SIZING OF ULTRASONICALLY DETECTED INDICATIONS IN THE POINT BEACH UNIT 1 RPV OUTLET NOZZLES

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INTRODUCTION

During the February 1984 remote mechanized examination of Wisconsin Electric Power Company's Point Beach Unit 1 reactor pressure vessel (RPV) by Southwest Research Institute (SwRI), indications were recorded which exceeded the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (Code) allowable sizing criteria. This report describes the examination rules and measurement techniques used in the detection, recording, and preliminary sizing of reflectors found near the root of the outlet nozzle-to-vessel welds. Previous experience with reflectors exhibiting similar ultrasonic responses is reviewed. The conclusion of the review is that the indications are due to reflections from thin planar slag inclusions in the root of the weld. Beam spread measurements performed on a reflector of similar geometry and reflectivity give beam spread corrections for the recorded indications. Applying the corrections shows the recorded indications are Code allowable. SwRI has evaluated the reflectors in question in considerable detail both ultrasonically and by fracture mechanics techniques and is confident that they pose no threat to the continued safe operation of the vessel.

DISCUSSION

The February 1984 mechanized ultrasonic examination of outlet nozzles in the RPV of Point Beach Unit 1 was a routine scheduled examination. It was performed in accordance with the rules of the ASME Boiler and Pressure Vessel Code 1977 Edition, with Addenda through Summer 1979. Section V, Article 4, provides examples of acceptable techniques for distance amplitude correction, beam spread measurements, and the indication readings needed for sizing. These techniques are provided in the nonmandatory appendix. It is expected that they will not be appropriate to all situations and that variations and alternates to these techniques must be applied as appropriate.

The U.S. Nuclear Regulatory Commission Regulatory Guide 1.150, Rev. 1, February 1983, provides recommendations for indication reporting. It also recommends examination with a beam perpendicular to the weld/parent-metal interface. Rules for beam spread measurement and correction of indication dimensions with those measurements are also provided.

Distance Amplitude Correction

Distance amplitude correction of the ultrasonic beam is performed on the basic calibration block containing holes drilled with their length parallel to the examination surface. These SDH (side-drilled hole) reflectors provide the same cylindrical reflecting surface to longitudinal and shear beams of any angle. Locating these SDH reflectors at 1/4, 1/2, and 3/4 thickness depths below the examination surface provides equal reflectors at different metal paths (directly proportional to depth) such that the maximum amplitude from each can be marked on the screen and connected to form the 100 percent DAC (distance amplitude correction) line. This calibration is performed with search units held statically at the point of maximum response while the mechanized examination moves the search units dynamically during recording of t : indications. Reference 1 shows that under our scanning conditions, amplitudes are equal for static and dynamic readings and that no correction factor is required for correlating static calibration to the mechanized scans. A gain increase of 6 dB will double the amplitude so the line represents 50 percent DAC. A gain increase of 14 dB from the 100 percent DAC level will quintuple the amplitude so the line represents 20 percent DAC. The appropriate gain increase is used to accurately read the 50 percent DAC and 20 percent DAC points using the 100 percent DAC points measured on the side-drilled holes.

Beam Spread Measurements

Beam spread measurements of the ultrasonic beam are made on the SDH reflectors in the basic calibration block. The method is: (1) While maintaining the beam direction which provided the maximum amplitude from the SDH, move the SU (search unit) toward the reflector until amplitude falls to the 20 percent DAC level; (2) Then move the SU away from the reflector successively through 50 percent, maximum amplitude, 50 percent, and to the 20 percent DAC level; (3) Measure the surface distance between SU positions which give these amplitudes; (4) Project the surface distances to center on the hole depth and give the 20 percent and 50 percent beam spread at that depth.

Measurements must be repeated for SDHs at other depths. While making these measurements, the metal path to the reflector varies and must be recorded. An exception would be in the case of low-angle longitudinal beams where ΔMP (change in metal path) is insignificant. A discussion of the method used under these circumstances follows under indication sizing.

Indication Sizing

Indication sizing in the Code is an angle beam technique utilizing the ΔMP response from a reflector moved through the beam. The ΔMP is read at the higher of 50 percent DAC or half the maximum amplitude. Since metal paths are directly proportional to depth, ΔMP converts into the throughwall dimension of the reflector. Length is measured between the 50 percent DAC ends of the reflector. The Code does not provide for beam spread correction of the dimensions. However, the Regulatory Guide adds the requirement for 20 percent DAC sizing but permits correcting that dimension by deducting

20 percent DAC ΔMP or SU movement as appropriate from the SDH at the depth nearest that of the reflector. Appendix A of the Regulatory Guide permits application of 20 percent DAC recording to the inner quarter of wall thickness and 20 percent DAC sizing on those recorded indications having a measurable ΔMP.

Reflectors parallel to the examination surface and perpendicular to the beam provide high amplitudes but insignificant ΔMP and must be dimensioned according to SU movement on the examination surface related to the through-wall thickness. This technique is not described in the Code.

Onsite Examinations

During the February 1984 Inservice Examination of the Wisconsin Electric Power Company Point Beach Unit 1 plant, a mechanized nozzle examination from the nozzle bore was performed (see Figure 1) of the two RPV outlet nozzle-to-shell welds. The PaR device used in the mechanized examination is tripod mounted on the vessel flange. A vertical boom extends down into the vessel to the elevation of the nozzle centerline. A horizontal boom extends from the vertical boom into the central axis of the nozzle where position with respect to the vessel wall is registered as "Y" count at 100 counts to the inch. Angle beam search units are pneumatically extended from the horizontal boom to the nozzle bore where the beams are directed toward the inside surface of the vessel through the nozzle-to-vessel weld. The circumferential length of the weld is scanned by rotating the search unit module through 360 degrees of nozzle azimuth and is registered as two "X" counts per degree of azimuth scanned. Search unit position is then indexed in the "Y" boom extend direction and scanned through 720 "X" counts. Indexing "Y" and scanning "X" is continued until the beams have successively passed through the accessible volume of the nozzle-to-vessel weld.

Upon completion of the initial examination scans, sizable indications are rescanned with a motion that is essentially at a right angle to the original motion. In this case, scanning is in the "Y" boom extend direction and indexing is in the "X" azimuth direction in 1/2-degree increments. This improves the throughwall dimensioning by moving the beam across the reflector in the throughwall direction. The 1/2-degree increment between scans moves the beam 0.21 inch. This complies with the Regulatory Guide 1.150, Paragraph 6.2a, requirement for "—scan intervals no greater than one-fourth inch."

The data acquisition system uses conventional Sonic Mark II ultrasonic instruments. The instrument's gates provide analog output of indication amplitude and time (metal path) for strip chart recording. The examination is also recorded on videotape so the indications appearing on the screens of the instruments can be reviewed as they were recorded together with the coordinates of the search unit position from the PaR device movements.

A remote pulser is used to avoid deterioration of indications through long cables. The entire system is calibrated prior to installing it into the vessel and rechecked upon removal from the vessel. The calibration block is made from SA 508 Class II forging material. Stainless steel weld overlay clad is provided on surfaces used for the calibration of examinations from the inside surface of the nozzle. Side-drilled hole calibration reflectors are provided at 4-, 8-, and 12-inch depths to qualify the examination over the entire metal path range. The SwRI standard, very sensitive ultrasonic examination uses the 10°L angle-beam longitudinal wave which recorded four sizable (sizable, in this sense, means that the detected indications were of sufficient amplitude to allow applying the sizing process and comparison to Code-allowable sizes) indications in outlet A (weld No. 2-686-A at vessel azimuth 28.5 degrees) and seven sizable indications in outlet C (weld No. 2-686-C at vessel azimuth 208.5 degrees). Figure 2 shows the nozzle azimuth position of reflectors found to have sizable dimensions in the 1984 examination. Figure 2 also shows the nozzle azimuth positions of the same reflectors as recorded in the 1981 examination. The 1984 results were checked using the same search unit, procedure, and instrument used in 1981 to qualify duplication of the examination. This confirmed that the recorded reflectors produced higher amplitude in 1984 than those recorded in 1981. The indications have insignificant changes in metal path showing that they are in a plane approximately parallel to the conical bore examination surface. Since the indications could not be sized by the ΔMP technique, the 50 percent DAC amplitude search unit positions in azimuth "X" and boom extend "Y" are plotted for sizing in the cylindrical plane of the nozzle through the root of the weld.

Additional examinations of the reflectors from the nozzle bore confirmed nine out of eleven with both a 5°L and a 15°L (5-degree and 15-degree angle-beam longitudinal wave). However, a 45°S (45-degree angle-beam shear wave) from the nozzle bore passed through the volume of material containing the reflectors without detecting those reflectors. Correlation between the 1981 and 1984 examinations is excellent. The change in reflector amplitude from 1981 to 1984 is shown in Figure 3. The amplitude change ranges from a low of 2 dB (125 percent) to a high of 13 dB (447 percent).

Sizing of the Point Beach Unit 1 RPV Indications

One of the eleven indications is in the inner 25 percent of wall thickness; therefore, in accordance with the U.S. Nuclear Regulatory Commission Regulatory Guide 1.150, Revision 1, February 1983, Appendix A, Paragraph 6.3(b), the indication was sized at 20 percent DAC with beam spread correction and in accordance with the Code at 50 percent DAC without beam spread correction. Both sizing techniques show the indication is allowable.

Code sizing of the other ten reflectors (adapted to SU position readings since the indications have an insignificant ΔMP) to their 50 percent DAC limits shows that eight of these flaw indications have allowable dimensions. As shown in Figure 4, weld A indication 2 outlines the 50 percent DAC dimensions while the area exceeding 100 percent DAC is shaded. Similarly, Figure 5 shows the weld C indication 4 . Both indications are centered at horizontal boom extend register reading of Y2100, which places the reflectors in the position of the root of the weld. Metal paths to these reflectors show that they are near the root interface or possibly at the interface of a repair weld. Figure 6 shows that the 50 percent DAC and half maximum amplitude dimensions measured by the search unit position plotting technique exceed the allowable limits given by Section XI Table IWB-3512-1.

In accordance with the rules of Section XI IWB-2430(a), dealing with indications exceeding the allowable size standards of IWB-3000, the examination was extended to include the two inlet nozzle-to-shell welds. No indications were recorded in the additional examinations.

Weld Fabrication

The weld design drawings show a double penetration with a central land. Tie-in welds between the central land of the nozzle and the vessel shell are made during fit-up. The root passes are then made from one side. In order to eliminate entraped foreign materials, the root and tie-ins are back-gouged from the other side to sound weld and base metal. Due to the curvature of the weld groove, access to and view of the weld interface are restricted during welding. After filling the weld grooves, a fillet weld is applied to the outside surface to provide the barrel nozzle-to-shell blend radius.

Flaw Identification

As shown in Figures 4 and 5, the barrel nozzle design (nozzle forging boss and weld interface have the same diameter) with integral extension and the angular orientation of the reflector with respect to the radiographic source-to-film line make radiographic detection of these indications unlikely. Orientation and geometry of reflectors are therefore important considerations when determining the identity of an indication. A comparison of the existing Point Beach Unit 1 RPV indication records with excavated flaws and reflectors recorded at other plants reveals a logical conclusion as to the identity of the reflector producing the Point Beach Unit 1 RPV indications.

In March 1979, an indication similar to the Point Beach Unit 1 RPV indications was recorded in the N2B nozzle of the RPV at Rochester Gas and Electric Company's Robert E. Ginna plant. The indication was recorded with a 15°L from the nozzle bore but was not detected by the 45°S from the same surface. The 45°S beam passed through the volume of material containing the reflectors without detecting those reflectors. Analysis of these ultrasonic examination responses showed the reflector to be thin, smooth, nearly parallel to the nozzle bore, and perpendicular to the 15°L beam. A flat-bottom hole with a diameter and metal path approximating the orientation and reflectivity of the recorded indication was measured at 50 percent DAC. The diameter of the FBH (flat-bottom hole) was subtracted from the 50 percent DAC dimensions to give the beam spread correction. The correction applied to the recorded indication showed the indication to be within the allowable limits of Table IWB-3512.1.

Section XI, Paragraph IWA-2240 of the Code, allows for alternate techniques to be used in lieu of the Code-specified techniques if it can be demonstrated to the satisfaction of the Inspection Specialist that the alternate techniques provide results which are equal or superior to the Code-specified techniques. Identical sizing techniques were demonstrated and accepted by an Authorized Inspector during the 1979 Ginna evaluation; therefore, we are confident that the FBH 50 percent DAC correction sizing is acceptable to the requirements of Section XI of the Code.

The presence of thin planar slag inclusions in heavy section welds is well recognized. In fact, the writer has personally witnessed the fabrication shop excavation of a 1/32-inch thick planar, smooth, large slag inclusion near midwall at the shell side of the fusion line of a nozzle-to-vessel weld in the Fermi Unit 2 RPV. This planar reflector was at an angle to the 45°S which was used to examine this volume of weld and was not detected ultrasonically. The planar reflector was favorably oriented for radiographic detection and was recorded and repaired as a result of the radiographic examination.

In 1972, the writer witnessed the site excavation of shell weld interface heat-affected-zone cracks in three nozzle-to-vessel welds in the RPV. These preservice repairs were performed at Georgia Power Company's Edwin I. Hatch Unit 1 plant. Indications from these cracks had been recorded with 45°S and 60°S from the outside shell surface. The reflectors had been confirmed with 45°S and 60°S from the clad inside shell surface, recorded with 0°L from the clad inside weld surface, and recorded with 10°L from the clad bore of the nozzle. The irregularities on the crack surface reflected a portion of the beam from the six incident beam directions.

The ultrasonic reflections from the Hatch Unit 1 RPV cracks were quite different from the Point Beach Unit 1 RPV indications which give responses similar to the Ginna RPV indications and the indications from the 1/32-inch thick planar, smooth, large slag inclusion near midwall at the fusion line of a nozzle-to-vessel weld which was excavated from the Fermi Unit 2 RPV. The conclusion from this comparison is that the Point Beach Unit 1 RPV indications are reflections from a thin, smooth, planar slag inclusion at the root of the outlet nozzle-to-vessel welds. The plane of the reflectors is nearly parallel to the nozzle bore examination surface and the reflector plane is perpendicular to the 10°L beam. Therefore, beam spread correction of the recorded indications requires measurements on a planar reflector of known size which gives similar amplitude at a similar metal path to that of the recorded indications.

Beam Correction Study

The eleven indications in the two outlet nozzle-to-vessel shell weld roots were recorded at metal paths ranging from 7.3 to 9.2 inches. Side-drilled holes 3/8-inch diameter at depths of 4, 8, and 12 inches located in the appropriate calibration block, FS-NS-CSCL-5PTB, were used to provide the distance amplitude correction (DAC) calibration. Noninterfering space was found on the calibration block for a 3/8-inch diameter FBH at a depth of 8 inches. This block was fabricated from a forging and stainless steel clad so calibration conditions are representative of examination conditions. Figure 7 shows 50 percent to 50 percent DAC beam spread from the 8-inch deep SDH to be 8.5 degrees while 8 degrees was measured on the FBH. These measurements were made at SwRI using the same Point Beach basic calibration block, the angle-beam wedge, and search unit used in the examination at the Point Beach site. The examination and measurements were made with a Sonic Mark II instrument.

In addition, amplitude measurements between the FBH and the root reflectors were also compared. The maximum amplitude from the 3/8-inch diameter FBH and the root reflections in nozzles A and C is practically identical at 159 percent DAC. The 100 percent DAC throughwall apparent ultrasonic dimensions (determined by search unit movement from 100 percent DAC, through maximum amplitude to 100 percent DAC) of the FBH and the two root reflectors are very similar at 0.75 ±0.05 inch. This similarity confirms that the 3/8-inch diameter FBH is representative of the root reflectors in nozzles A and C. The 50 percent DAC dimensions of the 3/8-inch diameter FBH are 1.4 inch length and 1.09 inch throughwall. Deducting the hole dimensions from the 50 percent DAC dimensions gives the size correction of 1.035 inch length and 0.709 inch throughwall.

As shown in Figure 8, applying these corrections to indications 2 and 4 in the root of nozzle-to-vessel shell welds A and C shows the indications to be within the allowable limits of Table IWB-3512.1.

In review,

Fig. 1. A 10-degree angle-beam longitudinal-wave mechanized examination from the outlet nozzle bore was performed in compliance with the 1977 Edition of ASME Section XI with Addenda through Summer 1979 and U.S. Nuclear Regulatory Commission, Regulatory Guide 1.150, Paragraph 5, "...such that the beam is almost perpendicular (±15 degrees to the perpendicular) to the weld/parent-metal interface..."

Fig. 2. This examination recorded eleven indications exceeding 50 percent DAC in the outlet nozzle-to-vessel shell welds.

Fig. 3. Each of these reflectors had been recorded at a lower amplitude in the 1981 examination.

Fig. 4. Nozzle A indication 2 is sketched in detail from the 1984 examination record.

Fig. 5. Nozzle C indication 4 is sketched in detail from the 1984 examination record.

Fig. 6. Using Code sizing procedures on these indications without beam spread correction, indication 2 in weld 2-686-A and indication 4 in weld 2-686-C exceed the allowable limits of ASME Boiler and Pressure Vessel Code, 1977 Edition with Addenda through Summer 1979, Section XI, Table IWB-3512-1. The indications were not detected in the 45-degree angle-beam shear-wave examination performed at the same time from the bore of the nozzles.

Based on related experience of observing the ultrasonic response of confirmed slag and crack indications in other vessels, SwRI concludes that the reflectors are smooth flat slag inclusions near the root of the nozzle-to-vessel shell welds. The change in metal path observed on a reflector is a significant factor in Code sizing of indications. It is generally recognized that these Code sizing procedures are not appropriate for sizing such flaws under these examination conditions and that they exaggerate the true flaw size.

Fig. 7. Due to the geometry of the reflector, it was decided to drill a flat-bottomed 3/8-inch diameter hole normal to the 10-degree angle-beam shear-wave at a depth of 8 inches under the clad surface of the Point Beach basic calibration block, FS-NS-CSCL-5-PTB, in an area which will not interfere with later calibrations. The calibration block, angle-beam wedge, and search unit used in the site examination with a Sonic Mark II were used for DAC calibration on the 3/8-inch diameter SDHs at 4, 8, and 12 inches below the clad examination surface in the calibration block and for measurement of the 50 percent and 100 percent DAC dimensions (search unit position change distances between the stated amplitude levels) of the 3/8-inch diameter FBH at 8-inch depth. Thus, reproducing the essential parameters of the examination and making an appropriate beam spread measurement. The 50 percent DAC length and throughwall dimensions of 1.41 and 1.09 inches reduced by the 3/8-inch diameter FBH dimensions gave 1.035-inch length and .709-inch throughwall corrections.

Fig. 8. Applying these corrections to the indications in nozzle-to-vessel weld 2-686-A and 2-686-C shows the indications to be within the allowable limits of Table IWB-3512.1.

CONCLUSION

The information accumulated relative to the Point Beach Unit 1 reflectors gives a high level of confidence that the true size, orientation, and identity are as reported and that the practice of basing the size on the 50 percent DAC limits corrected for beam spread is appropriate. This technique is more accurate than Code procedures and is consistent with the requirements of the Code and Regulatory Guide 1.150. The beam spread corrected size of the indications shows that they are Code allowable and fracture mechanics analysis supports the acceptability of these indications as shown in Reference 2. SwRI has evaluated the reflectors in question in considerable detail both ultrasonically and by fracture mechanics techniques and is confident that they pose no threat to the continued safe operation of the vessel.

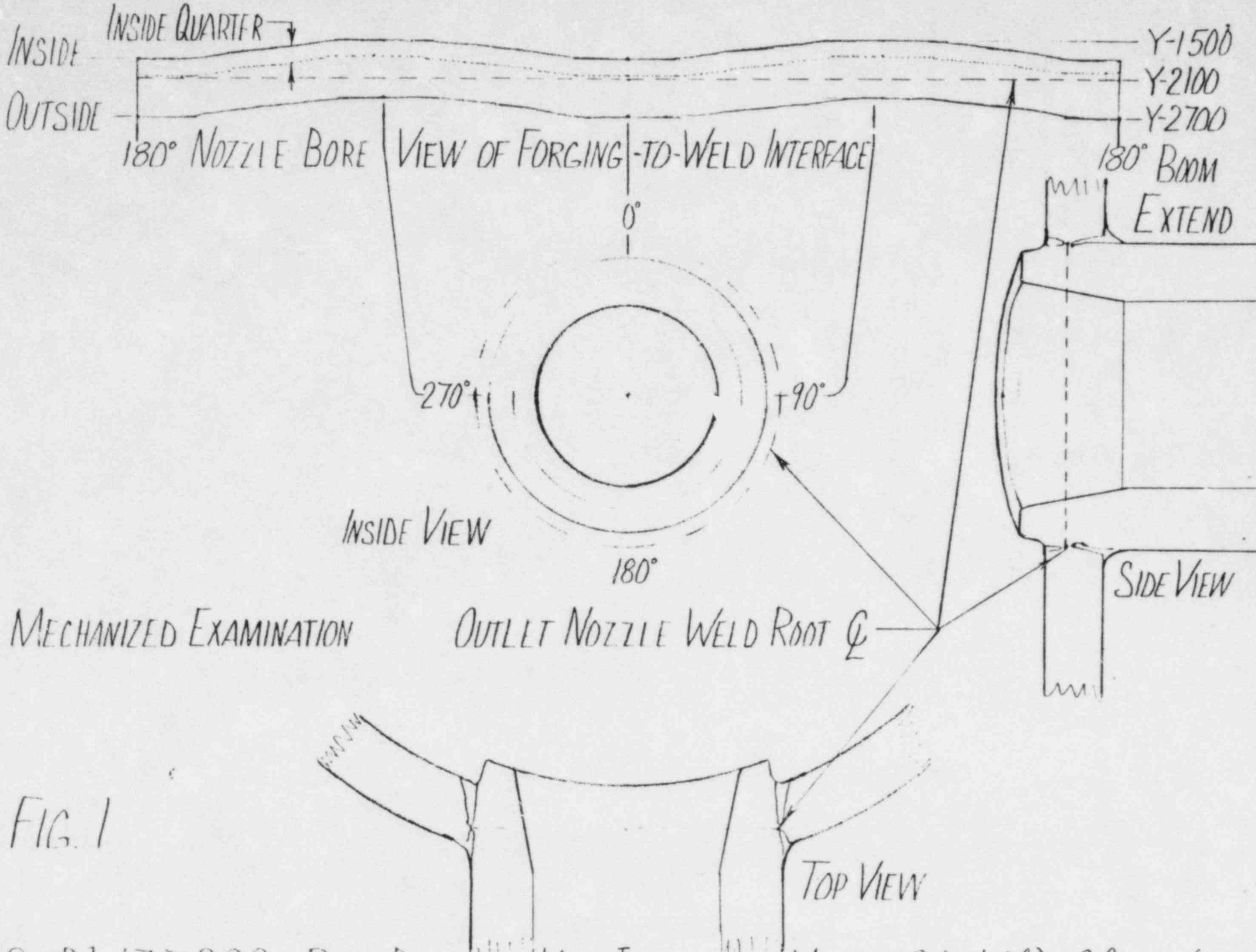


FIG. 1

SwRI 17-7222 POINT BEACH UNIT I 14 MAR 84 W.C. McGaughey

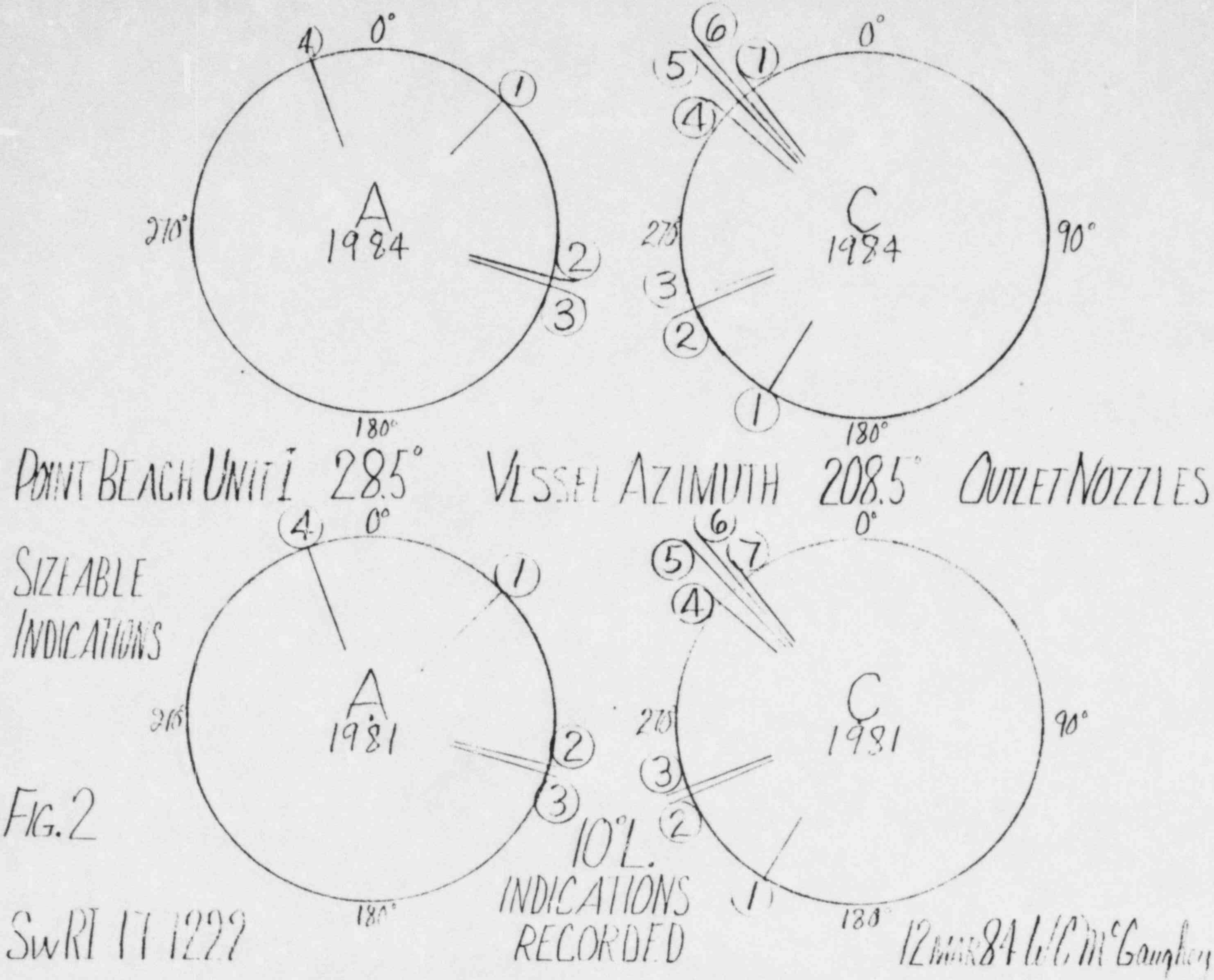

0°
90°
180°
270°
A
1984
C
1984
1
2
3
4
5
6
7
POINT BEACH UNIT I 28.5° VESSEL AZIMUTH 208.5° OUTLET NOZZLES
SIZEABLE INDICATIONS
A
1981
C
1981
10° L. INDICATIONS RECORDED
SwRI 17 1222
12 MAR 84 W.C. McGaughey

FIG. 2

POINT BEACH UNIT 1

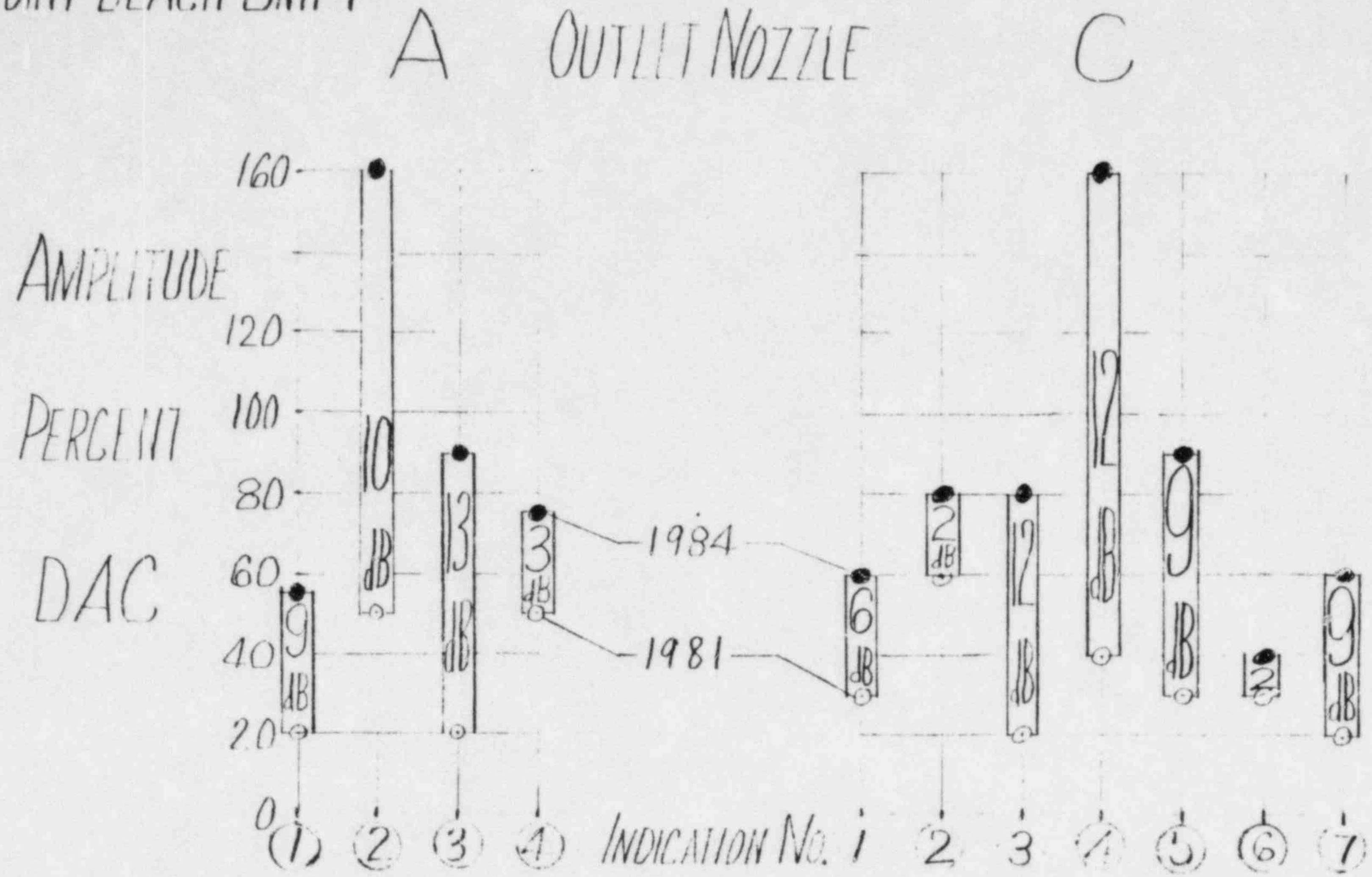


FIG. 3 AMPLITUDE CHANGE ON 10°L. INDICATIONS

SwRI 17-7222

12 MAR 84 WCM Gourley

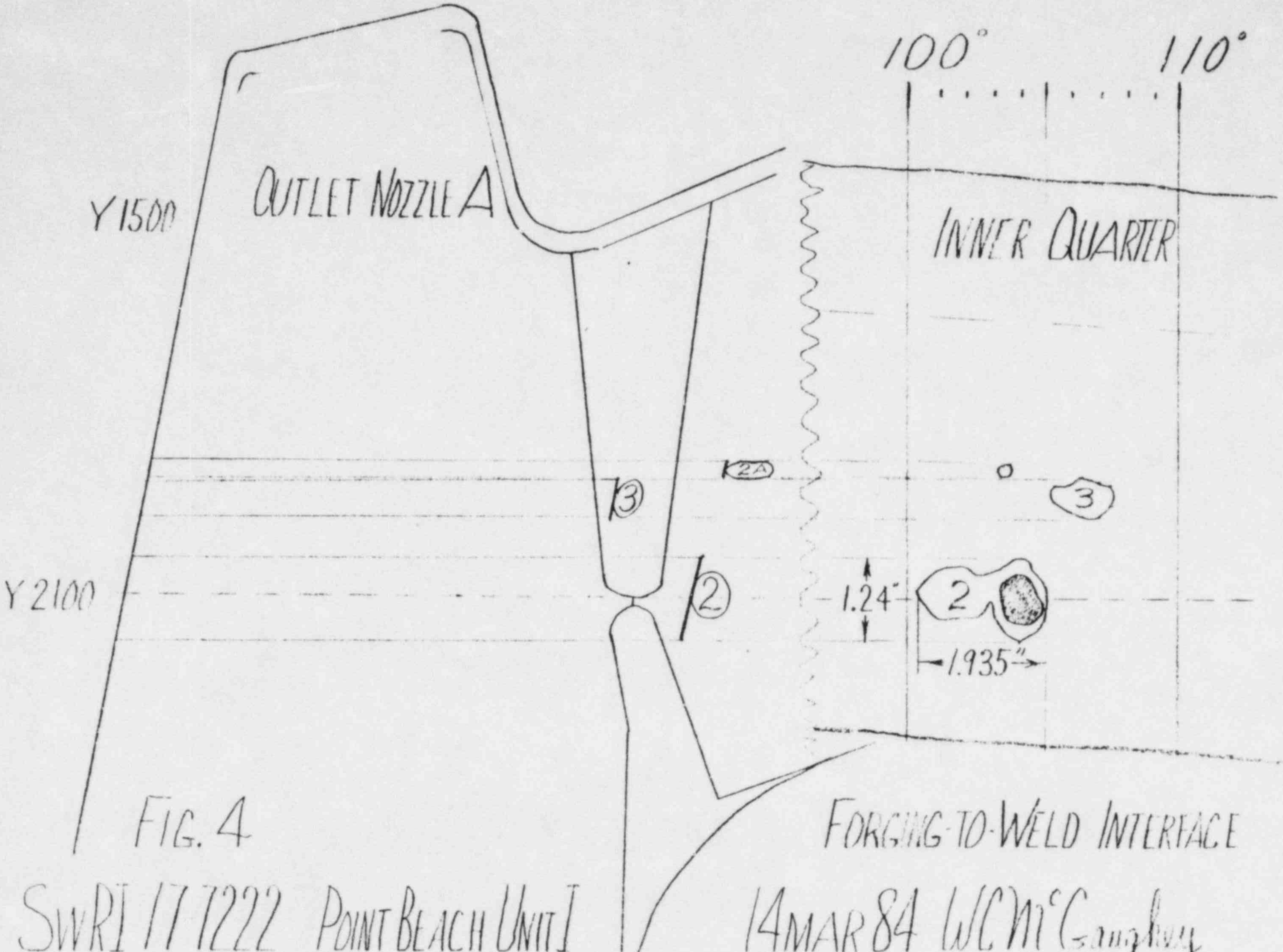


FIG. 4

SwRI 17 7222 POINT BEACH UNIT I 14 MAR 84 W.C. McGaughey

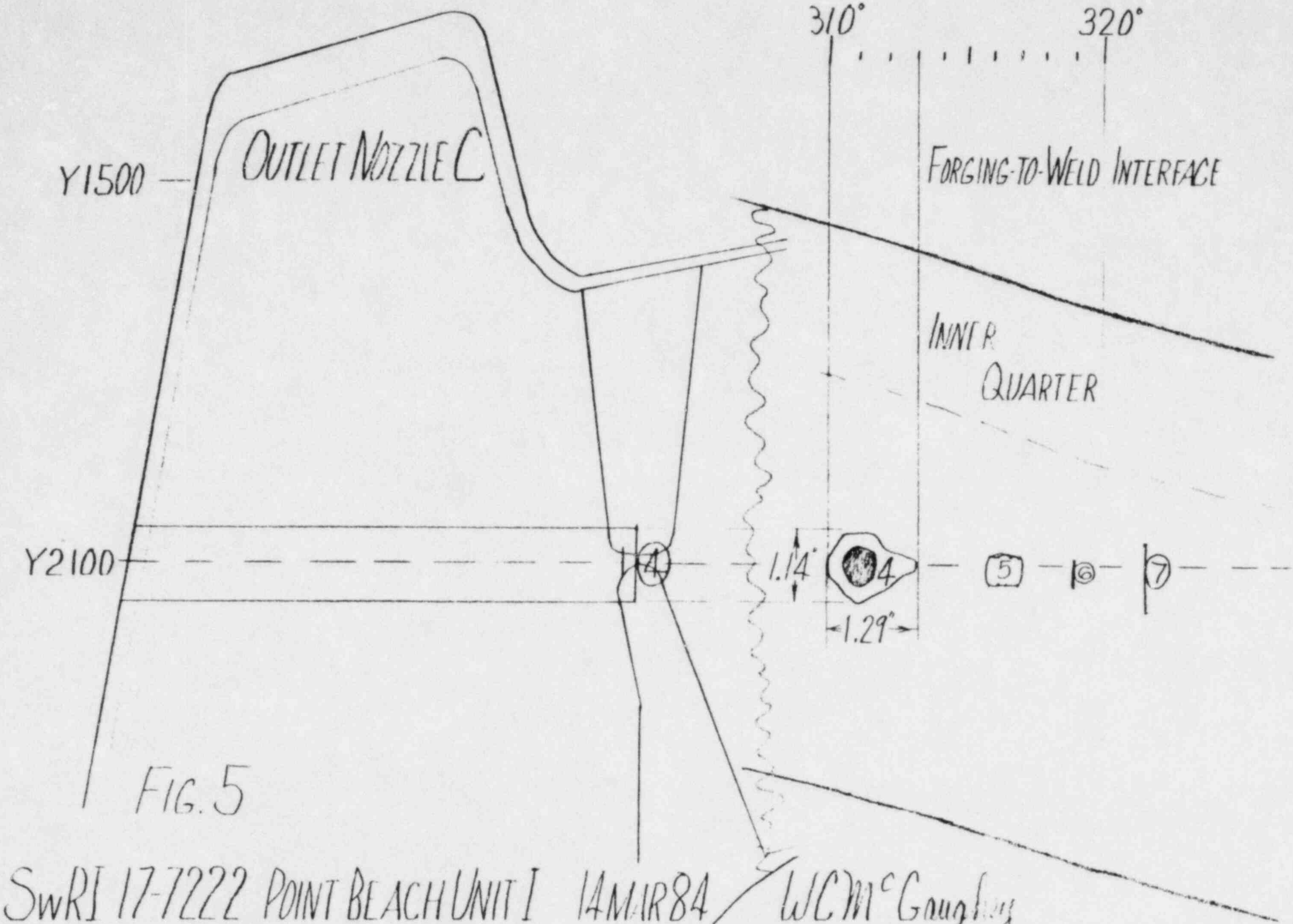
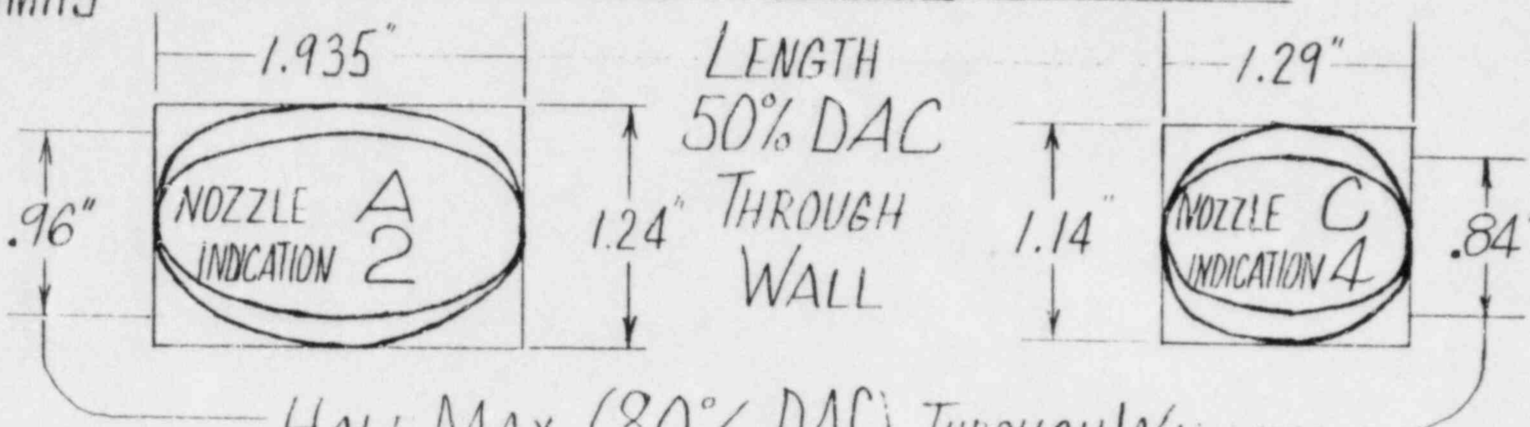


FIG. 5

SwRI 17-7222 POINT BEACH UNIT I 14MAR84 / WC McGaughey

INDICATIONS EXCEED LIMITS

1.24"	2a	1.14"
1.935"	ℓ	1.29"
.32	a/ℓ	.44
4.3	a/t% ALLOWABLE	5.8
6.8	a/t% MEASURED	6.2



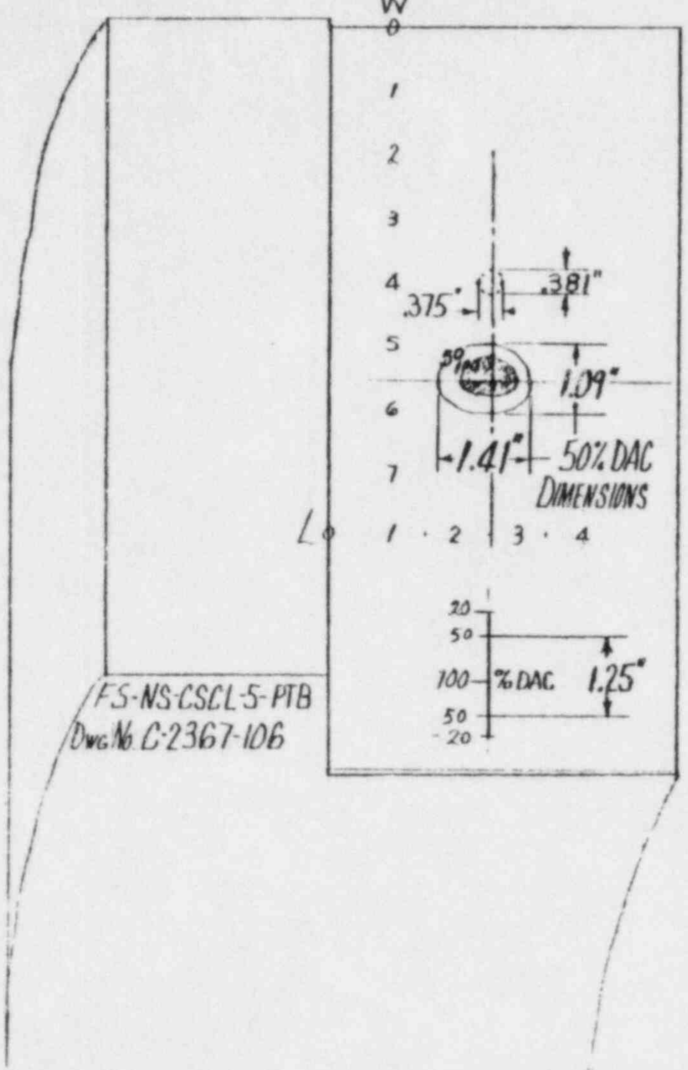
HALF MAX. (80% DAC) THROUGH WALL

.96"	2a	.84"
1.935"	ℓ	1.29"
.25	a/ℓ	.33
3.7	a/t% ALLOWABLE	4.4
5.26	a/t% MEASURED	4.6

FIG. 6

SwRI 17-7222 POINT BEACH UNIT I 13 MAR 84 WC McGaughey

	Length	Through Wall
50% DAC Dimensions	1.41"	1.09"
Flat Bottom Hole Dimensions	.375"	.381"
Correction	1.035"	.709"



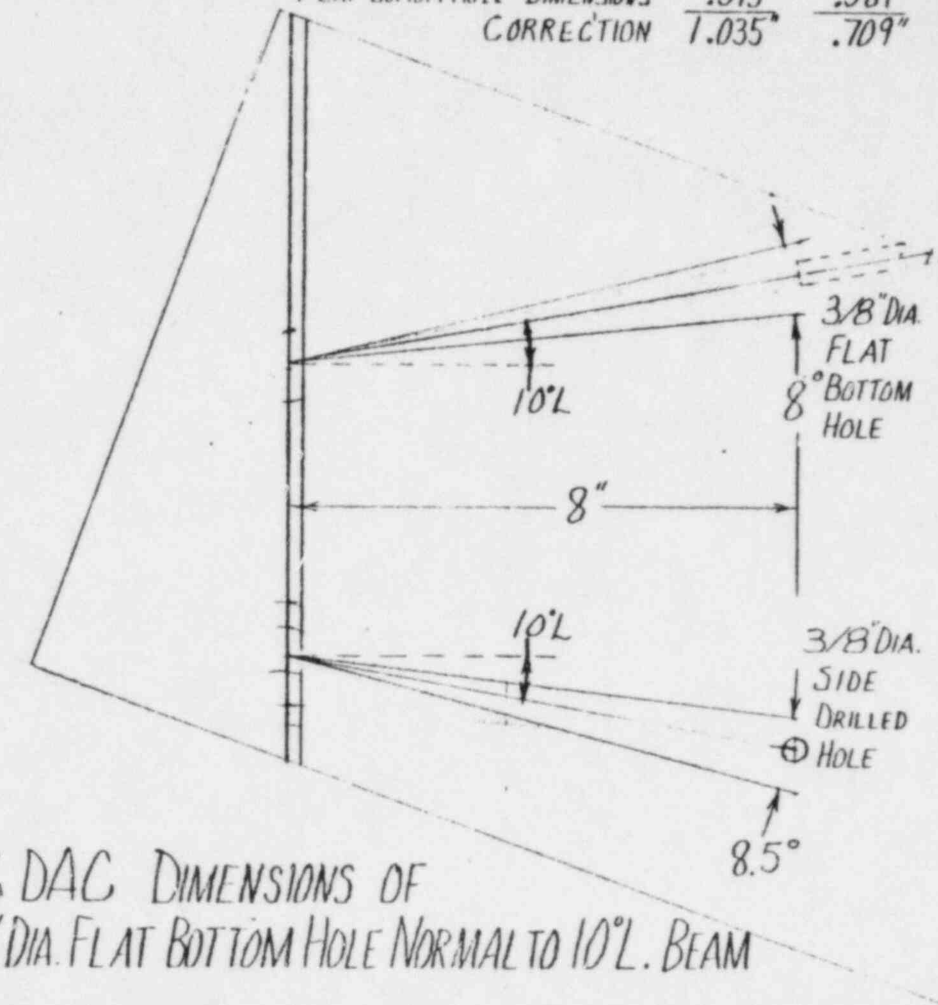
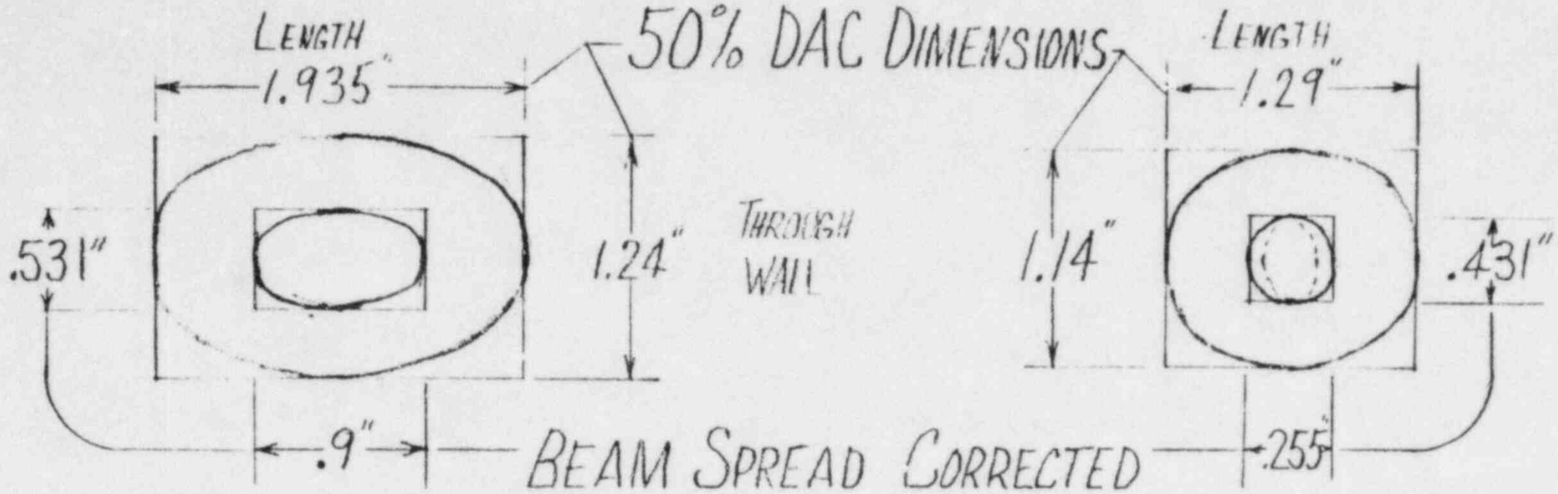


Fig. 7

50% DAC Dimensions of
3/8" Dia. Flat Bottom Hole Normal to 10°L. Beam

SwRI 17-7222 Point Beach Unit I 9 Mar 84 WCMcGaughey



NOZZLE A INDICATION (2)   NOZZLE C INDICATION (4)

.531	2a	.431
.9	l	.255
.295	a/l	.5 (LIMIT)
4.05	a/t % ALLOWABLE	6.5
2.9	a/t % MEASURED	2.4

FIG. 8

INDICATIONS ALLOWABLE

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