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NRC PRESENTATION REPORT ON
STEAM GENERATOR TUBE INTEGRITY
FOR DC COOK UNIT 2, SEPTEMBER 1986

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Reference Submittals

1. AEP:NRC: 0936A, letter to Mr. Harold R. Denton, NRR-USNRC, "Steam Generator Tube Plugging - Interim Status Report", dated October 10, 1985, plus Attachments 1,2, and 3.
2. AEP:NRC: 0936C, letter to Mr. Harold R. Denton, NRR-USNRC, "Steam Generator Tube Integrity - Interim Status Report", dated February 7, 1986, plus Attachment 1,2,3, and 4.

INTRODUCTION

On September 16, 1986 American Electric Power Service Corporation (AEPSC), acting on behalf of Indiana & Michigan Electric Company (I&M), presented to the NRC staff a discussion of recent DC Cook Unit 2 steam generator issues. The presentation served to provide justification for continued operation through the end of the current fuel cycle and to inform the staff of I&M's intentions regarding future replacement of the steam generators. The purpose of this report is to document that portion of the presentation dealing with continued operation.

1.0 OVERVIEW OF RECENT PLANT OPERATING HISTORY

1.1 Background

DC Cook Unit 2 incorporates a nuclear steam supply system manufactured by Westinghouse, and is licensed for 3411 MW_t. Initial criticality occurred on March 10, 1978. The unit is currently operating in its sixth fuel cycle; as of August 31, 1986, about 5.4 effective full power years of operation have been accrued.

Unit 2 has four Westinghouse Series 51 steam generators of the type illustrated in Figure 1.1.1. A description of significant features and a review of the types of tube degradation experienced prior to November 1983 are contained in Reference Submittal 2.

The first significant indication of secondary side tube corrosion in the Unit 2 steam generators occurred in November 1983. A chronology of steam generator events from then until December 1985 is attached as Table 1.1.1. Details of these events are documented in Reference Submittals 1 and 2, and were presented and discussed by AEPSC in a meeting with the NRC staff on December 4, 1985.

As a result of that meeting, I&M was given approval to continue Cook 2 operation through the end of Cycle 5, at which time steam generator tube surveillance would be required in accordance with plant Technical Specifications. The NRC staff also agreed that, following surveillance and plugging of any degraded tubes in excess of the plugging limit that may be found, I&M could restart and operate Cook 2 for up to three effective full power months in Cycle 6 without further review by the NRC.

1.2 Operating Experience During Remainder of Cycle 5

Unit 2 operated from October 24, 1985 through the remainder of Cycle 5. A summary of operating experience for the period is given in Table 1.2.1.

From start-up in October 1985 (following the last forced outage due to tube leakage) until February 28, 1986 (when the Cycle 6 refueling outage began), the reactor generated 6,959,834 MWh hrs., or about 85 effective full power days (EFPDs).

Unit thermal power output was administratively limited - typically to about 80 percent - in order to reduce the primary side temperature and perhaps slow the rate of tube degradation. Secondary side chemistry treatment included on-line addition of boric acid to inhibit caustic-induced tube corrosion; boron concentration was maintained at 5 to 10 ppm. The apparent impact of these measures is addressed in Section 4.0.

Two outages occurred during the period but were unrelated to steam generator tube degradation. Following the second of these outages, primary-to-secondary steam generator leakage, which had been consistently measured at about 0.001 gpm since the October start-up, increased to about 0.038 gpm, an order of magnitude less than the Technical Specification limit of 0.35 gpm.

Upon unit shutdown, visual inspection of each steam generator's primary tubesheet surface under a static head of water revealed no leakage. After establishing a 600 psi nitrogen overpressure, water was observed to be slowly dripping from the hot leg tube end of tube R16C45 in SG 22. Subsequently, eddy current testing confirmed the presence of an indication in the tubesheet crevice region.

Steam generator activities during the refueling outage included bobbin coil probe eddy current testing in accordance with Technical Specification requirements, tube plugging as required, and crevice flushing and low power soaks with boric acid. Also, limited eddy current testing with a rotating pancake coil probe to validate the analysis techniques used at support plate intersections was performed. These activities are discussed in later sections of this report.

1.3 April/May 1986 Eddy Current Testing - Inspection Plan and Results

A steam generator tube eddy current inspection in accordance with Technical Specification 4.4.5.0 surveillance requirements was performed in April/May 1986. Table 1.4.1 summarizes the initial sample selection and subsequent expansions to include the appropriate areas of each steam generator.

Data collection and primary evaluation were performed by Westinghouse. An independent analysis of the data was performed by Conam Inspection. Conam also conducted a comparison of each indication (including distorted indications or other anomalous eddy current signals, etc.) with corresponding data from the Fall 1985 inspection, and re-evaluated the 1985 data using the analysis criteria developed for the 1986 inspection. The 1986 analysis criteria are based on Westinghouse and AEPSC correlation of bobbin coil data with tube sample metallographic results, and are discussed in detail in Section 2.0.

Approximately 75 tubes were also inspected by Westinghouse with a rotating pancake coil eddy current probe, primarily to help validate the analysis criteria used at the tube support plate intersections. Results are discussed in Section 2.0.

1.4 April/May 1986 Eddy Current Testing - Summary of Results

Figure 1.5.1 is a tabulation of eddy current results for the hot legs of the four DC Cook Unit 2 steam generators. The area inside the boundary represents the plugging criteria implemented by I&M.

1.5 Cycle 6 Operating Experience

Unit 2 began operation in Cycle 6. A summary of operating experience through August 31, 1986 is given in Table 1.3.1.

Thermal power output remains administratively limited - again to typically 80 percent, although operation at 90 percent has occurred in order to perform certain tests and to meet high system load demand during the summer peak period. Thermal generation through the end of August has been 3,015,035 MWhrs, or about 37 EFPDs.

From start-up on July 7 through the date of this writing in late October 1986, no indication of steam generator primary-to-secondary leakage has been detected.

2.0 APRIL/MAY 1986 EDDY CURRENT TESTING - DISCUSSION OF RESULTS

2.1 Eddy Current Analysis Criteria

The eddy current analysis criteria used during the 1986 inspection for dispositioning tubes was derived from prior eddy current results at Cook Unit 2 and using the tube pull examination data collected in 1985. A summary of the criteria used for tube plugging is shown in Figure 2.1.1. This is shown by the enclosed area which indicates tube condition definitions which were plugged in the "85" outage and in the "86" outage. The enclosed area is larger in the 1986 outage compared to the 1985 outage. The area of expanded administrative plugging was at the tubesheet surface.

In general, the technical specification plugging criteria of indications greater than 40% was used in two areas, the tube support plate elevations and with miscellaneous indications. In all other locations, more conservative administrative plugging criteria were utilized. In 1985, this included all indications observed in the crevice region and those indications that were at or above 30% through-wall at the tubesheet surface. In 1986, the plugging criteria was expanded to include all indications observed at the tubesheet surface.

Conservatism was implemented in the 1986 inspection in the regions of the crevice and the tubesheet surface through the elimination of a threshold voltage criteria which is typically used as a signal to noise measure to discriminate between reportable and nonreportable indications. In 1985 a threshold voltage criteria was utilized; however, in 1986 any indication, independent of the amplitude or voltage, was considered. Consequently, a more conservative plugging plan was implemented in the area of the tubesheet crevice and just above the tubesheet. Relative to distorted indications at the tube support plate elevations, an inspection criterion based on signal amplitude, i.e., threshold voltage, was developed and used.

2.2 Special Analysis Criteria for Hot Leg Tube Support Plates

2.2.1 Definitions

In the 1986 outage an overall signal classification plan for the hot leg tube support plates was implemented which benefitted from the tube sample metallography and additional laboratory diagnostics conducted prior to the outage. A summary of the signal classifications is shown in Table 2.2.1. The first classification is that of a percent through-wall indication which was based upon criteria of a distorted 400 KHZ support plate signal with a signal in the mixed channel output whose magnitude exceeded a threshold voltage level. This degradation was treated as tube wall degradation in excess of the technical

specification plugging limit of 40 percent. The threshold voltage level will be discussed later but was based upon data obtained from the tube pull from DC Cook Unit 2 and additional laboratory generated specimens. The second criteria, a Distorted Indication or DI, was that associated with a distorted 400 KHZ support plate signal with a signal in the mixed channel whose magnitude was less than the threshold voltage. This condition was treated as tube wall degradation but less than the plugging limit of 40% and would be identified such that it could be monitored during subsequent inspections. The third condition identified is No Detectable Degradation or NDD. This is a condition which is observed to be typical of signals obtained from normal tube support plate intersection tube signals not indicative of tube wall degradation.

2.2.2 Review of Inservice Inspection Criteria

To better understand the 1986 inspection criteria implemented for the hot leg tube support plate intersections, a brief review of the eddy current data observed in 1985 is provided. Figure 2.2.1 is typical of a large amplitude signal observed in the 1985 inspection. The top half of the figure demonstrates the information obtained using single frequency 400 KHZ diagnostics and the bottom of the figure illustrates a mix of 100/400 KHZ frequencies. In contrast, Figure 2.2.2 shows a small amplitude signal. The normal depth interpretation of a signal is based upon the phase angle of the signal. However, due to the small amplitude of signals as shown in Figure 2.2.2, this methodology was not considered to be reliable. Consequently, tube samples were removed during the 1985 outage and analyzed with the objective of refining the eddy current evaluation technique.

Table 2.2.2 summarizes the actions which have been implemented to disposition the tube degradation occurring at the tube support plate intersections. For the 1986 outage, the correlations established for eddy current inspection analysis were based on metallographic data and were confirmed utilizing a rotating pancake eddy current probe.

2.2.3 Development of the Threshold Voltage Concept

In developing the 1986 inspection criteria, a comparison of the eddy current estimated depth based upon the 100/400 KHZ mix was compared to the depth of degradation as determined by metallographic examination. Based on measuring tube wall degradation utilizing signal phase angle, as can be seen in Figure 2.2.3, above []^{a,c,e} wall degradation eddy current accuracy is maintained within a []^{a,c,e} scatterband. The extent of the tube wall depth of penetration is also reflected in eddy current signal amplitude, which is measured by voltage as shown in Figure 2.2.4. Eddy current signal displays representing both classes of signals, small and large

amplitude, are shown in Figure 2.2.5. Based upon the above, a threshold signal amplitude voltage was selected which discriminates between low voltage signals in which the phase angle determination of depth is not as accurate and high voltage signals in which the phase angle determination of depth is more accurate.

2.2.4 Verification of Threshold Voltage Concept

To confirm the 1986 criteria, a supplemental eddy current inspection program was conducted. This program utilized a rotating pancake coil probe inspection to validate the logic for dispositioning the indications at the hot leg support plates and to confirm that degradation conditions were still confined within the support plate. See Table 2.2.3.

The basic design of the rotating probe, illustrated in Figure 2.2.6, utilizes a surface riding eddy current probe forced into contact against the inner diameter of the tube by a spring loaded mechanism. The assembly is rotated circumferentially as it is translated axially through the tube resulting in a closely spaced helical pattern. Utilizing this inspection technique, a detailed description of the condition of localized tube degradation can be obtained and characteristics of the indication morphology identified. Shown in Figure 2.2.7, this type of information is demonstrated for an inspection standard consisting of several artificially induced flat bottom holes. In addition, the edge of a tube support plate placed in proximity to the tube with the flat bottom holes is also indicated.

Each class of signal in which the bobbin coil inspection criteria was implemented was confirmed utilizing the rotating pancake coil. Figure 2.2.8 illustrates a comparison between the bobbin coil data and the rotating pancake coil data for a class of signals identified as No Detectable Defect (NDD). As observed in the top half of this figure, an essentially normal tube support plate signal is shown in the 400 KHZ frequency, and in the bottom half of the figure, the rotating probe data is shown which illustrates the absence of any significant irregularities in the eddy current field.

Figure 2.2.9 demonstrates the Distorted Indication or DI class. As discussed earlier, this class was concluded from the tube sample examination results to be evidence of actual wall degradation but below the plugging limit. The results of the rotating pancake coil inspection is shown in Figure 2.2.10. In the top half of the figure the isometric image of the area inspected is shown and it reveals minor "peaks and valleys" indicative of some minor wall degradation. Also, in the vertical channel, the data confirms that these indications are confined to the space within the support plate. The use of phase angle determination of wall depth with the rotating pancake coil inspection at the deepest indicated location showed that the depth of penetration is indeed less than the plugging limit.

The third classification of signals were those determined to be quantifiable in terms of depth of penetration. As shown in Figure 2.2.11, both the 400 KHZ detection frequency and the 100/400 mix show the presence of quantifiable wall degradation. Utilizing the criteria of the inspection these would be quantified using the phase angle from the 100/400 KHZ mix, and in the particular case shown, determined to be a pluggable indication. To confirm this condition the rotating pancake coil probe was applied as shown in Figure 2.2.12. The isometric display of the data shows more pronounced "peaks and valleys" than is shown in the case for the distorted indication. Also shown are the edges of the tube support plate. As can be seen in the vertical display, the extent of degradation is confined to the support plate region.

From the comparison of the bobbin coil criteria developed from the tube samples and the rotating pancake coil supplemental inspections, several conclusions can be derived:

- o Based upon the bobbin coil probe inspection, the threshold voltage concept is accurate in discriminating between pluggable and nonpluggable tubes based on a 40 percent wall reduction level.
- o Rotating pancake coil probe data confirms that the tube degradation in the DC Cook Unit 2 steam generators is confined to within the thickness of the tube support plate.
- o Areas in which no wall degradation has been observed based upon the bobbin coil inspection data have no evidence of wall degradation using the rotating pancake coil probe data.

2.3 Overview of 1986 Eddy Current Inspection Results

Figures 2.3.1 through 2.3.6 demonstrate the spatial location and extent of wall degradation in the steam generator tubing. Figure 2.3.6 indicates the areas of pluggable indications and demonstrates the contribution of pluggable indications both on the basis of quantifiable percent wall loss based upon typical eddy current data interpretation as well as the areas of less quantifiable interpretation which were administratively plugged. This figure shows that the crevice area is the dominant area of tube degradation followed by the area at the tubesheet surface (which is significantly influenced by the conservative plugging limit imposed in which all evidence of degradation was removed from service). Most importantly, tubes with wall degradation at the hot leg tube support plate intersections in excess of 40% wall loss have been removed from service.

The integrity of the tube bundle has been established in two manners. First, the condition of the steam generator tubing has been assessed through eddy current inspection. The uncertainties associated with inspection have been minimized through knowledge from tube pulls and complementary inspection techniques transferred to the nominal inspection method. Secondly, conservative, administrative, plugging levels have been implemented by I&M for DC Cook Unit 2 in areas where corrosion growth rates have historically been more significant.

2.4 Present Growth Rate Data Derived from "85"- "86" Inspection Results

In addition to the absolute level of wall degradation, a comparison of the eddy current indicated wall degradation in 1985 to 1986 was made to both assess the extent of degradation in the various portions of the steam generator and determine the rate of growth within the different tube bundle elevations. Also, the effect of revised operating conditions was considered in the growth assessment and will be discussed in Section 4.

In general, the rate of degradation in the various portions of the steam generator; the tubesheet crevice, the tubesheet surface, and the tube support plate were compared to the prior observations in 1985. The observations in the "85" to "86" operating period are consistent with that previously observed. The apparent rate in the tubesheet crevice is above that at the tubesheet surface which leads the tube support plates. This comparison is shown in Table 2.4.1 which also shows the percent wall penetration change at each of the three locations.

Additionally the rates observed in the operating periods in "84" to "85" and "85" to "86" were compared on a per effective full power month basis. The results of this comparison are shown in Table 2.4.2. Not only is the trend of rate of degradation among each of the three most significant locations consistent between the two operating periods, but also there is a consistent trend of reduced wall degradation in the overall comparison of "84"- "85" and "85"- "86" data. The variation in the three locations can be associated with the conditions in the steam generator in terms of potential for corrodent concentration. The change in degradation between the different operating periods can be associated with the changes in secondary side water chemistry and also operating conditions. These will be discussed in Section 4.0. Because of the consistency of the degradation rates observed in the three locations and the consistency between these rates and the change in operating conditions, the "85" to "86" corrosion/degradation rates are considered to be the rates most appropriate for evaluation of current conditions within the steam generators.

3.0 EVALUATION OF OPERATION THROUGH END OF CYCLE 6

3.1 Structural Integrity Conservatism

Minimum wall requirements for the DC Cook Unit 2 steam generator tubing were calculated in accordance with the criteria of USNRC Regulatory Guide 1.121, entitled "Basis for Plugging Degraded PWR Steam Generator Tubes". Confirmation of consistency with these requirements was demonstrated previously in 1985 based upon tube sample examinations and testing. They are summarized in Tables numbered 3.1.1 and 3.1.2. The basic requirements consist of:

I. Allowable minimum wall determination per the following:

1. For normal plant operation, primary tube stresses are limited such that a margin of safety of 3 is provided against exceeding the ultimate tensile strength of the tube material, and the yield strength of the material is not exceeded, considering normal and upset conditions
2. For accident condition loadings, the requirements of paragraph NB-3225 of Section III of the Code are to be met.

In addition, it must be demonstrated that applied loads are less than the burst strength of the tubes at operating temperature as determined by testing.

3. For all design transients, the cumulative fatigue usage factor must be less than unity.

- II. Leak Before Break demonstration, i.e., that a single through-wall crack with a specified leakage limit (Technical Specification leak rate limit) during normal operation would not propagate and result in tube rupture during postulated accident condition loadings.

In establishing the safe limiting condition of a tube in terms of its remaining wall thickness, the effects of loadings during both the normal operation and postulated accident conditions must be evaluated. [

]a,c,e Therefore, Item I.3 above need not be addressed for the DC Cook Unit 2 steam generator tubes.

In the calculation of tube minimum wall, three distinct areas of tube degradation within the DC Cook Unit 2 steam generators were addressed: tubesheet crevice, tubesheet surface (defined as the area from the very top of the tubesheet on the secondary side extending approximately 6 inches into the free span of the tube) and tube support plate intersections.

Based on the destructive examination of the five tube samples removed from steam generator 22 in 1985, the tube minimum wall determination for localized tube degradation occurring at the tube support plate elevations in the DC Cook Unit 2 steam generators assumed:

1. Tube degradation was characterized as multiple SCC, 0.1-0.2 inch in axial extent.
2. Partial through-wall cracking was evaluated as single and multiple cracks.
3. As tube support plate degradation was confined to the thickness of the tube support plate, the maximum macrocrack length is equal to support plate thickness or 0.75 inch.
4. Link up of multiple SCC was considered improbable at postulated accident condition pressure differential as reflected in the tube specimen burst tests.

Likewise, a tube minimum wall determination for localized tube degradation occurring at the tubesheet crevice/ top of the tubesheet assumed:

1. Tube degradation to be characterized as either multiple SCC or intergranular SCC combined with shallower, more widely spread intergranular attack (IGA/SCC).
2. Tubesheet crevice/ top of the tubesheet tube wall degradation was evaluated as equivalent thinning (as a result of IGA) with a superimposed crack.
3. The axial extent of the equivalent thinned length of tube degradation is 1.5 inches. Also, the IGA (equivalent thinning) was uniform around the tube circumference.

Per NUREG/CR-718, "Steam Generator Tube Integrity program Phase I Report", a tube uniformly thinned around its circumference for an axial length of 1.5 inches would be expected to have a burst pressure equivalent to an undegraded tube having the same wall thickness and outside diameter as the thinned region.

Results of these calculations are provided in Table 3.1.1 for each of the above areas of the tube degradation. Moreover, Table 3.1.2 provides a summary of minimum wall determination for the three regions of localized tube degradation occurring in the DC Cook Unit 2 steam generators. In each case, the limiting criterion for determining the allowable tube wall reduction is the RG 1.121 criterion for normal operation that requires a margin of safety of 3 against exceeding the ultimate tensile strength of the tube material.

3.2 Leak Before Break Verification

The leak before break rationale is to limit the maximum allowable primary-to-secondary leak rate during normal operation such that the associated crack length through which technical specification leakage occurs is less than the critical crack length corresponding to tube burst at the maximum postulated pressure condition loading (FLB). Thus, on the basis of normal operation, unstable crack growth is not expected to occur in the unlikely event of the limiting accident. Previously, it has also been demonstrated that growth of partial through-wall cracks exhibit a limited aspect ratio. This characteristic results in crack extension through-wall prior to reaching the SLB/FLB critical crack length.

For tube support plate intersections, an examination of metallographic sections from steam generator 22 has characterized the morphology of the cracks to be multiple SCC. All tube support plate SCC has been of short axial extent (0.1-0.2 inch) confined within the tube support plate thickness. The single crack length corresponding to the plant Technical Specification leak rate limit of 0.35 gpm at a normal operating pressure differential is approximately []^{a,c,e} inch. The critical crack length corresponding to burst during a postulated FLB accident is approximately []^{a,c,e} inch; therefore, a leak before break margin of 52 percent is demonstrated.

For the tubesheet crevice region, localized tube wall degradation has been characterized through metallography to be multiple SCC. At a range of 0 to 6.0 inches above the top of the tubesheet, metallography has shown localized tube wall degradation to be combination IGA/SCC.

The superimposed crack length corresponding to a leak rate of 0.35 gpm at normal operating pressure differential for a tube "thinned" uniformly 62 percent through-wall around the circumference for an axial length of 1.5 inches is approximately []^{a,c,e} inch. The critical crack length corresponding to burst during a postulated FLB event is approximately []^{a,c,e} inch; therefore a leak-before-break margin of 25 percent is demonstrated.

The utilization of a leak rate monitoring policy which emphasizes both absolute leak rate measurement and rate of change and includes the initiation of action prior to reaching the Technical Specification limit (0.35 gpm) yields additional safety margin; for example, at a leak rate of 0.25 gpm and a pressure of 1400 psid, the factor of safety is at least []^{a,c,e} relative to tube burst. It is important to note that very low leakage rates are detectable by leakage monitoring.

3.3 Operating Interval Determination

The influence of the operating environment may affect some of the tubes in a steam generator and result in localized wall degradation. As part of a preventative program to detect tubing wall loss, inservice inspection using eddy current techniques is performed. Affected tubes with a wall thickness greater than the minimum acceptable wall thickness are acceptable for continued service, provided margin is added to the minimum required tube wall thickness to account for eddy current measurement uncertainty and an operational allowance for continued degradation until the next scheduled inspection.

Table 3.3.1 summarizes the operating interval justification for locally degraded steam generator tubing, by tube elevation, upon completion of Cycle 6 operation of DC Cook Unit 2. The required tube plugging levels are based on the maximum permissible wall loss per tube location calculated in accordance with RG 1.121 criteria ($[]^{a,c,e}$ percent for the tubesheet crevice/top of the tubesheet, $[]^{a,c,e}$ percent for tube support plate location degradation), the established eddy current measurement uncertainty for steam generator tube degradation ($[]^{a,c,e}$ percent), growth rate allowances from Section 2.4, and the duration of Cycle 6 (13.5 EFPM's). The eddy current measurement uncertainty and crack penetration growth rate allowance utilized in the above safety margin determinations represent conservative allowances based on previously reported tube sample metallography results.

4.0 STATUS OF REMEDIAL MEASURES

Table 4.0.1 provides a checklist of remedial measures undertaken by I&M to mitigate the effects of steam generator tube degradation. The first item, continuation of the leak rate monitoring program, is not a remedial measure per se, but is included here to emphasize that I&M has been able to detect and successfully deal with tube leaks well below the leakage rate allowed by the plant Technical Specifications. This fact provides even more margin on the leak-before-break demonstration discussed in Section 3.2.

4.1 Improve and Maintain Proper Water Chemistry

Reference Submittal 2 discusses I&M's efforts to improve secondary and maintain proper water chemistry at DC Cook Unit 2. That effort is continuing and has been quite successful. Figures 4.1.1 through 4.1.4 provide yearly average values for four important chemistry parameters - steam generator cation conductivity, steam generator sodium, steam jet air ejector air flow, and condensate/feedwater dissolved oxygen. These plots show that the better chemistry realized as a result of an all-out effort beginning in 1983 is still continuing, and is still improving.

4.2 Boric Acid Treatment Assessment

In the past both empirical and field information on the effects of boric acid treatment in reducing the occurrence and rate of IGA and IGSCC have been presented. The remedial actions have been based upon caustic factors. These are summarized in Table 4.2.1 and in overview are expected to: a) neutralize the caustic environment which has contributed to the stress corrosion cracking and IGA occurrence, b) change the environment to move the alloy 600 from the susceptible electrical potential range for corrosion, c) prevent mass transfer within the inhibitor film or by reformation of passive film. Additionally, I&M has been supporting these reductions of caustic factors through processes to open restrictive crevices and remove sludge and to reduce contamination input through improved chemistry control.

In the prior meeting, the effects in laboratory tests of the reduction of stress corrosion cracking incidence through the use of boric acid, as shown in Figure 4.2.1, and also in the effect of boric acid in reducing the growth rate of preinitiated cracks, as shown in Figure 4.2.2, were presented. Additionally the reduction of the occurrence of IGA has been demonstrated in laboratory tests as shown in Figure 4.2.3 with overall conclusions that boric acid has prevented crack initiation in testing in reference conditions, that boric acid has reduced crack propagation rate with preexisting cracks by a substantial margin, and that boric acid has inhibited intergranular attack in reference environments.

The translation of the laboratory observed conditions to plant observed conditions is given in Figure 4.2.4 which shows the performance of an international operating plant over several years without boric acid treatment and the effect of boric acid addition in terms of reduced number of ECT indications. As can be seen in this figure, for several years before the introduction of boric acid treatment, the number of eddy current indications was increasing steadily. The number of indications reduced substantially following the introduction of boric acid to reduce intergranular attack and stress corrosion cracking in crevice locations. Additionally a second plant was introduced to this treatment and its experience was also similarly positive with a corresponding reduction in tubing ECT indications. The latter also is illustrated in Figure 4.2.4.

The assessment of the boric acid treatment recently initiated at DC Cook Unit 2 is summarized in Table 4.2.3. This assessment used the most relevant data available which is the eddy current testing results from "84" to "85" in comparison to the results from "85" to "86". The effects of the somewhat reduced temperatures associated with recent operation are also encompassed in this comparison. In order to compare the "84" to "85" results on an equivalent basis to the "85" to "86" results, the eddy current data of "84" to "85" was reevaluated using the "85" to "86" analysis criteria. This comparison provided a basis for determining, in a near-term manner, that the remedial effects are directed in the proper direction of reducing corrosion rate and thus tube plugging level. As shown in Table 4.2.3, the data indicates that the plugging rate trend is lower as a result of the boric acid treatment than that which would be expected had no changes in operating chemistry or parameters been implemented. Although these data are based upon relatively short operating experience, the results are clearly in the appropriate and anticipated direction.

In addition the growth rate data previously discussed was compared to the plugging rate data previously developed in the above paragraph. This data is also shown in Table 4.2.3 and reveals that the "85"- "86" growth rate is somewhat below the "84" - "85" growth rate. This is consistent with the expected versus observed plugging rate data. These observations in both plugging levels and growth rate are consistent in trend and magnitude. Regarding the growth rate data, the most substantial improvements in growth rate reduction have been seen in the area in the tubesheet and just above the tubesheet. The lowest reduction has been seen in the tube support plate area which has previously exhibited the lowest level of growth rate. These conclusions are summarized in Table 4.2.4.

4.3 Study of Corrosion Factors

As noted earlier, in addition to the improved secondary chemistry efforts and the use of boric acid treatments, I&M has administratively limited thermal power on Unit 2 to reduce the primary temperature and possibly slow the rate of corrosion.

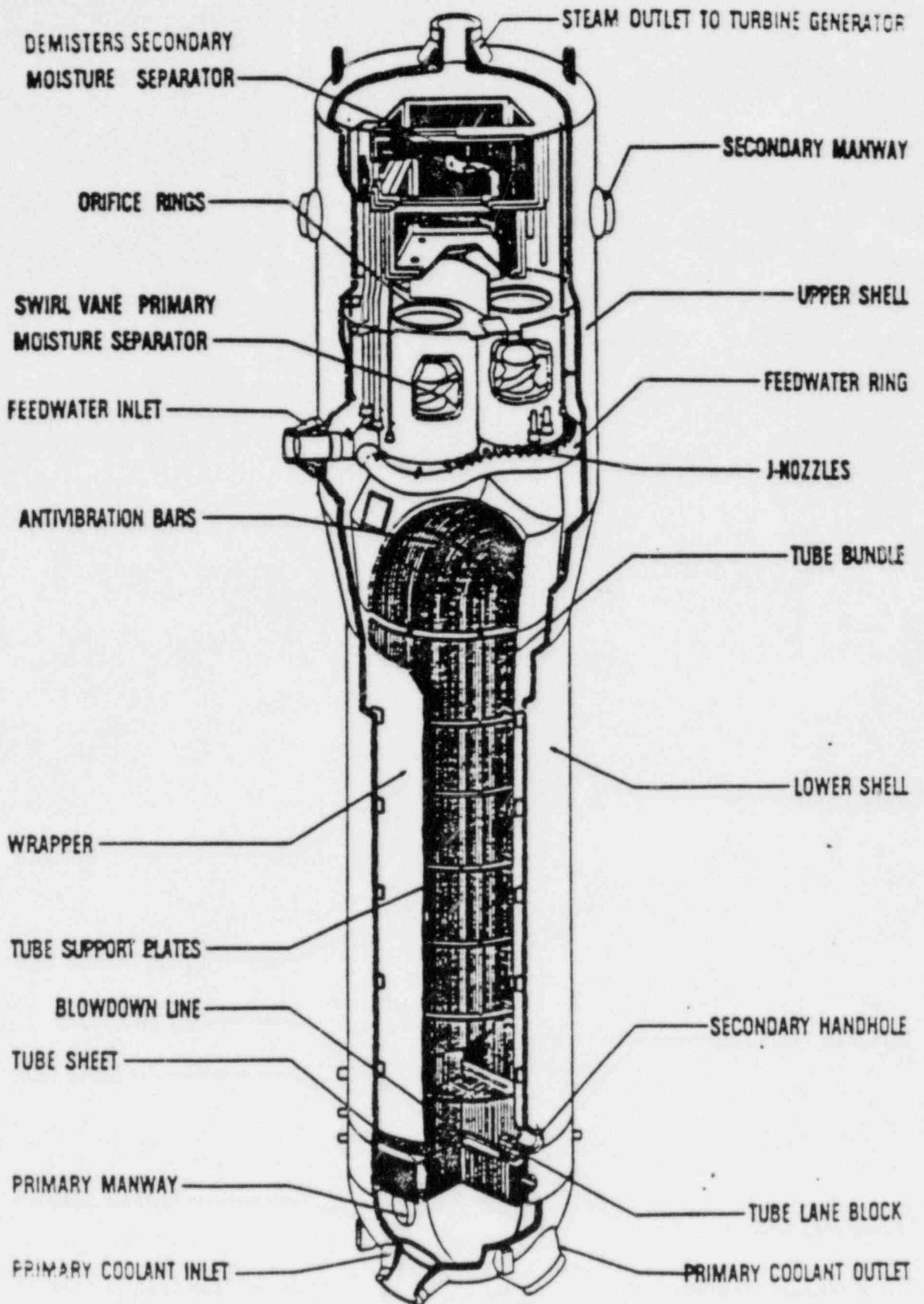
To assess the effectiveness of this temperature reduction, AEPSC and Westinghouse are conducting a sensitivity evaluation of parameters affecting tube corrosion rate in the Unit 2 steam generators. The intent of the study is to illustrate the impact on corrosion rate of various parameters (e.g. - temperature, pressure, bulk water chemistry) so that the benefits of the current temperature reduction program can be better quantified and a more formal temperature reduction program - if warranted - implemented using optimum conditions for corrosion rate reduction consistent with plant capabilities.

Study results are due later this year, and will be used to make recommendations for future operation of Unit 2.

4.4 Mechanical Pairs

AEPSC has commissioned and received licensing studies for tubesheet sleeving from two domestic vendors. However, because of degradation at higher elevations in the tube bundle, I&M has no current plans to pursue a Technical Specification change to allow tubesheet sleeving in the Unit 2 steam generators.

Because of the significant economic impact of reduced power operation and poor unit availability, I&M is currently planning to replace the Unit 2 steam generators. New state-of-the-art steam generator lower assemblies have been purchased from Westinghouse, and are scheduled for delivery in August 1988. Planning and preparation are being made to support a replacement outage beginning as early as mid-1988, although the actual date of the replacement will depend on the success of current actions to arrest the corrosion in the existing steam generators. AEPSC is preparing a Steam Generator Repair Report describing the proposed project for submittal to the NRC staff for review.



SERIES 51 STEAM GENERATOR

Figure 1.1.1

NOT TO SCALE
9916

D. C. COOK UNIT 2

CHRONOLOGY OF SG EVENTS THROUGH DECEMBER 1985

- March 10, 1978 Initial Criticality
- November 7, 1983 Forced Outage - first SG tube leak due to secondary side corrosion
- SG 21, Tube R16C40
 - Leak Rate 0.29 gpm
 - ECT of 1225 Tubes in 2 SGs
 - Plugged 3 tubes
 - Restart November 22
- March 10, 1984 Refueling Outage
- 100% ECT all 4 SGs
 - 7 tubes samples removed
 - Plugged 402 tubes (320 were Row 1 tubes)
 - Restart July 7
- July 15, 1985 Forced Outage - SG Tube Leak
- SG 23, Tube R16C56
 - Leak Rate 0.22 gpm
 - ECT of 25 tubes in SG 23
 - Plugged 2 tubes
 - Attempted restart August 2
- August 2, 1985 Forced Outage - SG Tube Leak During Start-Up
- SG 23, Tubes R7C28 & R14C70
 - Leak Rate Measurements Not Possible
 - ECT of 1500 Tubes in SG 23
 - Plugged 35 tubes
 - Initiated Boric Acid Treatment (Low Power Soak, On-Line Addition)
 - Restart August 22
- August 23, 1985 Forced Outage - SG Tube Leak During Low Power Soak
- SG 22, Tube R14C41; SG 24, Tube R19C52
 - Leak Rate 0.2 gpm
 - 100% ECT All 4 SGs
 - 5 tube samples removed
 - 110 tubes plugged
 - Restart October 23

D. C. COOK UNIT 2

OPERATING EXPERIENCE DURING REMAINDER OF CYCLE 5 (October 24, 1985 - February 28, 1986)

- o Unit power level administratively limited
- o 6,959,834 MW-HRS generated; corresponds to 85 EFPDs
- o 2 outages during the period (Mode 5), both unrelated to SG tube degradation
- o SG leakage in the range of 0.001 to 0.038 gpm
- o Visual inspection after shutdown revealed one leaking tube - SG 22, Tube R16C45

D. C. COOK UNIT 2

OPERATING EXPERIENCE FOR BEGINNING OF CYCLE 6
(July 7, 1986 - Present)

- 0 Unit power level administratively limited
- 0 3,015,035 MW-HRS generated as of August 31, 1986;
corresponds to 37 EFPDs
- 0 One outage during the period (Mode 3), unrelated to
SG tube degradation
- 0 Steam generator leakage virtually undetectable

D. C. COOK UNIT 2

APRIL/MAY 1986 ECT INSPECTION PLAN

- 0 Performed in accordance with Tech. Spec. surveillance requirements 4.4.5.0
- 0 Initial sample selection
 - SG 21 - 165
 - SG 22 - 120
 - SG 23 - 105
 - SG 24 - 160
 - Total 550 (4.1%)
- 0 SG 22 entered C-3 category, which required expansion to 100% of SG 22, plus an additional 2S tubes in the remaining SGs
- 0 Subsequent classification of SG 24 as C-3 made it necessary to expand the inspection to include the affected areas of the remaining tubes in all four SGs
- 0 Prompt notification of C-3 classification was made to NRC in accordance with Tech. Spec. 4.4.5.5c
- 0 Inspection results and intended actions were discussed via telecon with NRC staff on April 23, 1986

D. C. COOK UNIT 2

SUMMARY OF SG HOT LEG EDDY CURRENT INSPECTION RESULTS

APRIL/MAY 1986

| | < 20 | 20-29 | 30-39 | ≥ 40 | DI | SQR | UDS | Total |
|-------------------|------|-------|-------|------|-----|-----|-----|-------|
| Support Plates | 1 | 5 | 10 | 19 | 279 | N/A | NR | 314 |
| Crevice Region | 0 | 1 | 1 | 33 | 0 | 56 | 3 | 94 |
| Tubesheet Surface | 7 | 3 | 8 | 8 | 11 | N/A | NR | 37 |
| Miscellaneous | 27 | 13 | 13 | 0 | 0 | N/A | NR | 53 |
| Total | 35 | 22 | 32 | 60 | 290 | 56 | 3 | 498 |

DI - DISTORTED INDICATION
 SQR - "SQUIRREL"
 UDS - UNDEFINED SIGNAL

N/A - NOT APPLICABLE
 NR - NOT REPORTED

COMPARISON OF '85 & '86
PLUGGING CRITERIA

..... 1985

| LOCATION | <20 | 20-29 | 30-39 | >40 ... | SOR ... | DI .. |
|-------------------|--------------|----------------|----------------|------------|----------------------|--------------------|
| SUPPORT PLATE | | | | | | AD HOC CRITERIA |
| CREVICE REGION | | | | | THRESHOLD VOLTAGE | |
| T'SHEET SURFACE | | | | | | |
| MISC. | | | | | | |

..... 1986

| LOCATION | <20 | 20-29 | 30-39 | >40 ... | SOR ... | DI .. |
|-------------------|--------------|----------------|----------------|------------|-------------------------|------------------------------------|
| SUPPORT PLATE | | | | | | CRITERIA BASED ON '85 TUBE PULL |
| CREVICE REGION | | | | | NO THRESHOLD VOLTAGE | |
| T'SHEET SURFACE | | | | | | |
| MISC. | | | | | | |

Figure 2.1.1

EDDY CURRENT SIGNAL
CLASSIFICATION
- 1986 -

TUBE SUPPORT PLATE REGION

o PERCENT THROUGH-WALL (Z)

DISTORTED 400 KHZ SUPPORT PLATE
SIGNAL WITH A SIGNAL IN THE MIXED
CHANNEL OUTPUT WHOSE MAGNITUDE
EXCEEDS A THRESHOLD VOLTAGE

o DISTORTED INDICATION (DI)

DISTORTED 400KHZ SUPPORT PLATE
SIGNAL WITH A SIGNAL IN THE MIX
CHANNEL WHOSE MAGNITUDE IS LESS
THAN A THRESHOLD VOLTAGE; TREATED
AS TUBE WALL DEGRADATION LESS
THAN THE PLUGGING LIMIT. MONITORED
DURING FUTURE INSPECTIONS

o NO DETECTABLE DEGRADATION (NDD)

"STATISTICALLY" NORMAL SUPPORT
PLATE SIGNAL

CREVICE REGION

o "SQUIRREL"

A SIGNAL IN THE TUBESHEET CREVICE
WHOSE TRACE AT 400KHZ IS COMPLEX
AND PHASE ANGLE UNCLEAR; SIGNAL
EXHIBITS CHARACTERISTICS OF TUBE
WALL DEGRADATION.

LARGE AMPLITUDE SIGNAL
IN MIX CHANNEL

a,c,e

Figure 2.2.1

SMALL AMPLITUDE SIGNAL
IN MIX CHANNEL

a.c.e

1985 OUTAGE TUBE SUPPORT PLATE
INSPECTION RESULTS

IN-PLANT OBSERVATIONS

- o EDDY CURRENT INDICATIONS AT HOT-LEG
SUPPORT PLATES
 - FIRST OCCURRENCE IN A DOMESTIC
PWR. NEEDED TO ESTABLISH CAUSE

- o ANALYSIS OF IN-PLANT EDDY CURRENT
DATA WAS GIVING INCONSISTENT
RESULTS
 - THE 100KHZ/400KHZ MIX SHOWED
INCONSISTENCIES BETWEEN SIGNAL
AMPLITUDE AND PHASE ANGLE
SUGGESTING THE PRESENCE OF TUBE
WALL DEGRADATION AND POSSIBLY
CREVICE DEPOSITS.

ACTIONS

- o PULLED FIVE TUBES

- o CONDUCTED EXTENSIVE METALLOGRAPHY
AT SUPPORT PLATE INTERSECTIONS

- o ESTABLISHED CORRELATION BETWEEN IN-
PLANT EDDY CURRENT BOBBIN COIL DATA
AND METALLOGRAPHY RESULTS

- o ESTABLISHED ANALYSIS CRITERIA FOR
USE DURING MARCH 1986 INSPECTION

- o CONDUCTED IN-PLANT CONFIRMATION
WITH ROTATING PANCAKE COIL

EDDY CURRENT MEASUREMENT ACCURACY
- STRESS CORROSION CRACKING -

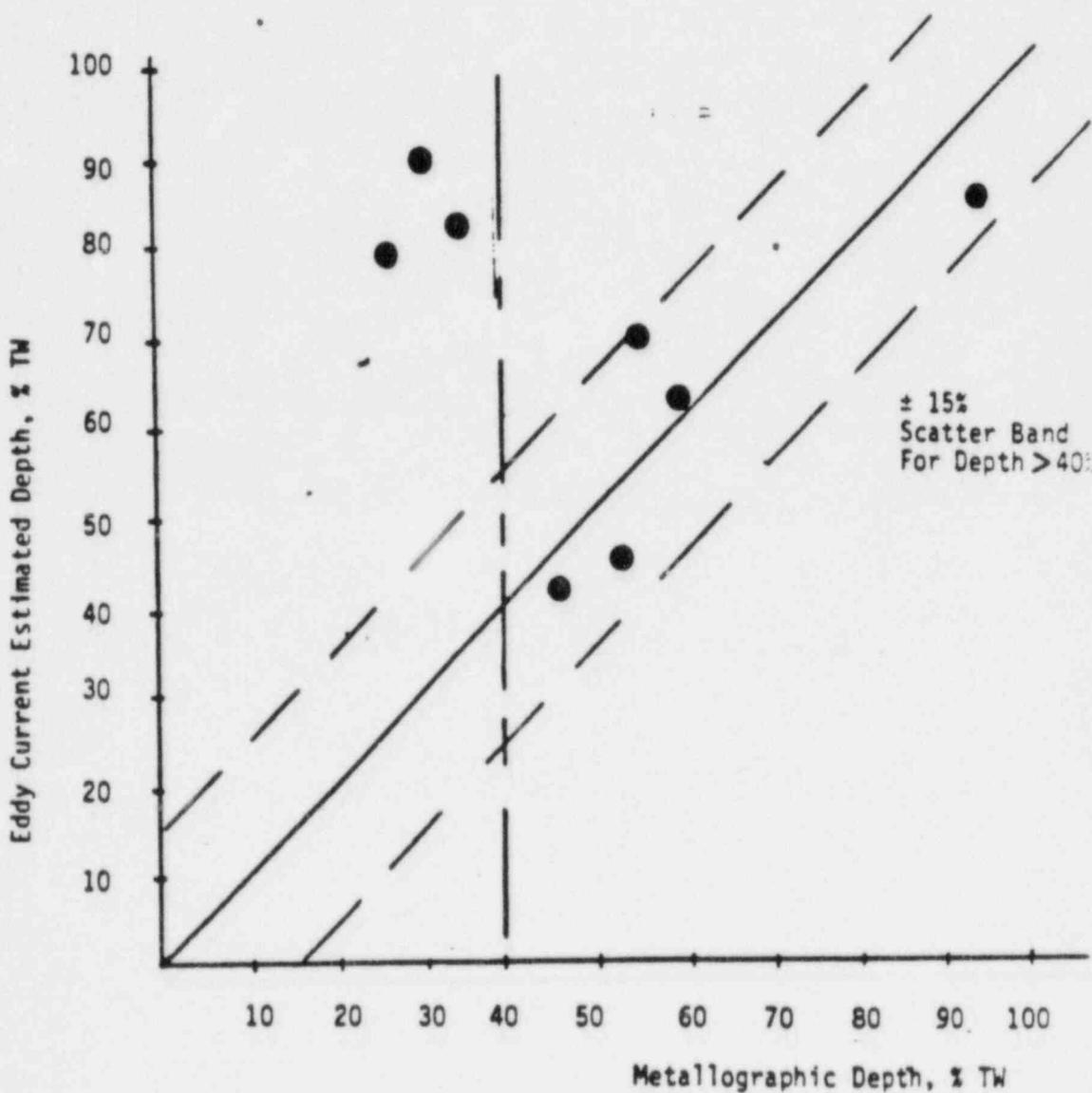


Figure 2.2.3

SIGNAL THRESHOLD ESTABLISHMENT
IN MIX CHANNEL



Figure 2.2.4

TYPICAL SUPPORT PLATE MIX SIGNALS

a.c.e

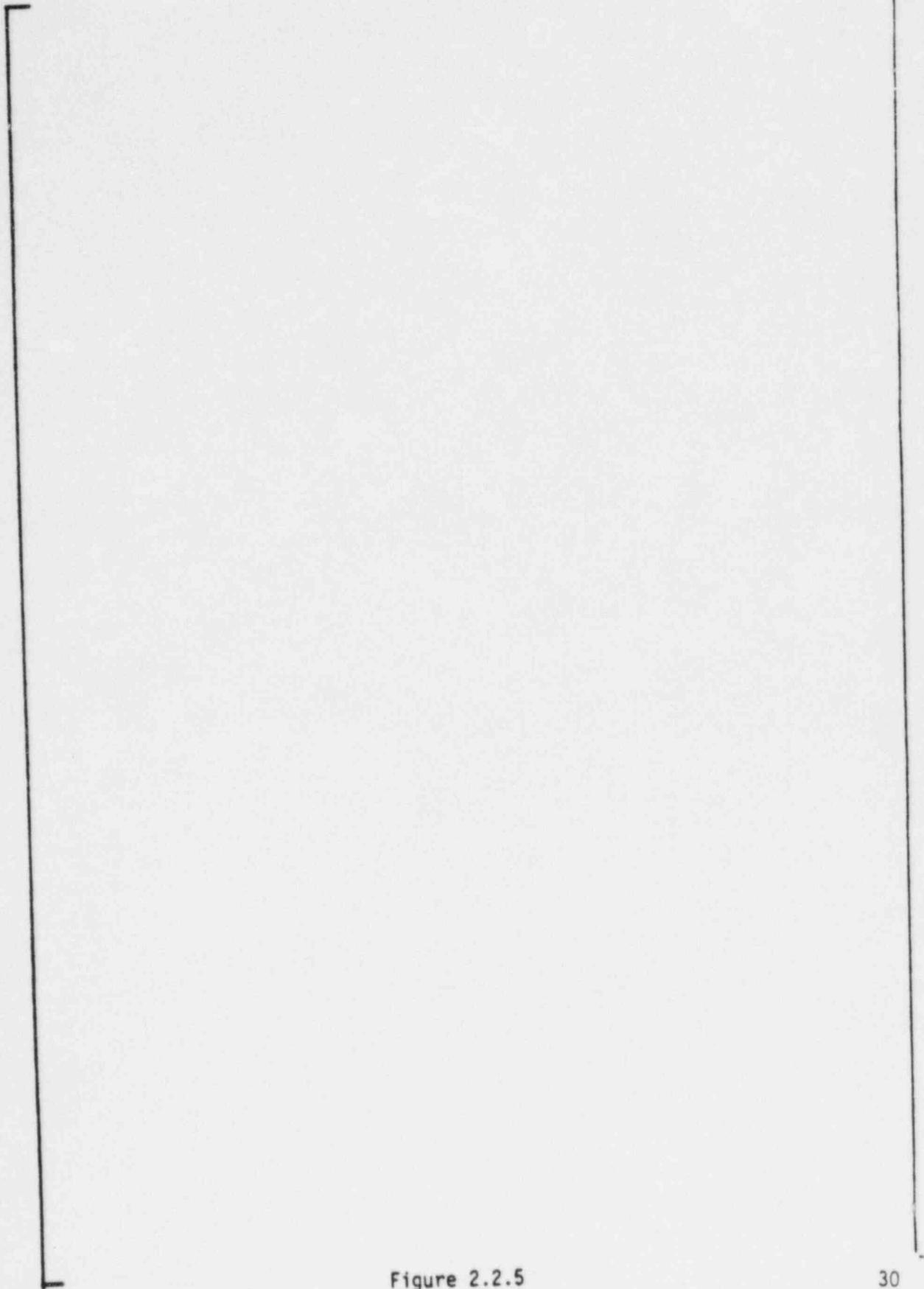


Figure 2.2.5

MARCH 1986
ROTATING PROBE INSPECTION

o OBJECTIVES

- VALIDATE LOGIC FOR DISPOSITIONING INDICATIONS AT HOT LEG SUPPORT PLATES
 - o QUANTIFIABLES (X)
 - o DISTORTED INDICATIONS (DI #)
 - o NO DETECTABLE INDICATIONS (NDD #)

- CONFIRM STRESS CORROSION CRACKING IS CONFINED WITHIN SUPPORT PLATE EDGES

PANCAKE COIL

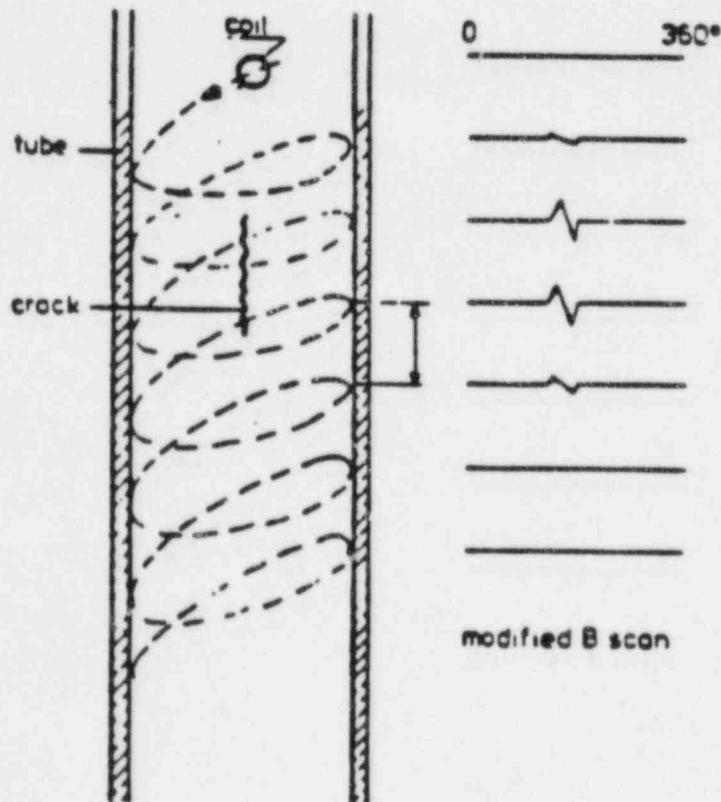
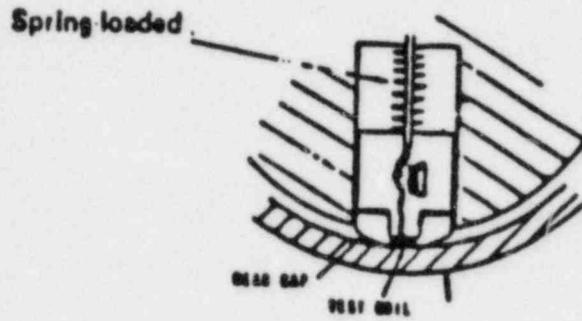


Figure 2.2.6

PANCAKE COIL "IMAGING"

a,c,e

Figure 2.2.7

Support Plate NDD

a,c,e

Figure 2.2.8

Support Plate DI

a, c, e

Figure 2.2.9

SUPPORT PLATE DI CONFIRMATION

a.l.e

a.l.e

Figure 2.2.10

Support Plate Quantifiable

a,c,e

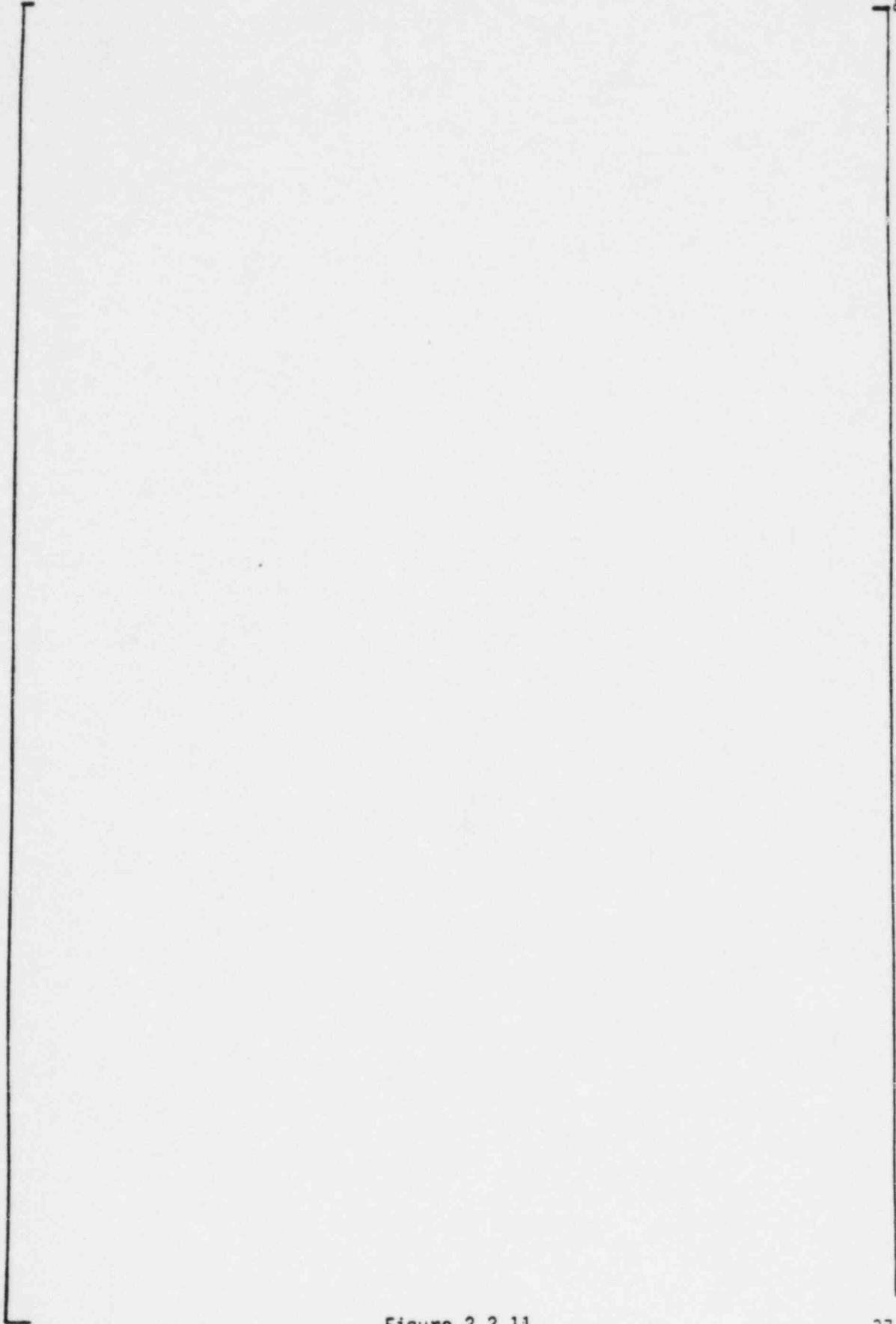


Figure 2.2.11

SUPPORT PLATE QUANTIFIABLE CONFIRMATION

a,c,e

Figure 2.2.12

DONALD COOK UNIT 2 S/G 1 Model 51

March 1986 Hot Leg Inspection

% Indications/Non-Quantifiable Indications

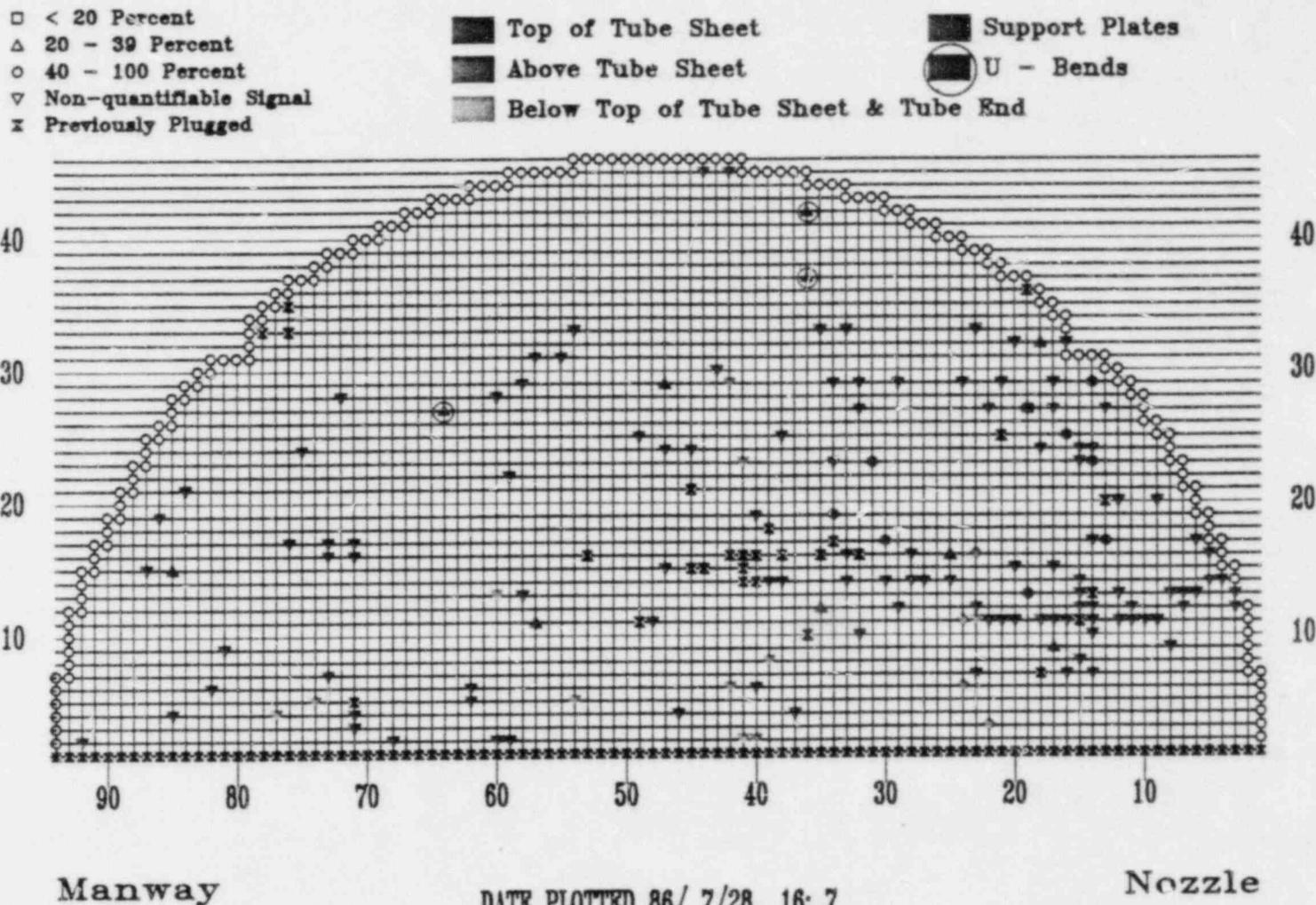


Figure 2.3.1

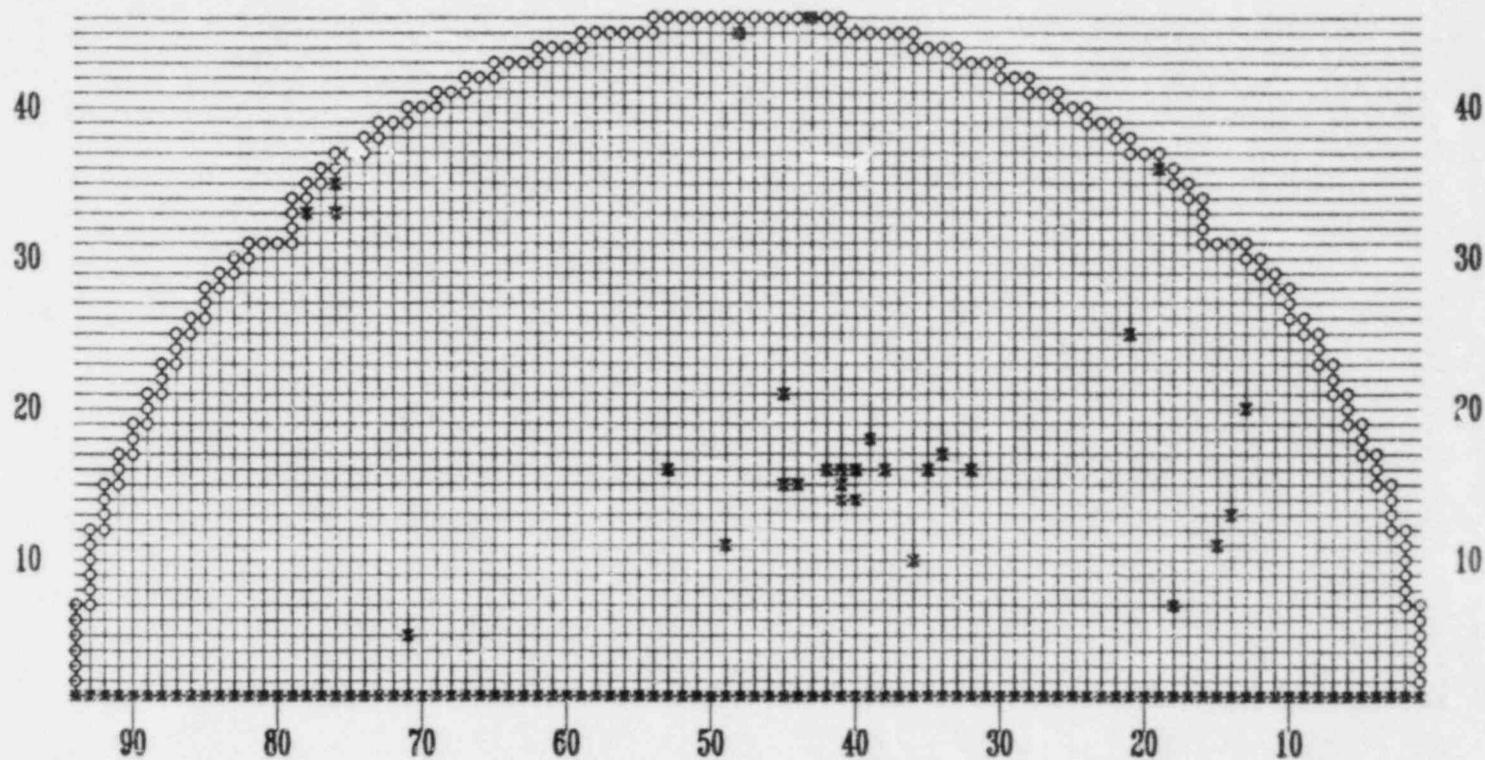
WESTINGHOUSE PROPRIETARY CLASS 2

DONALD COOK UNIT 2 S/G 1 Model 51

March 1986 Cold Leg Inspection

PERCENT INDICATION MAP

- | | | |
|----------------------|---------------------|-----------------------|
| □ < 20 Percent | ■ Top of Tube Sheet | ■ Support Plates |
| △ 20 - 39 Percent | ■ Above Tube Sheet | ○ Anti-Vibration Bars |
| ○ 40 - 100 Percent | ■ Within Tube Sheet | |
| x Previously Plugged | | |



Manway

DATE PLOTTED 86/ 7/15 12:31

Nozzle

GENASYS Steam Generator Analysis System

Copyright Westinghouse Electric Corp. 1986

D.C. COOK UNIT 2 INDICATION COUNT 3/86

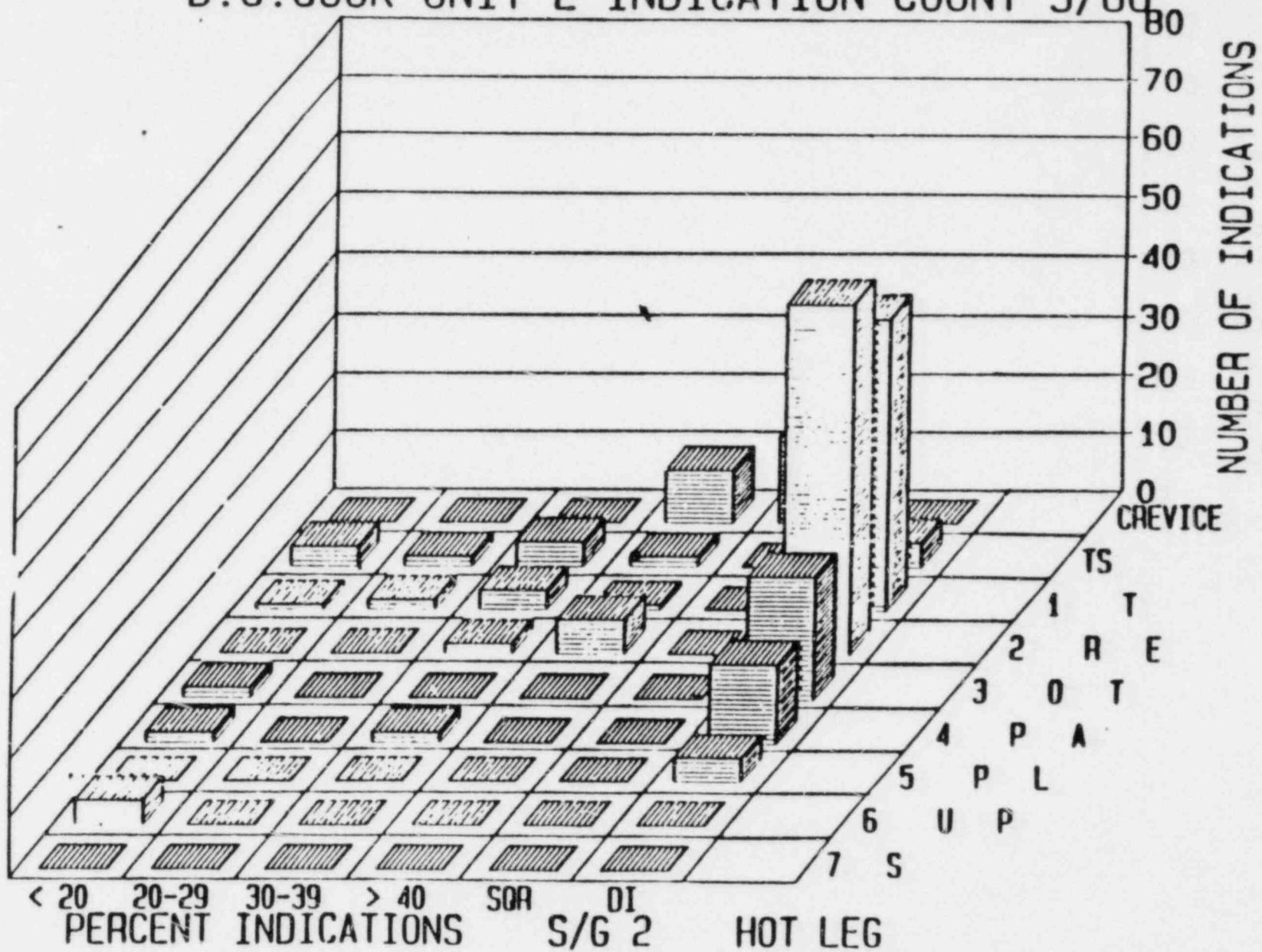


Figure 2.3.3

D.C. COOK UNIT 2 INDICATION COUNT 3/86

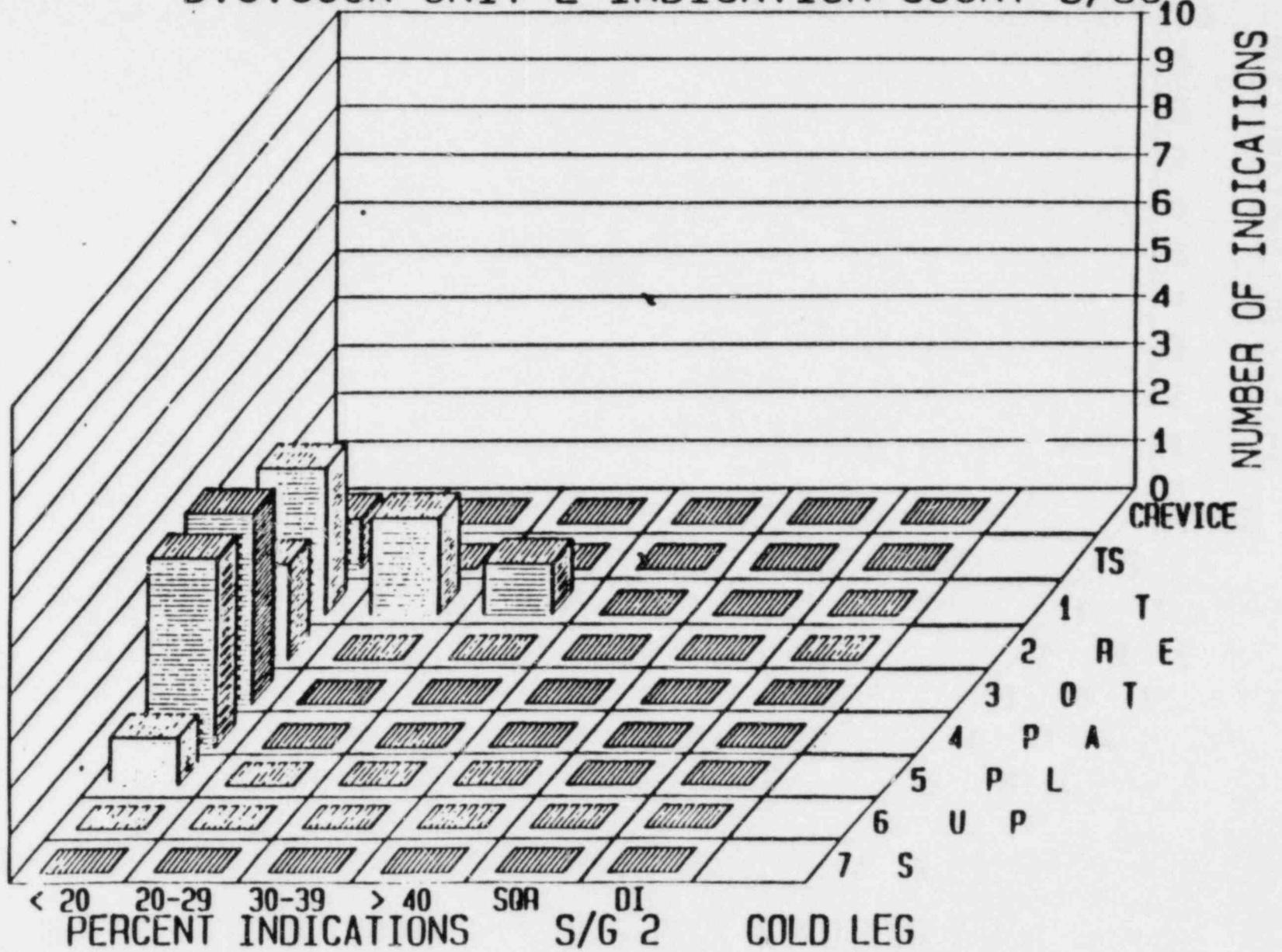


Figure 2.3.4

D.C. COOK UNIT 2 PLUGGABLE INDICATIONS

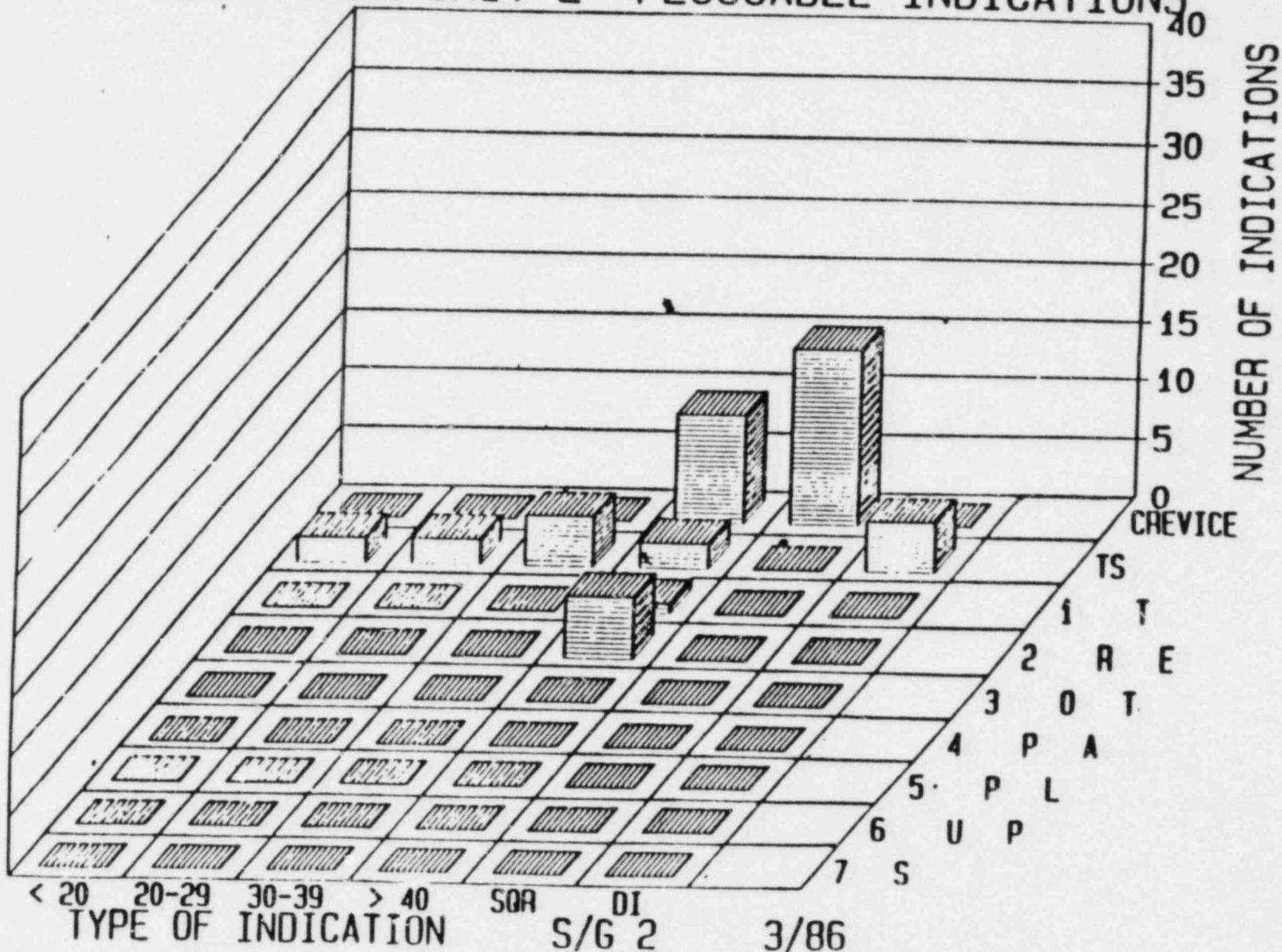


Figure 2.3.5

D.C. COOK UNIT 2 PLUGGABLE INDICATIONS

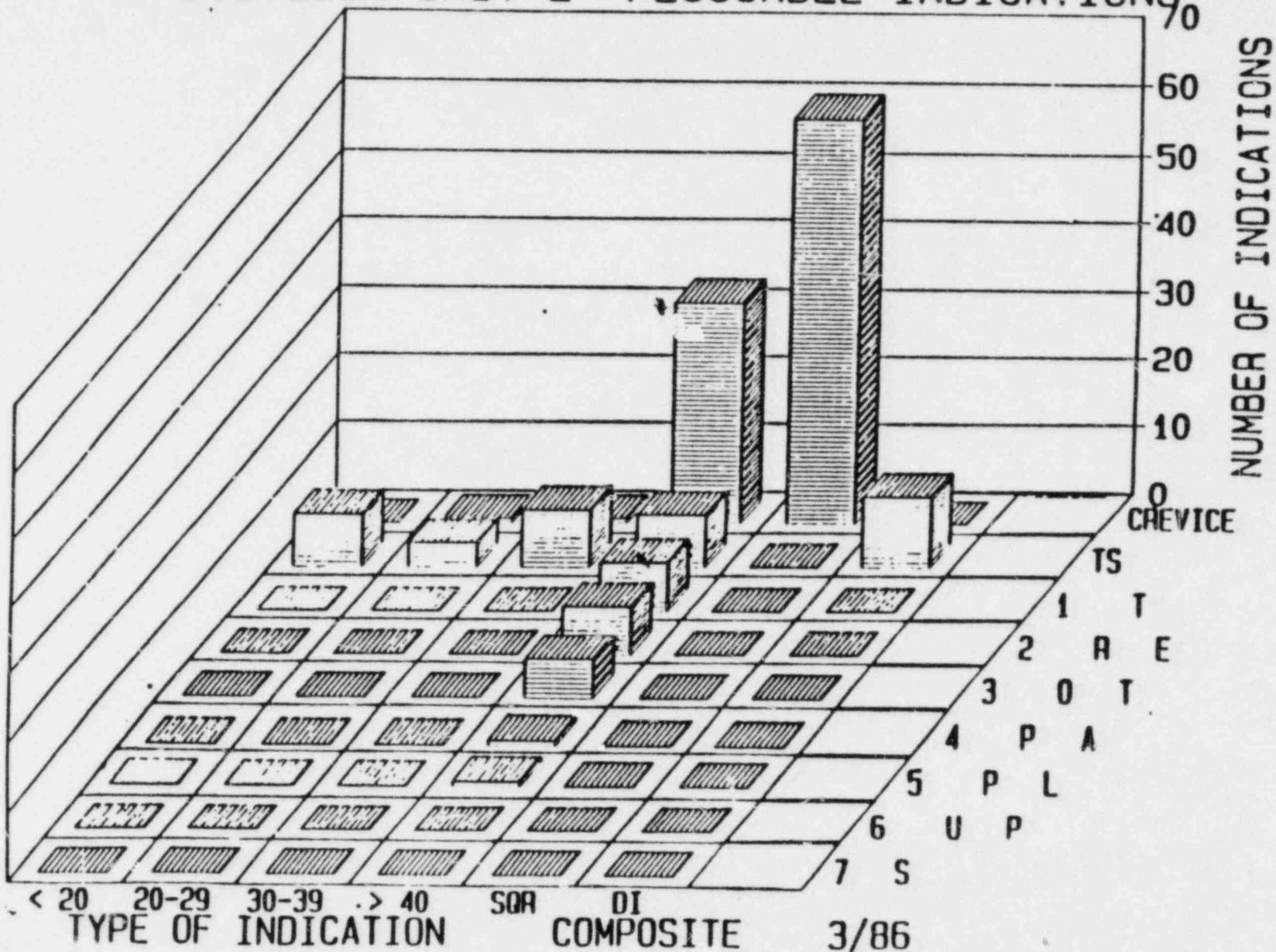


Figure 2.3.6

3/86

**COMPARISON OF '84-'85' AND '85-'86'
DEGRADATION RATES, % PER MONTH**

| OPERATING PERIOD ***** | LOCATION | | |
|---------------------------|----------------------------|--------------------------|------------------------------|
| | TUBESHEET CREVICE ***** | ABOVE TUBESHEET ***** | TUBE SUPPORT PLATES ***** |
| '84-'85' | 2.66% | 1.33% | 0.76% |
| '85-'86' | 1.60% | 0.82% | 0.66% |

DC COOK UNIT 2 STEAM GENERATOR TUBE
 MINIMUM ACCEPTABLE WALL REQUIREMENTS

TUBE SUPPORT PLATE ELEVATION

| <u>CRITERIA</u> | <u>CONDITION</u> | <u>MINIMUM WALL (INCHES)</u> |
|-----------------|------------------|------------------------------|
| YIELD | NORMAL |] a, c, e |
| ASME CODE | FAULTED | |
| $S\sqrt{3}$ | NORMAL | |

TUBESHEET CREVICE AND
 ABOVE THE TOP OF THE TUBESHEET ELEVATION

| <u>CRITERIA</u> | <u>CONDITION</u> | <u>MINIMUM WALL (INCHES)</u> |
|-----------------|------------------|------------------------------|
| YIELD | NORMAL |] a, c, e |
| ASME CODE | FAULTED | |
| $S\sqrt{3}$ | NORMAL | |

DC COOK UNIT 2
ALLOWABLE WALL LOSS DETERMINATION

| <u>SG LOCATION</u> | <u>GEOMETRIC CONDITION</u> | <u>§ BASIS</u> |
|------------------------|--|--------------------|
| TUBE SUPPORT PLATE | DEGRADATION AXIAL EXTENT LIMITED TO 0.75 IN. |] a,c,e |
| TOP OF TUBESHEET | DEGRADATION AXIAL EXTENT GREATER THAN 1.5 IN. | |
| TUBESHEET | DEGRADATION AXIAL EXTENT GREATER THAN 1.5 IN. | |

TUBE ALLOWABLE WALL LOSS IS BASED ON THE FOLLOWING RG 1.121
CONSIDERATIONS:

- * DURING NORMAL OPERATION, PRIMARY TUBE STRESSES ARE LIMITED SUCH THAT A MARGIN OF 3 IS PROVIDED AGAINST EXCEEDING THE ULTIMATE TENSILE STRESS OF THE TUBE MATERIAL
- * DURING NORMAL OPERATION, THE YIELD STRESS OF THE MATERIAL IS NOT EXCEEDED
- * FOR POSTULATED ACCIDENT CONDITIONS, THE REQUIREMENTS OF SECTION NB-3225 OF SECTION III OF THE ASME CODE ARE MET

CONSERVATIVELY, THE CONSTRAINING EFFECT OF THE TUBESHEET/TUBE SUPPORT PLATE IN RESISTING TUBE BURST IS NOT CONSIDERED

OPERATING INTERVAL JUSTIFICATION
DC COOK UNIT 2

| <u>CATEGORY</u> | <u>CREVICE</u> | <u>ABOVE TS</u> | <u>TSP</u> | |
|-----------------------------------|----------------|-----------------|------------|---------|
| ALLOWABLE % | [| |] | a, c, e |
| ECT UNCERTAINTY | | | | |
| GROWTH | 22** | 11** | 10** | |
| PLUGGING LEVEL REQUIRED (%) | 24 | 35 | 44 | |
| PLUGGING LEVEL IMPLEMENTED (%) | ALL | ALL | 40 | |

* TUBE BURST WITHIN THE TS CREVICE OR THE TUBE SUPPORT PLATE IS CONSIDERED TO BE INCREDIBLE

** PROJECTED GROWTH RATE FOR 13.5 EFPM OPERATION PER RESPECTIVE TUBE ELEVATION

D. C. COOK UNIT 2

STATUS OF REMEDIAL MEASURES

- 0 Continuing leak rate monitoring program
- 0 Continuing emphasis on improved water chemistry
- 0 Continuing boric acid treatment
 - crevice flushing (2000 ppm)
 - low power soaks (50 ppm)
 - on-line addition (10 ppm)
- 0 Unit-specific study of interactive SCC parameters currently in progress
- 0 Mechanical repairs
 - SG tube sleeving
 - SG replacement

D.C. COOK UNIT 2

S.G. CAT. COND. (UMHOS) YEARLY AVG.

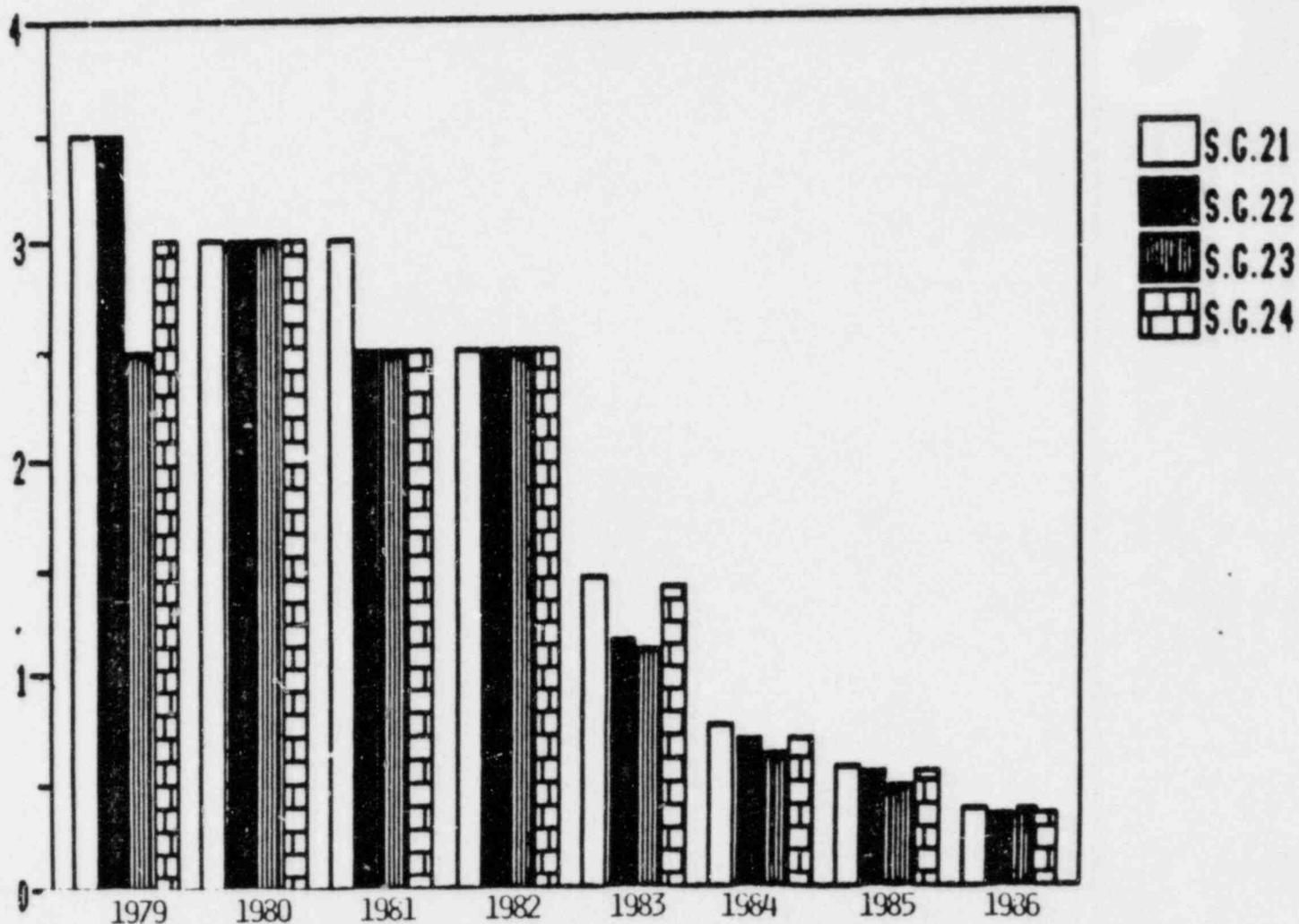


Figure 4.1.1

D.C. COOK UNIT 2

S.G. SODIUM (ppb) YEARLY AVG.

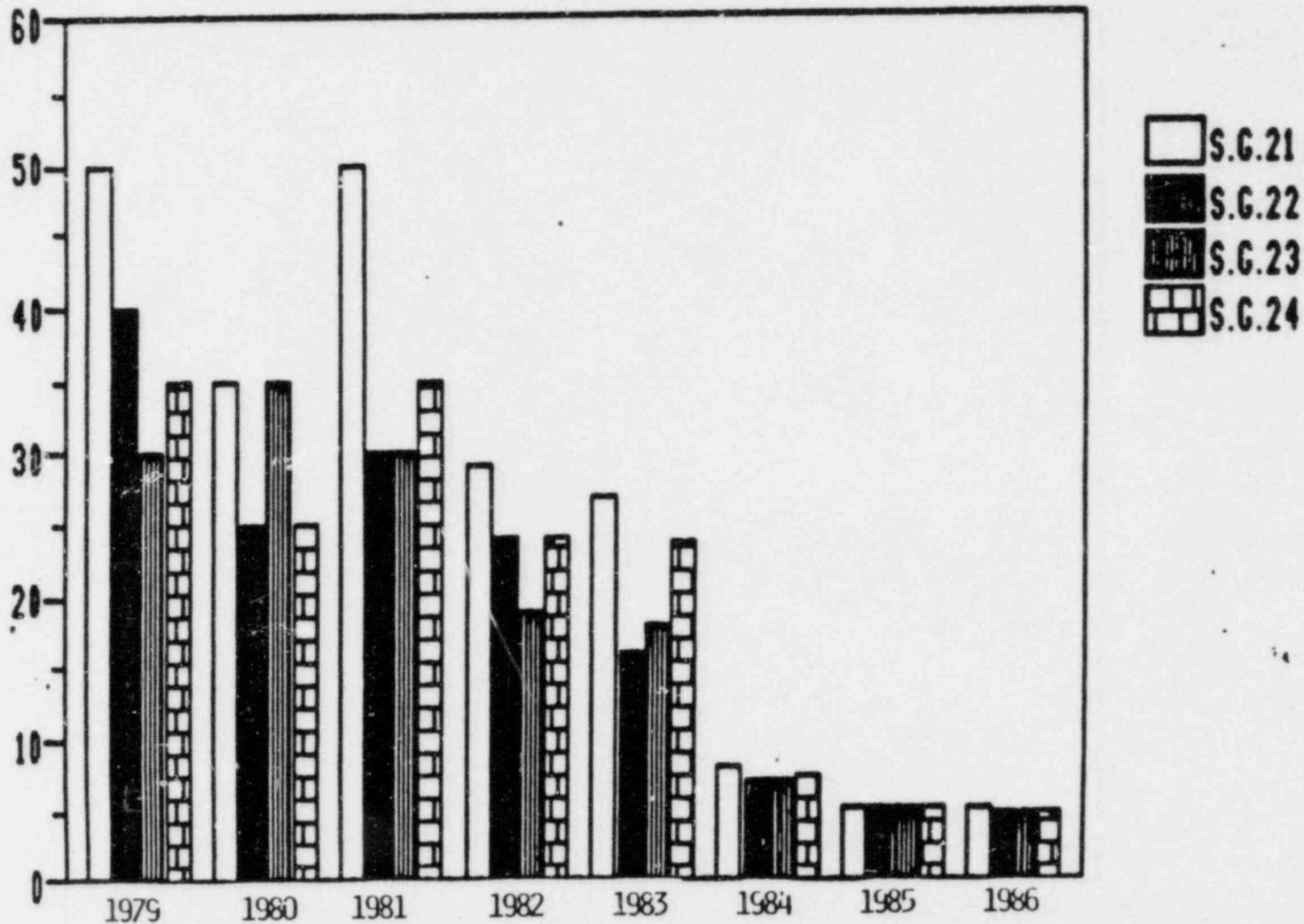


Figure 4.1.2

D.C. COOK UNIT 2
SJA/E (scfm) YEARLY AVG.

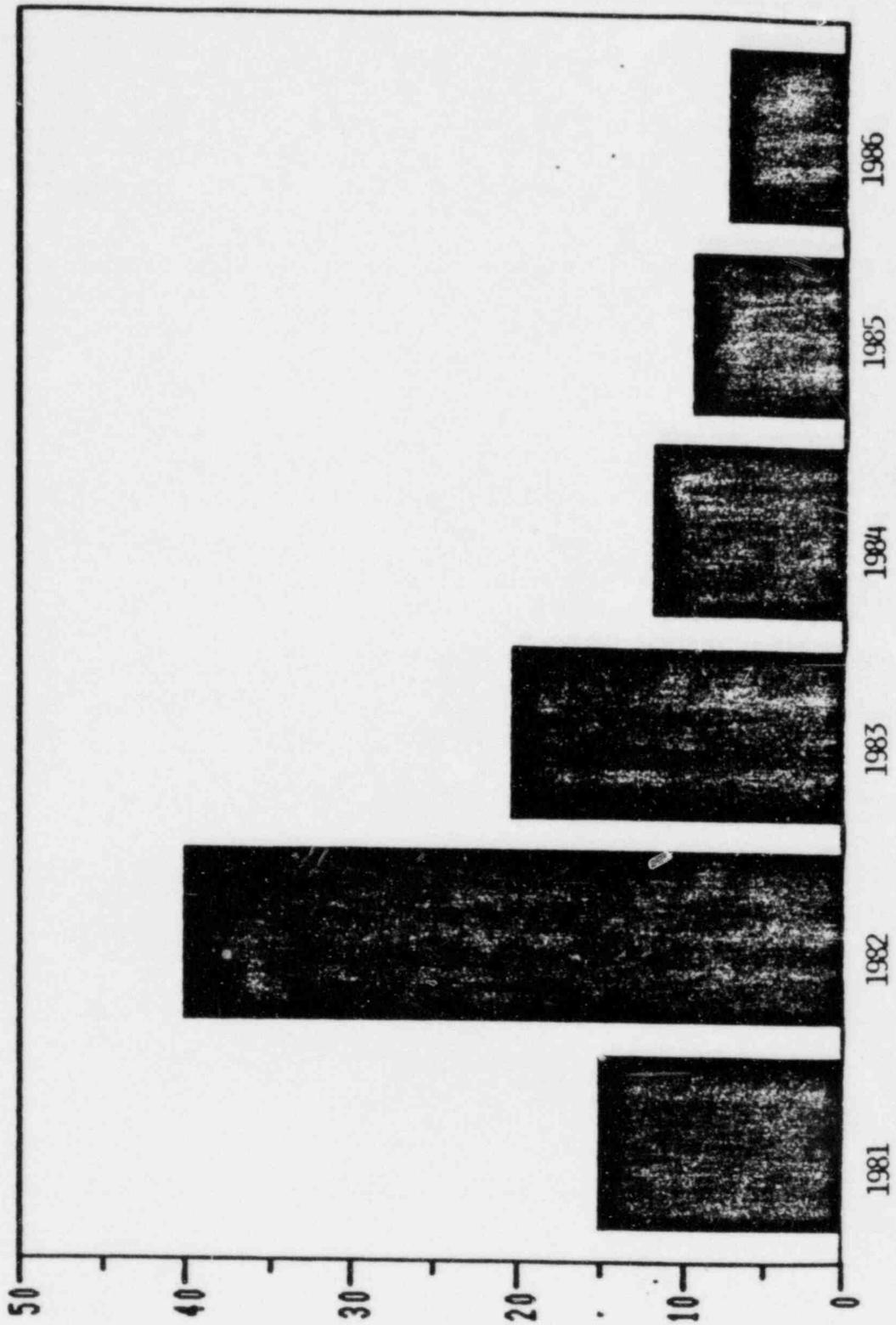


Figure 4.1.3

D.C. COOK UNIT 2
CONDENSATE AND FEEDWATER D.O. (ppb) YEARLY AVG.

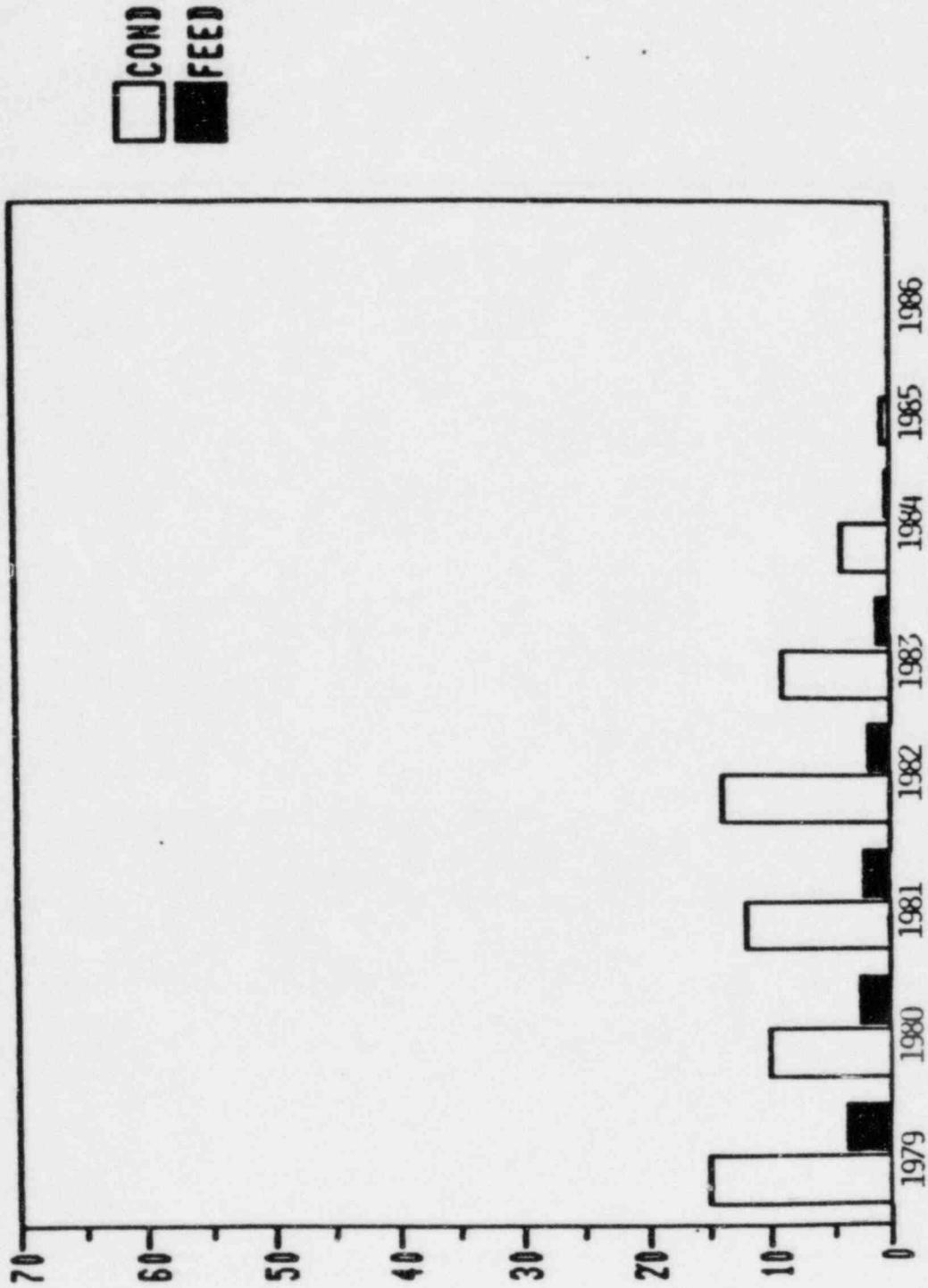


Figure 4.1.4

REMEDIAL ACTIONS BASED ON CAUSATIVE FACTORS



1. Neutralize caustic
2. Keep alloy 600 out of susceptible potential range
3. Prevent mass transfer with an inhibitor film or by reformation of passive film
4. Open restricted crevices - remove sludge
5. Reduce contaminant input - improve chemistry control

Table 4.2.1

EFFECT OF BORIC ACID IN REFERENCE SCC TESTS



a, c, e

Figure 4.2.1

000 816667 029

EFFECT OF BORIC ACID ON PRE-INITIATED CRACKS



Figure 4.2.2

900 B1667.032

BORIC ACID TEST PROGRAM CONCLUSIONS



- Boric acid prevented crack initiation in the reference []^{a,c,e}
 - Without boric acid throughwall cracking in []^{a,c,e}
 - With boric acid no cracking in []^{a,c,e}
- Addition of boric acid after crack initiation reduces the crack propagation rate by a factor of []^{a,c,e}
- Boric acid inhibited IGA in the reference []^{a,c,e}
 - Without boric acid []^{a,c,e} IGA
 - With boric acid, isolated intergranular penetrations []^{a,c,e} deep

Table 4.2.2

EFFECT OF BORIC ACID IN REFERENCE IGA TESTS



IGA Depth μm



a, c, e

Figure 4.2.3

UPDATE OF BORIC ACID OPERATING EXPERIENCE

WESTINGHOUSE
PROPRIETARY

INTERNATIONAL PLANT OPERATING EXPERIENCE
WITH BORIC ACID

NUMBER OF ECT
INDICATIONS

a,c,e

EVALUATION OF BORIC ACID TREATMENT
ON COOK 2 STEAM GENERATORS

ASSESSMENT BY TUBE PLUGGING RATE -

| OPERATING PERIOD | CREVICE | LOCATION | | TOTAL |
|--|---------|------------|-----|--------|
| | | ABOVE I.S. | ISP | |
| 84-85 (1) | 75 | 51 | 16 | 145 |
| 84-85 (2) | 138 | 77 | 33 | 248 |
| 85-86 (2) (EXPECTED WITHOUT BORIC ACID) (3) | 37 | 21 | 9 | 65 (4) |
| 85-86 (2) | 28 | 9 | 2 | 39 |

- (1) 84-85 INSPECTION/PLUGGING CRITERIA.
(2) 85-86 INSPECTION/PLUGGING CRITERIA.
(3) LINEAR EXTRAPOLATION BY TIME.

[a.c.e]

ASSESSMENT BY GROWTH RATE, % PER MONTH -

| OPERATING PERIOD | CREVICE | LOCATION | |
|------------------|---------|------------|-------|
| | | ABOVE I.S. | ISP |
| 84-85 | 2.66% | 1.33% | 0.76% |
| 85-86 | 1.60% | 0.82% | 0.66% |

**EVALUATION OF BORIC ACID TREATMENT
ON COOK 2 STEAM GENERATORS**

CONCLUSIONS TO DATE -

1. TUBE PLUGGING RATE ASSESSMENT -

- INDICATES A SIGNIFICANT REDUCTION IN NEW
NEW PLUGGABLE TUBES.
- REDUCTION IS COMPARABLE TO OTHER EXPERIENCE.

2. GROWTH RATE ASSESSMENT -

- OBSERVED RATES LESS WITH BORIC ACID TREATMENT.

3. EFFECTIVENESS IN REDUCING CORROSION-

- NO DETRIMENTAL EFFECTS OBSERVED.
- ALL INDICATORS SHOW REDUCED CORROSION.

4. RECOMMENDATIONS -

- CONTINUE BORIC ACID TREATMENT.
- USE OVER A LONGER EFFECTIVE PERIOD TO
ACHIEVE MAXIMUM BENEFITS.