterion may be lowered to compensate for the excess variation; for the case above tubes with amplitudes $\geq$0.98 volts times the voltage criterion could be subject to repair.

A.2.3.1 Placement of Wear Standards

Under ideal circumstances, the incorporation of a wear standard in line with the conduit and guide tube configuration would provide continuous monitoring of the behavior of bobbin probe wear. However, the curvature of the channelhead places restrictions on the length of in line tubing inserts which can be accommodated. The spacing of the ASME Section XI holes and the wear standard results in a length of tubing which cannot be freely positioned within the restricted space available. The flexible conduit sections inside the channelhead, together with the guide tube, limit the space available for additional in line components. Voltage responses for the wear standard are sensitive to bending of the leads, and mock up tests have shown sensitivity to the robot end effector position in the tubesheet, even when the wear standard is placed on the bottom of the channelhead. Effects such as bending of the probe leads can result in premature probe replacement. Wear standard measurements must permit some optimization of positions for the measurement and this should be a periodic measurement for inspection efficiency. The pre-existing requirement to check calibration using the ASME tubing standard is satisfied by periodic probing at the beginning and end of each probe's use as well as at four hour

intervals. This frequency is adequate for wear standard purposes as well. Evaluating the probe wear under uncontrollable circumstances would present variability in response due to channelhead orientations rather than changes in the probe itself.

A.2.4 Acquisition Parameters

The following parameters apply to bobbin coil data acquisition and should be incorporated in the applicable inspection procedures to supplement (not necessarily replace) the parameters normally used.

Test Frequencies

This technique requires the use of 400 kHz and 100 kHz test frequencies in the differential mode. It is recommended that the absolute mode also be used, at test frequencies of 100 kHz and 10 kHz. The low frequency (10 kHz) channel should be recorded to provide a positive means of verifying tube support plate edge detection for flaw location purposes. The 400 kHz channel or the 400/100 kHz mix are also used to assess changes in signal amplitudes for the probe wear standard as well as for flaw detection.

RPC frequencies should include 400 kHz, 300 kHz and 10 kHz.

Digitizing Rate

A minimum bobbin coil digitizing rate of 30 samples per inch should be used. Combinations of probe speeds and instrument sample rates should be chosen such that:

$$\frac{\text{Sample Rate (samples/sec.)}}{\text{Probe Speed (in./sec.)}} \geq 30 \text{ (samples/in.)}$$

Spans and Rotations

Spans and rotations can be set at the discretion of the user and/or in accordance with applicable procedures, but all TSP intersections must be viewed at a span setting one-half or less than that which provides 3/4 full screen amplitude for 4 x 20% holes with

bobbin probes and 1/10 or less than the corresponding span for 0.5" throughwall slot (EDM notch) with RPC probes.

Mixes

A bobbin coil differential mix is established with 400 kHz as the primary frequency and 100 kHz as the secondary frequency, and suppression of the tube support plate simulation should be performed. Complementary information may be obtained from a 200 kHz/100 kHz mix; e.g., influence of dents at TSP's can be inferred from the difference with the 400 kHz/100 kHz mix.

A.2.5 Analysis Parameters

This section discusses the methodology for establishing bobbin coil data analysis variables such as spans, rotations, mixes, voltage scales, and calibration curves. Although indicated depth measurement may not be required to support an alternative repair limit, the methodology for establishing the calibration curves is presented. The use of these curves is recommended for consistency in reporting and to provide compatibility of results with subsequent inspections of the same steam generator and for comparison with other steam generators and/or plants.

Rotation

The signal from the 100% through wall hole at 400 kHz should be set to 40° (±1°), with the initial signal excursion down and to the right during probe withdrawal. The signal from the probe motion for the 400/100 kHz differential mix should be set to horizontal, with the initial excursion of the 100% through wall hole signal going down and to the right during probe withdrawal.

Voltage Scale

1) Bobbin - The peak-to-peak signal amplitude of the signal from the four 20% OD flaws should be set to produce a field voltage equivalent to that obtained for the EPRI lab standard. The EPRI laboratory standard normalization voltages are 4.0 volts at 400 kHz for 20% ASME holes and 2.75 volts at 400/100 kHz mix for 20% ASME holes. The field standard will be calibrated against the laboratory standard using a reference laboratory probe to establish voltages for

the field standard that are equivalent to the above laboratory standard. These equivalent voltages are then set on the field standard to establish the calibration voltages. Voltage normalization for the specific standard in the 400/100 mix is recommended to minimize analyst sensitivity in establishing the mix.

2) RPC - The RPC amplitude shall be set to 20 volts for the 0.5 inch throughwall notch at 400 kHz and 300 kHz; i.e., the amplitude shall be set to 20 volts for each channel.

Calibration Curve

For the 400 kHz differential channel, establish a curve using measured signal phase angles in combination with the "as-built" flaw depths for the 100%, 60%, and 20% flaws on the calibration standard. The "as read" depth of the drilled holes should be determined from the 400 kHz differential channel. This should be accomplished by setting the phase angle of the 100% drilled holes to 40° and then determining the "as read" depth of the 60% and 20% drilled holes. These "as read" depths should then be employed for the setup of all phase angle calibration curves. For the 400/100 kHz differential mix channel, establish a curve using measured signal phase angles in combination with the "as-built" flaw depths for the 100%, 60%, and 20% flaws on the calibration standard.

A.2.6 Analysis Methodology

Bobbin coil indications attributable to ODSCC at support plates are quantified using the Mix 1 (400 kHz/100 kHz) data channel. This is illustrated with the example shown in Figure A-3. The 400/100 kHz mix channel and other channels appropriate for flaw detection (400 kHz, 200 kHz) can be used to locate the indication of interest within the support plate signal. The largest amplitude portion of the lissajous signal representing the flaw should be measured using the 400/100 kHz Mix 1 channel to establish the peak-to-peak voltage as shown in Figure A-4. Initial placement of the dots for identification of the flaw may be performed from the raw frequencies as shown in Figures A-3 to A-5, but the final peak-to-peak measurements must be performed on the Mix 1 lissajous signal to include the full flaw segment of the signal. It may be necessary to iterate the position of the dots between the identifying frequency data (e.g., 400 kHz) and the Mix 1 data to assure proper placement of the dots. As can be seen in Figures A-4 and A-5, failure to do so can significantly change the amplitude

measurement of Mix 1 due to the interference of the support plate signal in the raw frequencies. The voltage measured from Mix 1 is then entered as the analysis of record for comparison with the repair limit voltage.

To support the uncertainty allowances maintained for the Plugging Criterion, the difference in amplitude measurements between independent analysts for each indication will be limited to 20%. If the voltage values called by the independent analysts deviate by more than 20% and one or both of the calls exceeds the voltage repair criterion, resolution by the lead analyst will be performed. This resolution process results in enhanced confidence that the reported voltage departs from the correct call by no more than 20%.

A.2.7 Reporting Guidelines

The reporting requirements identified below are in addition to any other reporting requirements specified by the user.

Minimum Requirements

At a minimum, flaw signals in the 400/100 mix channel at the tube support plate intersections whose peak-to-peak signal amplitude exceeds the voltage repair criterion or a threshold voltage for RPC inspection, whichever is lower, must be reported. Flaw signals, however small, should also be reported for historical purposes and to provide an assessment of the overall condition of the steam generator(s).

Additional Requirements

For each reported indication, the following information should be recorded:

Tube identification	(row, column)
Signal amplitude	(volts)
Signal phase angle.	(degrees)
Indicated depth	(%) †

† It is recommended that an indicated depth be reported as much as possible rather than some letter code. While this measurement is not required to meet the alternate repair limit, this information might be required at a later date and/or otherwise be used to develop enhanced analysis techniques.

Test channel	(ch#)
Axial position in tube	(location)
Extent of test	(extent)

RPC reporting requirements should include a minimum of: type of degradation (axial, circumferential or other), maximum voltage, phase angle, crack lengths, and location of the center of the crack within the TSP. The crack axial center may not coincide with the position of maximum amplitude. For IPC applications, locations which do not exhibit flaw-like indications in the RPC isometric plots may continue in service, except that all intersections exhibiting flaw-like bobbin behavior and bobbin amplitudes in excess of an upper voltage limit typical of the full APC repair limit (defined by approved IPC criteria) must be repaired, notwithstanding the RPC analyses. RPC isometrics should be interpreted by the analyst to characterize the signals observed; only featureless isometrics are to be reported as NDD. Signals not interpreted as flaws include dents, lift off, deposits, copper, magnetite, etc.; these represent "non-relevant" conditions which do not impact tube integrity as reported.

A.3 DATA EVALUATION

A.3.1 Use of 400/100 Differential Mix for Extracting the Bobbin Flaw Signal

In order to identify a discontinuity in the composite signal as an indication of a flaw in the tube wall, a simple signal processing procedure of mixing the data from the two test frequencies is used which reduces the interference from the support plate signal by about an order of magnitude. The test frequencies most often used for this signal processing are 400 kHz and 100 kHz for 50 mil wall Inconel-600 tubing. The processed data is referred to as 400/100 mix channel data. This procedure may also reduce the interference from magnetite accumulated in the crevices. Any of the differential data channels including the mix channel may be used for flaw detection (though the 100 kHz channel is subject to influence from many different effects), but the final evaluation of the signal detection, amplitude and phase will be made from the 400/100 differential mix channel. Upon detection of a flaw signal in the differential mix channels, confirmation from other raw channels is not required. The voltage scale for the 400/100 differential channel should be normalized as described in Section A.2.5.

With a typical bobbin calibration (Figure A-6), flaw signals in the upper half of the impedance plane (0° to 180°) are assumed to be I.D. in origin for phase angles from 0° to the angle corresponding to the 100% hole — typically around 35° in the 400/100 mix; phase angles from 35° to 180° are attributed to O.D. origin. Industry practice provides 10° variation about 0° or 180° due to redundancy of shallow flaws and probe wobble or denting, i.e., lift off signals. Thus, flaw signals are expected to be observed in the 10° - 170° range. Examination of the calibration curve shows that the 0% depth intercept occurs at phase angles below 170°, usually in the 125° - 150° range. Since ODSCC depth is not well represented by the phase angle measurement, especially for small amplitude signals, some flaw-like signals may exhibit phase angles at or beyond the 0% intercept but less than or equal to 170° (Figures A-7 and A-8). Industry practice regards these signals as non-reportable, and RPC testing of these signals at plants such as D. C. Cook-1 and Plant A has not confirmed the presence of detectable cracks. Nevertheless, inasmuch as these signals may represent ODSCC, they should be reported as O.D. indications of unmeasurable depth.

In some cases it has been observed (Figure A-9) that I.D. oriented flaw signals, those with phase angles ≥ 10° but ≤ 35° (100% hole phase angle in the 400/100 mix), are encountered in non-dented support plate intersections. It has been confirmed at Plant A-2 and at Plant L from tube pull information or from RPC testing (Figure A-10) that these apparent I.D. origin bobbin signals correlate well with ODSCC. To assure appropriate disposition of these signals within the alternate repair framework, these signals will be reported in the same fashion as those which present clear O.D. phase information.

The Cook 1 reporting guidelines require that TSP flaw signals with I.D. oriented phase angles be reported using the possible indication (PI) designation as is done for the measurable O.D. oriented indications. For the unmeasurable O.D. signals (phase angle ≥ 0% intercept), the designation applied is UOA (unusual O.D. phase angle). All PI's > the voltage threshold for RPC inspection or for repair (IPC currently 1.0 volts) will be subject to RPC testing.

PI's continued in service in prior years because of acceptable voltage or RPC NDD results may upon re-inspection in subsequent outages be evaluated as not exhibiting flaw characteristics. These signals will be designated INR (indication not reportable) but the location, phase angle, and amplitude will be recorded to facilitate year to year comparisons and growth rate determinations.

This evaluation procedure requires that there is no minimum voltage for flaw detection purposes and that all flaw signals, however small, be identified. The intersections with flaw signals (PIs) greater than the voltage threshold (e.g., IPC = 1.0 volts) will be inspected with RPC in order to confirm the presence of ODSCC. Although the signal voltage is not a measure of the flaw depth, it is an indicator of the tube burst pressure when the flaw is identified as axial ODSCC with or without minor IGA. UOA and INR signals will be included in the RPC sampling plan with emphasis on sample RPC inspection of indications greater than the voltage repair limit.

This procedure using the 400/100 mix for reducing the influence of support plate and magnetite does not totally eliminate the interference from copper, alloy property change or dents. These are discussed below.

A.3.2 Amplitude Variability

Figures A-11 and A-12 illustrate how significant amplitude differences between two analysts measurements might arise: Analyst 1 (Figure A-11) has made a more conservative estimate by placing his measurement dots where the differential phase in all channels trends out of the flaw plane, while flaw plane phase angles appear beyond the upper dot placement in Analyst 2's graphic (see Figure A-12). Analyst 1's conservative call produces a peak-to-peak voltage (1.72V) one-third (1/3) greater than Analyst 2's result. Figure A-12 represents an example in which the placement of the max-rate dots which establish the maximum estimated flaw depth under-estimates the apparent flaw-related peak-to-peak voltage. The correct placement (Figure A-11) also corresponds to the maximum voltage measurement on the 400 kHz raw frequency data channel.

In some cases, it will be found that little if any definitive help is available from the use of the raw frequencies. Such examples are shown in Figure A-13 and A-14. Consequently, the placement of the measurement dots must be made completely on the basis of the Mix 1 channel lissajous figure as shown in the lower right of the graphic. An even more difficult example is shown in Figure A-15. The logic behind the placement of the dots on Mix 1 is that sharp transitions in the residual support plate signals can be observed at the locations of both dots. This is a conservative approach and should be taken whenever a degree of doubt as to the dot placement exists.

The source of error becomes more noticeable when the data involves complicating factors or interferences which make the process of flaw identification more difficult; the contrast between tubes which exhibit signs of minor denting in the support plates and tubes which are essentially free from denting present such circumstances. How denting affects flaw detection is described in Section A.3.5.

By employing these techniques, identification of flaws is improved and conservative amplitude measurements are promoted. The Mix 1 traces which result from this approach conform to the model of TSP ODSCC which represents the degradation as a series of microcrack segments axially integrated by the bobbin coil; i.e., short segments of changing phase direction represent changes in average depth with changing axial position. This procedure is to be followed for reporting voltages for the plugging criteria of this report. This procedure may not yield the maximum bobbin depth call. If maximum depth is desired for information purposes, shorter segments of the overall crack may have to be evaluated to obtain the maximum depth estimate. However, the peak-to-peak voltages as described herein must be reported, even if a different segment is used for the depth call.

The Cook site guidelines for reporting EC indications require that indications reported by any of the independent analyses will cause the particular location to be identified with an indication. If the largest voltage call exceeds the voltage repair limit volts and another analysis is NDD, reporting as an indication or not will be determined by a resolution analyst. If the amplitude measurements reported from the analyses differ, the larger of the measurements will control unless the lead analyst (primary vendor Level III) clearly establishes that the higher amplitude measurement is erroneous. Lead analyst review is required on indications exceeding the voltage repair limit for which the reported voltages differ by more than 20%. Exercise of this review by the lead analyst will be denoted by use of LAR (Lead Analyst Review) as a comment associated with the data base entry for that indication. Each analyst's original call will be preserved on his individual report and stored on the permanent record optical disk for the inspection. This practice limits the uncertainty attributable to analyst uncertainty to 20%.

A.3.3 Copper Interference

In situations where significant copper interference in the eddy current data is noted, the eddy current technique could become unreliable. This results from the unpredictability of the amount and morphology of copper deposits on the tubes which may be found in operating steam generators. The above observation is true both for bobbin and RPC or any other eddy current probe. However, significant copper interference does not occur in the support plate crevice regions of Cook 1 steam generators. This is confirmed by destructive examination of the support plate intersections on tubes pulled from Cook and the original Cook 2 steam generators. No plated copper was found on the tube OD within the support plate crevice, although some minor plated copper patches outside the crevice region were sometimes observed.

Inspections with RPC and bobbin probes have shown good correlation for flaw amplitudes exceeding 1.0 volt; i.e., more than 50% of the bobbin signals identified have been confirmed to exhibit flaws to the RPC probe. This suggests that spurious signals from conductive deposits do not result in excessively high false call rates. Furthermore, signals judged as NDD with the bobbin guidelines have been confirmed to be free of RPC detectable flaws. Copper is a concern for NDE only when plated directly on the tube surface in elemental form. Copper particles with the sludge in the crevice do not significantly influence the eddy current response. To Westinghouse's knowledge, no pulled tubes have been identified with copper deposits on the tube at the TSP intersections — in contrast with free span tubing. If copper interference is observed at Cook 1, the existing rules and procedures for complying with the technical specifications plugging limit based on depth of wall penetration will apply.

A.3.4 Alloy Property Changes

This signal manifests itself as part of the support plate "mix residual" in both the differential and absolute mix channels. It has often been confused with copper deposit as the cause. Such signals are often found at support plate intersections of operating plants, as well as in the model boiler test samples, and are not necessarily indicative of tube wall degradation. Six support plate intersections from Plant A-2, judged as free of tube wall degradation on the basis of the mixed differential channel using the guidelines given in Section A.2.5 and A.2.6 of this document, were pulled in 1989. Examples of the bobbin coil field data are shown in Figures A-16 through A-18.

The mix residuals for these examples are between 2 and 3 volts in the differential mix channel and no discontinuity suggestive of a flaw can be found in this channel. All of them do have an offset in the absolute mix channel which could be construed as a possible indication. These signals persisted without any significant change even after chemically cleaning the OD and the ID of the tubes. The destructive examination of these intersections showed very minor or no tube wall degradation. Thus, the overall "residuals" of both the differential and absolute mix channels were not indications of tube wall degradation. One needs to examine the detailed structure of the "mix residual" (as outlined in Sections A.2.5 and A.2.6) in order to assess the possibility that a flaw signal is present in the residual composite. Similar offsets in the absolute channels have been observed at the top of the tubesheet in plants with partial length roll expansions; in such cases, destructive examination of sections pulled from operating plants have shown no indication of tube wall degradation. Verification of the integrity of intersections exhibiting alloy property or artifact signals is accomplished by RPC testing of a representative sample of such signals.

A.3.5 Dent Interference

There are essentially no corrosion induced dent signals of any significance at the support plate intersections of Cook 1. A small population of original condition dents, mainly at the upper support plates, with voltages up to about 10-15 volts, are present; this is typical of the as-built condition of a steam generator, which may have random local dents ("dings"), some at support plate elevations. These locations, when tested with bobbin probes, produce signals which are a composite of the dent signal plus other contributing effects such as packed magnetite, conductive deposits, alloy property change (artifacts) plus flaw signals if present and the support plate itself.

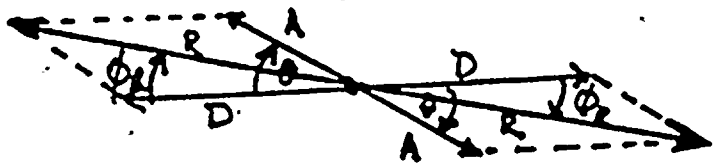
The 400/100 kHz (differential) support plate suppression mix reduces the support plate and the magnetite signals, but the resulting processed signal may still be a composite of the dent, artifact, and flaw signals. These composite signals represent vectorial combinations of the constituent effects, and as such they may not conform to the behavior expected from simple flaw simulations as a function of test frequency.

The effect of the dent on the detection and evaluation of a flaw signal depends on both the relative amplitudes of the flaw and dent signals and the relative spatial relationship between them. If the flaw is located near the center of the dent signal, interference with flaw detection may become insignificant, even for relatively large dent

to flaw signal amplitude ratios. The flaw signal in a typical support plate dent in this event occurs mid-plane — away from the support plate edges where the dent signal has maximum voltage; thus the flaw in the middle section of the support plate shows up as a discontinuity in the middle of the composite signal. Some examples of such cases in the field data obtained from another plant are shown in Figures A-17 to A-22 for dents with peak-to-peak amplitudes ranging from ~4 to 10 volts. The top pictures in these figures show the composite signal voltages; the pictures in the bottom half give the flaw voltages. For example, in Figure A-19, the dent voltage at 400 kHz is ~10.3 volts and the flaw signal voltage in the 400/100 kHz mix channel is ~1.3 volts. It can be observed from these figures that one can extract a flaw signal even when the signal to noise (S/N) ratio is less than unity. The question of S/N ratio requirements for the detection and evaluation of the flaw signal is answered by examination of Figures A-19 to A-24. In all cases shown, S/N is less than 1, and the flaw signal can be detected and evaluated.

The greatest challenge to flaw detection due to dent interference occurs when the flaw signal occurs at the peak of the dent signal. Detection of flaw signals of amplitudes equal to or greater than 1.0 volts — the criterion associated with IPC confirmatory RPC testing — in the presence of peak dent voltages can be understood by vectorial combination of a 1.0 volt flaw signal across the range of phase angles associated with 40% (110 degrees) to 100% (40 degrees through wall penetrations with dent signals of various amplitudes. It is easily shown that 1.0 volt flaw signals combined with dent signals up to approximately 5 volts peak-to-peak will yield resultant signals with phase angles that fall within the flaw reporting range, and in all cases will exceed 1.0 volts. All such signals with a flaw indication signal will be subjected to RPC testing. To demonstrate this, one-half the dent peak-to-peak voltage (entrance of exit lobe) can be combined with the 1.0 volt flaw signal at the desired phase angle. The inspection data shown in Figures A-19 through A-24 illustrates flaw detection and evaluation for flaws situated away from the peak dent voltages. The vector combination analysis shows that for moderate dent voltages where flaws occur coincident with dent entrance or exit locations, flaw detection at the 1.0 volts amplitude level is successful via phase discrimination of combined flaw/dent signals from dent only signals.

The vector addition model for axial cracks coincident with denting at the TSP edge is illustrated as follows:



where

R	=	Resultant Signal Amplitude
A	=	Flaw Signal Amplitude
D	=	TSP Dent Amplitude - one edge (Peak to Peak = 2D)
θ	=	Flaw Signal Phase Angle (100% = 40°; 40% ~ 110°)
ϕ_R	=	Phase Angle of Resultant Signal

and $R^2 = (D + A\cos\theta)^2 + (A\sin\theta)^2$

$\phi_R = \arctan^{-1} (A\sin\theta/D + A\cos\theta)$

For dents without flaws, a nominal phase angle of 180° (0°) is expected. The presence of a flaw results in rotation of the phase angle to < 180° and into the flaw plane. A phase angle of 170° (10° away from nominal dent signal) provides a sufficient change to identify a flaw. For dents with peak-to-peak amplitudes of 5 volts, D = 2.5V and the minimum phase angle rotation (ϕ_R) for a 1.0V ODSCC flaw signal greater than 40% throughwall is predicted to be at least 11°, sufficiently distinguishable from the 180° (0°) phase angle associated with a simple dent. Such signals should be reported as possible flaws and subjected to RPC testing for final disposition.

Supplemental information to reinforce this phase discrimination basis for flaw identification can be obtained by examination of a 200 kHz/100 kHz mix channel; the dent response would be lessened while the OD originating flaw response is increased relative to the 400 kHz/100 kHz mix. RPC testing of indications identified in this fashion will confirm the dependability of flaw signal detection. A sample of intersections with dent voltages (phase angle 180° 0° +/- 10°) exceeding 5.0 volts will be RPC tested.

A.3.6 RPC Flaw Characterization

The RPC inspection of the intersections with bobbin coil flaw indications exceeding the voltage threshold is recommended in order to verify the applicability of the alternate repair limit. This is based on establishing the presence of ODSCC with minor IGA as the cause of the bobbin indications.

The signal voltage for the RPC data evaluation will be based on 20 volts for the 100% throughwall, 0.5" long EDM notch at all frequencies. The nature of the degradation and its orientation (axial or circumferential) will be determined from careful examination of the isometric plots of the RPC data. The presence of axial ODSCC at the support plate intersections has been well documented, but the presence of cellular corrosion which includes elements of circumferential ODSCC at the support plate intersections has also been established by tube pull in several plants. Figures A-25 to A-27 show examples of single and multiple axial ODSCC. Figure A-28 is an example of a circumferential indication related to ODSCC at a tube support plate location from another plant. If circumferential involvement results from circumferential cracks as opposed to multiple axial cracks, discrimination between axial and circumferential oriented cracking can be generally established for affected arc lengths greater than about 45 degrees to 60 degrees.

Pancake coil resolution is considered adequate for separation between circumferential and axial cracks. This can be supplemented by careful interpretation of 3-coil results. Circumferential cracking is not expected to occur in the Cook 1 steam generators since denting is limited to random locations affecting a small number of tubes. If a well defined circumferential indication is identified at a tube support plate location in the Cook 1 steam generators (>60 degrees circumferential extent), guidelines for RPC interpretation will be reviewed and consideration given to supplemental inspection techniques for resolution of the degradation mode.

The isometric graphics which are produced to illustrate the distribution of signals in a TSP may sometimes exhibit distributed extents of flaw content not readily identified with the discrete axial indications associated with cracks; this may occur with or without the presence of crack signals. The underlying tubing condition represented by volumetric flaw indications is interpreted in the context of the relative sensitivity of various flaw types (pits, wastage/wear, IGA, distributed cracks) potentially present.

The response from pits of significant depth is expected to produce geometric features readily identifiable with small area to amplitude characteristics. When multiple pits become so numerous as to overlap in the isometric display, the practical effect is to mimic the response from wastage or wear at comparable depths. In these circumstances the area affected is generally large relative to the peak amplitudes observed.

The presence of IGA as a local effect directly adjacent to crack faces is expected to be indistinguishable from the crack responses and as such of no structural consequence. When IGA exists as a general phenomenon, the EC response is proportional to the volume of material affected, with phase angle corresponding to depth of penetration and amplitude relatively larger than that expected for small cracks. The presence of distributed cracking, e.g., cellular SCC, may produce responses from microcracks of sufficient individual dimensions to be detected but not resolved by the RPC, resulting in apparent volumetric responses similar to wastage and IGA.

For hot leg TSP locations, there is little industry experience on the basis of tube pulls that true volumetric degradation, i.e., actual wall loss or generalized IGA, actually occurs. Figure A-29 illustrates the RPC response from a Plant A pulled tube in which closely spaced axial cracks (lower portion of Figure) produced an indication suggestive of a circumferential or volumetric condition. All cases reviewed for the APC present morphologies representative of ODSCC with varying density of cracks and penetrations but virtually no loss of material in the volumetric sense. Appendix C of EPRI Report NP-7480-L, Volume 1, Revision 1 provides a mode detailed discussion of RPC response characteristics consistent with the APC database. The available data in this report indicate that RPC responses < 150° in azimuthal extent and > 0.2 inch axial length are acceptable responses for RPC applications. For cold leg TSP locations, considerable experience has accrued that volumetric degradation in the form of wastage has occurred on peripheral tubes, favoring the lower TSP elevations.

Therefore, hot leg RPC volumetric flaw indications within the TSP intersections will be presumed to represent ODSCC, while only peripheral tube, lower TSP locations on the cold leg with RPC volumetric flaw indications will not be so characterized.

A.3.7 Confinement of ODSCC/IGA Within the Support Plate Region

In order to establish that bobbin indication is within the support plate, the displacement of each end of the signal is determined relative to the support plate center. The field measurement is then corrected for field spread (look-ahead) to determine the true distance from the TSP center to the crack tip. If this distance exceeds one-half the support plate axial length (0.375"), the crack will be considered to have progressed outside the support plate. Per the repair criteria (Section 10) indications extending outside the support plate require tube repair or removal from service.

A.3.7.1 Crack Length Determination with RPC Probes

The measurement of axial crack lengths from RPC isometrics is presently a standard portion of the Cook 1 EC interpretation practices. For the location of interest, the low frequency channel (e.g., 10 kHz) is used to set a local scale for measurement. By establishing the midpoint of the support plate response and storing this position in the 300 kHz and 400 kHz channels, a reference point for crack location is established. Calibration of the distance scale is accomplished by setting the displacement between the 10 kHz absolute, upper and lower support plate transitions, equal to 0.75 inch.

At the analysis frequency, either 300 kHz or 400 kHz, the ends of the crack indication are located using the slope-intercept method; i.e., the leading and trailing edges of the signal pattern are extrapolated to cross the null baseline (see Figure A-30). The difference between these two positions is the crack length estimate. The slope-intercept method, studied by Junker and Shannon[1],

[1]EPRI TR-101104, W. R. Junker and R. E. Shannon, August 1992

utilizes the total impedance data profile to predict the actual crack length from pancake EC data. This technique, which is illustrated in Figure 31, yields measurements which are less affected by the shape of the crack than does the amplitude threshold technique commonly used in field measurements. The measurements obtained consistently oversized the true crack length by approximately one coil diameter.. Thus, for calculations using crack lengths, the field measured lengths should be adjusted for pancake coil diameter. Alternately, the number of scan lines indicating the presence of flaw behavior time the pitch of the RPC provides an

estimate of the crack length which must be corrected for EC field spread. Figures A-32 and A-33 illustrate the identification of the first and last scan lines of the linear indication from which the length of the underlying flow can be determined.

A.3.8 RPC Inspection Plan

The RPC inspection plan will include the following upon implementation of the APC repair limits:

- Bobbin voltage indications greater than the authorized voltage threshold. (for example, IPC = 1.0 volts)

- A representative sample of 100 TSP intersections based on the following:

    1) Dented tubes at TSP intersections with bobbin dent voltages exceeding 5 volts, (~40)

    2) Artifact signals (alloy property changes) spanning the range of amplitudes observed in the Cook 1 SGs. (~40)

    3) Bobbin indications less than 1.0 volts for support of these indications as typical of ODSCC. (~5)

    4) Non-measurable depth O.D. indications (UOAs) with amplitudes greater than 1.0 volts. (~10)

    5) Indications not reportable (NRs) with amplitudes greater than 1.0 volts (~5 if identified)

Considerations for expansion of the RPC inspection would be based on identifying unusual or unexpected indications such as clear circumferential cracks. In this case, structural assessments of the significance of the indications would be used to guide the need for further RPC inspection.

A.3.8.1 3-Coil RPC Usage

Cook 1 standard practice allows for use of 3-coil RPC probes, incorporating a pancake coil, an axial preference coil, and a circumferential preference coil. Comparisons for ODSCC with bobbin amplitudes exceeding 1.0 volts have shown that the pancake coil fulfills the need for discrimination between axial and circumferential indications, when compared against the outputs of the preferred direction coils. Pancake coils have been the basis for reporting RPC voltages for model boiler and pulled tube indications in the APC database. These data permit semi-quantitative judgements on the potential significance of RPC indications. The requirement for a pancake coil is satisfied by the single coil, 2-coil, and 3-coil probes in common use for RPC inspections. Supplemental information, if needed, may be obtained from review of the preference coils on the 3-coil RPC if desired.

TABLE A-1

EFFECT OF MAGNETS ON RESPONSE OF ECHORAM BOBBIN PROBES
7/8" TUBING STANDARD 0.720 MIL PROBES
AVERAGE AMPLITUDES @ 400 kHz

	With Magnets	Without Magnets	Ratio With Magnets/Without Magnets
ASME			
4 x 20%	4.04	4.01	1.008
4 x 40%	3.42	3.42	1.000
4 x 60%	3.73	3.74	0.993
4 x 80%	3.92	3.94	0.995
4 x 100%	5.97	6.01	0.997
Support Plate	6.60	6.35	1.040
WEAR STANDARD			
100%	5.87	5.71	1.028
100%	5.83	5.84	0.998
100%	5.68	5.75	0.987
100%	5.86	5.65	1.032
0.5" EDM STANDARD			
20%	—	—	—
40%	0.78	0.79	0.988
60%	1.92	1.93	0.995
80%	2.61	2.61	1.000
100%	73.43	74.06	0.992

TABLE A-2

MAG BIAS VERSUS NON-MAG BIAS PROBES COMPARISON
PLANT R PULLED TUBES (SUPPORT PLATE SUPPRESSION MIX)

Mag Bias	Non-Mag Bias	% Change
PULLED TUBES (B&W): 3/4" TUBING, 550/130 KHZ MIX		
0.38	0.37	+2.7%
5.23	5.06	+3.4%
4.10	4.13	-0.1%
2.11	2.07	+1.9%
5.38	5.34	+0.1%
3.26	3.31	-1.5%
0.18	0.82	-1.2%
1.06	1.04	+1.9%
MACHINED HOLE (B&W): 3/4" TUBING, 550/130 KHZ MIX		
5.24	5.40	-3.0%
5.43	5.54	-2.0%
2.74	2.76	-0.1%
11.60	11.78	-1.5%
19.82	20.17	-1.7%
4.67	4.80	-2.7%

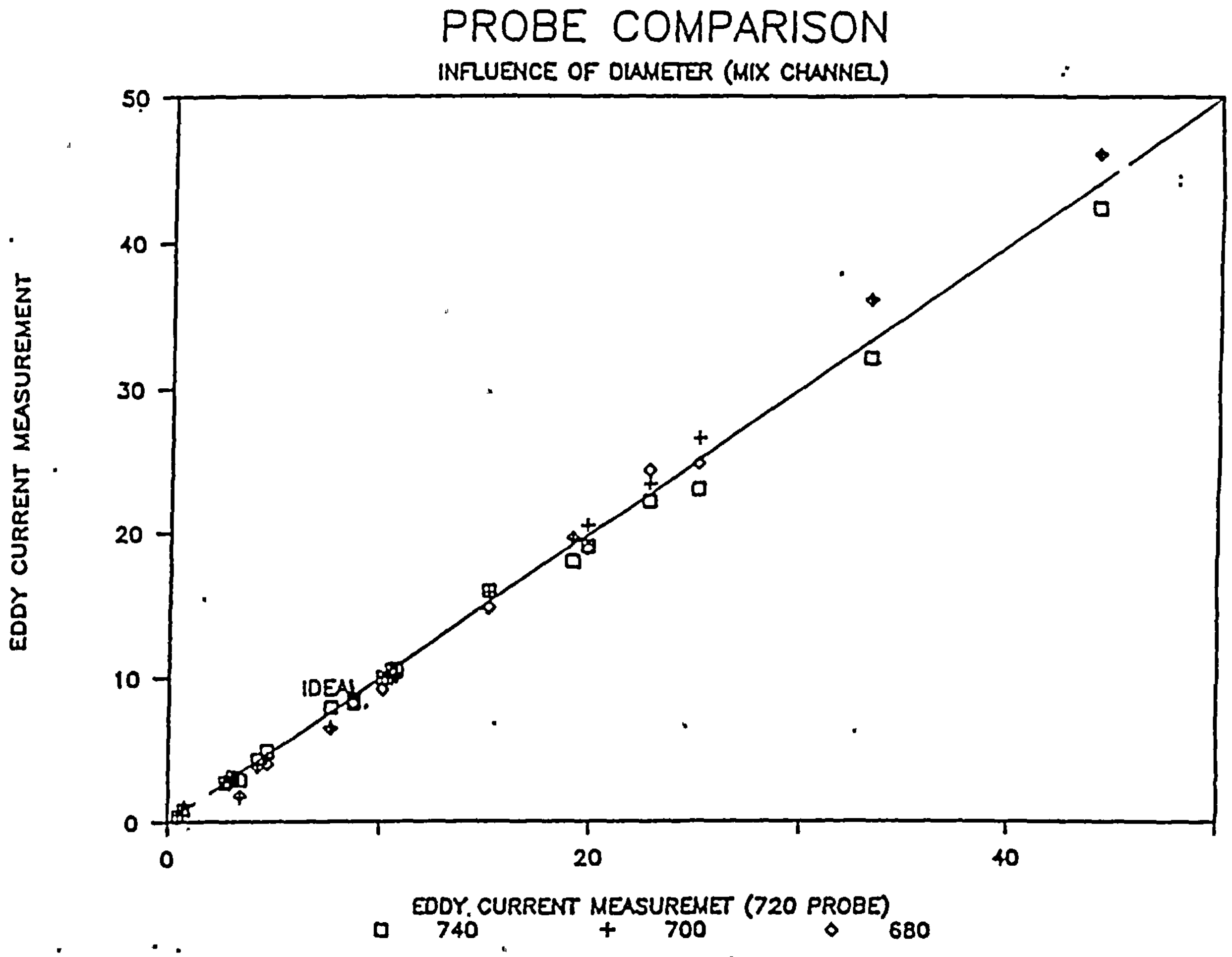


Figure A-1. Probe Comparison.

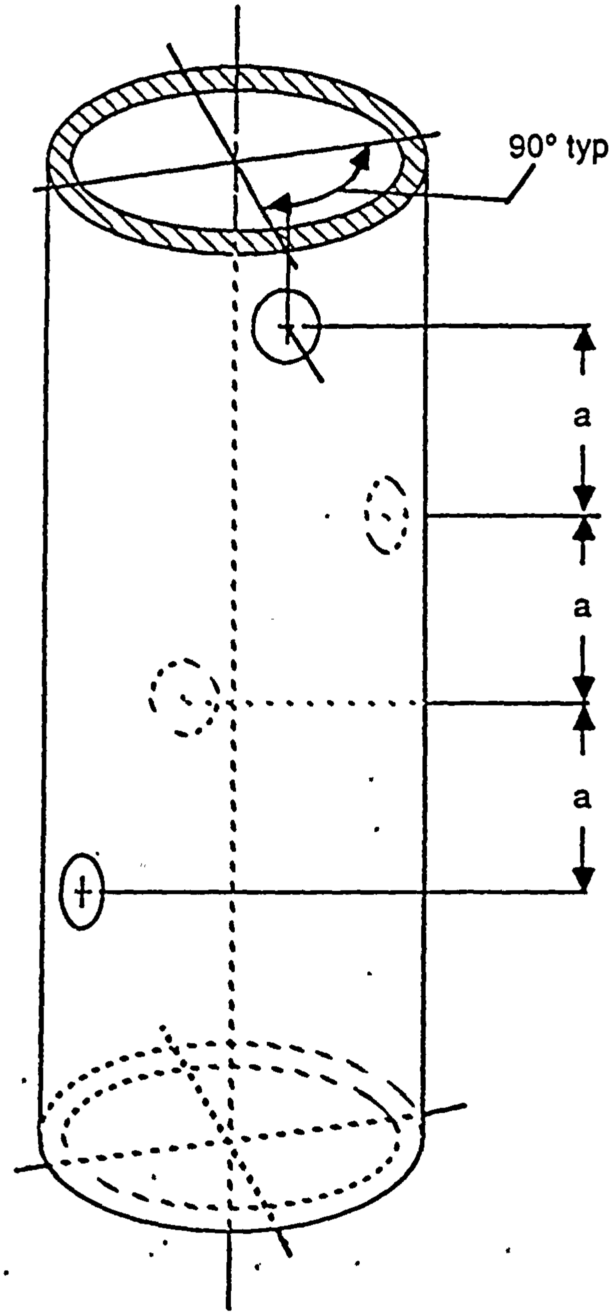


Figure A-2. Probe Wear Calibration Standard.

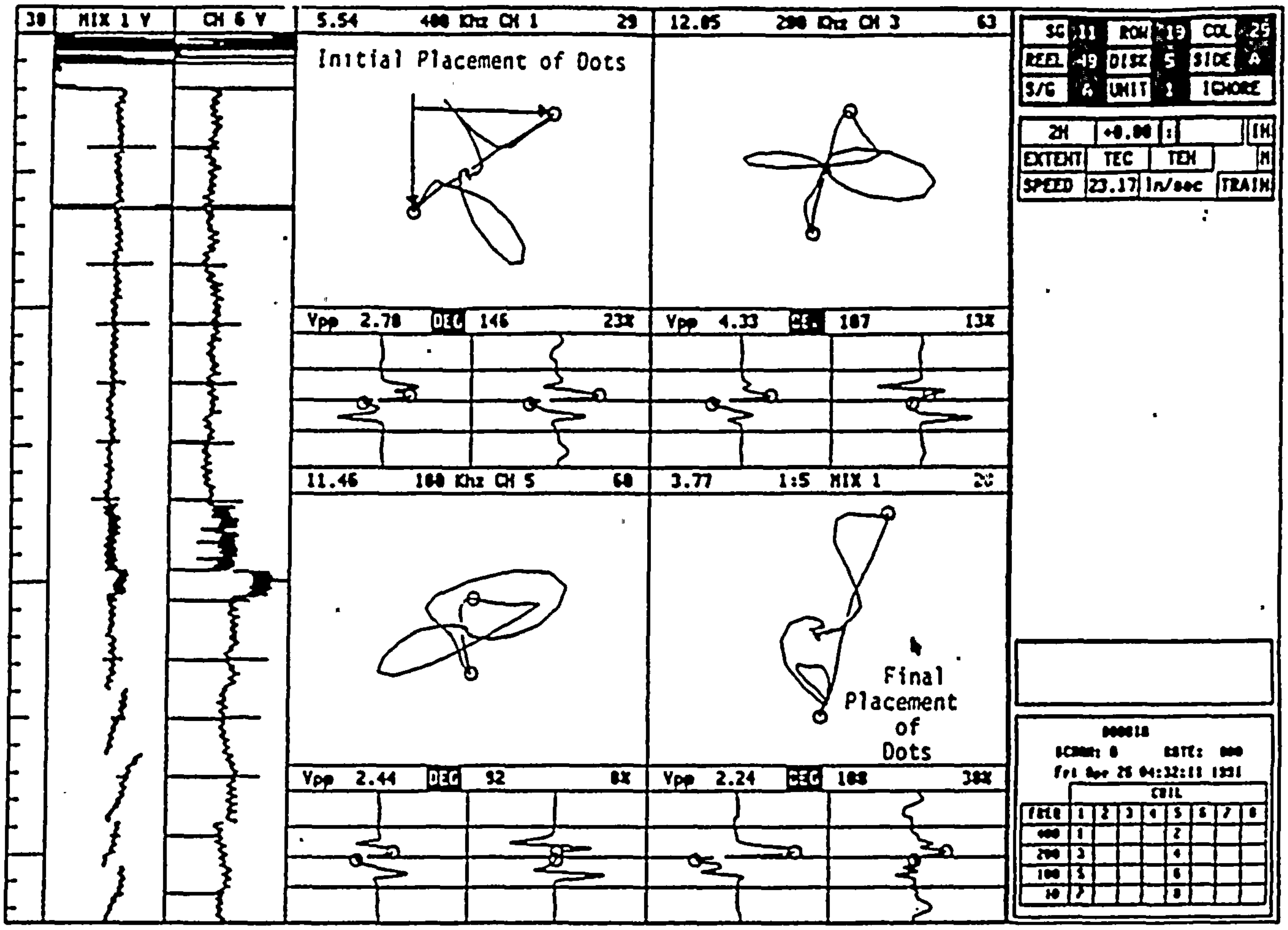


Figure A-3. Bobbin Coil Amplitude of ODSCC at TSP.

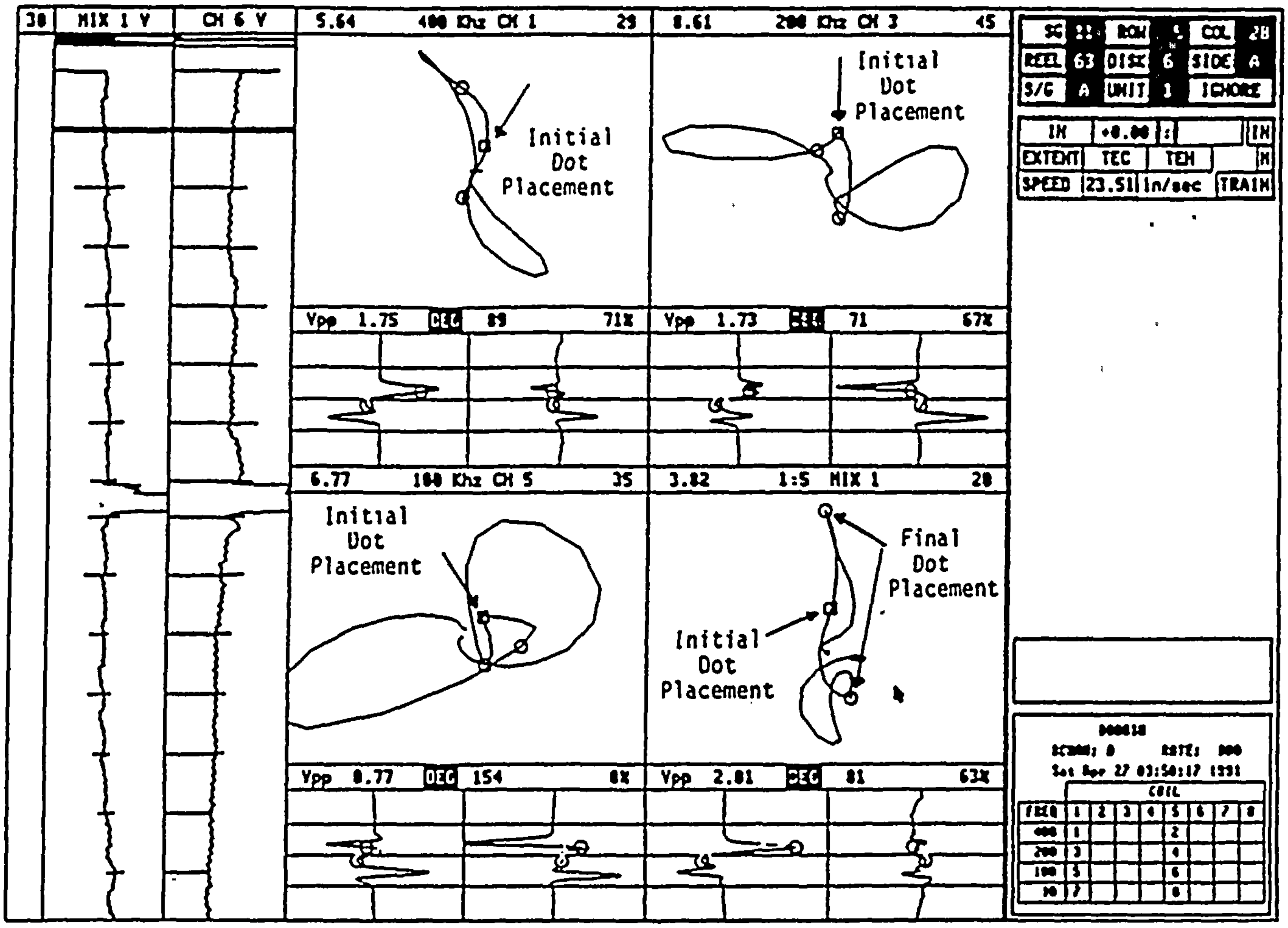


Figure A-4. Bobbin Coil Amplitude of ODSCC at TSP - Improper Identification of Full Flaw Segment.

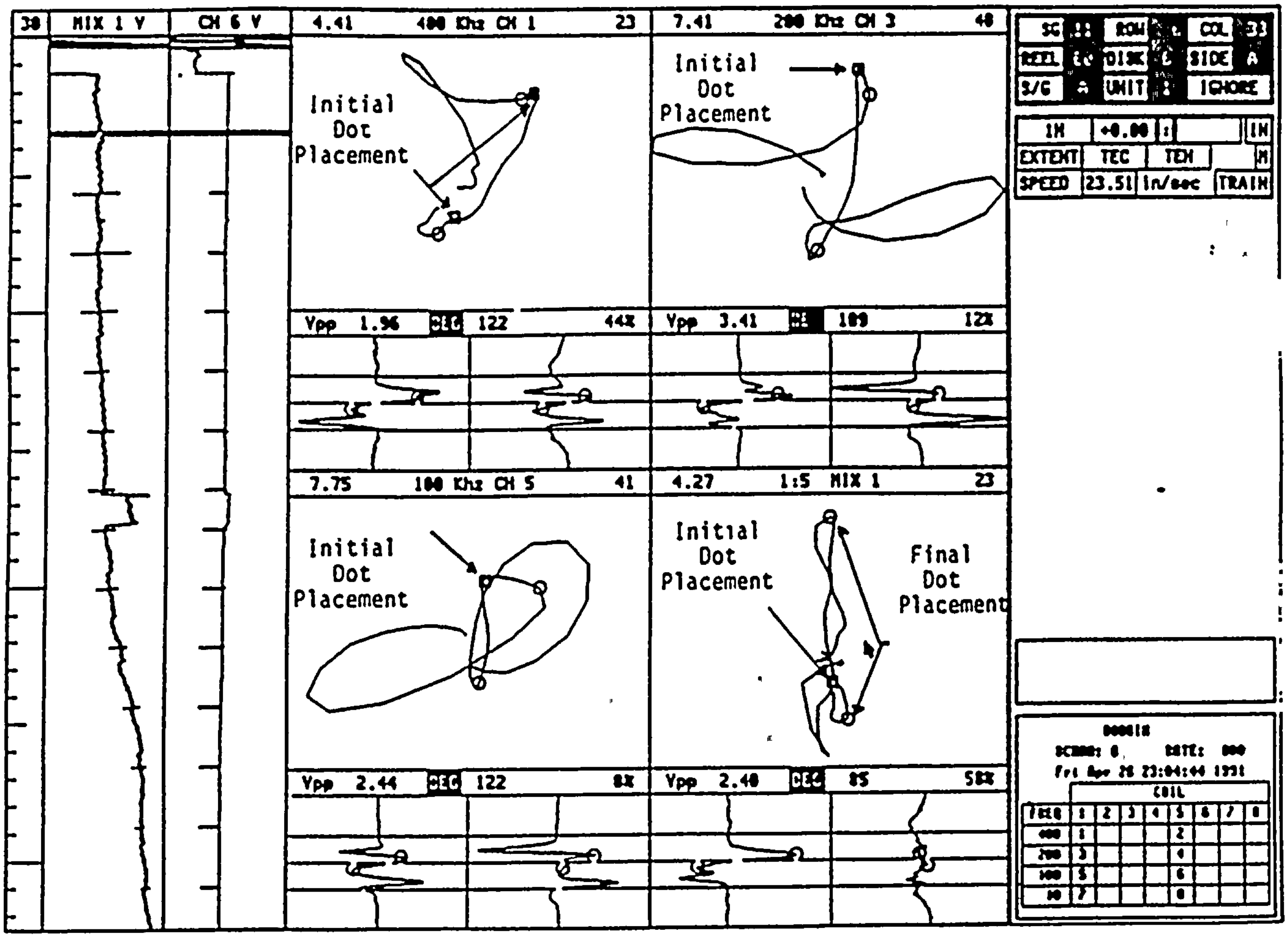
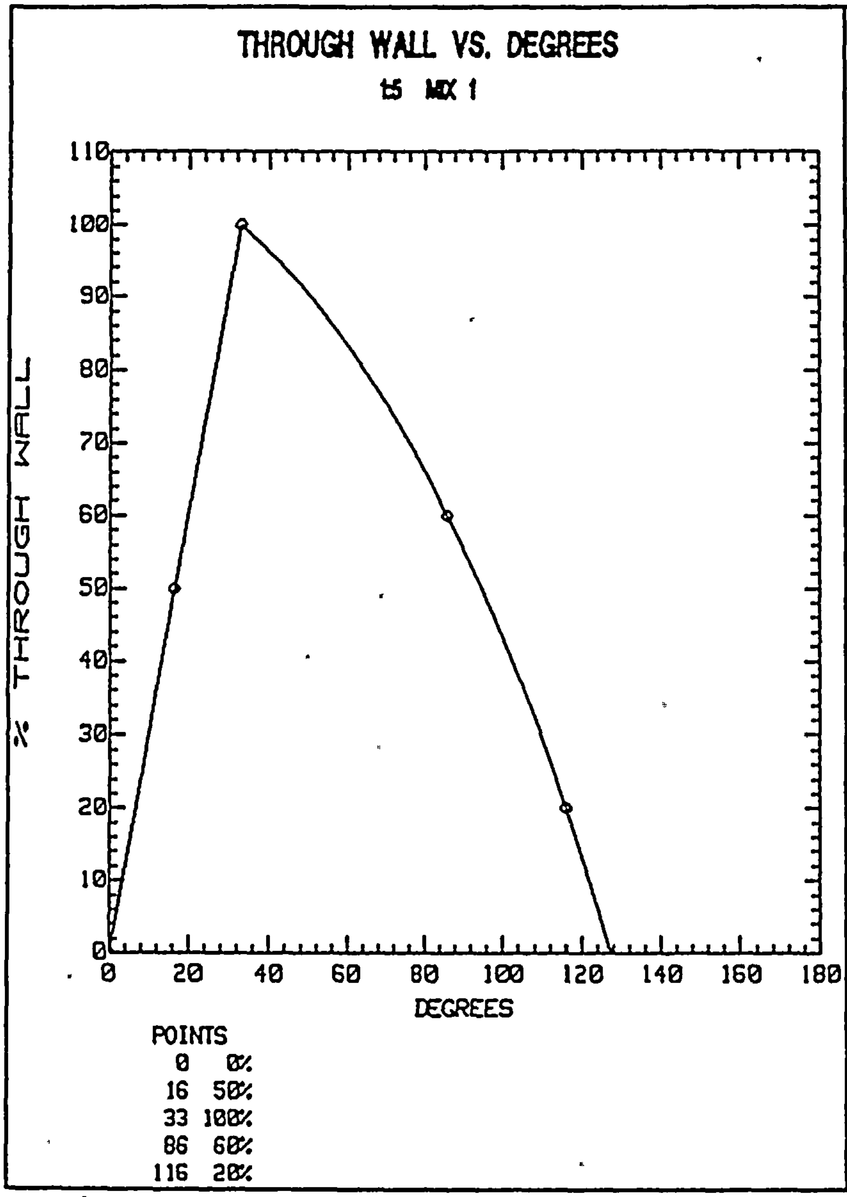


Figure A-5. Bobbin Coil Amplitude of ODSCC at TSP Improper Identification of Full Flaw Segment.



DEG	%	DEG	%	DEG	%	DEG	%
0	0	45	93	90	56	135	0
1	3	46	93	91	54	136	0
2	6	47	92	92	53	137	0
3	9	48	92	93	52	138	0
4	12	49	91	94	51	139	0
5	15	50	90	95	50	140	0
6	18	51	90	96	48	141	0
7	21	52	89	97	47	142	0
8	24	53	88	98	46	143	0
9	27	54	88	99	45	144	0
10	30	55	87	100	43	145	0
11	33	56	86	101	42	146	0
12	36	57	86	102	41	147	0
13	39	58	85	103	39	148	0
14	42	59	84	104	38	149	0
15	45	60	83	105	37	150	0
16	48	61	83	106	35	151	0
17	52	62	82	107	34	152	0
18	55	63	81	108	32	153	0
19	58	64	80	109	31	154	0
20	61	65	79	110	29	155	0
21	64	66	79	111	28	156	0
22	67	67	78	112	26	157	0
23	70	68	77	113	25	158	0
24	73	69	76	114	23	159	0
25	76	70	75	115	22	160	0
26	79	71	74	116	20	161	0
27	82	72	74	117	18	162	0
28	85	73	73	118	17	163	0
29	88	74	72	119	15	164	0
30	91	75	71	120	13	165	0
31	94	76	70	121	12	166	0
32	97	77	69	122	10	167	0
33	100	78	68	123	8	168	0
34	99	79	67	124	6	169	0
35	99	80	66	125	4	170	0
36	98	81	65	126	2	171	0
37	98	82	64	127	1	172	0
38	97	83	63	128	0	173	0
39	97	84	62	129	0	174	0
40	96	85	61	130	0	175	0
41	96	86	60	131	0	176	0
42	95	87	59	132	0	177	0
43	95	88	58	133	0	178	0
44	94	89	57	134	0	179	0

Figure A-6. Bobbin Coil Calibration Curve for 400/100 Mix.

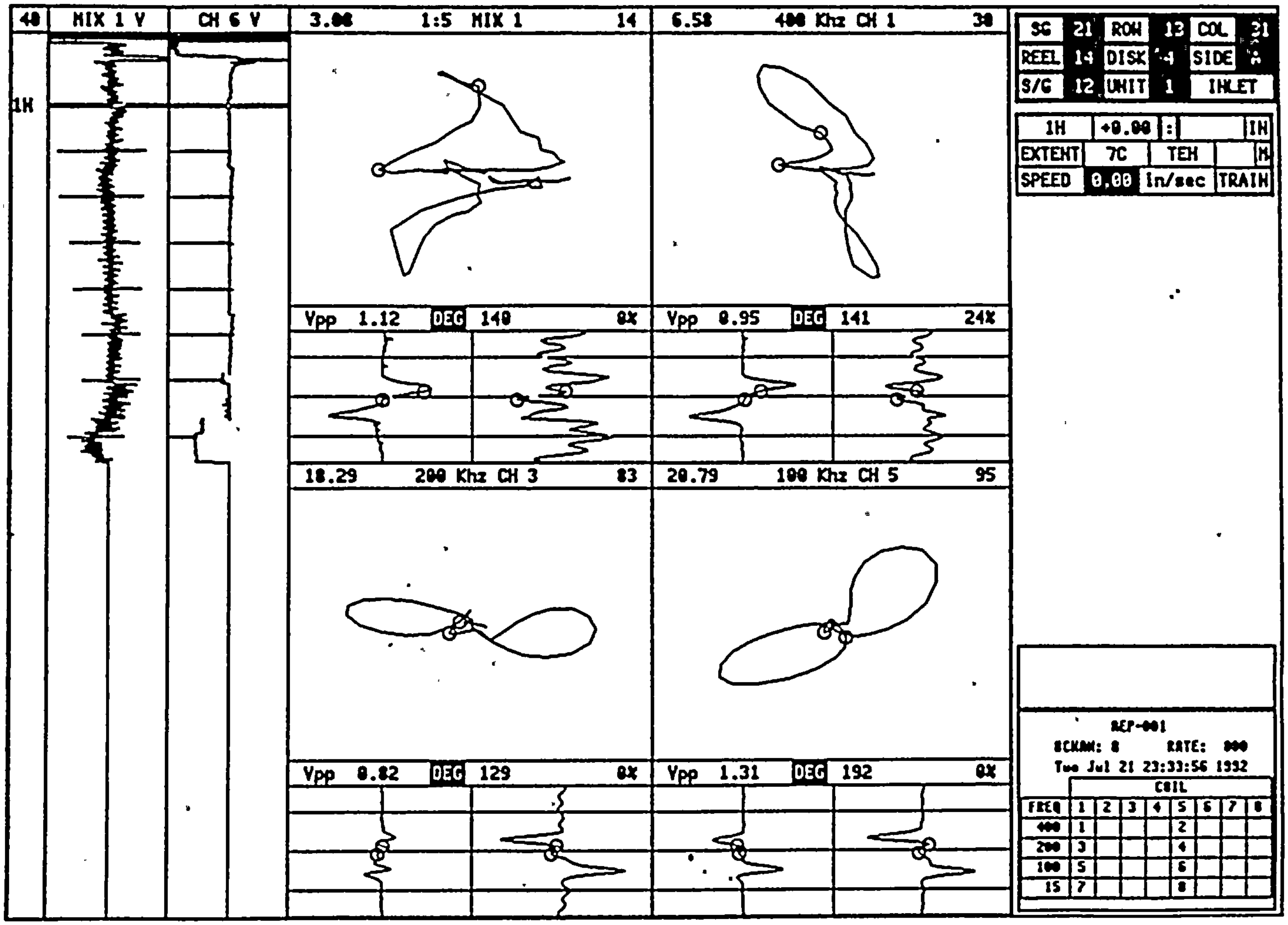


Figure A-7. O.D. Origin Signal With Phase Angle Greater Than 0% Intercept on Calibration Curve.

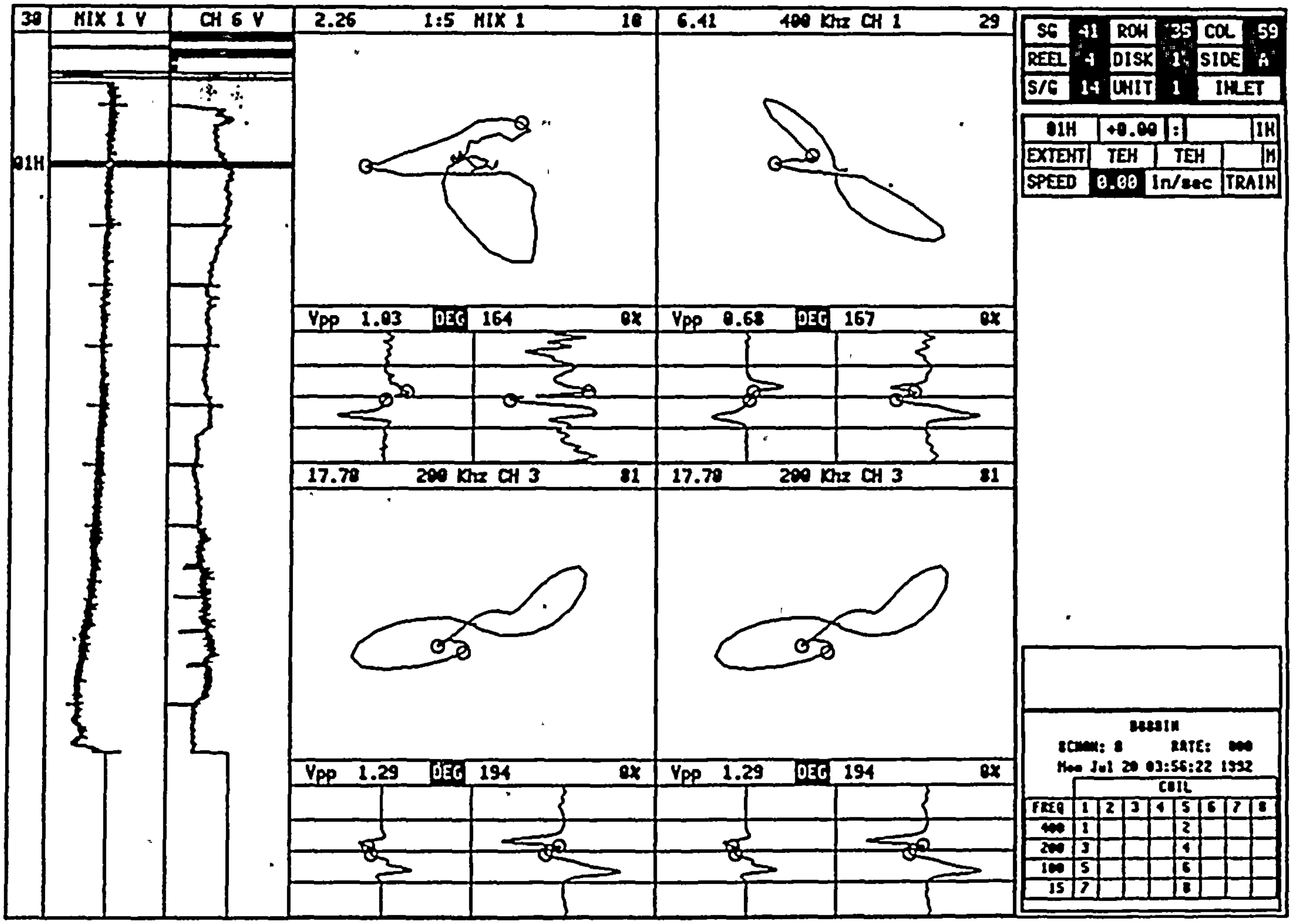


Figure A-8. O.D. Origin Signal With Phase Angle Greater Than 0% Intercept on Calibration Curve.

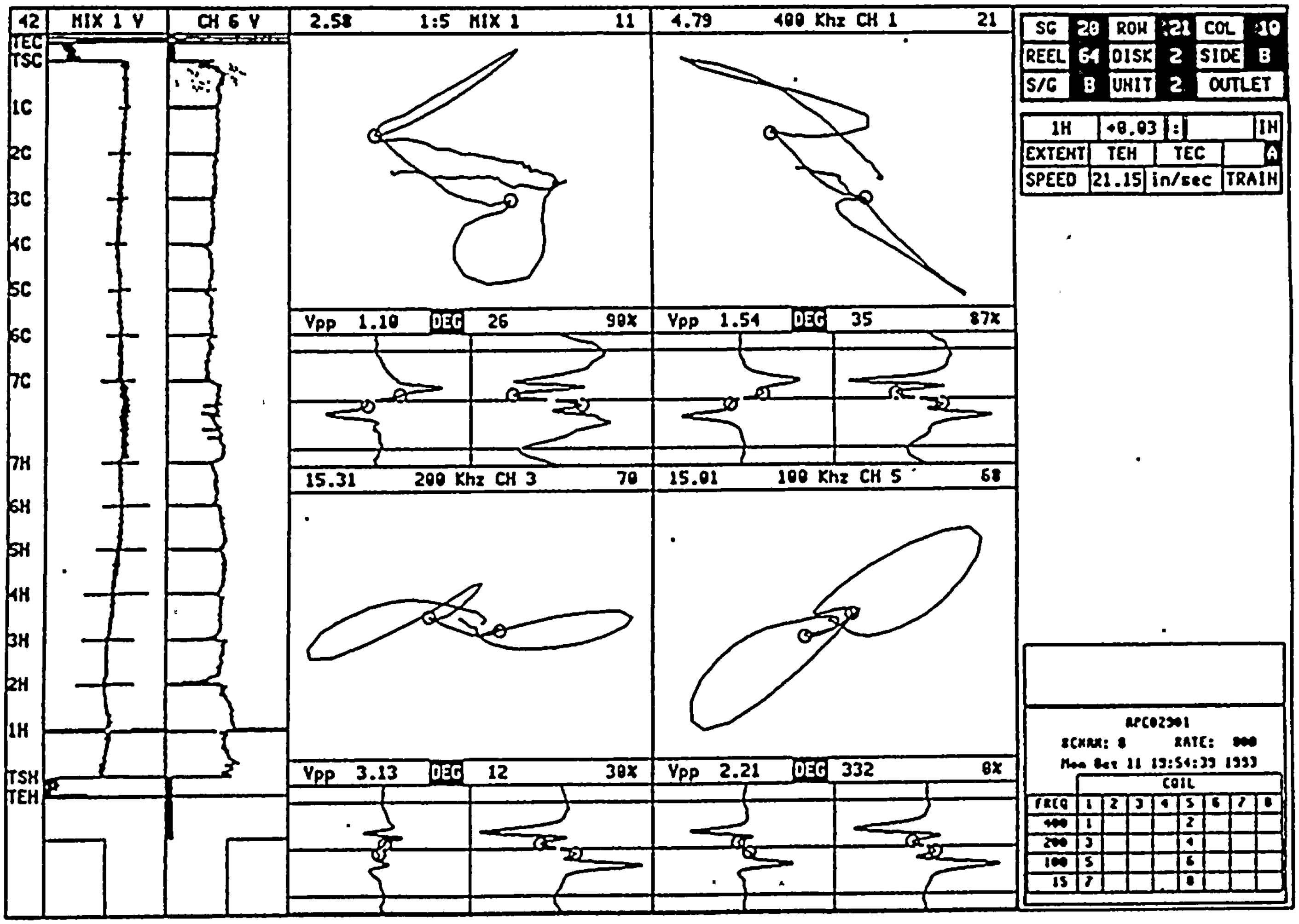


Figure A-9. I.D. Origin Signal Observed in Plant A-2 Support Plate (400/100 Mix).

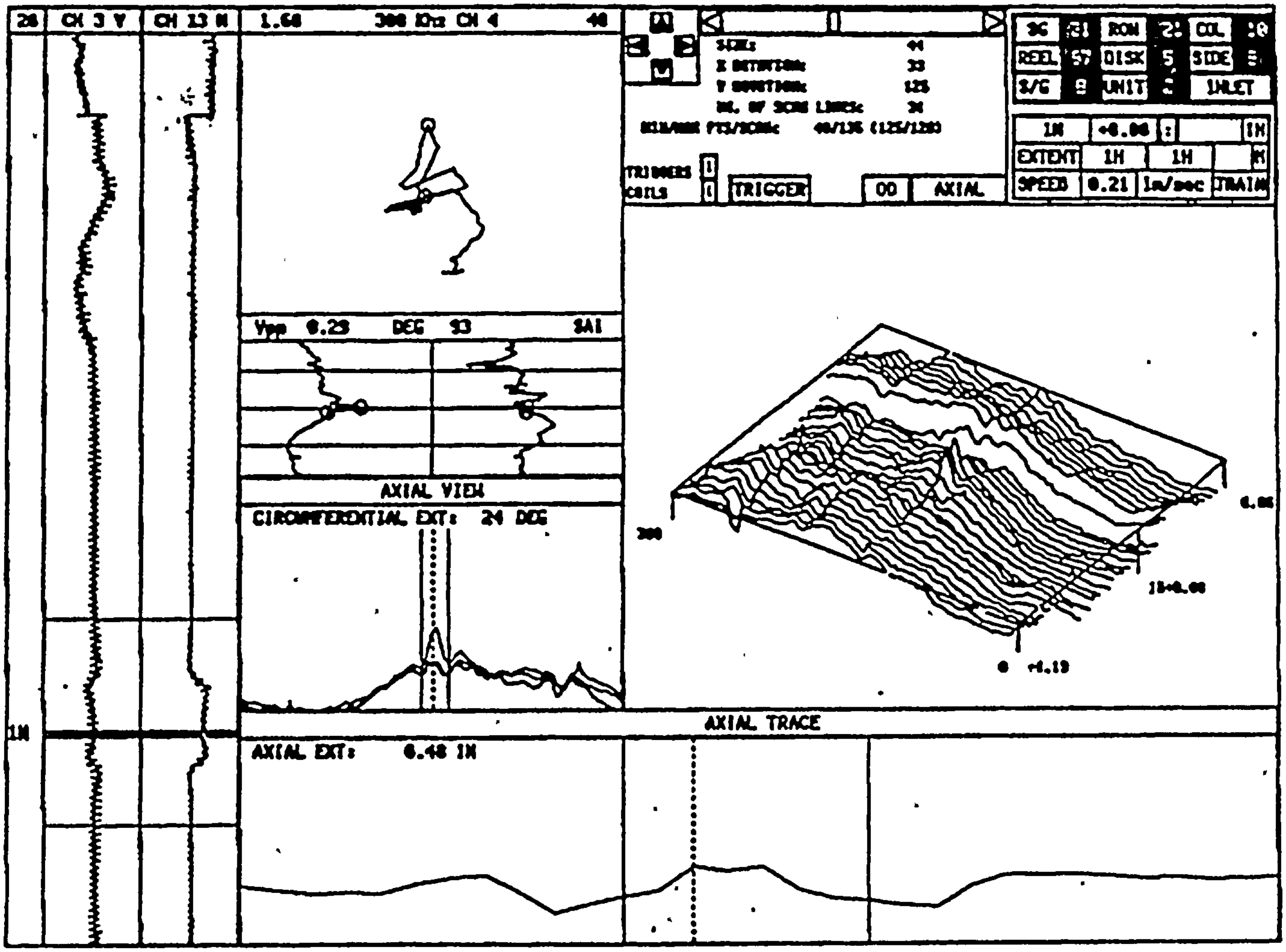


Figure A-10. RPC Confirmation of ID-Oriented TSP Signal as O.D. Flow.

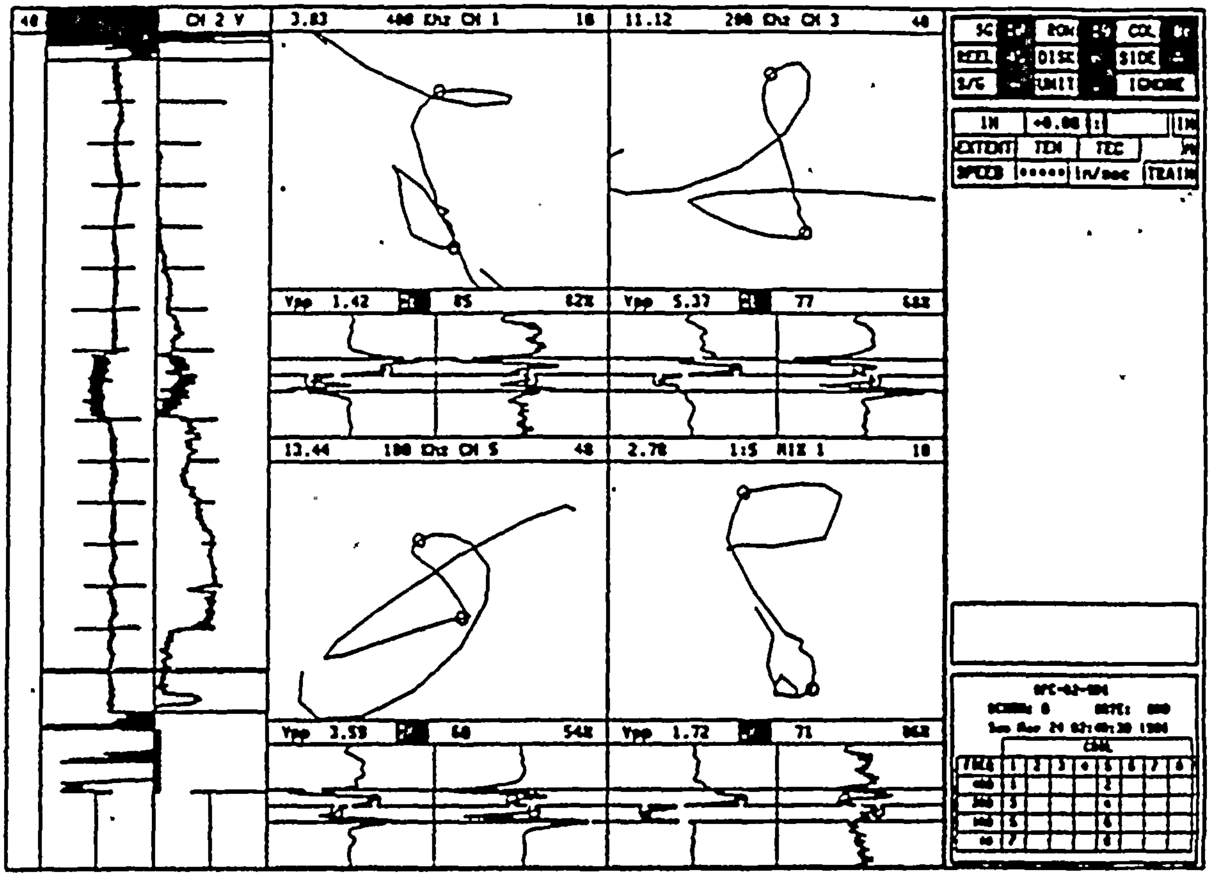


Figure A-11. Placement of Dots Marking Lissajous Traces for R19C86 - Analyst 1.

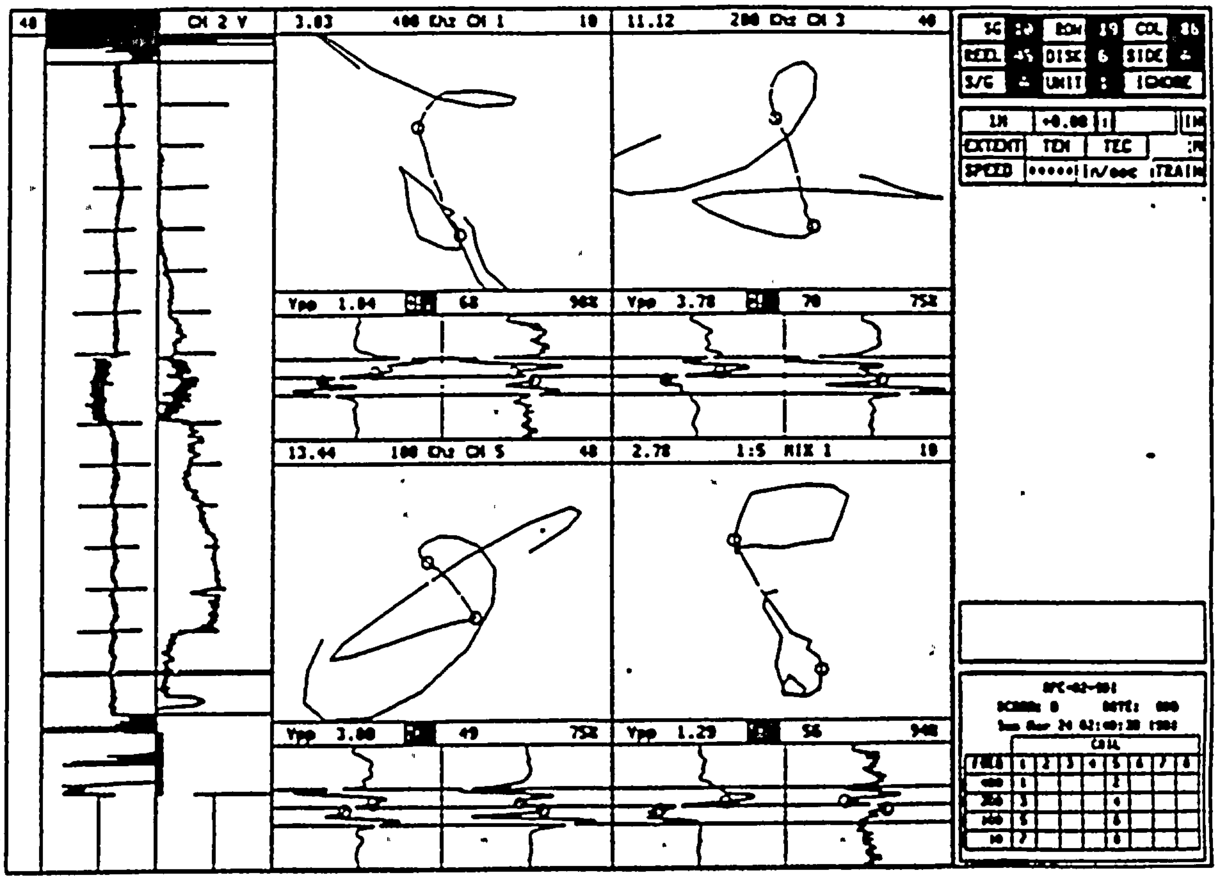


Figure A-12. Placement of Dots Marking Lissajous Traces for R19C86 - Analyst 2.

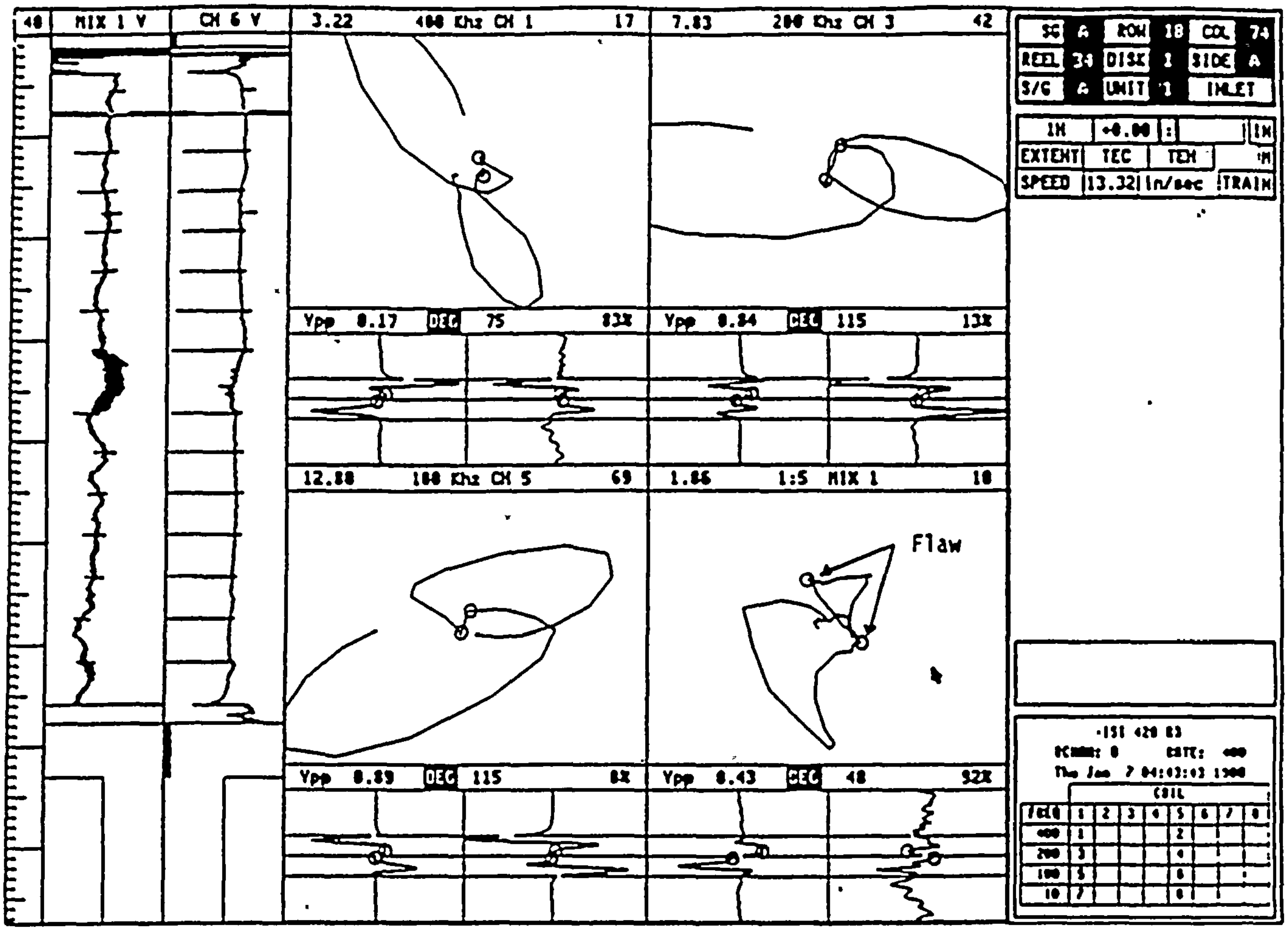


Figure A-13. Bobbin Coil Amplitude Analysis of ODSCC at TSP.

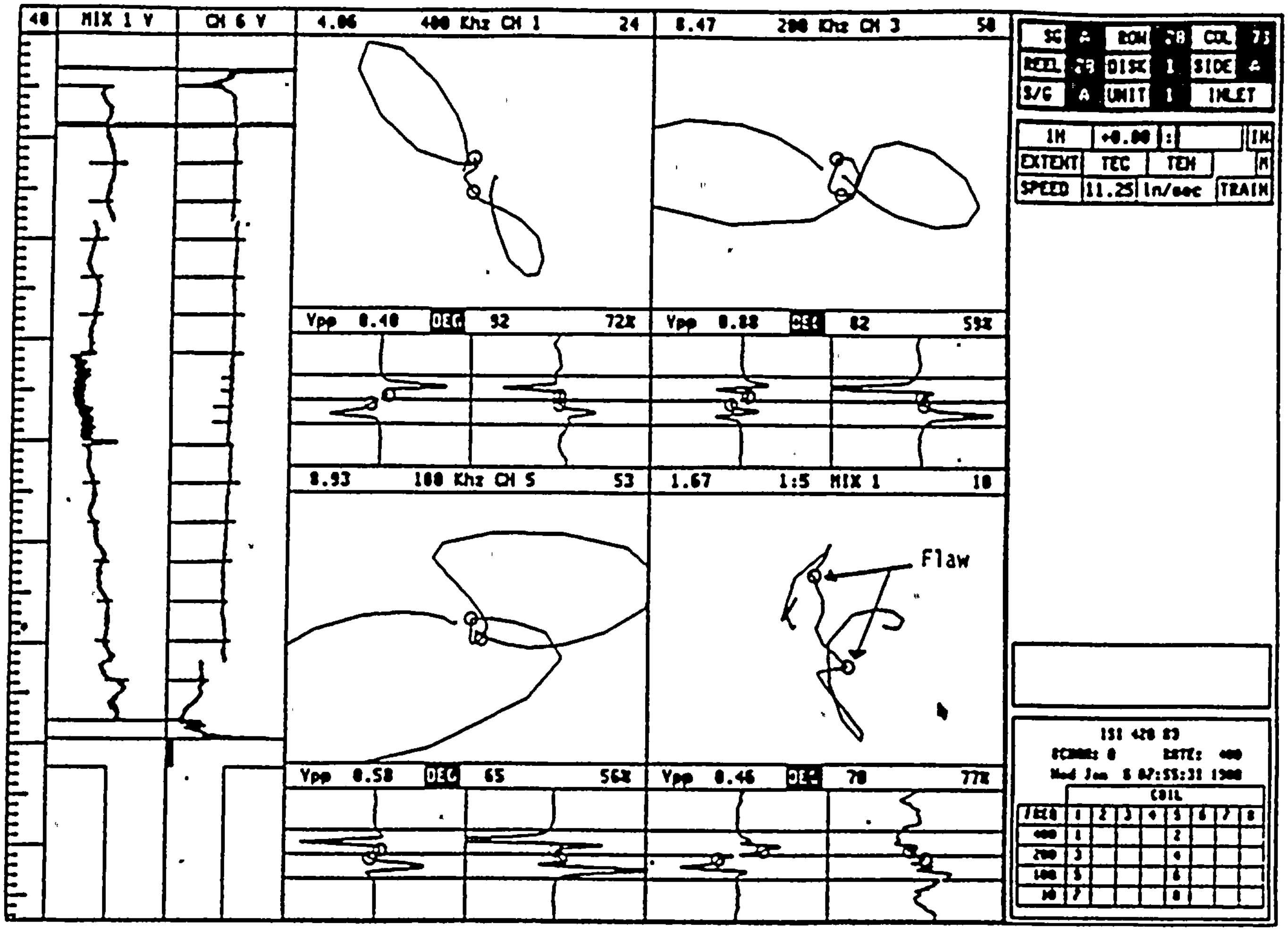


Figure A-14. Bobbin Coil Amplitude Analysis of ODSCC at TSP.

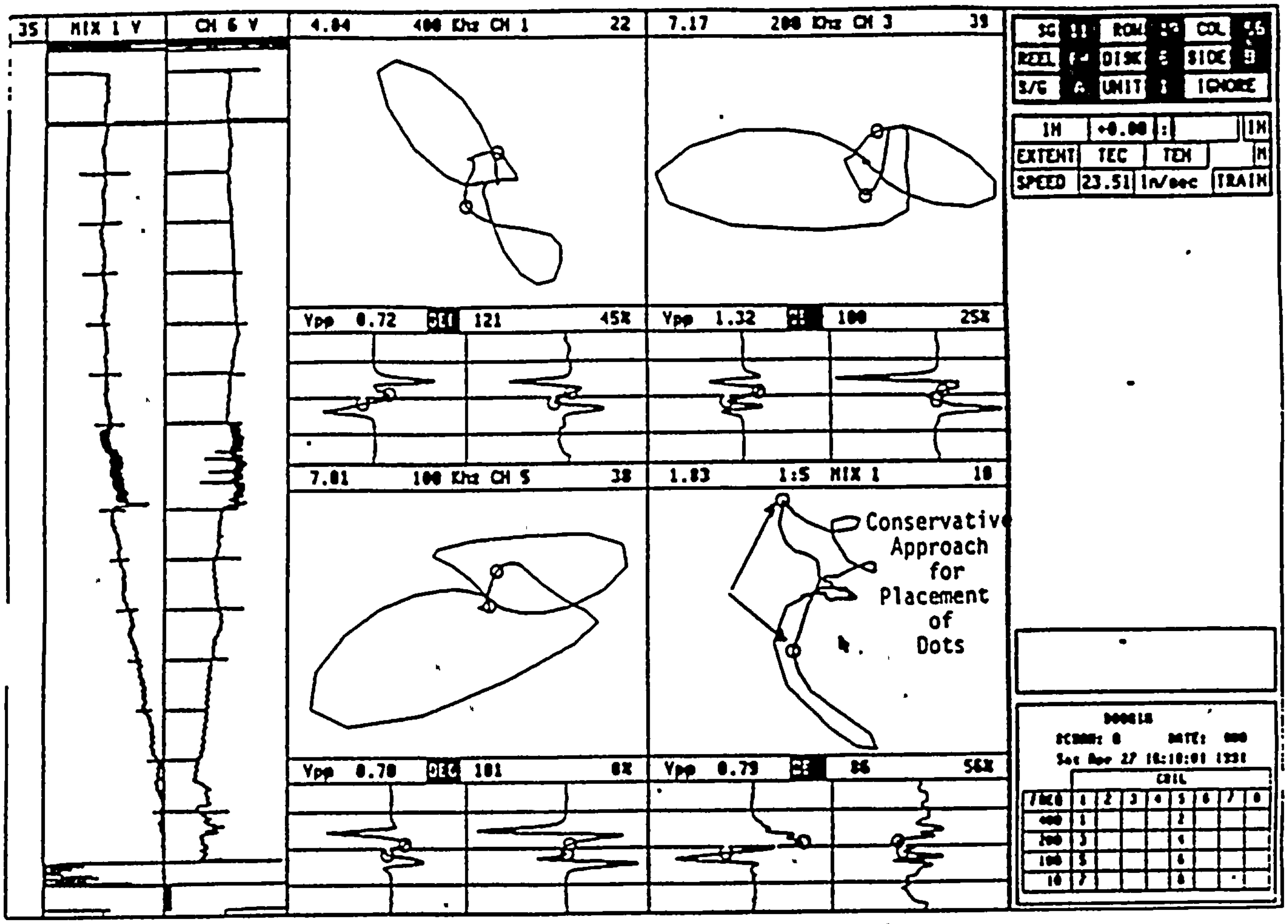


Figure A-15. Bobbin Coil Amplitude Analysis of ODSCC at TSP.

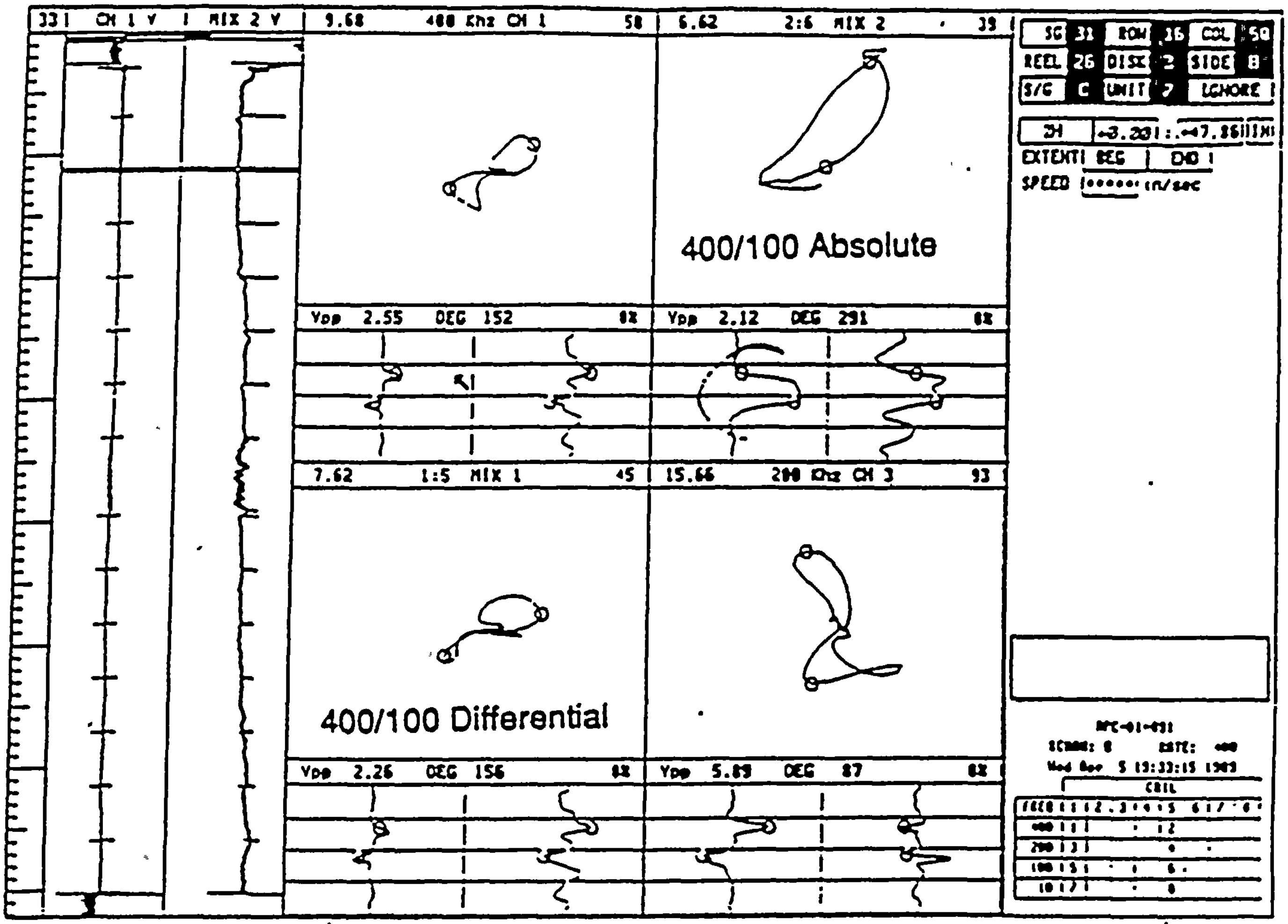


Figure A-16. Example of Bobbin Coil Field Data From Plant A - Absolute Mix With No ODSCC.

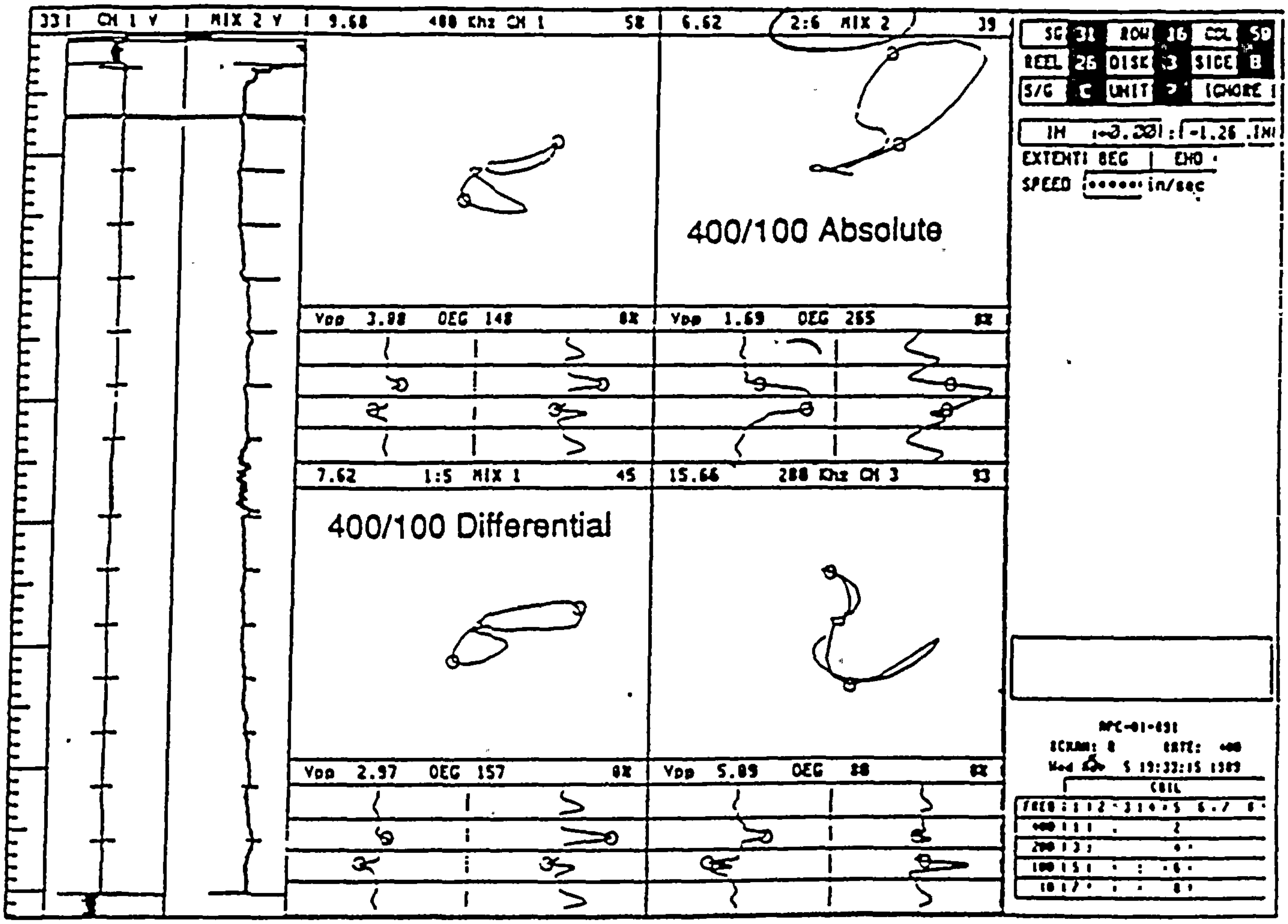


Figure A-17. Example of Bobbin Coil Field Data From Plant A - Absolute Mix With No ODSCC.

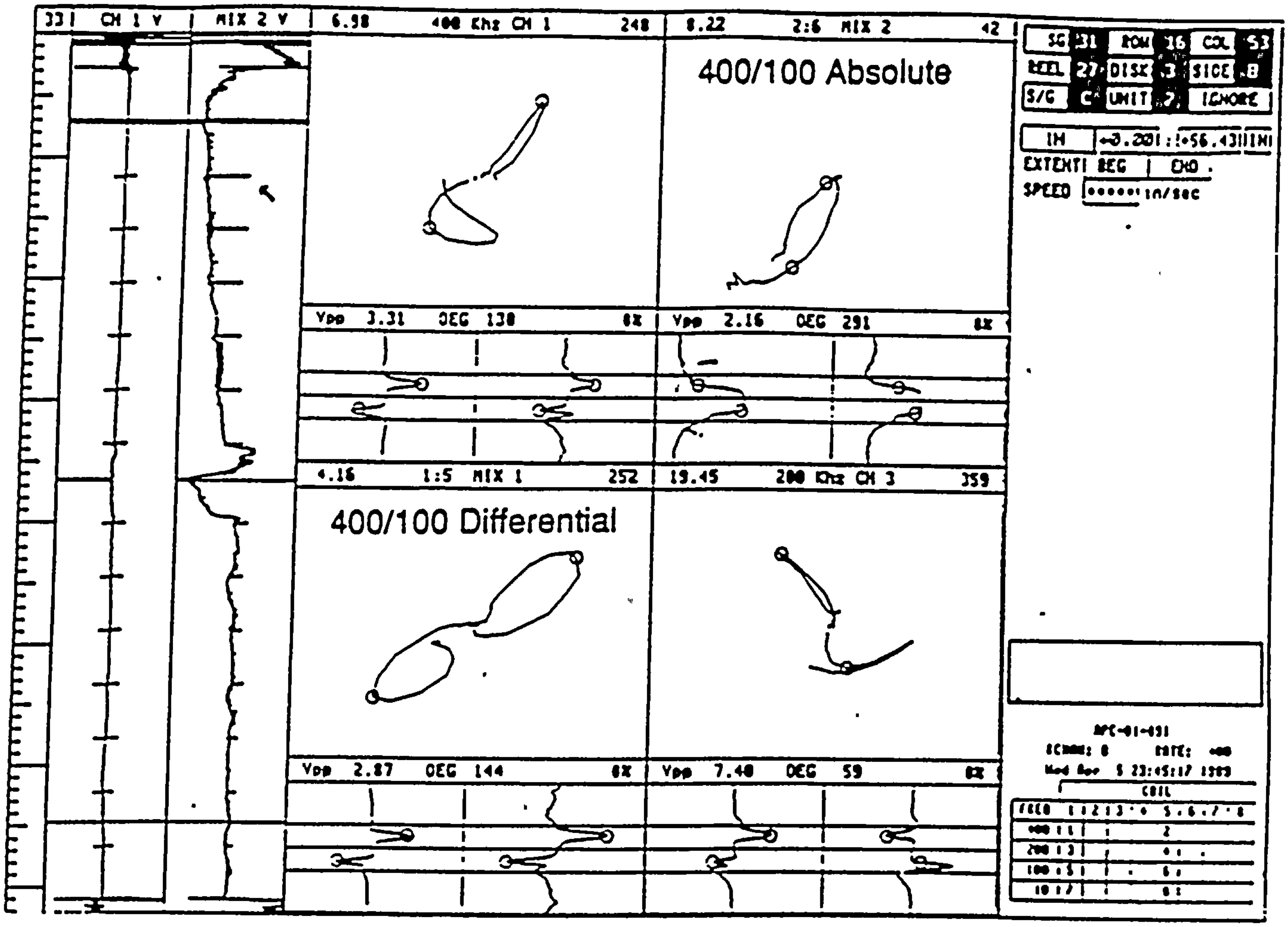


Figure A-18. Example of Bobbin Coil Field Data From Plant A - Absolute Mix With No ODSCC.

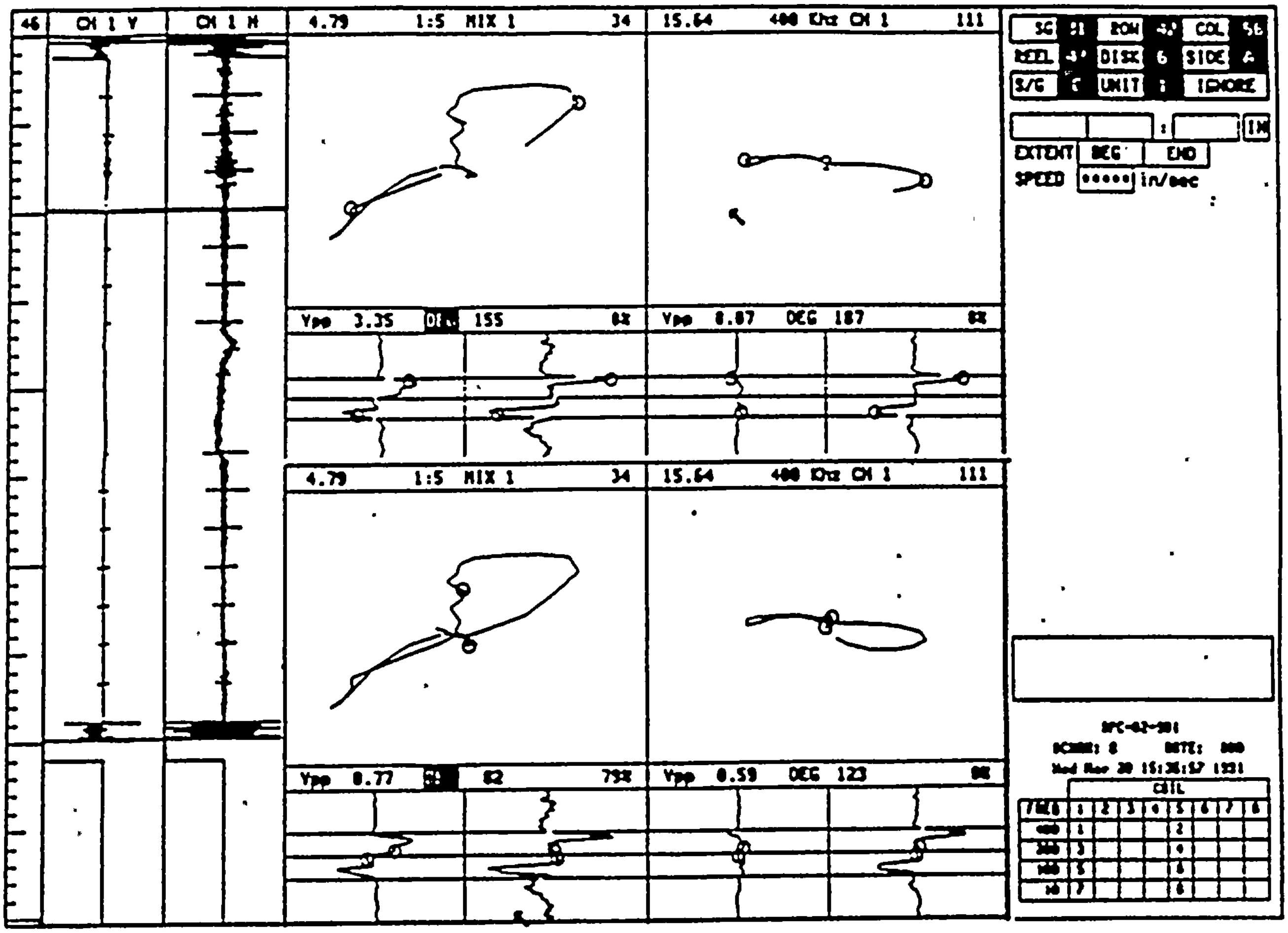


Figure A-19. Example of Bobbin Coil Field Data - Flaw Signals for ODSCC at Dented TSP Intersection.

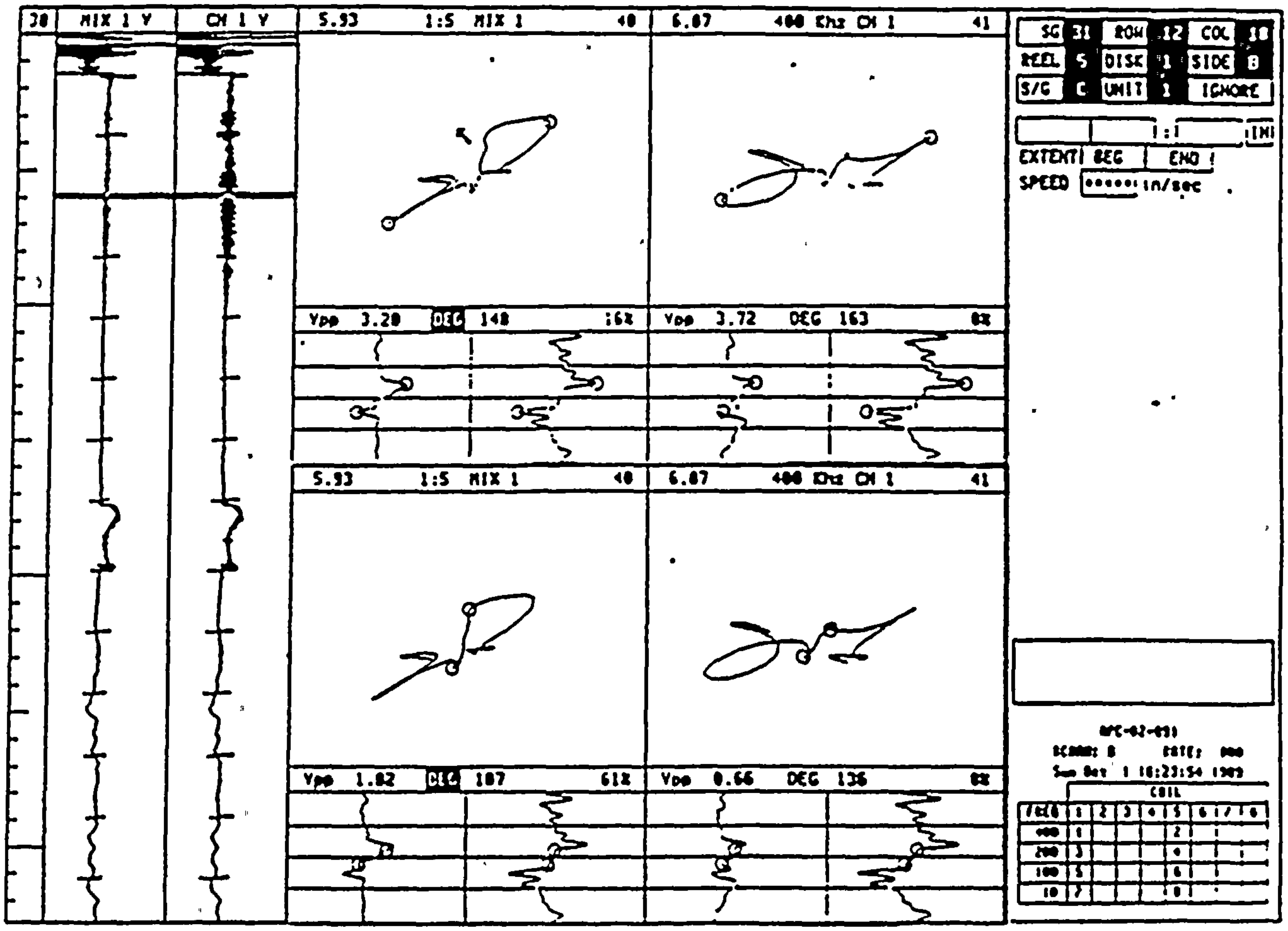


Figure A-20. Example of Bobbin Coil Field Data - Flaw Signals for ODSCC at Dented TSP Intersection.

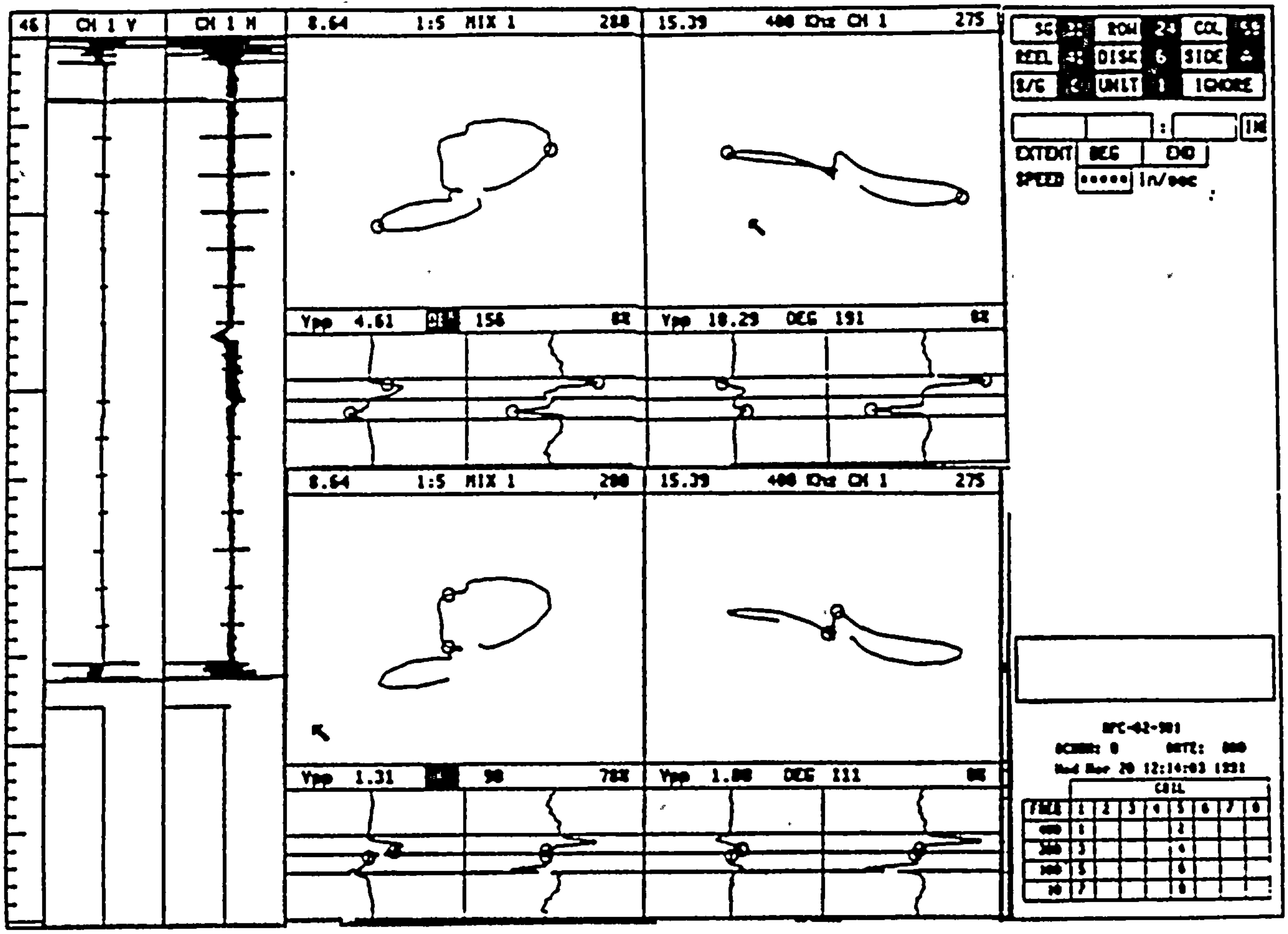


Figure A-21. Example of Bobbin Coil Field Data - Flaw Signals for ODSCC at Dented TSP Intersection.

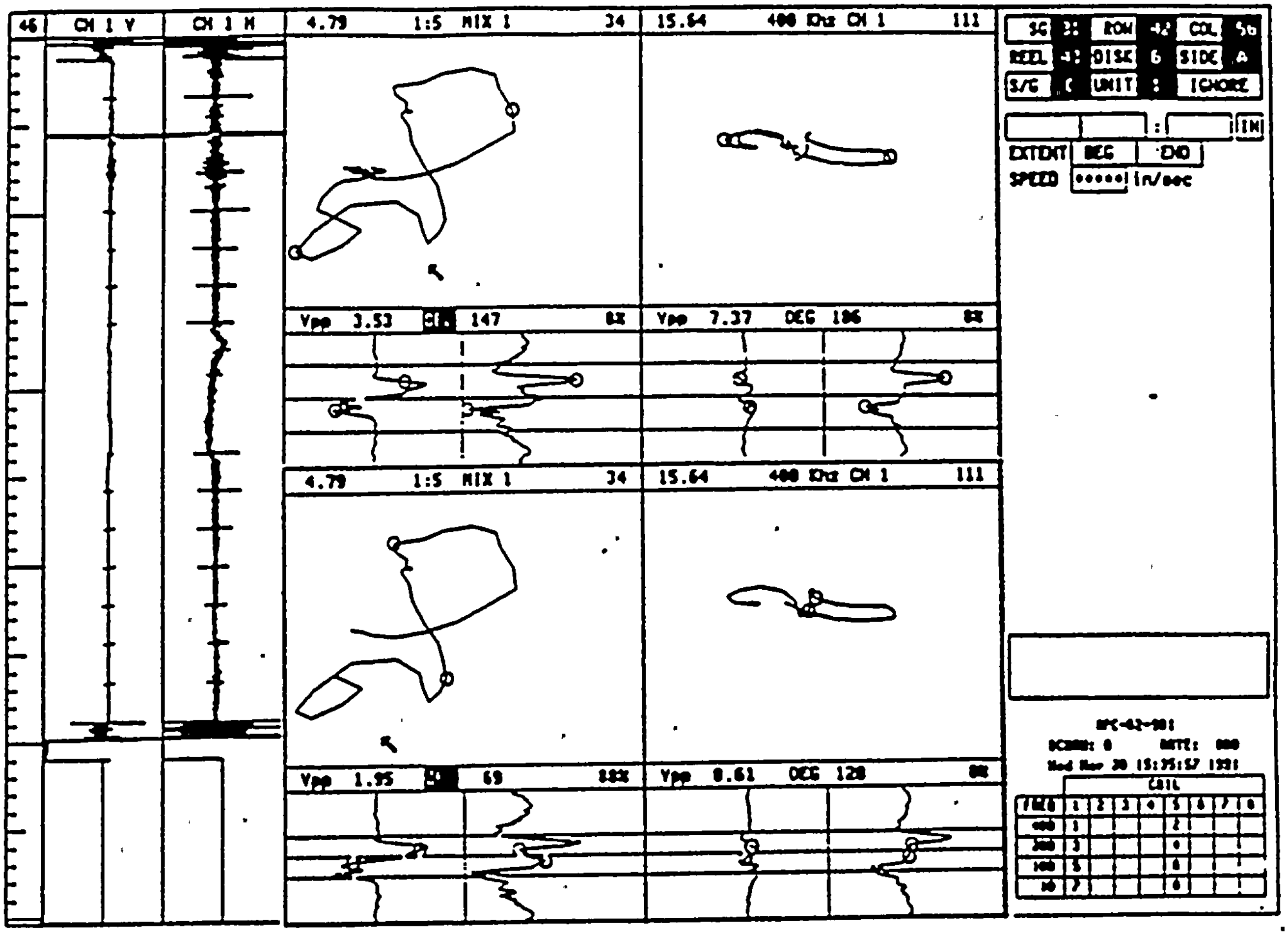


Figure A-22. Example of Bobbin Coil Field Data - Flaw Signals for ODSCC at Dented TSP Intersection.

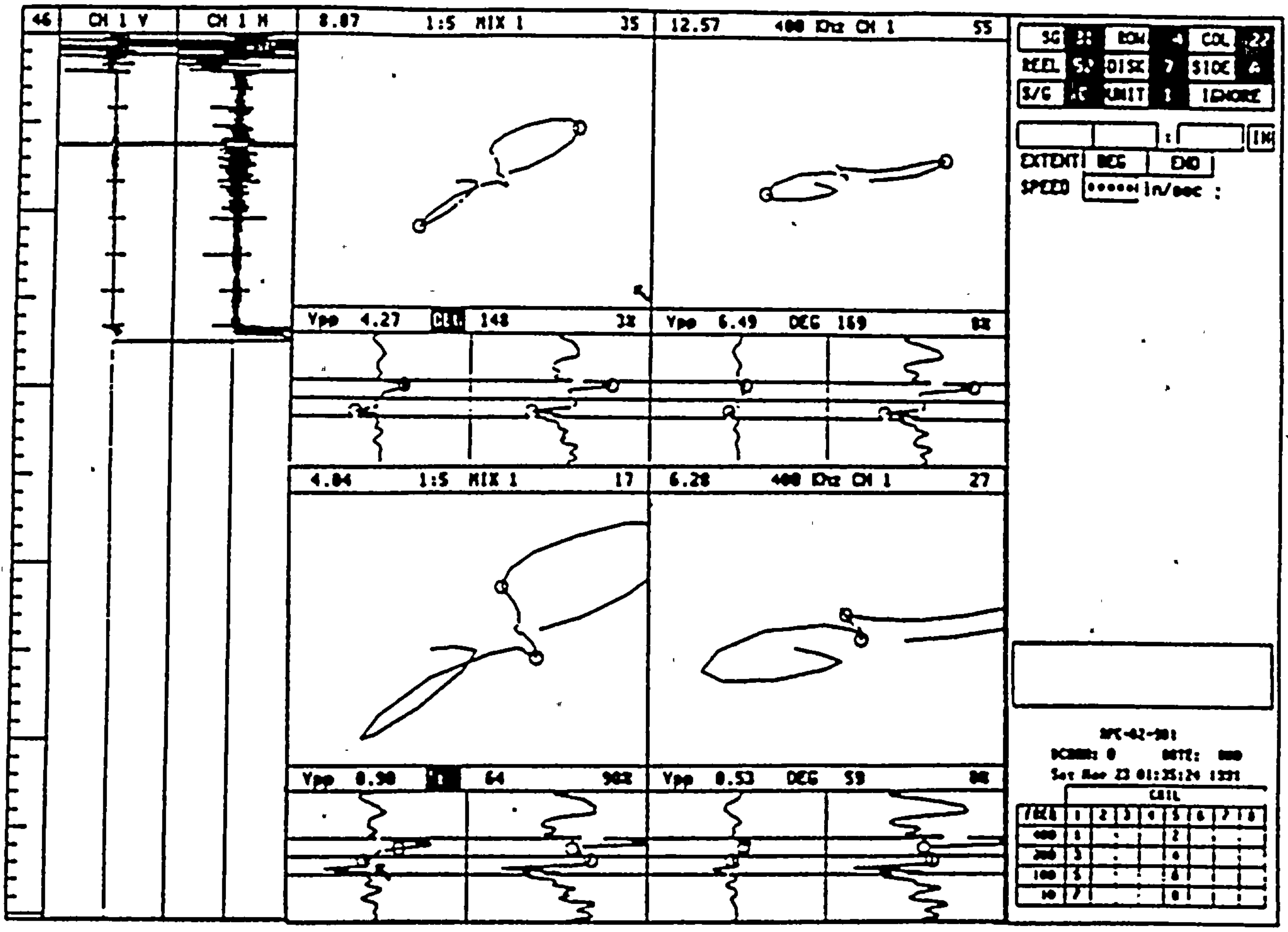


Figure A-23. Example of Bobbin Coil Field Data - Flaw Signals for ODSCC at Dented TSP Intersection.

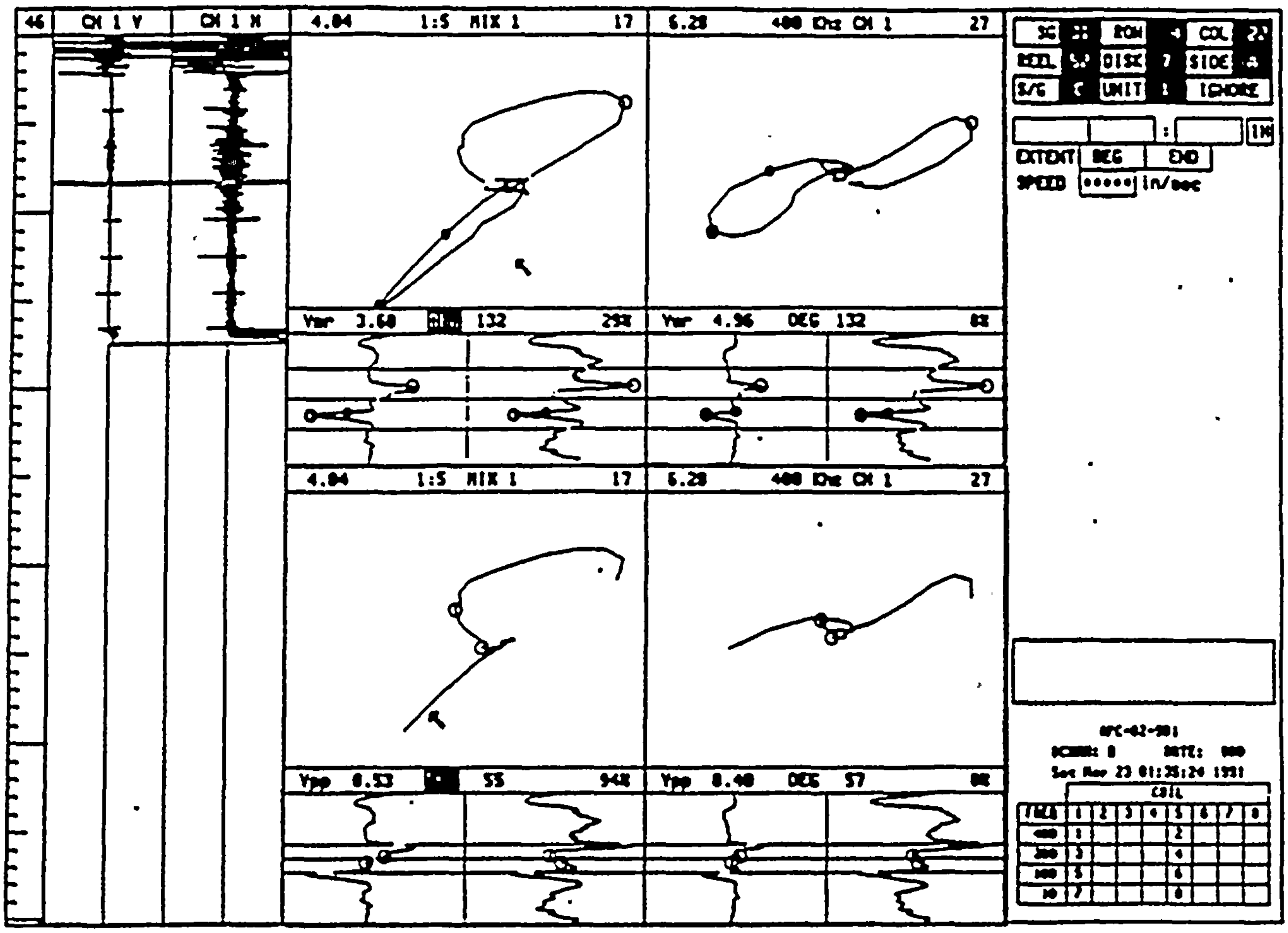


Figure A-24. Example of Bobbin Coil Field Data - Flaw Signals for ODSCC at Dented TSP Intersection.

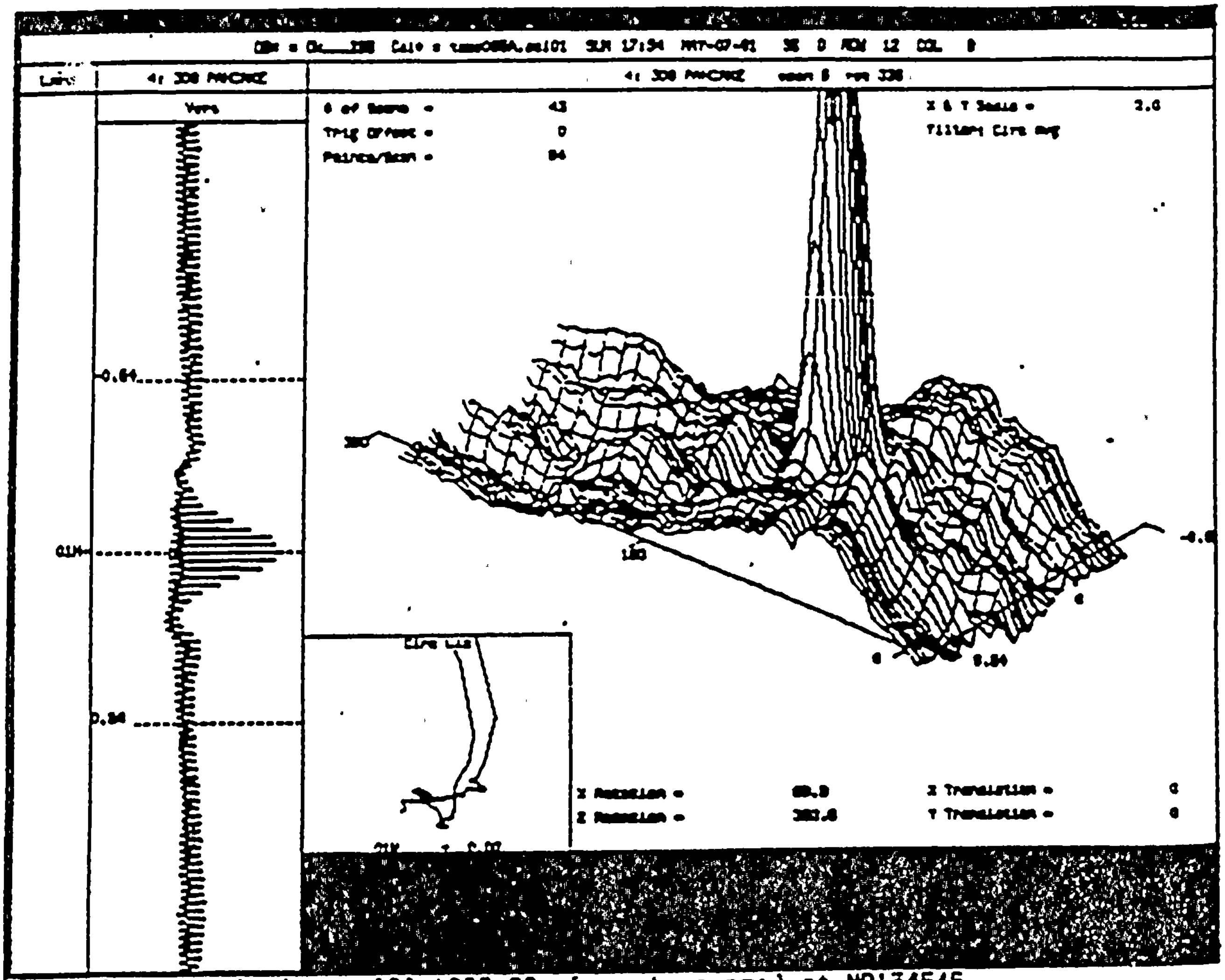


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Figure A-25.. Example of Axial ODSCC Indication at TSP 1.

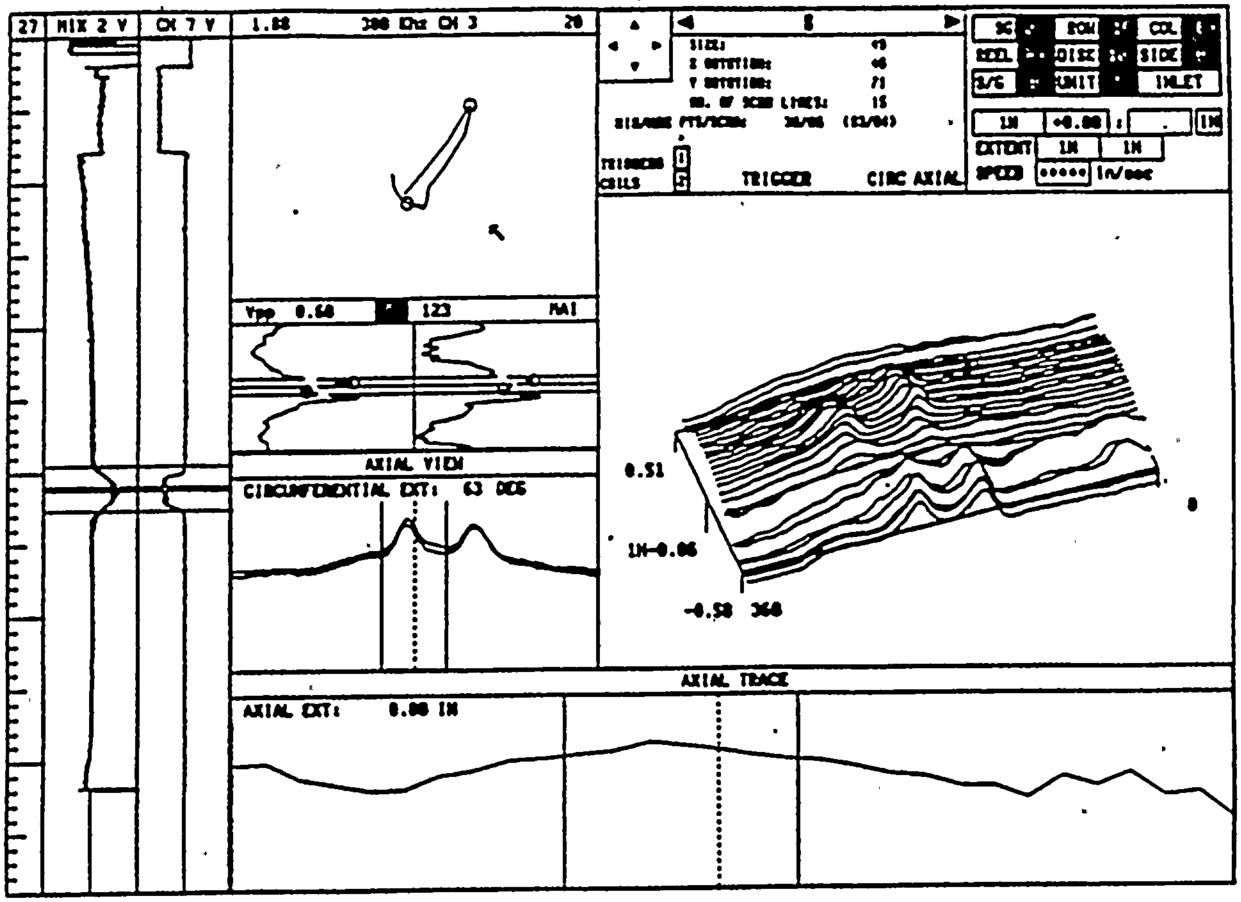

Figure A-26. Axial ODSCC Indication at TSP - Plant A-1.

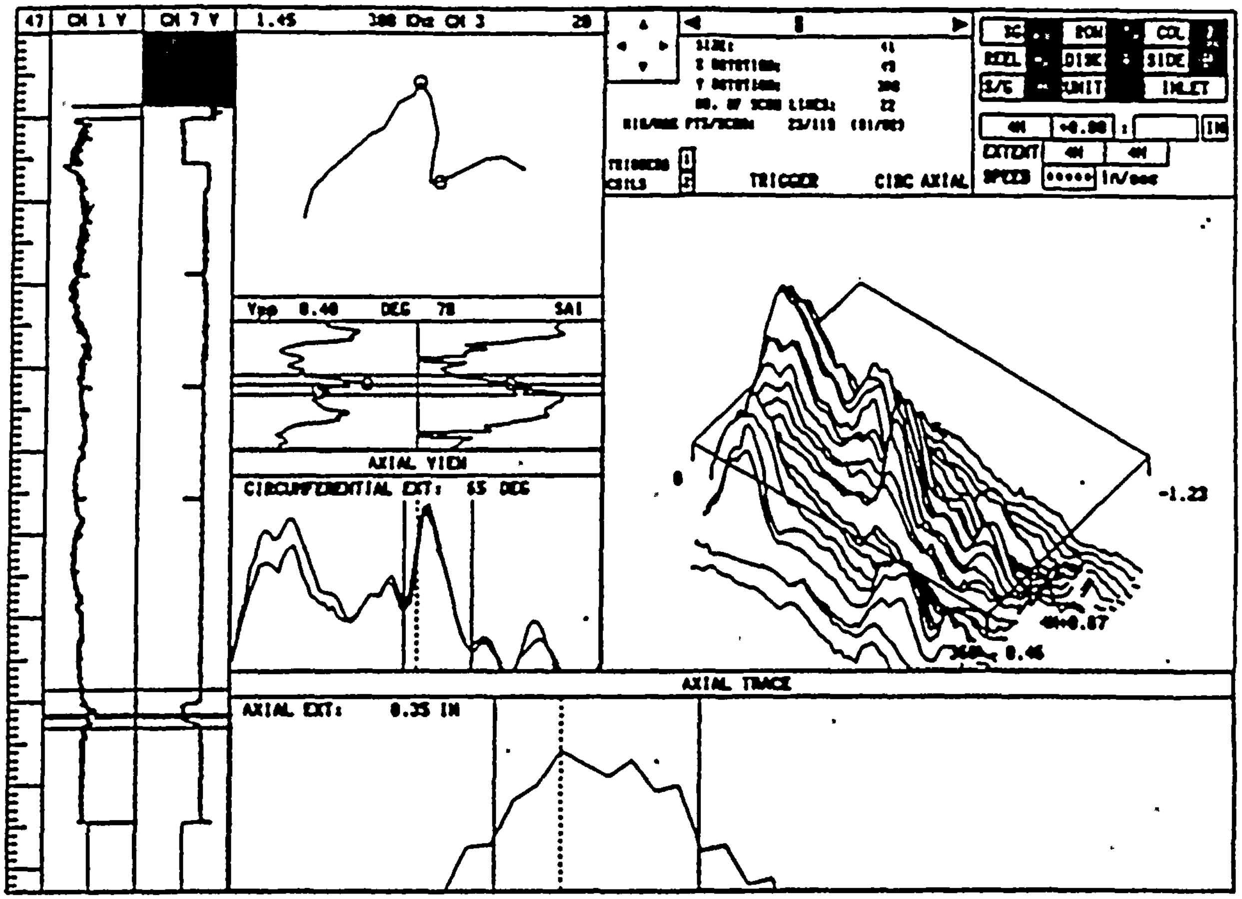

Figure A-27. Axial ODSCC Indications (MAI) at TSP - Plant A-1.

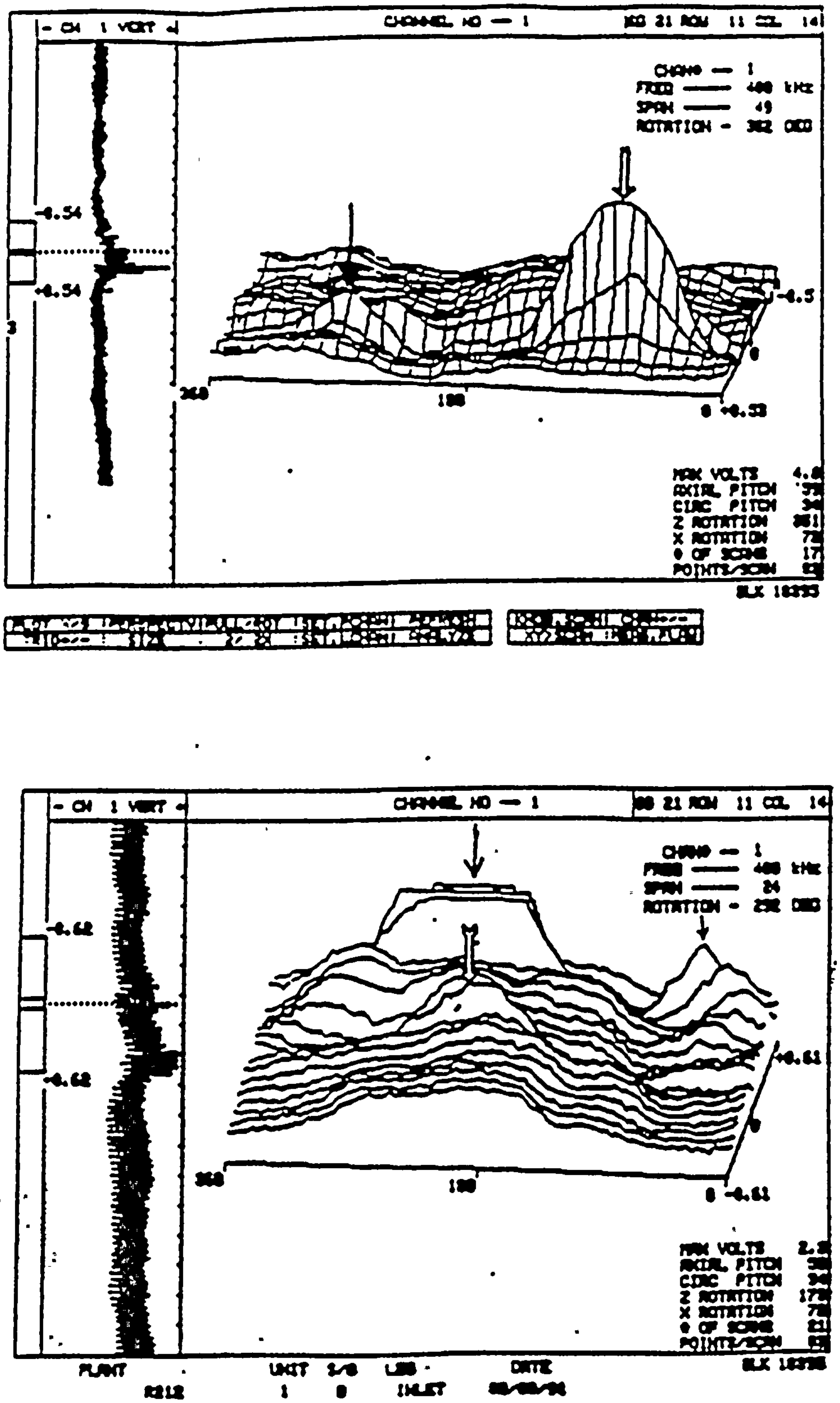

Figure A-28. Circumferential ODSCC Indications at Support Plates (Plant G-1).

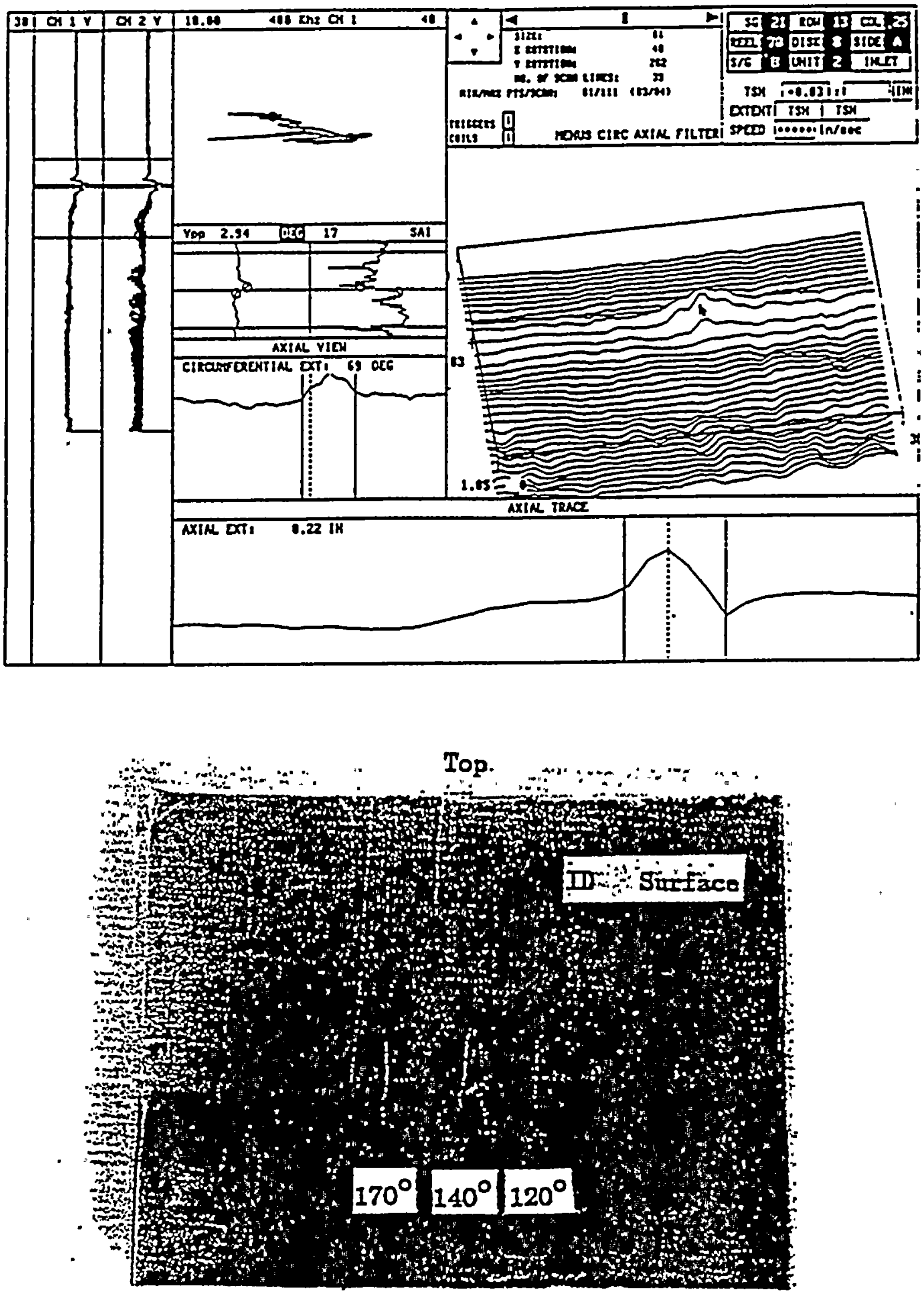

Figure A-29. Plant A-2 RPC and Destructive Exam Results for Closely Spaced Axial Cracks.

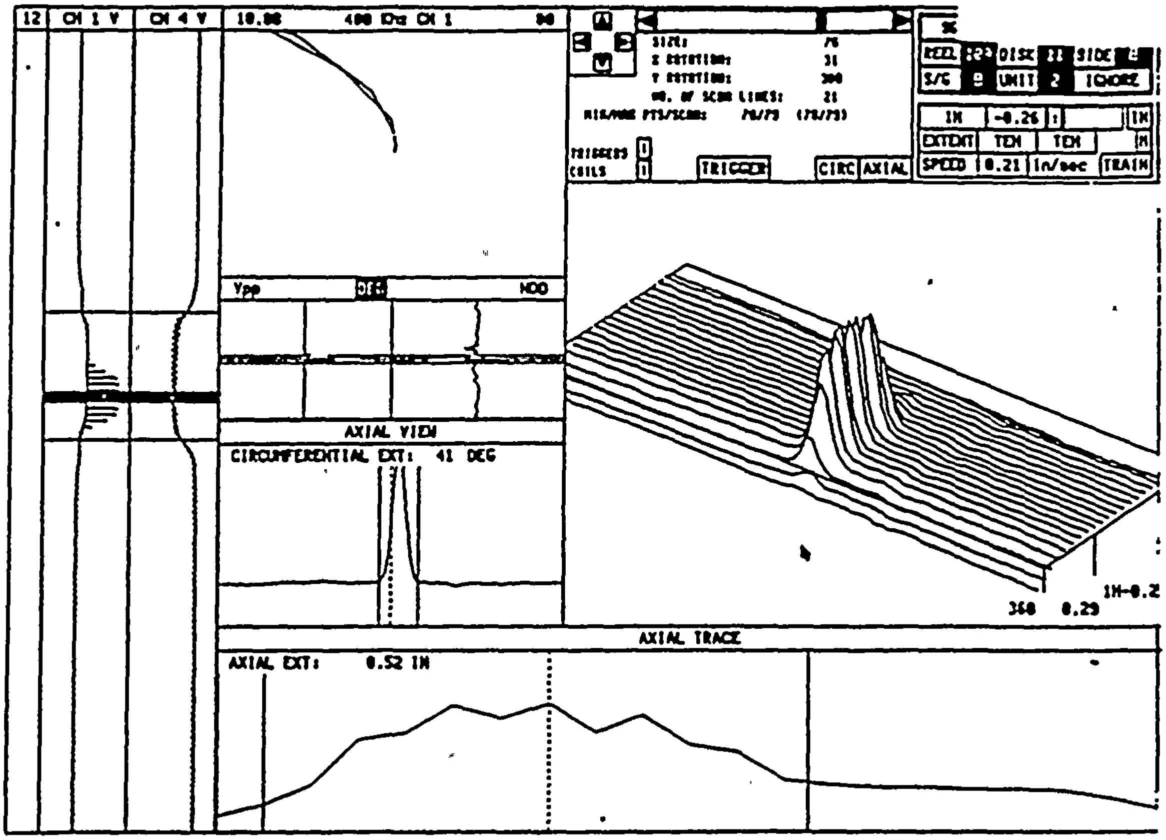

Figure A-30. Slope Intercept Measurement of Crack Length.

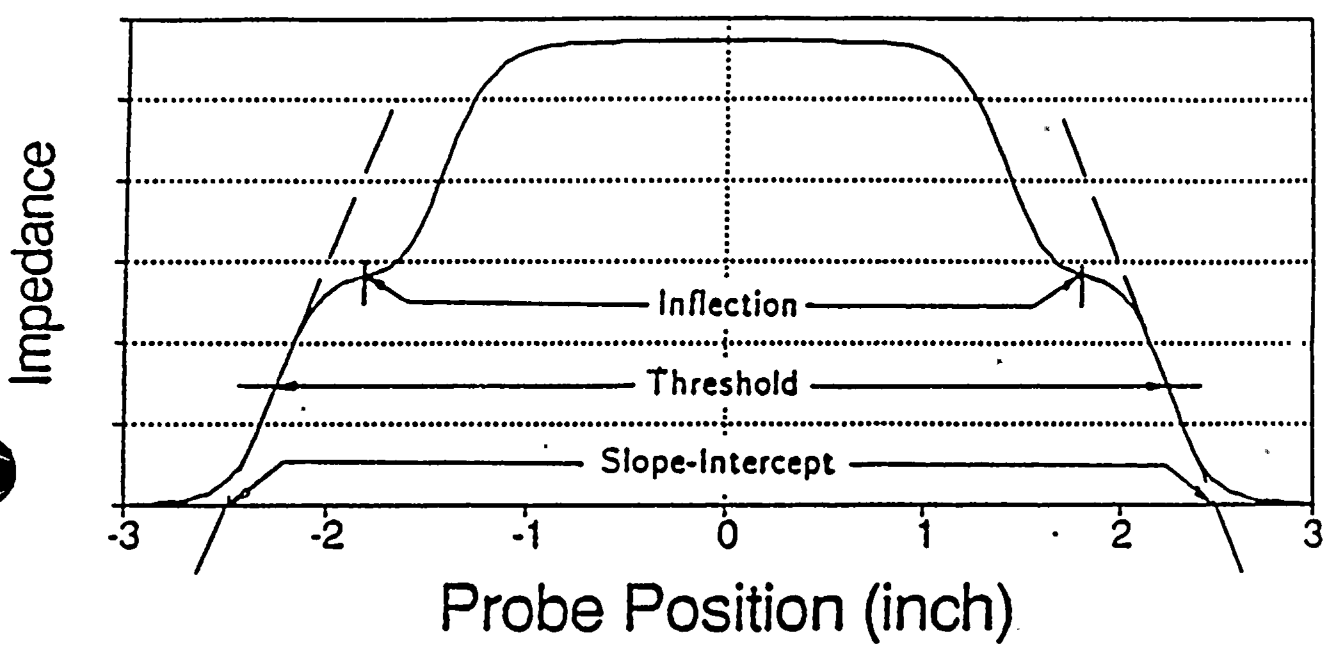

Figure A-31. Techniques for Measuring Crack Lengths From Eddy Current.

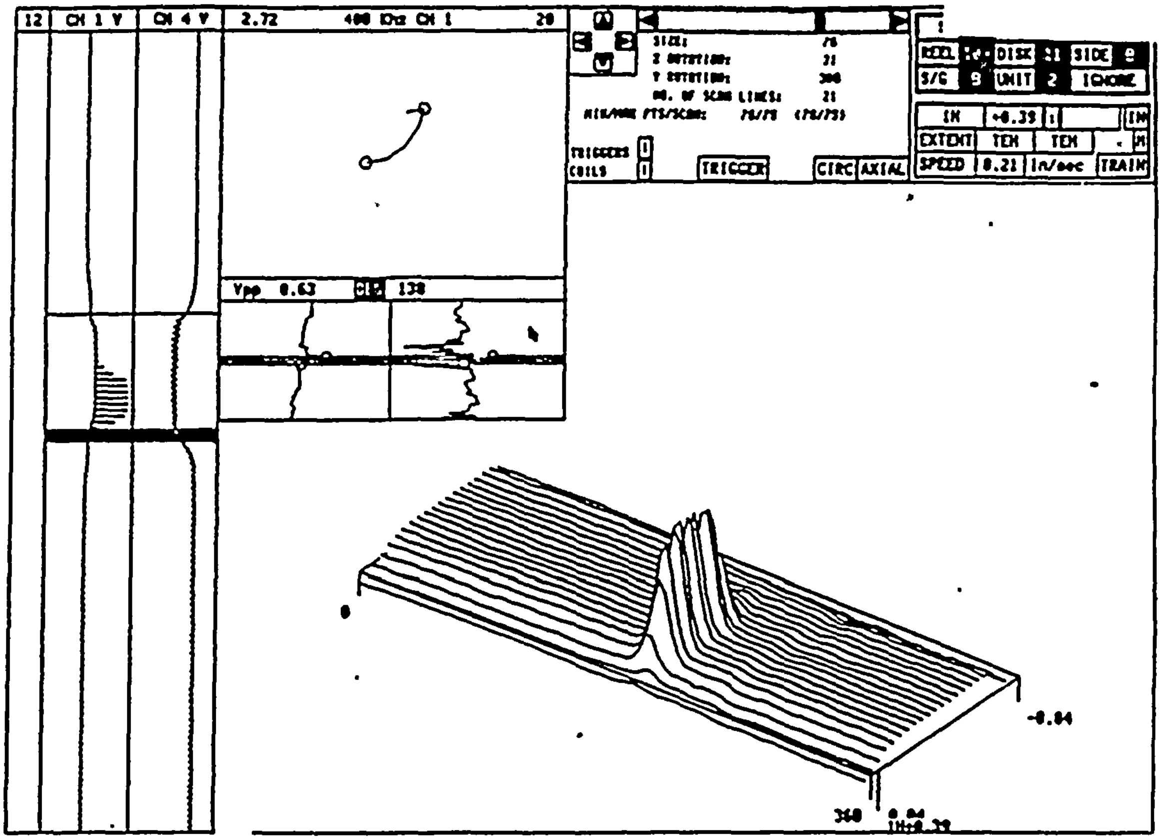

Figure A-32. First Scan Line Flaw Limit.

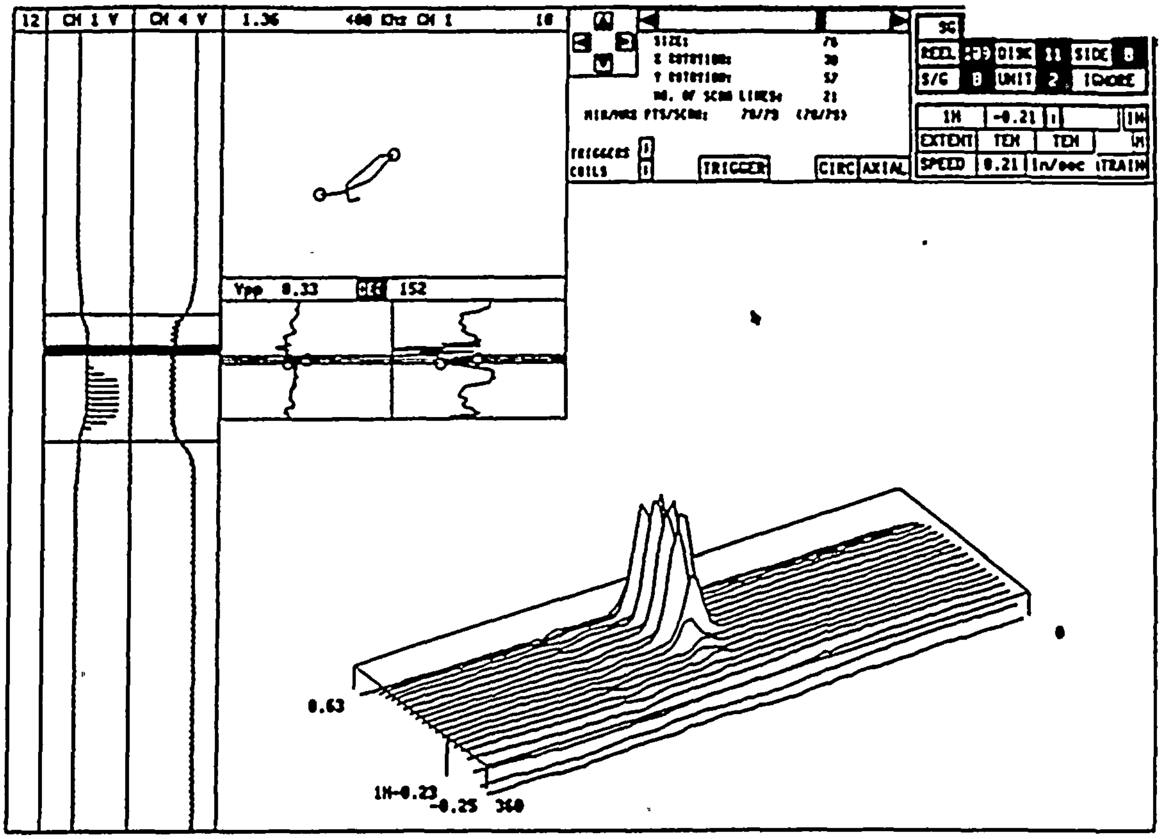

Figure A-33. Last Scan Line Flaw Limit.