Docket #50-305
Accession #9109050075
Date 8/30/91 of Ltr
Regulatory Docket File

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Westinghouse Energy Systems

WCAP-11476
Revision 3

HANDBOOK ON FLAW EVALUATION
KEWAUNEE UNIT 1 STEAM GENERATORS
UPPER SHELL TO CONE WELD

May 1991

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SECTION 1

INTRODUCTION

This flaw* evaluation handbook has been designed for the evaluation of indications which may be discovered during inservice inspection of the Kewaunee Unit 1 steam generators. The tables and charts provided herein allow the evaluation of any indication discovered in the upper shell to cone weld region without further fracture mechanics calculations. The fracture analysis work is documented in this report. Use of the handbook will allow the acceptability (by analysis) of larger indications than would be allowable by only using the standards tables of the ASME Code Section XI. This report also provides the background and technical basis for the handbook charts. This handbook was prepared as a result of the discovery of indications in the upper shell to cone weld of the "B" steam generator in spring of 1987. Details of these indications and their evaluations are contained in Appendix A.

The geometry of this region is shown in Figure 1-1.

The highlight of the handbook is the design of a series of flaw evaluation charts for both surface flaws and the embedded flaws. Since the fracture mechanics characteristics of the two types of flaws are different, the evaluation charts are distinctively different in style. One section of this handbook deals with surface flaws, and another section concentrates on the evaluation of embedded flaws.

The flaw evaluation charts were designed based on the Section XI code criteria of acceptance for continued service without repair. Through use of the charts, a flaw can be evaluated by code criteria instantaneously, and no follow-up hand calculation is required. Most important of all, no fracture mechanics knowledge is needed by the user of the handbook charts.

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* The use of the term "flaw" in this document should be taken to be synonymous with the term "indication" as used in Section XI of the ASME Code.

It is important to note that indications which are large enough that they exceed the standards limits, and must be evaluated by fracture mechanics, will also require additional inservice inspection in the future, as discussed in Section XI, paragraph IWC-2420[1]. Note that subsection IWC applies specifically to the upper shell to cone weld, but it is not yet complete, and the user is often referred to subsection IWB. This is presently the case for subsection IWC-3600, which refers the user to IWB-3600.

1.1 CODE ACCEPTANCE CRITERIA

There are two alternative sets of flaw acceptance criteria for continued service without repair in paragraph IWB-3600 of ASME Code Section XI [1]. Namely,

1. Acceptance Criteria Based on Flaw Size (IWB-3611)
2. Acceptance Criteria Based on Stress Intensity Factor (IWB-3612)

The choice of criteria is at the convenience of the user, per IWB-3610. Both criteria are comparable in accuracy for thick sections, and the acceptance criteria (2) have been assessed by past experience to be generally less restrictive for thin sections, and for outside surface flaws in many cases. In all cases, the most beneficial criteria has been used, generally criteria (2). Although the steam generator wall thickness in the region of concern is slightly less than 4 inches, both sets of criteria from IWB 3600 may be applied.

1.1.1 CRITERIA BASED ON FLAW SIZE

The code acceptance criteria stated in IWB-3611 of Section XI are:

$a_f < .1\ a_c$ For normal conditions (upset & test conditions inclusive)

and $a_f < .5\ a_i$ For faulted conditions (emergency condition inclusive)

where

a_f = The maximum size to which the detected flaw is calculated to grow in a specified time period, which can be the next scheduled inspection of the component, or until the end of vessel design lifetime.

a_c = The minimum critical flaw size under normal operating conditions (upset and test conditions inclusive)

a_i = The minimum critical flaw size for initiation of nonarresting growth under postulated faulted conditions. (emergency conditions inclusive)

To determine whether a flaw is acceptable for continued service without repair, both criteria must be met simultaneously. However, both criteria have been considered in advance before the charts were constructed. Only the most restrictive results were used in the charts.

1.1.2 CRITERIA BASED ON STRESS INTENSITY FACTOR

As mentioned in the preceeding paragraphs, the criteria used for the construction of the charts in this handbook are from the least restrictive of IWB-3611 or IWB-3612 of Section XI. The criteria in IWB-3612 are based on safety margins between the applied stress intensity factor and the fracture toughness of the material.

The term stress intensity factor (K_I) is defined as the driving force on a crack. It is a function of the size of the crack and the applied stresses, as well as the overall geometry of the structure. In contrast, the fracture toughness (K_{Ia}, K_{Ic}) is a measure of the resistance of the material to propagation of a crack. It is a material property, and varies as a function of temperature.

The criteria are stated in IWB-3612:

$K_I < \frac{K_{Ia}}{\sqrt{10}}$ For normal conditions (upset & test conditions inclusive)

$K_I < \frac{K_{Ic}}{\sqrt{2}}$ For faulted conditions (emergency conditions inclusive) where

K_I = The maximum applied stress intensity factor for the flaw size a_f to which a detected flaw will grow, for a specified time period, which must equal or exceed the time until the next inspection.

K_{Ia} = Fracture toughness based on crack arrest for the corresponding crack tip temperature.

K_{Ic} = Fracture toughness based on fracture initiation for the corresponding crack tip temperature.

To determine whether a flaw is acceptable for continued service without repair, both criteria for normal and faulted conditions must be met simultaneously. However, both criteria have been considered in advance before the charts were constructed. Only the most restrictive results (for either normal or faulted conditions) were used in the charts.

1.1.3 PRIMARY STRESS LIMITS

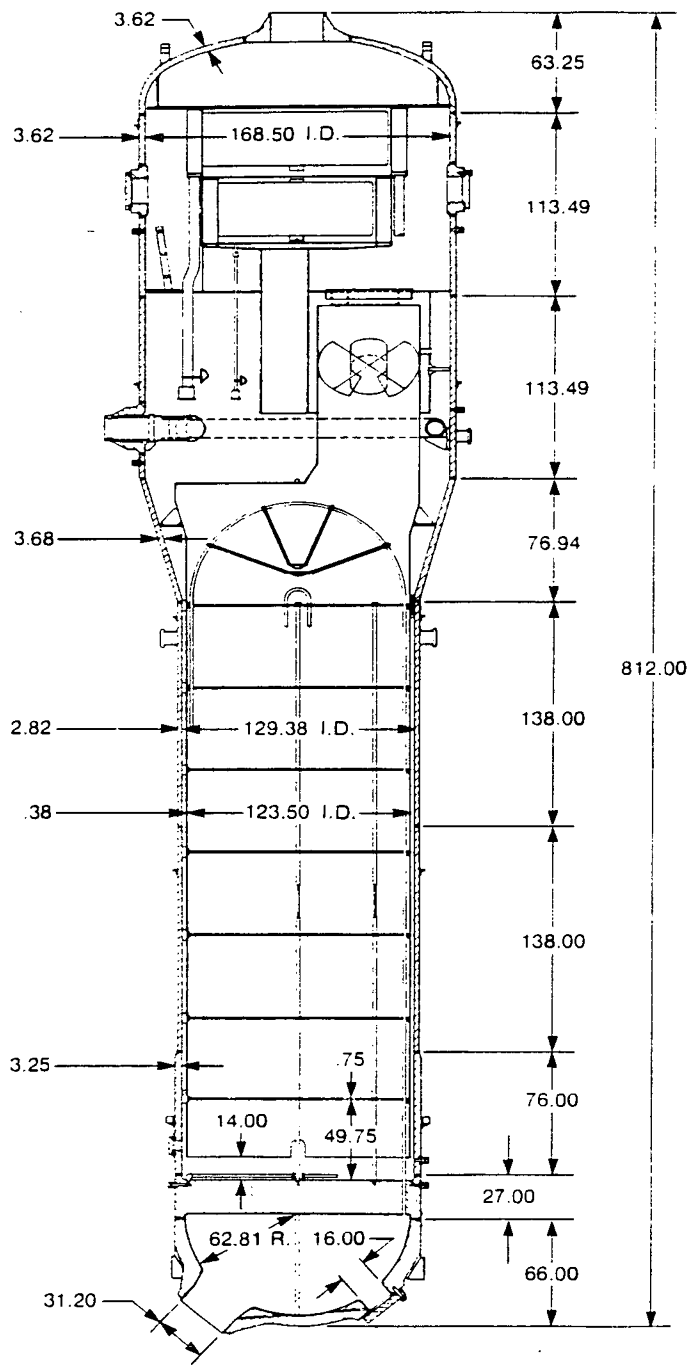
In addition to satisfying the fracture criteria, it is required that the primary stress limits of Section III, paragraph NB 3000 be satisfied. A local area reduction of the pressure retaining membrane must be used, equal to the area of the indication, and the stresses increased to reflect the smaller cross section. All the flaw acceptance tables provided in this handbook have included this consideration, as demonstrated herein. The allowable flaw depth "a" determined using this criterion is 1.20 in. for a surface flaw in the upper shell to cone weld region, and for an embedded flaw the allowable depth "2a" is 2.6 inches. Thus the fracture mechanics criteria are governing.

1.2 GEOMETRY

The geometry of the upper shell to cone weld region of the Kewaunee Unit 1 steam generators is shown in Figure 1-1. The dimensions shown are the minimum values from the design drawings. For purposes of heat transfer, the outside surfaces have been assumed to be insulated. The notation used for both surface and embedded flaws in this work is illustrated in Figure 1-2.

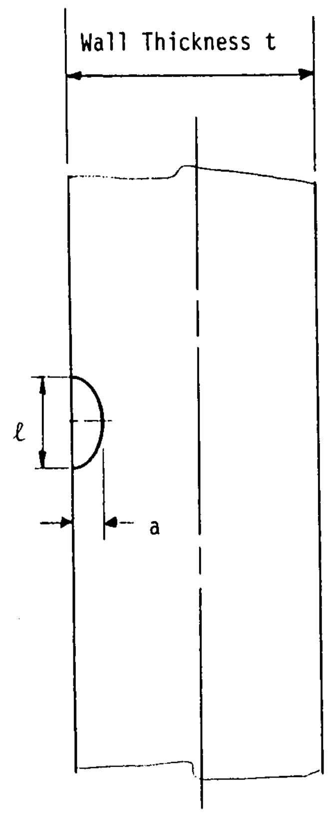
FIGURE 1-1

Geometry of Upper Shell to Cone Intersection for Kewaunee Unit 1

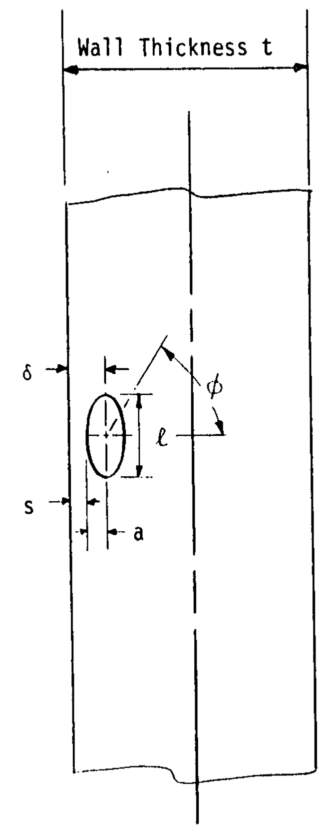


Note: All dimensions in inches.

Figure 1-2 Typical Notations of Surface and Embedded Flaw Indications



TYPICAL SURFACE FLAW INDICATION



TYPICAL EMBEDED FLAW INDICATION

SECTION 2

LOAD CONDITIONS, FRACTURE ANALYSIS METHODS AND MATERIAL PROPERTIES

2.1 TRANSIENTS FOR THE STEAM GENERATOR

The design transients for the Kewaunee Unit 1 steam generators are listed in Table 2-1. Both the minimum critical flaw sizes, such as a_c under normal operating conditions, or a_i under faulted conditions for criteria (1) of IWB-3611, and the stress intensity factors, K_I, for criteria (2) of IWB-3612, are a function of the stresses at the cross-section where the flaw of interest is located, and the material properties. Therefore, the first step for the evaluation of a flaw indication is to determine the appropriate limiting load conditions for the location of interest.

For the region of interest, the upper shell to cone weld, the full range of design transients was considered. Transients such as pressure tests, including both hydrostatic and leakage tests, can be controlled by setting the test temperature. Therefore, in determining the governing normal condition only the operational transients were considered, and a separate determination was made as to any required changes in the pressure test temperatures, to ensure that they would not be limiting. A discussion of this subject is provided in Section 6.2. On this basis, the governing normal condition is the heatup condition, while the governing emergency and faulted condition is the feedwater-line break. All the transients were considered in calculation of fatigue crack growth, as discussed in Section 3.

2.2 STRESS INTENSITY FACTOR CALCULATIONS

One of the key elements of the critical flaw size calculations is the determination of the driving force or stress intensity factor (K_I). This was done using expressions available from the literature. In all cases the stress intensity factor for the critical flaw size calculations utilized a representation of the actual stress profile rather than a linearization. This was necessary to provide the most accurate determination possible of the critical flaw size, and is particularly important for consideration of emergency and faulted conditions, where the stress profile is generally nonlinear and often very steep. The stress profile was represented by a cubic polynomial:

$$\sigma(x) = A_0 + A_1 \frac{x}{t} + A_2 \left(\frac{x}{t}\right)^2 + A_3 \left(\frac{x}{t}\right)^3$$

where x is the coordinate distance into the wall

t = wall thickness

σ = stress perpendicular to the plane of the crack

In construction of the surface flaw charts (Section 4) three flaw shapes were used, continuous ($a/\ell = 0.0$) semielliptical, with length six times the depth ($a/\ell = 0.167$) and semi circular ($a/\ell = 0.5$). As will be seen in Section 4, the charts cover the full range of shapes between these values.

For the surface flaw with length six times its depth ($a/\ell = 0.167$), the stress intensity factor expression of McGowan and Raymund [2] was used.

The stress intensity factor $K_I(\phi)$ can be calculated anywhere along the crack front, where ϕ is the angular position, as defined in Figure 1-2. The point of maximum crack depth is represented by $\phi = 0$. The following expression is used for calculating $K_I(\phi)$:

$$K_I(\phi) = \left[\frac{\pi a}{Q}\right]^{0.5} \left(\cos^2 \phi + \frac{a^2}{c^2} \sin^2 \phi\right)^{1/4} \left(A_0 H_0 + \frac{2}{\pi}\frac{a}{t} A_1 H_1 + \frac{1}{2}\frac{a^2}{t^2} A_2 H_2 + \frac{4}{3\pi}\frac{a^3}{t^3} A_3 H_3\right)$$

The magnification factors $H_0(\phi)$, $H_1(\phi)$, $H_2(\phi)$ and $H_3(\phi)$ were obtained by the procedure outlined in Reference [2].

The stress intensity factor calculation for a semi-circular surface flaw, ($a/\ell = 0.5$) was carried out using the expressions developed by Raju and Newman [3]. Their expression utilizes the same cubic representation of the stress profile and gives precisely the same result as the expression of McGowan and Raymund for the flaw with $a/\ell = 0.167$, and the form of the equation is similar to that of McGowan and Raymund above.

The stress intensity factor expression used for a continuous surface flaw was that developed by Buchalet and Bamford [4]. Again the stress profile is represented as a cubic polynomial, as shown above, and these coefficients as well as the magnification factors are combined in the expression for K_I below:

$$K_I = [\pi a]^{0.5} [A_0 F_1 + \frac{2a}{\pi} A_1 F_2 + \frac{a^2}{2} A_2 F_3 + \frac{4}{3\pi} a^3 A_3 F_4]$$

where F_1, F_2, F_3, F_4 are magnification factors, available in [4].

The embedded flaw charts were constructed for a wide range of flaw sizes and shapes. The stress intensity factor calculation for embedded flaws was taken from work by Shah and Kobayashi [5] which is applicable to an embedded flaw in an infinite medium, subjected to an arbitrary stress profile. This expression has been shown to be applicable to embedded flaws in a pressure vessel in a recent paper by Lee and Bamford [6].

2.3 FRACTURE TOUGHNESS

The other key element in the determination of critical flaw sizes is the fracture toughness of the material. The fracture toughness has been taken directly from the reference curves of Appendix A, Section XI. In the transition temperature region, these curves can be represented by the following equations:

$$K_{Ic} = 33.2 + 2.806 \text{ exp. } [0.02 (T-RT_{NDT} + 100°F)]$$

$$K_{Ia} = 26.8 + 1.233 \text{ exp. } [0.0145 (T-RT_{NDT} + 160°F)]$$

where K_{Ic} and K_{Ia} are in ksi$\sqrt{\text{in}}$.

The upper shelf temperature regime requires utilization of a shelf toughness which is not specified in the ASME Code. A value of 200 ksi$\sqrt{\text{in}}$ has been used here. This value is consistent with general practice in such evaluations, as shown for example in reference [7], which provides the background and technical basis of Appendix A of Section XI.

The fracture toughness of steam generator malerials has been examined in recent years relative to the reference toughness curves of the ASME code. Dynamic fracture toughness tests were conducted on base metal, weldments, and heat-affected zones, and were all found to be bounded by the ASME K_{Ia} curve. Behavior was found to be very similar to that of the reactor vessel steels and weldments for which the K_{Ia} curve was developed. Thus, even though the minimum specified yield strength of these materials is in excess of the 50 ksi value specified for the ASME reference K_{Ia} curve, these results show that these materials should also be covered. Further discussion and details are found in References 8-11.

The other key element in the determination of the fracture toughness is the value of RT_{NDT}, which is a parameter determined from Charpy V-notch and drop-weight tests.

To allow determination of RT_{NDT} for the upper shell and cone materials, a compilation was made of the properties listed on the original material test certificates. The materials used in the steam generators were tested after a post-weld heat treatment cycle of 1050-1150°F for approximately 7 hours, as shown in Table 2-2. The Charpy impact properties of these materials are listed in Table 2-3.

The U.S. Nuclear Regulatory Commission has established guidelines for estimating the value of RT_{NDT} from Charpy properties in their Standard Review Plan [12]. Review of Table 2-3 shows that in general the materials in the shell and cone region have excellent Charpy properties, and therefore the value of RT_{NDT} is equal to the test temperature, which is 10°F for all the materials. This value has been used in the development of the flaw evaluation charts.

Once the value of RT_{NDT} is established, the reference toughness curves of the ASME Code discussed above may be used directly, since the materials are SA533 grade A class 1 which has a minimum specified yield strength of 65 ksi.

2.4 CRITICAL FLAW SIZE DETERMINATION

The applied stress intensity factor (K_I) and the material fracture toughness values (K_{Ia} and K_{Ic}) were used to determine the allowable flaw size values used to construct the handbook charts. For normal, upset and test conditions, the critical flaw size a_c is determined as the depth at which the applied stress intensity factor K_I exceeds the arrest fracture toughness K_{Ia}.

For emergency and faulted conditions the minimum flaw size for crack initiation is obtained from the first intersection of the applied stress intensity factor (K_I) curve with the static fracture toughness (K_{Ic}) curve.

TABLE 2-1
TRANSIENT GROUPING FOR FATIGUE CRACK GROWTH ANALYSIS

Transient Group	Description	Cycles	Total Cycles In Group
1	Heatup and Cooldown* Turbine Roll Test	200 10	210
2	Plant Loading 15% to 100% and Plant Unloading 100% to 15%	18300	18300
3	Large Step Load Decrease* Small Step Load Increase Small Step Load Decrease	200 2000 2000	4200
4	Hot Standby Operation* (includes feedwater cycling)	18300	18300
5	Loss of Load	80	80
6	Loss of Power	40	40
7	Loss of Flow	80	80
8	Reactor Trip	400	400
9	Secondary Side Pipe Break	1	1
10	Secondary Hydrostatic Test	5	5
11	OBE	50	50
12	RCS Pipe Break	1	**
13	Primary Hydrostatic	5	**

Notes

* Umbrella Transient

**These transients do not affect this region

TABLE 2-2
POSTWELD HEAT TREATMENT OF UPPER SHELL - CONE WELDS

Steam Generator A

Heatup to 1120°F	11.5 hours
Soak at 1050-1150°F	7 hours
Cooldown in air	6 hours

Steam Generator B

Soak at 1050 - 1150	7.5 hours
Cooldown in air	6 hours

TABLE 2-3

MATERIAL PROPERTIES OF UPPER SHELL-CONE REGION

KEWAUNNE NUCLEAR PLANT

Location	Material Type	Charpy Values (10°F) (ft-lb)	Lateral Expansion (inches)	RT_{NDT}
Cone materials, SG/A				
heat C5798-1	SA 533-65 Gr A C1	67,63,72	0.067, 0.060, 0.068	10°F
heat C5798-5	SA 533-65 Gr A C1	110,132,111	0.088, 0.092, 0.076	10°F
heat 5816-4	SA 533-65 Gr A C1	110,82,110	0.082, 0.084, 0.087	10°F
Upper shell materials, SG/A				
heat 75E553	SA 533-68 Gr A C1	75,65,51	0.050, 0.044, 0.040	10°F
heat 6589-4	SA 533-67 Gr A C1	44,95,71	0.036, 0.056, 0.040	10°F
Cone materials, SG/B				
heat 5798-1	SA 533-65 Gr A C1	67,63,72	0.067, 0.060, 0.068	10°F
heat 5798-3	SA 533-65 Gr A C1	96,80,114	0.063, 0.078, 0.087	10°F
heat 5816-4	SA 533-65 Gr A C1	110,82,110	0.082, 0.084, 0.087	10°F
Upper shell materials SG/B				
heat 216881	SA 533-68 Gr A C1	79,70,95	0.053, 0.048, 0.067	10°F
heat 796419	SA 533-66 Gr A C1	95,70,86	0.065, 0.057, 0.064	10°F
Weld - Shielded Metal Arc				
top location		104,105,102	Not	10°F
1/4 T location		95,45,103	Available	10°F

SECTION 3
FATIGUE CRACK GROWTH

In applying code acceptance criteria as introduced in Section 1 of this report, the final flaw size a_f used in criteria (1) is defined as the flaw size to which the detected flaw is calculated to grow at the end of the specified service period. In this handbook, ten-, twenty-, and thirty-year service periods are assumed.

These crack growth calculations have been carried out for the upper shell to cone weld of the Kewaunee Unit 1 steam generators for which evaluation charts have been constructed. This section will examine the calculations, and provide the methodology used as well as the assumptions.

The crack growth calculations reported here are rather extensive, because a range of flaw shapes have been considered, to encompass the range of flaw shapes which could be encountered in service.

3.1 ANALYSIS METHODOLOGY

The fatigue crack growth analysis procedure involves postulating an initial flaw at a specific region and predicting the growth of that flaw due to an imposed series of loading transients. The input required for a fatigue crack growth analysis is basically the information necessary to calculate the parameter ΔK_I which depends on crack and structure geometry and the range of applied stresses in the area where the crack exists. Once ΔK_I is calculated, the growth due to that particular stress cycle can be calculated by equations given in Section 3.3 and Figure 3-1. This increment of growth is then added to the original crack size, and the analysis proceeds to the next transient. The procedure is continued in this manner until all the transients known to occur in the period of evaluation have been analyzed.

The transients considered in the analysis are all the design transients contained in the Final Safety Analysis Report and the steam generator equipment specification, as shown in Section 2, Table 2-1. These transients are spread equally over the design lifetime of the vessel, with the exception that the preoperational tests are considered first. Faulted conditions are not considered in the crack growth analysis because their frequency of occurrence is too low to affect fatigue crack growth.

Crack growth calculations were carried out for a range of flaw depths, and three basic types. The first type was a surface flaw with length equal to six times its depth (a/ℓ = 0.1667), and whose analysis was previously reported. The second was a continuous surface flaw (a/ℓ = 0.0), which represents a worst case for surface flaws, and the third was an embedded flaw, with length equal to five times its width. For all cases the flaw was assumed to maintain a constant shape as it grew. Calculations for other flaw shapes were unnecessary because the selected types conservatively model the crack growth of the other flaws of interest for construction of the charts.

3.2 STRESS INTENSITY FACTOR EXPRESSIONS

Stress intensity factors were calculated from methods available in the literature for each of the flaw types analyzed. The surface flaw with aspect ratio 6:1 was analyzed using an expression developed by McGowan and Raymund [2] where the stress intensity factor K_I is calculated from the actual stress profile through the wall at the location of interest.

The maximum and minimum stress profiles corresponding to each transient are represented by a third order polynomial, such that:

$$\sigma (X) = A_0 + A_1 \frac{x}{t} + A_2 \frac{x^2}{t^2} + A_3 \frac{x^3}{t^3}$$

The stress intensity factor K_I (ϕ) can be calculated anywhere along the crack front. The point of maximum crack depth is represented by ϕ = 0. The following expression is used for calculating K_I (ϕ), where ϕ is the angular location defined in Figure 1-1.

$$K_I(\phi) = [\frac{\pi a}{Q}]^{0.5} (\cos^2\phi + \frac{a^2}{c^2}\sin^2\phi)^{1/4} (A_0 H_0 + \frac{2}{\pi}\frac{a}{t} A_1 H_1$$

$$+ \frac{1}{2}\frac{a^2}{t^2} A_2 H_2 + \frac{4}{3\pi}\frac{a^3}{t^3} A_3 H_3)$$

The magnification factors $H_0(\phi)$, $H_1(\phi)$, $H_2(\phi)$ and $H_3(\phi)$ are obtained by the procedure outlined in reference [2].

The stress intensity factor for a continuous surface flaw was calculated using an expression for an edge cracked plate [13]. The stress distribution is linearized through the wall thickness to determine membrane and bending stress and the applied K_I is calculated from:

$$K_I = \sigma_m Y_m \sqrt{a} + \sigma_B Y_B \sqrt{a}$$

The magnification factors Y_m and Y_B are taken from [13] and a is the crack depth.

For embedded flaws, the stress intensity factor expression of Shah and Kobayashi [5] was used, as discussed earlier in Section 2.2. The flaw shape was set with length equal to five times the width ($a/\ell = 0.10$), and the eccentricity was varied, as shown in the Table 3-2. This flaw shape was chosen to provide a worst case calculation of stress intensity factor for embedded flaws. The calculated crack growth was very small for this case, so no other shapes were considered necessary to analyze.

3.3 CRACK GROWTH RATE REFERENCE CURVES

The crack growth rate curves used in the analyses were taken directly from Figure A4300-1 of Appendix A of Section XI of the ASME Code. Water environment curves were used for all inside surface flaws, and the air environment curve was used for embedded flaws and outside surface flaws.

The materials used for the pressure boundary of steam generators are basically higher strength versions of the reactor vessel steels, SA508 Class 2 and 3 and SA533 Gr B CI, and early designs had exactly the same materials as the reactor vessel.

A large number of specimens of steam generator materials, SA508 C 2a, SA553 Gr. A Cl. 2, SA508 Cl. 3a, and SA533 Gr. B C2 materials and two associated submerged arc weldments were tested at Westinghouse. The environments used were low and high temperature air, PWR primary water, and secondary side steam. These environments cover all the possible environments for both the primary and secondary side of the steam generator, but do not include any contaminants which could be present in the secondary side environment. Load ratios of 0.2 and 0.7 were employed for the air environment, and values of 0.2 and 0.5 were used in the PWR and steam environments.

Results showed that the reference crack growth rate curves for ferritic steel contained in Section XI were also applicable to these steels. The PWR environment was found to produce the highest growth rates, but the data were well below the ASME reference curves. The data obtained in the steam environment showed crack growth rates equal to or below the rates obtained in the PWR environment under the same conditions. These results are discussed in references 14-16. Therefore the ASME Code reference curves are applicable.

For water environments the reference crack growth curves are shown in Fig. 3-1, and growth rate is a function of both the applied stress intensity factor range, and the R ratio (K_{min}/K_{max}) for the transient.

For $R \le 0.25$

$$(\Delta K_I \le 19 \text{ ksi}\sqrt{\text{in}}) \frac{da}{dN} = (1.02 \times 10^{-6})\ \Delta K_I^{5.95}$$

$$(\Delta K_I > 19 \text{ ksi}\sqrt{\text{in}}) \frac{da}{dN} = (1.01 \times 10^{-1})\ \Delta K_I^{1.95}$$

where $\frac{da}{dN}$ = Crack Growth rate, micro-inches/cycle.

For $R \ge 0.65$

$$(\Delta K_I \le 12 \text{ ksi}\sqrt{\text{in}}) \frac{da}{dN} = (1.20 \times 10^{-5})\ \Delta K_I^{5.95}$$

$$(\Delta K_I > 12 \text{ ksi}\sqrt{\text{in}}) \frac{da}{dN} = (2.52 \times 10^{-1})\ \Delta K_I^{1.95}$$

For R ratio between these two extremes, interpolation is recommended.

The crack growth rate reference curve for air environments is a single curve, with growth rate being only a function of applied ΔK. This reference curve is also shown in Figure 3-1.

$$\frac{da}{dN} = (0.0267 \times 10^{-3}) \, \Delta K_I^{3.726}$$

where, $\frac{da}{dN}$ = Crack growth rate, micro-inches/cycle

ΔK_I = stress intensity factor range, ksi$\sqrt{in}$

$= (K_{Imax} - K_{Imin})$

3.4 FATIGUE CRACK GROWTH RESULTS

The fatigue crack growth results upon which handbook charts were developed are summarized in Tables 3-1 and 3-2, and shown graphically in Figure 3-2.

Table 3-1

Fatigue Crack Growth Results - Kewaunee Unit 1

Steam Generator Upper Shell to Cone Weld Region - Surface Flaws

Continuous Flaw ($a/\ell = 0$)

INITIAL DEPTH	CRACK DEPTH AFTER YEAR 10	20	30	40
0.500	0.71154	0.99030	1.35720	1.88252
0.600	0.84452	1.16395	1.59752	2.26478
0.700	0.97438	1.33694	1.84992	2.70801
0.800	1.10453	1.51543	2.12762	3.23917

$a/\ell = 0.1667$

INITIAL DEPTH	CRACK DEPTH AFTER YEAR 10	20	30	40
0.700	0.79232	0.90274	1.03399	1.19217
0.800	0.91140	1.04488	1.20470	1.39380
0.900	1.03072	1.18819	1.37449	1.57976
1.000	1.19063	1.33190	1.53259	1.75105
1.500	1.71524	1.94732	2.19663	2.46658

Table 3-2
Fatigue Crack Growth Results - Kewaunee Unit 1
Steam Generator Upper Shell to Cone Weld Region - Embedded Flaws

δ = T/16

INITIAL DEPTH	CRACK DEPTH AFTER YEAR 10	20	30	40
0.120	0.12015	0.12031	0.12046	0.12061
0.150	0.15024	0.15049	0.15073	0.15097
0.160	0.16027	0.16056	0.16083	0.16112
0.165	0.16529	0.16559	0.16589	0.16619

δ = 3T/32

INITIAL DEPTH	CRACK DEPTH AFTER YEAR 10	20	30	40
0.150	0.15017	0.15035	0.15052	0.15070
0.200	0.20032	0.20064	0.20096	0.20129
0.240	0.24047	0.24096	0.24144	0.24194

δ = T/8

INITIAL DEPTH	CRACK DEPTH AFTER YEAR 10	20	30	40
0.280	0.28048	0.28098	0.28147	0.28198
0.300	0.30057	0.30116	0.30173	0.30232
0.320	0.32066	0.32135	0.32202	0.32271
0.330	0.33071	0.33145	0.33217	0.33292

δ = 3T/16

INITIAL DEPTH	CRACK DEPTH AFTER YEAR 10	20	30	40
0.400	0.40059	0.40121	0.40180	0.40243
0.440	0.44076	0.44154	0.44231	0.44310
0.450	0.45080	0.45164	0.45245	0.45329
0.460	0.46085	0.46174	0.46259	0.46349

δ = T/4

INITIAL DEPTH	CRACK DEPTH AFTER YEAR 10	20	30	40
0.400	0.40031	0.40063	0.40095	0.40127
0.440	0.44040	0.44081	0.44121	0.44162
0.450	0.45042	0.45086	0.45128	0.45172
0.460	0.46044	0.46091	0.46136	0.46182

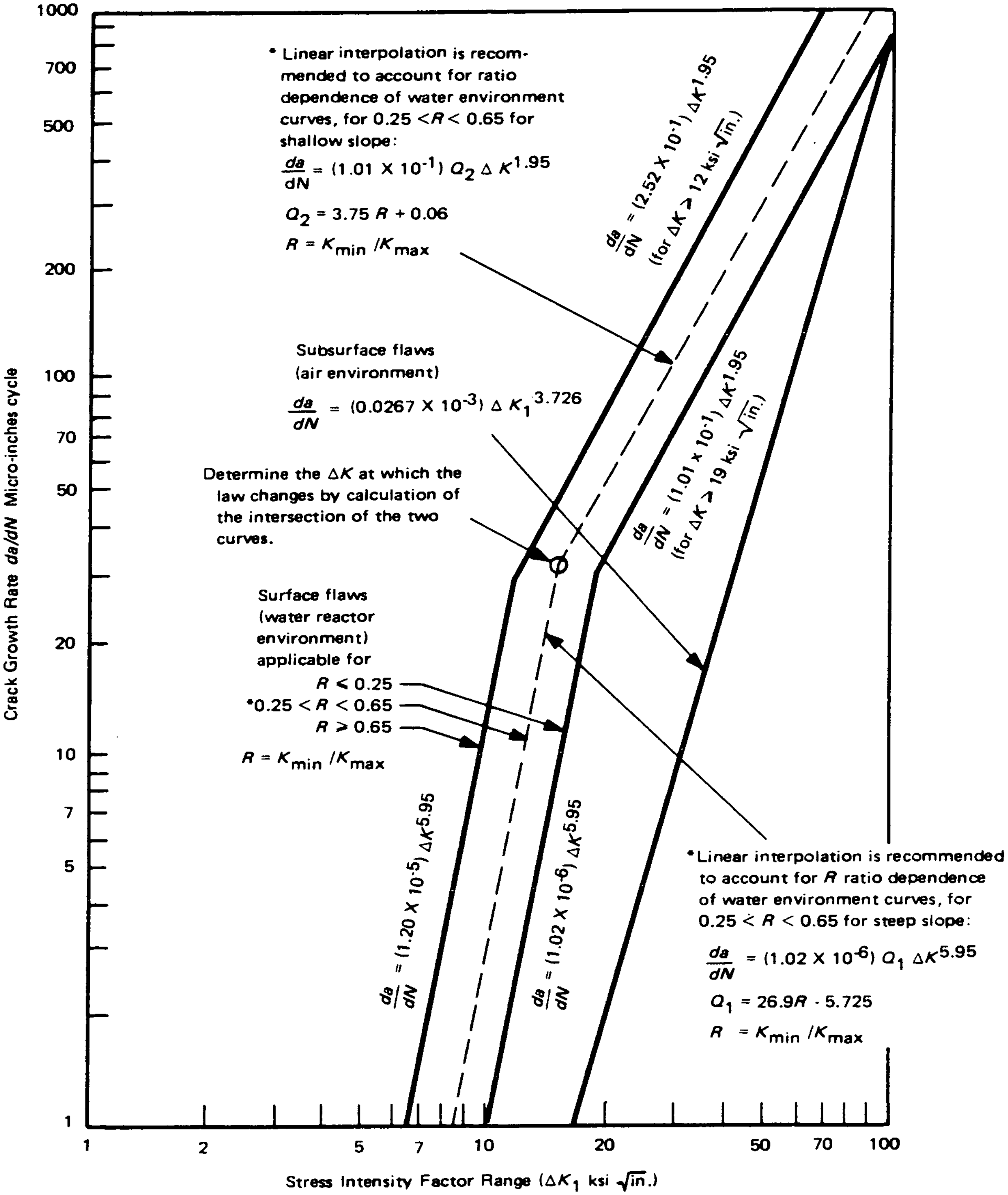


Figure 3-1 Reference Fatigue Crack Growth Curves for Carbon and Low Alloy Ferritic Steels

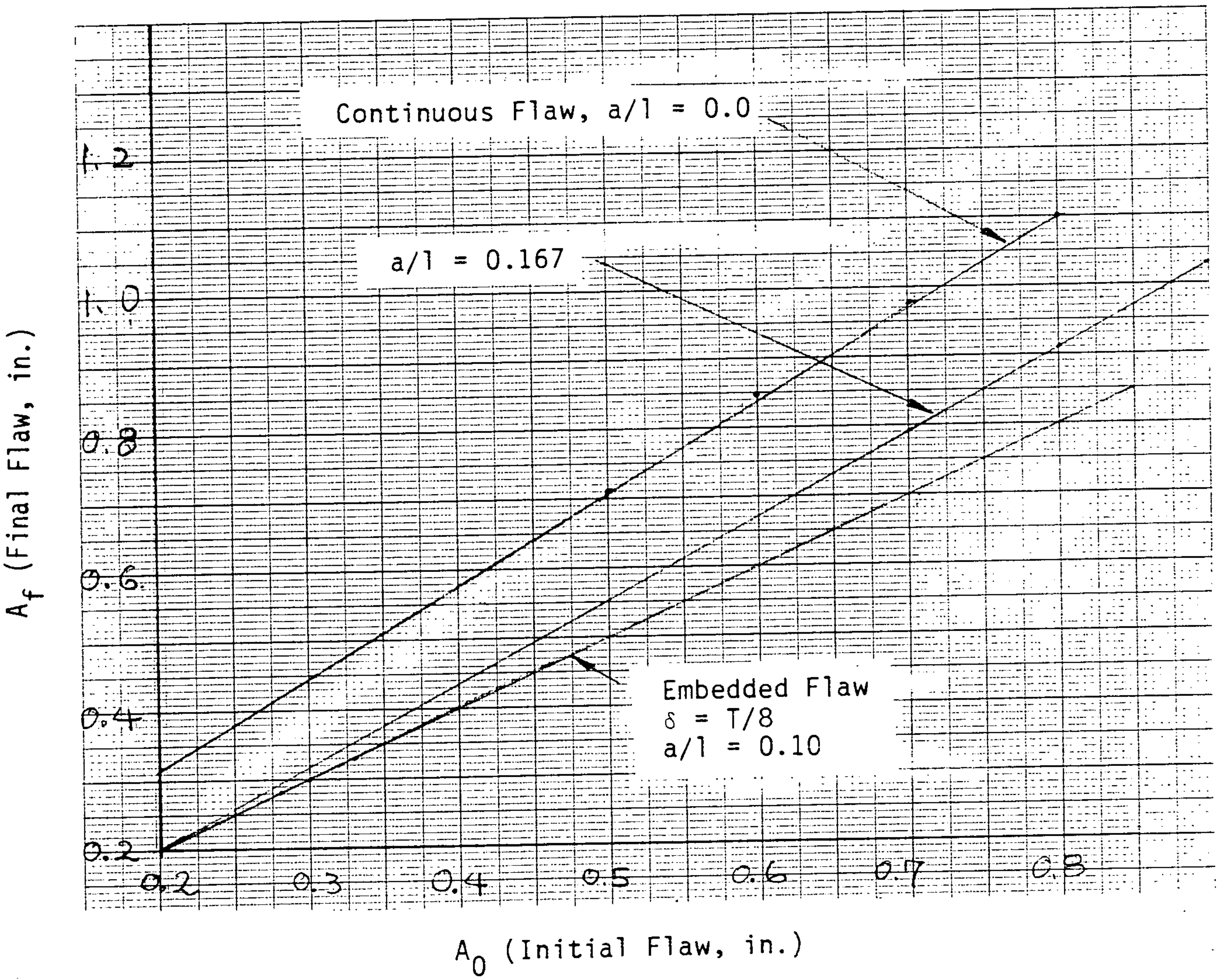


Figure 3-2 Fatigue Crack Growth Results - Upper Shell Cone Weld Section Circumferential Flaws for 10 Year Period

SECTION 4
SURFACE FLAW EVALUATION

4.1 SCOPE OF EVALUATION

The surface flaw evaluation covers the upper shell to cone weld region. This section describes the development of the inside surface flaw charts for that region.

4.2 CODE CRITERIA

The acceptance criteria for flaws have been readily presented in Section 1. For convenience they are repeated as follows:

$a_f < 0.1\, a_c$ For normal conditions (upset & test conditions inclusive)

and

$a_f < 0.5\, a_i$ For faulted conditions (emergency condition inclusive)

where

a_f - The maximum size to which the detected flaw is calculated to grow for a specified period, which must can be the next scheduled inspection of the component or until the end of vessel design lifetime.

a_c = The minimum critical flaw size under normal operating conditions (upset and test conditions inclusive)

a_i = The minimum critical flaw size for initiation of nonarresting growth under postulated faulted conditions. (emergency conditions inclusive)

Alternatively, criteria based on applied stress intensity factors may be used:

$$K_I < \frac{K_{Ia}}{\sqrt{10}} \text{ For normal conditions (upset \& test conditions inclusive)}$$

$$K_I < \frac{K_{Ic}}{\sqrt{2}} \text{ For faulted conditions (emergency conditions inclusive)}$$

where

K_I = The maximum applied stress intensity factor for the flaw size a_f to which a detected flaw will grow, for a specified period, which must be at least until the next inspection.

K_{Ia} = Fracture toughness based on crack arrest for the corresponding crack tip temperature.

K_{Ic} = Fracture toughness based on fracture initiation for the corresponding crack tip temperature.

The larger flaw size determined by these two criteria is used to develop the flaw charts.

4.3 BASIC DATA

In view of the criteria, it is noticed that three groups of basic data are required for the construction of charts for surface flaw evaluation. Namely, a_f, driving force (K_I), and fracture toughness (K_{Ia} and K_{Ic}).

The preparation of these three groups of basic data will be discussed in the following paragraphs. They are the key elements of the allowable flaw size and fatigue crack growth calculations upon which the evaluation charts are based. A schematic diagram of the evaluation procedure is shown in Figure 4-1. K_{Ic} and K_{Ia} are the initiation and arrest fracture toughnesses (respectively) of the vessel material at which the flaw is located. They can be calculated by formulas:

$$K_{Ic} = 33.2 + 2.806 \exp. [0.02(T-RT_{NDT} + 100°F)] \quad (1)$$

and

$$K_{Ia} = 26.8 + 1.233 \exp. [0.0145(T-RT_{NDT} + 160°F)] \quad (2)$$

Notice that both K_{Ic} and K_{Ia} are a function of crack tip temperature T, and the material property of RT_{NDT} at the tip of the flaw as discussed earlier, in Section 2.3. The upper shelf fracture toughness of the vessel steel is assumed to be 200 ksi$\sqrt{in}$, as discussed in Section 2.

The driving force, K_I, used in the determination of the flaw evaluation charts is the maximum stress intensity factor of the surface flaw under evaluation. The methods used for determining the stress intensity factors for surface flaws have been discussed in Section 2. It is important to note that the flaw size used for the calculation of K_I is not the flaw size detected by inservice inspection. Instead, it is the calculated flaw size which is projected to grow from the flaw size detected by inservice inspection. That means that the surface flaw size used for the calculation of K_I had to be determined by using fatigue crack growth results. This is equivalent to working backward in the chart of Figure 4-1 to determine the largest allowable flaw size.

As defined in IWB-3611 of Section XI, a_f is the maximum size resulting from growth during a specific time period, which can be the next scheduled inspection of the component, or until the end of vessel design lifetime. Therefore, the final depth, a_f after a specific service period of time must be used as the basis for evaluation. The charts have been constructed to allow the initial (measured) indication size to be used directly. Charts have been constructed for operational periods of 10, 20, and 30 years from the time of detection.

The final flaw size a_f has been calculated by fatigue crack growth analysis, which has been performed covering the range of postulated flaw sizes, and flaw shapes and locations within the wall needed for the construction of surface flaw evaluation charts in this handbook. All crack growth results have been summarized in Table 3-1, and a sample plotted in Figure 3-2.

Notice that all the finite surface flaws and embedded flaws analyzed are semi-elliptical in shape. Crack growth analyses for finite surface flaws with aspect ratio (a/ℓ) greater than 0.167 have utilized the results of 0.167, and for any flaw with aspect ratio less than 0.167, the results of the continuous flaw are used. This is conservative in both cases. It is noted that only the crack growth analysis for circumferential flaws was performed, because of the orientation of the indications found in the spring inspection of 1987, and the orientation of the upper shell-to-cone weld. Charts were not prepared for longitudinal flaws.

4.4 TYPICAL SURFACE FLAW EVALUATION CHART

The two basic dimensionless parameters, which can fully address the characteristics of a surface flaw are used for the evaluation chart construction. Namely,

- Flaw Shape Parameter a/ℓ
- Flaw Depth Parameter a/t

where,

t - wall thickness, in.
a - flaw depth, in.
ℓ - flaw length, in.

Now, consider the chart for the governing transient. Section 2.1 indicated that the most limiting normal condition expected to occur during the remaining plant life is the heatup transient. In addition, the governing emergency and faulted condition is the feedwater line break. The fracture and fatigue analyses showed that the heatup is the most governing of these transients. Figure 4-2 shows the results for the heatup transient, and it is constructed as follows:

- The flaw shape parameter a/ℓ was plotted as the abscissa from 0 (continuous flaw) to 0.5 (semi-circular flaw)

- The flaw depth parameter a/t in % was plotted as the ordinate.

- The lower curves are the code acceptable flaw depths tabulated in Section XI. These curves indicate the acceptance standards below which analytical evaluation is not required. Three curves are provided for the code acceptance standards, covering the versions of the ASME Code from 1980 until the present. The lowest curve is from Table IWB-3511, which was revised with the 1983 Winter Addendum resulting in the middle curve. Beginning with the 1986 edition of the ASME Code, acceptance standards for this region are provided in Table IWC 3510-1 and these have also been plotted, and are slightly more liberal.

- The upper boundary curves show the maximum acceptable flaw depth by code criteria beyond which no surface flaw is acceptable for continued service without repair. These upper bound curves have been determined by the fracture and fatigue evaluations described herein, and they are applicable for 10 years, 20 years, or 30 years as indicated.

- Any surface indication which falls between the two sets of boundary curves will be acceptable by the code, with the analytical justification provided herein. However, IWC-2420 of ASME Section XI requires future monitoring of such indications.

The inside surface flaw evaluation charts constructed for the upper shell to cone weld region of the Kewaunee Unit 1 steam generators are presented in Figure 4-2, and repeated in Section 6, where instructions are given for their use.

4.5 PROCEDURE FOR THE CONSTRUCTION OF A SURFACE FLAW EVALUATION CHART

This section describes how the inside surface flaw evaluation charts were constructed for the upper shell to cone weld region.

Step 1

Determine the critical flaw sizes from Table 4-1. These flaw sizes are used to determine allowable flaw sizes per IWB-3611.

Load Condition	Flaw Orientation	Critical Flaw Depth (in.) $a/\ell = 0.0$	$a/\ell = 0.167$	$a/\ell = 0.5$
N/U/T*	Circumferential	$a_c = 3.70$	$a_c = 3.70$	$a_c = 3.70$
E/F*	Circumferential	$a_i = 2.246$	$a_i = 3.70$	$a_i = 3.70$

Note that in some cases here the critical flaw depth is set equal to the wall thickness. This is for the case where the stress intensity factor for postulated flaws never exceeds the fracture toughness, regardless of flaw depth.

The maximum code allowable flaw depths using the criteria of IWB-3611 are then determined, using a factor of 10 for normal upset and test conditions and a factor of 2 for emergency and faulted conditions. The results are presented below:

Load Condition	Allowable Flaw Depth (in) $a/\ell = 0.0$	$a/\ell = 0.167$	$a/\ell = 0.5$
N/U/T	0.37	0.37	0.37
E/F	1.123	1.85	1.85

Step 2

Determine the maximum code allowable flaw depth (a_c or a_i), per IWB-3612:

Load Condition	Flaw Orientation	Code Criteria	Allowable Flaw Depth (in) a/ℓ = 0.0	a/ℓ = 0.167	a/ℓ = 0.5
N/U/T	Circumferential	$K_{Ia}/\sqrt{10}$	1.20	2.17	2.55
E/F	Circumferential	$K_{Ic}/\sqrt{2}$	1.51	2.74	3.70

Step 3

The allowable flaw depth is then determined from Step 1 and Step 2 allowable flaw depths. The most liberal results are taken for each type of load condition. Then the load condition which produces the smallest allowable is chosen, and this becomes the final allowable. For normal, upset and test conditions the allowable depths of step 2 are larger, and this is also the case for emergency and faulted conditions. Thus, from the results of step 2 we find:

a/ℓ = 0.0	allowable a = 1.20 in.
a/ℓ = 0.167	a = 2.17 in.
a/ℓ = 0.5	a = 2.55 in.

Step 4

Determine the corresponding initial flaw sizes which will grow to the above critical flaw sizes after 10, 20, and 30 years of service.

We define the above limiting critical flaw depth as a_f. The initial flaw size a_o can be found from the fatigue crack growth results of Table 3-1 and have been plotted in Figure 3-2.

---

* N/U/T normal, upset, and test conditions
E/F emergency and faulted conditions

The values of a_o which are applicable to 10 years of service, for example, are listed as follows:

	Continuous Flaw	$a/\ell = 0.167$	$a/\ell = 0.5$
a_f	1.20	2.17	2.55
a_o	0.87	1.90	2.24

This shows that the effect of fatigue crack growth in this region is very small.

Step 5

Determine a/ℓ vs. a/t% in the upper shell to cone weld region where t = 3.7", and a = a_o. For 10 years of service, the values are:

	Continuous Flaws	Finite Surface Flaws, $a/\ell = 0.167$	Finite Semicircular Surface Flaws
a/ℓ	0	.167	.5
a/t	0.235	0.514	0.605

Note that the allowable flaw depths here exceed 20 percent of the wall thickness, which has been set as an arbitrary limit, based on engineering judgement. The charts therefore reflect this value as an upper limit.

Step 6

The upper bound curves result from the plots of a/ℓ vs. a/t for 10, 20, 30 years of service as shown by Figure 4-2.

Step 7

Plot a/ℓ vs. a/t data from the standards tables of Section XI as the lower curve of Figure 4-2.

The values of the acceptance standards for this region from the various editions of the ASME Code are:

Aspect Ratio, a/ℓ	IWB-3511-1 (1980) a/t, %	IWB-3510-1 (1983, W83 Add.) a/t, %	IWC-3510-1 (1986) a/t, %
0.00	2.0	1.9	1.9
0.05	2.1	2.0	2.0
0.10	2.3	2.2	2.2
0.15	2.6	2.5	2.5
0.20	2.9	2.8	2.8
0.25	3.2	3.3	3.3
0.30	3.7	3.8	3.8
0.35	3.7	4.4	4.4
0.40	3.7	5.0	5.0
0.45	3.7	5.1	5.1
0.50	3.7	5.2	5.2

The above six steps would complete the procedure for the construction of the surface flaw evaluation charts for 10 years, 20 years, or 30 years of operating life.

In the interest of prudence, Figure 4-2 only shows the allowable flaw depths for these inside surface flaws up to 20 percent of the section thickness.

TABLE 4-1

BASIC DATA FOR SURFACE FLAW EVALUATION AT UPPER SHELL TO CONE WELD SECTION

REGION & LOCATION	CONDITION	FLAW ORIENTATION	MINIMUM CRITICAL FLAW SIZE					
			CONTINUOUS FLAW		ASPECT RATIO = 6:1		ASPECT RATIO = 2:1	
			INCHES	$(\frac{a}{t})$	INCHES	$(\frac{a}{t})$	INCHES	$(\frac{a}{t})$
Steam Generator Upper Shell to Cone Weld	N/U/T	LONG.	a_c = --	---	a_c = --	---	a_c = --	---
		CIRCUM.	a_c = 3.70	1.0	a_c = 3.70	1.0	a_c = 3.70	1.0
	E/F	LONG.	a_i = --	---	a_i = --	---	a_i = --	---
		CIRCUM.	a_i = 2.25	0.61	a_i = 3.70	1.0	a_i = 3.70	1.0

LEGEND :

a_c Minimum critical flaw size under normal conditions

a_i Minimum critical flaw size under faulted conditions

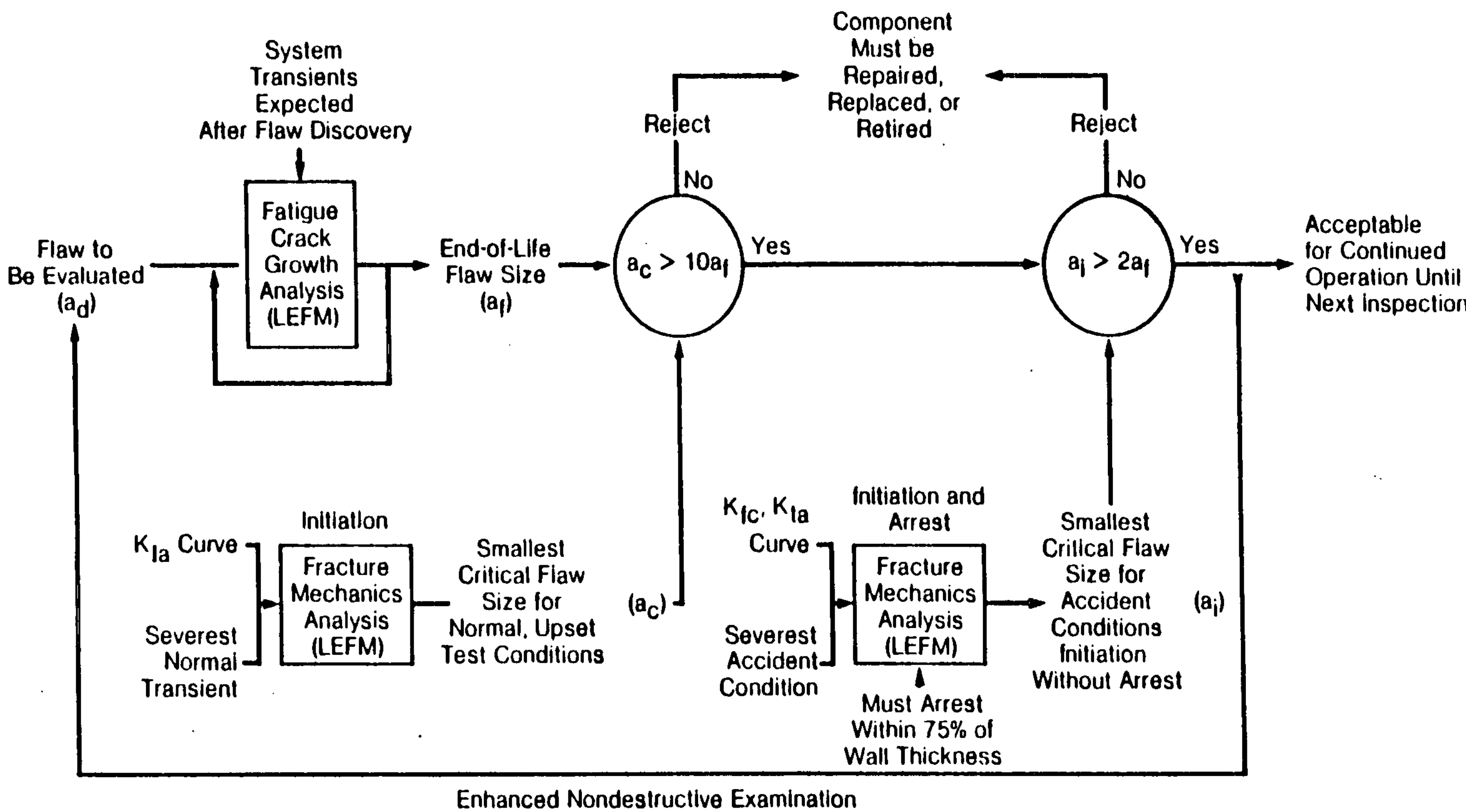


Figure 4-1 Schematic representation of Appendix A flaw evaluation process'

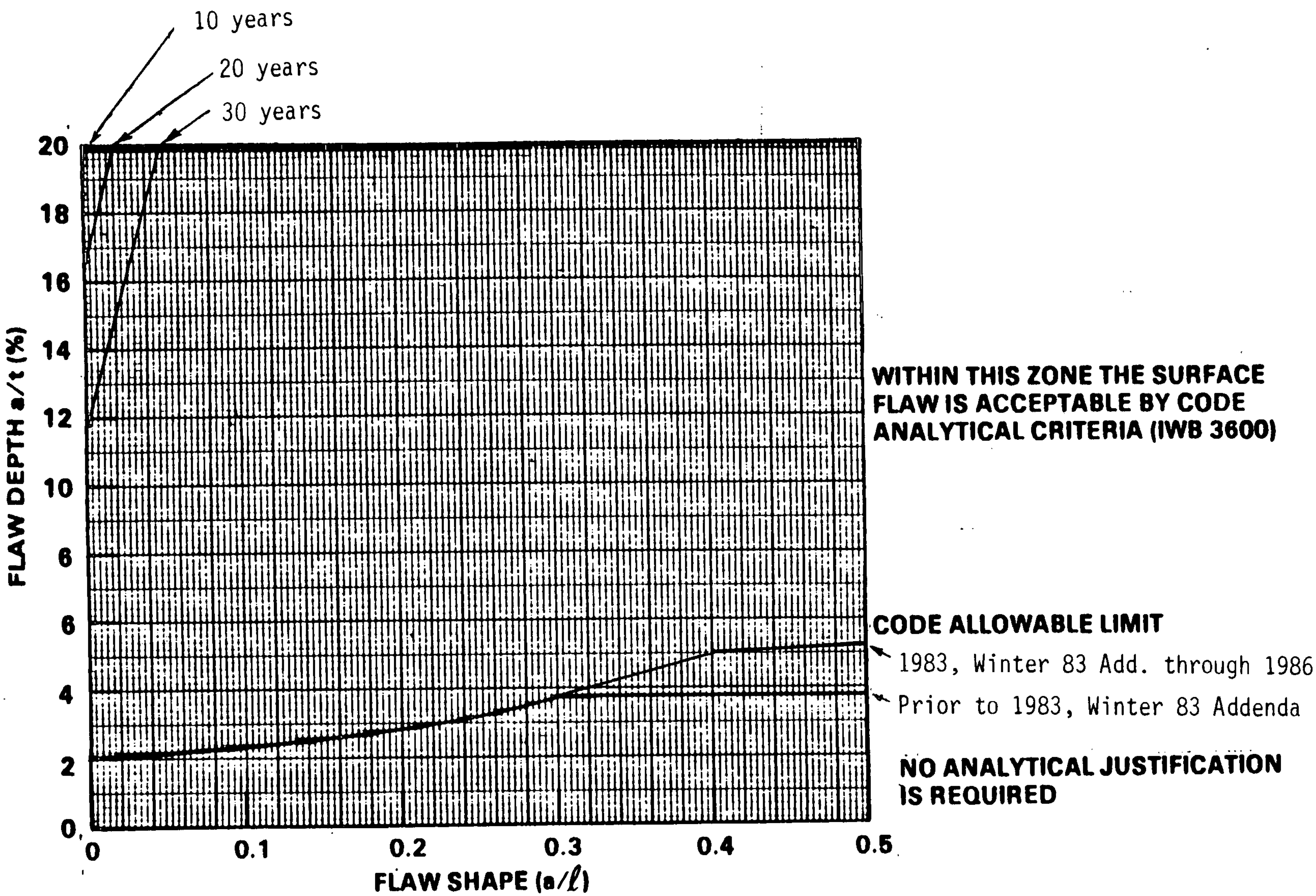


Figure 4-2 Flaw Evaluation Chart for Circumferential Inside Surface Flaws in the Upper Shell to Cone Region

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SECTION 5

EMBEDDED FLAW EVALUATION

5.1 SCOPE OF EVALUATION

Embedded flaw evaluations were performed for the upper shell to cone weld region. This section describes the development of the embedded flaw charts for that region.

5.2 EMBEDDED VS. SURFACE FLAWS

According to IWA-3300 of the ASME Code Section XI, a flaw is defined as embedded, as shown in Figure 5-1, whenever,

$$S \geq 0.4\ a \qquad (5\text{-}1)$$

where

S - the minimum distance from the flaw edge to the nearest vessel wall surface

a - the embedded flaw depth, (defined as the semi-minor axis of the elliptical flaw.)

The parameter δ has been defined in this document to facilitate the use of the charts. δ is defined as the distance from the centerline of the flaw to the surface of the vessel. Therefore, $\delta = S + a$. Substituting into the proximity limit in equation 5-1 gives a limiting definition of δ as a function of a, for the proximity limit.

$$a = \delta - S \qquad (5\text{-}2)$$

$$\delta \geq 1.4\ a \qquad (5\text{-}3)$$

Therefore, the limit for a flaw to be considered embedded is $a_o = 0.714\ \delta$.

A flaw lying within the embedded flaw domain is to be evaluated by the embedded flaw evaluation charts generated in this section of the handbook. On the other hand, a flaw lying beyond this domain should be evaluated as a surface flaw using the charts developed in Section 4 of the handbook instead. The demarcation lines between the two domains are shown graphically in Figure 5-2.

In other words, for any flaw indication detected by inservice inspection, the first step of evaluation is to define to which category the flaw actually belongs, and then to choose the appropriate charts for evaluation.

5.3 CODE CRITERIA

As mentioned in Section 1, the criteria used in most of the cases for embedded flaws are of IWB-3612 of Code Section XI. Namely,

$K_I < \frac{K_{Ia}}{\sqrt{10}}$ For normal conditions (upset & test conditions inclusive) (5-4)

$K_I < \frac{K_{Ic}}{\sqrt{2}}$ For faulted conditions (emergency conditions inclusive) (5-5)

where

K_I = The maximum applied stress intensity factor for the flaw size a_f to which a detected flaw will grow, during the period of evaluation, which must be at least until the next inspection.

K_{Ia} = Fracture toughness based on crack arrest for the corresponding crack tip temperature.

K_{Ic} = Fracture toughness based on fracture initiation for the corresponding crack tip temperature.

The above two criteria must both be met. In this handbook only the most limiting results have been used as the basis of the flaw evaluation charts.

5.4 BASIC DATA

In view of the criteria based on stress intensity factor, three basic groups of data are needed for construction of embedded flaw evaluation charts. They are: a_f, driving force (K_I), and fracture toughness (K_{Ia} and K_{Ic}).

K_{Ic} and K_{Ia} are the initiation and arrest fracture toughness (respectively) of the vessel material at which the flaw is located. They can be calculated by formulas:

$$K_{Ic} = 33.2 + 2.806 \text{ exp. } [0.02(T-RT_{NDT} + 100°F)] \qquad (5\text{-}6)$$

and

$$K_{Ia} = 26.8 + 1.233 \text{ exp. } [0.0145(T-RT_{NDT} + 160°F)] \qquad (5\text{-}7)$$

K_I is the maximum stress intensity factor for the embedded flaw of interest. The methods used for determining the stress intensity factors for embedded flaws have been referenced in Section 2.

Notice that both K_{Ic} and K_{Ia} are a function of crack tip temperature T, and the material property of RT_{NDT} at the tip of the flaw as discussed in Section 2. The upper shelf fracture toughness of the vessel steel is assumed to be 200 ksi$\sqrt{\text{in}}$.

K_I used in the determination of the flaw evaluation charts is the maximum stress intensity factor of the embedded flaw under evaluation. It is important to note that the flaw size used for the calculation of K_I is not the flaw size detected by inservice inspection. Instead, it is the calculated flaw size which is projected to grow from the flaw size detected by inservice inspection. That means that the embedded flaw size used for the calculation of K_I had to be determined by using fatigue crack growth results, similar to the approach used for surface flaw evaluation, as illustrated in the previous section.

However, unlike the surface flaw case, the fatigue crack growth for an embedded flaw (even after 30 years of additional service life) is very small in comparison with that of a surface flaw with the same initial depth. Consequently, in the handbook evaluations, the measured flaw size has been used for evaluation by the charts independent of the service period* because fatigue has little or no influence for embedded flaws as discussed below. This simplifies the evaluation procedure without sacrificing the accuracy of the results. A detailed justification of this conclusion is provided in the next section.

5.5 FATIGUE CRACK GROWTH FOR EMBEDDED FLAWS

The environment of an embedded flaw is considered to be inert, or air. The crack growth rate for air environment is far smaller than that of the water environment, to which the surface flaw is conservatively considered to be exposed. Consequently, the fatigue crack growth for an embedded flaw is far smaller than that of an inside surface flaw (of the same size and under the same transient conditions). Numerically, the fatigue crack growth of an embedded flaw is so low that the difference between the initial flaw depth and its final crack depth is negligible, as demonstrated in Table 3-2 for the upper shell to cone weld.

Therefore, in the construction of the evaluation charts for embedded flaws, the accuracy of the charts would not be impaired using the flaw size found by inservice inspection directly.

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* This conclusion holds for the range of flaw sizes acceptable by the rules of Section XI, IWB-3600. It would not necessarily hold for very large flaws of the order of 50 percent of the vessel wall thickness.

5.6 TYPICAL EMBEDDED FLAW EVALUATION CHART

The details of the procedures for the construction of an embedded flaw evaluation chart are provided in the next section.

In this section, instructions for developing a chart are provided by going through a typical chart, step by step. This would help the users to become familiar with the characteristics of each part of the chart, and make it easier to apply. This example utilizes the surface/embedded flaw demarcation criteria of the code, as discussed earlier.

Following are the highlights of auxiliary charts used to construct the embedded flaw evaluation chart for the upper shell to cone weld region.

1. The abscissa of the chart in Figures 5-3, 5-4, and 5-5 represents the flaw depth a, of the embedded flaw.

2. As defined by code, embedded flaws with a depth less than $a_o = 0.714\ \delta$ should be considered as embedded flaws. Any embedded flaws beyond the domain of $a_o = 0.714\ \delta$, should be evaluated by means of surface flaw charts instead.

3. A key parameter for evaluating an embedded flaw is δ, the distance between the centerline of the embedded flaw and the nearest surface of the steam generator wall.

   A range of δ between $\frac{1}{16}t$ and $\frac{1}{4}t$ has been considered in constructing Figures 5-3, 5-4, and 5-5.

4. For each specific value of δ, such as $\frac{1}{8}t$, $\frac{3}{16}t$, $\frac{1}{4}t$, etc., a family of curves were plotted for a range of a/ℓ values ranging from .333 to .100. For any specific flaw depth a at the abscissa, a corresponding value K_I at the ordinate can be found in Figures 5-3 through 5-5, for any distance to the surface, δ.

5. The range of a/ℓ values from 0.333 to 0.10 was chosen to encompass the range of flaws which might be detected. For the upper shell to cone region, fracture results are independent of the aspect ratio, as will be discussed further below.

6. In developing this specific chart, the code acceptance limit line of $K_{Ia}/\sqrt{10}$ as a function of flaw depth is shown in Figures 5-3 through 5-5.

7. The intersection of the K_I curve with the code acceptance limit line is the maximum flaw size acceptable by code for the specific curve, in accordance with the $K_I \leq K_{Ia}/\sqrt{10}$ from IWB-3612.

8. In view of Figures 5-3 through 5-5, it is seen that none of the curves intersect with the code acceptance limit line. That means that, up to a distance of $\delta = \frac{1}{4}$ t (= 0.925"), all embedded flaws are acceptable by the code criteria so long as their depth is within the domain of $a_o = 0.714\ \delta$.

9. The maximum acceptable flaw size can be found from the chart by determining the abscissa of the intersection points. Namely, for $\delta = 0.25$ t,

a/ℓ	Maximum Acceptable Flaw Depth a*(in.)
.100	0.4625
.167	0.4625 (= a_o = 0.4625)
.333	0.4625

* Maximum Acceptable Flaw Depth a is set at $\frac{1}{8}$t, based on engineering judgement, to limit the allowable through-wall penetration to 25 percent of the wall thickness.

10. The maximum acceptable embedded flaw size for $\delta = \frac{1}{4}t$ has been depicted in Figure 5-2. This simple flaw evaluation chart, described in the following paragraph, is the type to be used for evaluation, as may be seen in Section 6.

These embedded flaw evaluation charts, constructed for the upper shell to cone weld region of the steam generators, are presented in Figure 5-2 and are repeated along with instructions in Section 6.

5.7 PROCEDURE FOR THE CONSTRUCTION OF EMBEDDED FLAW EVALUATION CHARTS

This section shows how an embedded flaw evaluation chart was constructed for the upper shell to cone weld region during the governing transient which is the heatup (including feedwater cycling). The example here is for the case of RT_{NDT} = 10°F.

Step 1

Calculate K_I values for embedded flaws of various size, various aspect ratios, and at various distances underneath the surface. In total, 129 cases were analyzed by closed form stress intensity factor expressions. These 129 cases are listed in Table 5-1.

Step 2

The K_I results of the 129 cases were plotted in Figures 5-3 through 5-5.

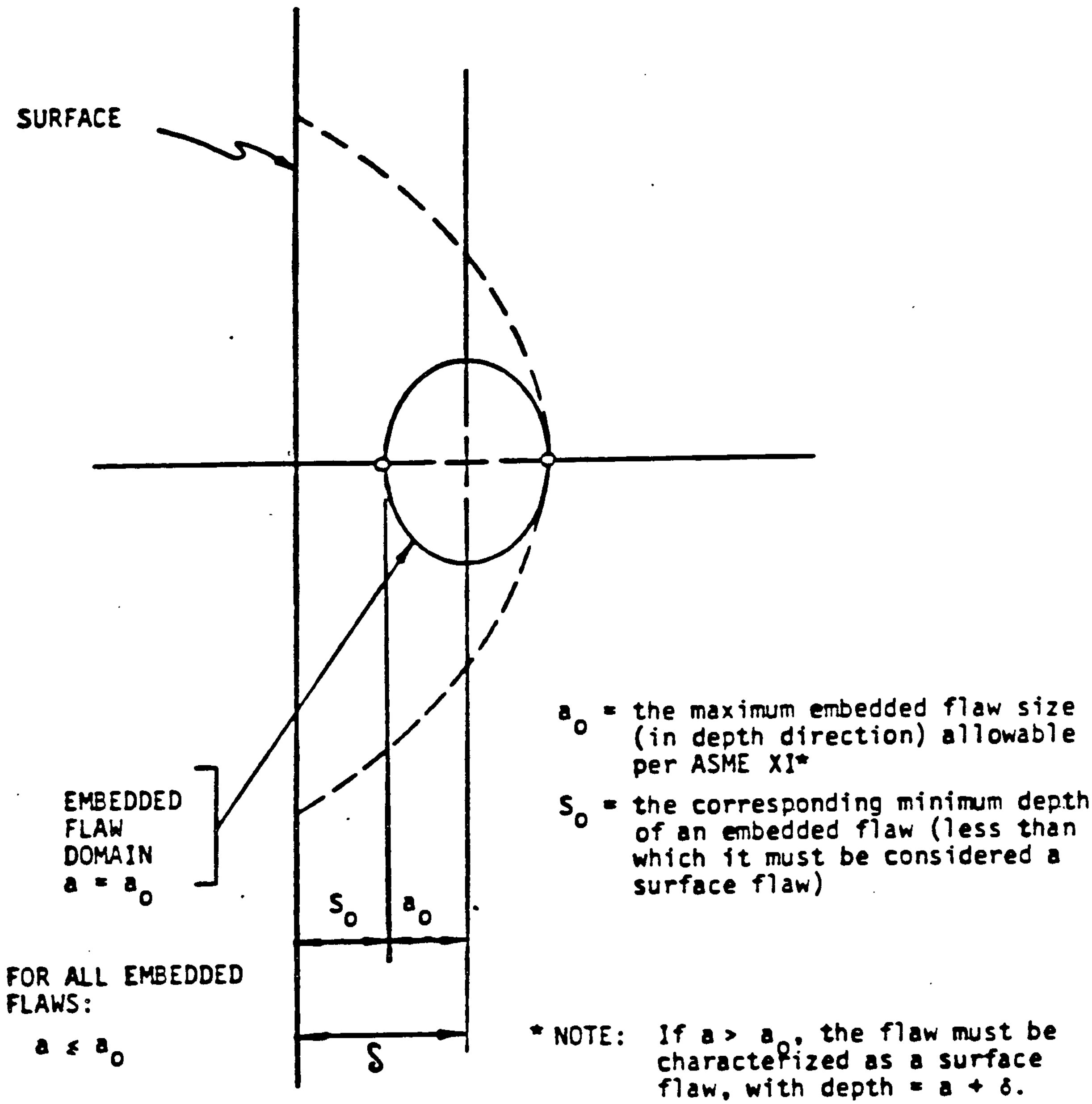
Step 3

Determine the allowable flaw size, from $a_c/10$ or $K_I \leq K_{Ia}/\sqrt{10}$ criteria as determined by Figures 5-3 through 5-5. Similar results could be obtained for the emergency/faulted conditions, but it can be seen from the surface flaw evaluation that they will not be governing so they have not been included here.

5.8 COMPARISON OF EMBEDDED FLAW CHARTS WITH ACCEPTANCE STANDARDS OF IWB-3500

The handbook charts for embedded flaws do not show the acceptance standards of Section XI, as the surface flaw charts do. Therefore, it is not clear from the charts themselves how much is gained from the analysis process over the standards tables contained in IWB-3500. Such a comparison cannot be made directly on the embedded flaw handbook charts, because the charts are applicable for a full range of sizes, shapes and locations. The purpose of this section is to provide such comparisons, and to discuss the results of those comparisons.

The handbook chart values have been compared with the acceptance standards tables in Figure 5-6. In this figure the values from Table IWB-3511-1 have been plotted as the base curve, and the limit curve for embedded flaws justified by analysis is shown as the other line. It can be seen that the range of embedded flaw shapes and depths justifiable by analysis is related to the flaw location within the wall. The deeper the indication, the more benefit is obtained from the analysis.



[a_o = 0.714δ for the 1980 Edition of the ASME Code and later editions]

Figure 5-1 EMBEDDED VS. SURFACE FLAW

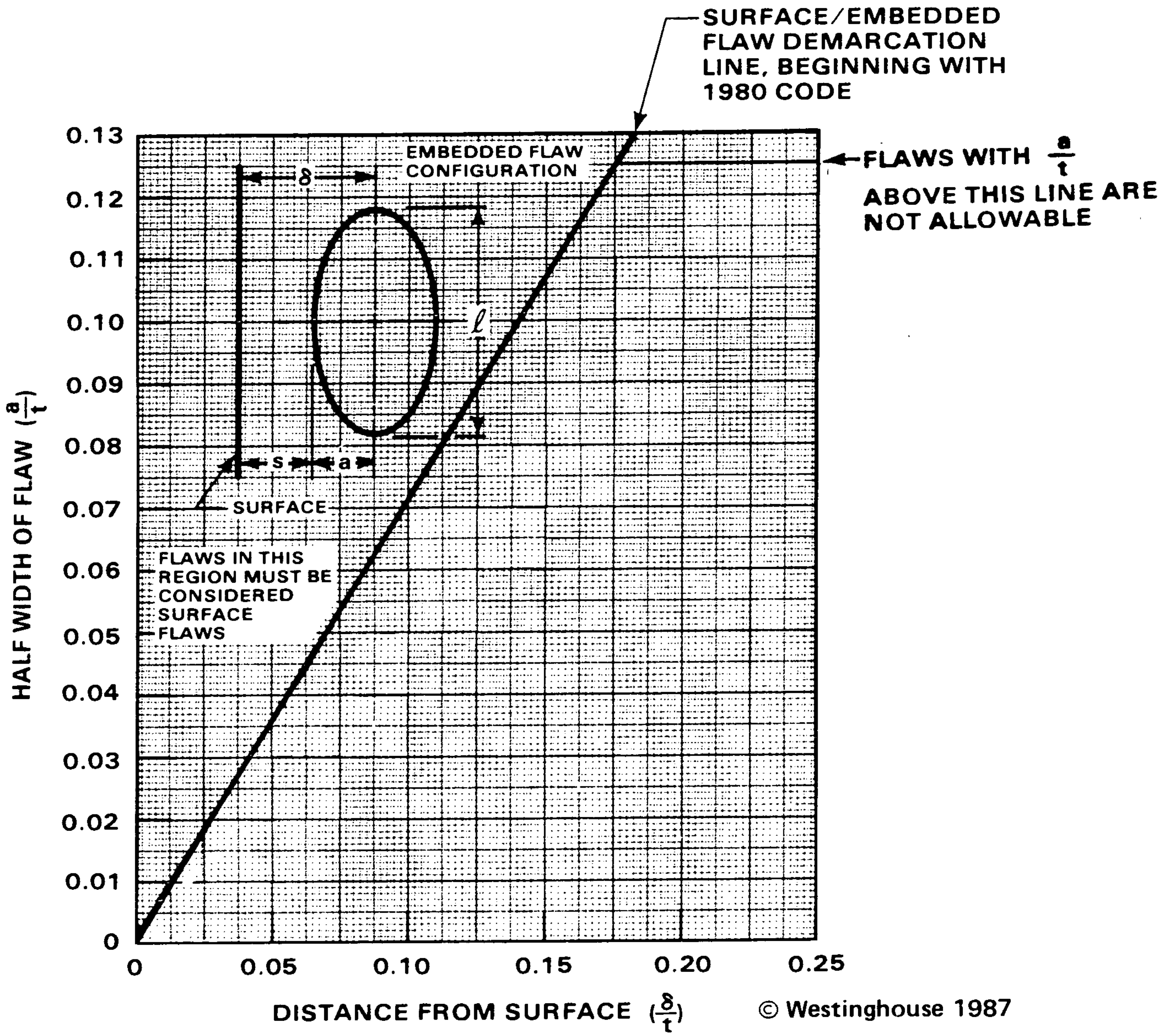


FIGURE 5-2 EMBEDDED FLAW EVALUATION CHART FOR CIRCUMFERENTIAL INDICATIONS IN THE UPPER SHELL TO CONE

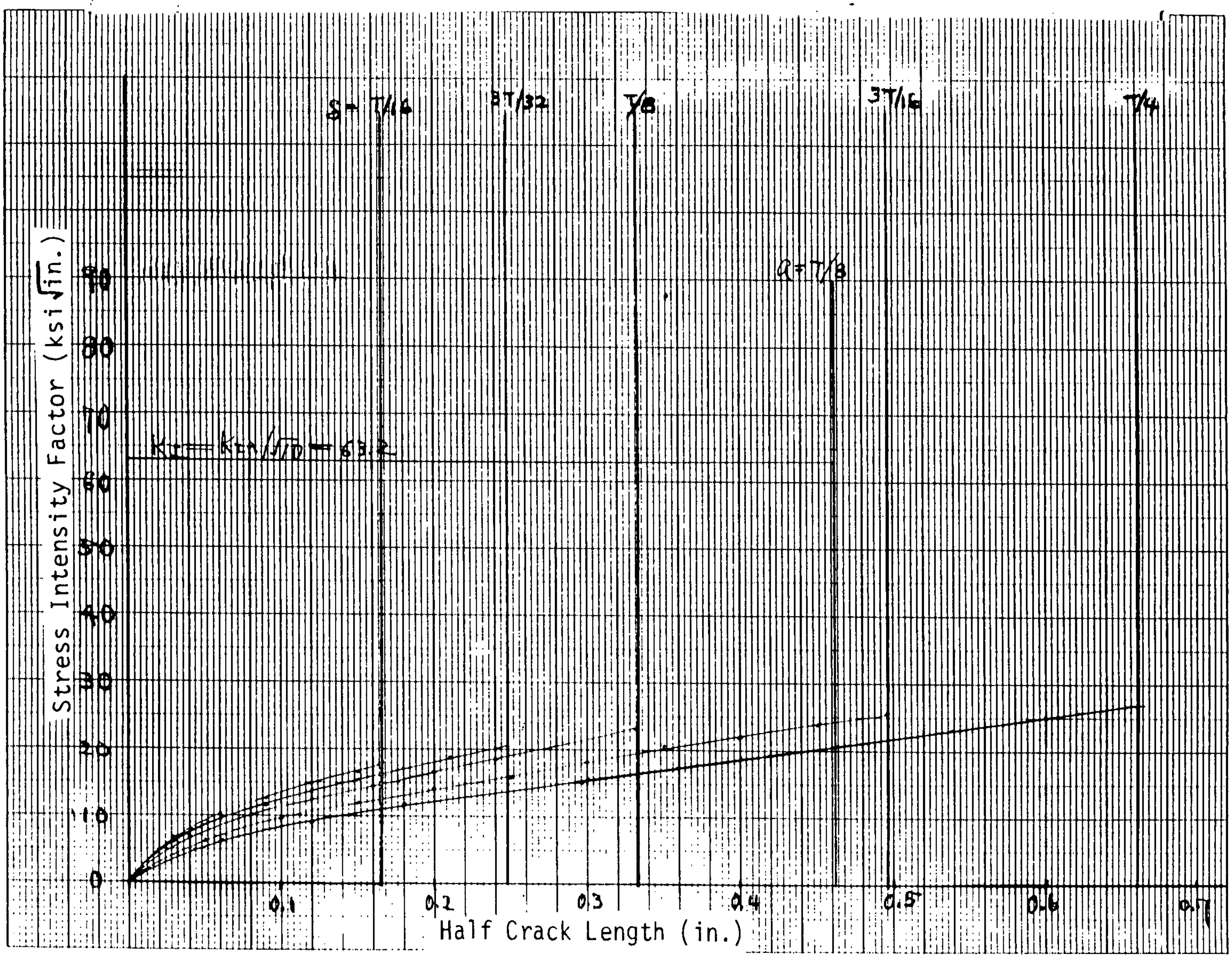


FIGURE 5-3 STRESS INTENSITY FACTOR PLOTS FOR a/ℓ = 0.333 USED IN CONSTRUCTION OF EMBEDDED FLAW CHARTS

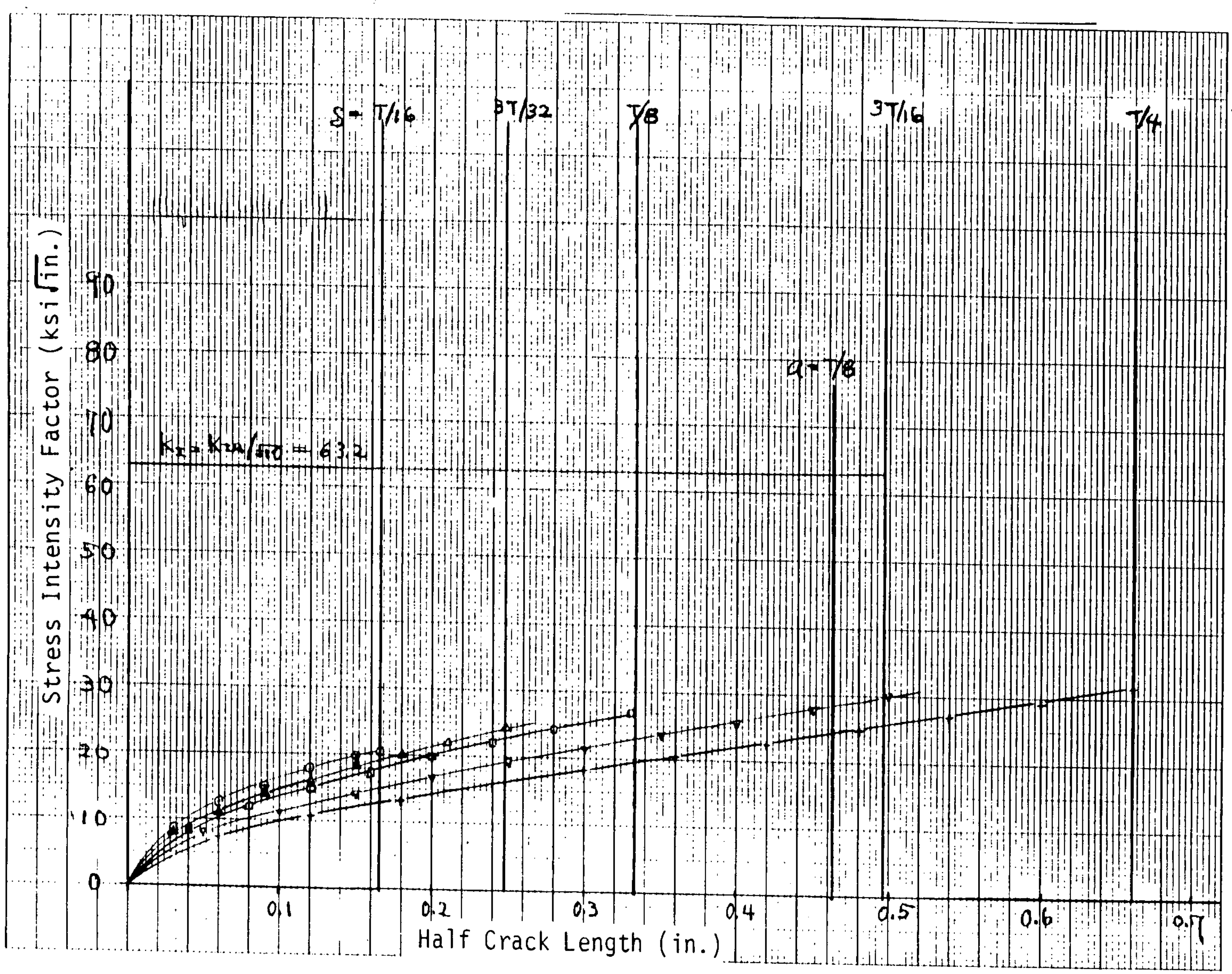


FIGURE 5-4 STRESS INTENSITY FACTOR PLOTS FOR a/ℓ = 0.1667 USED IN CONSTRUCTION OF FLAW EVALUATION CHARTS

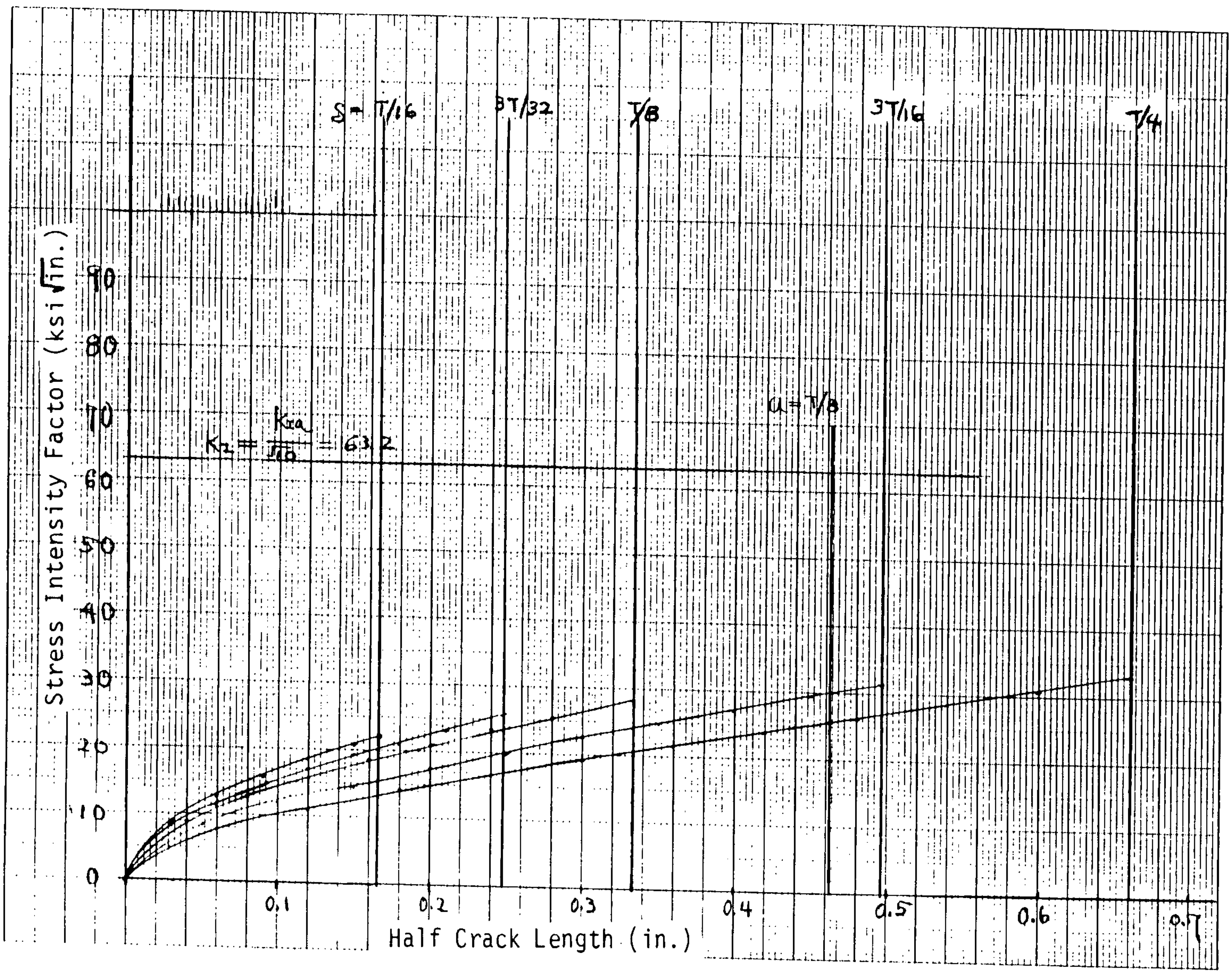


FIGURE 5-5 STRESS INTENSITY FACTOR PLOTS FOR a/ℓ = 0.10 USED IN CONSTRUCTION OF FLAW EVALUATION CHARTS

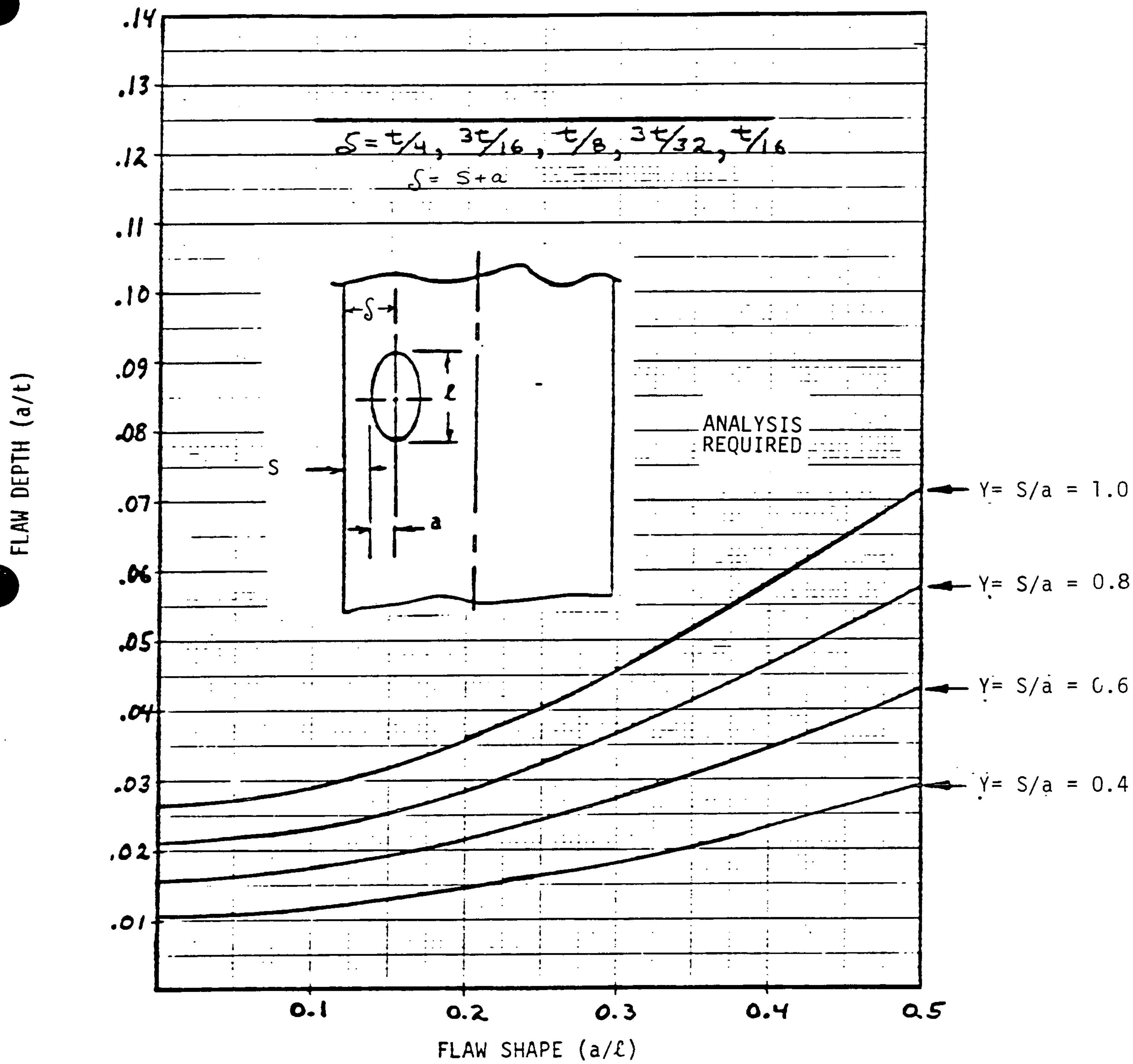


FIGURE 5-6 ACCEPTANCE STANDARDS FOR EMBEDDED FLAWS, FROM TABLE IWB-3511-1
(Note that for Y < 0.4 the flaw must be assumed to be a surface flaw)

TABLE 5-1

EMBEDDED FLAW CASES ANALYZED FOR THE UPPER SHELL TO CONE WELD REGION

DISTANCE OF FLAW TO SURFACE (δ in.)	EMBEDDED FLAW DEPTH (IN.)					
	a/l = 0.1		a/l = 0.167		a/l = 0.333	
T/16 δ = 0.2313	0.03 0.09 0.15	0.06 0.12 0.1652	0.03 0.09 0.15	0.06 0.12 0.1652	0.03 0.09 0.15	0.06 0.12 0.1652
3T/32 δ = 0.3469	0.03 0.09 0.15 0.21	0.06 0.12 0.18 0.2478	0.03 0.09 0.15 0.21	0.06 0.12 0.18 0.2478	0.03 0.09 0.150 0.210	0.06 0.120 0.180 0.2478
T/8 δ = 0.4625	0.04 0.12 0.20 0.28	0.08 0.16 0.24 0.3304	0.04 0.12 0.20 0.28	0.08 0.16 0.24 0.3304	0.04 0.12 0.20 0.28	0.08 0.16 0.24 0.3304
3T/16 δ = 0.6938	0.05 0.15 0.25 0.35 0.45	0.10 0.20 0.30 0.40 0.4955	0.05 0.15 0.25 0.35 0.45	0.10 0.20 0.30 0.40 0.4955	0.05 0.15 0.25 0.35 0.45	0.10 0.20 0.30 0.40 0.4955
T/4 δ = 0.925	0.06 0.18 0.30 0.42 0.54 0.6607	0.12 0.24 0.36 0.48 0.60	0.06 0.08 0.30 0.42 0.54 0.6607	0.12 0.24 0.36 0.48 0.60	0.06 0.08 0.30 0.42 0.54 0.6607	0.12 0.24 0.36 0.48 0.60

SECTION 6

FLAW EVALUATION CHARTS-UPPER SHELL TO CONE WELD

6.1 EVALUATION PROCEDURE

The evaluation procedures contained in ASME Section XI are clearly specified in paragraph IWB-3600. Use of the evaluation charts herein follows these procedures directly, but the steps are greatly simplified.

Once the indication is discovered, it must be characterized as to its location, length (ℓ) and depth dimension (a for surface flaws, 2a for embedded flaws), including its distance from the inside surface (S) for embedded indications. This characterization is discussed in further detail in paragraph IWA-3000 of Section XI.

The following parameters must be calculated from the above dimensions to use the charts (see Figure 1-2):

- o Flaw Shape parameter, $\frac{a}{\ell}$
- o Flaw depth parameter, $\frac{a}{t}$
- o Surface proximity parameter (for embedded flaws only), $\frac{\delta}{t}$

where

t	=	wall thickness of region where indication is located
ℓ	=	length of indication
a	=	depth of surface flaw; or half depth of embedded flaw in the width direction
δ	=	distance from flaw centerline to surface (for embedded flaws only) ($\delta = s + a$)
s	=	smallest distance from edge of embedded flaw to surface

Once the above parameters have been determined and the determination made as to whether the indication is embedded or surface, then the two parameters may be plotted directly on the appropriate evaluation chart. Its location on the chart determines its acceptability immediately.

Important Observations on the Handbook Charts

Although the use of the handbook charts is conceptually straight forward, experience in their development and use has led to a number of observations which will be helpful.

Surface Flaws

The handbook chart for inside surface flaws is shown in Figure 6-1. For outside surface flaws the chart is shown in Figure 6-2. The flaw indication parameters (whose calculation is described above) may be plotted directly on the chart to determine acceptability. The lower curve shown (labelled "code allowable limit") are simply the acceptance standards from IWB-3500 (or IWC-3500, for the newer code edition), which is tabulated in Section XI. If the plotted point falls below the appropriate line, the indication is acceptable without analytical justification having been required. If the plotted point falls between the code allowable limit line and the lines labelled "upper limits of acceptance by analysis" it is acceptable by virtue of its meeting the requirements of IWC 3600, which allow acceptance by fracture analysis. (Flaws between these lines would, however, require future monitoring per IWC-2420 of Section XI.) The analysis used to develop these lines is documented in this report. There are three of these lines shown in the charts, labelled 10, 20, and 30 years. The years indicate for how long the acceptance limit applies from the date that a flaw indication is discovered, based on fatigue crack growth calculations.

As may be seen for example in Figure 6-1, the chart gives results for surface flaw shapes up to a semi-circular flaw ($a/\ell = 0.5$). For the unlikely occurrence of flaws which the value of a/ℓ exceeds 0.5, the limits on acceptance for $a/\ell = 0.5$ should be used as required by article IWA-3300 of Section XI. The upper limits of acceptance have been set at (a maximum of) twenty percent of the wall thickness in all cases, as discussed in Section 4.

Embedded flaws

The evaluation chart for embedded flaws is shown in Figure 6-3. The heavy diagonal line in the figure can be used directly to determine whether the indication should be characterized as an embedded flaw or whether it is sufficiently close to the surface that it must be considered as a surface flaw (by the rules of Section XI). If the flaw parameters produce a plotted point below the heavy diagonal line, it is acceptable by analysis. If it is above the line, it must be considered a surface flaw and evaluated using the surface flaw chart in Figure 6-1 or Figure 6-2.

The standards for flaw acceptance without analysis cannot be shown in the embedded flaw charts because of their generality. Therefore, they have been plotted separately in Figure 6-4.

Detailed examples of the use of the charts for both surface and embedded flaws are presented in the following sections.

Surface Flaw Example

Suppose an indication has been discovered which is an inside surface flaw and has the following characterized dimensions:

$a = 0.12"$

$\ell = 1.2"$

$t = 3.7"$

The flaw parameters for the use of the charts are

$$\frac{a}{t} = 0.0324 \ (3.24\%)$$

$$\frac{a}{\ell} = 0.10$$

Plotting these parameters on Figure 6-1 it is quickly seen that the indication is acceptable by analysis. To support operation without repair it is necessary to submit this plot along with this document to the regulatory authorities.

Embedded Flaw Example

Assume that a circumferential embedded flaw of 0.24 x 5.00", located within 0.2817" from the surface, was detected. Determine whether this flaw should be considered as an embedded flaw.

$$2a = 0.24"$$
$$S = 0.2817"$$
$$\delta = S + a = 0.2817 + 1/2\ (0.24) = 0.4017"$$
$$t = 3.7"$$
$$\ell = 5.0"$$

and,

$$a = 1/2 \times 0.24"$$
$$= 0.12"$$

Using Figure 6-3:

$$\frac{a}{t} = \frac{0.12}{3.7} = 0.0324$$

$$\frac{\delta}{t} = \frac{0.4017}{3.7} = 0.109$$

Since the plotted point (X) is below the diagonal demarcation line, the flaw must be considered embedded. Since it is below the a/t = .125 limit line, the indication is acceptable.

6.2 Modification of Hydrostatic and Leakage Test Temperatures

If an indication is discovered in the Kewaunee Unit 1 steam generators which is justified for further service without repair by the flaw evaluation charts of this report, an increase in the minimum temperature at which the hydrotest and leak tests must be conducted may be necessary to ensure the required margins of Section XI are maintained. In this section, charts are provided for determination of this temperature, which is a function of the size and location of the indications discovered. Separate treatments have been developed for embedded and surface indications.

6.2.1 Embedded Flaw Hydrostatic and Leakage Test Temperature Requirements

The charts herein provide a simple method for determining the required minimum temperature for any subsequent hydrostatic or leakage tests. Once an indication has been characterized, its size and location within the wall of the vessel (δ/t) determine the allowable hydrostatic or leakage test temperature. This may be done by simply plotting the indication on the appropriate chart.

This determination has been made using the same methodology described earlier in Section 5. As discussed in Section 2 of this report, the value of RT_{NDT} = 10°F is conservatively applicable to all the steam generators. Figure 6-5 therefore covers the steam generator vessels for the hydrostatic test temperature, and Figures 6-6 through 6-8 cover test temperatures for a range of leakage test pressures. These figures cover the entire range of embedded flaw sizes and shapes.

6.2.2 Surface Flaw Hydro and Leak Test Temperature

Figures 6-9 through 6-12 provide charts for the determination of hydrostatic and leakage test temperature requirements in the event that surface flaws are detected and shown to be acceptable by the surface flaw evaluation charts of Section 6.

These figures provide test temperatures for a range of pressures, and it can be seen from these charts that in some cases the test temperature must be increased above the presently specified value, for flaws in a small range of sizes. The figures show that slightly more restrictive temperatures are required as the test pressure increases.

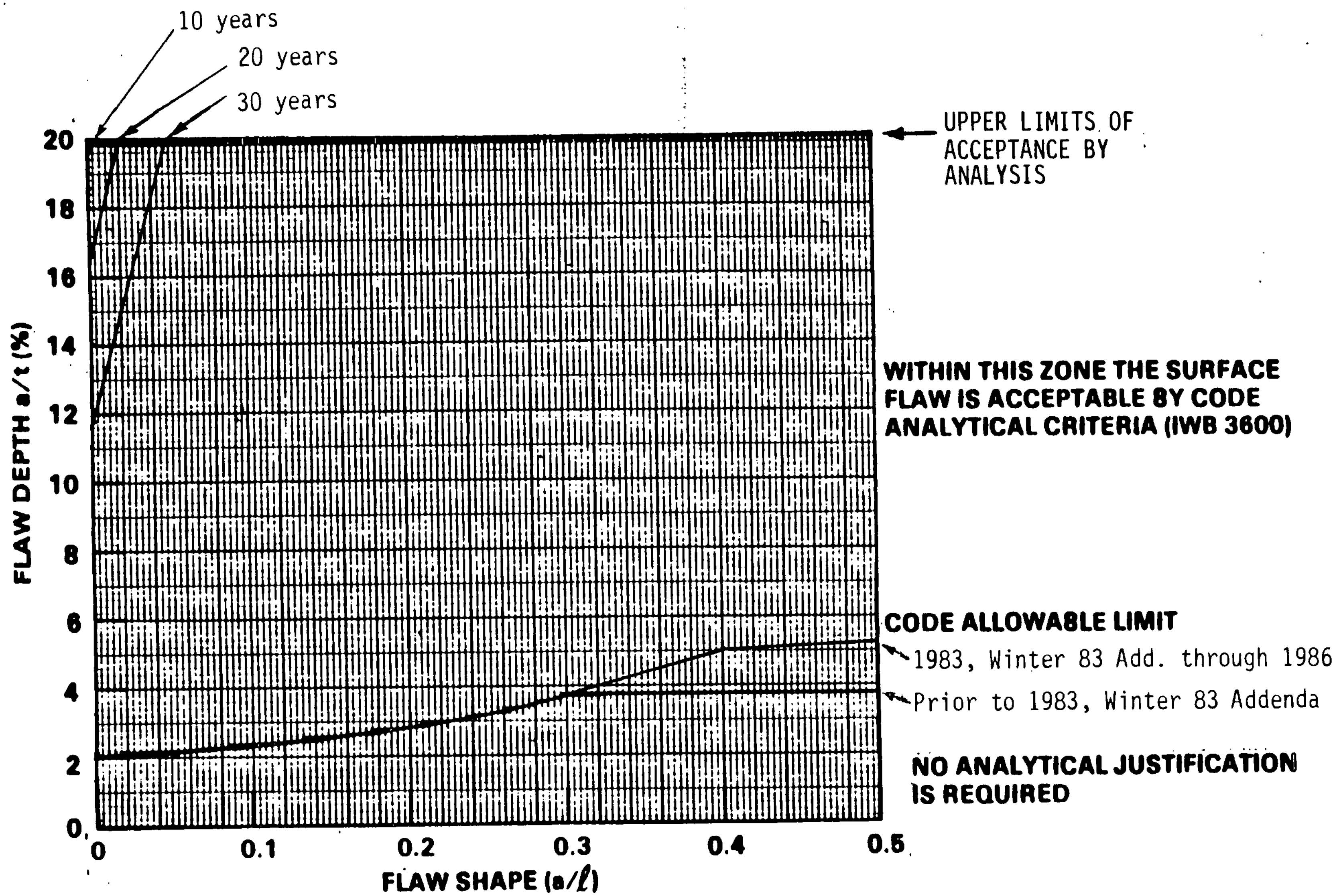


FIGURE 6-1 FLAW EVALUATION CHART FOR CIRCUMFERENTIAL INSIDE SURFACE FLAWS IN THE UPPER SHELL TO CONE REGION

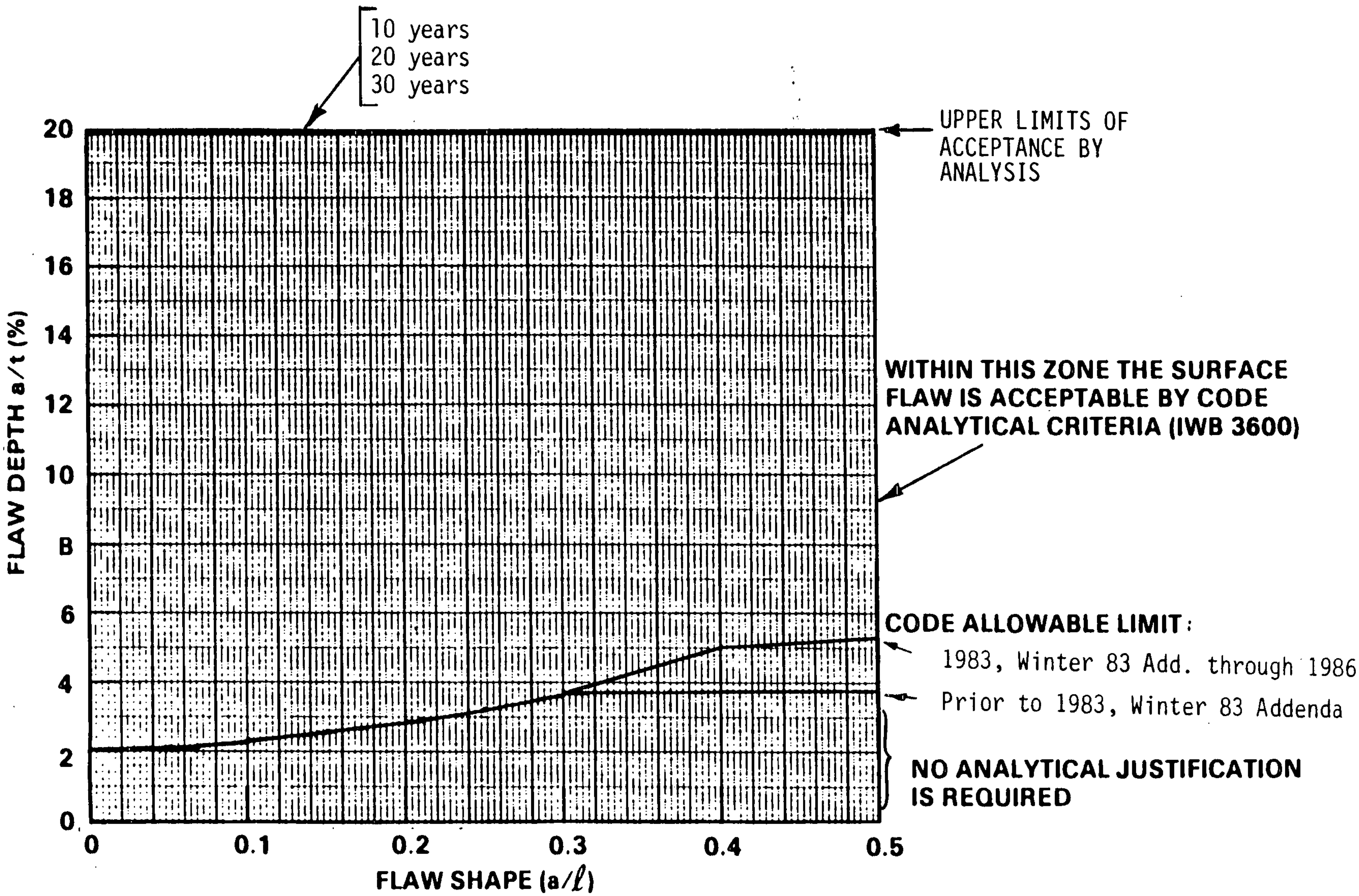


FIGURE 6-2 FLAW EVALUATION CHART FOR CIRCUMFERENTIAL OUTSIDE SURFACE FLAW IN THE UPPER SHELL TO CONE WELD

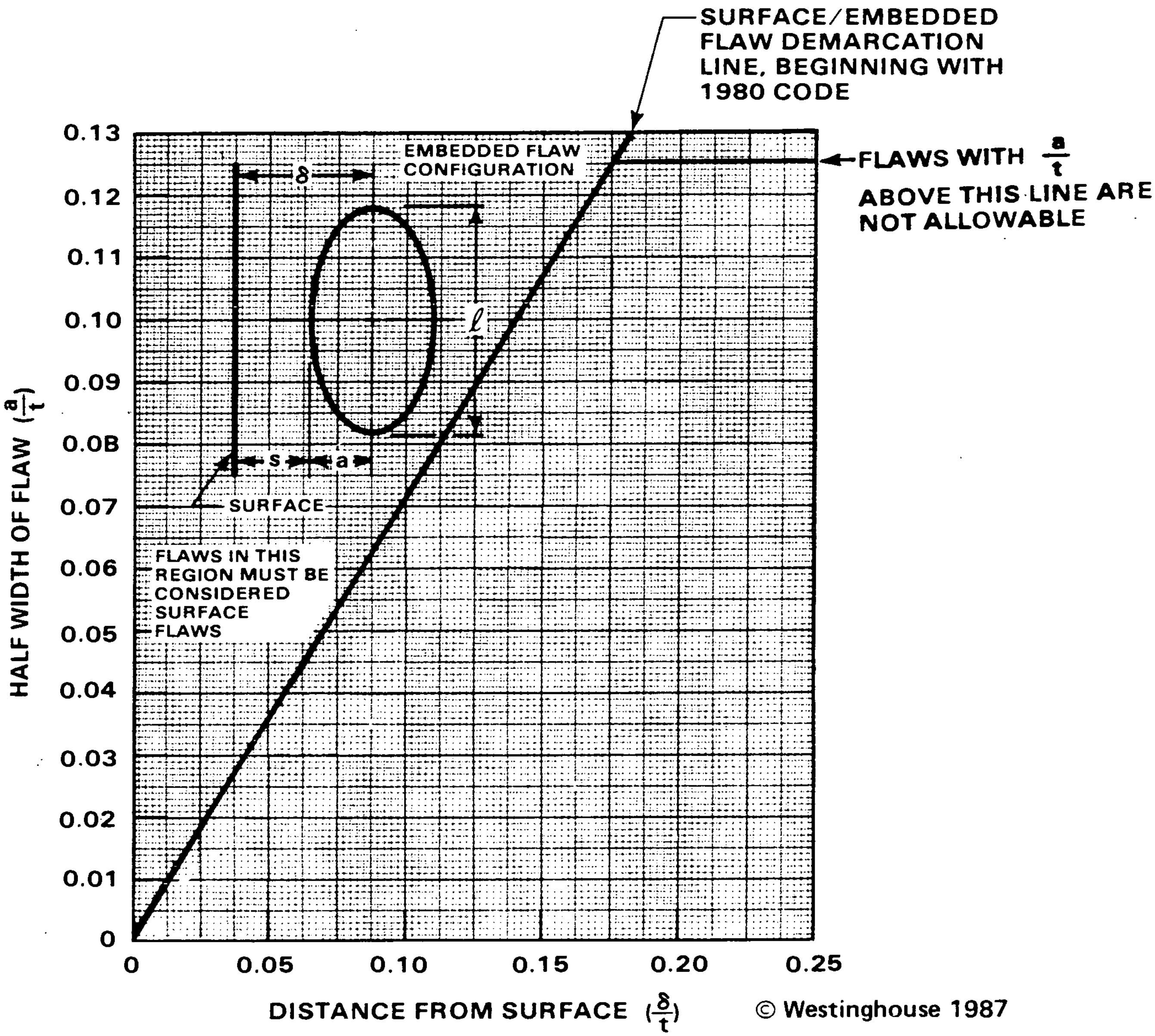


FIGURE 6-3 EMBEDDED FLAW EVALUATION CHART FOR CIRCUMFERENTIAL INDICATIONS IN THE UPPER SHELL TO CONE

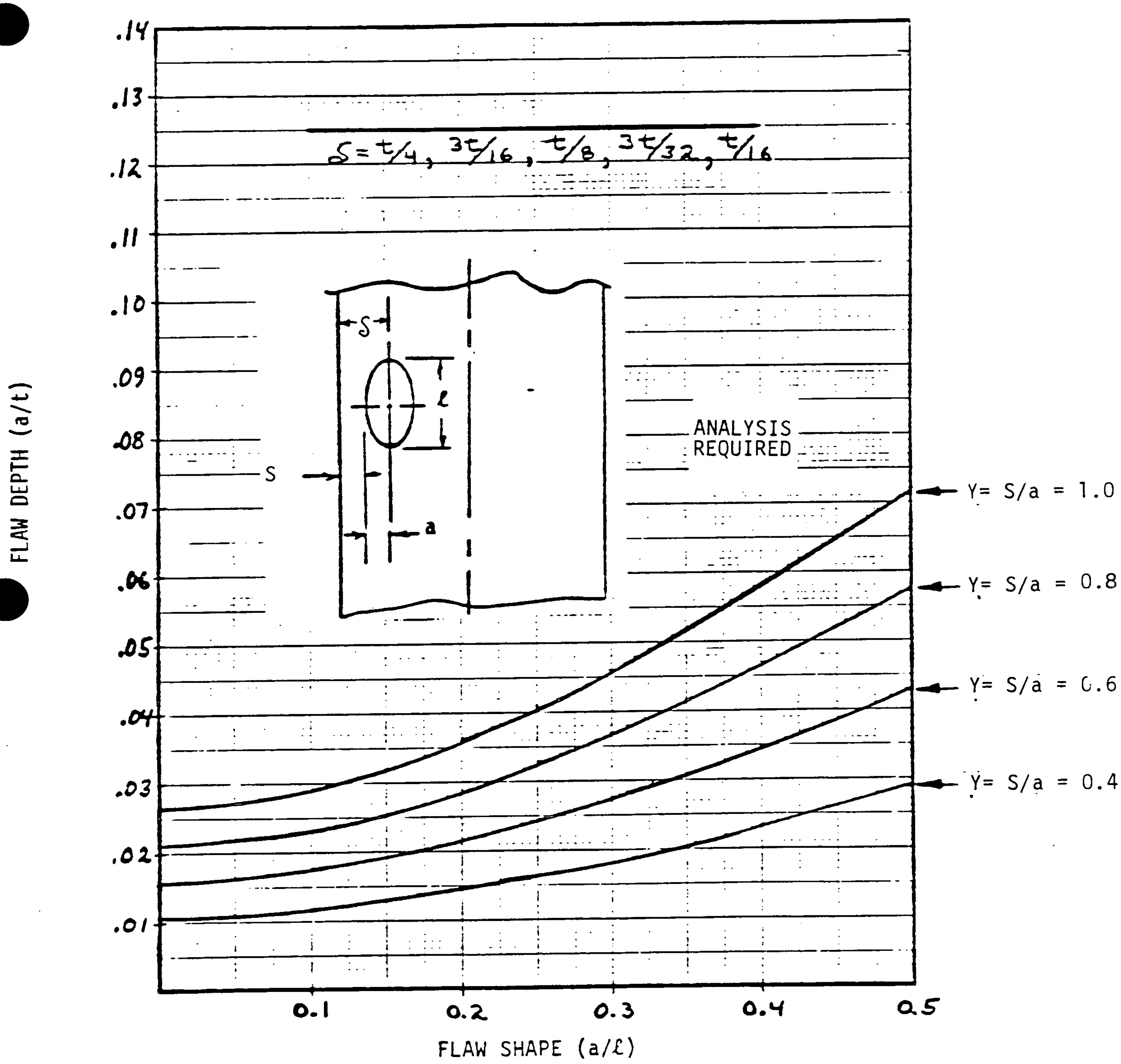


FIGURE 6-4 ACCEPTANCE STANDARDS FOR EMBEDDED FLAWS, FROM TABLE IWB-3511-1
(Note that for Y < 0.4 the flaw must be assumed to be a surface flaw)

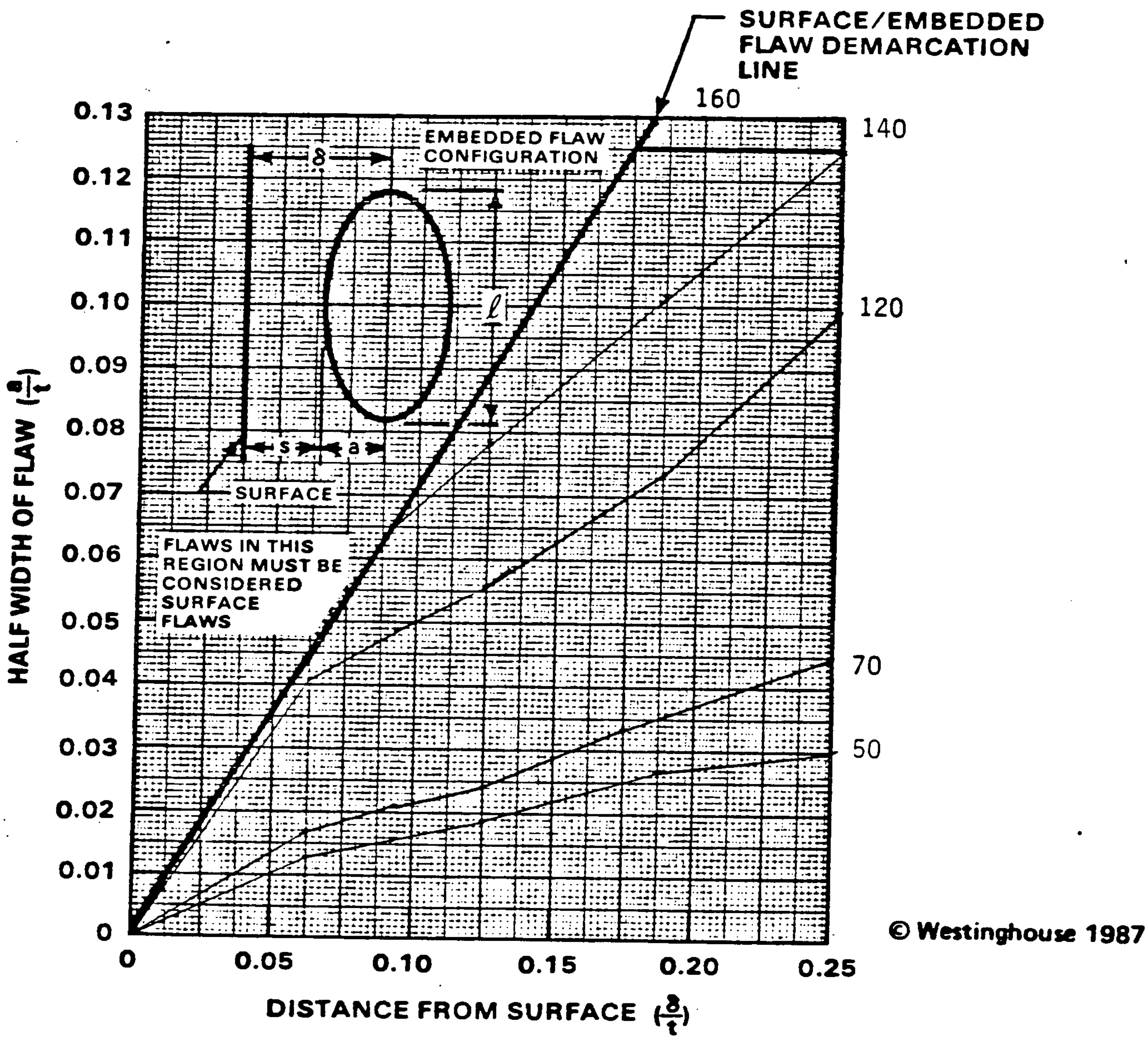


FIGURE 6-5 DETERMINATION OF HYDROSTATIC TEST TEMPERATURES FOR CIRCUMFERENTIAL EMBEDDED FLAWS (P = 1356 psi)

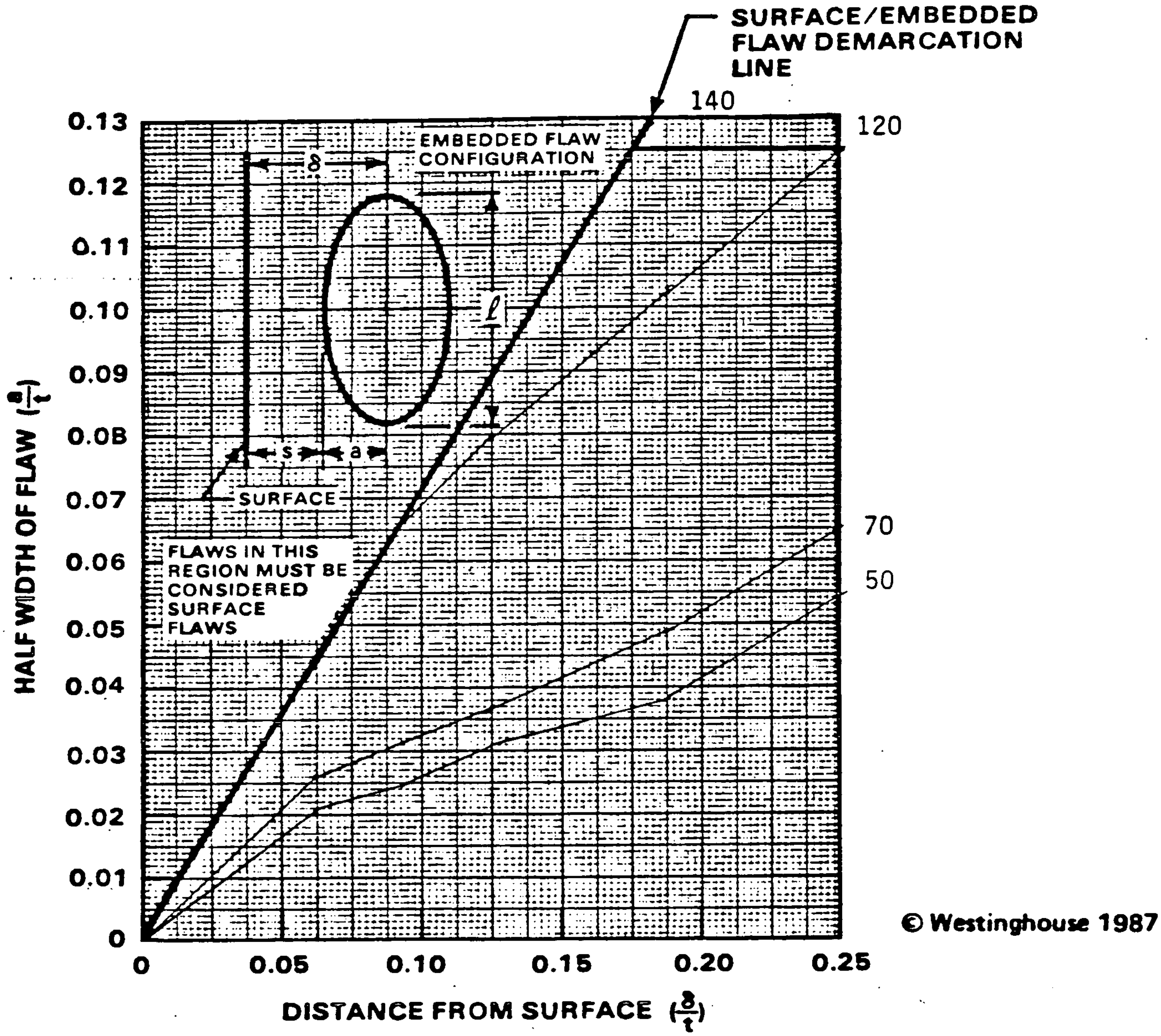


FIGURE 6-6 DETERMINATION OF LEAKAGE TEST TEMPERATURES FOR CIRCUMFERENTIAL EMBEDDED FLAWS (P = 1085 psi)

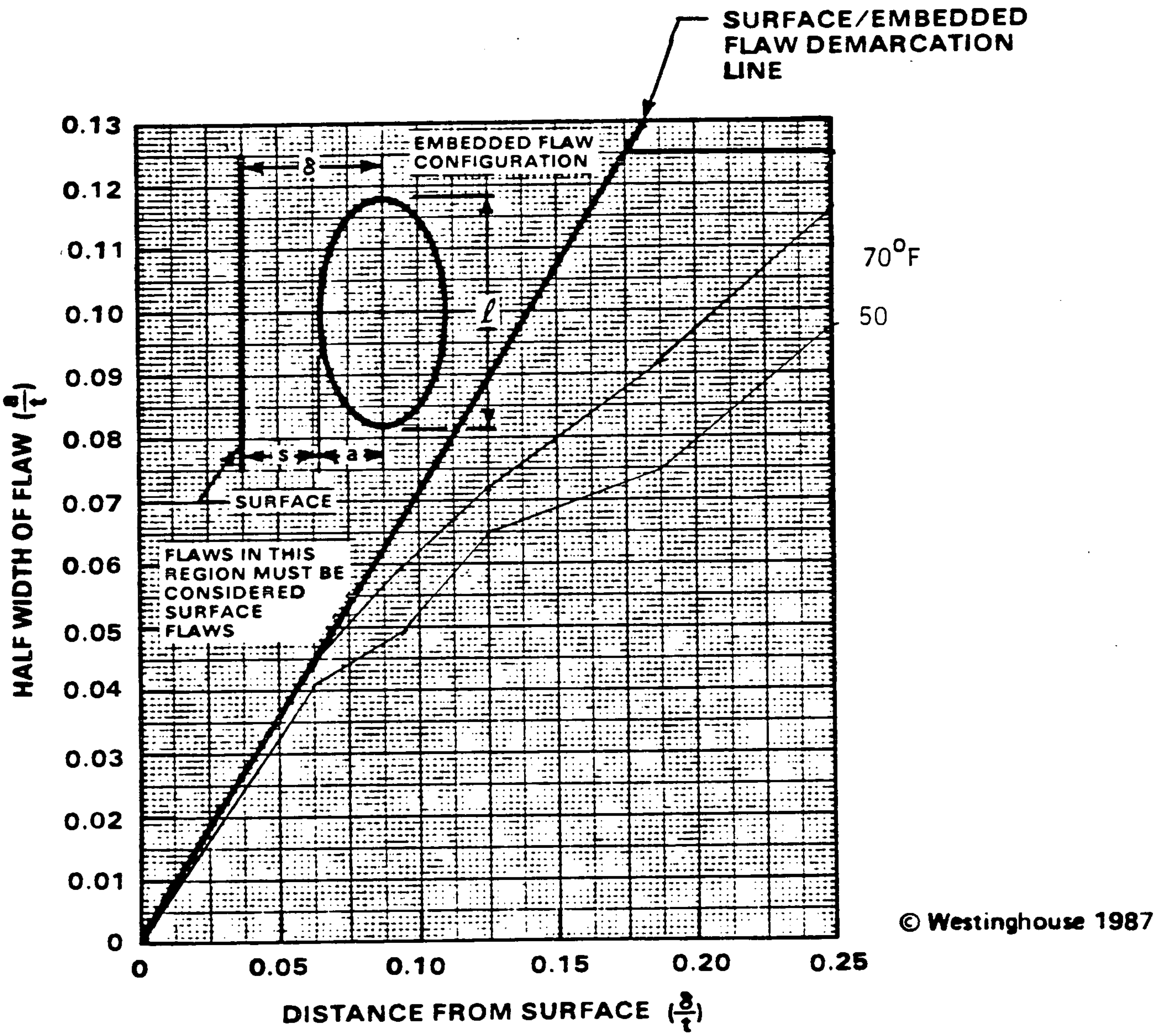


FIGURE 6-7 DETERMINATION OF LEAKAGE TEST TEMPERATURES FOR CIRCUMFERENTIAL EMBEDDED FLAWS (p = 750 psi)

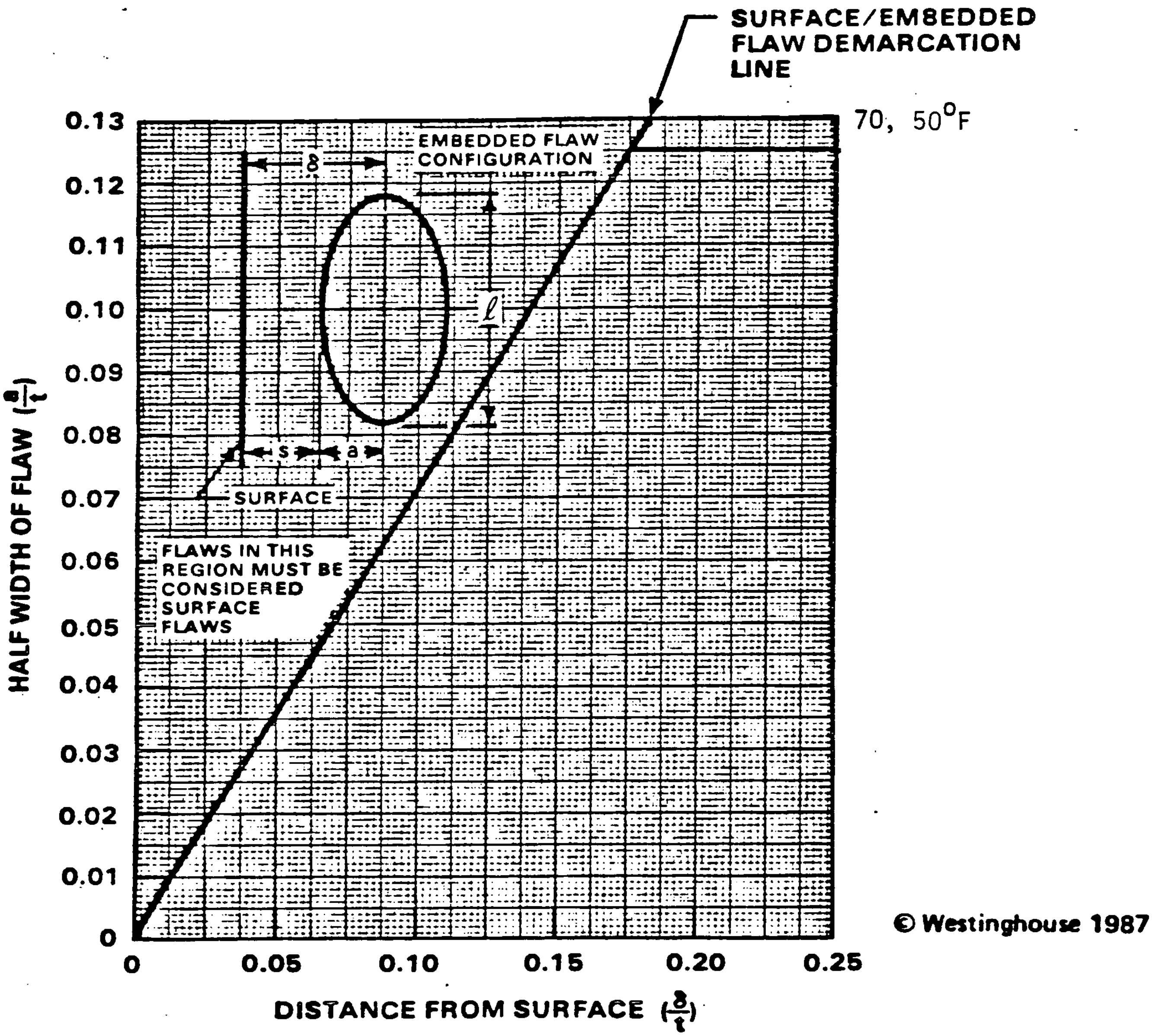


FIGURE 6-8 DETERMINATION OF LEAKAGE TEST TEMPERATURES FOR CIRCUMFERENTIAL EMBEDDED FLAWS (p = 500 psi)

2330s/0355s/071987:10

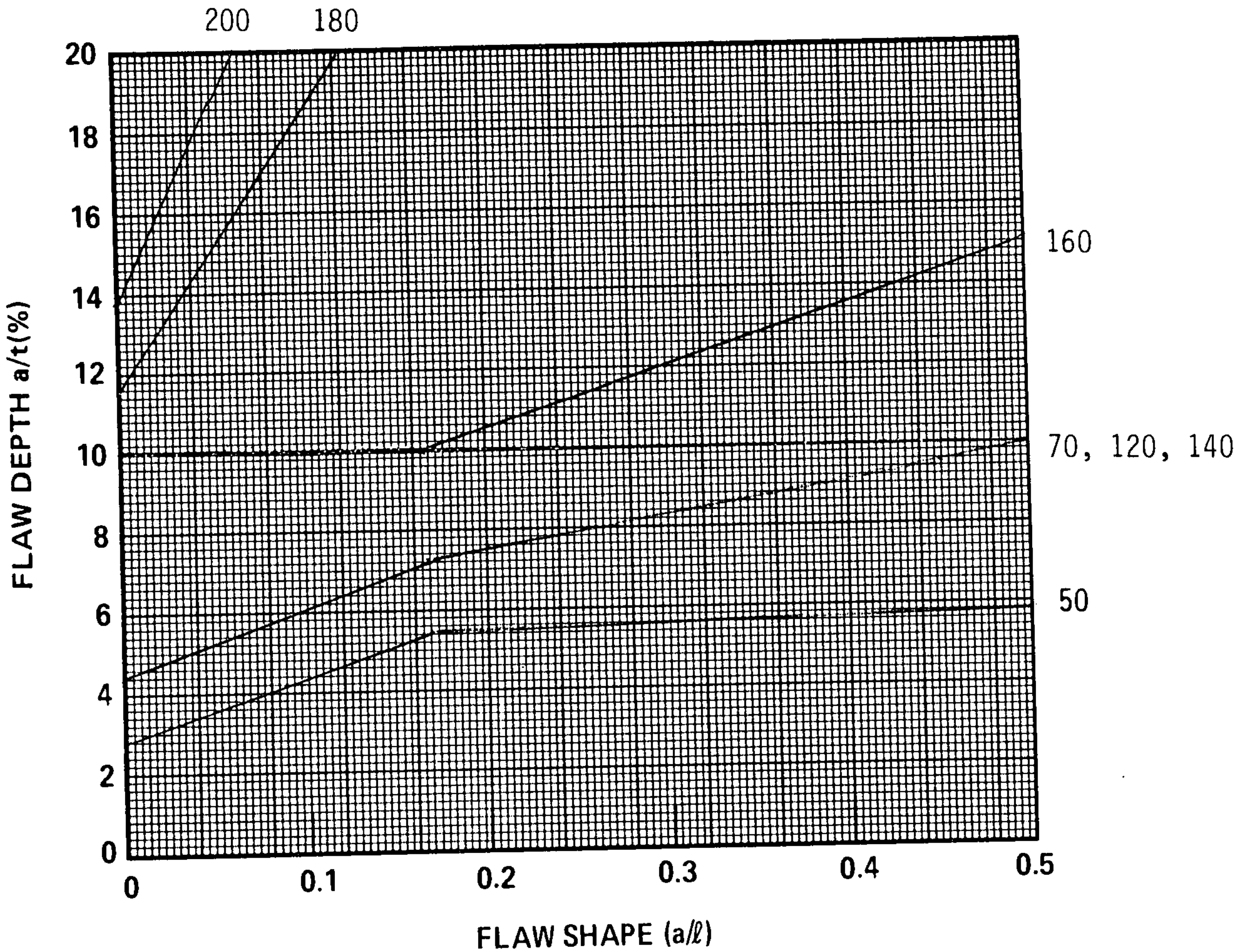


FIGURE 6-9 DETERMINATION OF HYDROSTATIC TEST TEMPERATURES FOR CIRCUMFERENTIAL SURFACE FLAWS (p = 1356 psi)

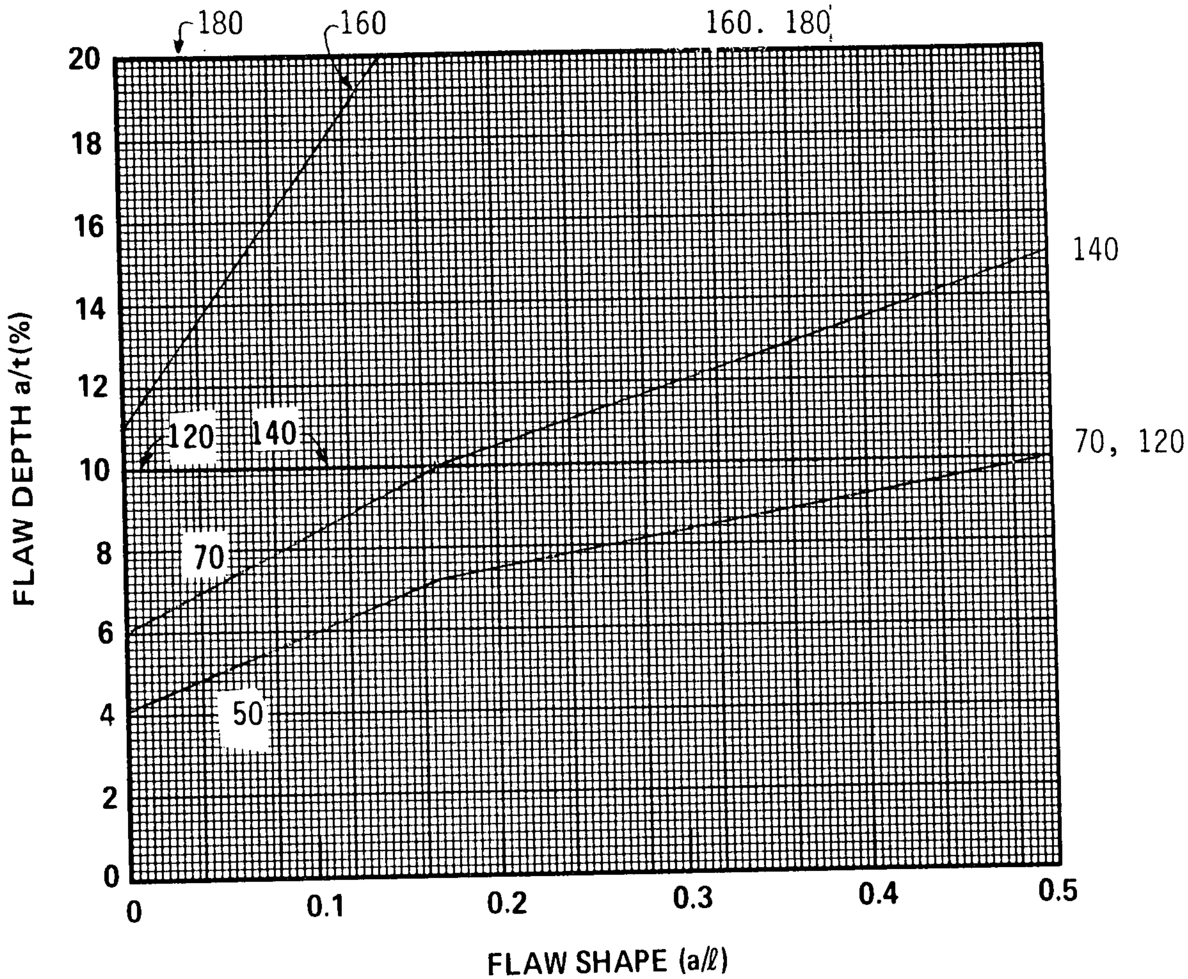


FIGURE 6-10 DETERMINATION OF LEAKAGE TEST TEMPERATURES FOR CIRCUMFERENTIAL SURFACE FLAWS (p = 1085 psi)

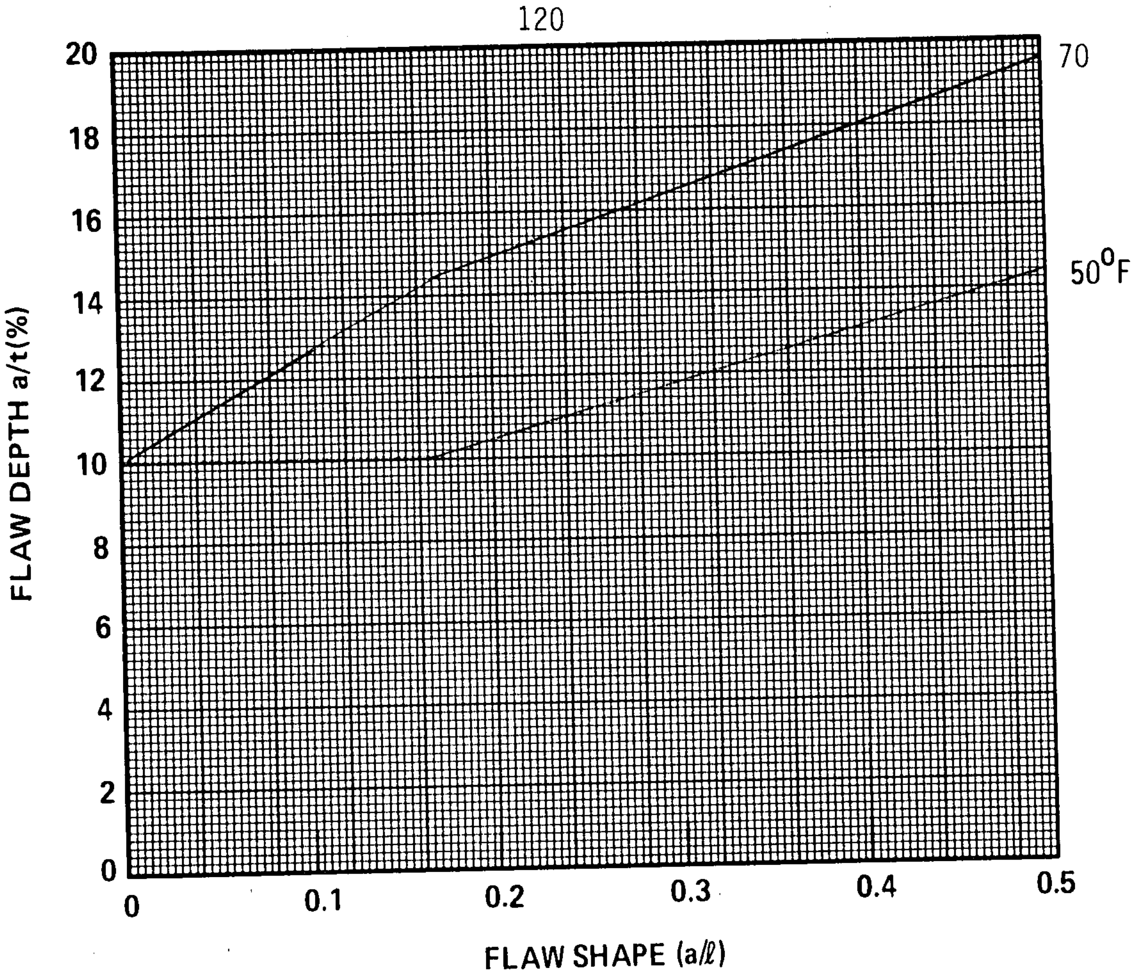


FIGURE 6-12 DETERMINATION OF LEAKAGE TEST TEMPERATURES FOR CIRCUMFERENTIAL SURFACE FLAWS (p = 500 psi)

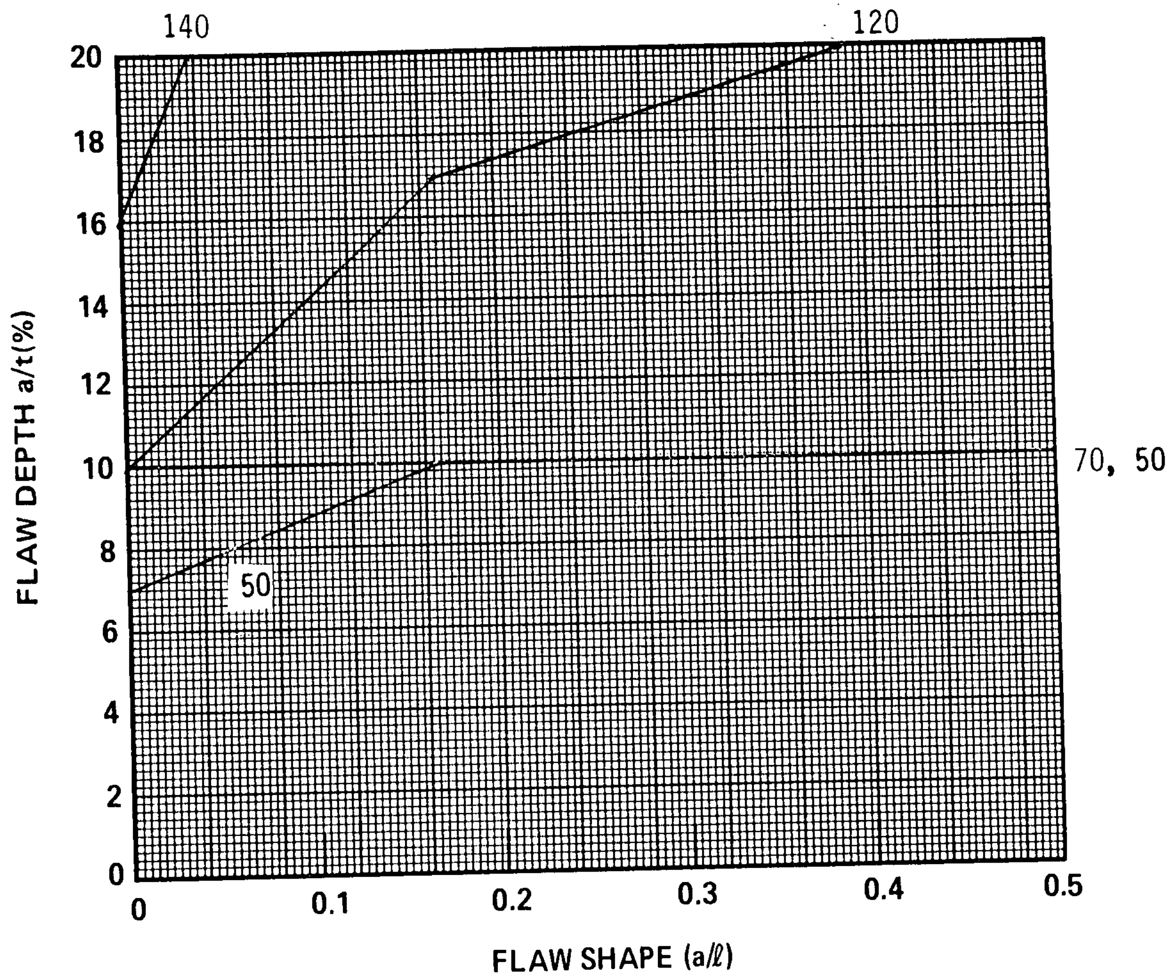


FIGURE 6-11 DETERMINATION OF LEAKAGE TEST TEMPERATURES FOR CIRCUMFERENTIAL SURFACE FLAWS (p = 750 psi)

SECTION 7
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APPENDIX A

RESULTS OF THE INSPECTION OF SPRING 1987

A-1 SUMMARY

During the Spring 1987 ultrasonic examination of the Kewaunee Unit 1 Steam Generator "B" upper shell to cone weld, nine recordable indications were noted. Two of these were detected with the 45 degree, 2.25 MHz shear wave examinations, and the remaining seven were detected with the 60 degree, 2.25 MHz shear wave examinations. The location of these indications in the weld and past experience with the same weld in other steam generators at other plants indicates that all these indications are volumetric in nature, i.e., small slag inclusions and/or voids. An evaluation of these indications (using 50% DAC sizing criteria) to the acceptance standards in Table IWB-3511-1 of the ASME Code Section XI, 1980 Edition results in seven indications which are unacceptable. In a similar evaluation using the acceptance standards in Table IWC-3510-1 of the ASME Code Section XI, 1986 Edition results in six unacceptable indications.

Using the fracture analysis rules of IWB-3600 and the guidelines of Appendix A, both from the ASME Code Section XI, 1980 Edition, all the indications are acceptable using 50% DAC sizing levels (2.25 and 5.0 MHz transducer data), and 20% DAC sizing levels without beam spread correction factors (5.0 MHz transducer data).

A-2 ULTRASONIC EVALUATION AND DISCUSSION

Nine recordable indications were noted during the recent examinations of the Kewaunee Unit 1 Steam Generator "B" upper shell to cone weld. Summary tables of the indications are presented in Tables A-1 and A-2. Table A-1 provides the measured "2a" value, the measured "S" value, and the measured length all with respect to the normal to the inside pressure retaining surface of the component and determined using a 5.0 MHz transducer and 50% DAC sizing criteria. Table A-2 shows the same parameters using a 2.25 MHz transducer and 50% DAC sizing criteria. These values are measured using indication plots rather than calculated from the raw data due to the geometry of the weld. The majority of the indications were detected from the outer diameter surface of the transition cone but are physically located in the upper shell portion of the weld. The indication parameters ("2a", "ℓ", and "S") therefore have been taken from the surfaces of the upper shell. The 45 degree sizing data was taken using a 2.25 MHz transducer and a 50% DAC sizing criteria. The 60 degree sizing data, with the exception of Indication C, was taken using a 5.0 MHz transducer and the same 50% DAC sizing criteria. Sizing data using a 60 degree, 2.25 MHz transducer and 50% DAC sizing criteria were also taken. Although both 2.25 MHz and 5.0 MHz sizing data were taken, the primary sizing data used for the fracture mechanics analysis was based on that taken with the 5.0 MHz transducer. Experience has shown that 2.25 MHz testing is excellent for detection in this application, but tends to oversize when used in conjunction with the Section XI criteria.

The 2.25 MHz transducer produces a beam spread which is wider than that of a similar size 5.0 MHz transducer. This factor typically results in an unavoidable overestimate of the true size of volumetric reflectors such as slag, which is believed to be present in this case. An example will illustrate this fact. Consider an indication which is being sized with a 2.25 MHz, 45° shear wave transducer, as shown in Figure A-1.

As the transducer is moved along the examination surface it picks up an indication (shown by the dot), and the first step is to locate the peak response of the indication, as shown in illustration (b). For illustration purposes, assume the amplitude is 100% of the distance amplitude correction curve (DAC). The peak response of the indication is then plotted in illustration (e), at an angle of 45 degrees from the transducer location. The distance along the 45 degree line is determined from the time base of the ultrasonic test instrument, which is a function of the speed of sound in the material.

The extent of the indication is then determined by moving the transducer along the surface until the amplitude drops to 50% DAC. This point is shown in illustration (c) for one direction, and corresponds to a reduction in the signal amplitude of the indication of 6 dB or one half. Section XI requires this point to also be plotted at an angle of 45 degrees [see (f)] even though it is clear from (c) that the angle is less than 45 degrees. A similar procedure is then followed to get the extent of the indication in the other direction (d) and the location is again plotted at 45 degrees [see (g)] even though in this case the angle is clearly greater than 45 degrees. The through wall dimension of the indication, "2a", is then determined from projection of a line through the peak point perpendicular to the vessel inside surface, as shown in (g). The through wall dimension then follows from projection of the end points onto the perpendicular.

An illustration of how the flaw sizing and location changes with a narrower beam is shown in Figure A-2. Here the example is exactly the same, but a 5.0 MHz transducer of similar size is used. The peak location or center of the indication is found to be identical to the previous example, as shown in (e) but the outer extent of the indication is considerably different, because the beam is narrower, and the projection of the outer 50% DAC limits of the indication is less, as shown in (f) and (g). The through wall depth is much smaller, and also the distance from the inside surface is also much greater. This is exactly the situation which occurred with the indications in steam generator B, although the actual details were more complex.

Therefore in the case of volumetric flaws a reduction in beam spread is desired. There are a number of ways to minimize the beam speed, including use of a higher frequency transducer, a focused transducer, a larger transducer size or a combination of these. The beam spread, θ, can be shown by simple physics [A1] to be related to the diameter (D) of the transducer and its frequency (f) as follows:

$$\sin \theta = \frac{k\lambda}{D} = \frac{kC}{fD}$$

where K = a constant

C = speed of sound in the material

λ = wave length

θ = beam spread angle, defined in Figures A-1 and A-2

Beam spread effects can also be minimized by use of beam spread correction, which is essentially a correction on the plotted extremities of the indications, but data to support the accuracy of these calculations is limited. The use of other transducers is permitted by Paragraph T-451.1 of the ASME Code Section V, Article 4 which states that "other ultrasonic techniques and nondestructive examination methods may be helpful in determining a reflector's true position, size, and orientation".

A-2.2 Experience With Other Plants

The indications in steam generator B appear to be quite characteristic of experience with various welds in steam generators and pressurizers at other plants where preservice ultrasonic examination results based on 2.25 MHz, 50% DAC sizing methods predicted reflectors detected in weld backchip regions had dimensions in excess of those allowable values provided in Section XI of the ASME Code. Attempts were made to confirm the size, location, and orientation of these indications by complementary nondestructive examination methods, i.e. 0 degree longitudinal wave examinations, and both fabrication and field radiography. No reliable responses could be observed from the shear wave indications using the straight beam examinations. In terms of the radiography, the fabrication radiographs of the areas in question were reviewed with no conclusive results. Additionally, field radiography was performed in selected areas but again no confirmation of the shear wave examination indications could be obtained.

These inconclusive results led to physical removal of some of the suspect indications by mechanical means for complete metallurgical characterization. The indications were found to have been caused by small slag inclusions and voids between weld passes in the weld backchip area near the inside surface. Measurements made during the destructive analysis showed that the ultrasonic sizing using 2.25 MHz, 50% DAC sizing methods exaggerated the true size of the discontinuities in terms of length and/or through-wall dimensions. These results are presented in Table A.3, and plotted in Figure A-3. These results agree closely with the illustrations previously presented.

Furthermore, this experience correlates well with investigations to date which have shown that when sizing volumetric-type reflectors by amplitude drop methods, i.e. 2.25 MHz, 50% DAC, the typical result is that the beam size rather than the reflector size is measured. For example, the lower the test frequency, the larger the beam width resulting in a larger than actual apparent flaw size (References A2-A7).

A-2.3 1987 Inspection Conclusions

Since the indications found in these examinations are ultrasonically similar to those detected at other plants it was appropriate to use higher frequency transducers to obtain more realistic data concerning the through-wall dimensions of the indications. Since the 45 degree indications sized with 2.25 MHz, 50% DAC methods were within the acceptance standards in Table IWC-3510-1 (ASME Section XI, 1986 Edition), no high frequency data were taken. This is shown in Table A-5.

Using the data in Tables A-1 and A-2, two sets of evaluation calculations were performed. The first evaluation compared the characteristics of the indications to the acceptance standards described in Table IWB-3511-1 of the ASME Code Section XI, 1980 Edition. This evaluation resulted in seven indications which were unacceptable (Table A-4). The second evaluation used the acceptance standards of Table IWC-3510-1 of the ASME Code Section XI, 1986 Edition as the acceptance criteria. This evaluation resulted in six unacceptable indications (Table A-5). The latter ASME Code was considered for information only because it contained acceptance standards strictly for Class 2 component welds such as the upper shell to cone weld.

To be more conservative, additional data were taken using a 20% DAC sizing criteria but without the use of beam spread correction factors. The use of this sizing criteria is specified in Nuclear Regulatory Guide 1.150 but with the use of beam spread correction factors. Of course, the size of the indication as delineated in this same regulatory guide is determined, though, by using the greater of the values obtained by the 50% DAC sizing criteria and the 20% DAC sizing criteria with beam spread correction. The 5.0 MHz, 20% DAC sizing data are summarized on Table A-6.

A.3 FRACTURE ANALYSIS

There are two alternative sets of acceptance criteria for continued service without repair in paragraph IWB-3600 of the ASME Code Section XI:

1. Acceptance criteria based on flaw size (IWB-3611)
2. Acceptance criteria based on stress intensity factor (IWB-3612)

The more beneficial criteria of IWB-3612 have been used for evaluating the nine indications.

To determine the allowable flaw sizes in a weld, finite element analysis methods were used.

All applicable plant transients were analysed to select the most severe stress profiles through the thickness of the weld. The actual stress profiles were then approximated by third order polynomials and used for calculating the stress intensity factor (K_I) for various crack sizes and aspect ratios.

The resulting K_I values were compared to fracture toughness values (K_{Ia} and K_{Ic}). Critical flaw sizes were then obtained, and allowable flaw sizes determined using the acceptance criteria discussed above.

The final step involves calculation of crack growth due to fatigue loading. All anticipated plant transients were utilized in determining the resulting flaw size for a specified period of time. This was done for 10, 20, and 30 year intervals.

In addition to satisfying the fracture criteria, it is required that the primary stress limits of Section III paragraph NC-3000 be satisfied. A local area reduction of pressure retaining membrane must be used, equal to the area of indication; and the stresses increased to reflect the smaller cross section.

The nine indications found are all subsurface flaws as defined by IWB-3500. As shown in Figures A-1 and A-2, all nine indications are acceptable per the fracture analysis criteria of IWB-3600. The fracture evaluation methods used for these analyses have been documented in the main body of this report.

It should be mentioned that some elevation of the hydrotest and leak test temperatures over the specified temperature will be required to ensure the margins of IWB-3600 are maintained, and these temperatures have been provided along with the complete technical details of the analysis in the main body of this report. The revised hydrotest and leak test temperatures from this inspection are provided in Figures A-6 and A-7.

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A6. Mudge, P. J. and Jessop, T. J., " Size Measurement and Characterization of Weld Defects by Ultrasonic Testing: Findings of a Collaborative Programme," Proceedings of NDE in Relation to Structural Integrity, Paris, France, Aug. 24-25, 1981. Applied Science Publishers, Ltd., London, England.

A7. Rishel, R.D., "Summary Report: Volumetric Flaw Depth Sizing," MT-SMART-807, September 12, 1985 (submitted to Seabrock Power Station).

TABLE A-1

SUMMARY OF ULTRASONIC TEST INDICATIONS FOUND IN THE KEWAUNEE UNIT 1 STEAM GENERATOR "B" WELD 2-5 (5.0 MHZ TRANSDUCER, 50% DAC SIZING)

	DATA	INDICATION	MEASURED "2a"	"S" (inside surface)	LENGTH
1.	45 degree	A	--	--	--
2.	45 degree	B	--	--	--
3.	60 degree	A	0.37"	1.02"	0.75"
4.	60 degree	B	0.35"	0.75"	0.50"
5.	60 degree **	C	--	--	--
6.	60 degree	D	0.28"	0.69"	1.10"
7.	60 degree	E	0.65"	0.75"	0.63"
8.	60 degree	F	0.26"	1.93"	1.00"
9.	60 degree	G	0.35"	1.79"	2.75"

NOTE:

** Using the 5.0 MHz transducer this indication only had a ultrasonic signal response of 50% DAC. According to the examination procedure no further sizing data needed to be taken. As a result the 2.25 MHz transducer data is given.

TABLE A-2

SUMMARY OF ULTRASONIC TEST INDICATIONS FOUND IN THE
KEWAUNEE UNIT 1 STEAM GENERATOR "B" WELD 2-5
(2.25 MHZ TRANSDUCER, 50% DAC SIZING)

	DATA	INDICATION	MEASURED "2a"	"S" (inside surface)	LENGTH
1.	45 degree	A	0.61"	0.37"	0.60"
2.	45 degree	B	0.43"	0.45"	0.10"
3.	60 degree	A	0.69"	0.67"	1.20"
4.	60 degree	B	0.81"	0.24"	1.50"
5.	60 degree	C	0.65"	0.63"	0.90"
6.	60 degree	D	0.55"	0.53"	1.10"
7.	60 degree	E	0.46"	0.37"	1.50"
8.	60 degree	F	0.61"	1.67"	3.10"
9.	60 degree	G	0.41"	1.63"	1.80"

TABLE A-3
NONDESTRUCTIVE VERSUS DESTRUCTIVE TESTING RESULTS
USING 2.25 MHZ, 50% DAC SIZING

PHYSICAL SAMPLE	DISTANCE FROM ID SURFACE		THROUGH-WALL DEPTH		LENGTH	
	UT	ACTUAL	UT	ACTUAL	UT	ACTUAL
CORE #1 (Plant 1)	**	**	.37" to 1.03	0.09"	1.18" to 3.18"	1.15"
CORE #2 (Plant 1)	**	**	.16" to .58"	0.02"	.63" to .75"	0.45"
CORE #1 (Plant 2)	0.00"	0.08" to 0.33" *	0.24"	0.01" to 0.33"	0.88"	0.25" to 0.28"
CORE #2 (Plant 2)	0.16"	0.82"	0.53"	0.18"	0.88"	0.27"
GRINDING (Plant 2)	0.05"	**	0.37"	**	1.00"	**
GRINDING (Plant 2)	0.00"	0.375"	0.45"	0.094"	3.5"	**
GRINDING (Plant 2)	0.00"	0.125"	0.51"	0.156"	3.25"	**
GRINDING (Plant 2)	0.02"	0.156"	0.43"	0.219"	0.75"	0.375"
GRINDING (Plant 2)	0.00"	**	0.24"	**	0.75"	**
GRINDING (Plant 2)	0.00"	0.219"	0.33"	0.343"	1.0"	0.438"

* One UT indication was found to be four indications upon metallurgical evaluation. The values show the range of sizes for these four defects.

** Dimensions not reported.

TABLE A-4
RESULTS OF THE ASME SECTION XI, 1980 EDITION CALCULATIONS USING THE ACCEPTANCE STANDARDS OF TABLE IWB-3511-1

	DATA	IND.	MEASURED "2a" [1]	TYPE OF IND.	"a"	"S"	"ℓ"	a/t ALLOW.	a/t * ACT.
1.	45 deg.	A	0.61"	subsurf.	0.31"	0.37"	0.60"	7.2%	8.4%
2.	45 deg.	B	0.43"	subsurf.	0.22"	0.45"	0.10"	7.2%	5.9%
3.	60 deg.	A	0.37"	subsurf.	0.19"	1.02"	0.75"	4.1%	5.1%
4.	60 deg.	B	0.35"	subsurf.	0.18"	0.75"	0.50"	5.3%	4.9%
5.	60 deg.	C	0.65"	subsurf.	0.33"	0.63"	0.90"	5.4%	8.9%
6.	60 deg.	D	0.28"	subsurf.	0.14"	0.69"	1.10"	3.1%	3.8%
7.	60 deg.	E	0.65"	subsurf.	0.33"	0.75"	0.63"	7.2%	8.9%
8.	60 deg.	F	0.26"	subsurf.	0.13"	1.93"	1.00"	3.1%	3.5%
9.	60 deg.	G	0.35"	subsurf.	0.18"	1.79"	2.75"	2.8%	4.9%

NOTES:

* The measured base metal thickness of 3.7" was used rather than the measured weld thickness of 3.9" due to the irregular nature of the weld crown.

[1] From Table A-1, except for indications 1.2 and 5 which are from Table A-2.

TABLE A-5
RESULTS OF THE ASME SECTION XI, 1986 EDITION CALCULATIONS USING THE ACCEPTANCE STANDARDS OF TABLE IWC-3510-1

	DATA	IND.	MEASURED "2a" [1]	TYPE OF IND.	"a"	"S"	"ℓ"	a/t ALLOW.	a/t * ACT.
1.	45 deg.	A	0.61"	subsurf.	0.31"	0.37"	0.60"	8.9%	8.4%
2.	45 deg.	B	0.43"	subsurf.	0.22"	0.45"	0.10"	8.9%	5.9%
3.	60 deg.	A	0.37"	subsurf.	0.19"	1.02"	0.75"	4.4%	5.1%
4.	60 deg.	B	0.35"	subsurf.	0.18"	0.75"	0.50"	6.0%	4.9%
5.	60 deg.	C	0.65"	subsurf.	0.33"	0.63"	0.90"	6.2%	8.9%
6.	60 deg.	D	0.28"	subsurf.	0.14"	0.69"	1.10"	3.1%	3.8%
7.	60 deg.	E	0.65"	subsurf.	0.33"	0.75"	0.63"	8.9%	8.9%
8.	60 deg.	F	0.26"	subsurf.	0.13"	1.93"	1.00"	3.1%	3.5%
9.	60 deg.	G	0.35"	subsurf.	0.18"	1.79"	2.75"	2.6%	4.9%

* The measured base metal thickness of 3.7" was used rather than the measured weld thickness of 3.9" due to the irregular nature of the weld crown.

[1] From Table A-1, except for indications, 1, 2, and 5 which are from Table A-2.

TABLE A-6
SUMMARY OF ULTRASONIC TEST INDICATIONS FOUND IN THE KEWAUNEE UNIT 1 STEAM GENERATOR "B" WELD 2-5
(5 MHZ TRANSDUCER, 20% DAC SIZING)

	DATA	IND. I.D.	MEASURED "2a"	"S" (inside surface)	LENGTH
1.	45 deg.	A	*	*	*
2.	45 deg.	B	*	*	*
3.	60 deg.	A	0.52"	0.96"	1.05"
4.	60 deg.	B	0.47"	0.79"	1.05"
5.	60 deg.	C	0.57"	0.65"	0.90"
6.	60 deg.	D	0.73"	0.51"	1.50"
7.	60 deg.	E	0.65"	0.83"	0.95"
8.	60 deg.	F	0.39"	1.89" **	1.20"
9.	60 deg.	G	0.35"	1.67"	3.13"

* Data not taken.
** The reflector is nearer to the outside surface than the inside surface. "S" to the outside surface is 1.77".

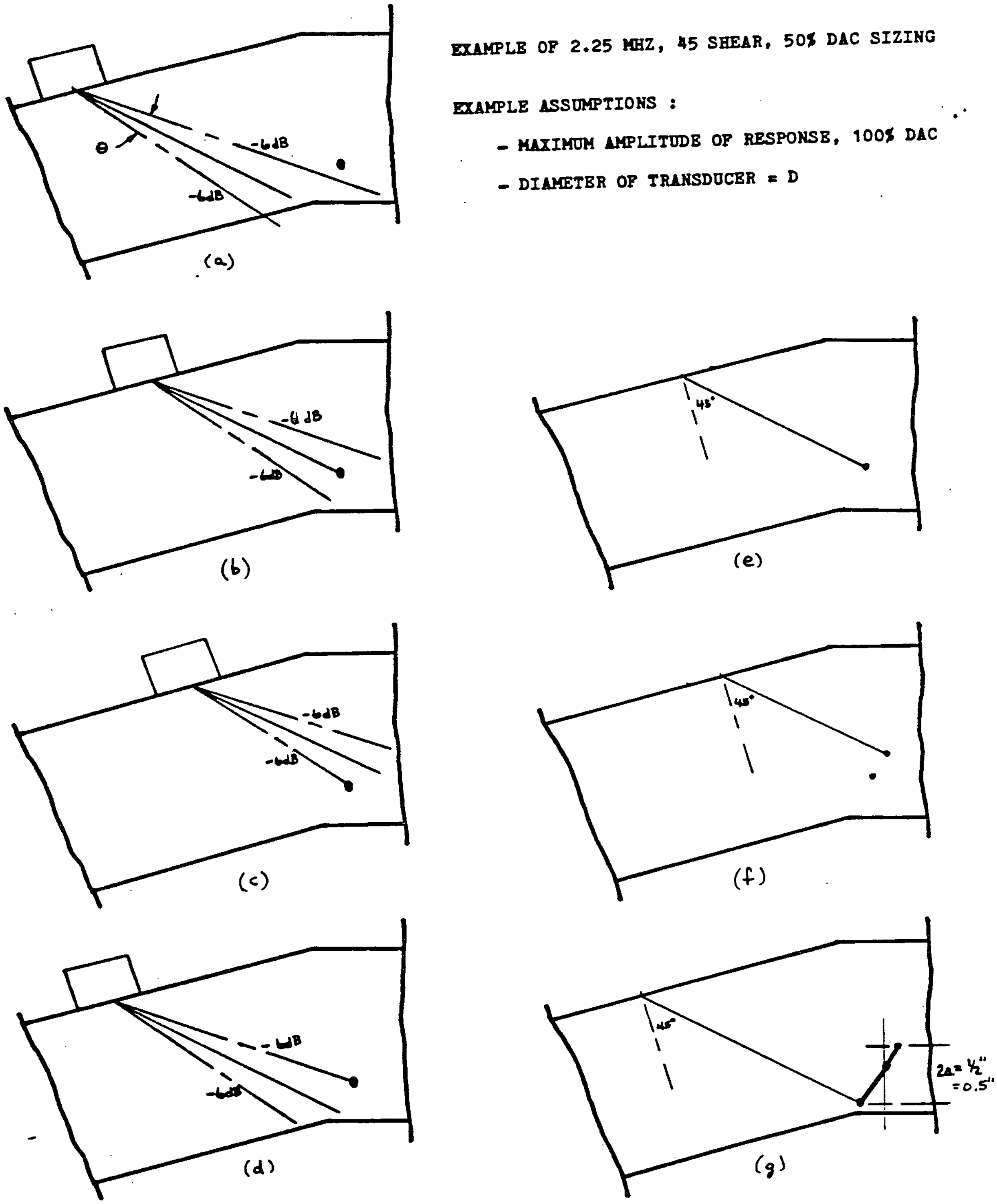


FIGURE A-1 SCHEMATIC EXAMPLE OF FLAW SIZING WITH 2.25 MHZ TRANSDUCER, USING 50% DAC.

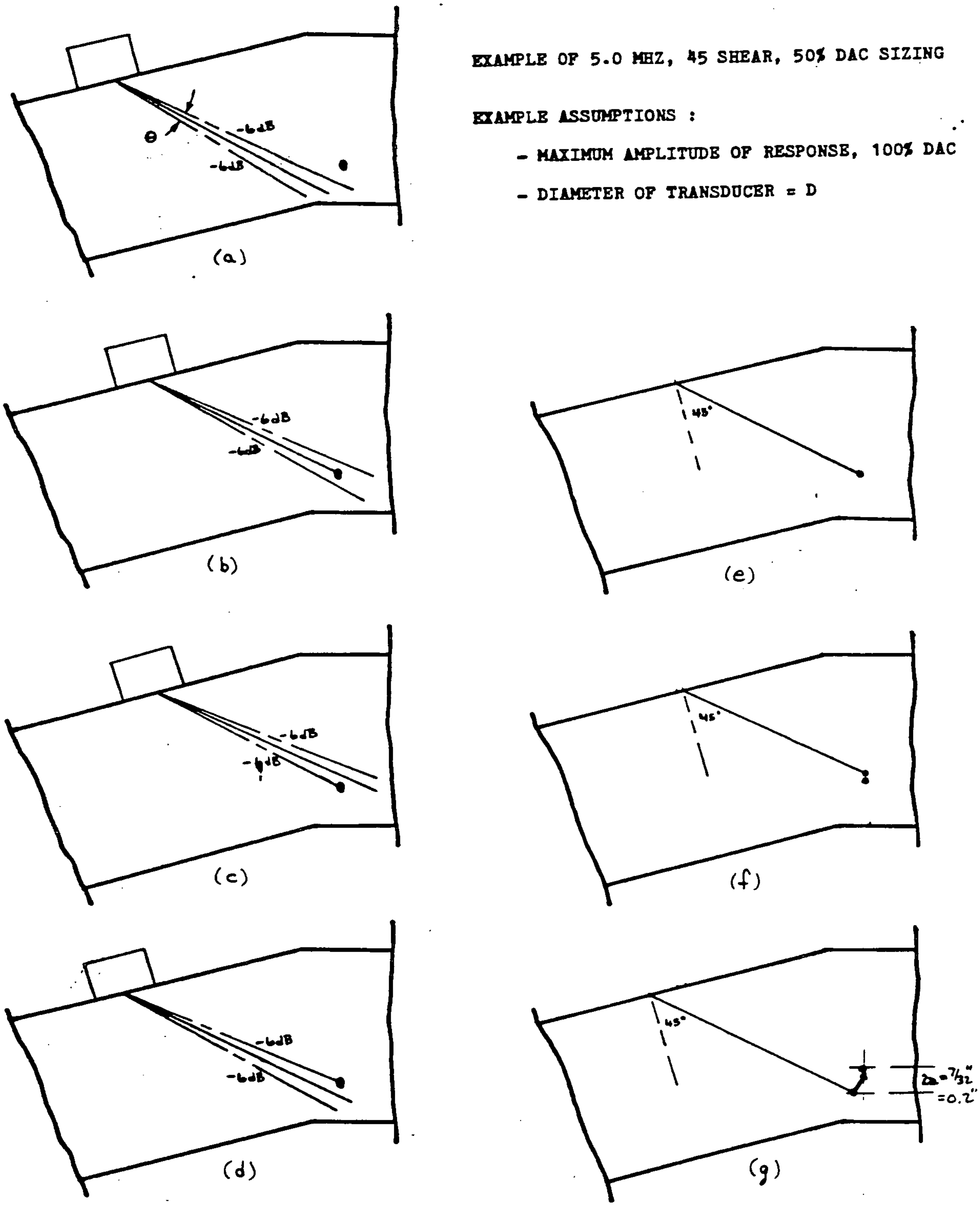


FIGURE A-2 SCHEMATIC EXAMPLE OF FLAW SIZING WITH 5.0 MHZ TRANSDUCER, USING 50% DAC.

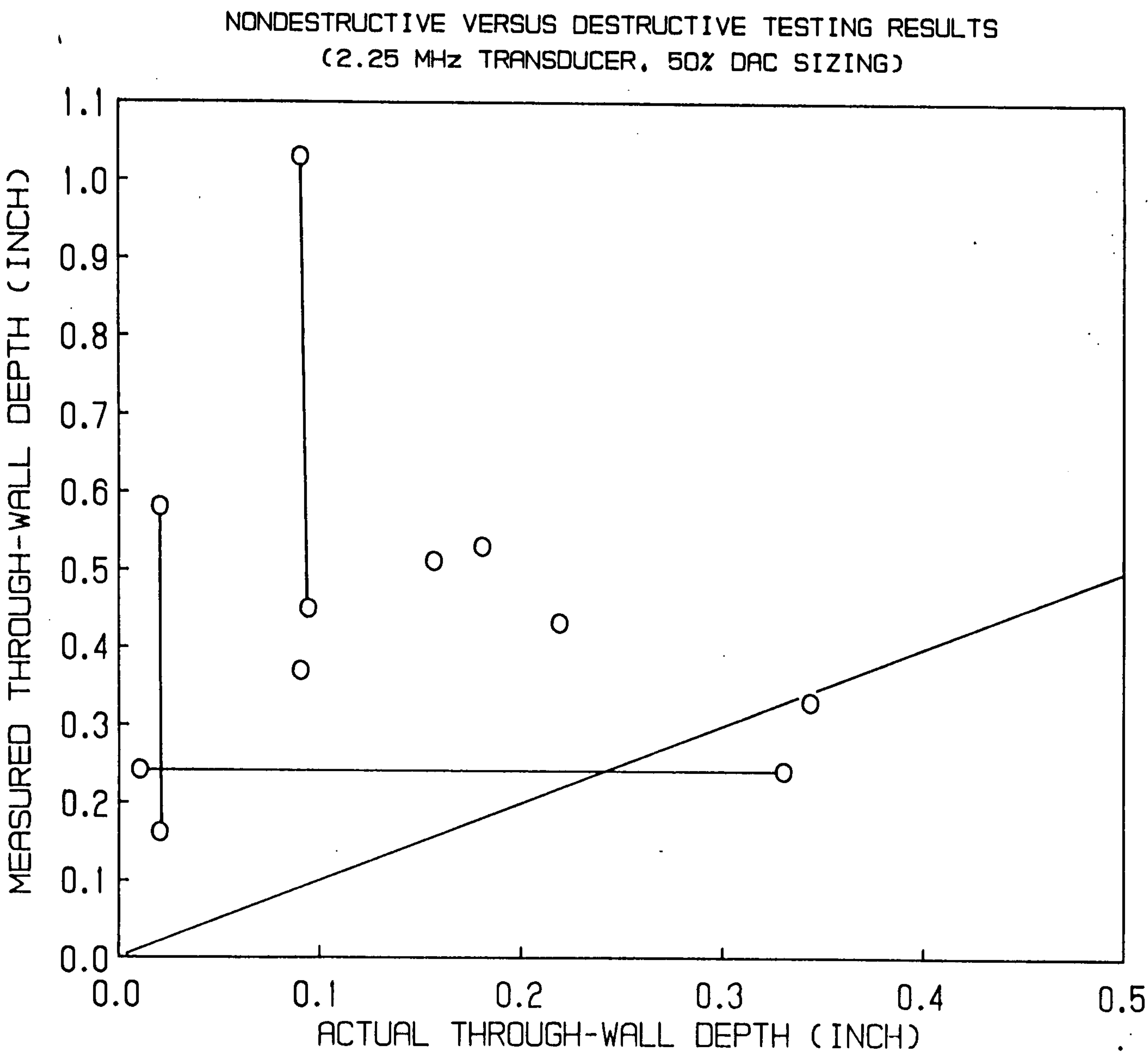
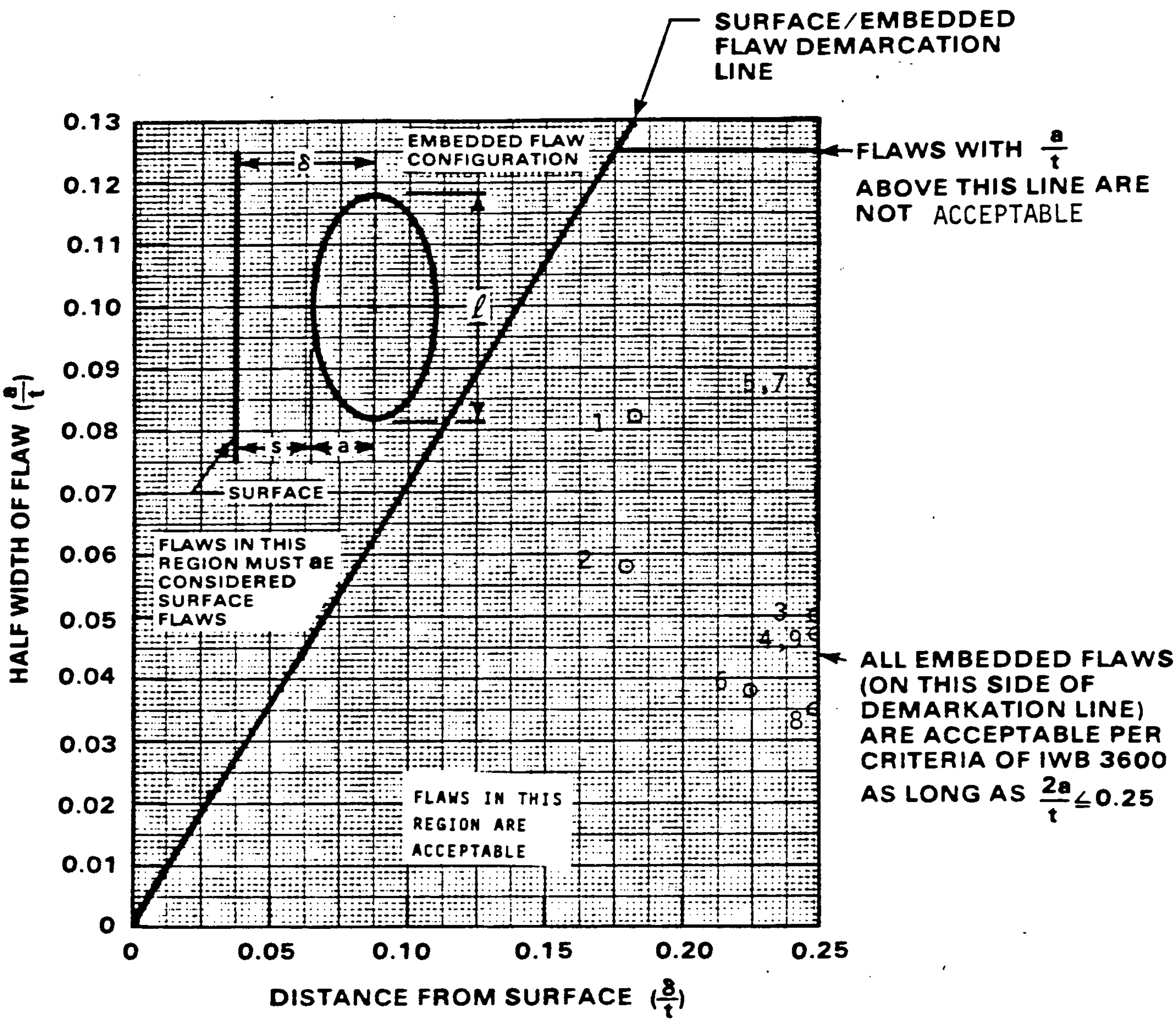
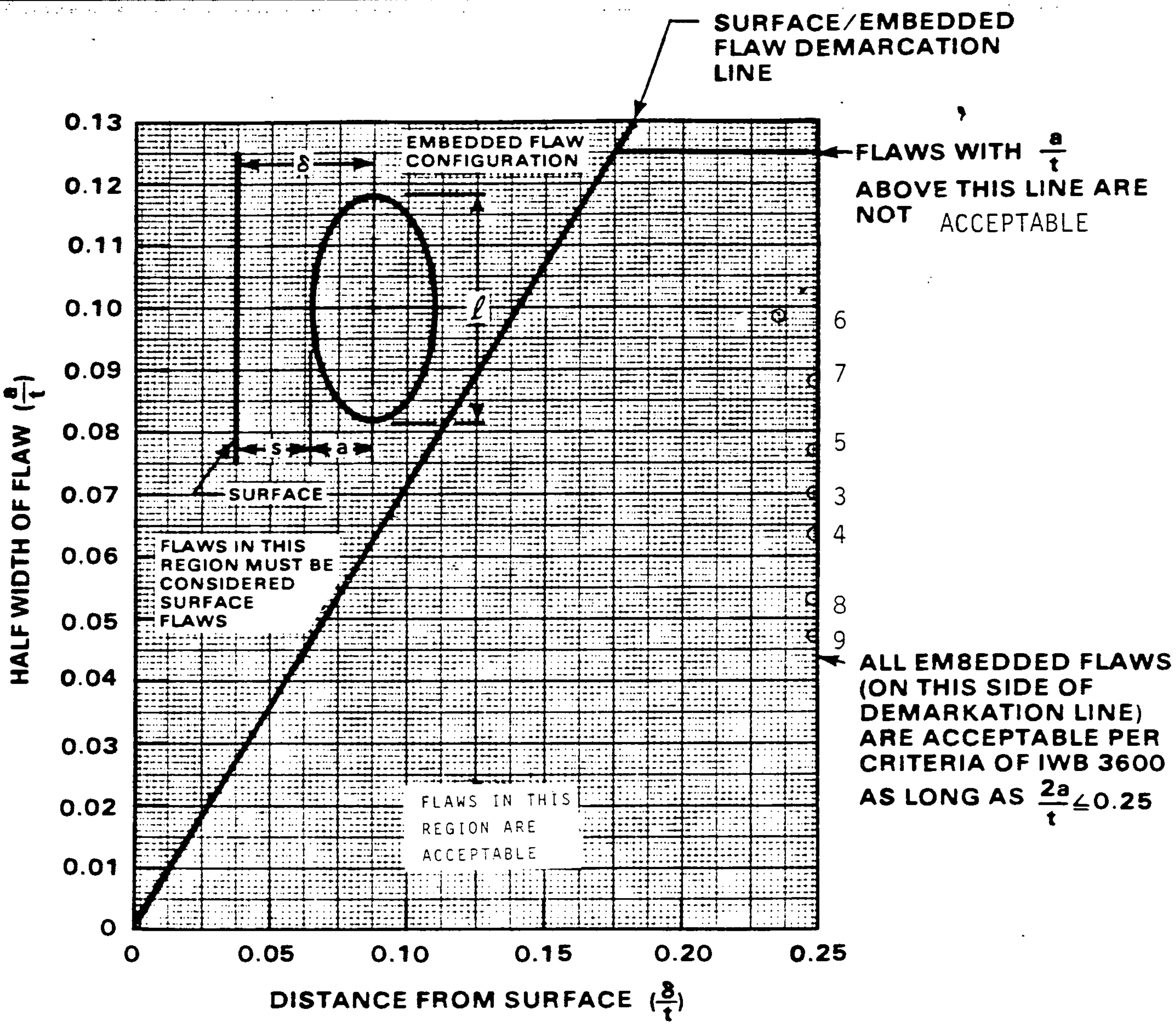


FIGURE A-3 NONDESTRUCTIVE VS DESTRUCTIVE TESTING RESULTS, 2.25 MHZ TRANSDUCER WITH 50% DAC SIZING



	DATA	IND.	MEASURED "2a"	TYPE OF IND.	"S"	"l"	a/t * ACT.	δ/t	Accept-able?
1.	45 deg.	A	0.61"	subsurf.	0.37"	0.60"	8.4%	0.182	Yes
2.	45 deg.	B	0.43"	subsurf.	0.45"	0.10"	5.9%	0.180	Yes
3.	60 deg.	A	0.37"	subsurf.	1.02"	0.75"	5.1%	0.326	Yes
4.	60 deg.	B	0.35"	subsurf.	0.75"	0.50"	4.9%	0.250	Yes
5.	60 deg.	C	0.65"	subsurf.	0.63"	0.90"	8.9%	0.258	Yes
6.	60 deg.	D	0.28"	subsurf.	0.69"	1.10"	3.8%	0.224	Yes
7.	60 deg.	E	0.65"	subsurf.	0.75"	0.63"	8.9%	0.291	Yes
8.	60 deg.	F	0.26"	subsurf.	1.93"	1.00"	3.5%	0.557	Yes
9.	60 deg.	G	0.35"	subsurf.	1.79"	2.75"	4.9%	0.531	Yes

FIGURE A-4 FRACTURE ANALYSIS RESULTS FOR INDICATIONS FOUND IN THE KEWAUNEE UNIT 1 STEAM GENERATOR "B" WELD 2-5 (50% DAC SIZING, 5.0 MHz)



SUMMARY OF ULTRASONIC TEST INDICATIONS FOUND IN THE
KEWAUNEE UNIT 1 STEAM GENERATOR "B" WELD 2-5
(20% DAC SIZING)

	DATA	IND. I.D.	MEASURED "2a"	a/t	"S" (inside surface)	ℓ/t	LENGTH
1.	45 deg.	A	*		*		*
2.	45 deg.	B	*		*		*
3.	60 deg.	A	0.52"	0.0703	0.96"	0.330	1.05"
4.	60 deg.	B	0.47"	0.0635	0.79"	0.278	1.05"
5.	60 deg.	C	0.57"	0.0770	0.65"	0.253	0.90"
6.	60 deg.	D	0.73"	0.0986	0.51"	0.236	1.50"
7.	60 deg.	E	0.65"	0.0878	0.83"	0.312	0.95"
8.	60 deg.	F	0.39"	0.0530	1.89" **	0.560	1.20"
9.	60 deg.	G	0.35"	0.0470	1.67"	0.498	3.13"

* Data not taken.
** The reflector is nearer to the outside surface than the inside surface. "S" to the outside surface is 1.77".

FIGURE A-5 SUMMARY OF ULTRASONIC TEST INDICATIONS FOUND IN THE KEWAUNEE UNIT 1 STEAM GENERATOR "B" WELD 2-5 (20% DAC SIZING, 5.0 MHz)

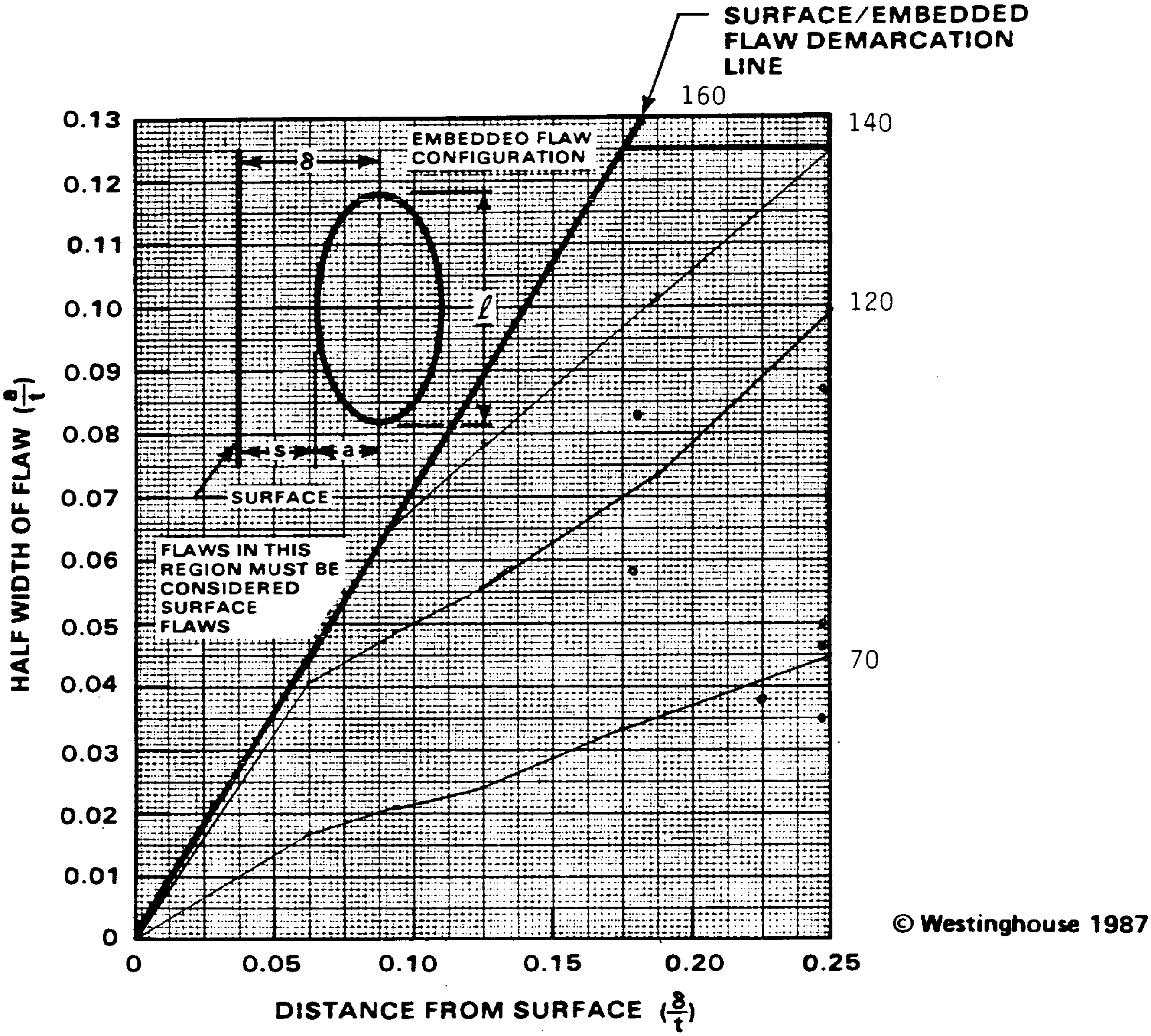


FIGURE A-6 DETERMINATION OF HYDROSTATIC TEST TEMPERATURES FROM RESULTS OF THE SPRING 1987 INSPECTION

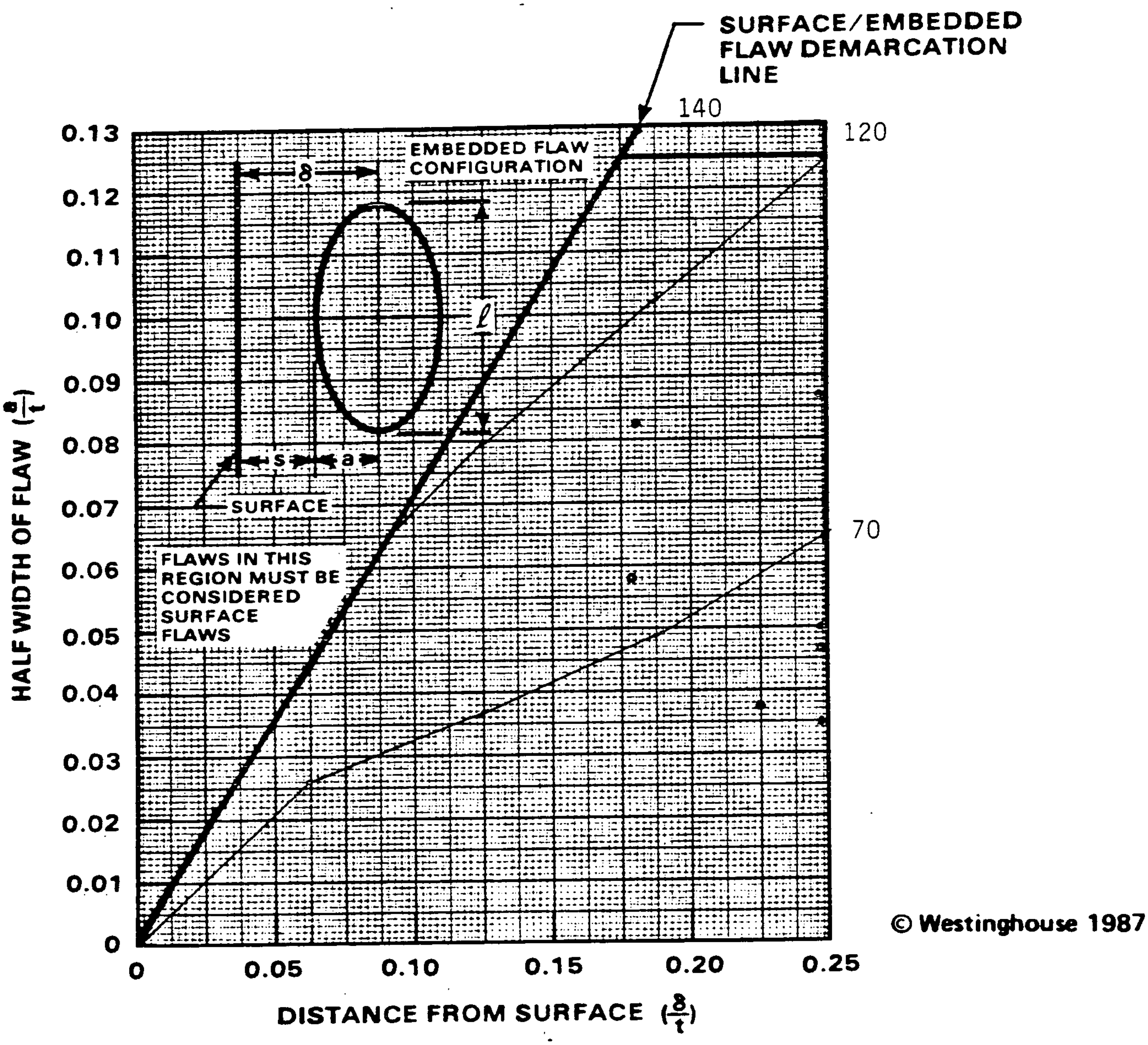


FIGURE A-7 DETERMINATION OF LEAKAGE TEST TEMPERATURES FROM RESULTS OF THE SPRING 1987 INSPECTIONS

APPENDIX B

RESULTS OF THE INSPECTION OF MARCH 1988 ON STEAM GENERATOR "A"

B-1 SUMMARY

During the March 1988 ultrasonic examination of the Kewaunee Unit 1 steam generator "A" upper shell to cone weld [SG-W2 (Weld 1-5)], nineteen recordable indications were noted. Seven of these were detected with the 45 degree, 2.25 MHz shear wave examinations, and the remaining twelve were detected with the 60 degree, 2.25 MHz shear wave examinations. The location of these indications in the weld, past experience with the same weld in other steam generators at other plants, and supplemental examinations performed on this steam generator indicate that all these indications are volumetric in nature, i.e., small slag inclusions and/or voids. An evaluation of these indications (using -6 dB drop or half maximum amplitude sizing criteria) to the acceptance standards in table IWB-3511-1 of the ASME Code Section XI, 1980 Edition with the Winter 1981 Addenda results in fourteen indications which are unacceptable.

Using the fracture analysis rules of IWB-3600 and the guidelines of appendix A, both from the ASME Code Section XI, 1980 Edition with the Winter 1981 Addenda, all the indications are acceptable using 50% DAC sizing levels (2.25 MHz transducer data), and using -6 dB drop or half maximum amplitude sizing levels (5.0 MHz transducer data).

These examinations were performed with the same personnel and procedures utilized on numerous other plants. These other plants exhibited both inner diameter cracking conditions, subsurface fabrication flaws, or a combination of both at the recording levels established in the test procedures. The evaluation of examination data and the performance of supplemental investigations were conducted by engineering personnel directly involved with the evaluation of data from the same plants as specified above.

B-2 ULTRASONIC EVALUATION AND DISCUSSION

Nineteen recordable indications were noted during the recent examinations of the Kewaunee Unit 1 steam generator "A" upper shell to cone weld. Summary tables of the indications are presented in tables B-1 and B-2. Table B-1 provides the measured "2a" value, the measured "S" value, and the measured length all with respect to the normal to the inside pressure retaining surface of the component and determined using a 5.0 MHz transducer and -6 dB drop or half maximum amplitude sizing criteria. Table B-2 shows the same parameters using a 2.25 MHz transducer and 50% DAC sizing criteria. These values are measured using indication plots rather than calculated from the raw data due to the geometry of the weld. This evaluation scheme is to maintain adherence to the flaw indication characterization criteria provided in IWA-3300 and table IWB-3511-1 of Section XI. The majority of the indications were detected from the outer diameter surface of the transition cone but are physically located in the upper shell portion of the weld. The indication parameters ("2a", "ℓ", and "S") therefore have been taken primarily from the surfaces of the upper shell. The 45 degree sizing data, with the exception of indications 4, 5, and 6, was taken using a 5.0 MHz, 45 degree shear wave transducer and a -6 dB drop or half maximum amplitude sizing criteria. The 45 degree shear wave indications 4, 5, and 6 were sized only using the detection data (2.25 MHz, 45 degree shear wave transducer, and 50% DAC sizing criteria.) The 60 degree sizing data was taken using a 5.0 MHz, 60 degree shear wave transducer and -6 dB drop or half maximum amplitude sizing criteria. Sizing data using a 60 degree, 2.25 MHz transducer and 50% DAC sizing criteria were also taken. Although both 2.25 MHz and 5.0 MHz sizing data were taken, the primary sizing data used for the fracture mechanics analysis was based on that taken with the 5.0 MHz transducer. Experience has shown that 2.25 MHz testing is excellent for detection in this application, but tends to oversize when used in conjunction with the Section XI criteria, and volumetric-type reflectors.

The 2.25 MHz transducer produces a beam spread which is wider than that of a similar size 5.0 MHz transducer. This factor typically results in an unavoidable overestimate of the true size of volumetric reflectors such as slag, which is believed to be present in this case. An example will illustrate this fact. Consider an indication which is being sized with a 2.25 MHz, 45° shear wave transducer and 50% DAC sizing criteria, as shown in figure B-1.

As the transducer is moved along the examination surface it picks up an indication (shown by the dot), and the first step is to locate the peak response of the indication, as shown in illustration (b). For illustration purposes, assume the amplitude is 100% of the distance amplitude correction curve (DAC). The peak response of the indication is then plotted in illustration (e), at an angle of 45 degrees from the transducer location. The distance along the 45 degree line is determined from the time base of the ultrasonic test instrument, which is a function of the speed of sound in the material.

The extent of the indication is then determined by moving the transducer along the surface until the amplitude drops to 50% DAC. This point is shown in illustration (c) for one direction, and corresponds to a reduction in the signal amplitude of the indication of 6 dB or one half in this case. Section XI requires this point to also be plotted at an angle of 45 degrees [see (f)] even though it is clear from (c) that the angle is less than 45 degrees. A similar procedure is then followed to get the extent of the indication in the other direction (d) and the location is again plotted at 45 degrees [see (g)] even though in this case the angle is clearly greater than 45 degrees. The through wall dimension of the indication, "2a", is then determined from projection of a line through the peak point perpendicular to the vessel inside surface, as shown in (g). The through wall dimension then follows from projection of the end points onto the perpendicular.

An illustration of how the flaw sizing and location changes with a narrower beam is shown in figure B-2. Here the example is exactly the same, but a 5.0 MHz transducer of similar size is used. The peak location or center of the indication is found to be identical to the previous example, as shown in (e) but the outer extent of the indication is considerably different, because the beam is narrower, and the projection of the outer 50% DAC limits (or in this case -6 dB drop or half maximum amplitude limits) of the indication is less, as shown in (f) and (g). The through wall depth is much smaller, and also the distance from the inside surface is also much greater. This is exactly the situation which occurred with the indications in steam generator A, although the actual details were more complex.

Therefore, in the case of volumetric flaws a reduction in beam spread is desired to obtain a more realistic size. There are a number of ways to minimize the beam spread, including use of a higher frequency transducer, a focused transducer, a larger transducer size or a combination of these. The beam spread, θ, can be shown by simple physics [B1] to be related to the diameter (D) of the transducer and its frequency (f) as follows:

$$\sin \theta = \frac{k\lambda}{D} = \frac{kC}{fD}$$

where K = a constant

C = speed of sound in the material

λ = wave length

θ = beam spread angle, defined in figures B-1 and B-2

f = frequency

Beam spread effects can also be minimized by use of beam spread correction, which is essentially a correction on the plotted extremities of the indications, but data to support the accuracy of these calculations is limited. The use of other transducers is permitted by Paragraph T-451.1 of the ASME Code Section V, Article 4 which states that "other ultrasonic techniques and nondestructive examination methods may be helpful in determining a reflector's true position, size, and orientation".

The raw indication data from the detection examinations in steam generator A clearly indicate that the detected reflectors are embedded rather than surface. This is seen in the location of the peak responses. No peak response is observed at or near the inner diameter surface which would be expected for a surface breaking flaw. In addition the test operators did not observe any low level amplitude signals below the recording level located at the inner diameter surface indicative of those found in plants having an inner diameter surface cracking condition. Supplemental examinations on three of the 60 degree shear wave indications originally determined to be surface by the rules established in Section XI resulted in the fact that these indications could be observed from both sides of the weld in a normal half-vee technique fashion as well as a 5/8-node technique with the peak locations embedded within the weld. The longest indication (approximately 12 inches long) was scanned with a 0 degree, 5 MHz longitudinal wave probe resulting in a confirmation of a cluster of reflectors at positions approximately 3.2 to 3.4 inches below the outer diameter surface for the entire length of the indication. At the same transducer position that this cluster was detected, a backwall response at 3.9 inches below the outer diameter surface was noted. This indicates a thickness of 3.9 inches and a difference in position between the volumetric reflectors and the inner diameter surface of 0.5 to 0.7 inch. All examination data, therefore, clearly suggest embedded flaws.

B-2.2 Experience With Other Plants

The indications in steam generator A at KNPP appear to be quite characteristic of experience with various welds in steam generators and pressurizers at other plants where preservice ultrasonic examination results based on 2.25 MHz, 50% DAC sizing methods predicted reflectors detected in weld backchip regions had dimensions in excess of those allowable values provided in Section XI of the ASME Code. Attempts were made at other plants to confirm the size, location, and orientation of these indications by complementary nondestructive examination methods, i.e. 0 degree longitudinal wave examinations, and both fabrication and field radiography. No reliable responses could be observed from the shear wave indications using the straight beam examinations. In terms of the radiography, the fabrication radiographs of the areas in question were reviewed with no conclusive results. Additionally, field radiography was performed in selected areas at these plants but again no confirmation of the shear wave examination indications could be obtained.

These inconclusive results led to physical removal of some of the suspect indications by mechanical means for complete metallurgical characterization.

The indications were found to have been caused by small slag inclusions and voids between weld passes in the weld backchip area near the inside surface. Measurements made during the destructive analysis showed that the ultrasonic sizing using 2.25 MHz, 50% DAC sizing methods exaggerated the true size of the discontinuities in terms of length and/or through-wall dimensions. These results are presented in table B-3, and plotted in figure B-3. These results agree closely with the illustrations previously presented.

Furthermore, this experience correlates well with investigations to date which have shown that when sizing volumetric-type reflectors by amplitude drop methods, i.e. 2.25 MHz, 50% DAC, the typical result is that the beam size rather than the reflector size is measured. For example, the lower the test frequency, the larger the beam width resulting in a larger than actual apparent flaw size (references B2-B7).

B-2.3 1988 Inspection Conclusions

Since the data clearly suggested volumetric-type reflectors at KNPP the use of a more realistic volumetric flaw sizing approach was implemented. This sizing approach consisted of using a 5.0 MHz transducer and a -6 dB or half maximum amplitude sizing criteria. The angle used in sizing was dependent on the angle which detected the indication. The 5.0 MHz transducer resulted in a smaller beam spread in comparison with the true size of the suspect reflectors. The -6 dB or half maximum sizing criteria was selected because it has provided the better accuracies when compared with 50% DAC or 20% DAC sizing levels (reference B8).

Using the data in tables B-3 and B-4, two sets of evaluation calculations were performed. The first evaluation compared the characteristics of the 2.25 MHz detection data to the acceptance standards described in table IWB-3511-1 of the ASME Code Section XI, 1980 Edition with the Winter 1981 Addenda. This evaluation resulted in sixteen indications which were unacceptable (table B-5). The second evaluation compared the characteristics of the data composite sizing (5.0 MHz and 2.25 MHz data) to the acceptance standards described in table IWB-3511-1 of the ASME Code Section XI, 1980 Edition with the Winter 1981 Addenda. This resulted in fourteen indications which were unacceptable (table B-4). All indications sized with the 5.0 MHz transducer are classified as subsurface indications.

Since the indications found in these examinations are ultrasonically similar to those detected at other plants it was appropriate to use higher frequency transducers to obtain more realistic data concerning the through-wall dimensions of the indications. Since 45 degree indications numbers 4, 5, and 6 sized with 2.25 MHz, 50% DAC methods were within the acceptance standards in table IWB-3511-1 (ASME Section XI, 1980 Edition with the Winter 1981 Addenda), no high frequency data were taken.

B.3 FRACTURE ANALYSIS

There are two alternative sets of acceptance criteria for continued service without repair in paragraph IWB-3600 of the ASME Code Section XI:

1. Acceptance criteria based on flaw size (IWB-3611)
2. Acceptance criteria based on stress intensity factor (IWB-3612)

The choice of criteria is at the convenience of the user per IWB-3610. The more beneficial criteria of IWB-3612 have been used for evaluating the nineteen indications.

To determine the allowable flaw sizes in a weld, finite element analysis methods were used.

All applicable plant transients were analyzed to select the most severe stress profiles through the thickness of the weld. The actual stress profiles were then approximated by third order polynomials and used for calculating the stress intensity factor (K_I) for various crack sizes and aspect ratios.

The resulting K_I values were compared to fracture toughness values (K_{Ia} and K_{Ic}). Critical flaw sizes were then obtained, and allowable flaw sizes determined using the acceptance criteria discussed above.

The final step involves calculation of crack growth due to fatigue loading. All anticipated plant transients were utilized in determining the resulting flaw size for a specified period of time. This was done for 10, 20, and 30 year intervals.

In addition to satisfying the fracture criteria, it is required that the primary stress limits of Section III paragraph NC-3000 be satisfied. A local area reduction of pressure retaining membrane must be used, equal to the area of indication; and the stresses increased to reflect the smaller cross section.

The nineteen indications found are all subsurface flaws as defined by IWB-3500. As shown in figure B-4, all nineteen indications are acceptable per the fracture analysis criteria of IWB-3600. The fracture evaluation methods used for these analyses have been documented in the main body of this report.

It should be mentioned that some elevation of the hydrotest and leak test temperatures over the specified temperature will be required to ensure the margins of IWB-3600 are maintained, and these temperatures have been provided along with the complete technical details of the analysis in the main body of this report. The revised hydrotest and leak test temperatures from this inspection are provided in figures B-5, B-6 and B-7.

B-4 SECONDARY WATER CHEMISTRY AND TUBE MATERIAL

Between 1979 and 1988 copper tubing in all the major secondary side heat exchangers and the condenser were replaced with stainless steel. The Plant Chemistry Group has interfaced with the Plant Operations Group to ensure favorable secondary side water chemistry. (Table B-6) KNPP S/G Chemistry limits are based on both EPRI and Westinghouse chemistry guideline philosophy. Efforts towards the optimization of water chemistry inside the steam generators has resulted in maintaining a suitable environment in terms of preventing the corrosion of the steam generator girth weld.

All of the indications noted during the 1988 inspections of Steam Generator "A" are volumetric in nature, subsurface, and are prior existing slag inclusions and/or voids. Further, the steam generator water chemistry and sludge data would support the conclusion the indications are not corrosion induced or crack-like.

B-5 REFERENCES

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B7. Rishel, R.D. "Summary Report: Volumetric Flaw Depth Sizing," MT-SMART-807, September 12, 1985 (submitted to Seabrook Power Station).

B8. Willetts, A. J., Ammirato, F. V., and Kietzman, E. K., Jones, J. A. Applied Research Company. Accuracy of Ultrasonic Flaw Sizing Techniques for Reactor Pressure Vessels, EPRI RP1570-2 Draft Interim Report, March 1988.

B9. Letter, Tomes WPS to Kurek W PSD. June 10, 1988, Subject: "Secondary Side Water Chemistry."

TABLE B-1

SUMMARY OF ULTRASONIC TEST INDICATIONS FOUND IN THE
KEWAUNEE UNIT 1 STEAM GENERATOR "A" WELD 1-5
(5.0 MHZ TRANSDUCER, -6 dB DROP SIZING, SIZING DATA)

	DATA	INDICATION	MEASURED "2a"	"S" (inside surface)	LENGTH
1.	45 degree	1	0.14"	0.08"	0.35"
2.	45 degree	2	0.30"	1.04"	0.50"
3.	45 degree	3	0.37"	0.28"	0.95"
4.	45 degree	4	--	--	--
5.	45 degree	5	--	--	--
6.	45 degree	6	--	--	--
7.	45 degree	7	0.31"	0.59"	1.0"
8.	60 degree	1	0.23"	0.35"	0.75"
9.	60 degree	2	0.52"	0.26"	1.2"
10.	60 degree	3	0.35"	0.12"	1.55"
11.	60 degree	4	0.52"	0.26"	1.5"
12.	60 degree	5	0.30"	0.65"	2.1"
13.	60 degree	6	0.47"	0.41"	1.4"
14.	60 degree	7	0.30"	0.69"	2.9"
15.	60 degree	8	0.47"	0.20"	12.1"
16.	60 degree	9	0.35"	0.69"	13.25"
17.	60 degree	10	0.41"	0.71"	1.0"
18.	60 degree	11	0.47"	0.37"	1.8"
19.	60 degree	12	0.37"	0.30"	2.8"

TABLE B-2

SUMMARY OF ULTRASONIC TEST INDICATIONS FOUND IN THE KEWAUNEE UNIT 1 STEAM GENERATOR "A" WELD 1-5 (2.25 MHZ TRANSDUCER, 50% DAC SIZING, DETECTION DATA)

	DATA	INDICATION	MEASURED "2a"	"S" (inside surface)	LENGTH
1.	45 degree	1	0.35"	0.12"	1.25"
2.	45 degree	2	0.43"	0.51"	0.85"
3.	45 degree	3	0.39"	0.39"	0.85"
4.	45 degree	4	0.12"	0.59"	0.60"
5.	45 degree	5	0.23"	0.67"	*
6.	45 degree	6	*	0.87"	*
7.	45 degree	7	0.23"	0.53"	1.4"
8.	60 degree	1	0.76"	0.0"	0.75"
9.	60 degree	2	0.46"	0.35"	1.0"
10.	60 degree	3	0.76"	0.12"	1.55"
11.	60 degree	4	0.52"	0.41"	0.9"
12.	60 degree	5	0.41"	0.34"	0.75"
13.	60 degree	6	0.64"	0.41"	1.0"
14.	60 degree	7	0.47"	0.64"	0.7"
15.	60 degree	8	0.42"	0.07"	12.1"
16.	60 degree	9	0.29"	0.82"	13.25"
17.	60 degree	10	0.46"	0.65"	1.0"
18.	60 degree	11	0.46"	0.47"	1.8"
19.	60 degree	12	0.58"	0.23"	1.8"

*To small to measure

TABLE B-3
NONDESTRUCTIVE VERSUS DESTRUCTIVE TESTING RESULTS
USING 2.25 MHZ, 50% DAC SIZING

PHYSICAL SAMPLE	DISTANCE FROM ID SURFACE		THROUGH-WALL DEPTH		LENGTH	
	UT	ACTUAL	UT	ACTUAL	UT	ACTUAL
CORE #1 (Plant 1)	**	**	.37" to 1.03	0.09"	1.18" to 3.18"	1.15"
CORE #2 (Plant 1)	**	**	.16" to .58"	0.02"	.63" to .75"	0.45"
CORE #1 (Plant 2)	0.00"	0.08" to 0.33" *	0.24"	0.01" to 0.33"	0.88"	0.25" to 0.28"
CORE #2 (Plant 2)	0.16"	0.82"	0.53"	0.18"	0.88"	0.27"
GRINDING (Plant 2)	0.05"	**	0.37"	**	1.00"	**
GRINDING (Plant 2)	0.00"	0.375"	0.45"	0.094"	3.5"	**
GRINDING (Plant 2)	0.00"	0.125"	0.51"	0.156"	3.25"	**
GRINDING (Plant 2)	0.02"	0.156"	0.43"	0.219"	0.75"	0.375"
GRINDING (Plant 2)	0.00"	**	0.24"	**	0.75"	**
GRINDING (Plant 2)	0.00"	0.219"	0.33"	0.343"	1.0"	0.438"

* One UT indication was found to be four indications upon metallurgical evaluation. The values show the range of sizes for these four defects.

** Dimensions not reported.

TABLE B-4
RESULTS OF THE ASME SECTION XI, 1980 EDITION
WITH THE WINTER 1981 ADDENDA CALCULATIONS USING
THE ACCEPTANCE STANDARDS OF TABLE IWB-3511-1
(COMPOSITE SIZING DATA)

DATA	INDICATION NO.	MEASURED "2a"[1]	TYPE OF IND.	"a"	"S"	"ℓ"	a/t ALLOW.	a/t ACTUAL
1. 45 deg.	1	0.14"	subsurf.	0.07"	0.08"	0.35"	3.6%	1.9%
2. 45 deg.	2	0.30"	subsurf.	0.15"	1.04"	0.50"	4.6%	4.0%
3. 45 deg.	3	0.37"	subsurf.	0.19"	0.28"	0.95"	3.6%	5.1%
4. 45 deg.	4	0.12"	subsurf.	0.06"	0.59"	0.60"	2.9%	1.6%
5. 45 deg.	5	0.23"	subsurf.	0.12"	0.67"	*	7.2%	3.2%
6. 45 deg.	6	*	subsurf.	*	0.87"	*	*	*
7. 45 deg.	7	0.31"	subsurf.	0.16"	0.59"	1.0"	3.3%	4.2%
8. 60 deg.	1	0.23"	subsurf.	0.12"	0.35"	0.75"	3.2%	3.2%
9. 60 deg.	2	0.52"	subsurf.	0.26"	0.26"	1.2"	3.8%	6.8%
10. 60 deg.	3	0.35"	subsurf.	0.35"	0.12"	1.55"	2.0%	4.8%
11. 60 deg.	4	0.52"	subsurf.	0.26"	0.26"	1.5"	3.4%	7.0%
12. 60 deg.	5	0.30"	subsurf.	0.15"	0.65"	2.1"	2.8%	4.0%
13. 60 deg.	6	0.47"	subsurf.	0.24"	0.41"	1.4"	3.4%	6.4%
14. 60 deg.	7	0.30"	subsurf.	0.15"	0.69"	2.9"	2.8%	4.0%
15. 60 deg.	8	0.47"	subsurf.	0.24"	0.20"	12.1"	2.2%	6.1%
16. 60 deg.	9	0.35"	subsurf.	0.18"	0.69"	13.25"	2.6%	4.9%
17. 60 deg.	10	0.41"	subsurf.	0.21"	0.71"	1.0"	3.7%	5.7%
18. 60 deg.	11	0.47"	subsurf.	0.24"	0.37"	1.8"	3.1%	6.4%
19. 60 deg.	12	0.37"	subsurf.	0.19"	0.30"	2.8"	2.8%	5.1%

* To small to measure.

[1] From table B-1 except for 45 degree indications 4, 5, and 6 which are from table B-2.

TABLE B-5
RESULTS OF THE ASME SECTION XI, 1980 EDITION
WITH THE 1981 WINTER ADDENDA IWB CALCULATIONS USING
THE ACCEPTANCE STANDARDS OF TABLE 3511-1
2.25 MHZ TRANSDUCER, 50% DAC SIZING DETECTION DATA

DATA	INDICATION NO.	MEASURED "2a"	TYPE OF IND.	"a"	"S"	"ℓ"	a/t ALLOW.	a/t ACTUAL
1. 45 deg.	1	0.35"	subsurf.	0.18"	0.12"	1.25"	2.1%	4.8%
2. 45 deg.	2	0.43"	subsurf.	0.22"	0.51"	0.85"	4.2%	5.9%
3. 45 deg.	3	0.39"	subsurf.	0.20"	0.39"	0.85"	4.0%	5.4%
4. 45 deg.	4	0.12"	subsurf.	0.06"	0.59"	0.60"	2.9%	1.6%
5. 45 deg.	5	0.23"	subsurf.	0.12"	0.67"	*	7.2%	3.2%
6. 45 deg.	6	*	subsurf.	*	0.87"	*	*	*
7. 45 deg.	7	0.23"	subsurf.	0.12"	0.53"	1.4"	2.9%	3.1%
8. 60 deg.	1	0.76"	surface	0.76"	0.0"	0.75"	3.7%	20.4%
9. 60 deg.	2	0.46"	subsurf.	0.23"	0.35"	1.0"	3.9%	6.2%
10. 60 deg.	3	0.76"	surface	0.76"	0.12"	1.55"	3.7%	20.4%
11. 60 deg.	4	0.52"	subsurf.	0.26"	0.41"	0.9"	4.5%	7.0%
12. 60 deg.	5	0.41"	subsurf.	0.21"	0.34"	0.75"	4.3%	5.5%
13. 60 deg.	6	0.64"	subsurf.	0.32"	0.41"	1.0"	4.8%	8.6%
14. 60 deg.	7	0.47"	subsurf.	0.23"	0.64"	0.7"	5.1%	6.17%
15. 60 deg.	8	0.42"	surface	0.42"	0.07"	12.1"	1.7%	11.4%
16. 60 deg.	9	0.29"	subsurf.	0.15"	0.82"	13.25"	2.64%	4.1%
17. 60 deg.	10	0.46"	subsurf.	0.23"	0.65"	1.0"	3.9%	6.3%
18. 60 deg.	11	0.46"	subsurf.	0.23"	0.47"	1.8"	3.08%	6.17%
19. 60 deg.	12	0.58"	subsurf.	0.29"	0.23"	1.8"	2.59%	7.77%

* To small to measure.

TABLE B-6
SECONDARY SIDE HEAT EXCHANGER TUBING MATERIALS

COMPONENT	MATERIAL
Condenser	439 Stainless Steel
Feedwater Heaters 11A, 11B, 12A, 12B, 13A and 13B	439 Stainless Steel
Feedwater Heaters 14A, 14B, 15A and 15B	304 Stainless Steel
Moisture Separator Reheaters 1A1, 1A2, 1B1 and 1B2	439 Stainless Steel
Gland Steam Condenser	439 Stainless Steel

SECONDARY SIDE CHEMISTRY:

- Phosphates were eliminated from the secondary water during the middle of the first cycle.
- The in-line chemistry monitors, their ranges and the alarm setpoints are based on vendor recommendations, EPRI guidelines and plant experience.
- KNPP cleans-up the secondary water systems during start-ups.
- Sludge lancing, tube bundle washdowns, and wet lay-up are routine steam generator activities during refueling outages.
- Feedwater heater tube cleaning is routinely performed during refueling outages.
- There are chemistry hold points at low power operations at KNPP.

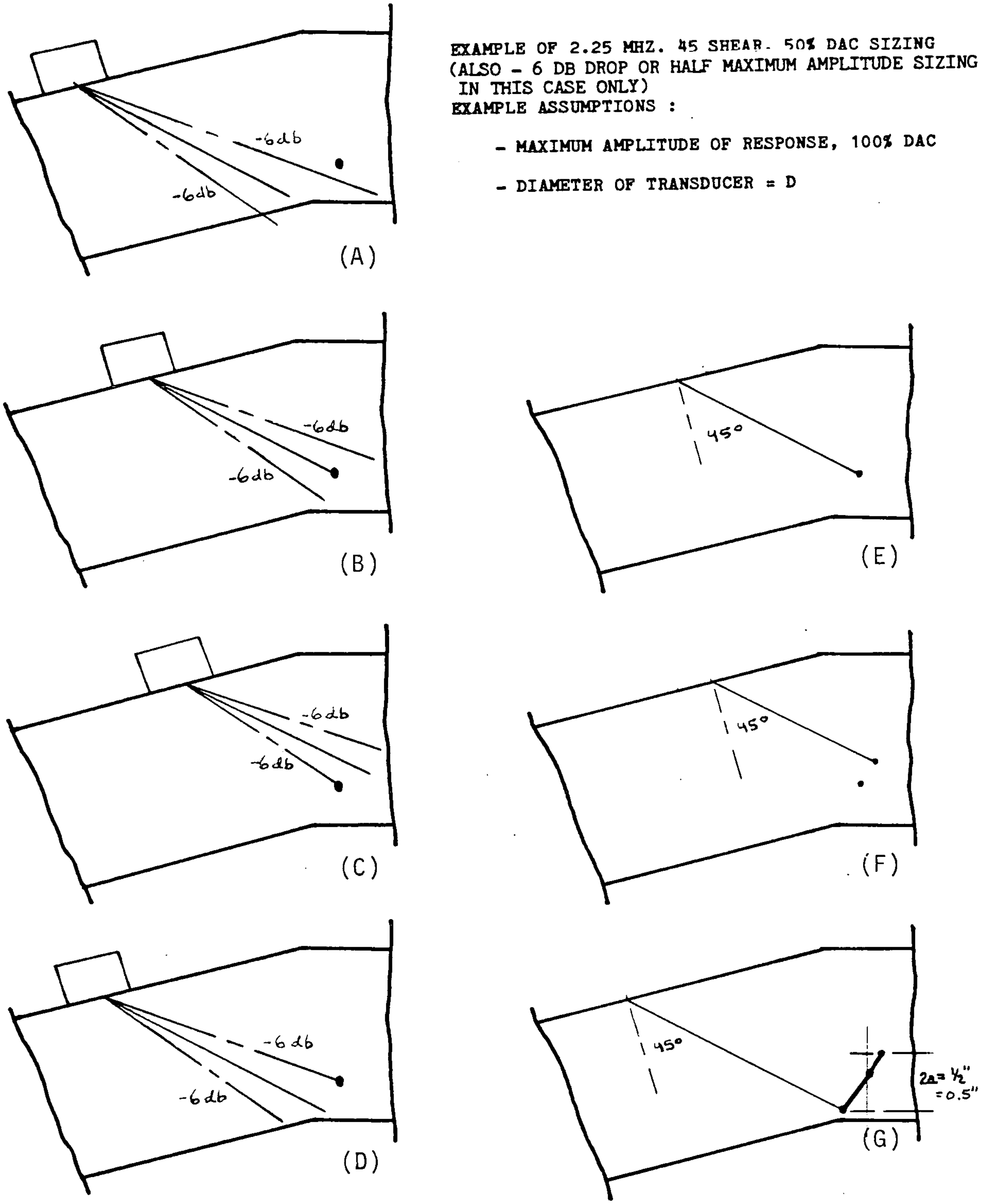


Figure B-1. Schematic Example of Flaw Sizing with 2.25 MHz Transducer Using 50% DAC Sizing Levels. (This particular example also shows -6 dB drop or half maximum amplitude sizing.)

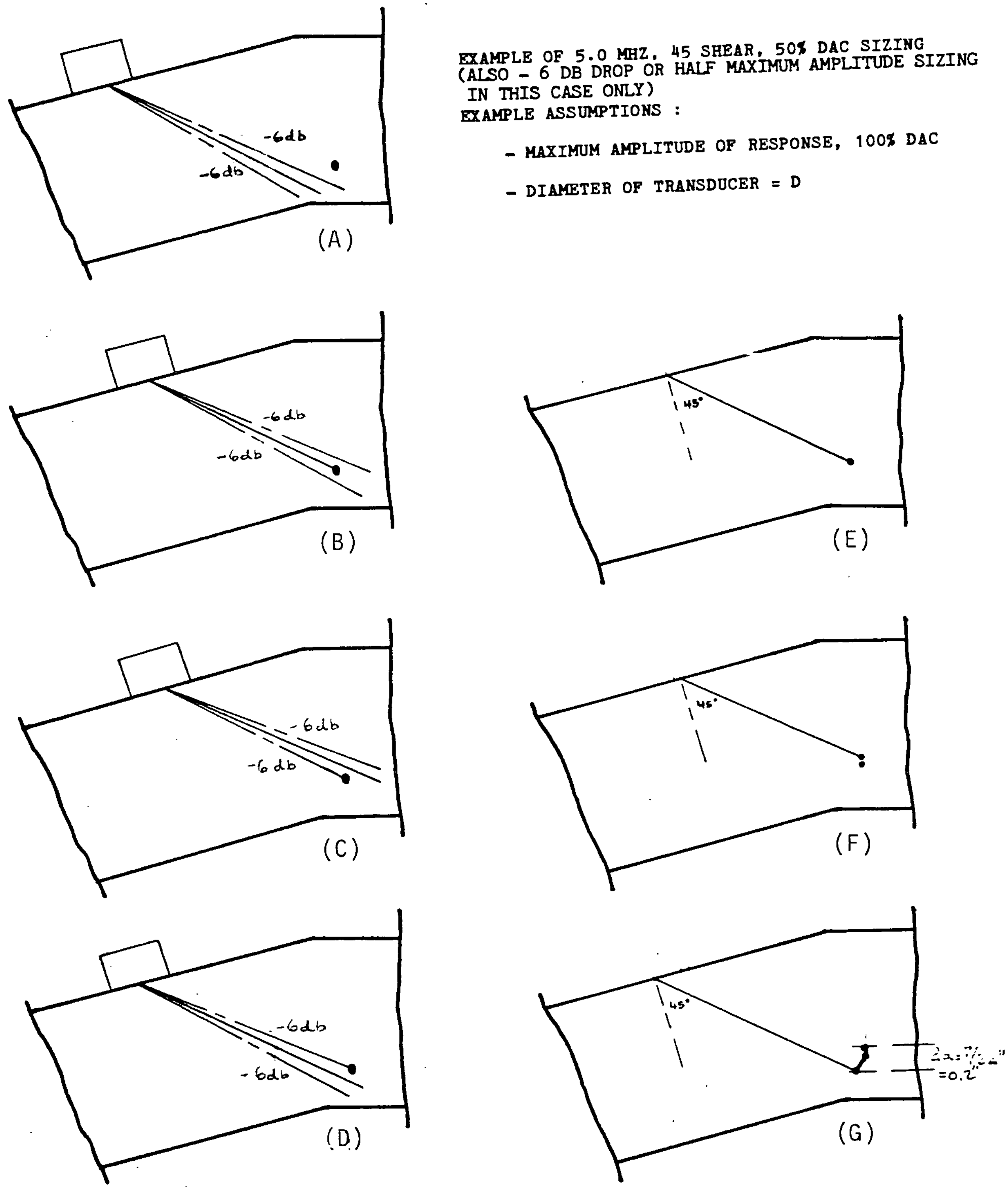


Figure B-2. Schematic Example of Flaw Sizing With 5.0 MHz Transducer Using 50% DAC Sizing Levels. (This particular example also shows -6dB drop or half maximum amplitude sizing.)

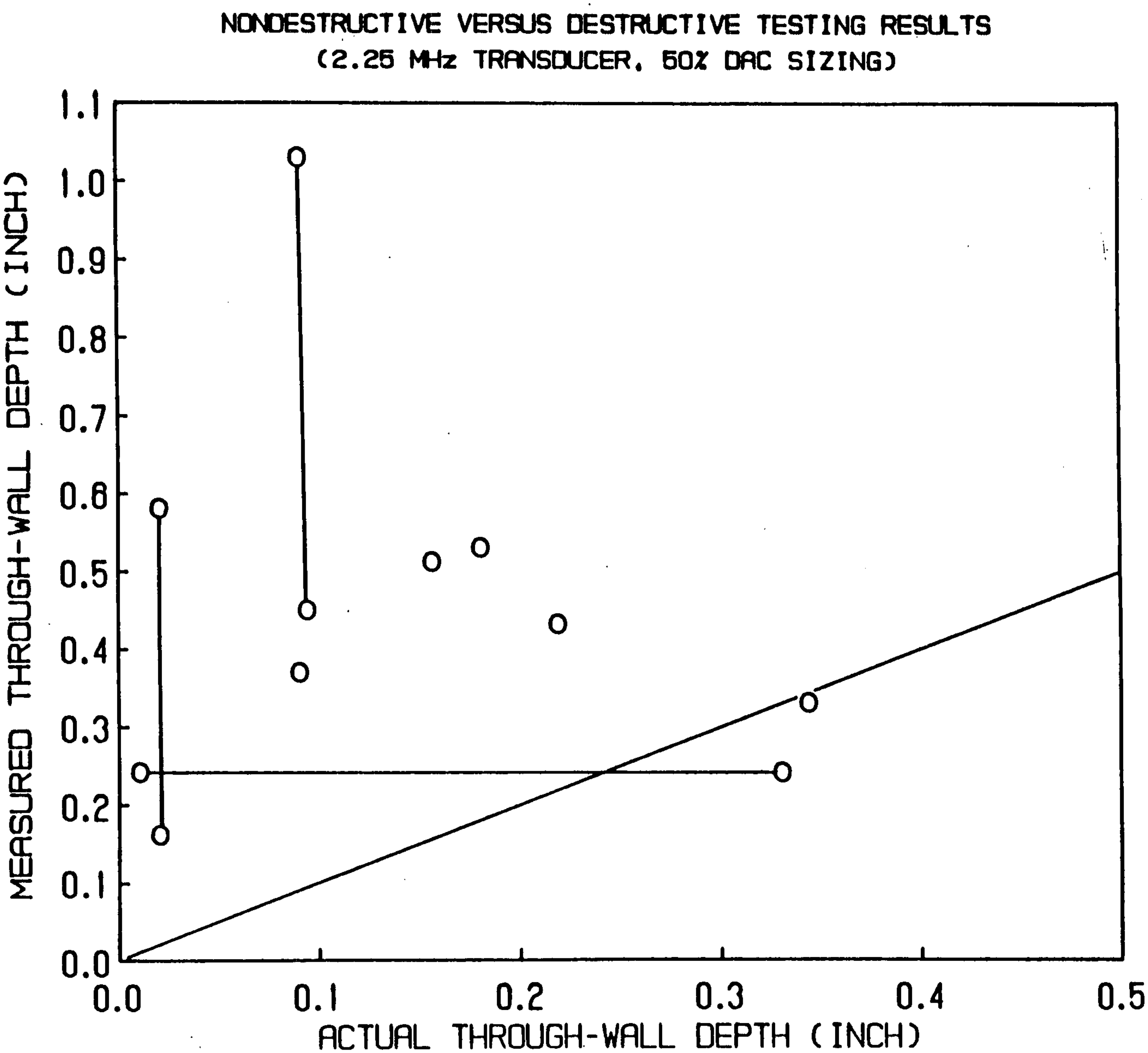
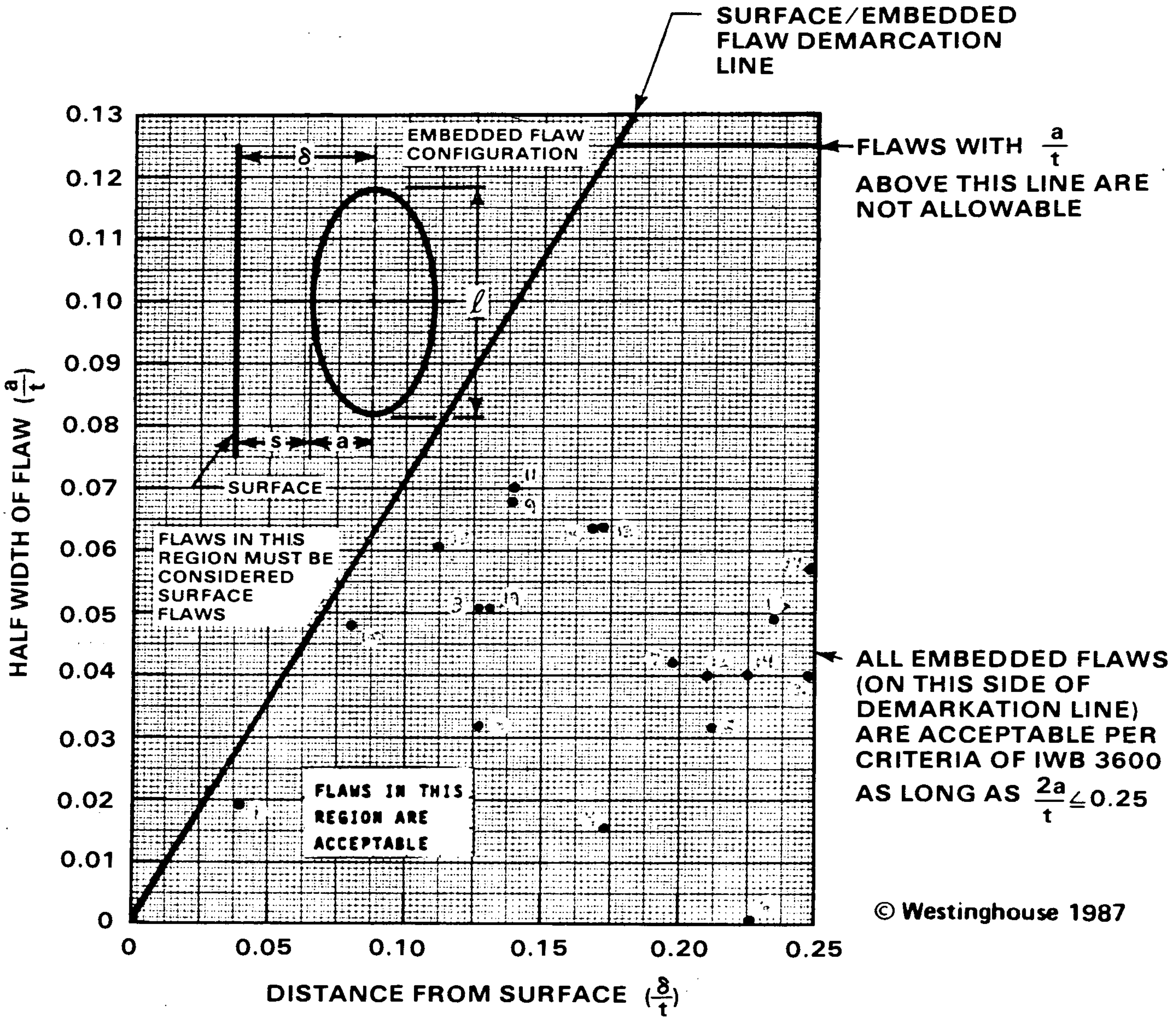


Figure B-3. Nondestructive vs. Destructive Testing Results, 2.25 MHz Transducer with 50% DAC Sizing

2949s/032588:10



	DATA	IND.	TYPE OF IND.	MEASURED "2a"	MEASURED "S"	MEASURED "t"	a/t	δ/t	ACCEPT-ABLE
1.	45 deg.	1	subsurf.	0.14"	0.08"	3.73"	0.019	0.040	yes
2.	45 deg.	2	subsurf.	0.30"	1.04"	3.73"	0.040	0.320	yes
3.	45 deg.	3	subsurf.	0.37"	0.28"	3.73"	0.051	0.126	yes
4.	45 deg.	4	subsurf.	0.12"	0.59"	3.73"	0.016	0.174	yes
5.	45 deg.	5	subsurf.	0.23"	0.67"	3.73"	0.032	0.212	yes
6.	45 deg.	6	subsurf.	0.00"	0.87"	3.73"	0.000	0.233	yes
7.	45 deg.	7	subsurf.	0.31"	0.59"	3.85"	0.042	0.195	yes
8.	60 deg.	1	subsurf.	0.23"	0.35"	3.73"	0.032	0.126	yes
9.	60 deg.	2	subsurf.	0.52"	0.26"	3.73"	0.068	0.139	yes
10.	60 deg.	3	subsurf.	0.35"	0.12"	3.73"	0.048	0.080	yes
11.	60 deg.	4	subsurf.	0.52"	0.26"	3.73"	0.070	0.139	yes
12.	60 deg.	5	subsurf.	0.30"	0.65"	3.79"	0.040	0.211	yes
13.	60 deg.	6	subsurf.	0.47"	0.41"	3.73"	0.064	0.174	yes
14.	60 deg.	7	subsurf.	0.30"	0.69"	3.37"	0.040	0.225	yes
15.	60 deg.	8	subsurf.	0.47"	0.20"	3.93"	0.061	0.112	yes
16.	60 deg.	9	subsurf.	0.35"	0.69"	3.68"	0.049	0.236	yes
17.	60 deg.	10	subsurf.	0.41"	0.71"	3.68"	0.057	0.250	yes
18.	60 deg.	11	subsurf.	0.47"	0.37"	3.73"	0.064	0.164	yes
19.	60 deg.	12	subsurf.	0.37"	0.30"	3.73"	0.051	0.131	yes

Figure B-4. Fracture Analysis Results for Indications Found in the Kewaunee Unit 1 Steam Generator "A" Weld 1-5 (Composite Sizing Data)

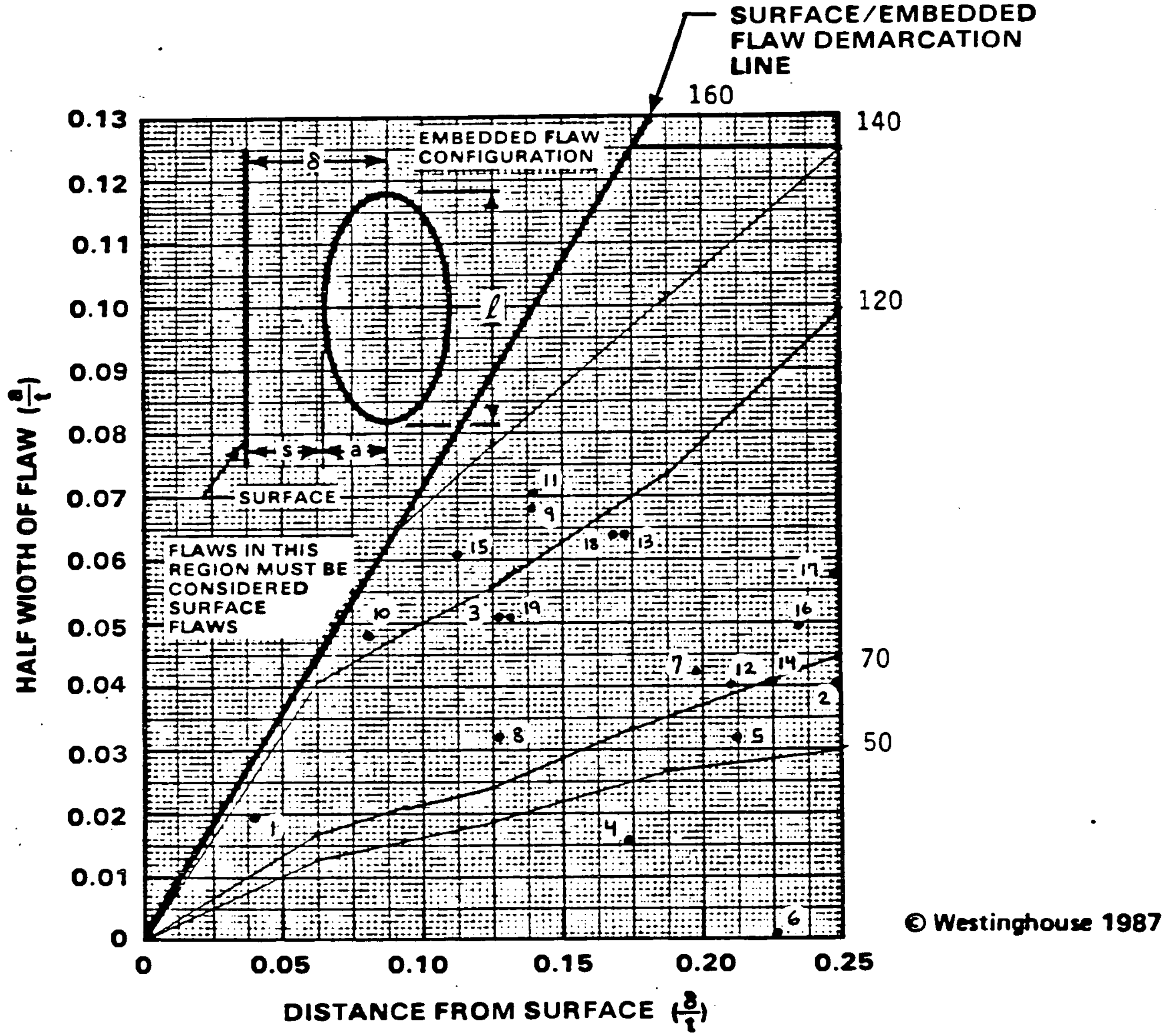


Figure B-5. Determination of Hydrostatic Test Temperatures from Results of the March 1988 Inspection (Composite Sizing Data) (p = 1356 psi)

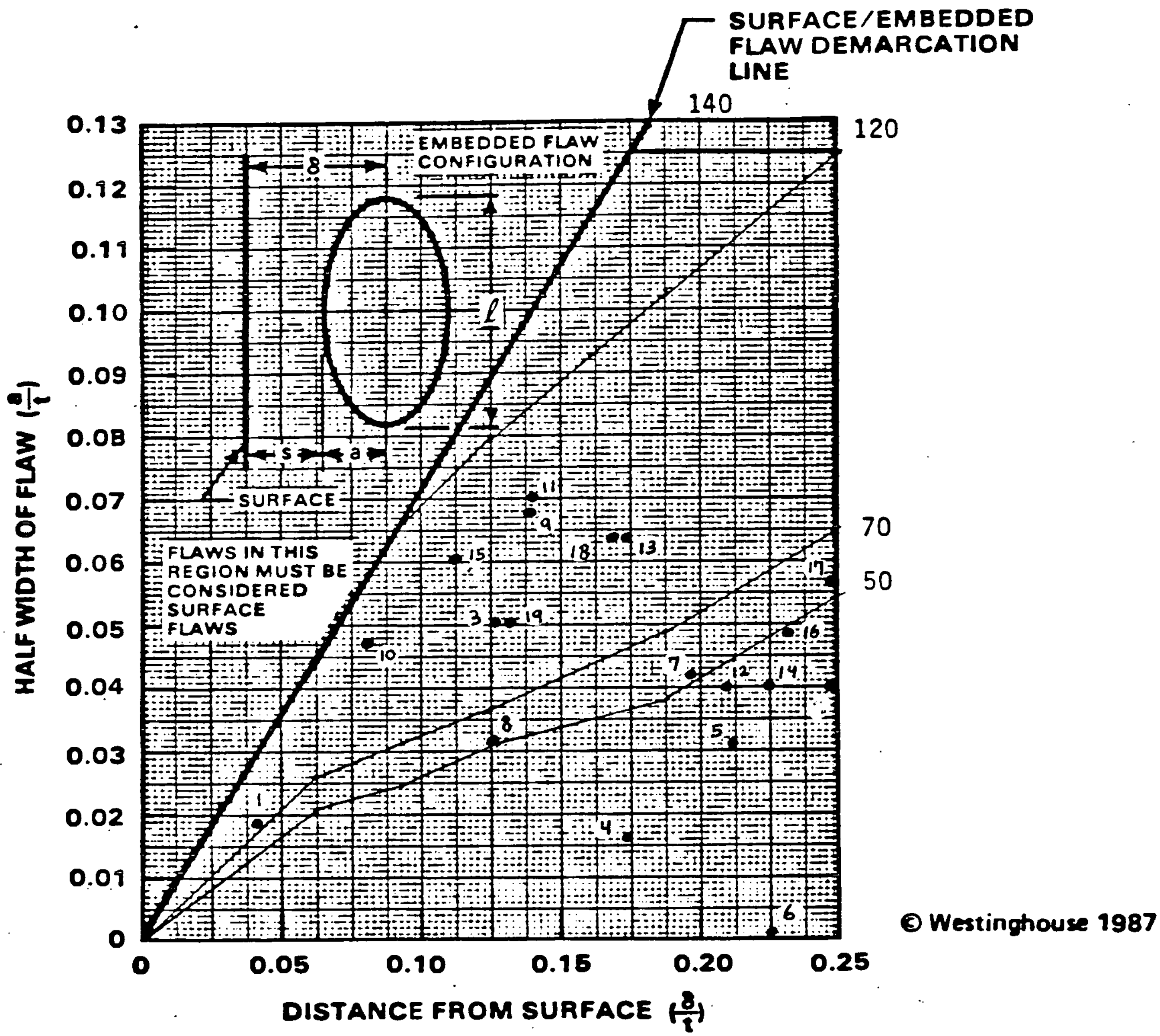


Figure B-6. Determination of Leakage Test Temperatures from Results of the March 1988 Inspections (Composite Sizing Data) (p = 1085 psi)

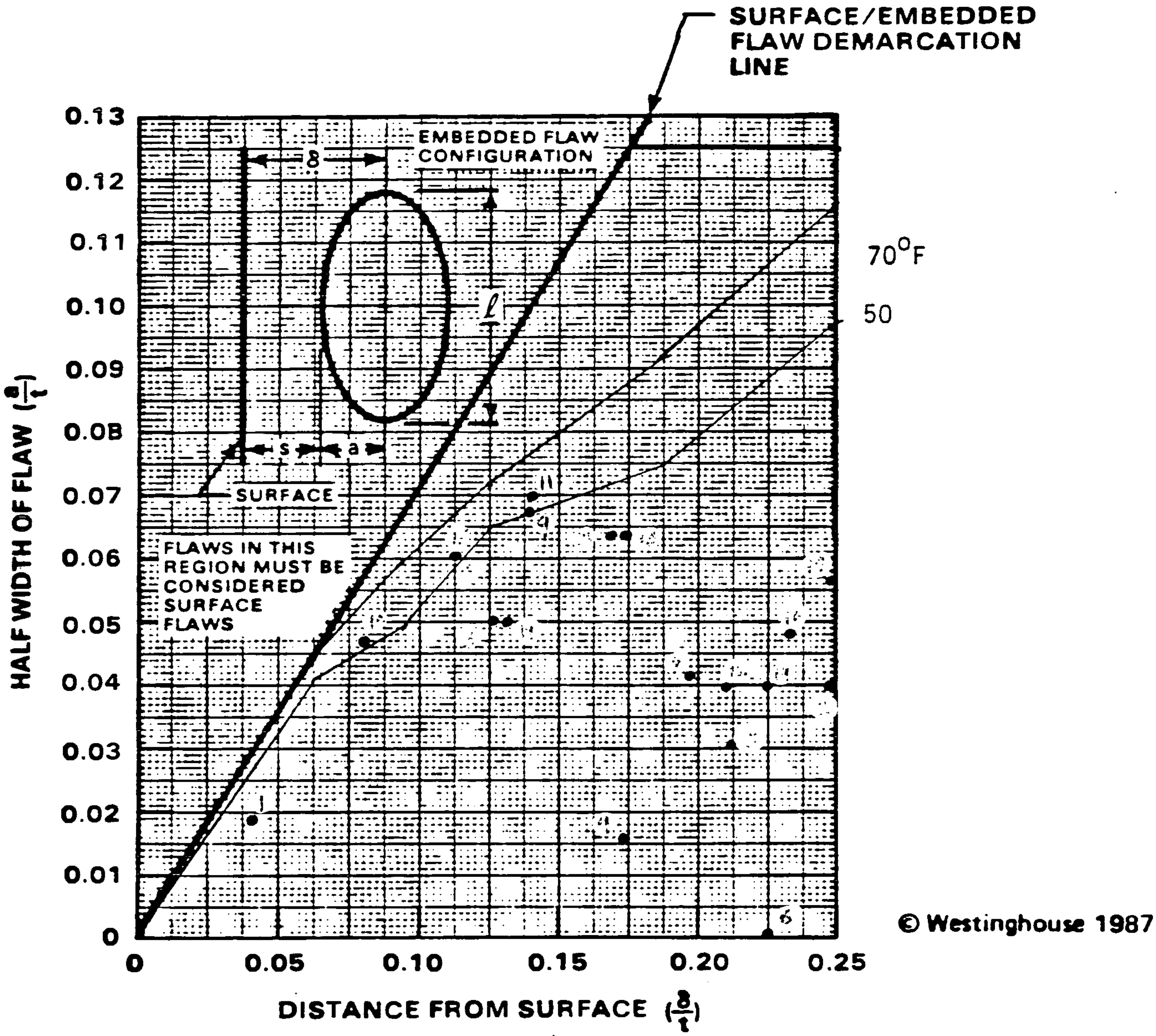


Figure B-7. Determination of Leakage Test Temperatures from Results of the March 1988 Inspections (Composite Sizing Data) (p = 750 psi)

APPENDIX C

RESULTS OF THE INSPECTION OF APRIL 1991, KEWAUNEE STEAM GENERATORS A AND B

C-1 SUMMARY

During the Spring 1987 manual ultrasonic examinations of the Kewaunee Unit 1 Steam Generator "B" upper shell to cone weld, a total of nine indications were detected and recorded with 45 and 60 degree, 2.25 MHz shear wave examinations. At that time, all available evidence including inspection experience with the same weld joint at other plants resulted in a conclusion that the indications were volumetric in nature, i.e., slag and small voids.

In the Spring 1988 examinations of the Kewaunee Unit 1 Steam Generator "A" upper shell to cone weld, a total of 19 indications were detected and recorded using the same examination methodology. The indications were quite similar to those found on Steam Generator "B" in terms of through-thickness location. Again, the evidence suggested that all of the recorded indications were volumetric in nature, occurring primarily in the weld "back chip" area within an inch of the I.D. surface.

In both investigations (detailed in Appendix A and B of this report) the indications were sized again with 5.0 MHz search units which resulted in a more realistic assessment of the through-wall dimensions. Investigations were also conducted with straight beam search units and several indication locations were confirmed, supporting the conclusion that the flaws were embedded.

The March 1991 examinations of the Kewaunee Unit 1 Steam Generator "A" and "B" upper shell to cone welds (weld numbers 1-5 and 2-5), were conducted in two phases which will be identified herein as manual and automated. In the manual examinations, which were conducted primarily as a detection and surveillance activity, both upper shell cone welds were completely re-examined with the previously used code compliant techniques requiring 2.25 MHz transducers and calibrations performed on the standard steam generator calibration block using side drilled holes. This examination served the purpose of relocating and measuring previously disclosed indications in both welds for comparison.

All recordable indications identified in the 2.25 MHz examinations on both upper shell to cone welds were sized again with 5 MHz transducers using -6dB drop or half maximum amplitude sizing criteria. In terms of the amplitude drop sizing methods, the 5 MHz data provides a more realistic estimate of flaw sizes due to the smaller beam size and the nature of embedded discontinuities. Since the majority of the indications in both girth welds are essentially point reflectors, where beam size rather than flaw size is measured, the 5 MHz data proved to be conservative and, therefore, appropriate for the current fracture mechanics evaluation.

In the automated examinations, all indication areas in both upper shell to cone welds were examined with techniques and equipment specifically designed to resolve flaw features in the greatest possible detail. Scanning routines were designed to allow for complementary angle/scan direction studies at high sensitivity to establish a) the through-thickness location of the indications, b) perform amplitude independent sizing measurements on all indications revealed in the manual examinations and c) examine the inner diameter surface of the steam generator for evidence of cracking.

The Dynacon Systems Inc. Ultrasonic Data Recording and Processing (UDRPS) system was utilized for all of the automated data acquisition and served as the primary analysis tool for indication through-wall sizing, for the assessment of indication through-thickness location, and for the measurement of the ligament of metal between the indication and the inside diameter surface. Nearly 100 data sets comprising approximately 1000 scans were performed and stored on optical disk for off line analysis.

Using the fracture analysis rules of IWB-3600 and the guidelines of Appendix A, both from the ASME Code Section XI, 1980 Edition with the Winter 1981 Addenda, all the indications are acceptable using -6dB or half maximum amplitude sizing levels with 5.0 MHz manual examination data (Ref. Figures C-1.1, C-1.2 and C-2).

Indication analysis conducted on the processed UDRPS data using amplitude independent sizing techniques resulted in the best possible estimate of through-wall extent. When combined with the 50% DAC length measurements from the manual examinations, the dimensions of all recorded flaws in both upper shell to cone welds are within the allowable limits of the ASME Code, Section XI, Table IWB 3511-1. Figures C-3 and C-4 show the UDRPS sizing data for Steam Generator A and B plotted on the fracture analysis flaw chart.

C-2 ULTRASONIC EVALUATION AND DISCUSSION

C-2.1 MANUAL EXAMINATIONS

In the 1991 manual examinations, both Steam Generator upper cone welds were completely re-examined with 2.25 MHz, 45 and 60 degree shear wave transducers. Calibrations for the examinations were conducted on block #WPS-36, a 3.5 inch thick carbon steel reference block used for all previous inspection work on the upper cone circumferential welds. The examinations were performed as the primary detection technique, for the purpose of identifying and measuring all previously disclosed ultrasonic indications, and to identify additional areas requiring further investigation. The results of these detection examinations are as follows:

In Steam Generator "A" (weld 1-5), a total of 32 indications were detected. This total included 19 recordings which were directly related by position to the 19 indications recorded in 1988 (12-60 degree and 7-45 degree). In 5 instances, the same indication was recorded by two beam angles or by the same beam angle in opposing directions. Comparison of the 1991 data and 1988 data was possible in all cases, and the recorded lengths, amplitudes and through-wall sizes were essentially unchanged. In addition, 13 previously unidentified volumetric type indications were recorded for further investigation (Figures C-5.1 through C-5.3).

In Steam Generator "B" (weld 2-5), a total of 17 indications were detected. This total included 9 recordings which were directly related by position to the 9 indications recorded in 1987. In 2 instances, the same indication was recorded by two beam angles. Comparison of the 1991 and 1987 data was possible in all cases, and the recorded lengths, amplitudes and through-wall sizes were essentially unchanged. In addition, 8 previously unidentified volumetric type indications were recorded for further investigation (Figures C-6.1 and C-6.2).

All 32 detections in Steam Generator "A" and the 17 detections from Steam Generator "B" were sized with a 5.0 MHz, 0.5 inch square transducer using the -6dB or half-maximum amplitude technique, regardless of their size or acceptability status. In the -6dB technique, the indication peak response was normalized at a level of 80% full screen height. The examiner then recorded the peak, and minimum and maximum sweep position and transducer location data as the amplitude dropped to 40% full screen height.

The purpose of the 5 MHz half maximum amplitude sizing data was to apply conservative amplitude based flaw measurements for the fracture mechanics analysis and to provide for a reliable baseline of recorded data if future manual examinations are required.

Supplemental 0 degree examinations using a 5.0 MHz, 0.5 inch dia. single and dual element transducers were performed on all the indication areas in both upper shell to cone welds. All indications were identified with these examinations.

C-2.2 AUTOMATED EXAMINATIONS

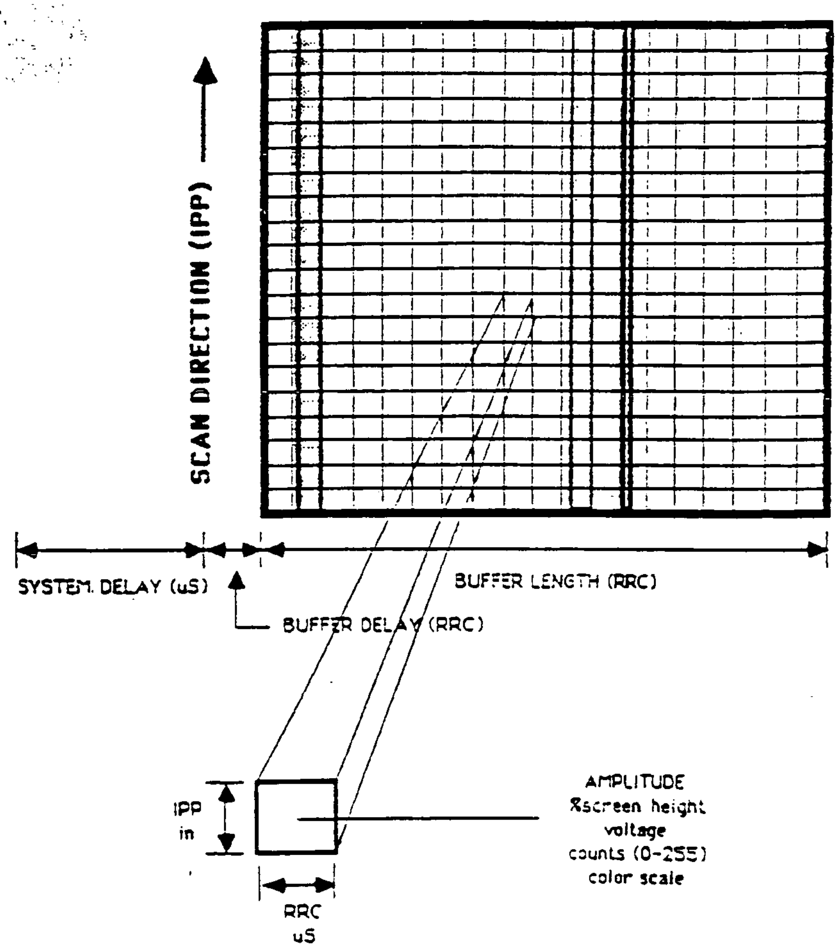
Automated examinations using the UDRPS system were conducted on all the indications areas identified in the detection examinations. Prior to conducting the examination, a system and sizing technique qualification demonstration was performed in the presence of the

Authorized Nuclear Inservice Inspector, and representatives from Wisconsin Public Service Plant Engineering, Quality Control, and Quality Assurance departments. The qualification process involved automated data acquisition with 45 and 60 degree shear wave transducers on the 3.5 inch Code calibration block, other reference blocks, and the detection and sizing of embedded and surface connected mechanical fatigue cracks in carbon steel qualification blocks.

C.2.2.1 TEST PARAMETERS

Transducer selection was based primarily on the potential for high resolution of specific flaw features. The KB Aerotech Alpha, 2.25 MHz 0.75 inch square element was chosen as the primary acquisition transducer in both the 45 degree and 60 degree examinations. The KB Aerotech Gamma, 2.25 MHz, 0.5 x 1.0 inch 45 degree search unit was also used effectively in both the demonstration and in a limited number of scans performed on Generator "A". Transducer frequency was limited to 2.25 MHz for the purposes of maximizing penetration with the least practical amount of system gain, enabling the analyst to increase gain in the range of 5 to 10 times ASME Code sensitivity (+14 to +20dB).

UDRPS acquisition parameters were adjusted for the highest possible effective digitization rate (EDR), which is expressed in range resolution cell size (RRC). The spacing or distance between consecutively recorded A-scans is referred to as the inter pulse period (IPP). On the UDRPS display, these values represent one pixel movement in the scan direction and one in the time domain as follows:



These values are a reflection of measurement capability in the processed data. In the case of the 45 degree transducer, the RRC size was 0.25 microseconds and in the 60 degree data, the RRC size was 0.5 microseconds, or metal path resolution values of 0.0313 and 0.0626 inches respectively. In both cases, the IPP was set at 0.02 inches.

System set-up parameters were established on the 3.5 inch Code calibration block. It is here that refracted angle, velocity, and pulses per beam width can be set, and system performance was verified at scanning speed.

The motorized scanner selected for this application was a standard Dynacon Systems "Dynascanner" equipped with encoder feedback. Scanning speed was maintained smoothly at 1.5 inches per second in both the qualification trials and during data acquisition. The distances between scan lines was maintained at 0.25 inches.

C-2.2.2 RESULTS OF THE SIZING QUALIFICATIONS

A total of 4 blocks were used in the sizing qualification demonstration. The 3.5 inch thick Code calibration block, identified as #WPS-36, contains 0.187 inch diameter side drilled holes and a 2% deep buttress notch. Scanning was performed over both reflector types. The side drilled holes (Fig. C-7) provided a reference source for verifying the calculation in the Satellite Pulse Observation Technique (SPOT)[1] as applied to an ideal cylindrical void. The buttress notch provided a good representation of a surface intersecting planar flaw. The notch reflector was scanned at a gain value of calibration sensitivity +6dB. From figure C-8, the notch target image is saturated, (highly reflective) showing an image on both sides of the block O.D. surface. Even though the notch is an ideal surface reflector, the response characteristics are similar to actual surface breaking cracks in ferritic specimens.

A second reference block, identified as the DSI block, provided a side drilled hole reference source for verifying the SPOT technique on ideal cylindrical void sizes significantly smaller than the code block (0.046" vs. 0.187"), (Fig. C-9). This range of hole sizes enabled the analysts to derive a simplified formula which could be effectively applied to the rounded inclusion sizes which might be expected in the examination.

$$d_o = \Delta Zt \times .7145$$

where: d_o = void diameter

ΔZt = metal path (synchronous satellite) - metal path (specular)

The satellite pulse observation technique has been proven effective in the initial classification of flaws and as the primary sizing method when synchronous satellite pulse responses are observed.[1]

In an effort to prove the capability for detection and accurate sizing of surface and near surface cracks, two 3 inch thick specimens containing cracks were included in the demonstration. The blocks, identified as NATD #3 and NATD #15 (Figures C-10 and C-11), were scanned at various sensitivity levels. Generally, for both the 45 degree and 60 degree search units, a sufficient number of target secondary responses can be observed to permit sizing by Backward Scattering Tip Diffraction (BSTD) at calibration sensitivity +12dB (Fig. C-12, C-13 and C-14). Adequate detection of both crack types is shown with the 45 degree transducer at calibration sensitivity +6dB (Fig. C-12 and C-13). Actual examination sensitivities in the automated scans ranged from +12 to +20dB above the calibration sensitivity.

C.2.2.3 AUTOMATED EXAMINATION TECHNIQUE

The automated scanner was applied to each indication area disclosed in the manual examinations. The indications were bounded by the Level II operators manually first, and then a scan routine was programmed to sweep across the indication at increments of 0.25 inch. All indication areas were scanned with at least 2 routines. The first routine was conducted with the same beam angle and scan direction as in the manual recordings. System sensitivity was generally increased during the first scan to identify the indication and obtain as much sizing information as possible. Since the majority of the indications were detected with the 60 degree beam angle, the target images were seen as single specular reflections embedded within the examination volume with a limited amount of sizing information available to the analyst. A second scan routine was performed over the target area with a complimentary beam angle, generally 45 degrees. Care was taken during the scanning operations to insure that both transducers started at the same point, insuring that the spatial coordinates for a given target could be verified.

The second scanning routines proved to be the most beneficial in terms of revealing discrete flaw secondary responses, which were useful for sizing, and for confirming the through-thickness locations of the embedded flaw indications by visualizing the flaws in the 5/8 node (skip response). In most cases, the girth weld inside diameter surface provided few direct geometric-type responses, even at +20dB, indicating that the surface is smoothly finished. For indications revealed originally with a 45 degree transducer, the necessary sizing and location confirmation information was obtained with complimentary 45 degree scans.

As previously stated, the gain control was adjusted frequently during the scanning routines to reveal flaw secondary responses and perform through-wall sizing by amplitude independent methodologies. Unfortunately, this did not permit assessment of indication length, which can only be done in automated scanning when the gain control knob is left alone. Therefore, the length measurements from the 2.25 MHz manual detection data was used in the calculations for code acceptability. From a limited number of length estimates obtained in the automated data, our conclusion is that the manual length data is realistic.

C-3 DISCUSSION OF RESULTS

The results of the analysis of the UDRPS processed data indicate that all of the ultrasonic detections in Steam Generator "A" and "B" are from small embedded welding type discontinuities having relatively smooth, simple geometric shapes. The distribution of the discontinuities in and about the weld I.D. back chip area (Fig. C-15) is consistent with results obtained in identical weld configurations at other plants where these types of indications were confirmed by non-destructive and destructive testing. All indications were determined to be within the allowable limits of the ASME Code, Section XI, Table IWB-3511-1, 1980 Edition with Addenda through Winter 1981.

This conclusion is supported primarily by the automated scan data. The results of investigations on a total of 49 indications (32 in Generator "A" and 17 in Generator "B") show clearly that the flaw indications have small through wall dimensions (ranging from 0.1 to 0.27 inch), and are not connected with the inside surface. Further, in all the processed data, there is no evidence of cracking on the inside diameter surface. Scanning sensitivities were conducted in a range of 5 to 10 times Code sensitivity with the 45 degree beam, leading to a high probability of detection if cracking were present. Summary tables for the through thickness location methodologies are included as Figures C-16.1, C-16.2 and C-17.

The UDRPS processed color hard copy data for each indication is presented in Supplement 1. The indication assessment summaries preceed the UDRPS color hardcopy for each weld. Note that several indications thought originally to be unique and separate were confirmed in the processed data as being multiple recordings of the same indication. Where this is the case, only one evaluation was conducted, as referenced in the comments section of the indication assessment sheets.

For a discussion of the evaluation technique supporting the aforementioned conclusions, three examples from the supplement will be described in further detail. These include an example of a small rounded volumetric indication judged to be typical for the majority of the indications (Indication #60-B Fig. B-5), a small embedded flaw close to the I.D. surface which proved to be the most difficult interpretation (Indication 45-1, Fig. A-2), and finally, an embedded flaw judged to have planar characteristics in the processed data (Indication #60-10 Fig. A-16).

For indication #60-B (Fig. B-5), a single embedded target is identified on the 60 degree transducer sweep. The lines which are transcribed on the plot for weld centerline and I.D. surface are points calculated and interpolated directly from the display. Peak reflectivity along the target line is represented by a black dot, drawn in later to identify the target through thickness location. As is the case in most 60 degree scans, very little information is revealed in the scan sweep other than the specular or direct response from the target. As noted previously, the I.D. surface did not provide a great deal of geometric shadowing, even at higher gain settings, as evidenced by the fact that no geometry is noted on the 60 degree scan sweep, conducted at approximately 2x calibration sensitivity. The 45 degree hi-resolution scan (figure insert) of the same indication reveals more features of the indication for sizing (SPOT), and provides proof that the indication is embedded and isolated from the backwall by the strong 5/8 node response with no flaw targets identified along the I.D. surface. If indication 60-B was connected to the I.D. surface, both the half-vee and 5/8 node targets would probably be connected, as one continuous target image intersecting the I.D. surface as shown in the 45 degree scan sweep over the cracked specimen (Fig. C-12).

Indication 45-1 (Fig. A-2 and A-3) is closer to the I.D. surface than any of the other 48 indications. The indication was originally recorded manually in 1988 from scan direction 5, and was confirmed as having identical dimensions in 1991 (ref. sketch, Fig. A-3). In the automated scans, more quantitative information was available from scan direction 2 (Fig. A-2), where a strong indication of satellite pulse is observed on the UDRPS processed data sweeps. The I.D. surface shape in the area of interest is drawn on the screen by connecting measurement points from direct I.D. reflections and by estimating the surface contour by interpolating between half-vee and 5/8 node responses from other low amplitude indications in the area of interest. The location of indication 45-1 was also confirmed by using a 5.0 MHz, dual element, 0 degree beam applied directly beneath the weld crown on scan surface 2 (Fig. A-3), where the indication is seen approximately 0.2 inches from the backwall surface. The straight beam indication has a smooth echodynamic response in both the X and Y scan planes, supporting the indication classification as volumetric.

Indication 60-10 (Fig. A-16) is an embedded flaw providing a single specular response in the 60 degree scan. The weld centerline and I.D. surface are plotted directly from position data on the display. In the 45 degree high resolution scan (figure insert), the indication is highly reflective in the 5/8 node, indicating a preferred orientation. A secondary response, asynchronous in nature, was judged by position data to be related to the primary response, and was seen for a duration of at least two scan sweeps. All the indication points were combined for the through-wall estimate. It should be noted that a 0 degree beam reflection was noted in the area of interest of indication 60-10, leading to the possibility that the indication could be volumetric with a complex shape rather than purely planar.

Using advanced sizing techniques, the through-wall estimates for the majority of indications is around 0.1 inch. Since all the indications in both generators are judged to be embedded, and are therefore, prior existing, the radiographs were again carefully reviewed by qualified personnel in an attempt to confirm the presence of the ultrasonic indications. From available information, it was determined that a panoramic technique was used, with the film wrapped around the outside diameter surface of the girth weld and the Cobalt source placed in the center of the generator. Considering the radiographic quality measure of 2-2T, with a 4.1 inch weld section thickness, the maximum defect detectability would be around 0.080 inches. Since the majority of indications lie in a band separated from the film by a distance greater than 3 inches, it is not unreasonable to assume that detection would be borderline.

Another possibility considered is whether or not the U.T. indication locations correlate with fabrication repair areas. The results of this investigation, conducted by the Kewaunee Plant technical staff, is presented as Supplement 2. Results indicate that there is no general correlation to be made between the two.

C-4 CONCLUSIONS

From the results of the automated and manual test data, the following conclusions are offered:

1. All of the indications detected in the Kewaunee Steam Generator "A" and "B" upper shell to cone welds are the result of prior existing welding type discontinuities.

2. Indication bounding measurements are within the allowable limits of the ASME Code, Section XI, Table IWB-3511-1.

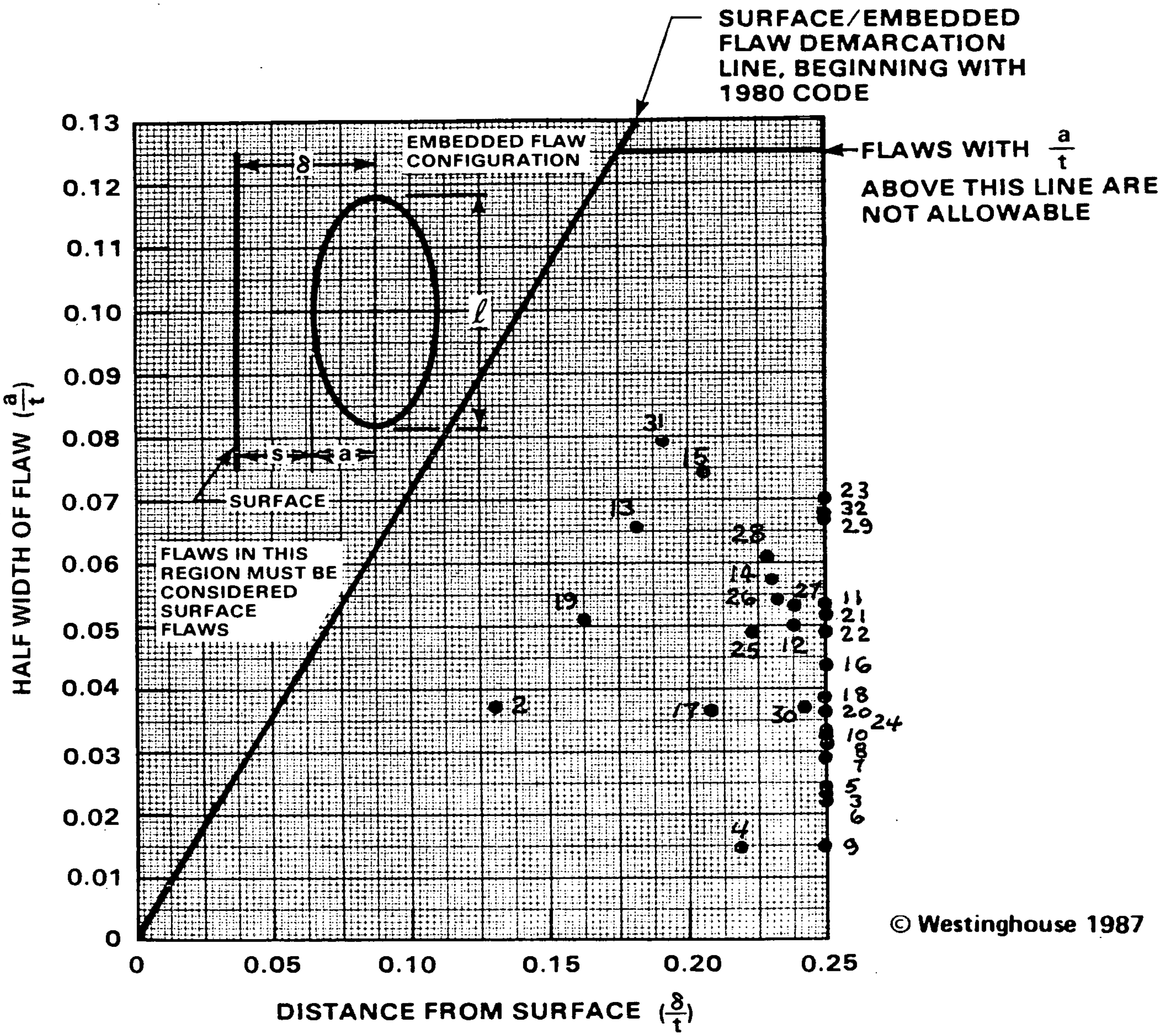
3. The indications are embedded, and generally located, within an inch of the inside diameter surface.

4. There is no evidence that the indications originate from or extend to the weld inside diameter surface.

5. Discontinuities remaining in the weld after fabrication were below the detection limits of the radiographic examination.

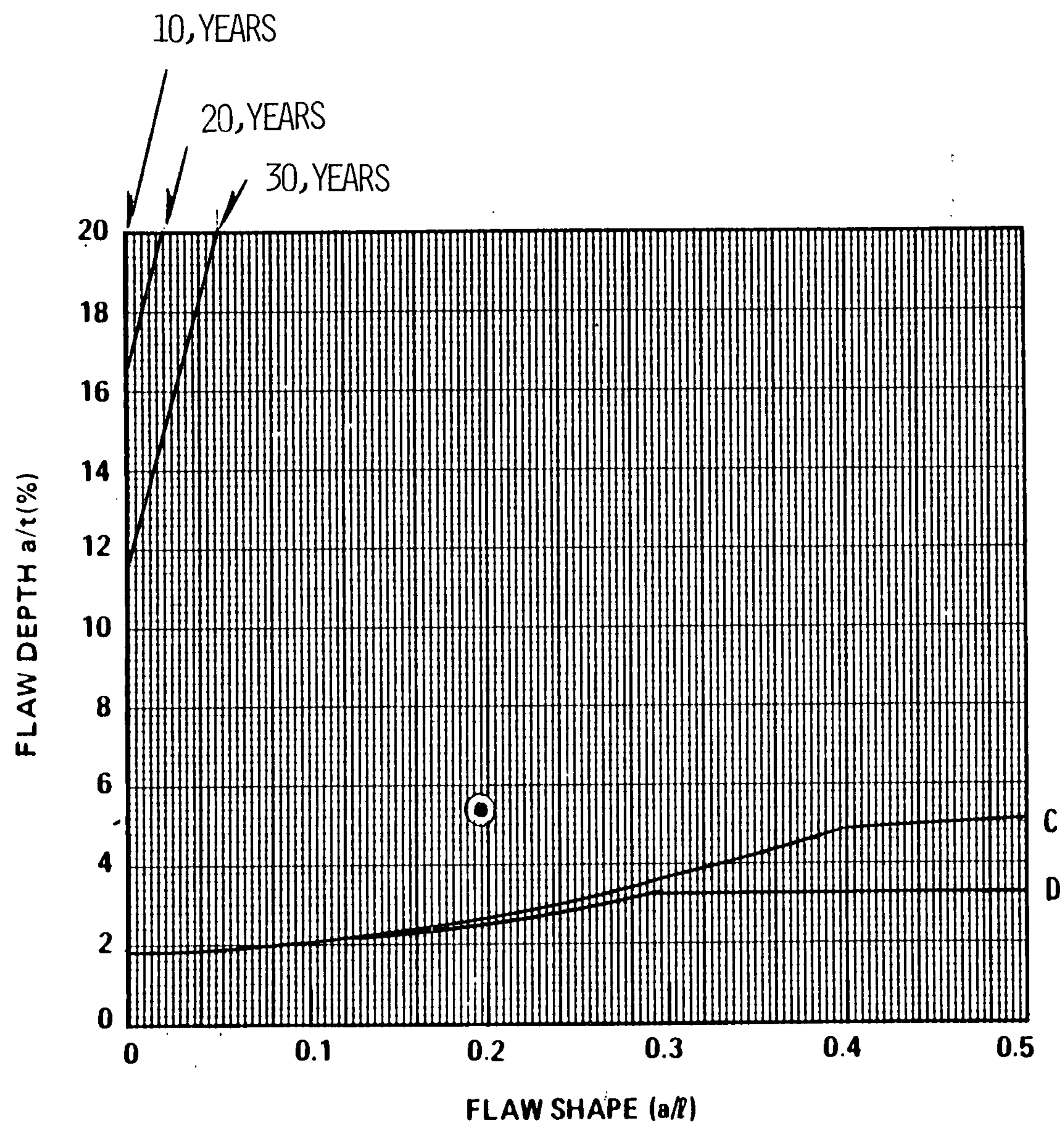
REFERENCES

(1) Kurek, D., "Alternative Sizing Techniques for Embedded Flaws", Westinghouse Electric Corporation, 1990, WCAP-12691.



DATA	INDICATION #	2a	a/t	S	ℓ/t
1	45-1	0.21	.027	0.01	.030
2	45-2	0.3	.038	0.36	.131
3	45-3	0.18	.023	0.98	.274
4	45-4	0.12	.015	0.8	.221
5	45-5	0.19	.024	1.47	.396
6	45-6	0.17	.022	1.53	.409
7	45-7	0.23	.029	1.16	.323
8	45-8	0.24	.031	0.99	.284
9	45-9	0.12	.015	0.97	.264
10	45-10	0.24	.032	0.95	.285
11	45-11	0.43	.054	0.95	.295
12	60-1	0.39	.050	0.73	.237
13	60-2	0.52	.066	0.46	.182
14	60-3	0.46	.058	0.69	.232
15	60-4	0.59	.074	0.52	.206
16	60-5	0.35	.044	0.86	.261
17	60-6	0.29	.037	0.69	.211
18	60-7	0.31	.039	1.26	.357
19	60-8	0.40	.051	0.44	.162
20	60-9	0.29	.037	0.92	.270
21	60-10	0.41	.052	0.97	.297
22	60-11	0.29	.049	0.94	.287
23	60-12	0.55	.070	0.83	.280
24	60-13	0.25	.032	0.98	.283
25	60-14	0.38	.049	0.68	.223
26	60-15	0.42	.054	0.7	.233
27	60-16	0.42	.053	0.73	.237
28	60-17	0.48	.061	0.67	.230
29	60-18	0.53	.067	0.76	.259
30	60-19	0.29	.037	0.81	.241
31	60-20	0.59	.079	0.42	.192
32	60-21	0.54	.068	0.76	.261

FIGURE C-1.1 FRACTURE ANALYSIS RESULTS FOR INDICATIONS FOUND IN THE KEWAUNEE UNIT 1 STEAM GENERATOR A WELD 1-5 (5.0 MHz DATA)



LEGEND

A - The 10, 20, 30 year acceptable flaw limits.

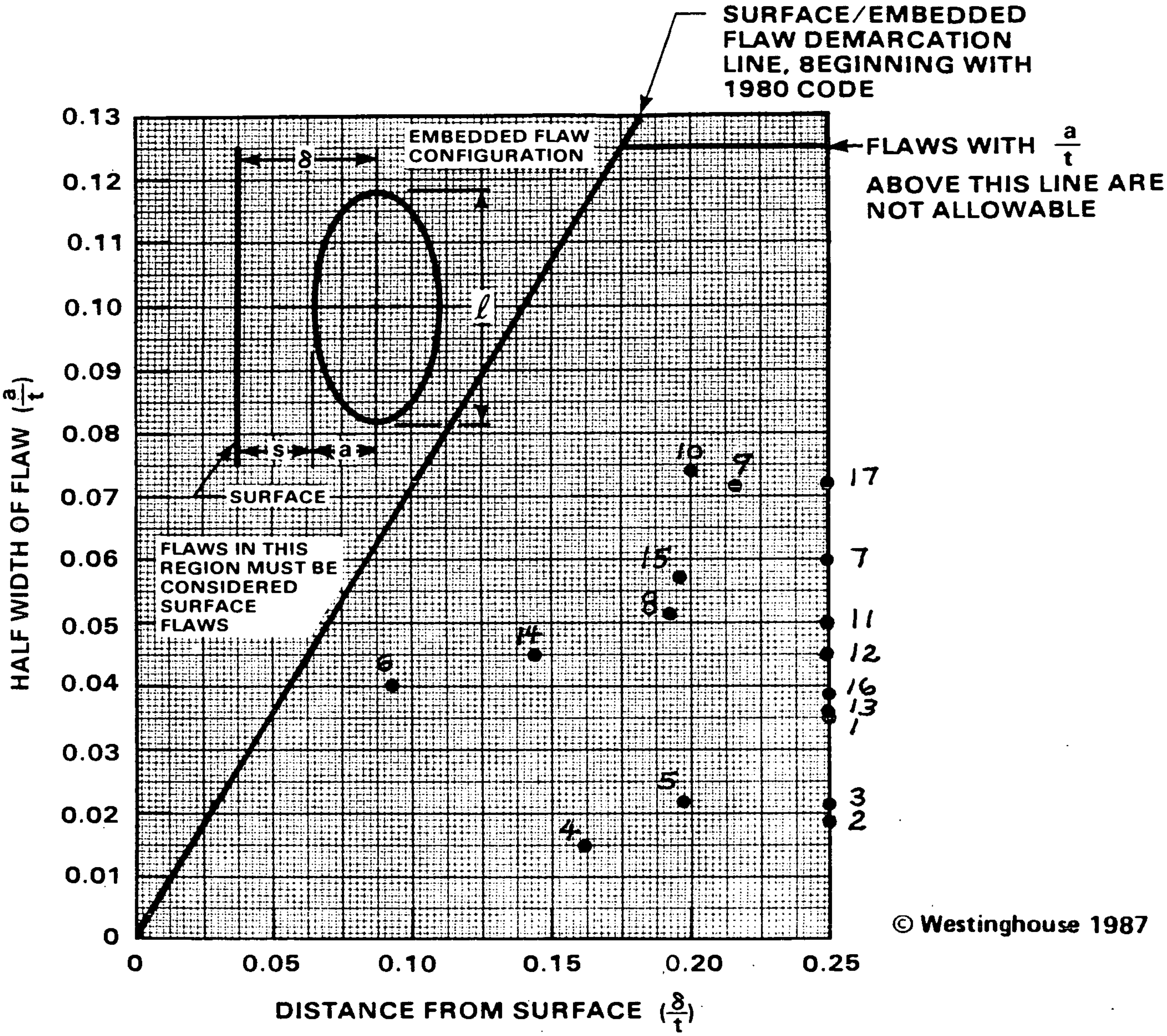
B - Within this zone, the surface flaw is acceptable by ASME Code analytical criteria in IWB-3600.

C - ASME Code allowable since 1983 Winter Addendum.

D - ASME Code allowable prior to 1983 Winter Addendum.

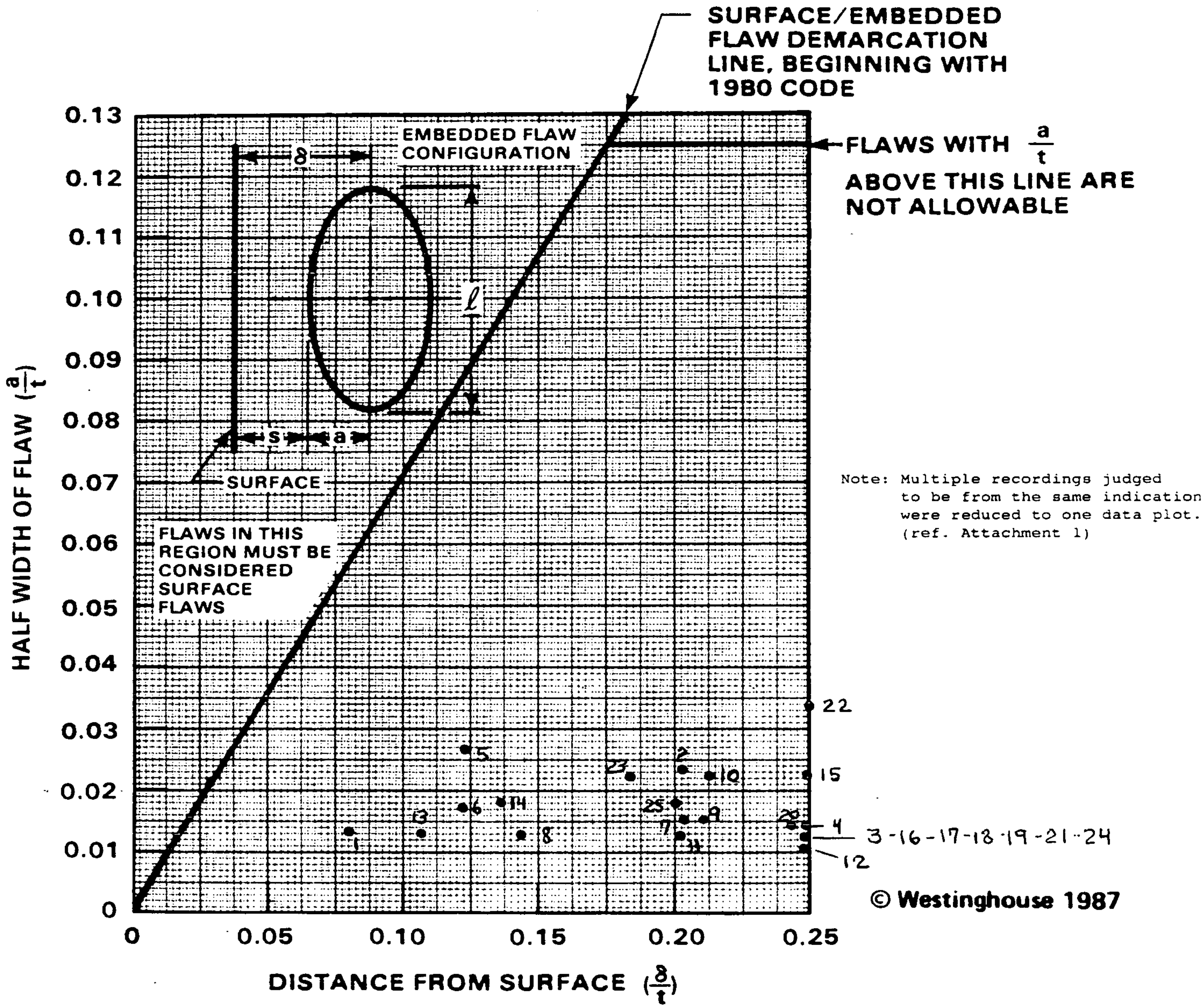
INDICATION 45-1 (REF. FIG. C-1.1)

FIGURE C-1.2 FRACTURE ANALYSIS RESULTS FOR INDICATIONS CLASSIFIABLE AS INSIDE SURFACE FLAWS IN THE UPPER SHELL TO CONE REGION, KEWAUNEE UNIT 1 STEAM GENERATOR A



DATA	INDICATION #	2a	a/t	S	δ/t
1	45-A	0.27	.035	0.98	.286
2	45-B	0.14	.018	1.10	.300
3	45-C	0.16	.021	0.95	.264
4	45-D	0.12	.015	0.57	.162
5	45-E	0.17	.022	0.69	.199
6	45-F	0.31	.040	0.22	.096
7	60-A	0.47	.060	0.75	.253
8	60-B	0.40	.051	0.55	.192
9	60-C	0.55	.071	0.57	.217
10	60-D	0.58	.074	0.49	.200
11	60-E	0.39	.050	0.78	.250
12	60-F	0.35	.045	1.80	.306
13	60-G	0.28	.036	2.3	.636
14	60-H	0.35	.045	0.4	.147
15	60-I	0.46	.058	0.55	.197
16	60-J	0.31	.039	0.86	.257
17	60-K	0.56	.072	0.81	.279

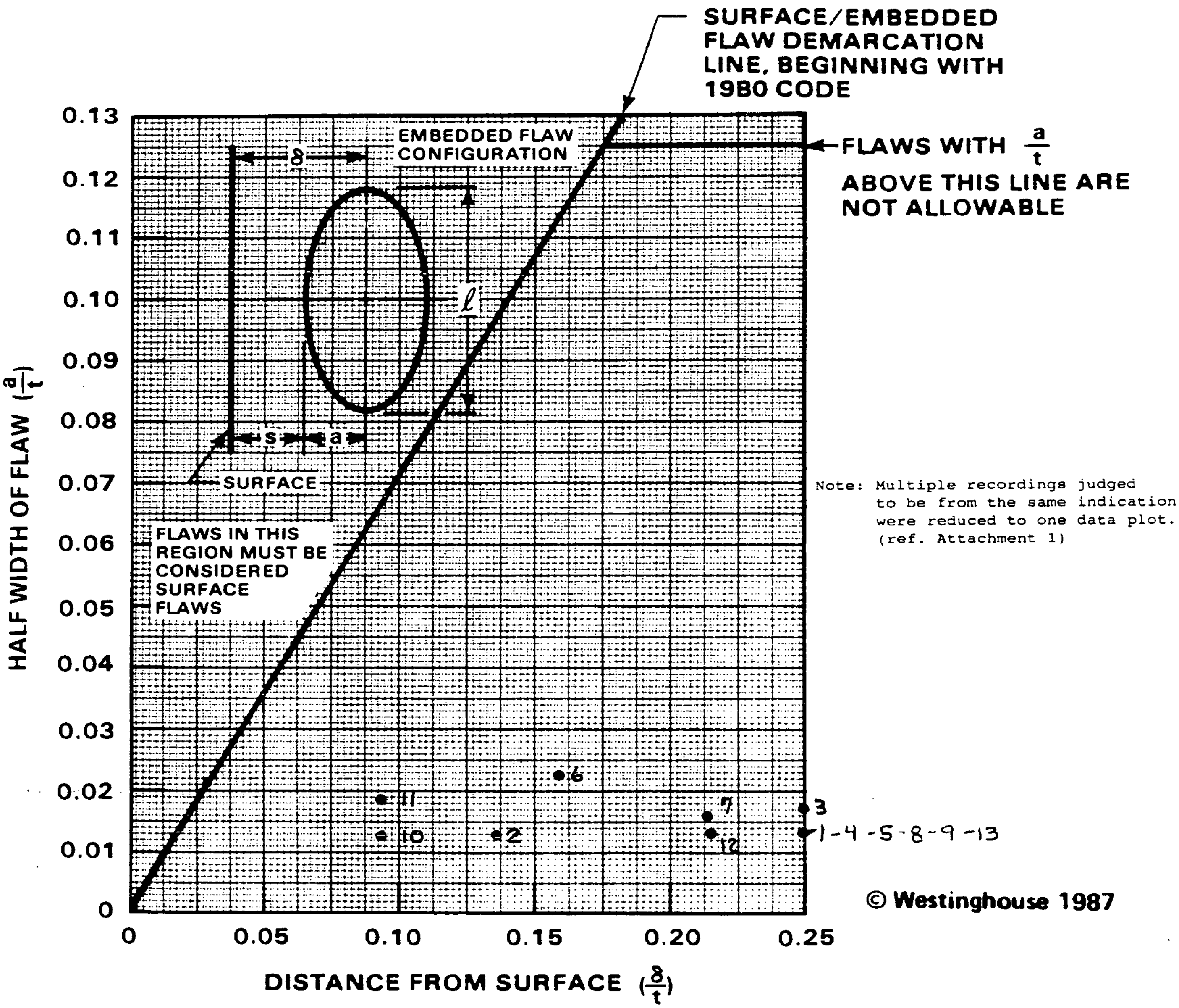
FIGURE C-2 FRACTURE ANALYSIS RESULTS FOR INDICATIONS FOUND IN THE KEWAUNEE UNIT 1 STEAM GENERATOR "B" WELD 2-5 (5.0 MHz DATA)



STEAM GENERATOR A - WELD 1-5

PLOT #	INDICATION #	PLOT #	INDICATION #	PLOT #	INDICATION #
1	45-1	9	60-4	17	60-12
2	45-5	10	60-5	18	60-13
3	45-8	11	60-6	19	60-14
4	45-9	12	60-7	20	60-15
5	45-10	13	60-8	21	60-16
6	60-1	14	60-9	22	60-17
7	60-2	15	60-16	23	60-19
8	60-3	16	60-11	24	60-20
				25	60-21

FIGURE C-3 FRACTURE ANALYSIS RESULTS FOR INDICATIONS FOUND IN THE KEWAUNEE UNIT 1 STEAM GENERATOR A, WELD 1-5 (UDRPS SIZING DATA)



STEAM GENERATOR B - WELD 2-5

PLOT #	INDICATION #	PLOT #	INDICATION #
1	45-E	8	60-F
2	45-F	9	60-G
3	60-A	10	60-H
4	60-B	11	60-I
5	60-C	12	60-J
6	60-D	13	60-K
7	60-E		

FIGURE C-4 FRACTURE ANALYSIS RESULTS FOR INDICATIONS FOUND IN THE KEWAUNEE UNIT 1 STEAM GENERATOR B, WELD 2-5 (UDRPS SIZING DATA)

SUMMARY OF SIZING RESULTS - CONVENTIONAL AND ADVANCED TECHNIQUES
Found in the KNPP Unit 1 S/G A Weld 1-5

		1988							1991							1991		
		2.25 MHz (1)				5.0 MHz (2)			2.25 MHz (1)				5.0 MHz (2)			UDRPS		
IND. NO.	BEAM ANGLE (DEGREES)	"2a"	ℓ	s	Peak Sweep	"2a"	ℓ	s	"2a"	ℓ	s	Peak Sweep	"2a"	ℓ	s	"2a"(3)	ℓ (4)	s (3)
1	45	0.35	1.25	0.12	6.8	0.14	0.35	0.08	0.29	0.80	0.06	6.8	0.21	1.13	0.01	0.10	0.80	0.17
2	45	0.43	0.85	0.51	8.3	0.30	0.50	1.04	0.24	0.60	0.61	8.3	0.30	0.31	0.36	Ref. 60-4		
3	45	0.39	0.85	0.39	5.6	0.37	0.95	0.28	0.21	0.50	0.82	5.7	0.18	0.56	0.98	Ref. 60-3		
4	45	0.12	0.60	0.59	5.3	---	---	---	(6)		0.81	5.3	0.12	0.44	0.80	Spot		
5	45	0.23	---	0.67	5.0	---	---	---	0.27	0.60	1.31	5.0	0.19	0.63	1.47	0.18	0.60	0.75
6	45	---	---	0.87	5.0	---	---	---	(6)		1.47	5.0	0.17	0.31	1.53	Ref. 60-7		
7	45	0.23	1.40	0.53	5.4	0.31	1.00	0.59	0.34	0.50	1.12	5.4	0.23	0.31	1.16	Ref. 60-11		
8	45	(7)				(7)			0.30	0.80	0.30	5.6	0.24	0.56	0.99	0.10	0.80	0.95
9	45	(7)				(7)			0.12	0.55	0.80	5.0	0.12	0.50	0.97	0.11	0.55	0.24
10	45	(7)				(7)			0.18	0.30	0.35	5.7	0.24	0.38	0.95	0.204	0.30	0.46
11	45	(7)				(7)			0.36	0.70	1.40	8.5	0.43	0.63	0.95	Ref. 60-11		
1	60	0.76	0.75	0.00	5.9	0.23	0.75	0.35	0.92	0.75	0.55	5.9	0.39	0.75	0.73	0.13	0.75	0.45

(1) 2.25 MHz data recorded at 50% DAC.
(2) 5.0 MHz data recorded at -6dB (half maximum amplitude).
(3) Measurements using advanced sizing techniques.
(4) Lengths taken from 1991 2.25 MHz manual data.
(5) Depth varies along length.
(6) Judged to be a "SPOT" reflector having no measurable length or "2a" dimension.
(7) Indications 45-8,9,10, and 11 and 60-13 through 21 (1991 data) are previously undisclosed volumetric type indications.

NOTE: All 1988 indications were located and measured in 1991 and were judged to be similar in amplitude and size.

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FIGURE C-5.1 Summary of Recorded Indication Sizes Conventional and Advanced Sizing Techniques Steam Generator A - Weld 1-5

SUMMARY OF SIZING RESULTS - CONVENTIONAL AND ADVANCED TECHNIQUES
Found in the KNPP Unit 1 S/G A Weld 1-5

		1988							1991							1991		
		2.25 MHz (1)				5.0 MHz (2)			2.25 MHz (1)				5.0 MHz (2)			UDRPS		
IND. NO.	BEAM ANGLE (DEGREES)	"2a"	l	s	Peak Sweep	"2a"	l	s	"2a"	l	s	Peak Sweep	"2a"	l	s	"2a"(3)	l (4)	s (3)
2	60	0.46	1.00	0.35	5.2	0.52	1.20	0.26	0.46	1.00	0.58	5.2	0.52	0.60	0.46	0.11	1.00	0.75
3	60	0.76	1.55	0.12	5.9	0.35	1.55	0.12	0.72	1.55	0.84	5.9	0.46	0.50	0.69	0.10	1.55	0.49
4	60	0.52	0.90	0.41	5.3	0.52	1.50	0.26	0.53	0.90	0.42	5.3	0.59	0.75	0.52	0.10	0.90	0.75
5	60	0.41	0.75	0.34	4.9	0.30	2.10	0.65	0.41	0.75	0.66	4.9	0.35	0.65	0.86	0.19	0.75	0.72
6	60	0.64	1.00	0.41	5.0	0.47	1.40	0.41	0.65	1.00	0.63	5.0	0.29	0.35	0.69	0.10	1.00	0.73
7	60	0.47	0.70	0.64	5.0	0.30	2.90	0.69	0.55	0.70	1.30	5.0	0.31	0.50	1.26	0.10	0.70	1.68
8	60	0.42	12.10	0.07	6.0	0.47	12.10	0.20	1.19	12.10	0.21	6.0	0.40	7.95	0.44	0.14	12.10	0.45/ 0.85 (5)
9	60	0.29	13.25	0.82	4.6	0.35	13.25	0.69	0.29	13.25	0.99	4.6	0.29	12.65	0.92	0.10	13.25	0.35/ 1.10 (5)
10	60	0.46	1.00	0.65	4.7	0.41	1.00	0.71	0.46	1.00	0.92	4.7	0.41	1.80	0.97	0.17	1.00	0.93
11	60	0.46	1.80	0.47	5.4	0.47	1.80	0.37	0.53	1.80	1.05	5.4	0.39	1.20	0.94	0.10	1.80	1.25
12	60	0.58	1.80	0.23	5.5	0.37	2.80	0.30	0.62	1.80	0.79	5.5	0.55	1.80	0.83	0.10	1.80	1.15

(1) 2.25 MHz data recorded at 50% DAC.
(2) 5.0 MHz data recorded at -6dB (half maximum amplitude).
(3) Measurements using advanced sizing techniques.
(4) Lengths taken from 1991 2.25 MHz manual data.
(5) Depth varies along length.
(6) Judged to be a "SPOT" reflector having no measurable length or "2a" dimension.
(7) Indications 45-8,9,10, and 11 and 60-13 through 21 (1991 data) are previously undisclosed volumetric type indications.

NOTE: All 1988 indications were located and measured in 1991 and were judged to be similar in amplitude and size.

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FIGURE C-5.2 Summary of Recorded Indication Sizes Conventional and Advanced Sizing Techniques Steam Generator A - Weld 1-5 (Continued)

SUMMARY OF SIZING RESULTS - CONVENTIONAL AND ADVANCED TECHNIQUES
Found in the KNPP Unit 1 S/G A Weld 1-5

		1988							1991							1991		
		2.25 MHz (1)				5.0 MHz (2)			2.25 MHz (1)				5.0 MHz (2)			UDRPS		
IND. NO.	BEAM ANGLE (DEGREES)	"2a"	l	s	Peak Sweep	"2a"	l	s	"2a"	l	s	Peak Sweep	"2a"	l	s	"2a"(3)	l (4)	s (3)
13	60	(7)				(7)			0.54	1.10	0.45	5.8	0.25	1.30	0.98	0.10	1.10	1.00
14	60	(7)				(7)			0.36	0.80	0.50	5.6	0.38	0.50	0.68	0.10	0.80	1.00
15	60	(7)				(7)			0.54	0.90	0.50	5.4	0.42	0.70	0.70	0.10	0.90	0.89
16	60	(7)				(7)			0.30	0.80	0.70	5.7	0.42	0.50	0.73	0.10	0.80	1.05
17	60	(7)				(7)			0.60	0.70	0.60	5.6	0.48	0.60	0.67	0.27	0.70	0.83
18	60	(7)				(7)			0.54	3.80	0.60	5.4	0.53	2.70	0.76	Ref. 60-19		
19	60	(7)				(7)			0.48	1.60	0.60	5.4	0.29	0.35	0.81	0.17	1.60	0.61
20	60	(7)				(7)			0.54	1.20	0.50	5.3	0.59	1.15	0.42	0.10	1.20	1.10
21	60	(7)				(7)			0.30	1.00	0.60	5.3	0.54	0.80	0.76	0.14	1.00	0.75

(1) 2.25 MHz data recorded at 50% DAC.
(2) 5.0 MHz data recorded at -6dB (half maximum amplitude).
(3) Measurements using advanced sizing techniques.
(4) Lengths taken from 1991 2.25 MHz manual data.
(5) Depth varies along length.
(6) Judged to be a "SPOT" reflector having no measurable length or "2a" dimension.
(7) Indications 45-8,9,10, and 11 and 60-13 through 21 (1991 data) are previously undisclosed volumetric type indications.

NOTE: All 1988 indications were located and measured in 1991 and were judged to be similar in amplitude and size.

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FIGURE C-5.3 Summary of Recorded Indication Sizes Conventional and Advanced Sizing Techniques Steam Generator A - Weld 1-5 (Continued)

SUMMARY OF SIZING RESULTS - CONVENTIONAL AND ADVANCED TECHNIQUES

Found in the KNPP Unit 1 S/G B Weld 2-5

		1987							1991							1991		
		2.25 MHz (1)				5.0 MHz (5)			2.25 MHz (1)				5.0 MHz (2)			UDRPS		
IND. NO.	BEAM ANGLE	"2a"	l	s	Peak Sweep	"2a"	l	s	"2a"	l	s	Peak Sweep	"2a"	l	s	"2a"(3)	l (4)	s (3)
A	45	0.61	0.60	0.37	5.6	---	---	---	0.35	1.00	0.69	5.6	0.27	0.38	0.98	Ref. 60-J		
B	45	0.43	0.10	0.45	5.9	---	---	---	0.44	0.60	0.61	5.9	0.14	0.25	1.10	Ref. 60-K		
C	45	(7)				(7)			0.35	(8)	0.50	5.5	0.16	0.50	0.95	Spot (8)		
D	45	(7)				(7)			0.18	0.80	0.50	5.6	0.12	0.75	0.57	Ref. 60-H		
E	45	(7)				(7)			0.12	0.25	0.60	5.4	0.17	0.38	0.69	0.10	0.25	1.05
F	45	(7)				(7)			0.29	0.80	1.20	8.1	0.31	0.88	0.22	0.10	0.80	0.45
A	60	0.69	1.20	0.67	5.5	0.37	0.75	1.02	0.66	1.20	0.76	5.5	0.47	0.60	0.75	0.13	1.20	1.10
B	60	0.81	1.50	0.24	6.0	0.35	0.50	0.75	~~0.27~~	~~1.50~~	~~0.46~~	~~6.2~~	~~0.40~~	~~1.40~~	~~0.55~~	0.10	1.50	1.10
C	60	0.65	0.90	0.63	5.4	---	---	---	(8)		0.95	5.4	0.55	0.70	0.57	0.10	0.90	0.80
D	60	0.55	1.10	0.53	5.3	0.28	1.10	0.69	0.36	0.80	0.68	5.4	0.58	0.90	0.49	0.18	0.80	0.53
E	60	0.46	1.50	0.37	5.5	0.65	0.63	0.75	0.78	1.10	0.69	5.5	0.39	0.50	0.78	0.12	1.10	0.79
F	60	0.61	3.10	1.67	3.9	0.26	1.00	1.93	0.53	2.40	1.81	3.9	0.35	1.30	1.80	0.12	2.40	2.28

(1) 2.25 MHz data recorded at 50% DAC.
(2) 5.0 MHz data recorded at -6dB (half maximum amplitude).
(3) Measurements using advanced sizing techniques.
(4) Lengths taken from 1991 2.25 MHz manual data.
(5) 5.0 MHz data recorded at 50% DAC.
(6) Value taken from inside surface, indication is 1.53" from outside surface.
(7) Indications 45-C,D,E, and F; and 60-H,I,J, and K are previously undisclosed volumetric indications.
(8) No measurable dimensions.

1SGB1A
Rev. 0

FIGURE C-6.1 Summary of Recorded Indication Sizes Conventional and Advanced Sizing Techniques Steam Generator B - Weld 2-5

SUMMARY OF SIZING RESULTS - CONVENTIONAL AND ADVANCED TECHNIQUES
Found in the KNPP Unit 1 S/G B Weld 2-5

		1987							1991							1991		
		2.25 MHz (1)				5.0 MHz (5)			2.25 MHz (1)				5.0 MHz (2)			UDRPS		
IND. NO.	BEAM ANGLE	"2a"	l	s	Peak Sweep	"2a"	l	s	"2a"	l	s	Peak Sweep	"2a"	l	s	"2a"(3)	l (4)	s (3)
G	60	0.41	1.80	1.63	3.1	0.35	2.75	1.79	(8)		2.03	3.2	0.28	0.80	2.34 (6)	0.10	2.30	2.00
H	60	(7)				(7)			0.36	0.90	0.50	5.7	0.35	2.00	0.40	0.10	0.90	0.30
I	60	(7)				(7)			0.35	0.60	0.50	6.0	0.46	0.40	0.55	0.15	0.60	0.28
J	60	(7)				(7)			0.23	0.80	0.70	5.4	0.31	0.80	0.86	0.10	0.80	0.80
K	60	(7)				(7)			0.17	1.20	0.65	5.4	0.56	0.30	0.81	0.10	1.20	1.10

(1) 2.25 MHz data recorded at 50% DAC.
(2) 5.0 MHz data recorded at -6dB (half maximum amplitude).
(3) Measurements using advanced sizing techniques.
(4) Lengths taken from 1991 2.25 MHz manual data.
(5) 5.0 MHz data recorded at 50% DAC.
(6) Value taken from inside surface, indication is 1.53" from outside surface.
(7) Indications 45-C,D,E, and F; and 60-H,I,J, and K are previously undisclosed volumetric indications.
(8) No measurable dimensions.

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Rev. 0

FIGURE C-6.2 Summary of Recorded Indication Sizes Conventional and Advanced Sizing Techniques Steam Generator B - Weld 2-5 (Continued)

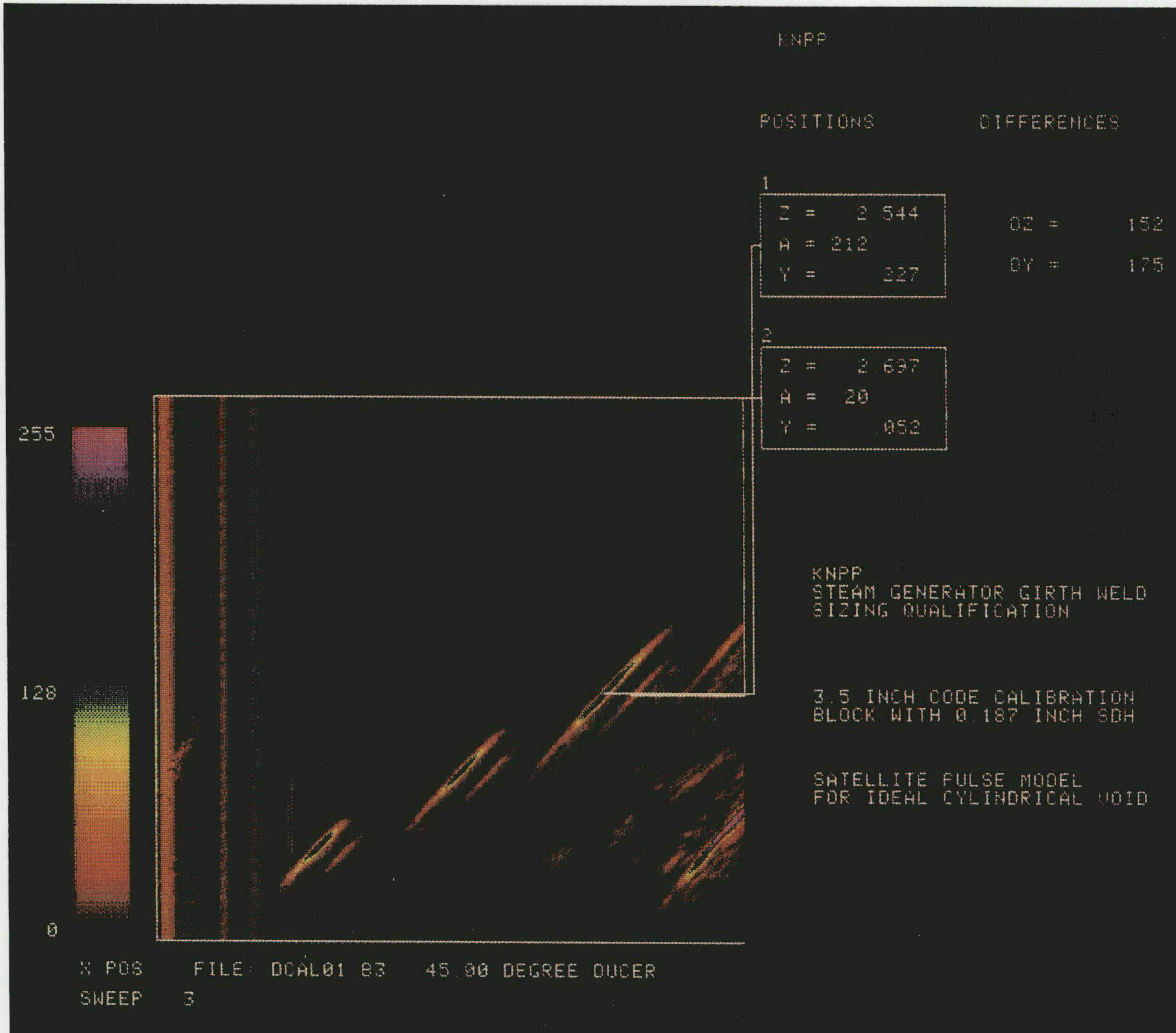


FIGURE C-7 UDRPS 45° Automated Scan Data 3.5" Thick Code Calibration Block (WPS-36) Side Drilled Hole Reflectors

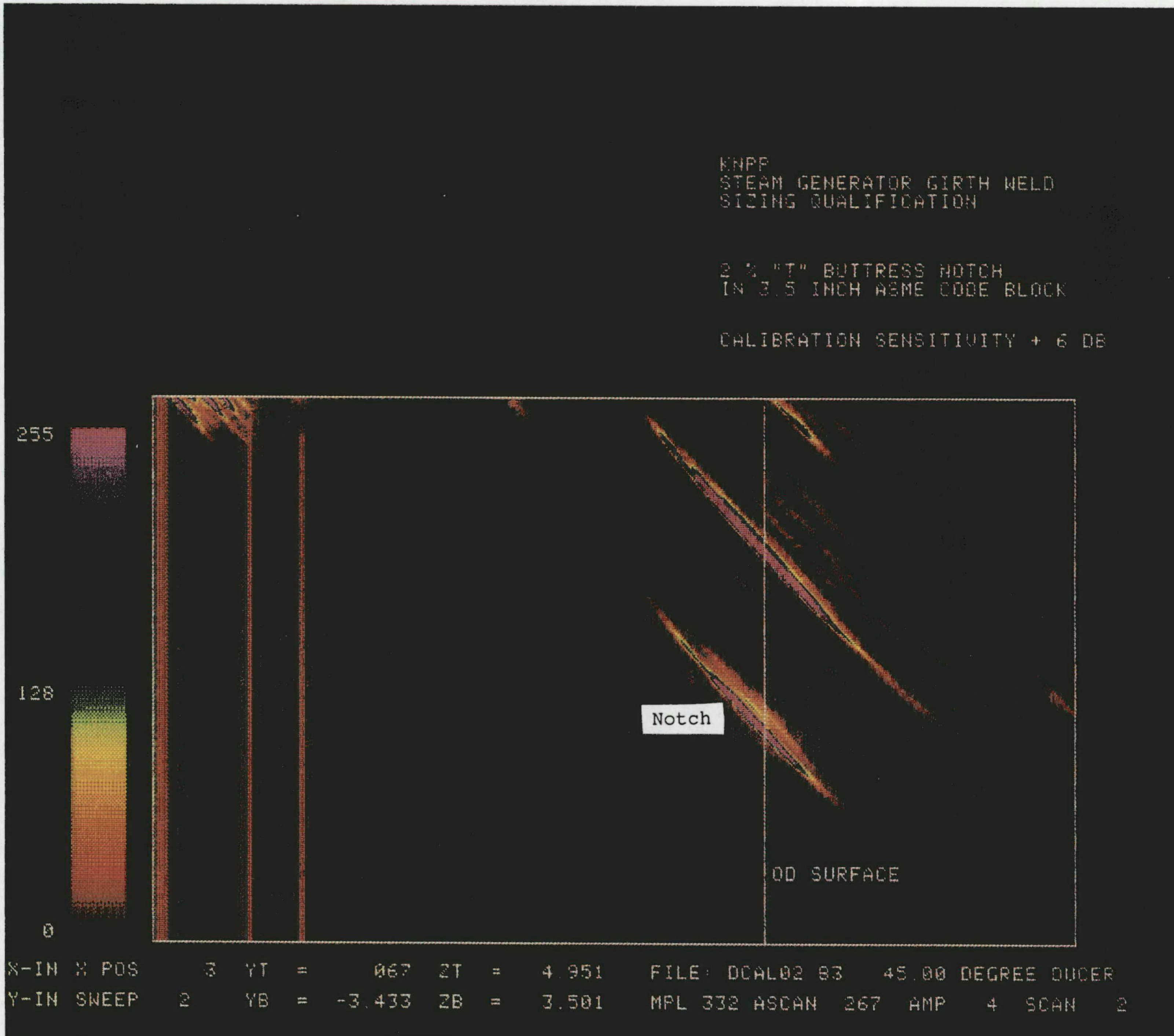


FIGURE C-8 UDRPS 45° Automated Scan Data 3.5" Thick Code Calibration Block (WPS-36) Buttress Notch Reflection

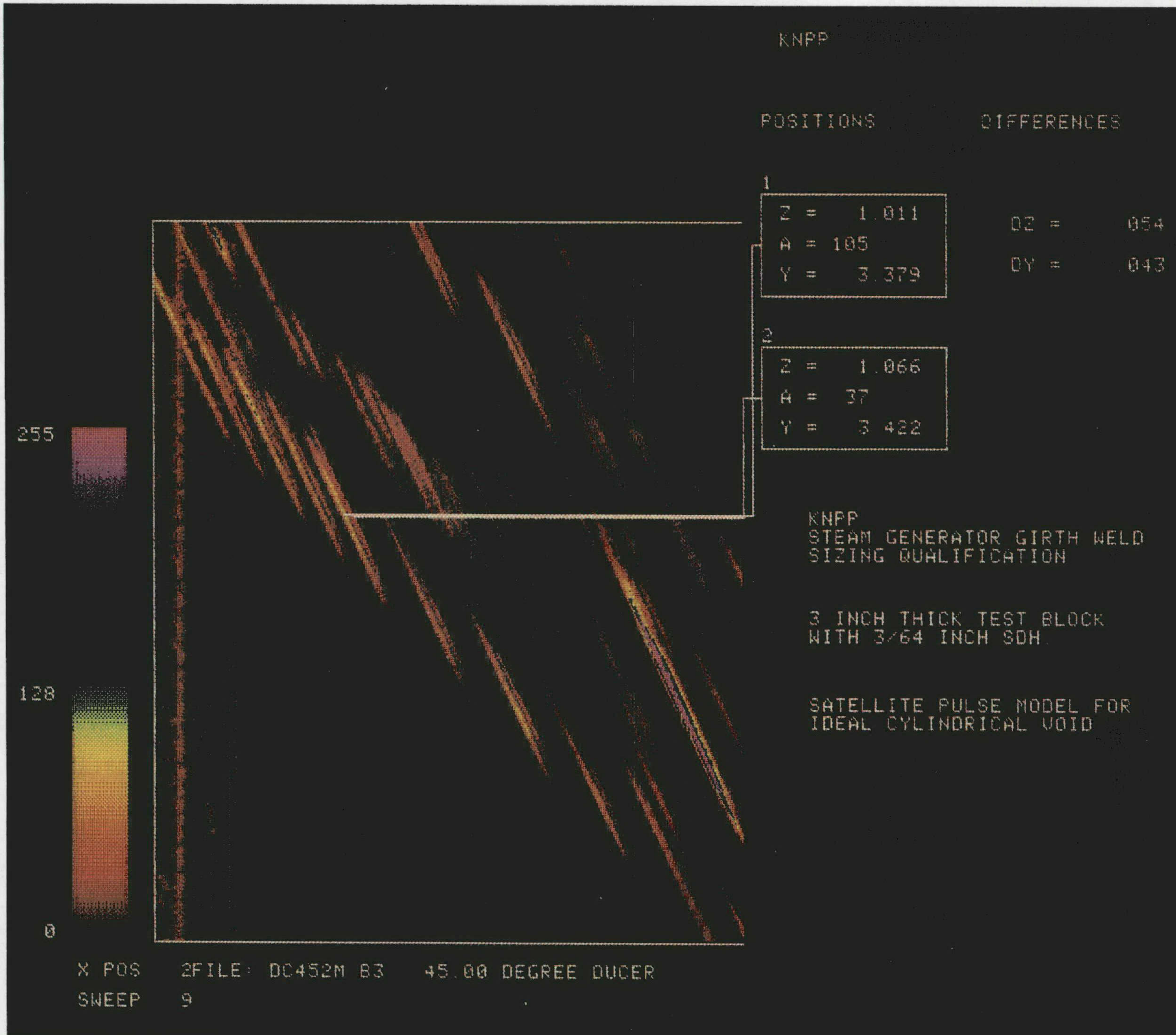


FIGURE C-9 UDRPS 45° Automated Scan Data DSI Block - 3/64" Dia. Side Drilled Holes in Line

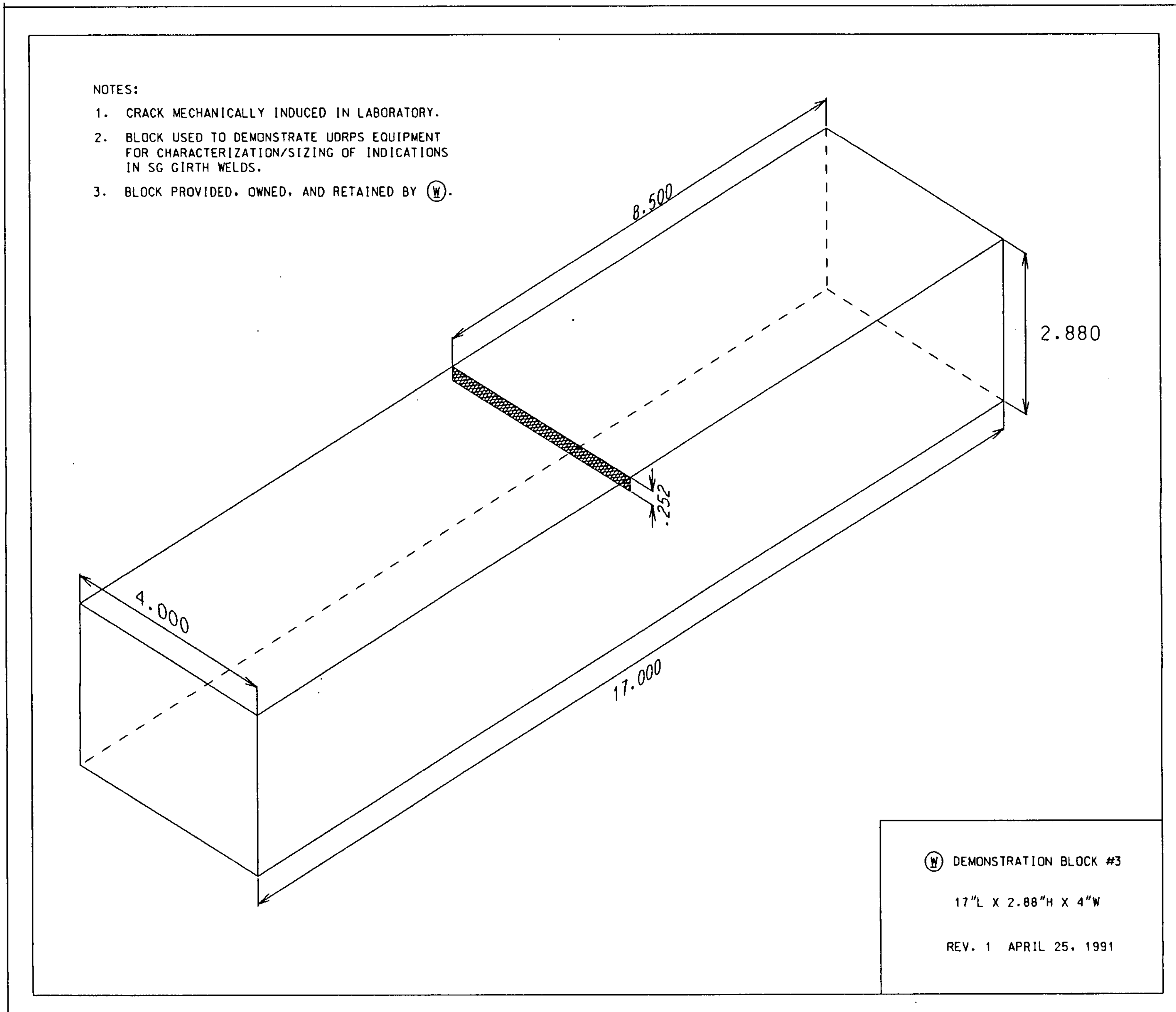


FIGURE C-10 NATD Block #3 Technique Qualification Specimen (Surface Connected Crack)

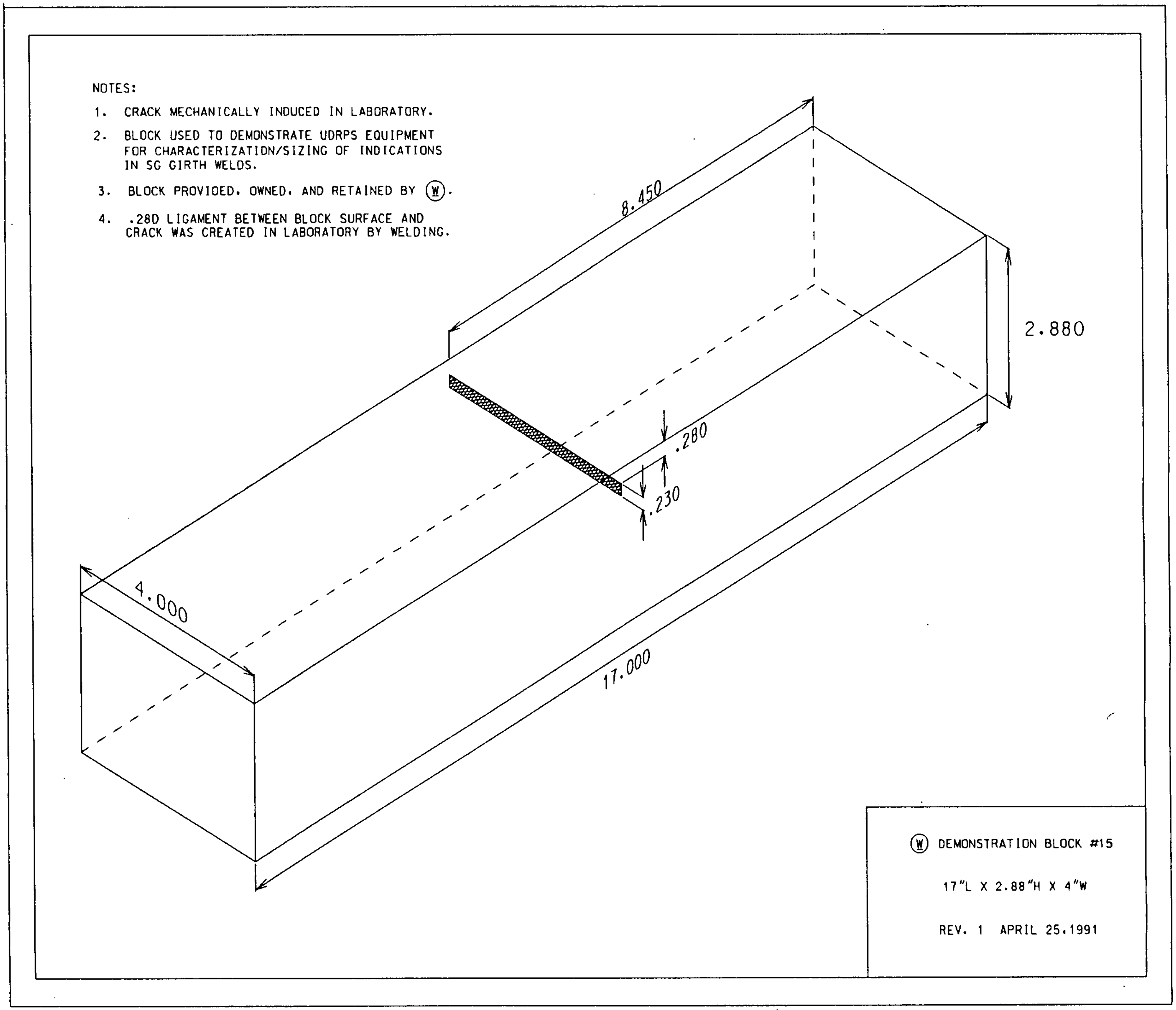


FIGURE C-11 NATD Block #15 Technique Qualification Specimen (Embedded Crack)

FIGURE C-12 NATD Block #3, 45° Scan at Sensitivity Levels +6dB and +12dB

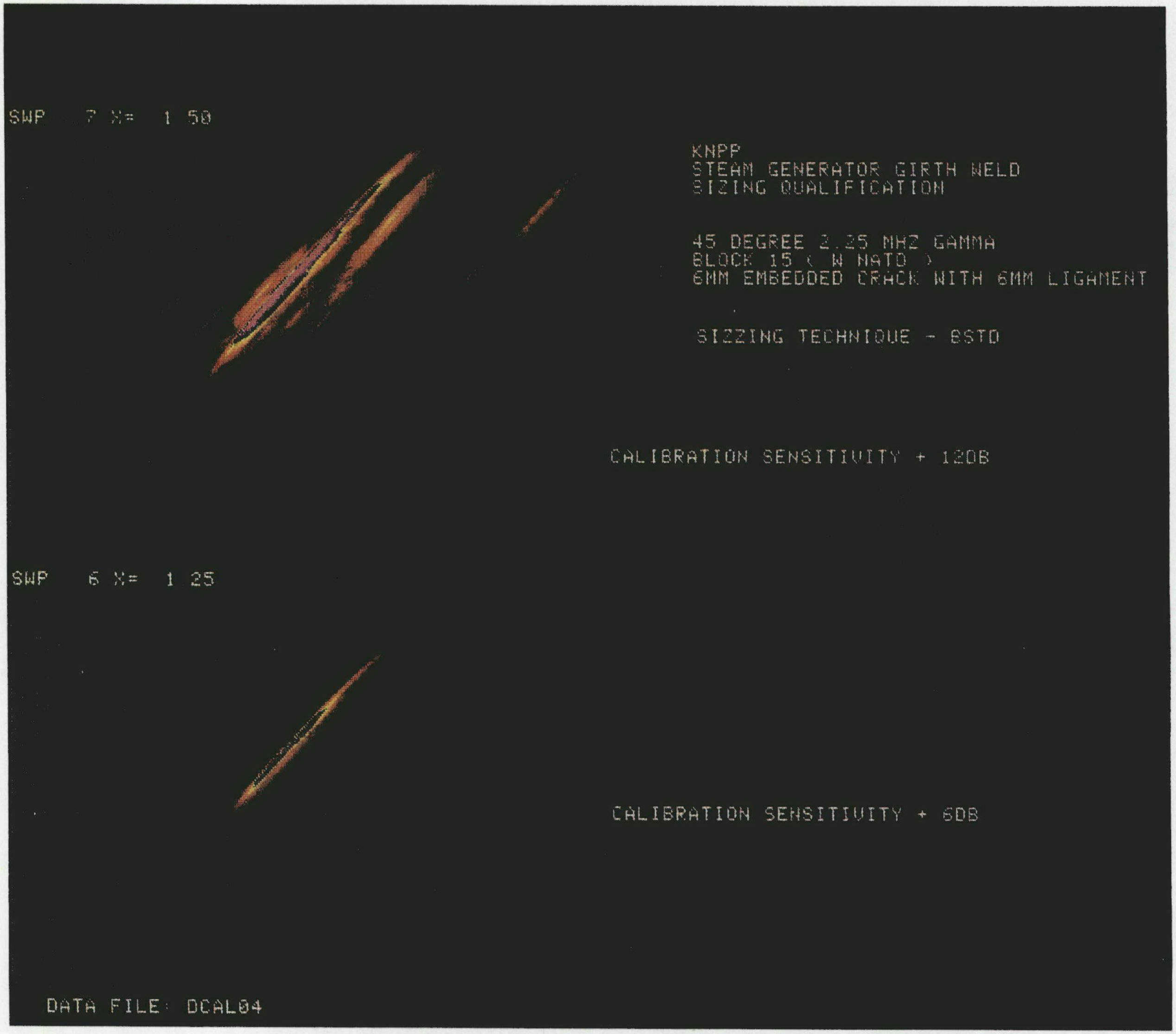


FIGURE C-13 NATD Block #15, 45^{o} Scan at Sensitivity Levels +6dB and +12dB

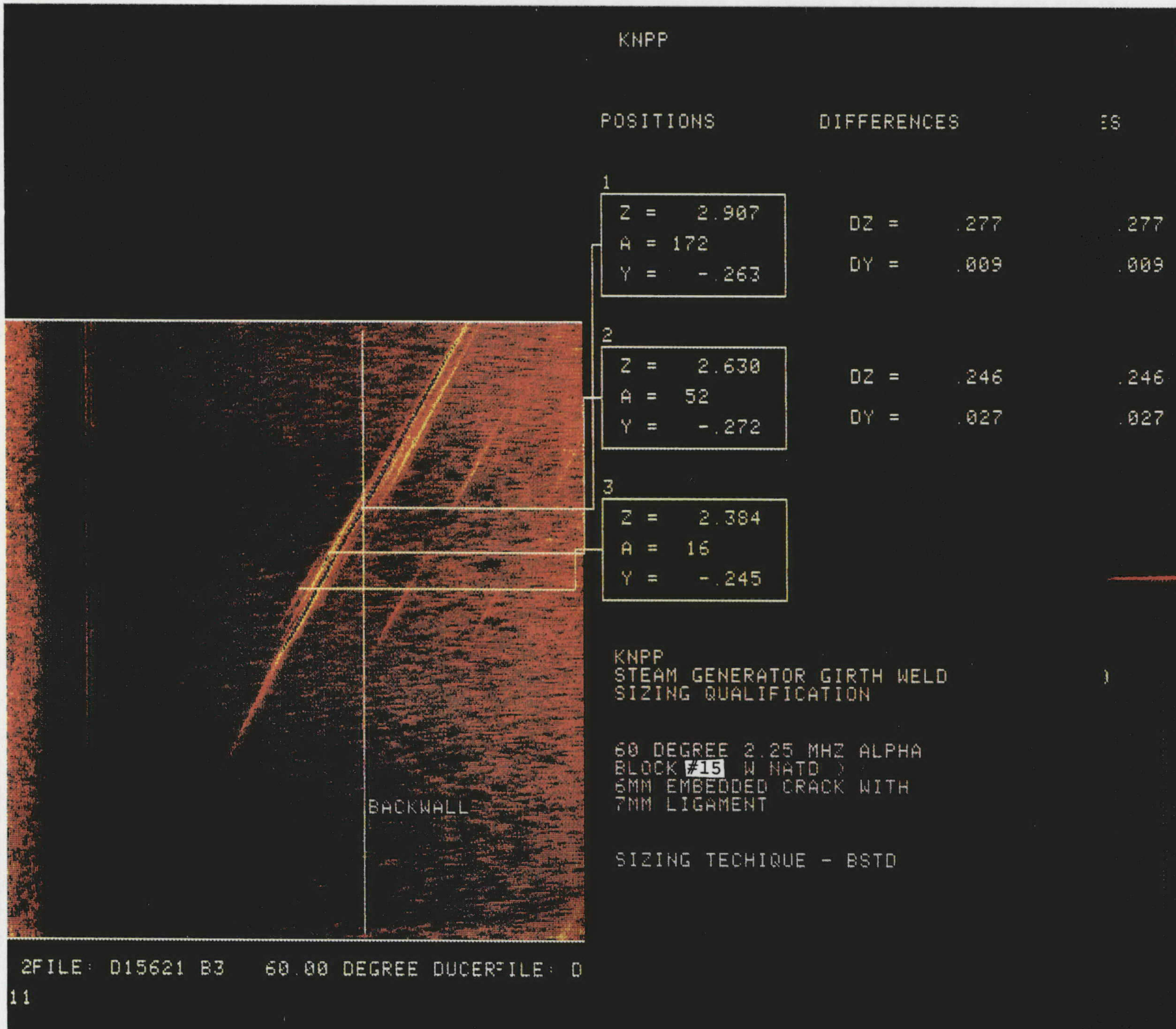
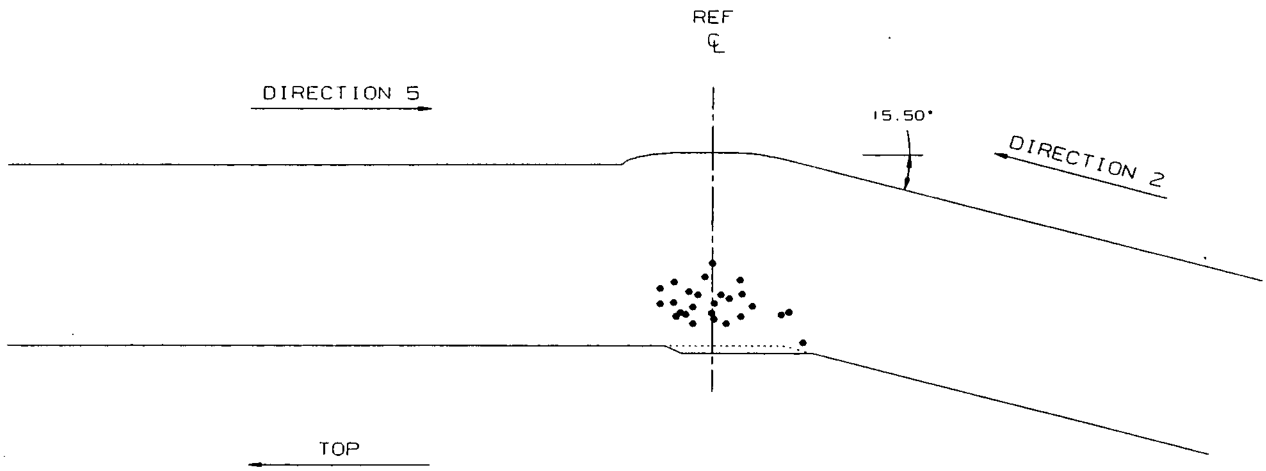
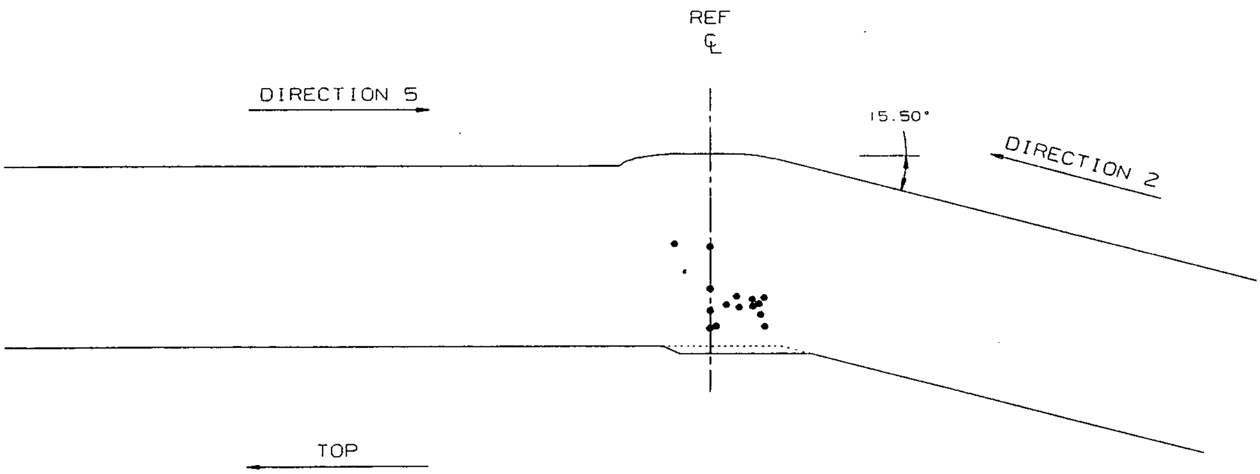


FIGURE C-14 NATD Block #15, -60° Scan at Sensitivity Level +12dB



Steam Generator A Weld 1-5 Flaw Distribution



Steam Generator B Weld 2-5 Flaw Distribution

FIGURE C-15 Flaw Distribution - Steam Generator A and B Upper Shell to Cone Welds Plots from UDRPS Data

Methods for Verifying the Through-Thickness Locations of Embedded Flaws
Found in the KNPP Unit 1 S/G A Weld 1-5

INDICATION NO.	MANUAL 5.0 MHz STRAIGHT BEAM	I.D. SURFACE "SHADOWING" FROM UDRPS HI-RES-SCANS	UDRPS COMPLIMENTARY ANGLE/5/8 NODE RESPONSE	COMMENTS
45-1	X (1)	X	X	
45-5	X	X	X	
45-8	X	X	X	
45-9	X	---	X	
45-10	X	X	X	
60-1	X	X	X	
60-2	X	X	X	
60-3	X	X	X	
60-4	X	---	X	
60-5	X	---	X	
60-6	X	X	X	
60-7	X	X	X	
60-8	X	---	X	
60-9	X	X	X	

(1) Indication located with 5.0 MHz dual element 0 degree transducer. Indication is 0.2 inches from I.D. surface having smooth echodynamic response in X and Y plane of transducer manipulation.

2SGA1A

FIGURE C-16.1 Summary of Through-Thickness Location Techniques - Steam Generator A - Weld 1-5

Methods for Verifying the Through-Thickness Locations of Embedded Flaws
Found in the KNPP Unit 1 S/G A Weld 1-5

INDICATION NO.	MANUAL 5.0 MHz STRAIGHT BEAM	I.D. SURFACE "SHADOWING" FROM UDRPS HI-RES-SCANS	UDRPS COMPLIMENTARY ANGLE/5/8 NODE RESPONSE	COMMENTS
60-10	X	X	X	
60-11	X	X	X	
60-12	X	X	X	
60-13	X	X	X	
60-14	X	X	X	
60-15	X	X	X	
60-16	X	X	X	
60-17	X	---	X	
60-19	X	X	X	
60-20	X	---	X	
60-21	X	---	X	

FIGURE C-16.2 Summary of Through-Thickness Location Techniques - Steam Generator A - Weld 1-5 (Continued)

2SGA1B

Methods for Verifying the Through-Thickness Locations of Embedded Flaws
Found in the KNPP Unit 1 S/G B Weld 2-5

INDICATION NO.	MANUAL 5.0 MHz STRAIGHT BEAM	I.D. SURFACE "SHADOWING" FROM UDRPS HI-RES-SCANS	UDRPS COMPLIMENTARY ANGLE/5/8 NODE RESPONSE	COMMENTS
45-E	X	X	X	
45-F	X	---	X	
60-A	X	---	X	
60-B	X	---	X	
60-C	X	---	X	
60-D	X	X	X	
60-E	X	---	X	
60-F	X	---	---	Shallow - mid-wall
60-G	X	---	---	Shallow - mid-wall
60-H	X	X	X	
60-I	X	---	X	
60-J	X	---	X	
60-K	X	---	---	

FIGURE C-17 Summary of Through-Thickness Location Techniques - Steam Generator B - Weld 2-5

2SGB1A

PROPRIETARY INFORMATION

NOTICE

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PROPRIETARY INFORMATION

SUPPLEMENT #1

KEWAUNEE UNIT 1

STEAM GENERATOR UPPER SHELL TO CONE WELDS

STEAM GENERATOR "A" WELD 1-5

STEAM GENERATOR "B" WELD 2-5

WITH

INDICATION ASSESSMENT TABLES

FIGURES A.1 THROUGH A.33 - STEAM GENERATOR A WELD 1-5

FIGURES B.1 THROUGH B-13 - STEAM GENERATOR B WELD 2-5

INDICATION ASSESSMENT

PLANT KEWAUNEE

WELD 1-5 (SG-W2) Sketch WPS-2-1100 {M-1206}

DESCRIPTION Steam Gen. A – UPPER TRANSITION GIRTH

Indication No.	Channel/TD	Beam angle/dir.	P = planar V = volumetric	Depth from OD surface MIN.	Depth from OD surface MAX.	Length l [in]	Through wall dimension 2a [in]	Applicable thickness [in]	S dim. [in]	Y value	Surface or subsurface	Aspect ratio a/l	a/t %	Allowable a/t %	Status	COMMENTS IWB - 3000 reference UDRPS File No. table IWB-3511-1 ASME XI 1980
45-1	/	45/2	V	3.68	3.78	0.8	0.10	3.95	0.17	1	Sub	.06	1.27	2.8	Acc.	Δ≠t SPOT
45-2																REF. 60-4 FOR SIZING
45/3																REF. 60-3 FOR SIZING
45/4		45/2	V	2.99	3.10											SPOT LENGTH,
45/5		45/2	V	2.92	3.10	0.6"	0.18	3.85	0.75	1	Sub	.15	2.34	3.2	Acc.	Δ≠B SPOT
45/6																SPOT LENGTH, REF. 60-7 FOR SIZING
45/7																REF. 60-11
45/8		45/2	V	2.8	2.9	0.8"	0.1	3.85	0.95	1	Sub	.08	1.3	2.9	Acc	Δ≠t SPOT
45/9		45/5	V	3.5	3.61	0.55	0.11	3.85	0.24	1	Sub	.1	1.43	2.9		REF 60-5 FOR SIZING Δ≠B SPOT
45/10		45/	V	3.186	3.39	0.3	.204	3.85	0.46	1	Sub	.34	2.64	5.1	Acc.	Δ≠B SPOT
45/11																REF 60-11

NOTE: "2a" dimensions calculated at less than 0.1 inch were assessed at 0.1 inch.

Analyst [illegible] **Level** III 4/8/91 [illegible] **Date** 04/08/91

FIGURE A-1.1 INDICATION ASSESSMENT TABLE STEAM GENERATOR A WELD 1-5

INDICATION ASSESSMENT

PLANT: KEWAUNEE

Page 2 of 3

WELD: 1-5 (SG-W2

DESCRIPTION: S.G. A Upper Transition Girth Weld

Indication No.	Channel/TD	Beam angle/dir.	P = planar V = volumetric	Depth from ID surface MIN.	Depth from ID surface MAX.	Length l [in]	Through wall dimension 2a [in]	Applicable thickness [in]	S dim. [in]	Y value	Surface or subsurface	Aspect ratio a/l	a/t %	Allowable a/t %	Status	COMMENTS IWB - 3000 reference UDRPS File No.
																SM = XI 1980 IWB 3511-1 Ab 3.1 A X
61	1	45/2	V	3.27	3.4	0.75	0.13	3.85	0.45 0	1	Sub	.08	1.68	2.9	Acc	¢ SPOT
62		45/2	V	2.99	3.1	1.0	0.11	3.85	0.75			.05	1.42	2.8	Acc	¢B SPOT
63		45/2	V	3.26	3.36	1.5	0.1	3.85	0.49	1		.03	1.3	2.7	Acc	Δ¢t SPOT — 4 OR S1
64	4	45/5	V	3.0	3.1	0.9	0.1	3.85	0.75	1		.05	1.3	2.8	Acc	Δ¢t SPOT — F 3 F S121
65		45/5	V	2.94	3.13	0.75	0.19	3.85	0.72	S		.12	2.3	3.0	Acc	Δ¢t SPOT — NGTH
66		45/5	V	3.02	3.12	1.0	0.1	3.85	0.73			.05	1.29	2.8	Acc	¢B SPOT
67 5		60/2	V	2.06	2.16	0.7	0.1	3.85	1.02	1		.07	1.3	2.8	Acc	Δ¢t SPOT
68		60/5	V	2.75	3.5*	13.25 0	0.1	3.85 3	0.35 1.1 0.48	1	Sub	.00	1.29	2.6	Acc A	* DEPT. CHANGE ACC. LENGTH Δ¢t SPOT
69 8 9		60/2	V	3.0	3.4*	12.1	0.14	3.85	0.25	1		.06	1.81	2.6	Acc	* C N F ALON LCN'T Δ¢B SPOT
70		45/2	P	2.75	2.92	1.6	0.17	3.85	0.93	1		.08	2.2	2.9	Acc	Δ¢B BSTD
71		45/2	V	2.5	2.6	1.2	0.1	3.85	1.25	1		.02	1.29	2.7	Acc	Δ¢t SPOT — 6 1
72		45/2	V	2.6	2.7	1.2	0.1	3.85	1.15	1		.02	1.29	2.7	Acc	Δ¢t SPOT
73		45/2	P	2.75	2.85	1.1	0.1	3.85	1.0	1		.04	1.3	2.8	Acc	Δ¢B SPOT
74		45/2	V	2.75	2.85	0.8	0.1	3.85	1.0	1		.06	1.29	2.6	Acc	Δ¢t SPOT
75		45/2	V	2.76	2.26	0.9	0.1	3.85	0.89	1		.05	1.33	2.8	Acc	¢B SPOT

Analyst: D. Kurtz — Level III 8-91 — Date 04 08 91

FIGURE A-1.2 INDICATION ASSESSMENT TABLE STEAM GENERATOR A WELD 1-5 (CONTINUED)

INDICATION ASSESSMENT

PLANT Kewaunee

WELD 1-5 (SG-W2)

DESCRIPTION S.G. A Upper Transition Girth Weld

Indication No.	Channel/TD	Beam angle/dir.	P = planar V = volumetric	Depth from ID OD surface MIN.	Depth from ID OD surface MAX.	Length l [in]	Through wall dimension 2a [in]	Applicable thickness [in]	S dim. [in]	Y value	Surface or subsurface	Aspect ratio a/l	a/t %	Allowable a/t %	Status	COMMENTS IWB - 3000 reference UDRPS File No.
60/16		45/2	V	2.75	2.85	0.8	0.1	3.9	1.05	1	Sub	.06	1.28	2.8	Acc.	Δ #B SPOT
60/17		45/2	V	2.8	3.07	0.7	0.27	3.9	0.83	1		.2	3.41	3.6	Acc.	Δ #B SPOT
60/18																REF. 60-19 FOR SIZING
60/19		45/5	V	3.125	3.29	1.6	.17	3.9	0.61	1		.05	2.17	2.8	Acc.	Δ #B SPOT
60/20		45/2	V	2.75	2.85	1.2	.1	3.9	1.1	1		.04	1.28	2.8	Acc.	Δ # [illegible] SPOT
60/21		45/2	V	3.01	3.15	1.0	.14	3.9	0.75	1		.07	1.79	2.8	Acc.	Δ [illegible]B SPOT

Analyst [signature] **Level** III 4-8-91 **Date** [signature] 04/08/91

FIGURE A-1.3 INDICATION ASSESSMENT TABLE STEAM GENERATOR A WELD 1-5 (CONTINUED)

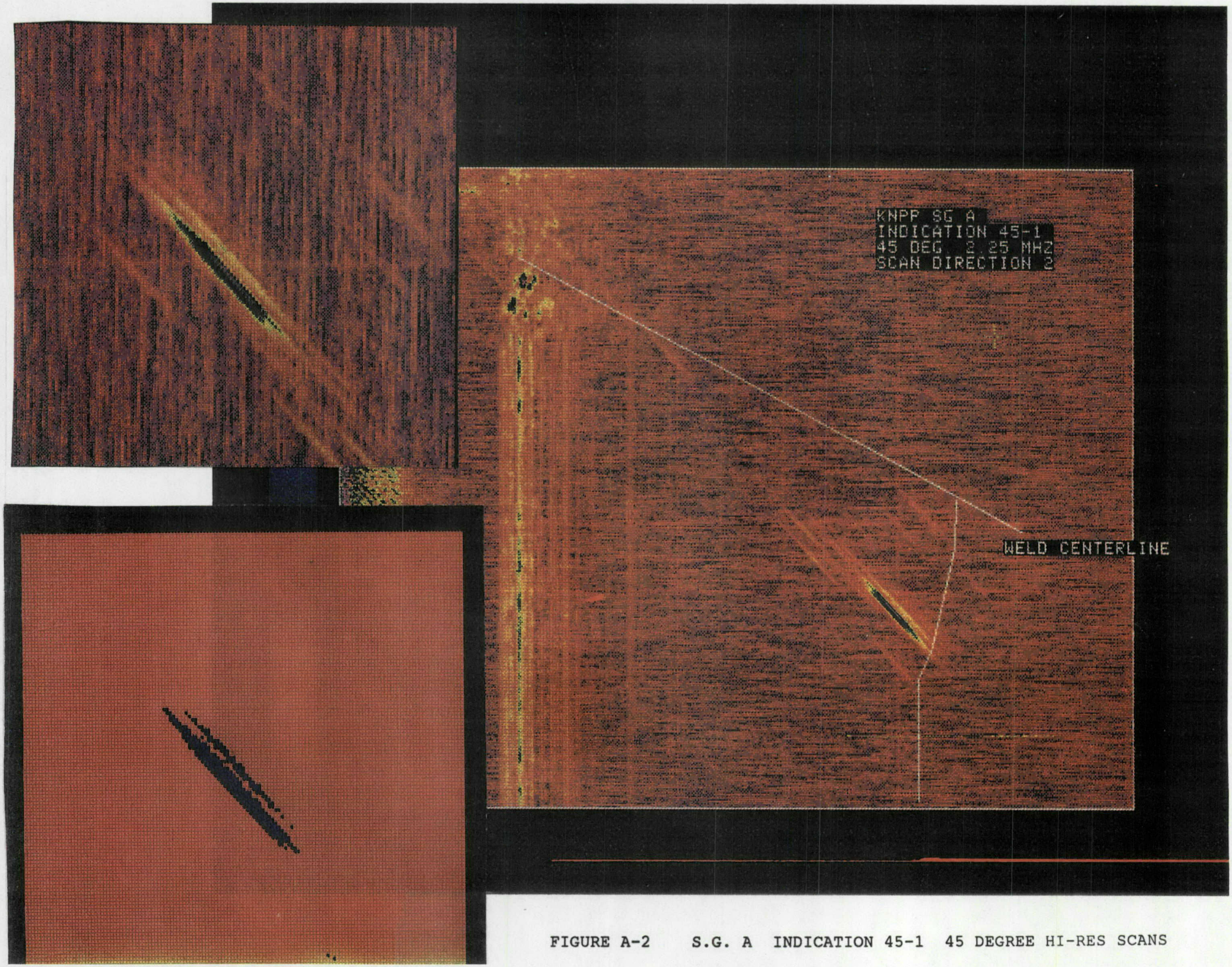


FIGURE A-2 S.G. A INDICATION 45-1 45 DEGREE HI-RES SCANS

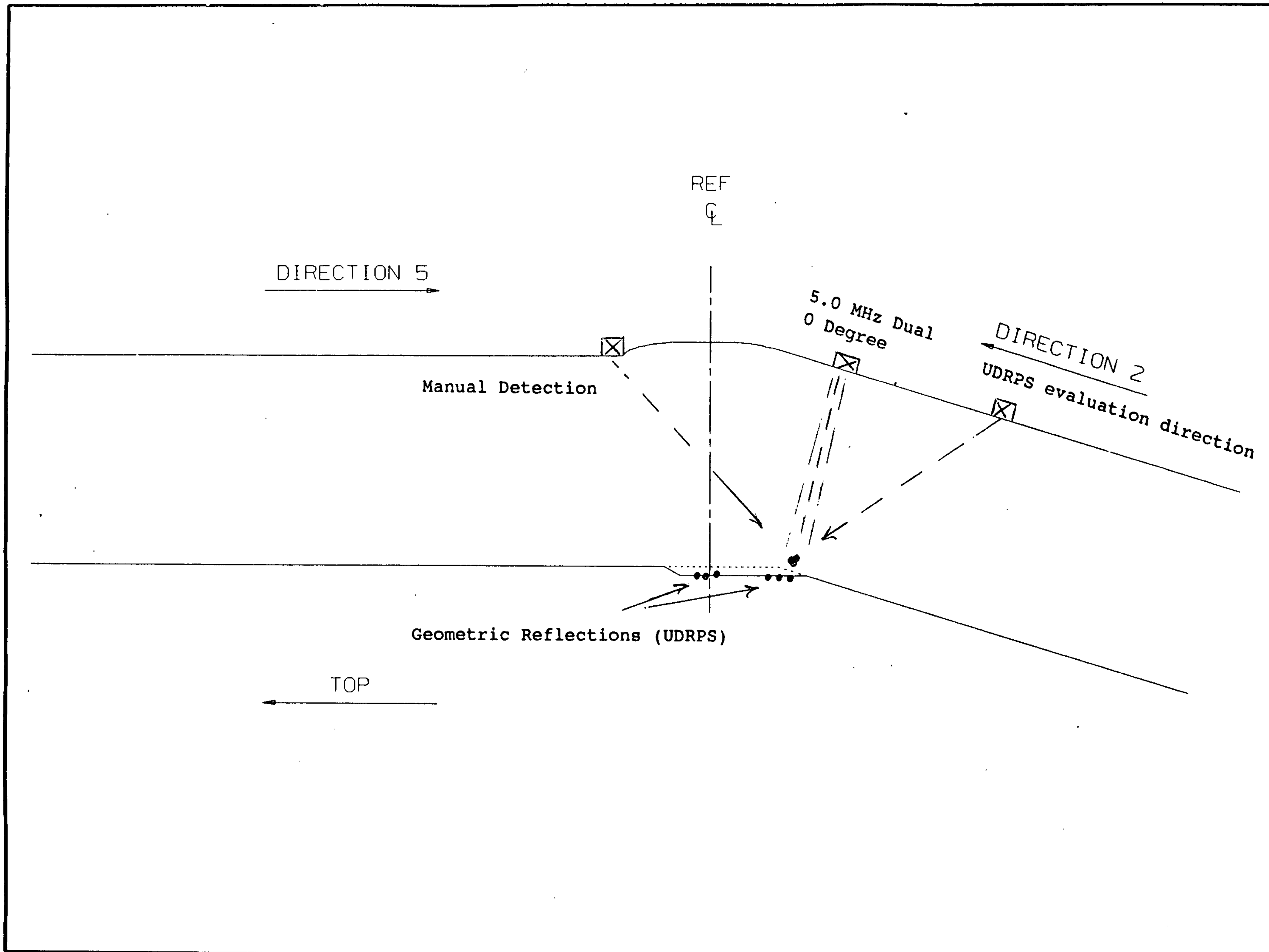


FIGURE A-3 S.G. A INDICATION 45-1 DATA POINT PLOTS

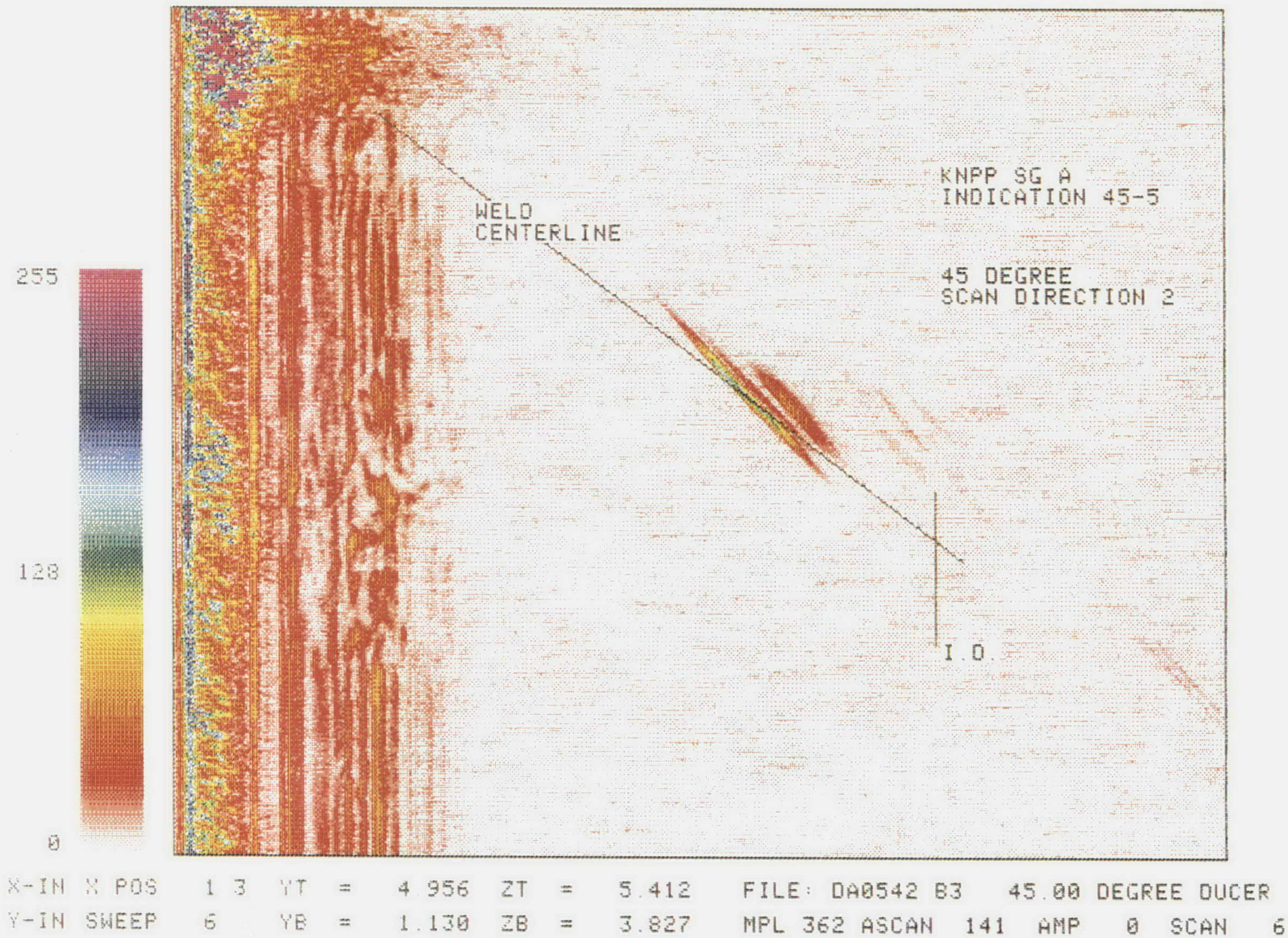


FIGURE A-4 S.G. A INDICATION 45-5, 45 DEGREE HI-RES SCAN

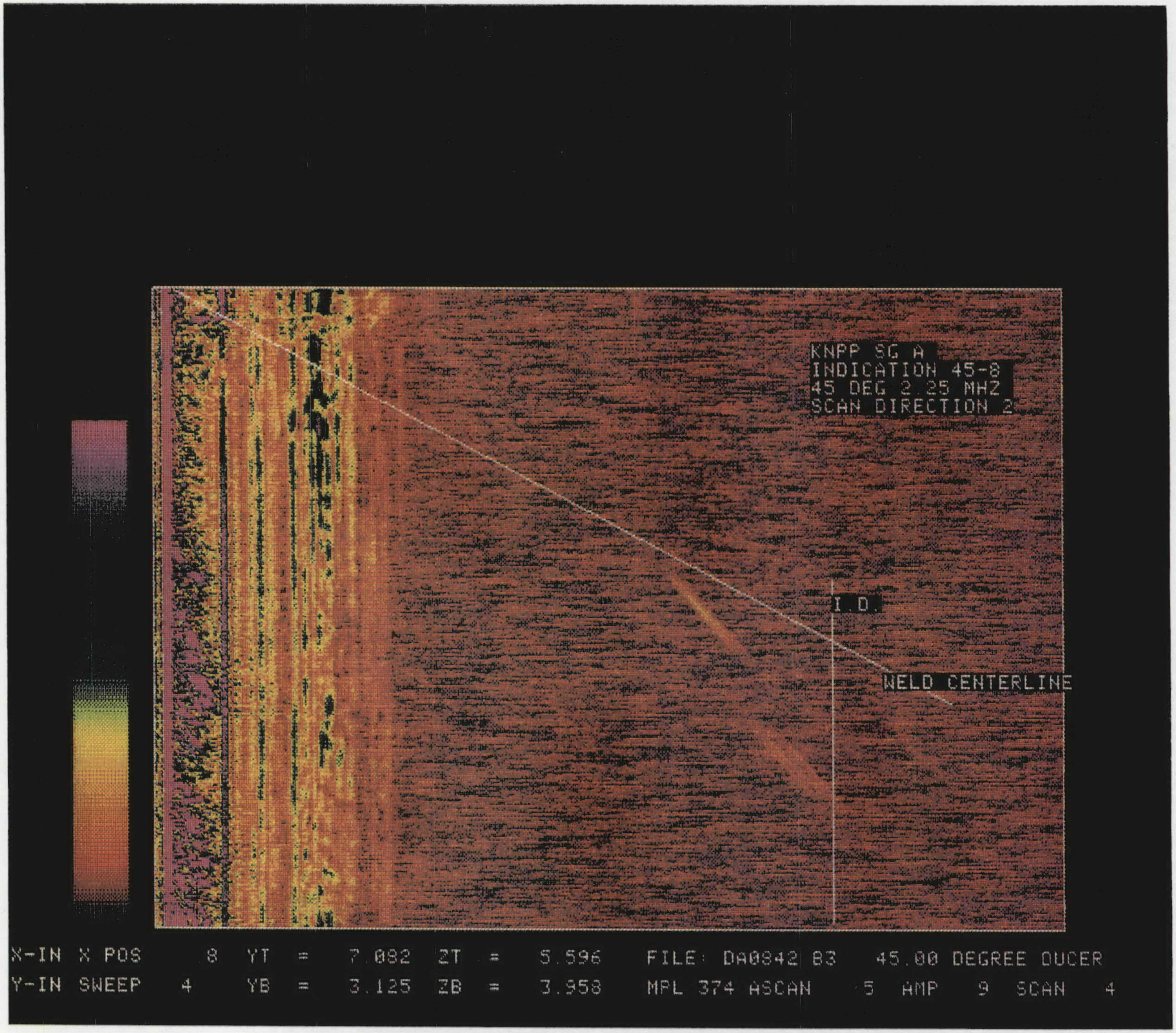


FIGURE A-5.1 S.G. A, INDICATION 45-8, 45 DEGREE HI-RES SCAN

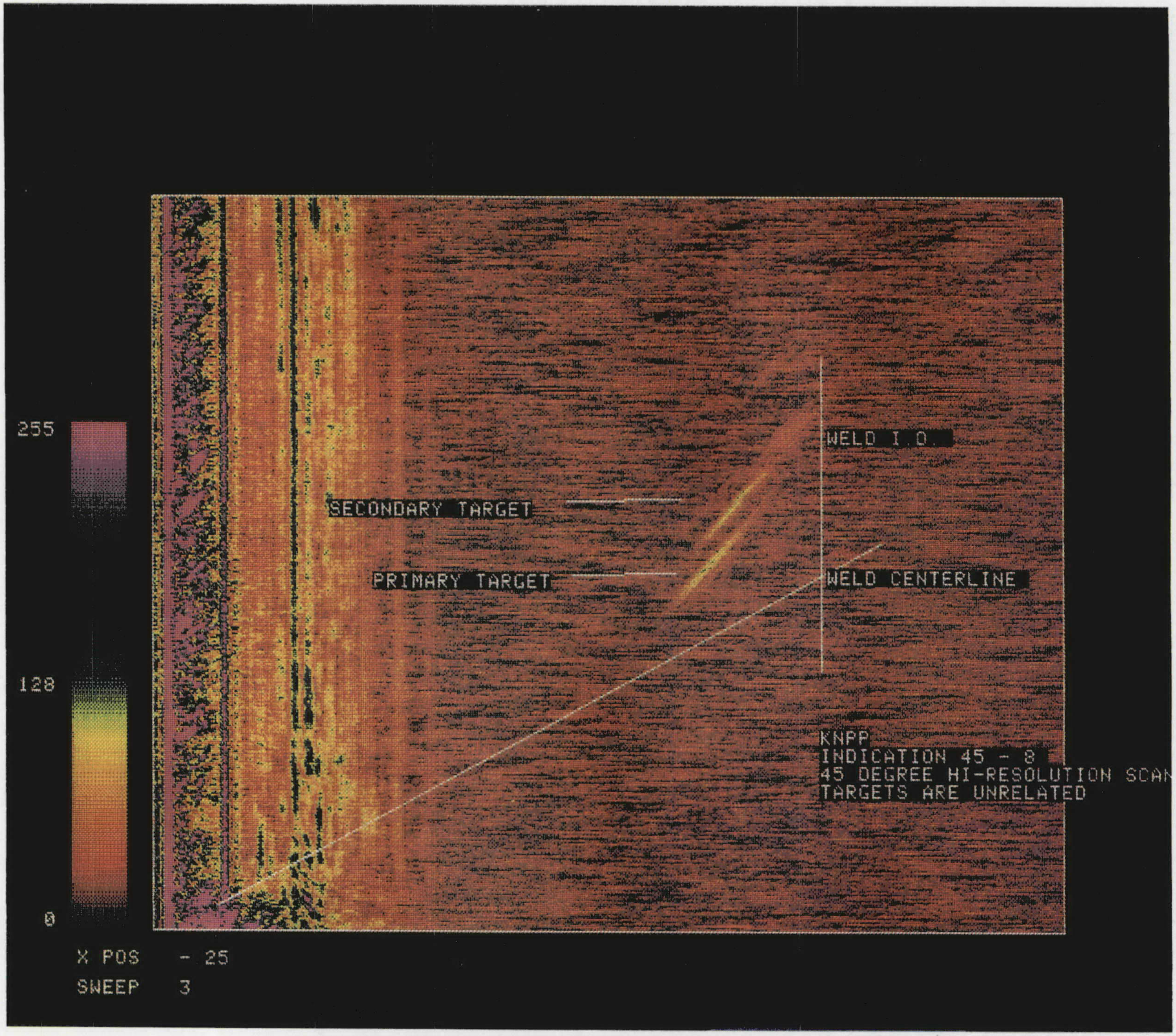


FIGURE A-5.2 S.G. A, INDICATION 45-8, 45 DEGREE HI-RES SCAN

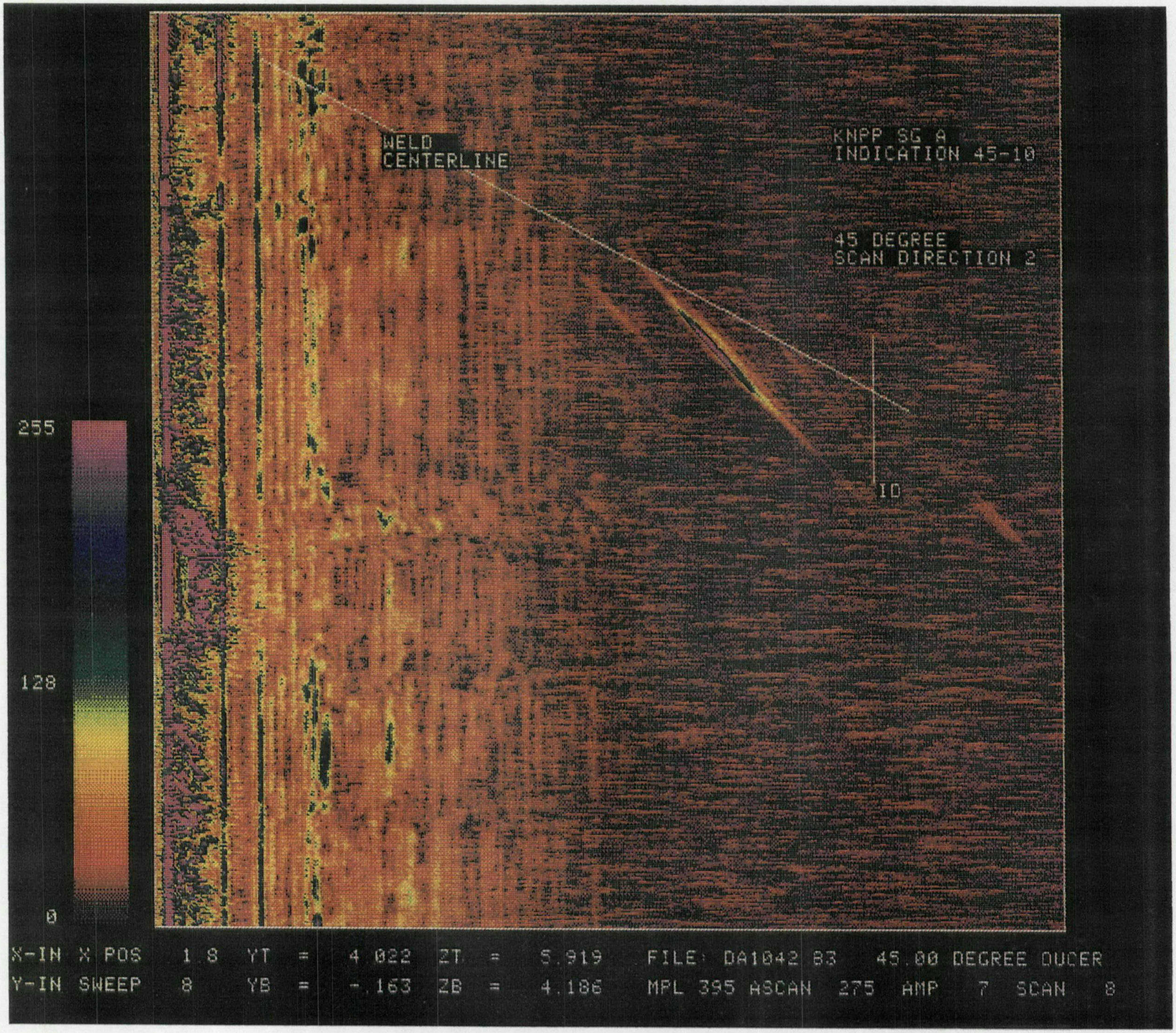


FIGURE A-6 S.G. A, INDICATION 45-10, 45 DEGREE HI-RES SCAN

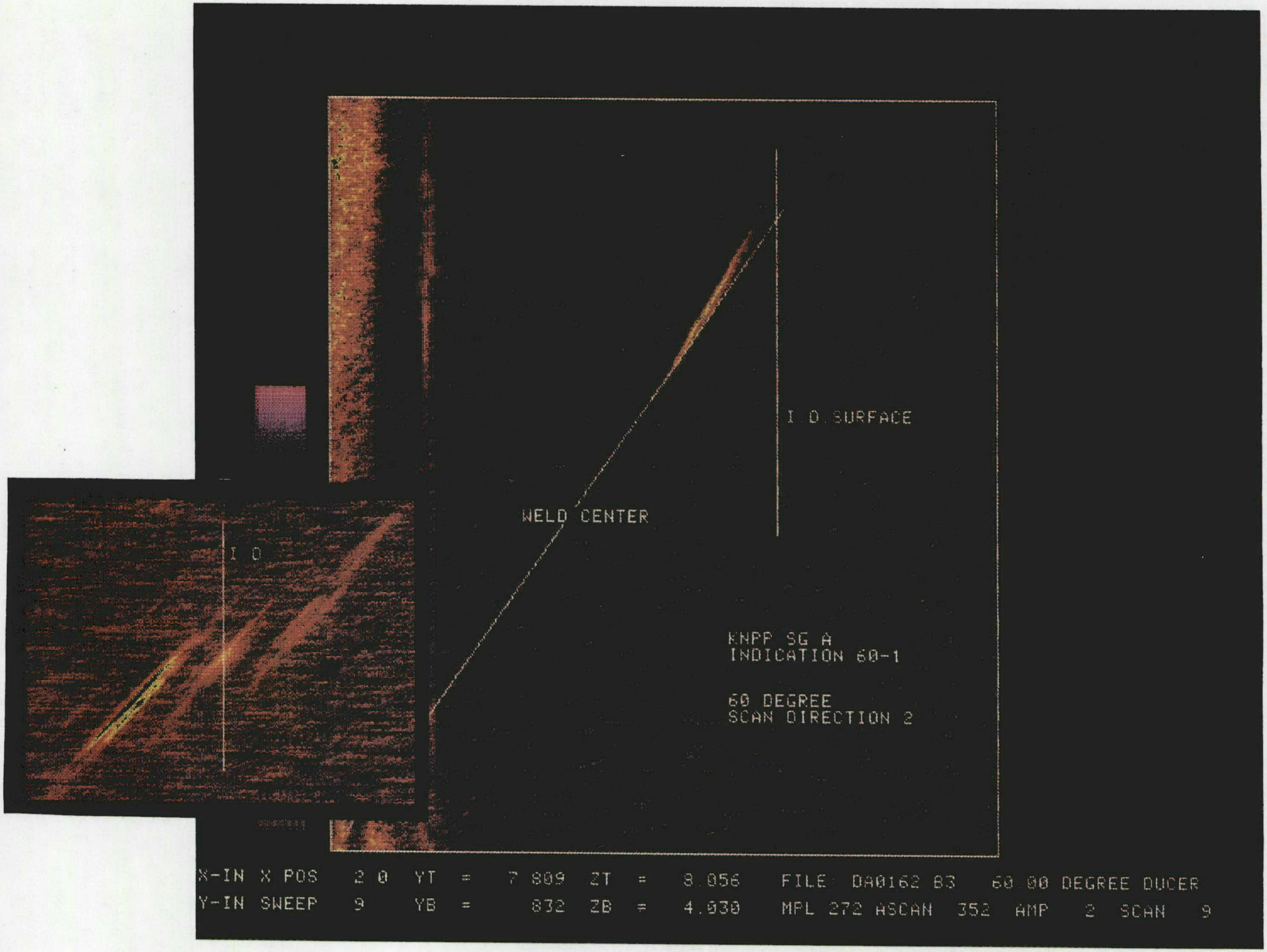


FIGURE A-7 S.G. A. INDICATION 60-1, 60 DEGREE SCAN WITH 45 DEGREE HI-RES SCAN (INSERT)

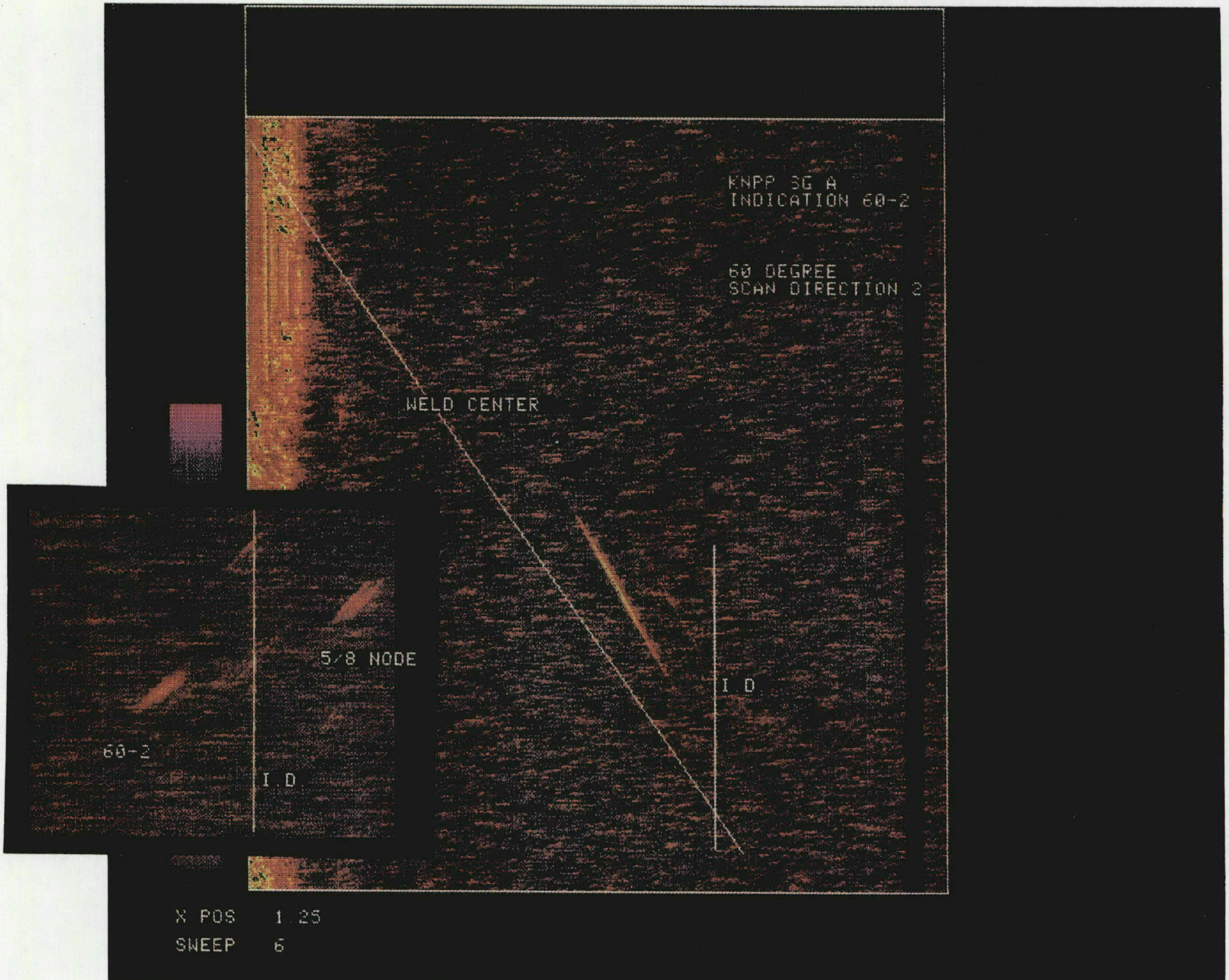


FIGURE A-8 S.G. A INDICATION 60-2, 60 DEGREE SCAN WITH 45 DEGREE HI-RES SCAN (INSERT)

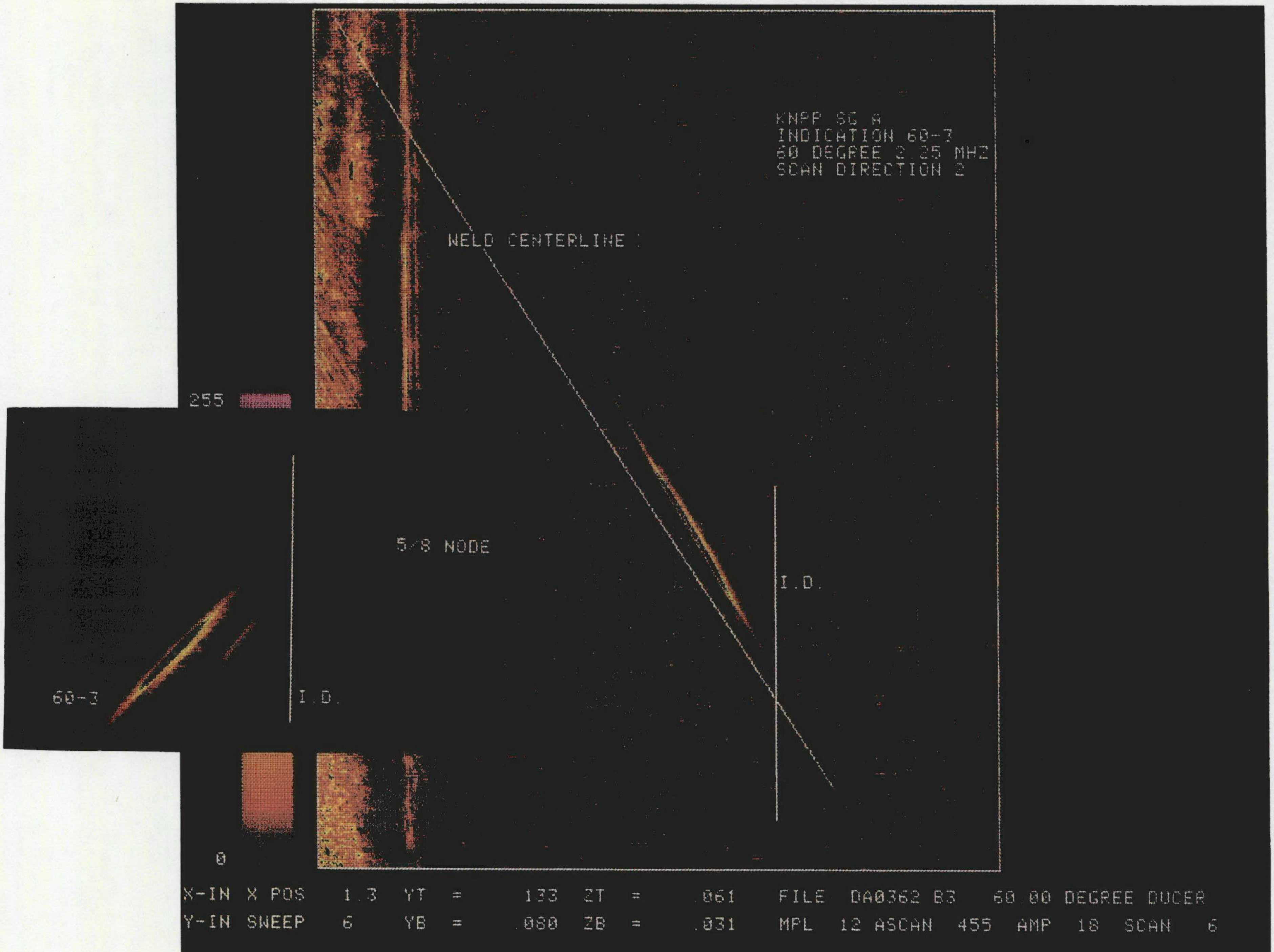


FIGURE A-9 S.G. A INDICATION 60-3, 60 DEGREE SCAN WITH 45 DEGREE HI-RES SCAN (INSERT)

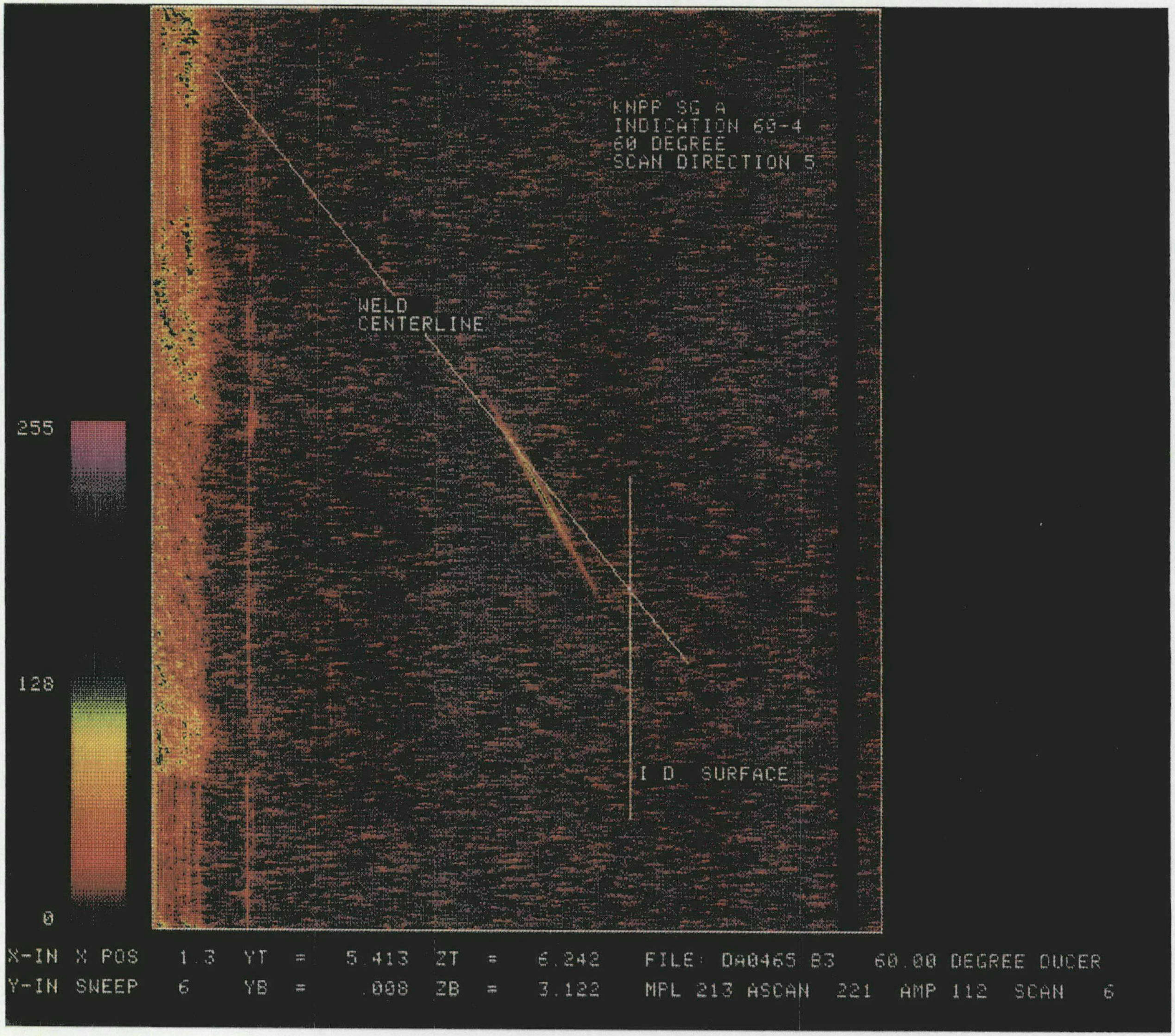


FIGURE A-10.1 S.G. A INDICATION 60-4, 60 DEGREE SCAN

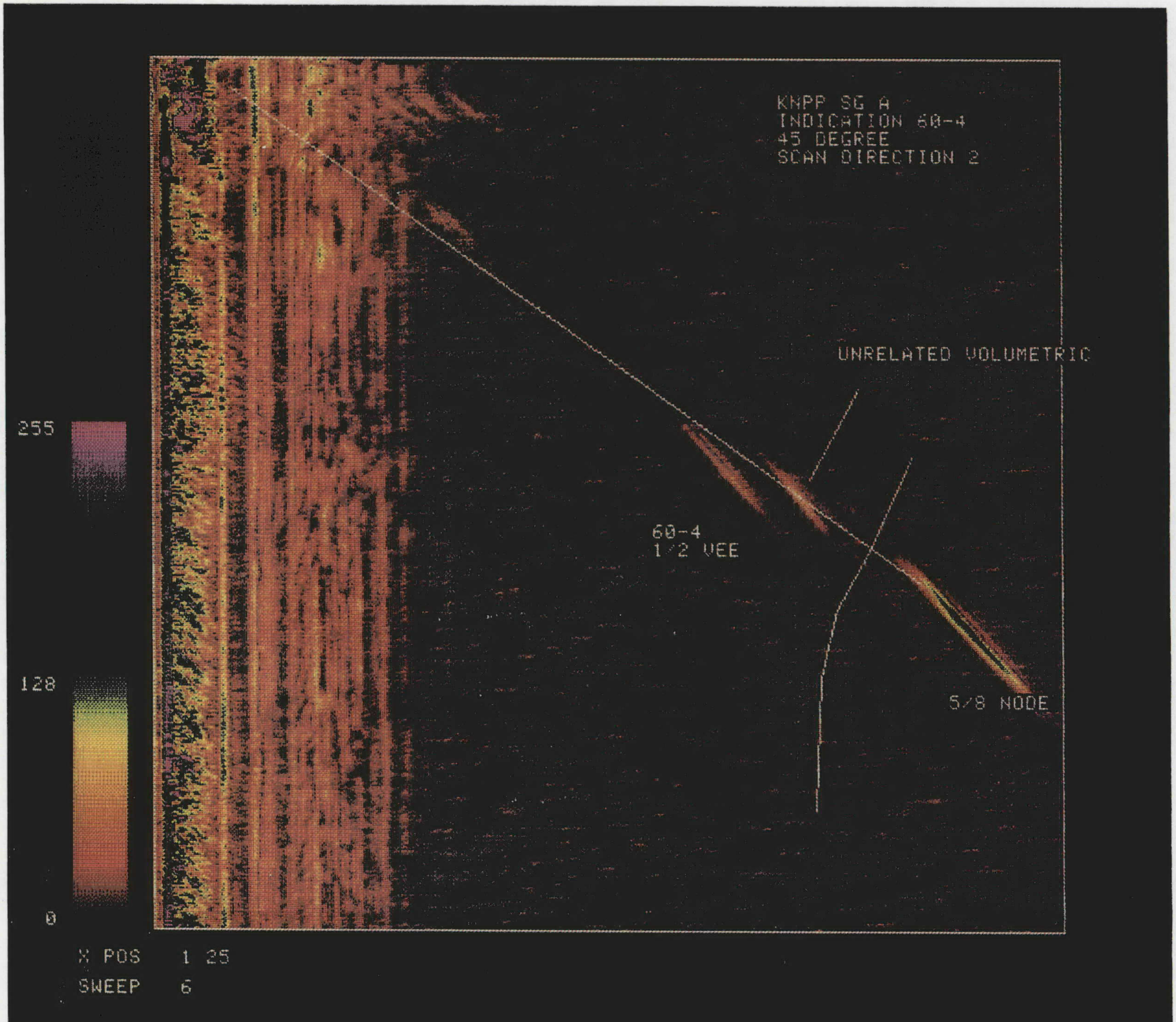


FIGURE A-10.2 S.G. A INDICATION 60-4, 45 DEGREE HI-RES SCAN

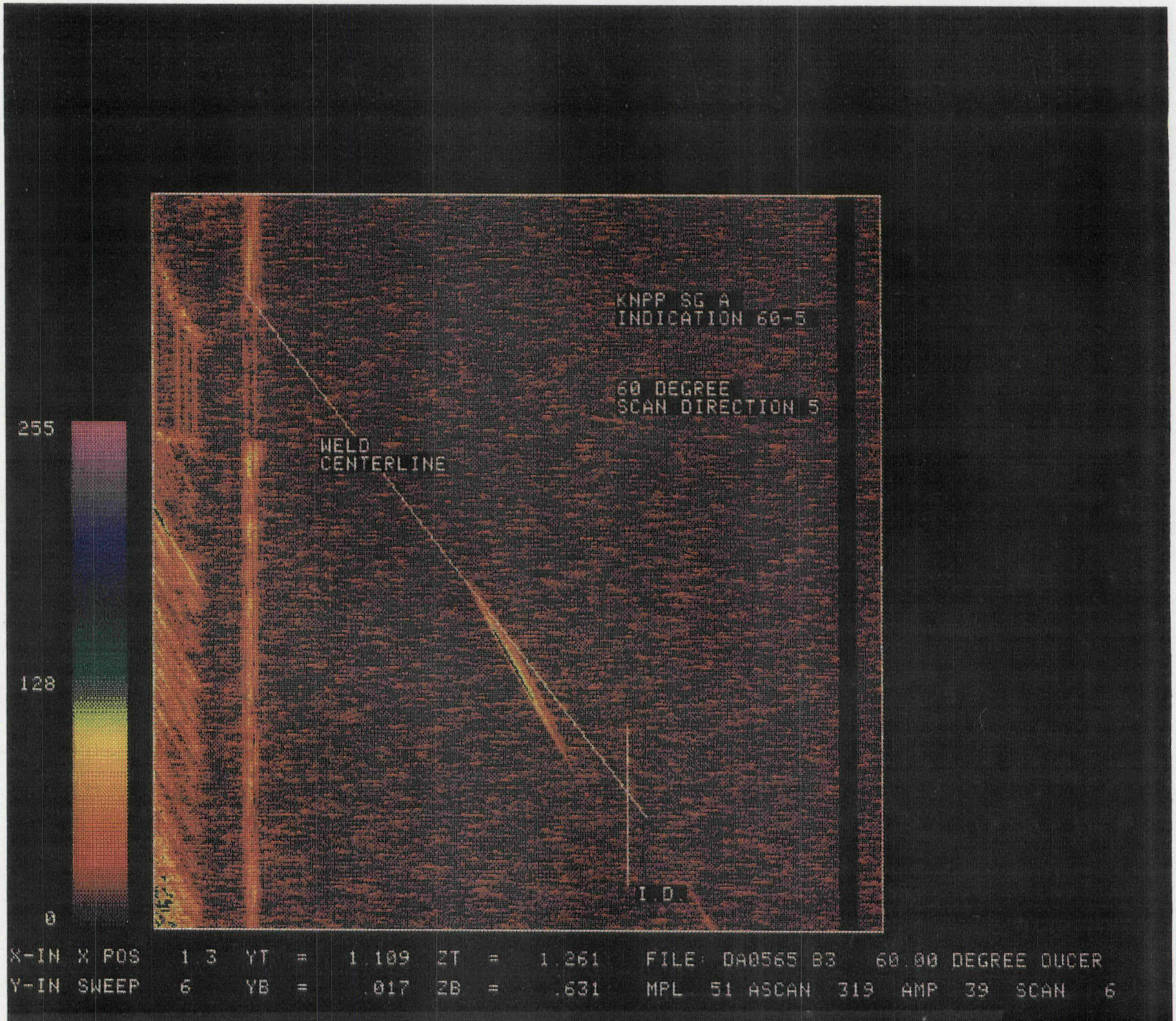


FIGURE A-11.1 S.G. A INDICATION 60-5, 60 DEGREE SCAN

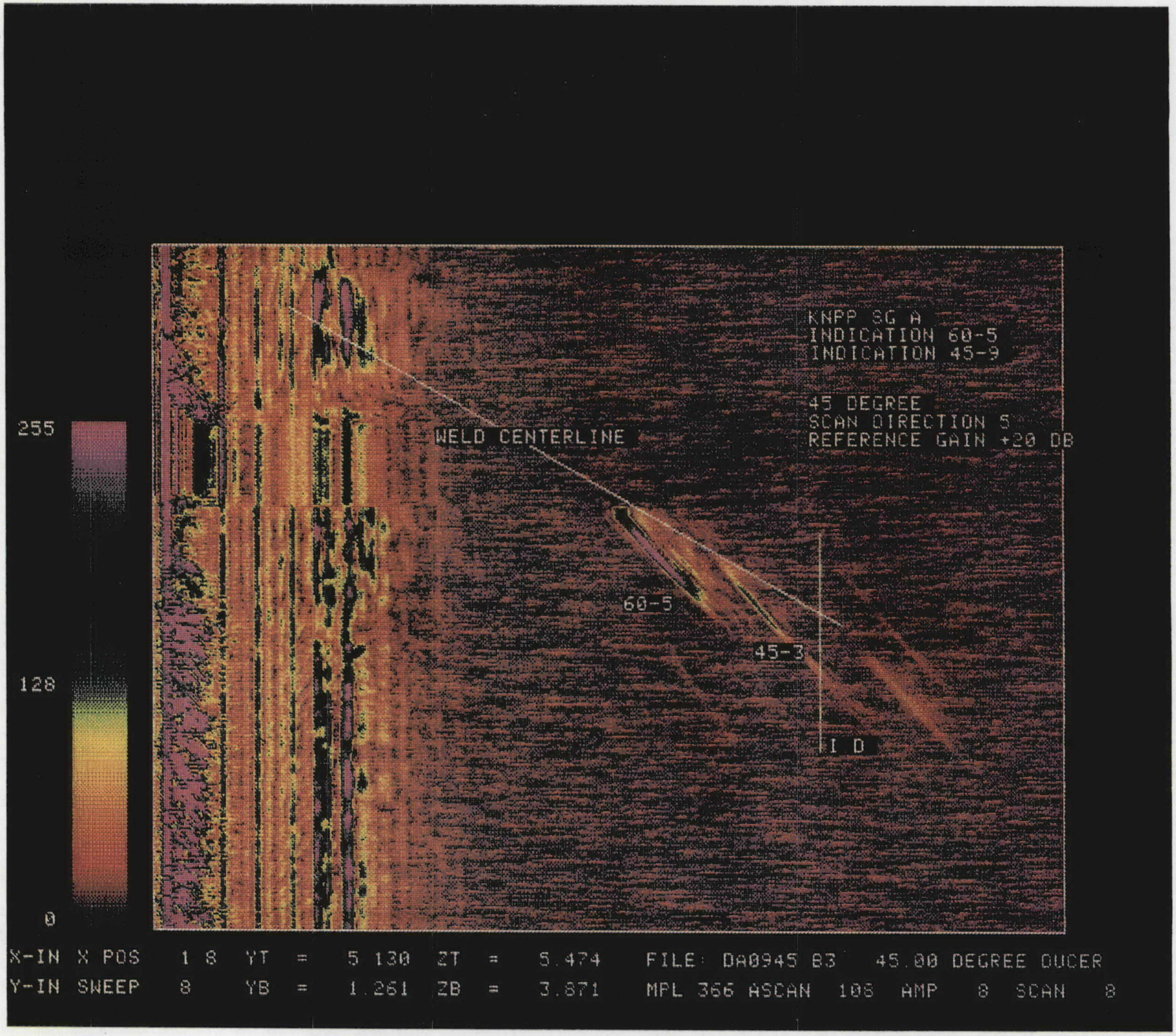


FIGURE A-11.2 S.G. A INDICATION 60-5, 45 DEGREE HI-RES SCAN

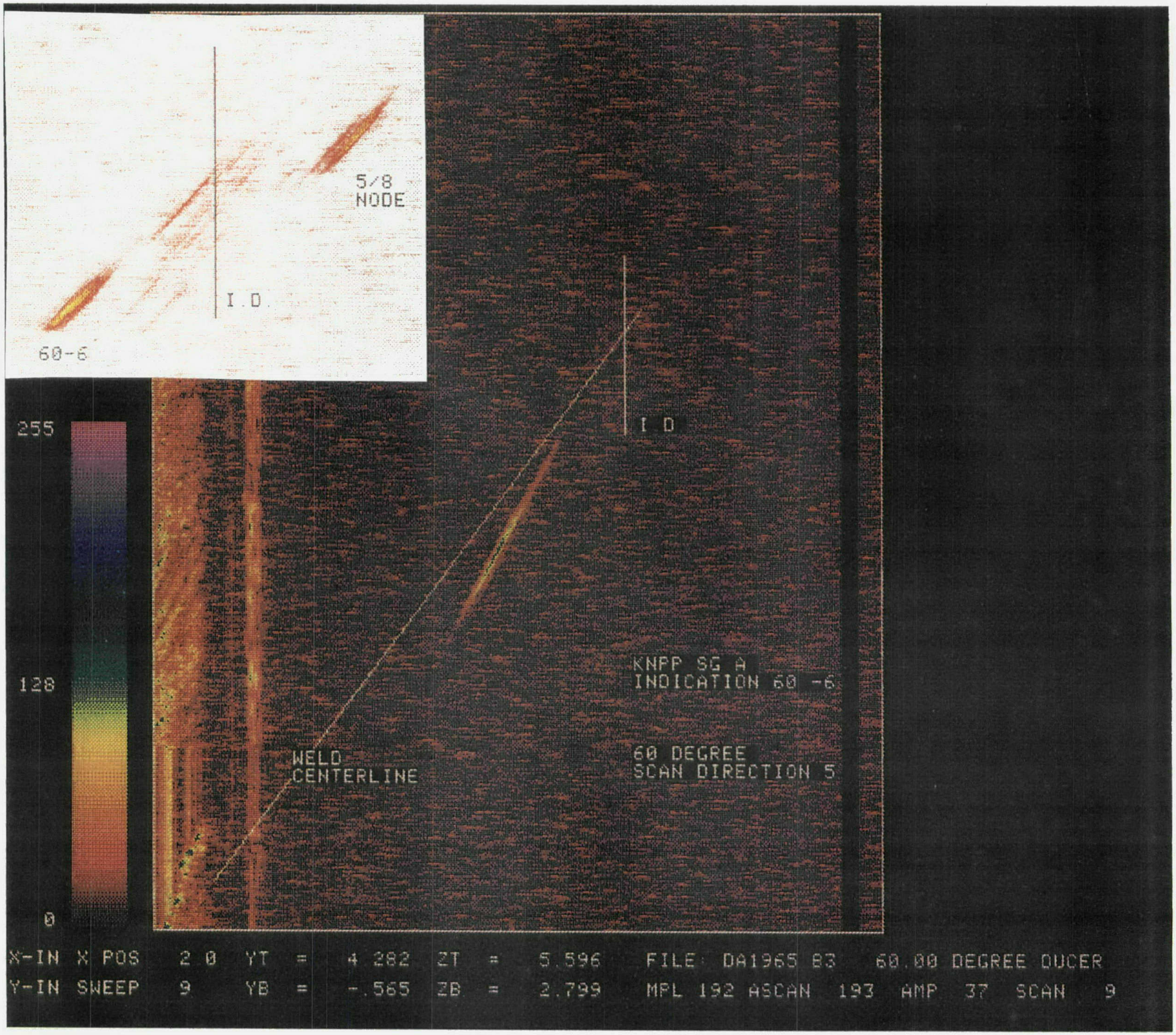


FIGURE A-12 S.G. A INDICATION 60-6, 60 DEGREE SCAN WITH 45 DEGREE HI-RES SCAN (INSERT)

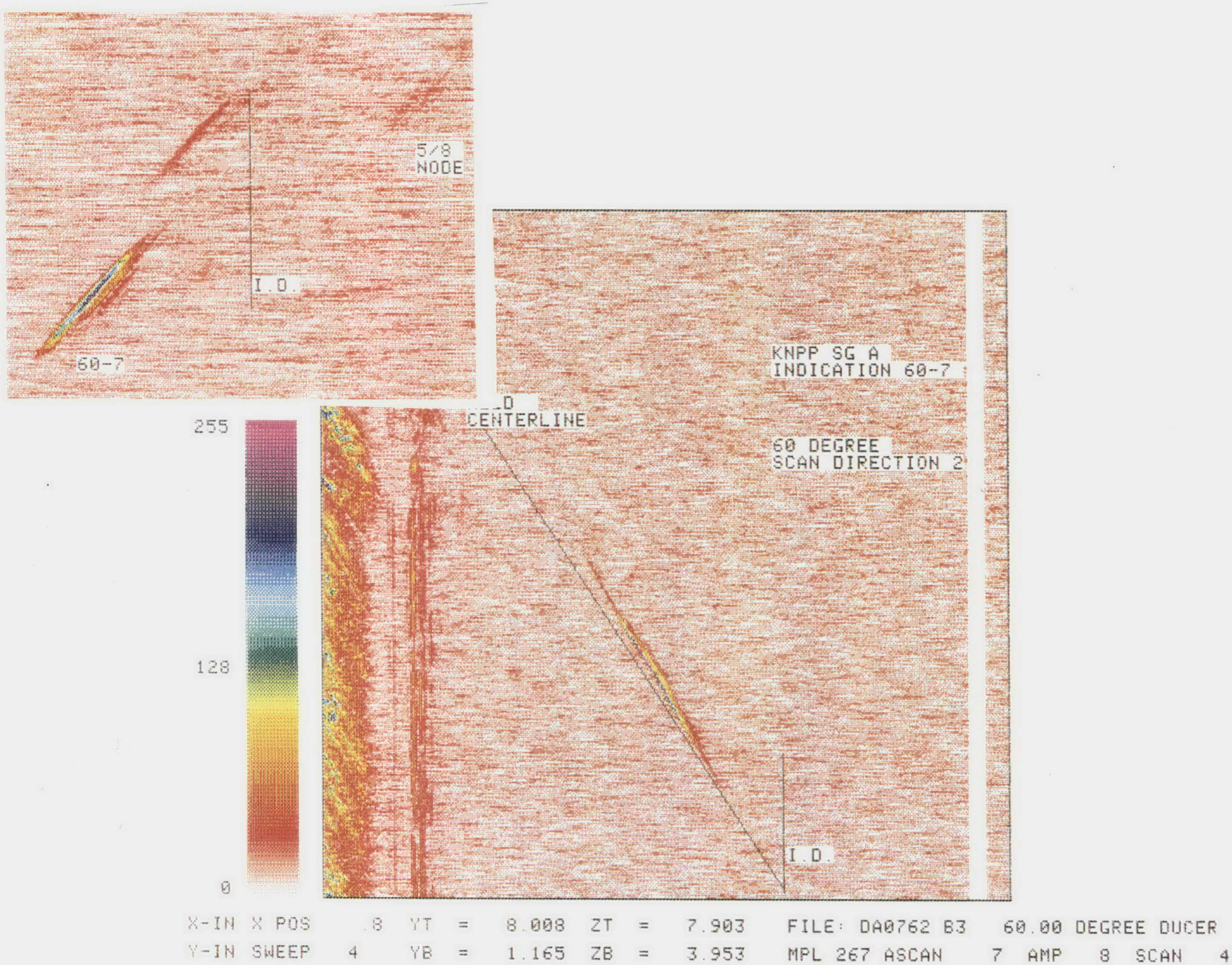


FIGURE A-13 S.G. A INDICATION 60-7, 60 DEGREE SCAN WITH 45 DEGREE HI-RES SCAN (INSERT)

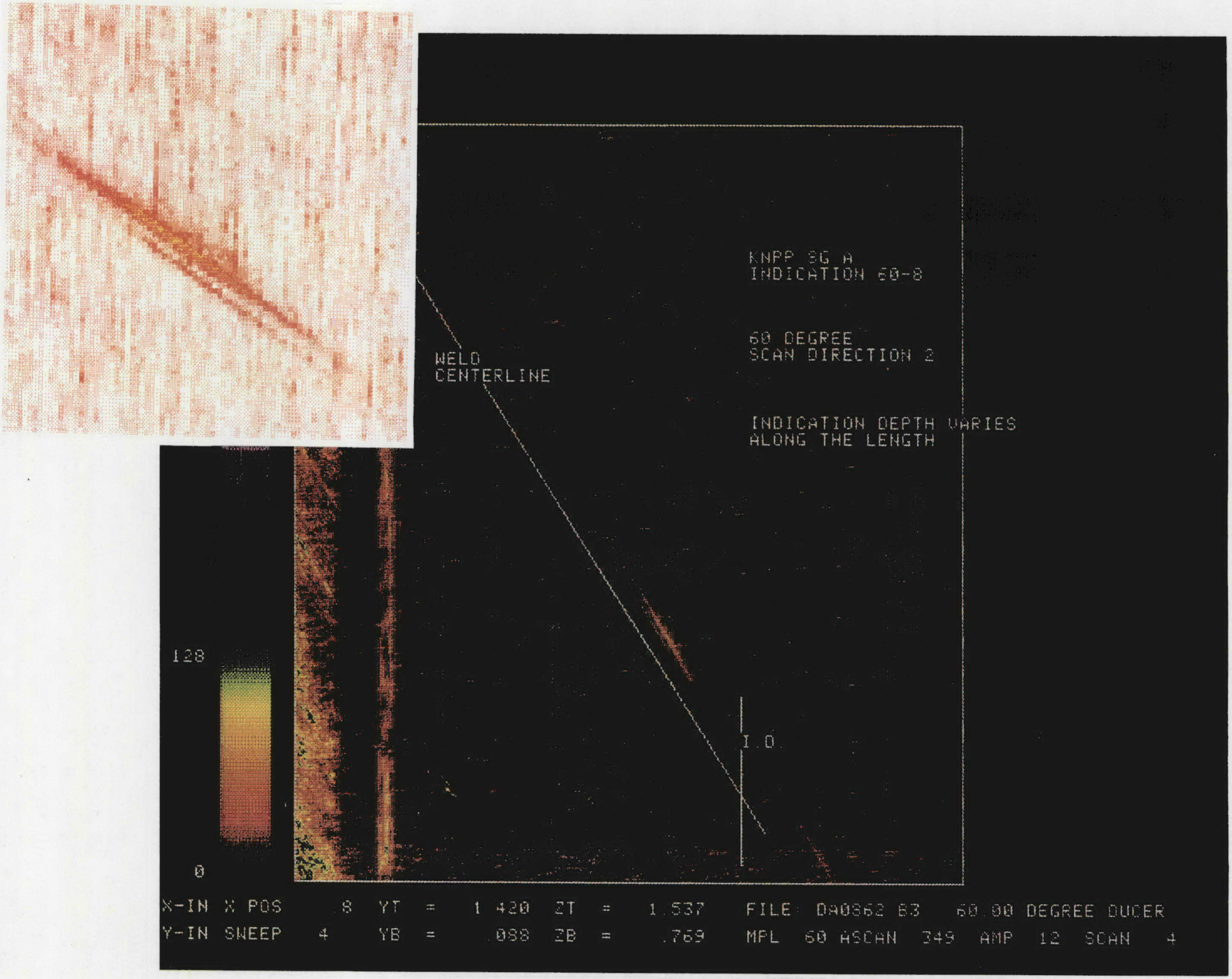


FIGURE A-14 S.G. A INDICATION 60-8, 60 DEGREE SCAN WITH 60 DEGREE HI-RES SCAN (INSERT)

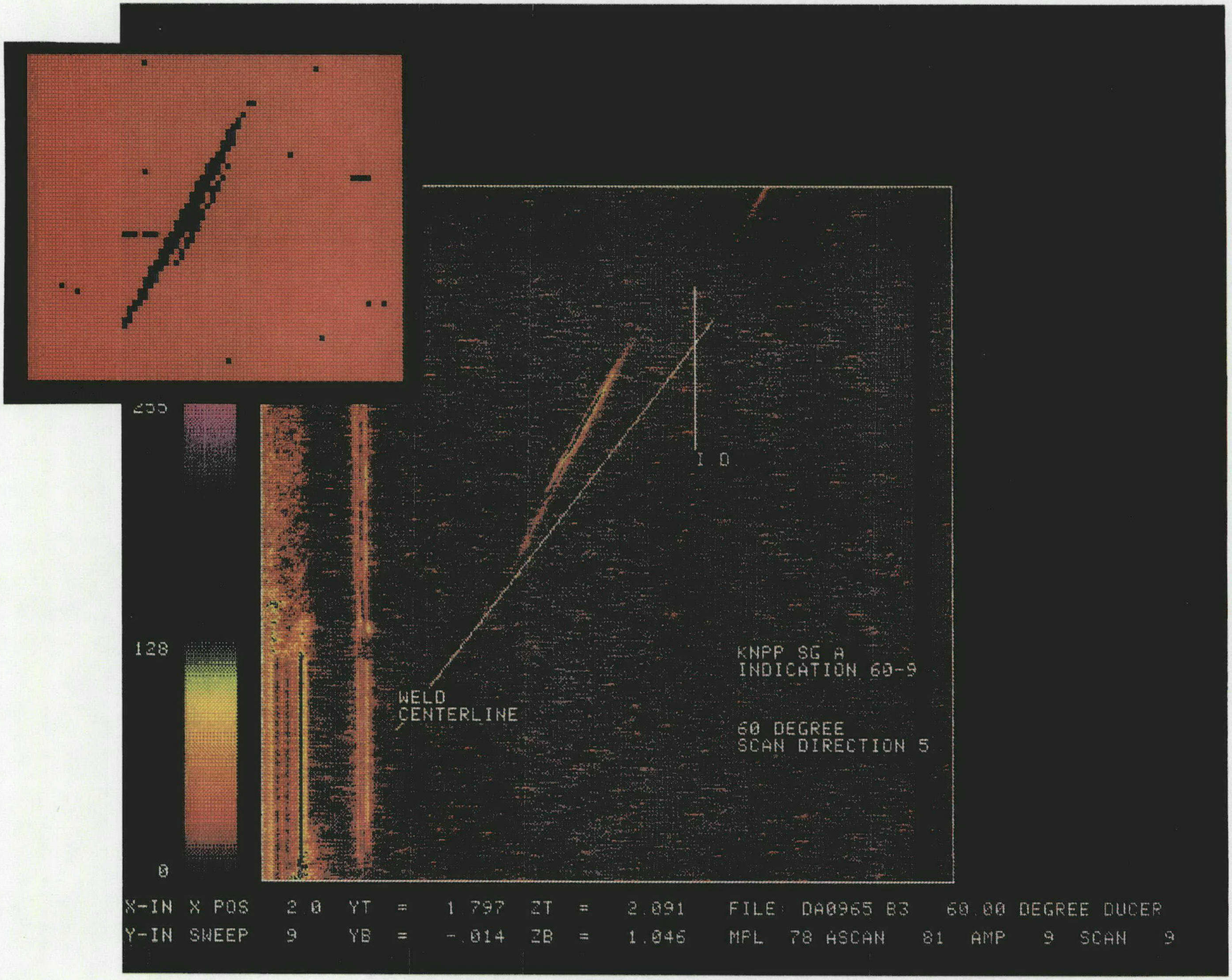


FIGURE A-15 S.G. A INDICATION 60-9, 60 DEGREE SCAN WITH 45 DEGREE HI-RES SCAN (INSERT)

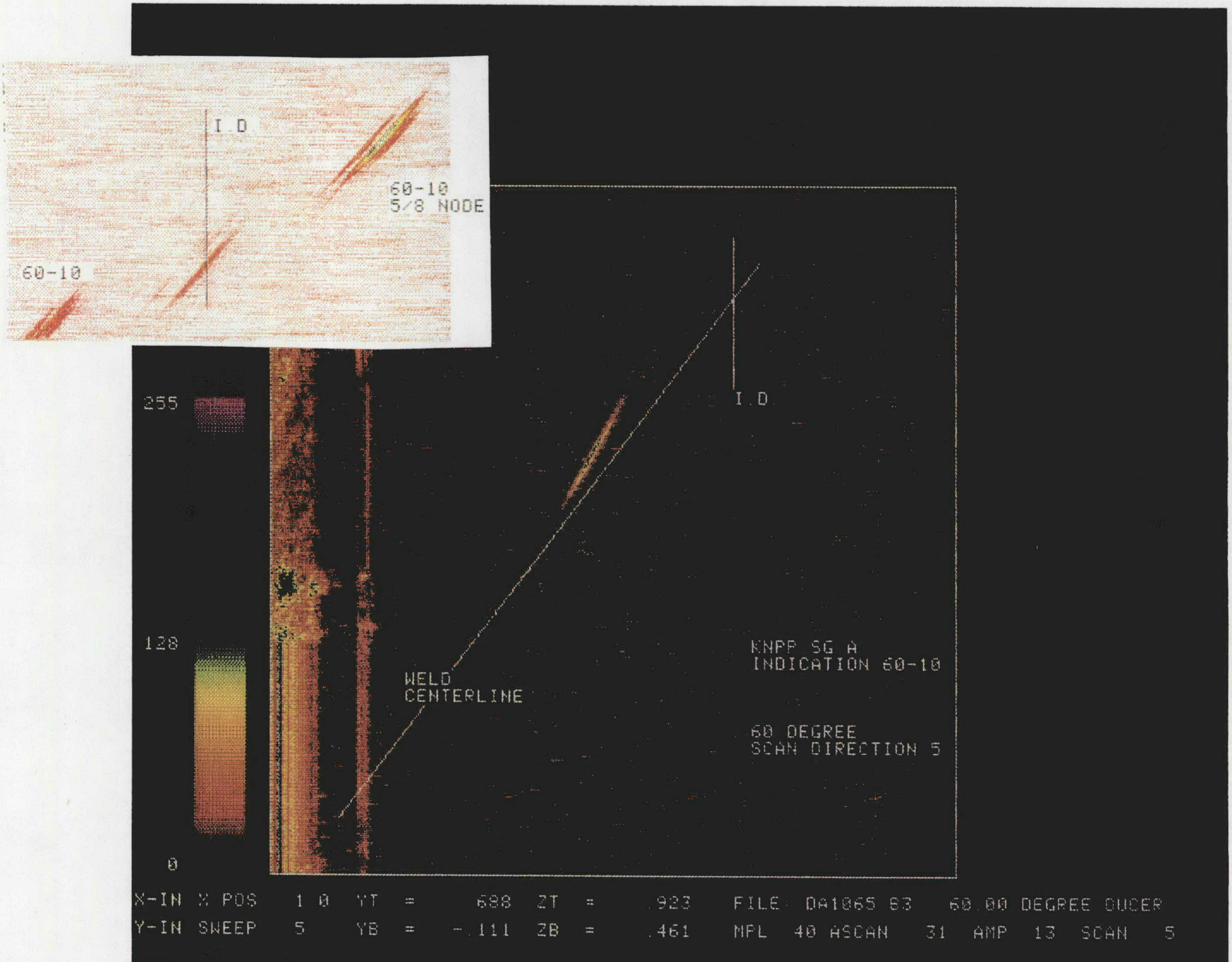


FIGURE A-16 S.G. A INDICATION 60-10, 60 DEGREE SCAN WITH 45 DEGREE
HI-RES SCAN (INSERT)

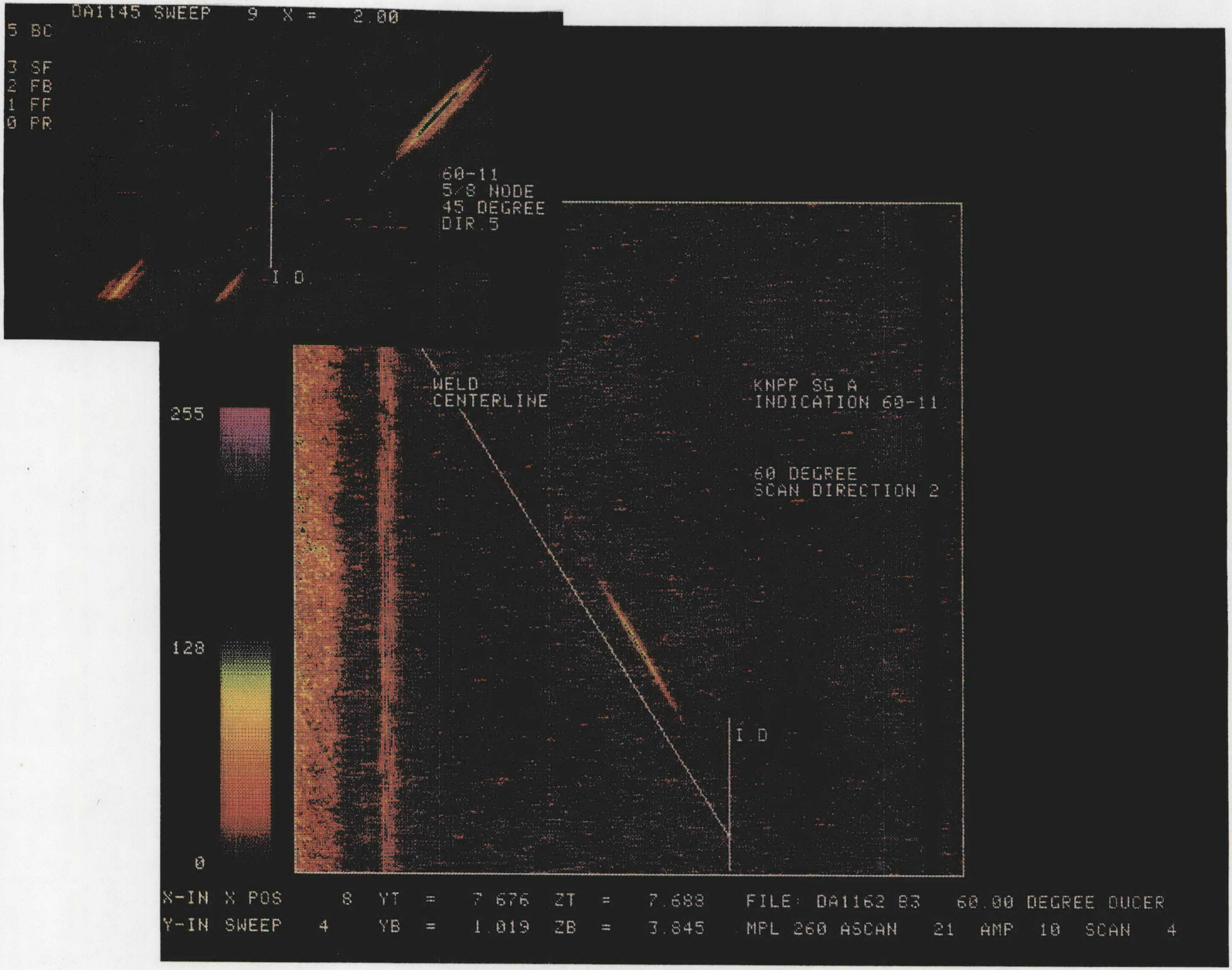


FIGURE A-17 S.G. A INDICATION 60-11, 60 DEGREE SCAN WITH 45 DEGREE HI-RES SCAN (INSERT)

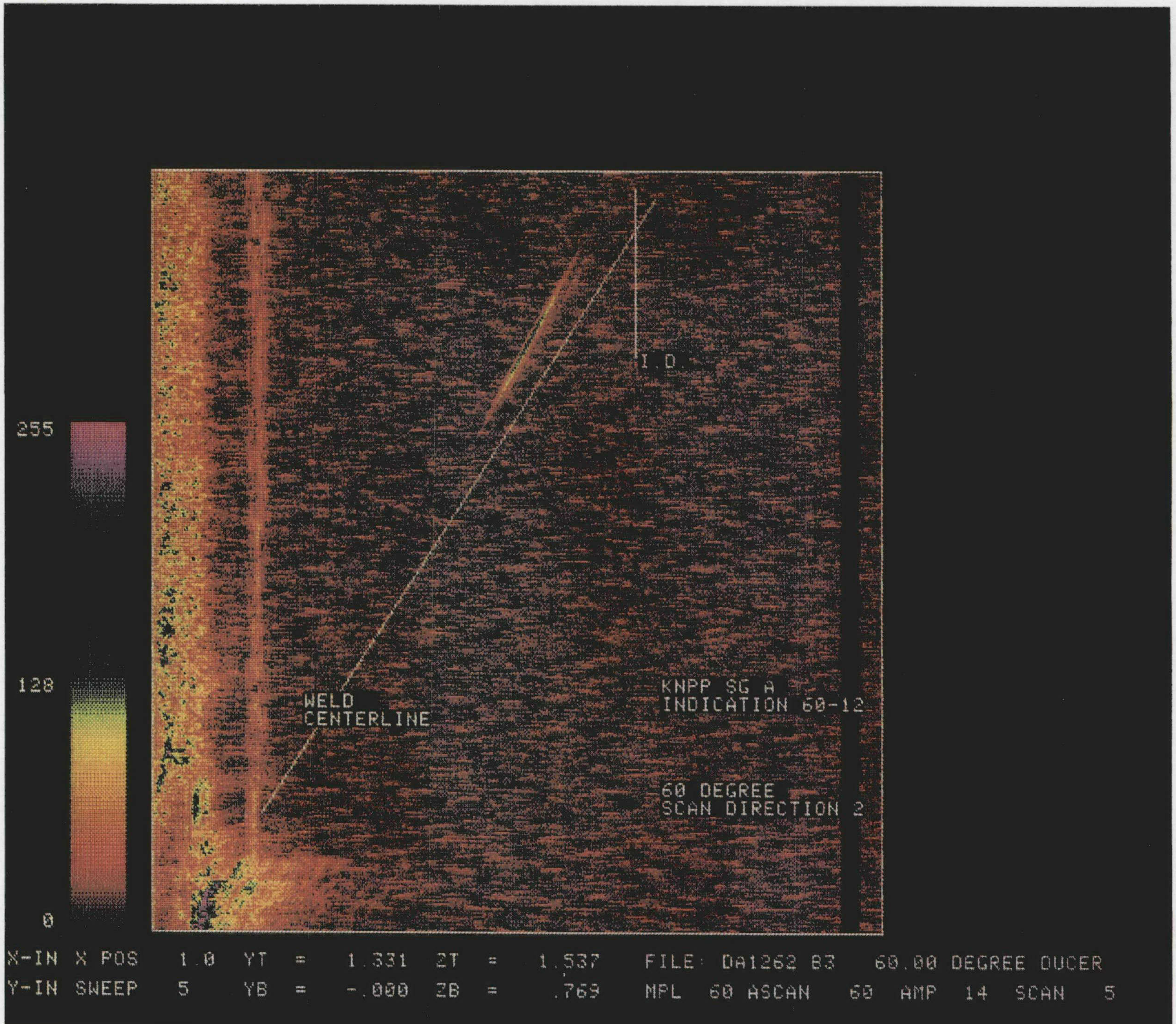


FIGURE A-18.1 S.G. A INDICATION 60-12, 60 DEGREE SCAN

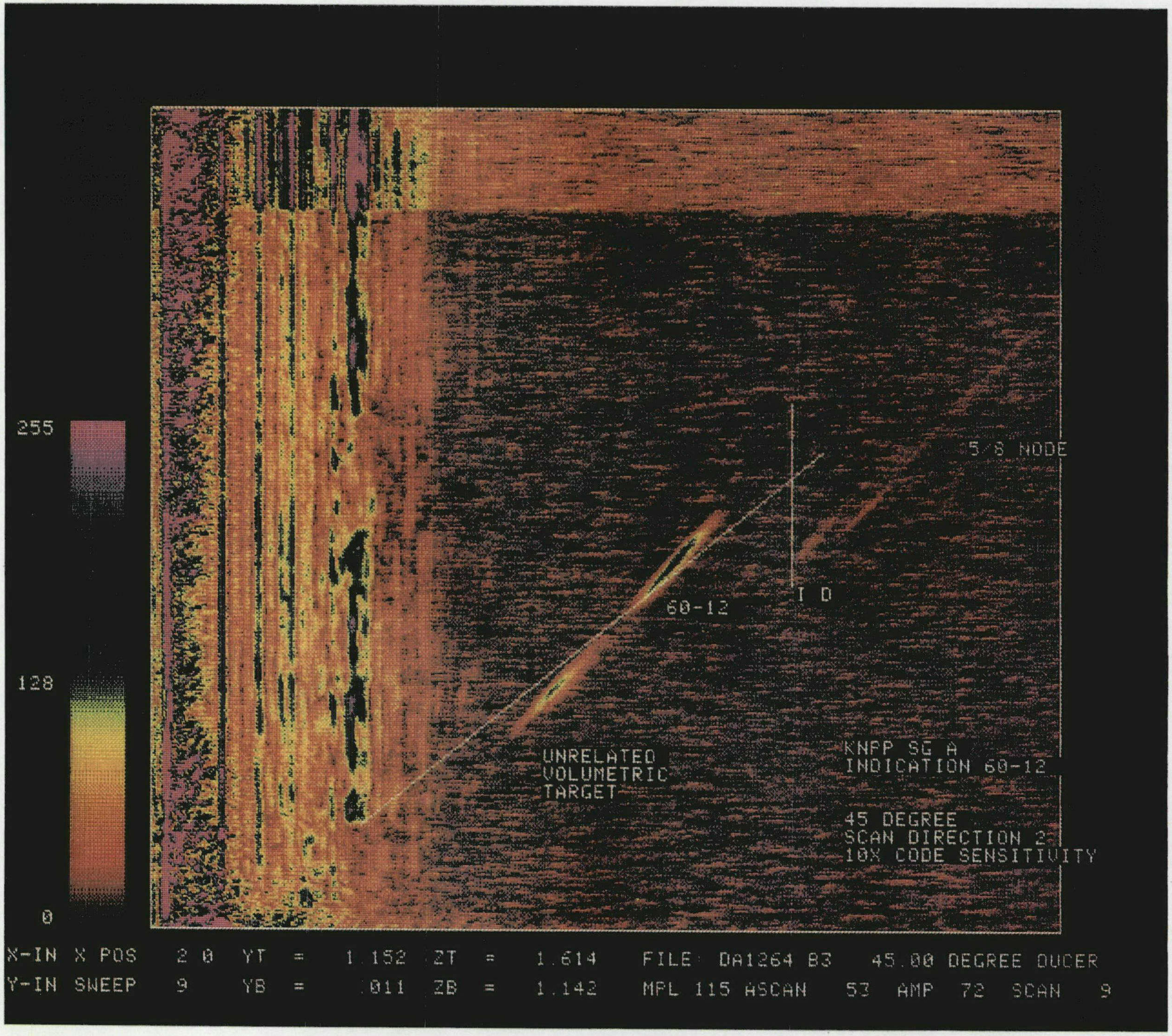


FIGURE A-18.2 S.G. A INDICATION 60-12, 45 DEGREE HI-RES SCAN

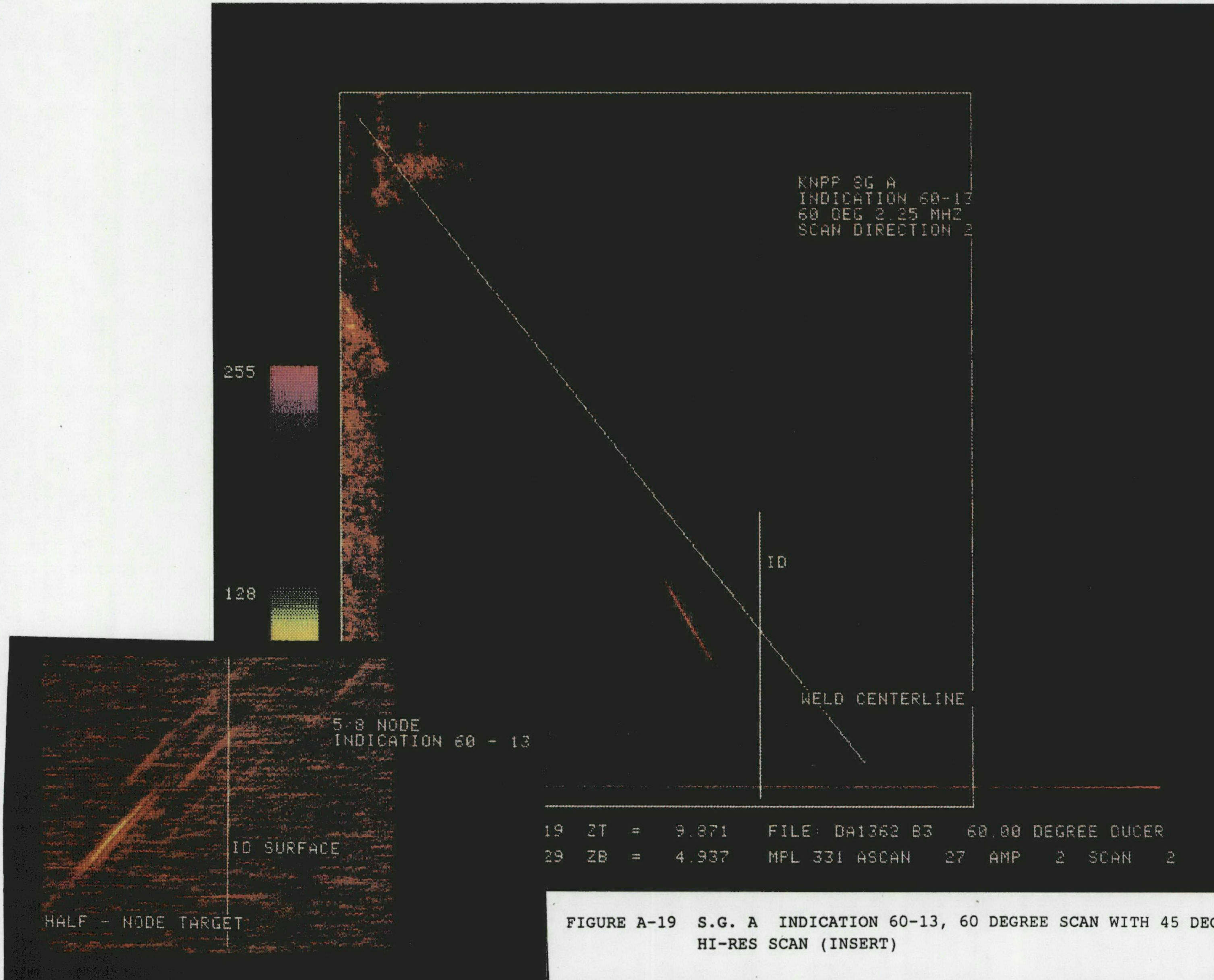


FIGURE A-19 S.G. A INDICATION 60-13, 60 DEGREE SCAN WITH 45 DEGREE HI-RES SCAN (INSERT)

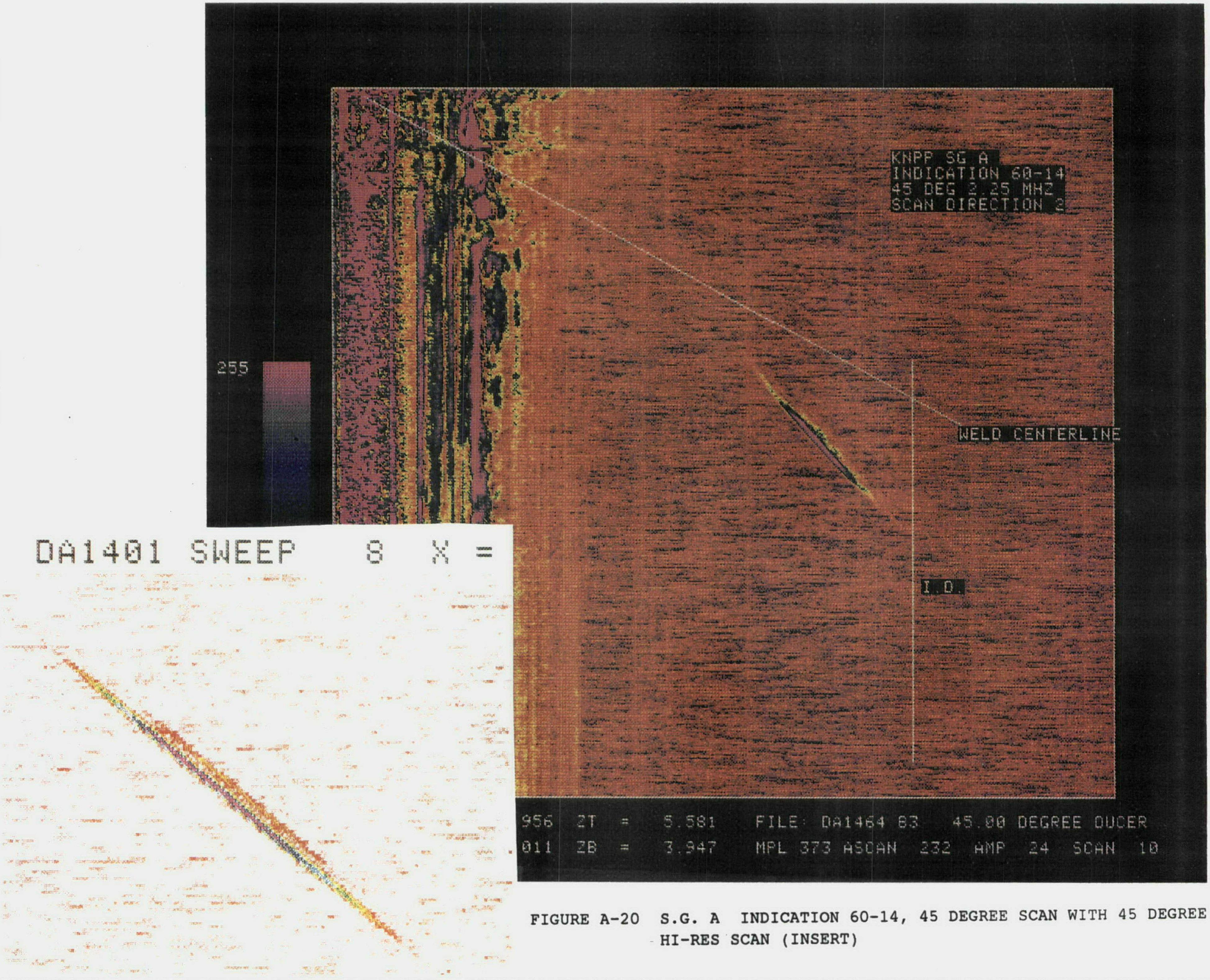


FIGURE A-20 S.G. A INDICATION 60-14, 45 DEGREE SCAN WITH 45 DEGREE HI-RES SCAN (INSERT)

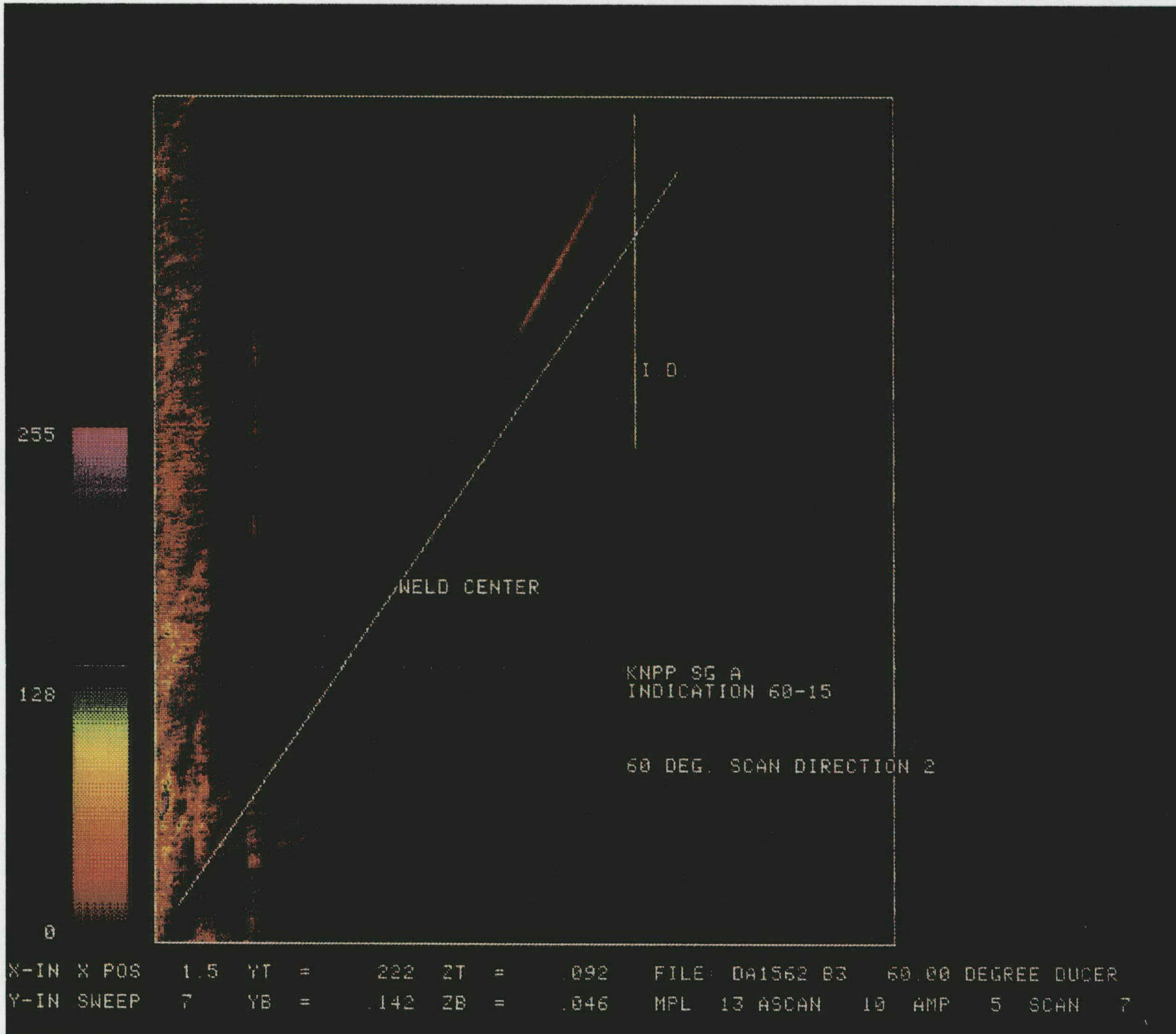


FIGURE A-21.1 S.G. A INDICATION 60-15, 60 DEGREE SCAN

FIGURE A-21.2 S.G. A INDICATION 60-15, 45 DEGREE HI-RES SCAN

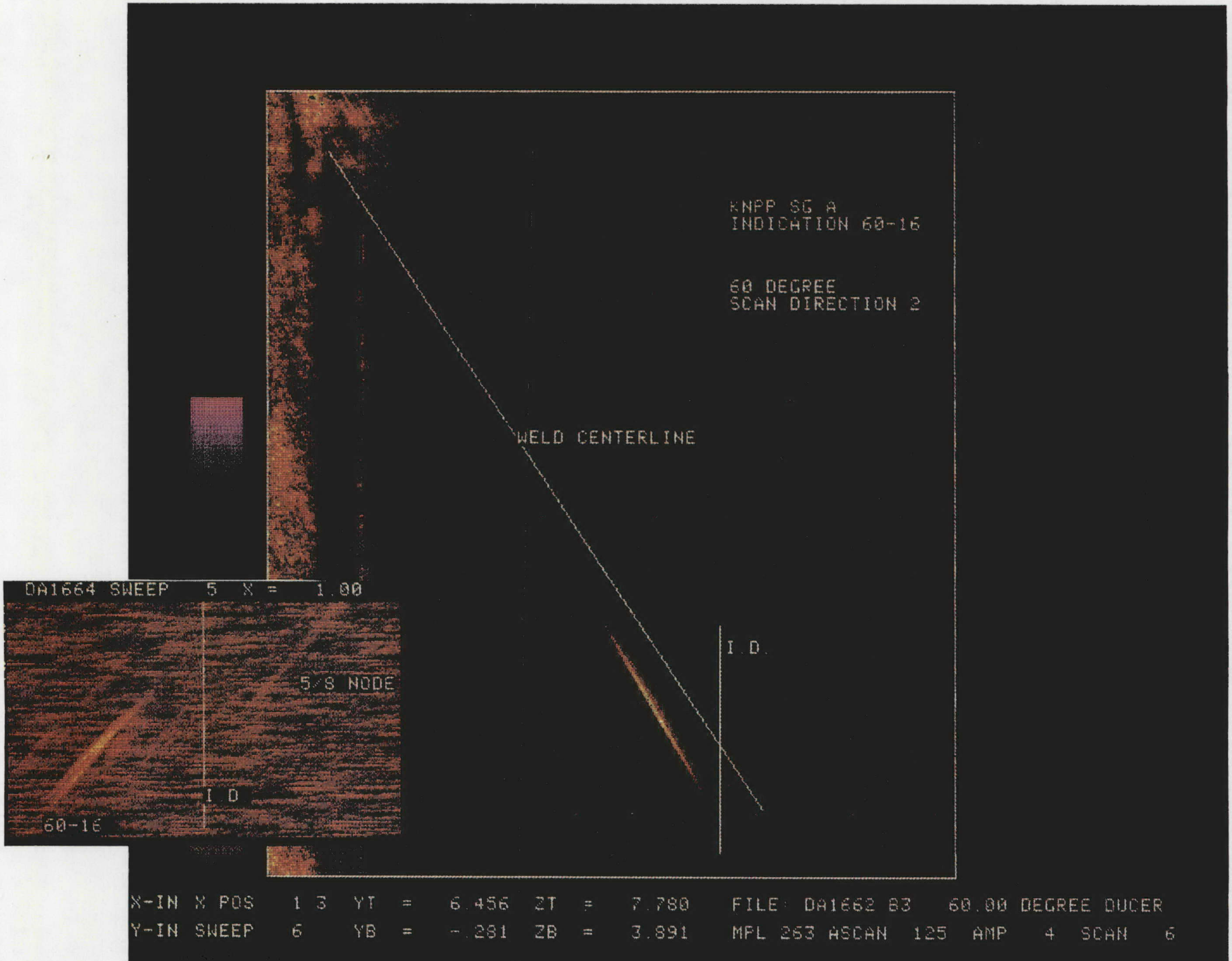


FIGURE A-22 S.G. A INDICATION 60-16, 60 DEGREE SCAN WITH 45 DEGREE HI-RES SCAN (INSERT)

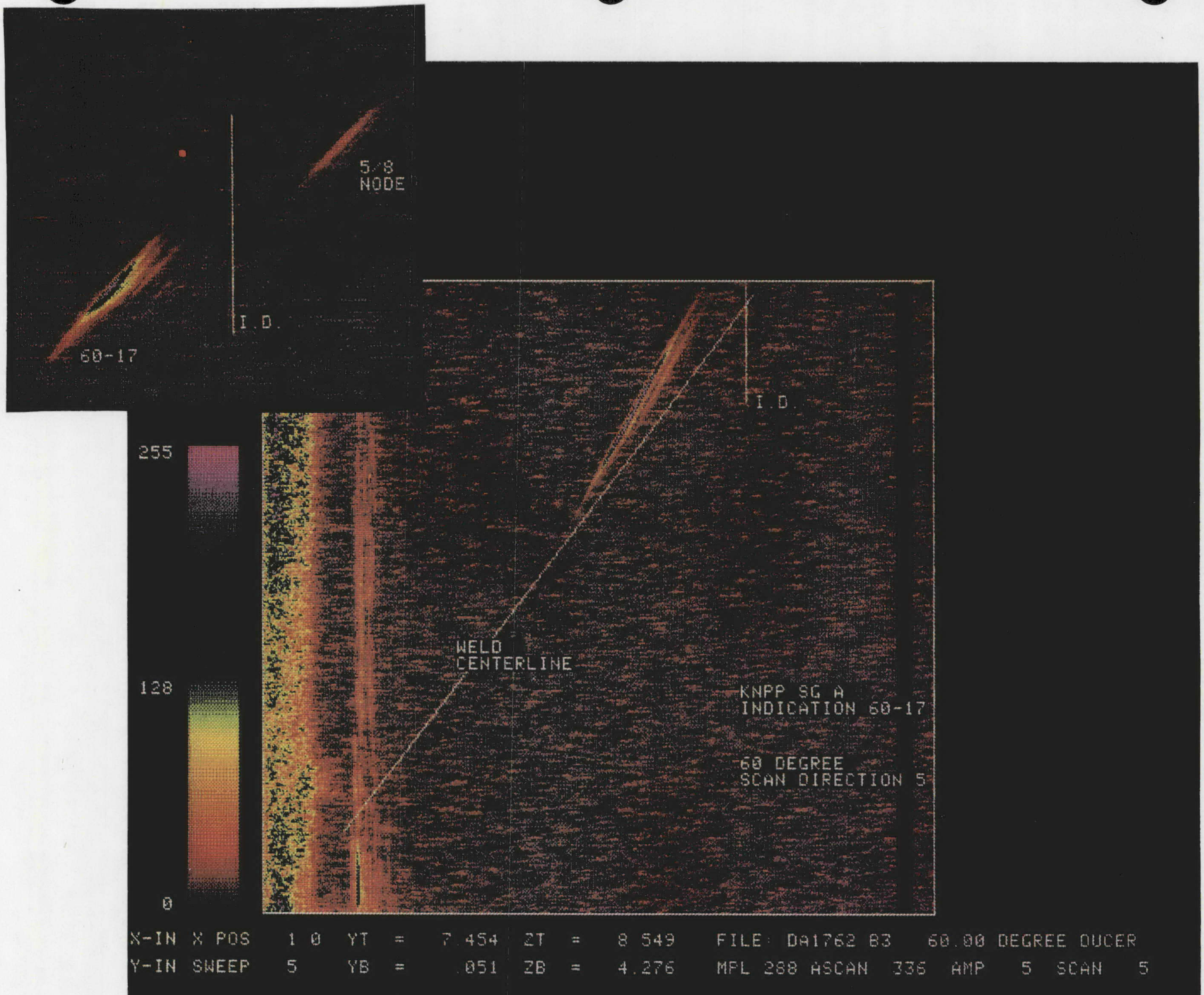


FIGURE A-23 S.G. A INDICATION 60-17, 60 DEGREE SCAN WITH 45 DEGREE HI-RES SCAN (INSERT)

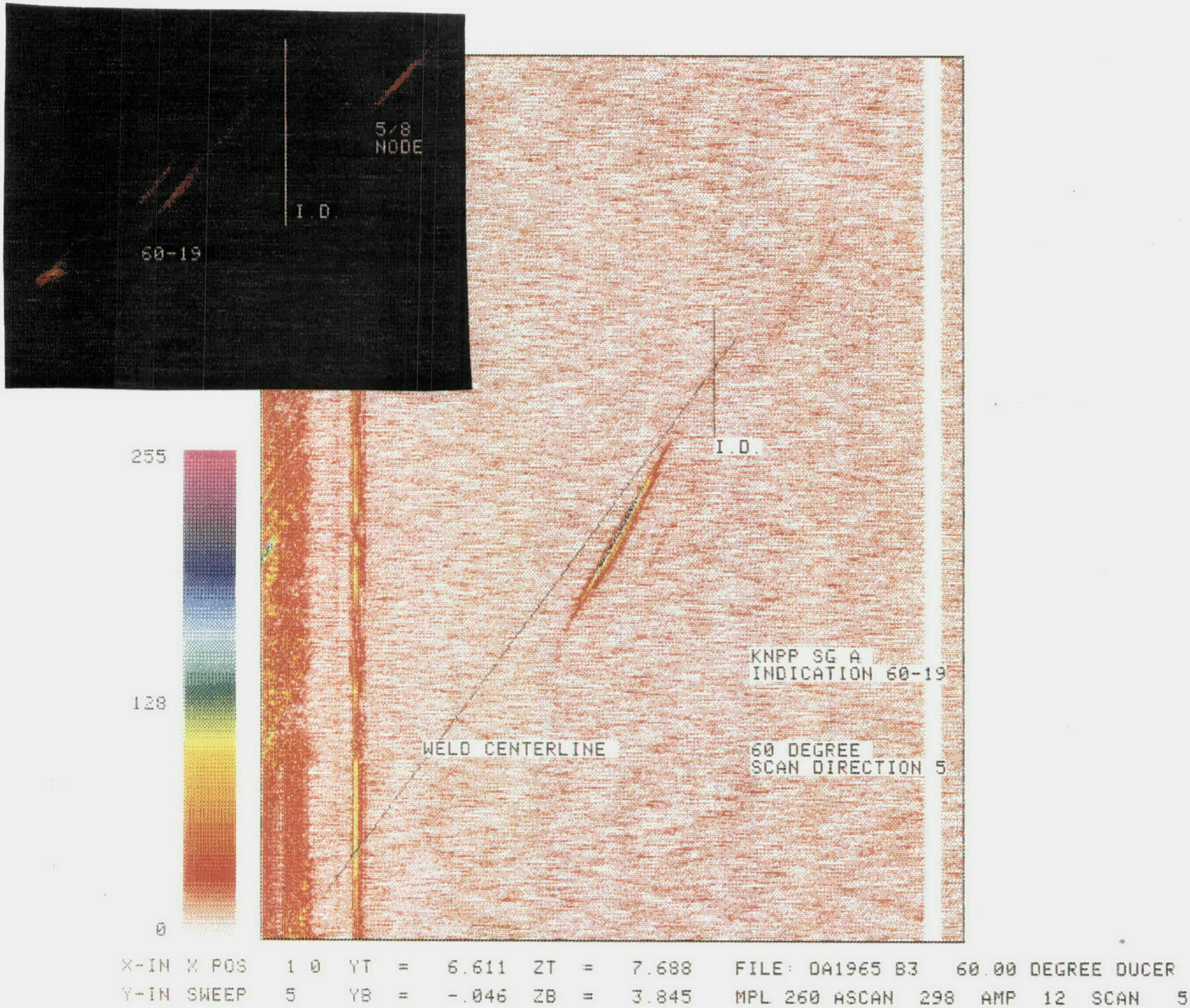


FIGURE A-24 S.G. A INDICATION 60-19, 60 DEGREE SCAN WITH 45 DEGREE HI-RES SCAN (INSERT)

FIGURE A-25 S.G. A INDICATION 60-20, 60 DEGREE SCAN WITH 45 DEGREE HI-RES SCAN (INSERT)

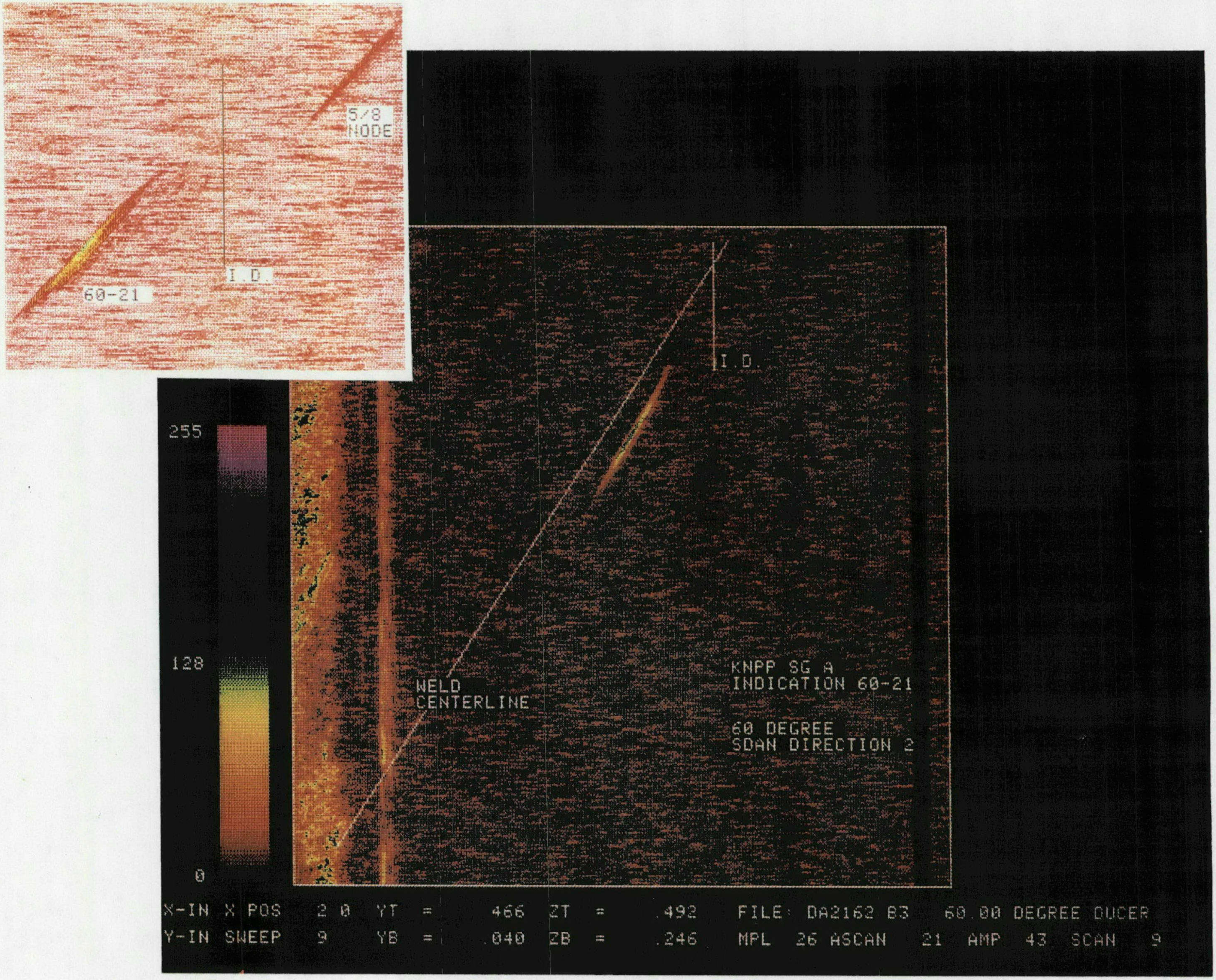


FIGURE A-26 S.G. A INDICATION 60-21, 60 DEGREE SCAN WITH 45 DEGREE HI-RES SCAN (INSERT)

INDICATION ASSESSMENT

PLANT Kewaunee | page 1 of 2

WELD 2-5 (SG-W10) | **DESCRIPTION** S G B UPPER TRANSITION GIRTH WELD

Indication No.	Channel/TD	Beam angle/dir.	P = planar V = volumetric	Depth from OD surface MIN.	Depth from OD surface MAX.	Length l [in]	Through wall dimension 2a [in]	Applicable thickness [in]	S dim. [in]	Y value	Surface or subsurface	Aspect ratio a/l	a/t %	Allowable a/t %	Status	COMMENTS IWB - 3000 reference UDRPS File No.
																TABLE IWB-3511-1 ASME XI 1980 Ed.
45/A																REF. 60-J FOR SIZING
45/B																REF. 60-K FOR SIZING
45/C																SPOT - NO measureable dim.
45/D																REF. 60-H FOR SIZING
45/E		45/5	V	2.75	2.85	0.25	0.1	3.9	1.05	1	Sub	.2	1.28	3.6	Acc.	Δ#t SPOT
45/F		45/2	V	3.45	3.55	0.8	0.1		0.45	1		.06	1.28	2.8	Acc.	Δ#t SPOT
60/A		45/2	V	2.6	2.79	1.2	0.13		1.1	1		.05	1.67	2.8	Acc.	Δ#t SPOT
60/B		45/2	V	2.75	2.85	1.5	0.1		1.1	1		.03	1.28	2.8	Acc.	Δ#t SPOT
60/C		45/2	V	3.0	3.1	0.9	0.1		0.8	1		.05	1.28	2.8	Acc.	Δ#t SPOT
60/D		45/2	P	3.19	3.37	0.8	0.18		0.53	1		.11	2.3	3.0	Acc.	Δ#B BSTD
60/E		45/2	V	2.99	3.11	1.1	0.12		0.79	1		.05	1.53	2.8	Acc.	Δ#B SPOT
60/F		45/2	V	1.5	1.62	2.4	0.12		2.28	1		.02	1.22	2.7	Acc.	Δ#B SPOT
60/G		60/5	V	1.75	1.85	2.3	0.1		2.0	1		.02	1.28	2.7	Acc.	Δ#t SPOT
60/H		45/5	V	3.5	3.6	0.9	0.1		0.3	1		.05	1.28	2.8	Acc.	Δ#t SPOT
60/I		45/2	V	3.47	3.62	0.6	0.15		0.28	1		.12	1.42	3.0	Acc.	Δ#t SPOT

NOTE: "2a" dimensions calculated at less than 0.1 inch were assessed at 0.1 inch.

Analyst D Kurz | **Level** III 4-8-91 | Dan S. D. **Date** 4/8/91

FIGURE B-1.1 INDICATION ASSESSMENT TABLE, STEAM GENERATOR "B", WELD 2-5

INDICATION ASSESSMENT

PLANT Kewaunee

WELD 2-5 (SG W10)

DESCRIPTION S.G. B Upper Transition Girth Weld.

Indication No.	Channel/TD	Beam angle/dir.	P = planar V = volumetric	Depth from OD surface MIN.	Depth from OD surface MAX.	Length l [in]	Through wall dimension 2a [in]	Applicable thickness [in]	S dim. [in]	Y value	Surface or subsurface	Aspect ratio a/l	a/t %	Allowable a/t %	Status	COMMENTS IWB - 3000 reference UDRPS File No. Table IWB-3511-1 ASME XI 1980 Ed.
60 J		45/2	V	3.0	3.1	0.8	0.1	3.9	0.8	1	Sub	.06	1.28	2.8	Acc.	ΔIt spot
60 K		45/2	V	2.7	2.8	1.2	0.1	3.9	1.1	1	Sub	.04	1.28	2.8	Acc.	ΔIt spot

Analyst [signature] Level III 4-8-91

Date [signature] 4/8/91

FIGURE B.1.2 INDICATION ASSESSMENT TABLE, STEAM GENERATOR "B", WELD 2-5 (continued)

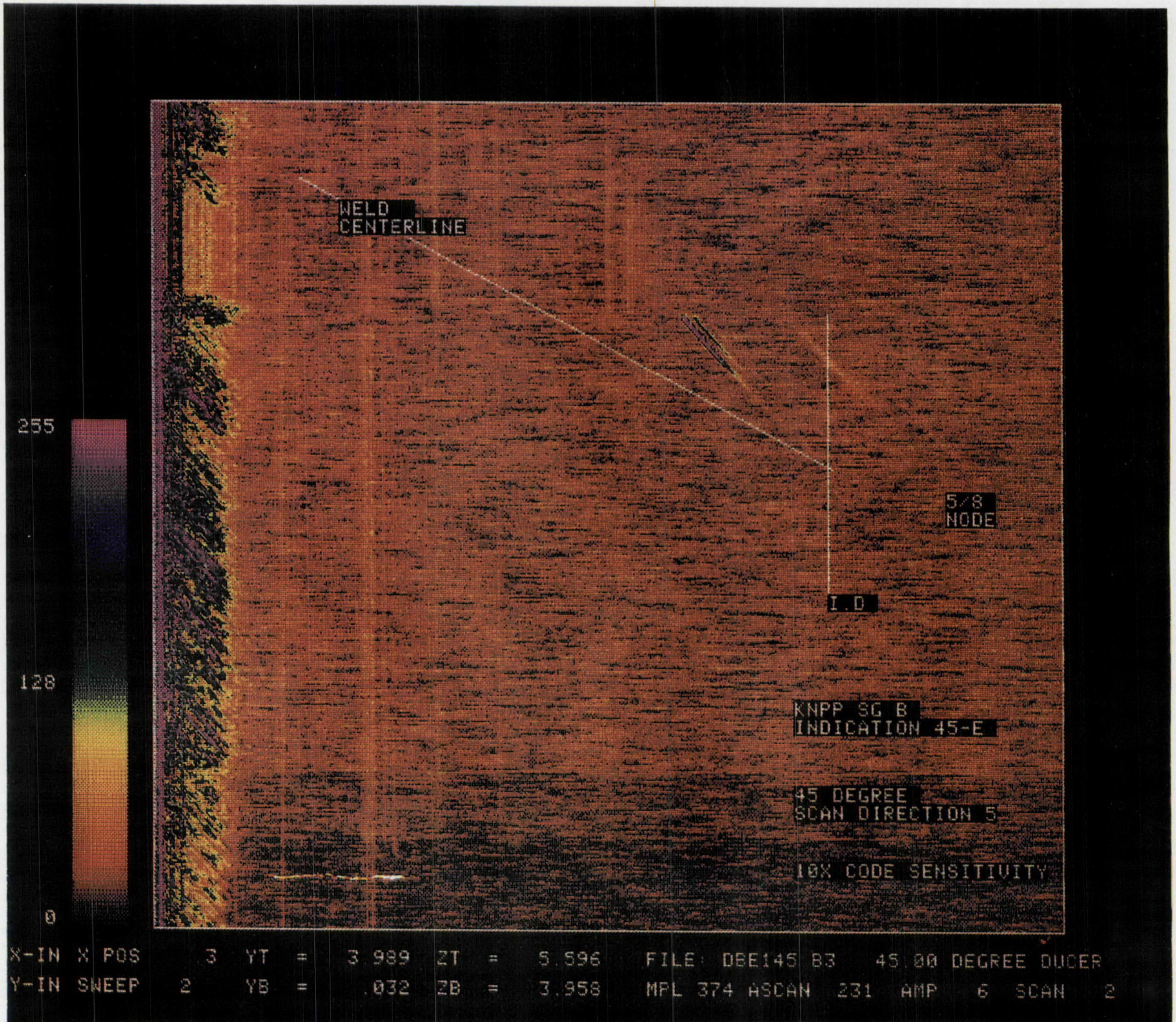


FIGURE B-2 S.G. B INDICATION 45-E, 45 DEGREE HI-RES SCAN

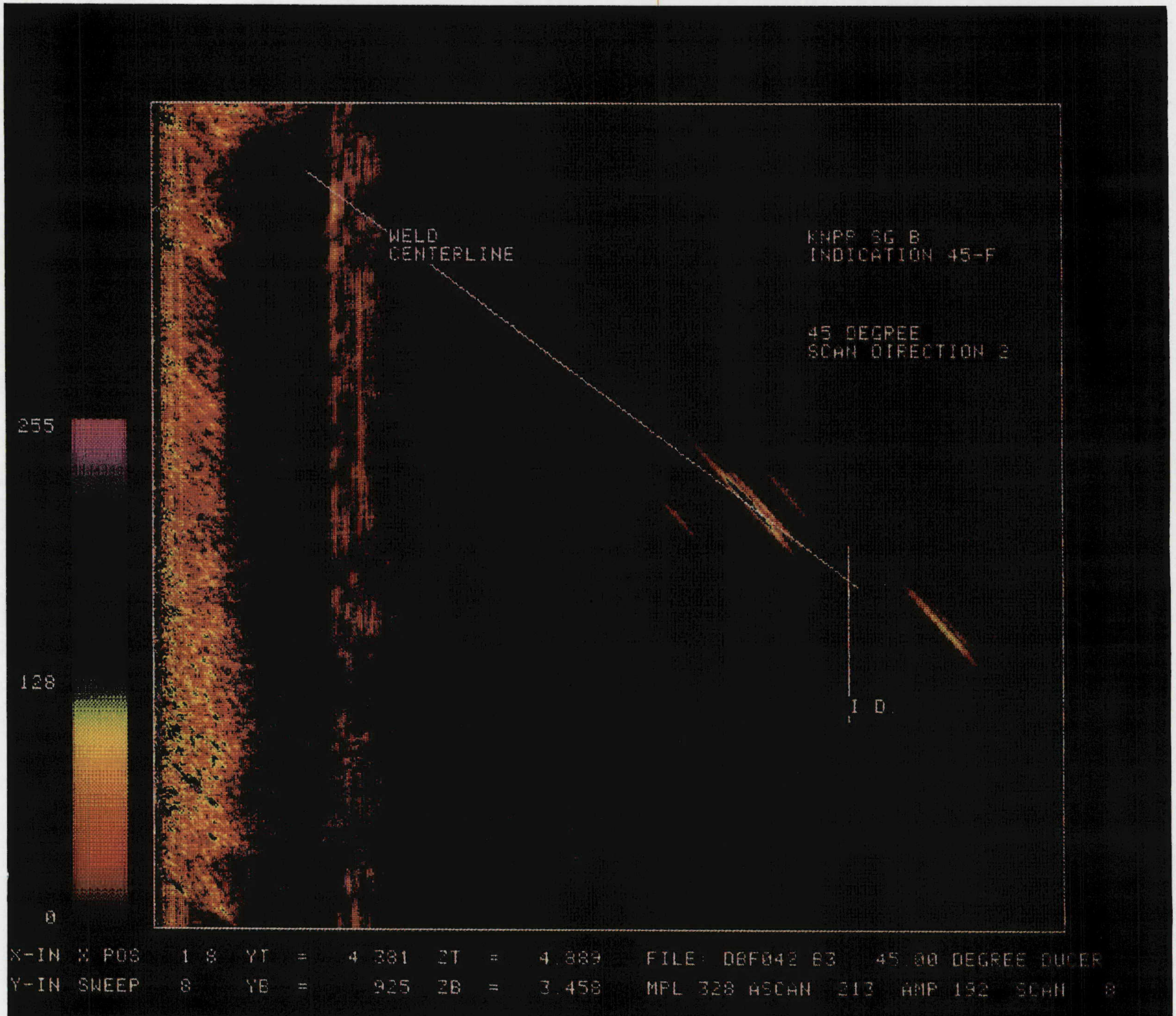


FIGURE B-3 S.G. B INDICATION 45-F, 45 DEGREE HI-RES SCAN

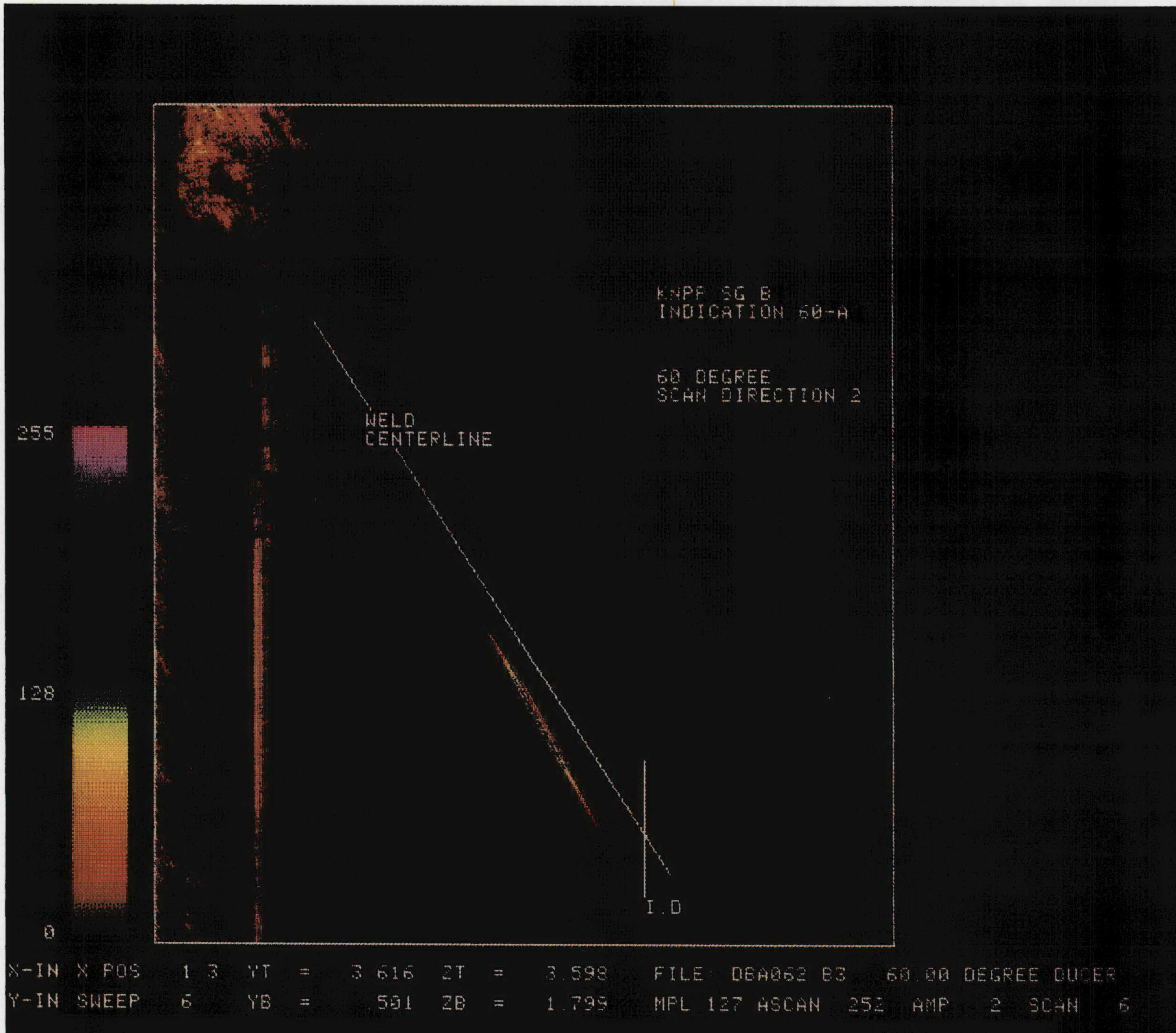


FIGURE B-4.1 S.G. B INDICATION 60-A, 60 DEGREE SCAN

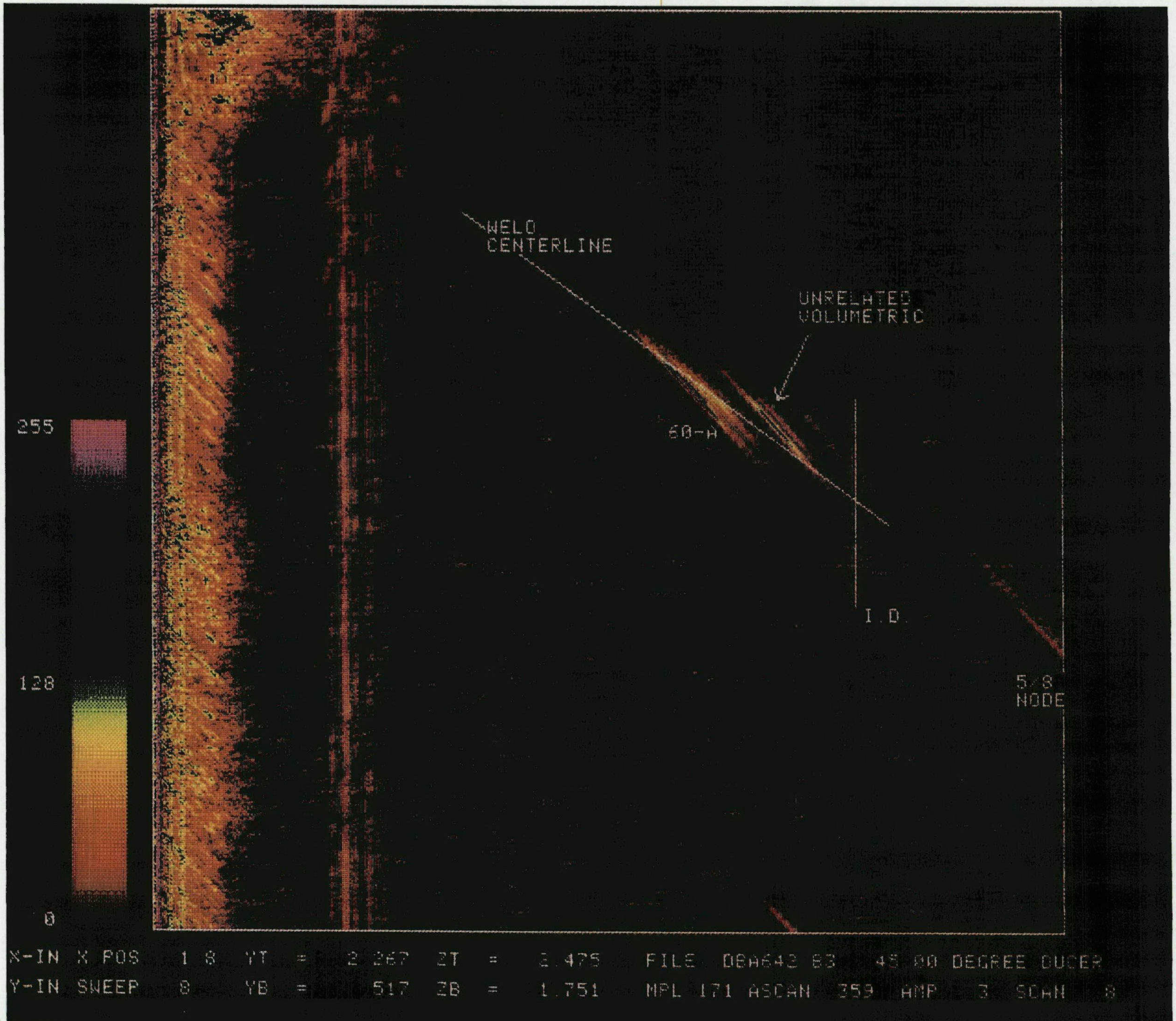
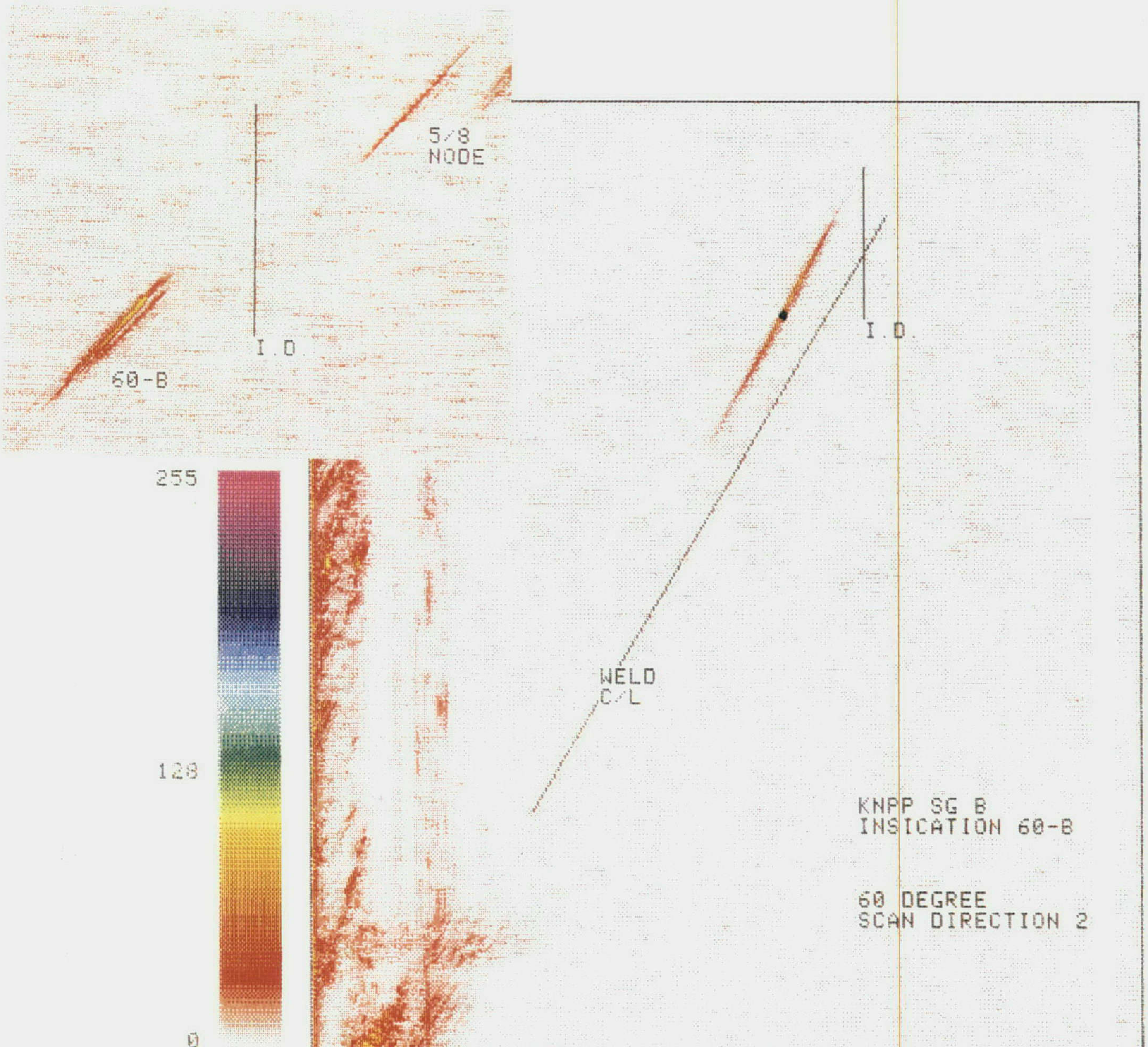


FIGURE B-4.2 S.G. B INDICATION 60-A, 45 DEGREE HI-RES SCAN



X-IN X POS 1 5 YT = 7.964 ZT = 7.933 FILE: DBB062 B3 60.00 DEGREE DUCER
Y-IN SWEEP 7 YB = 1.094 ZB = 3.968 MPL 268 ASCAN 359 AMP 1 SCAN 7

FIGURE B-5 S.G. B INDICATION 60-B, 60 DEGREE SCAN WITH 45 DEGREE HI-RES SCAN (INSERT)

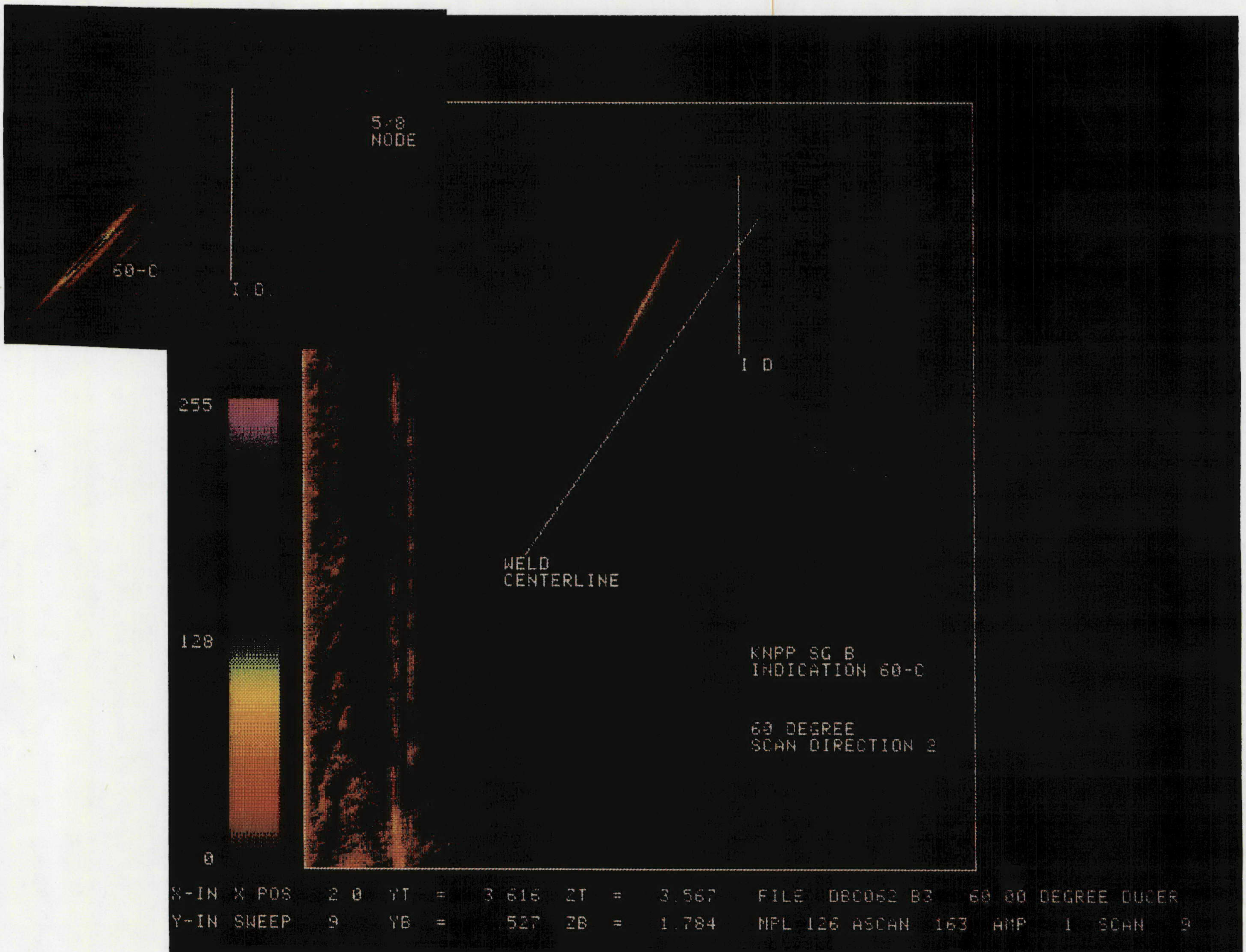


FIGURE B-6 S.G. B INDICATION 60-C, 60 DEGREE SCAN WITH 45 DEGREE HI-RES SCAN (INSERT)

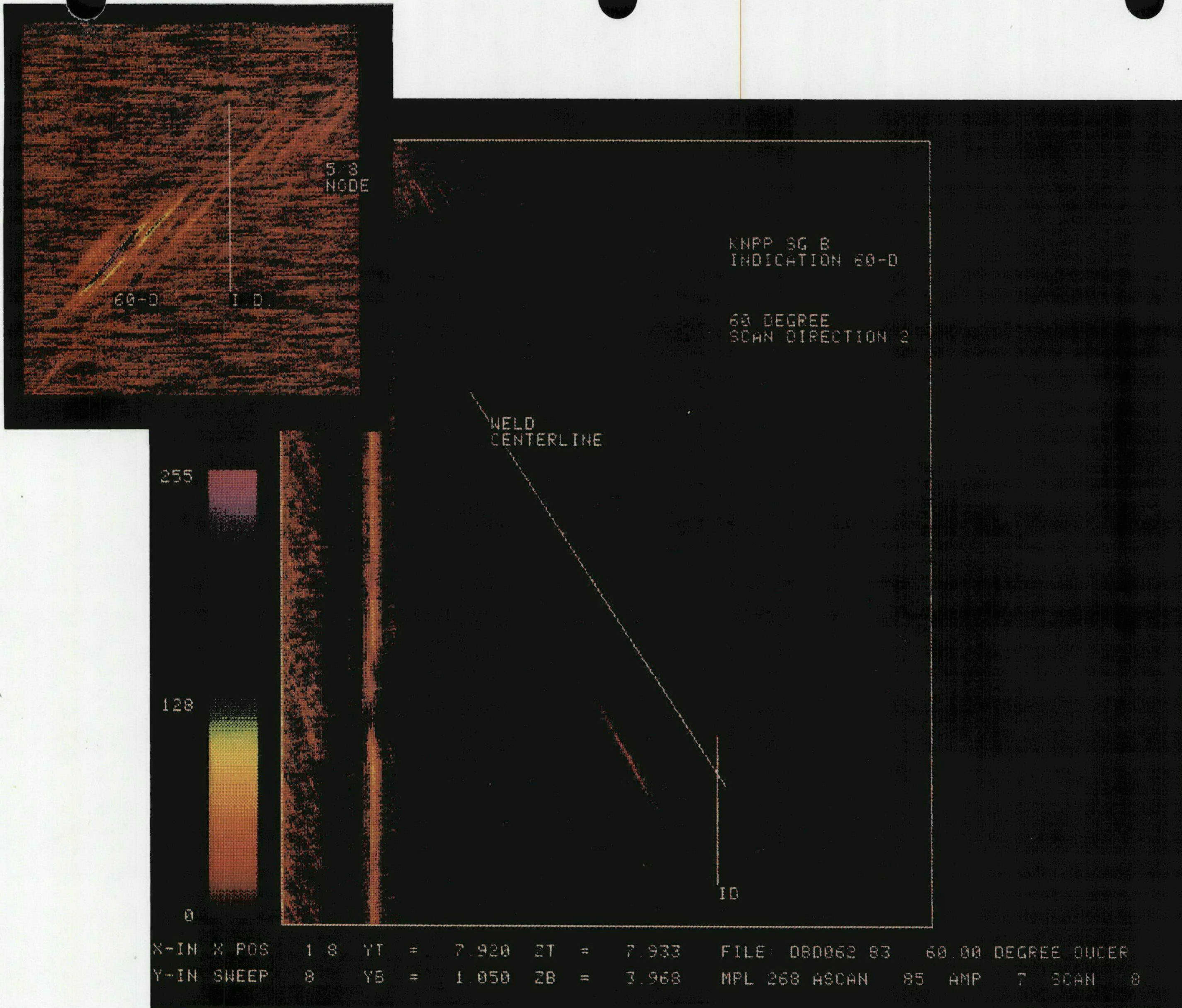


FIGURE B-7 S.G. B INDICATION 60-D, 60 DEGREE SCAN WITH 45 DEGREE HI-RES SCAN (INSERT)

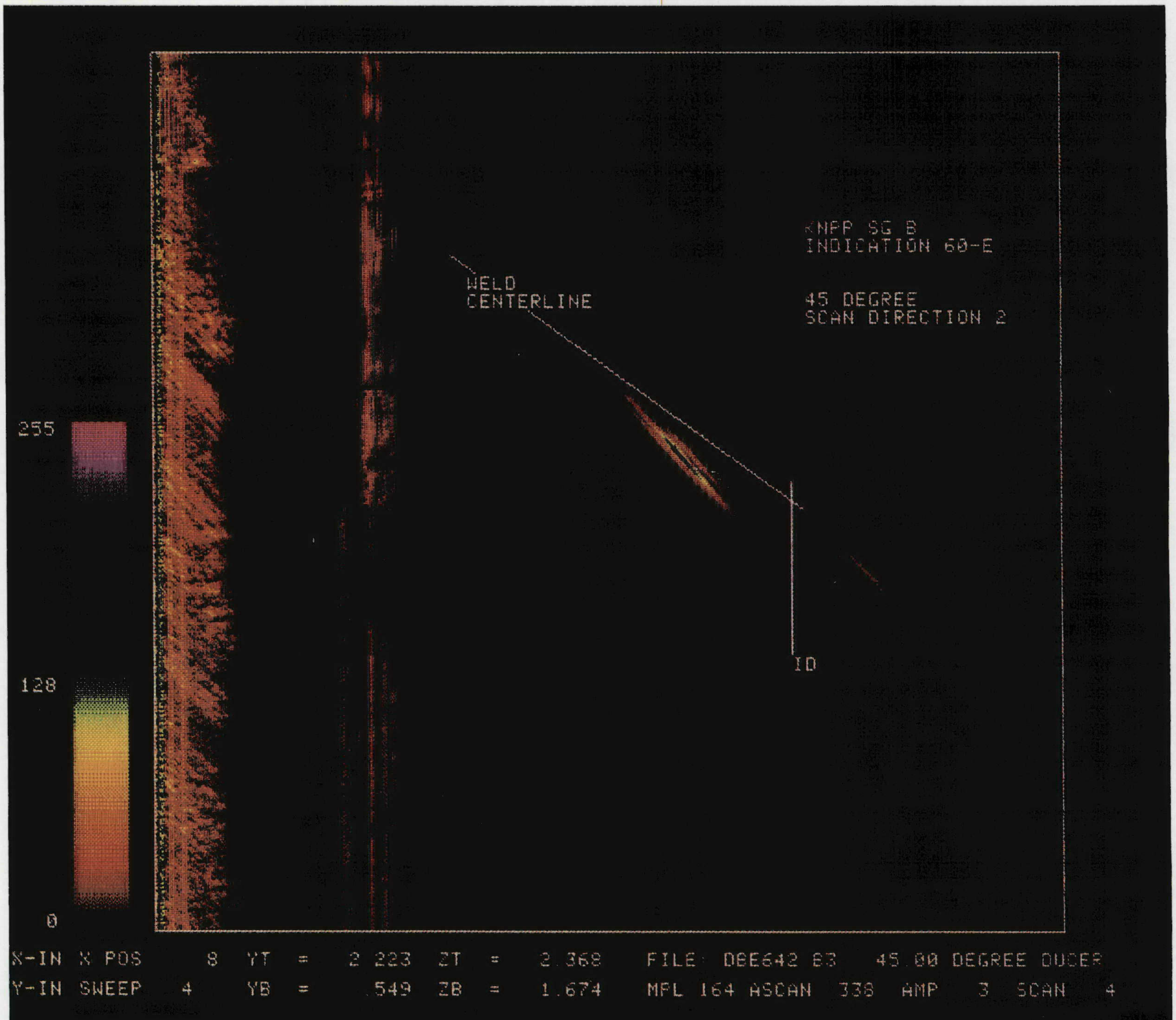


FIGURE B-8 S.G. B INDICATION 60-E, 45 DEGREE HI-RES SCAN

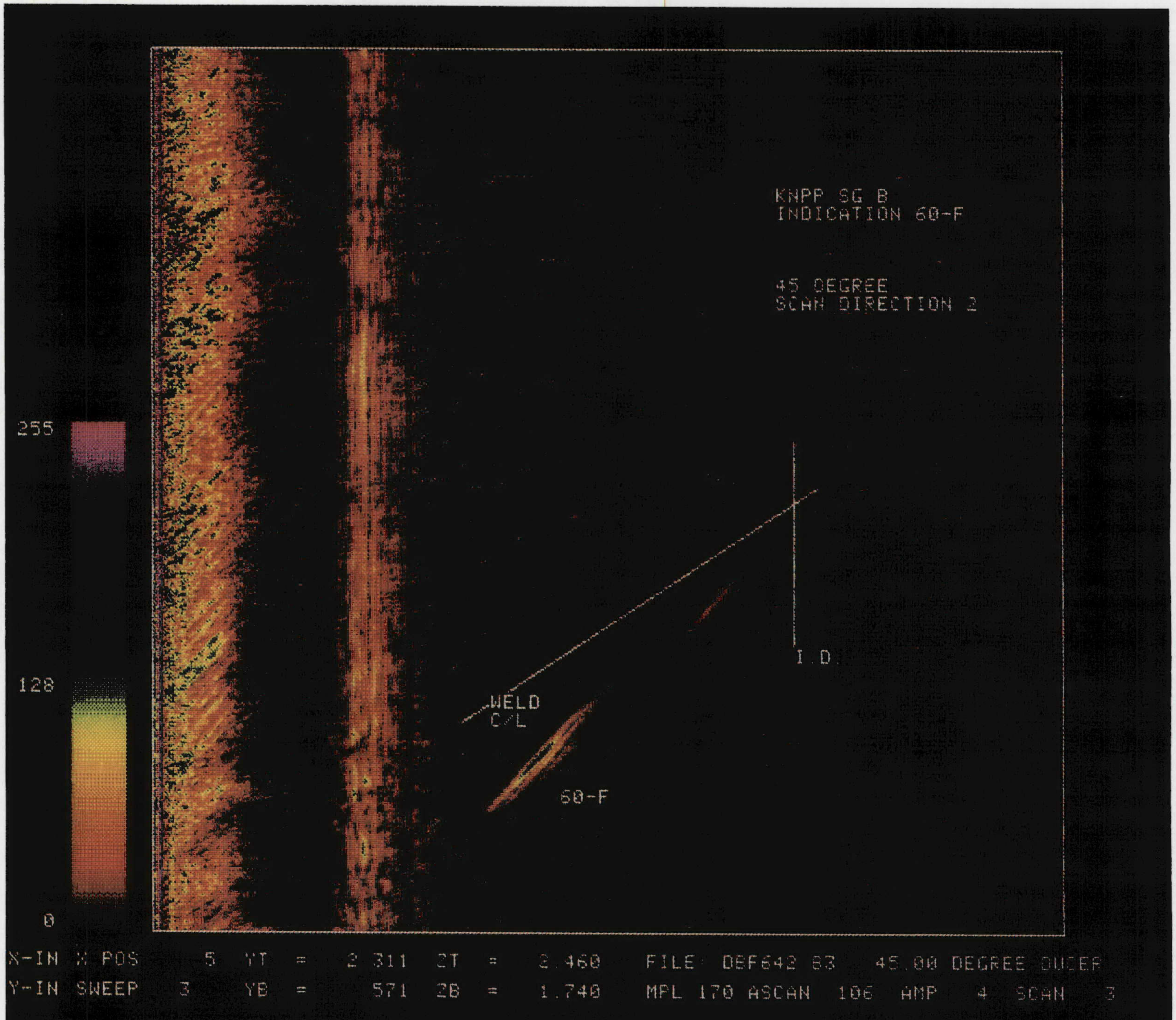


FIGURE B-9 S.G. B INDICATION 60-F, 45 DEGREE HI-RES SCAN

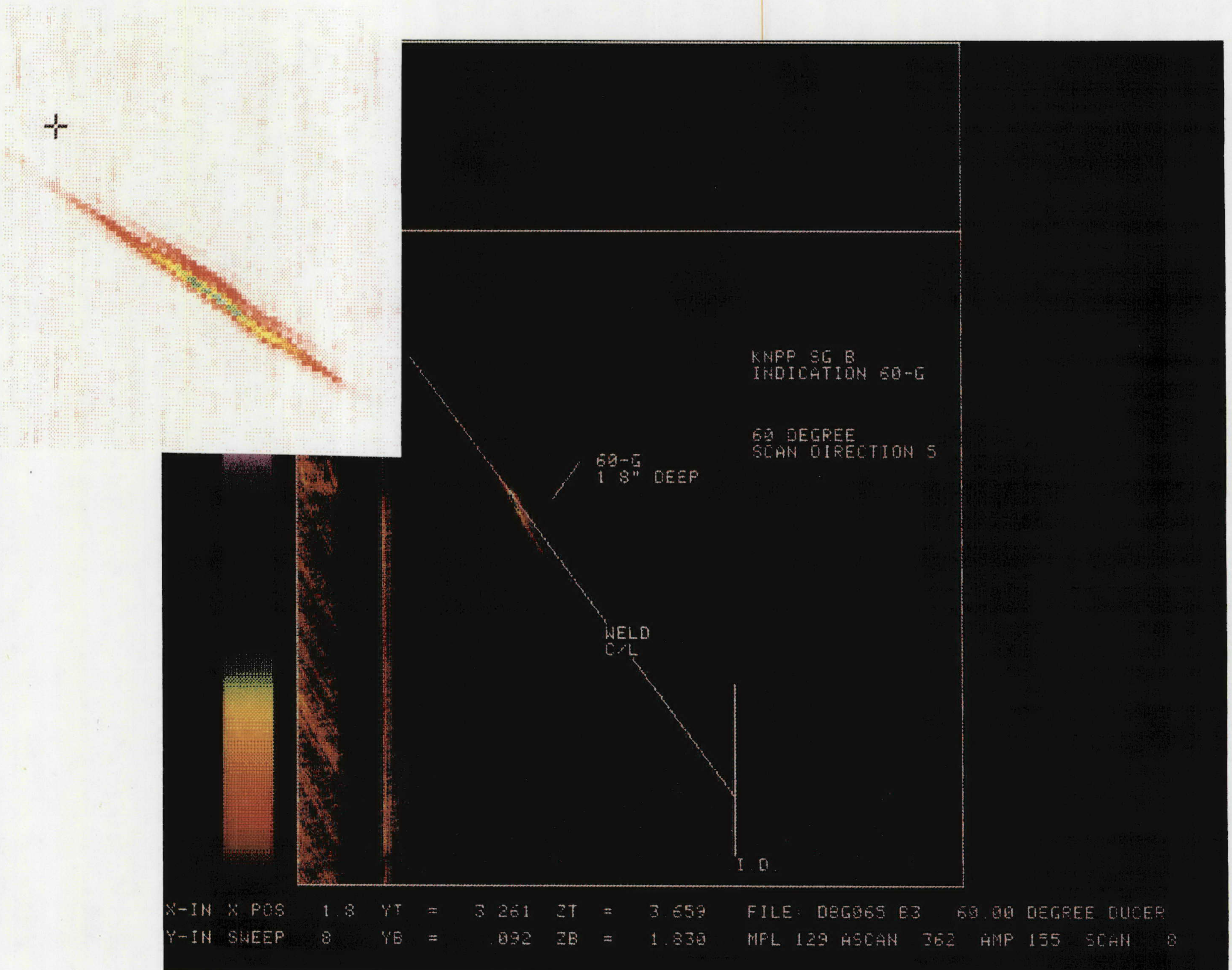


FIGURE B-10 S.G. B INDICATION 60-G, 60 DEGREE SCAN WITH 60 DEGREE HI-RES SCAN (INSERT)

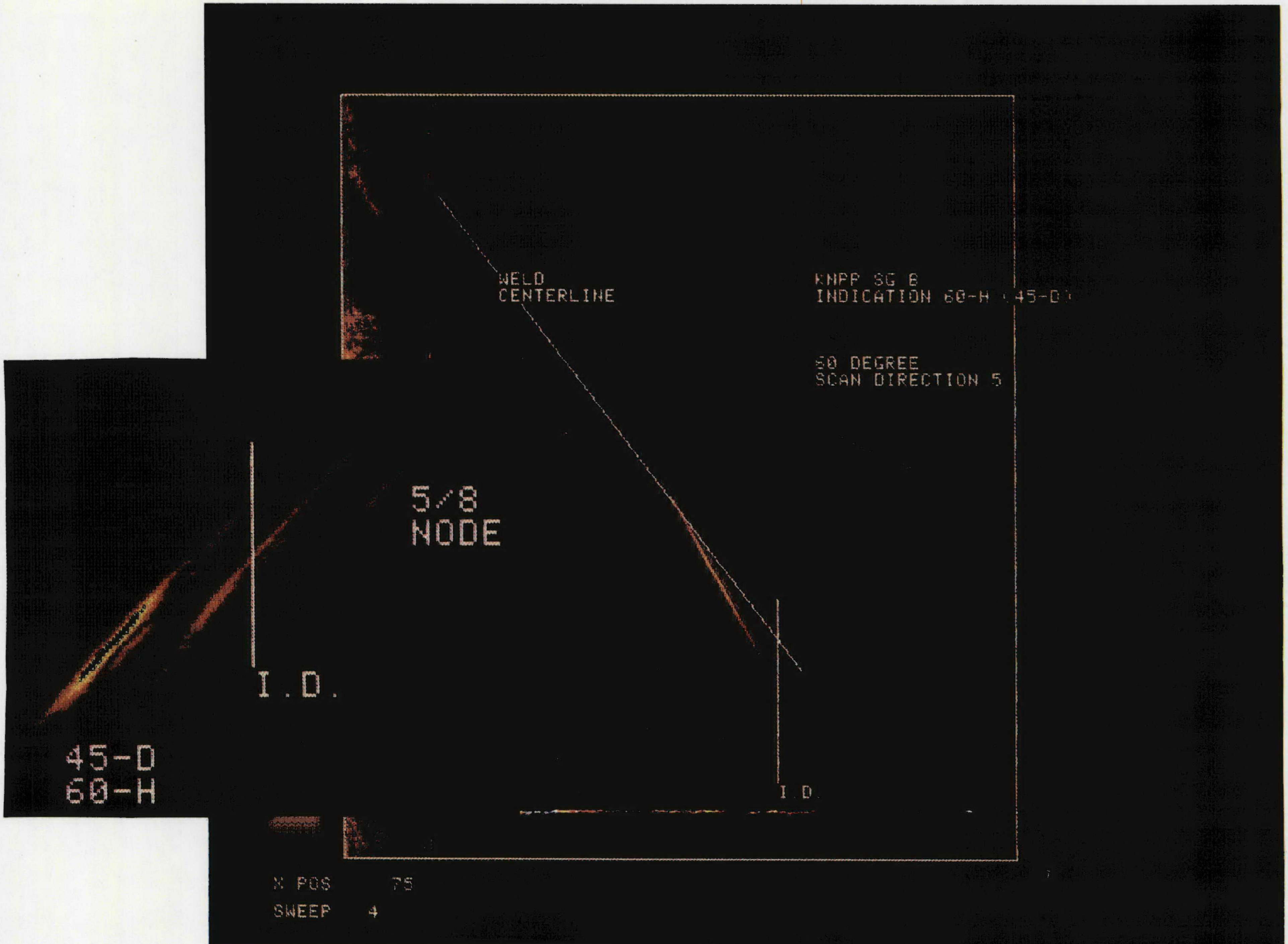


FIGURE B-11 S.G. B INDICATION 60-H, 60 DEGREE SCAN WITH 45 DEGREE HI-RES SCAN (INSERT)

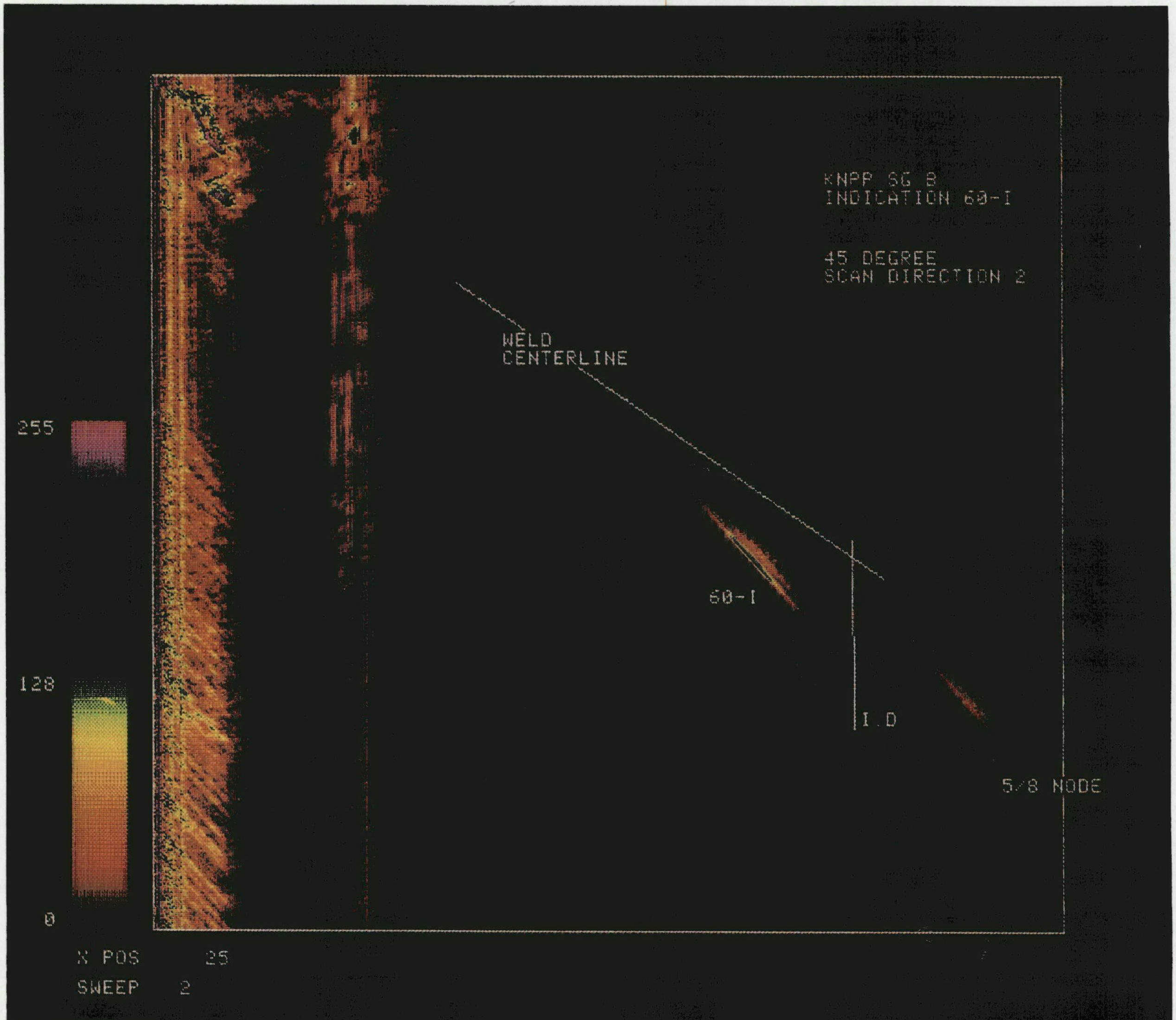


FIGURE B-12 S.G. B INDICATION 60-I, 45 DEGREE HIGH-RES SCAN

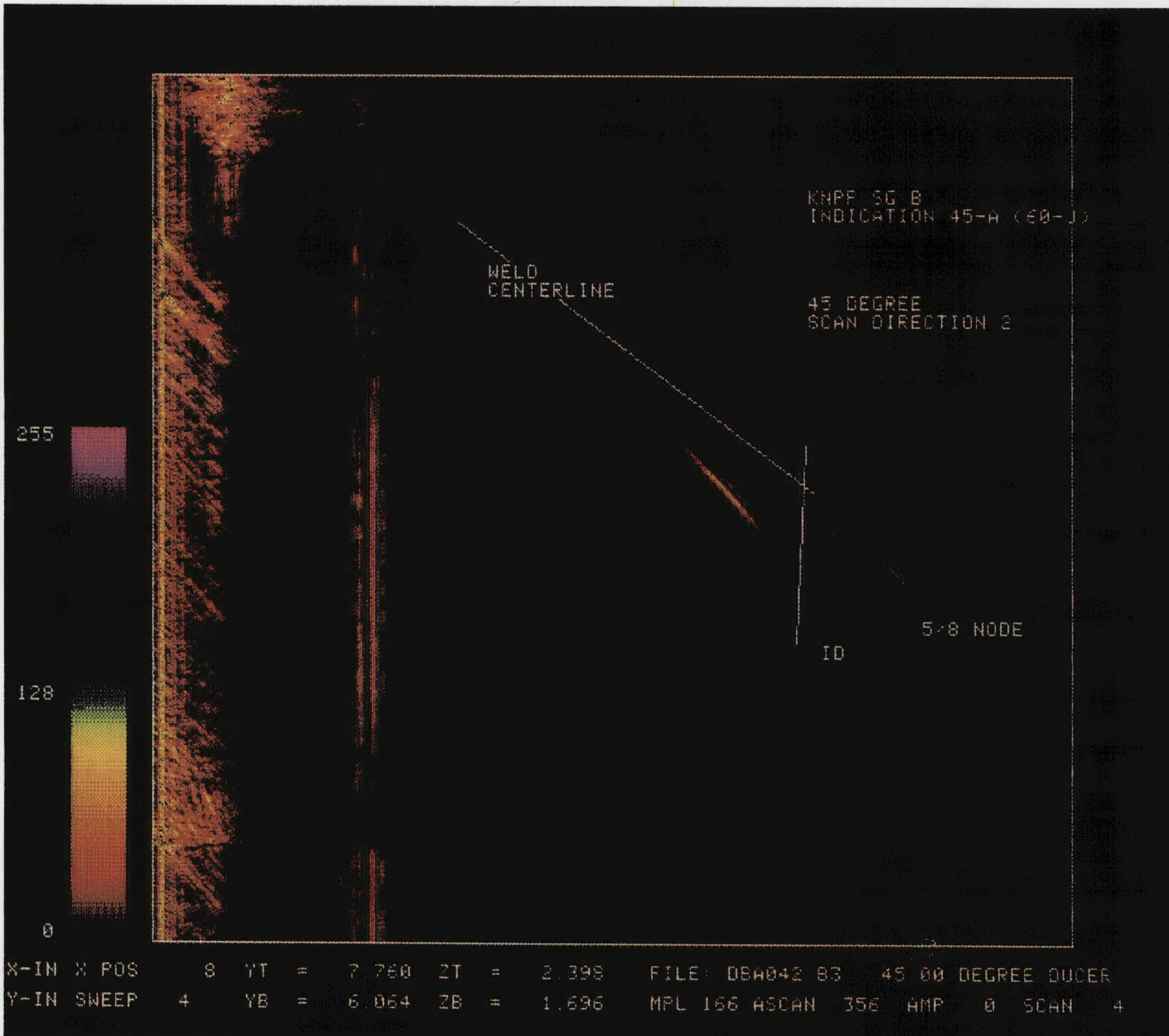


FIGURE B-13 S.G. B INDICATION 60-J, 45 DEGREE HIGH-RES SCAN

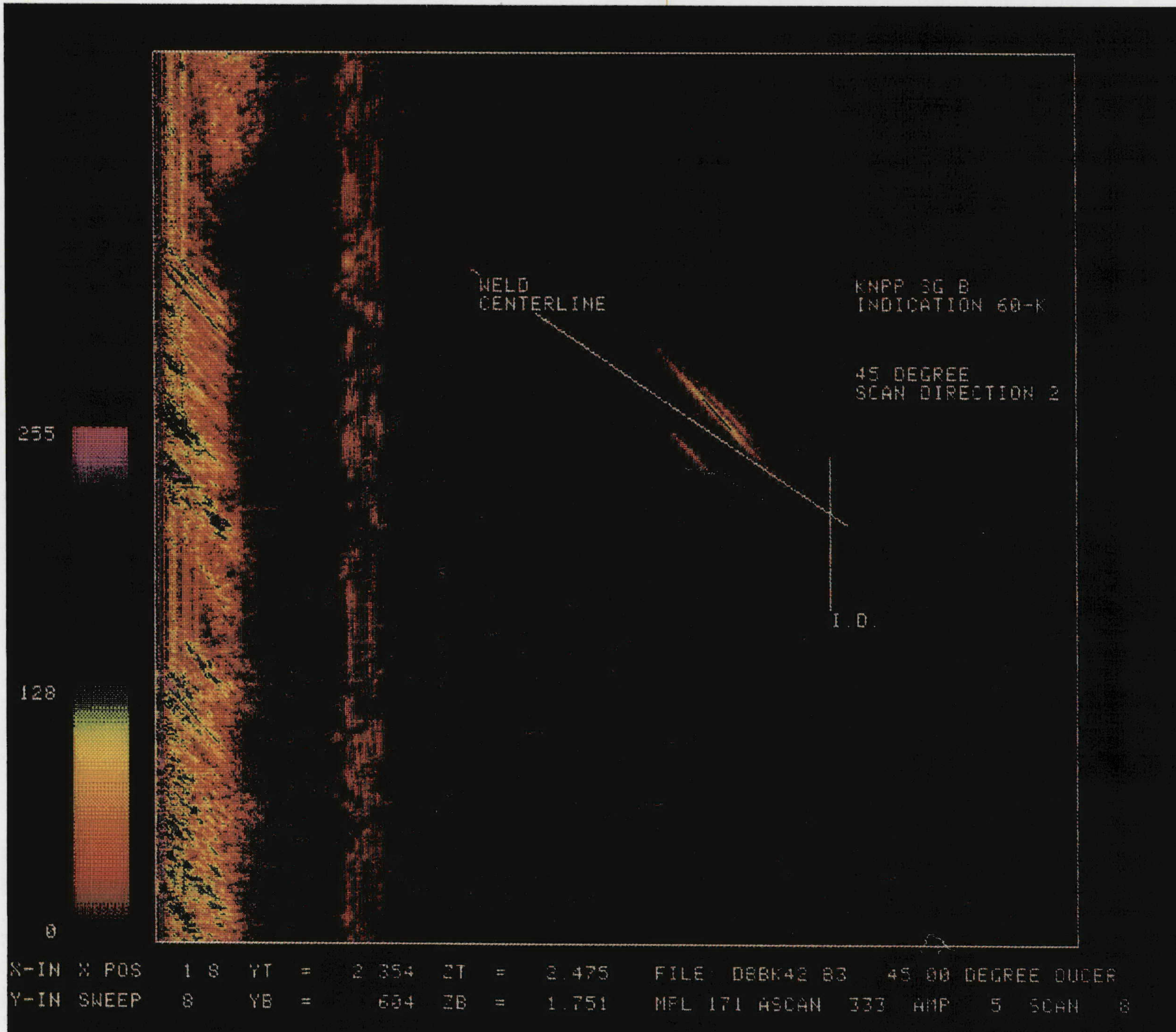


FIGURE B-14 S.G. B INDICATION 60-K, 45 DEGREE HI-RES SCAN

SUPPLEMENT 2

KEWAUNEE UNIT 1

STEAM GENERATOR UPPER SHELL TO CONE WELDS

STEAM GENERATOR "A" WELD 1-5

STEAM GENERATOR "B" WELD 2-5

COMPARISON OF THE LOCATION OF FABRICATION REPAIRS WITH ULTRASONIC TEST DETECTION DATA (1991)

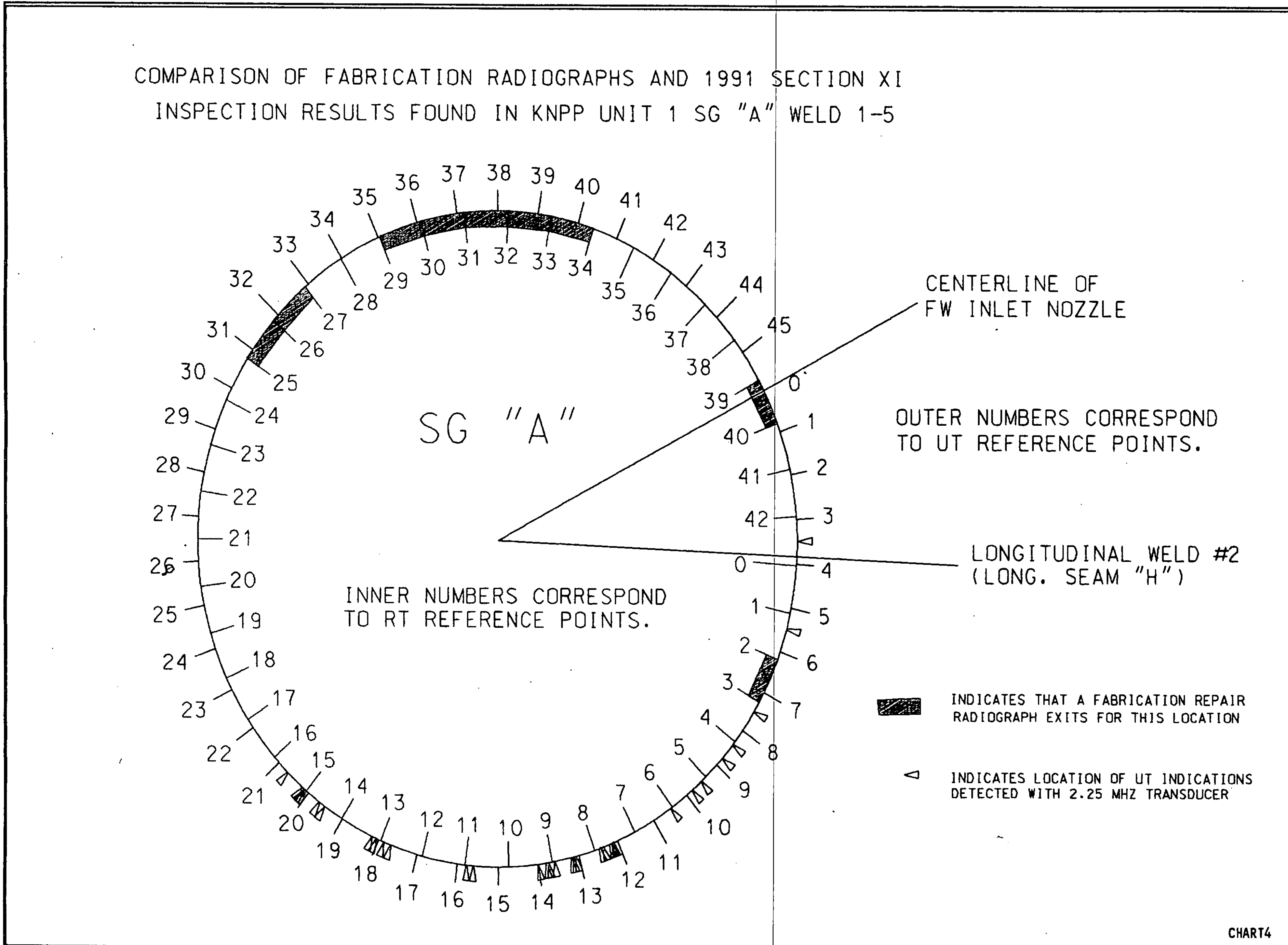


FIGURE 1 COMPARISON OF REPAIR RADIOGRAPHS AND UT INDICATION LOCATIONS
STEAM GENERATOR A WELD 1-5

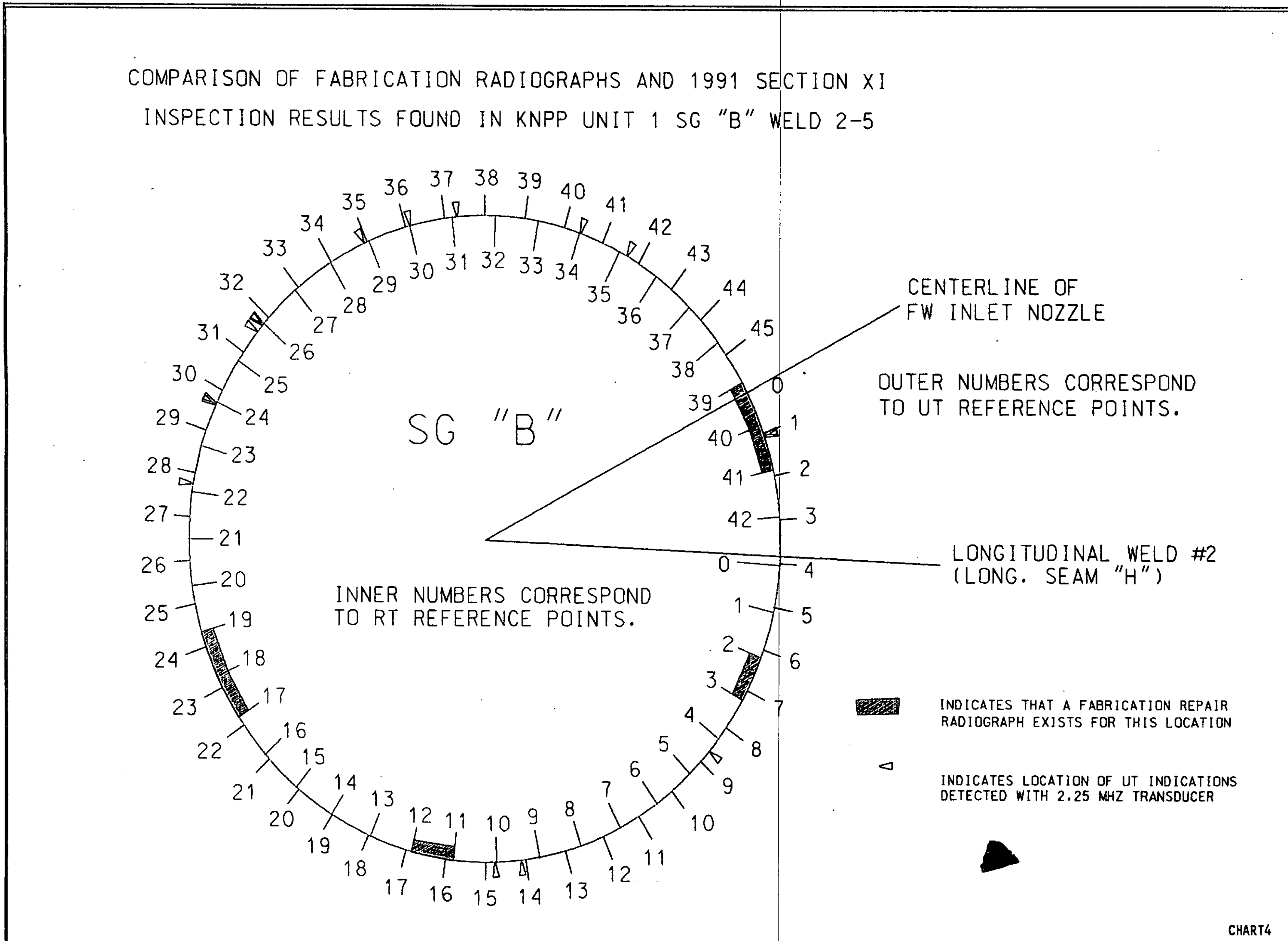


FIGURE 2 COMPARISON OF REPAIR RADIOGRAPHS AND UT INDICATION LOCATIONS
STEAM GENERATOR B WELD 2-5