Dominion Nuclear Connecticut, Inc.
Millstone Power Station
Rope Ferry Road
Waterford, CT 06385

Dominion

DEC 10 2002

Docket No. 50-336
B18802

U.S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, DC 20555

Millstone Nuclear Power Station, Unit No. 2
Supplemental Response to NRC Bulletin 2001-01
Circumferential Cracking of Reactor Pressure Vessel Head Penetration Nozzles

On January 24, 2002, Dominion Nuclear Connecticut, Inc. (DNC) met with the U.S. Nuclear Regulatory Commission (NRC) to discuss the inspection of the Millstone Unit No. 2 reactor head during the upcoming refueling outage. During this meeting the previous submittals made by DNC on September 4, 2001,[1] and December 28, 2001,[2] were discussed along with the plans and contingencies for the upcoming inspection.

Following the January 24, 2002 meeting, the NRC requested that the information presented be summarized and submitted on the docket by DNC. A summary of the inspection methodology, the statistical analysis used for the contingency plan, and the risk associated with a postulated catastrophic failure of a single reactor vessel head nozzle was provided in DNC's letter of February 7, 2002.[3]

In addition it was requested that DNC provide a copy of the Engineering Record of Correspondence (ERC), documenting DNC's inspection plan for ultrasonic examination of the interference fit of the nozzle penetrations with the reactor vessel head, to the NRC.

(1) J. A. Price letter to U.S. Nuclear Regulatory Commission, "Response to NRC Bulletin 2001-01, Circumferential Cracking of Reactor Pressure Vessel Head Penetration Nozzles," dated September 4, 2001.

(2) J. A. Price letter to U.S. Nuclear Regulatory Commission, "Supplemental Response to NRC Bulletin 2001-01, Circumferential Cracking of Reactor Pressure Vessel Head Penetration Nozzles," dated December 28, 2001.

(3) J. A. Price letter to U.S. Nuclear Regulatory Commission, "Supplemental Response to NRC Bulletin 2001-01, Circumferential Cracking of Reactor Pressure Vessel Head Penetration Nozzles," dated February 7, 2002.

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The requested information was provided in a letter to the NRC dated February 18, 2002.[4] Enclosure 1 of that letter contained an affidavit from Framatome ANP requesting that Enclosure 2 of that letter, ERC 25203-ER-02-0005, "Reactor Vessel Head Penetration Inspection Plan for Ultrasonic Examination of Interference Fit," be withheld from public disclosure in accordance with 10 CFR 2.790. Subsequently, the NRC requested that a non-proprietary version of the letter be provided. DNC has obtained a release from Framatome ANP and hereby provides, as Enclosure 1, the non-proprietary version of ERC 25203-ER-02-0005, "Reactor Vessel Head Penetration Inspection Plan for Ultrasonic Examination of Interference Fit."

There are no regulatory commitments contained within this letter.

Should there be any questions regarding this submittal, please contact Mr. Paul R. Willoughby at (860) 447-1791, extension 3655.

Very truly yours,

DOMINION NUCLEAR CONNECTICUT, INC.

J. Alan Price
Site Vice President - Millstone

Enclosures (1)

cc: H. J. Miller, Region I Administrator
R. Ennis, NRC Project Manager, Millstone Unit No. 2
NRC Senior Resident Inspector, Millstone Unit No. 2

[4] J. A. Price letter to U.S. Nuclear Regulatory Commission, "Supplemental Response to NRC Bulletin 2001-01, Circumferential Cracking of Reactor Pressure Vessel Head Penetration Nozzles," dated February 18, 2002.

Enclosure 1

Millstone Nuclear Power Station, Unit No. 2

ERC 25203-ER-02-0005
Reactor Vessel Head Penetration Inspection Plan
for Ultrasonic Examination of Interference Fit

Attachment 4
Engineering Record Correspondence Format

QA ☒ Non-QA ☐

DB or LB document change required? yes ☐ no ☒

DATE: 1/15/02

25203-ER-02-0005 Rev. 000

TO:

FROM: M Stark/ L. Loomis Michael Stark L Loomis 1/15/02

INDEPENDENT REVIEWER: See Attached

APPROVED: [illegible] 1/18/02

SUBJECT: **Reactor Vessel Head Penetration Inspection Plan for Ultrasonic Examination of Interference Fit**

REFERENCES:

Summary

This ERC provides an evaluation of an ultrasonic test technique which focusses on the amount of acoustic energy reflected at the interface between the Inconnel 600 penetration tube and the carbon steel vessel head. The technique is based on the fact that if the contact surface of the interference fit is disturbed by erosion, corrosion, or the deposits of foreign material (corrosion products or boron deposits), the amount of acoustic energy reflected at that interface is altered significantly.

This evaluation concludes that ultrasonic C-scan presentations can also be utilized to reliably detect a leak path through the interference fit portion of the annular region, above the J-groove weld in the Reactor Vessel Head Penetrations (RVHP). Based on review of actual empirical test data, the technique provides a reliable substitute, or alternate examination method, for a bare head visual inspection currently utilized for the detection of leaking RVHPs.

Ultrasonic inspection techniques have been successfully demonstrated, by Framatome Advanced Nuclear Products Inc, for the detection of axial and circumferential cracking in the Reactor Vessel Closure Head Penetrations (RVHPs), in the tube away from the J-groove weld and over the weld. The performance demonstration was witnessed by Dominion personnel, Electric Power Research Institute (EPRI) representatives, and personnel from various other utilities.

Introduction

ERC 25203-ER-02-0005 provides an evaluation of an ultrasonic testing technique for RVHP examination as an alternate technique in lieu of a bare head visual examination.

The primary application of ultrasonic inspections at nuclear power stations is for the detection of discontinuities in metals, particularly welded joints. But ultrasonic techniques have been developed for some very diverse applications including the study of press fits and material bonding.

Assurance that the contact surface of the interference fit has remained undisturbed is another approach to substitute for the absence of tenacious boron accumulations detected with a bare head visual for affirmation of the integrity of the RCS pressure boundary at RVHPs.

Discussion

Ultrasonic waves are mechanical waves propagating through an elastic medium as particle oscillations. They can propagate through solids, liquids, or gasses. The ultrasonic waves travel at a characteristic velocity in a given homogeneous medium. This velocity is a constant that is dependent upon the elastic properties of that particular medium. The velocity of ultrasonic waves differs greatly between solids, liquids, and gasses because of the large differences in the distance between the particles in these forms of matter.

When the ultrasonic wave traveling through a given medium reaches an interface between that medium and a second medium, a portion of the acoustic energy is transmitted into the second medium, and a portion of the acoustic energy is reflected from that interface. The amount of energy that is reflected and transmitted at this interface is dependent upon the differences in acoustic properties between the two mediums. If the acoustic impedance values of the two mediums is similar, (such as a metal to metal interface), then the amount of energy transmitted into the second medium is very high and the amount of reflected energy is very low. If the difference between the acoustic impedance values of the two mediums is great, (such as a metal to air interface), then the amount of transmitted energy is very low and the amount of reflected energy is very high.

Acoustic impedance is defined by the equation:

$$Z = \rho V$$

where;

Z = acoustic impedance in grams per square centimeter•second
ρ = the density of the material in grams per cubic centimeter
V = the velocity of sound in that medium in centimeters per second

And the percentage of reflected energy is defined by the equation:

$R = I_r/I_i = [(Z_2 - Z_1)/(Z_2 + Z_1)]^2 = [(r - 1)/(r + 1)]^2$

where;

- R = the ratio of reflected beam intensity to incident beam intensity
- I_r = the intensity of the reflected sound energy
- I_i = the intensity of the incident sound energy
- Z_1 = the acoustic impedance of the medium that the sound is propagating through
- Z_2 = the acoustic impedance of the medium that the sound is reflected from
- r = the impedance ratio Z_2/Z_1 also referred to as the mismatch factor

The acoustic impedance values for the materials of interest in this discussion are listed below as reported in the Metals Handbook, ninth edition, volume 17.

Material	**Acoustic impedance in 10^6 g/cm^2 • s**
Inconnel	4.95
Carbon steel	4.66
Air	0.00004
Water	0.149

As we can see from the values listed above, virtually all of the sound energy is reflected at a metal to air interface and only small percentage of the sound energy would be reflected at an Inconnel to Carbon Steel interface. In the case of a water to metal interface, approximately 89% of the sound energy that impinged on the external surface of the Inconnel tube would be reflected. A collection of deposits, between the Inconnel tube and Carbon Steel vessel head, would cause the magnitude of sound energy reflected at this interface to be inconsistent with some Inconnel to Carbon Steel contact areas, and some Inconnel to deposit material contact areas dispersed with water or air filling any voids in the deposit material.

Given that an ultrasonic wave propagates at a known velocity through a homogeneous material, the distance through the material being inspected is measured in time. That is to say that the amount of time that it takes for the sound to travel to a reflector and back is also a measure of distance. ($d=vt$). The ultrasonic inspection instruments allow for the display of information collected at a given point in time, (distance). This allows for a planar view of information collected at a given distance such as the external surface of the penetration tube, referred to as a C-scan display.

Another feature of the ultrasonic instrumentation of interest for this discussion is the ability to color-code the amplitude of sound energy. This is essential to further aid in the illustration of pertinent information.

Past inspection efforts have focussed on the detection of cracks in the penetration tube itself. No data has been collected to date for the sole purpose of detecting inconsistencies in the amount of energy reflected from the external surface of the Inconnel tube interface with the Carbon Steel vessel head. However, a review of this empirical data shows very promising results for this technique.

On Figure 1 (below), the analyst selected a slice of information (time/distance), which best illustrated the parameters of interest (cracks in relation to the weld). The areas of high energy are colored red and the areas of low energy are colored black. The large sinusoidal shape in the middle of the display is the weld. Note the total loss of back reflection in the area of the weld, indicating that the sound energy was allowed to propagate into the weld. The sound energy is also not reflected toward the receiving transducer at this point in time in the location of the four cracks labeled 2 through 5.

The small, vertical, multi-colored bar code in the bottom right corner of the illustration is set with a color range of 1 through 80.

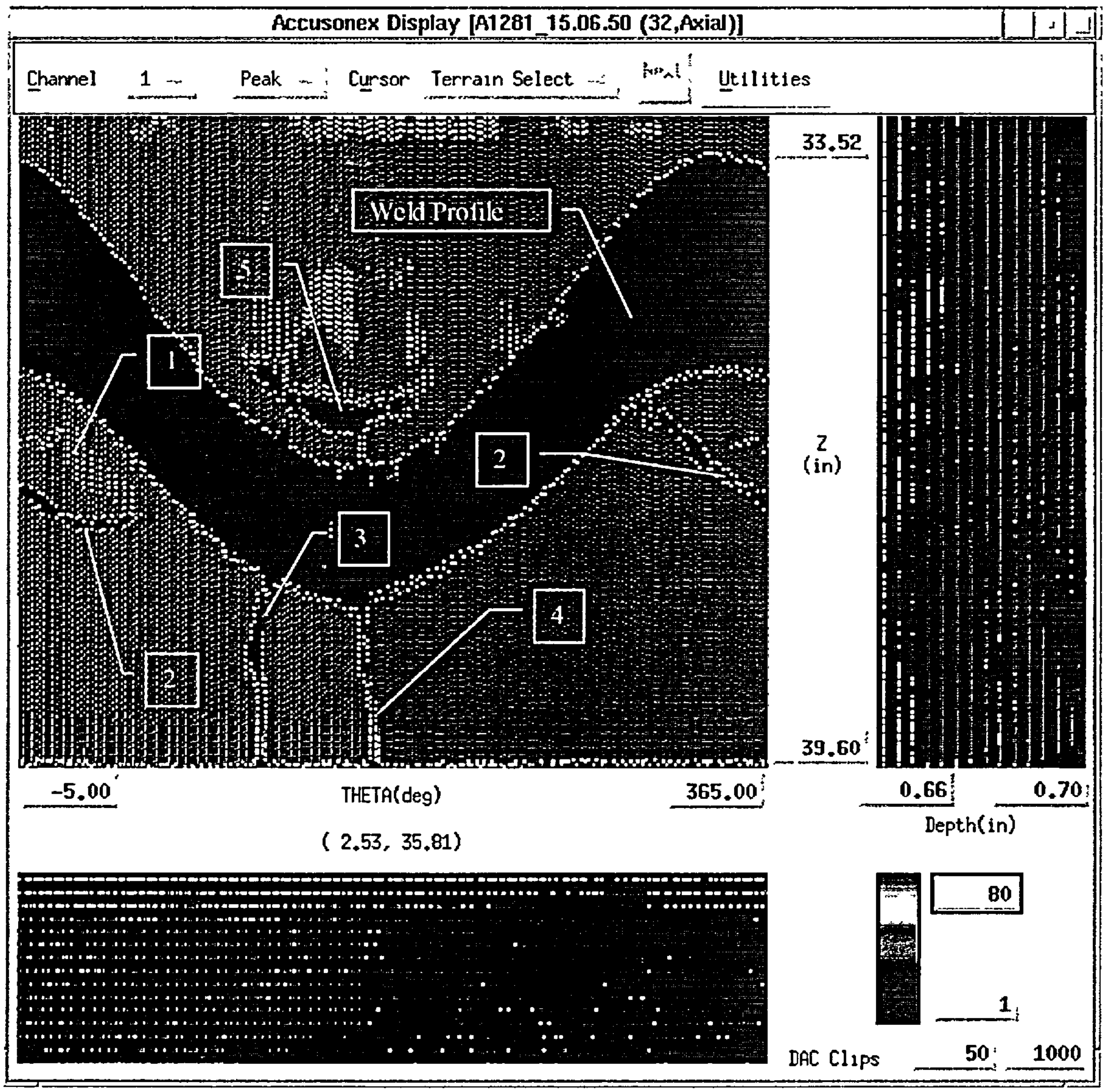


Figure 1

Figure 2, is the same penetration. In this illustration, the primary area of interest was to measure the location of the top of the vessel head, interference fit, and weld, before starting the repair. Location 26.35 is a transition area where there is a geometry change in the tube, above the top of the vessel head. Location 27.76 is the top of the vessel head on the uphill side of the nozzle and location 29.59 is the top of the vessel head on the downhill side of the nozzle. Note how the rise and fall of the vessel head conforms to the rise and fall of the weld indicating the geometry of the vessel head curvature. The area between location 29.59 and location 33.76 is the interference fit. The general area between the top and bottom of the interference fit has less sound energy reflected then any other area in this illustration other than the weld. Location 39.55 is the bottom of the nozzle. The area between 39.55 and the bottom of the weld is a metal to air interface.

Although the color scheme was set to optimize the other parameters, two distinct areas of high reflection are visible through the interference fit. These two areas are the RCS leak paths through the interference fit.

Note the color settings on the color bar code are 1 through 357.

Figure 3 and Figure 4 are both of another power station. Although a different color scheme was used for both of these illustrations, the leak path is clearly visible through the interference fit portion of the annular region above the weld. The area between the low side of the weld and the interference fit has a void with very high reflectivity. Numerous crack indications lead into this void with one clear leak path leading out.

Figure 5 is a printout of the ultrasonic C-scan display from another CRDM. In this illustration, numerous cracks are depicted leaking into the area between the interference fit and the low side of the weld, just as in Figures 3 and 4. In this Figure, the leak path through the interference fit is located on the high side of the weld.

Figure 6 is a printout of another CRDM. Notice the multiple crack indications with a visible leak path directly above them and the areas of low sound reflection on the high side of the weld.

Figure 7 is a printout from a different power station. Again we see an illustration that is less than ideal for a visual study in reflected energy. The color range is 30 to 286 but more importantly, magenta appears between dark blue and black on the color bar code. If the magenta areas that appear in the interference fit and weld portions of the illustration were a color between blue and black it would be more obvious where the areas of energy transmittance are. While an optimal color range selection would provide a better presentation, it is still evident that the area above the low side of the weld and under the interference fit has extremely high reflection. Large areas of high energy reflection are observed passing through the interference fit, denoting a leak. In this particular nozzle, the crack was not detected with ultrasonic flaw detection techniques but a liquid penetrant exam did detect a through wall crack in the weld. This leak would have been detected with an ultrasonic scan of the interference fit.

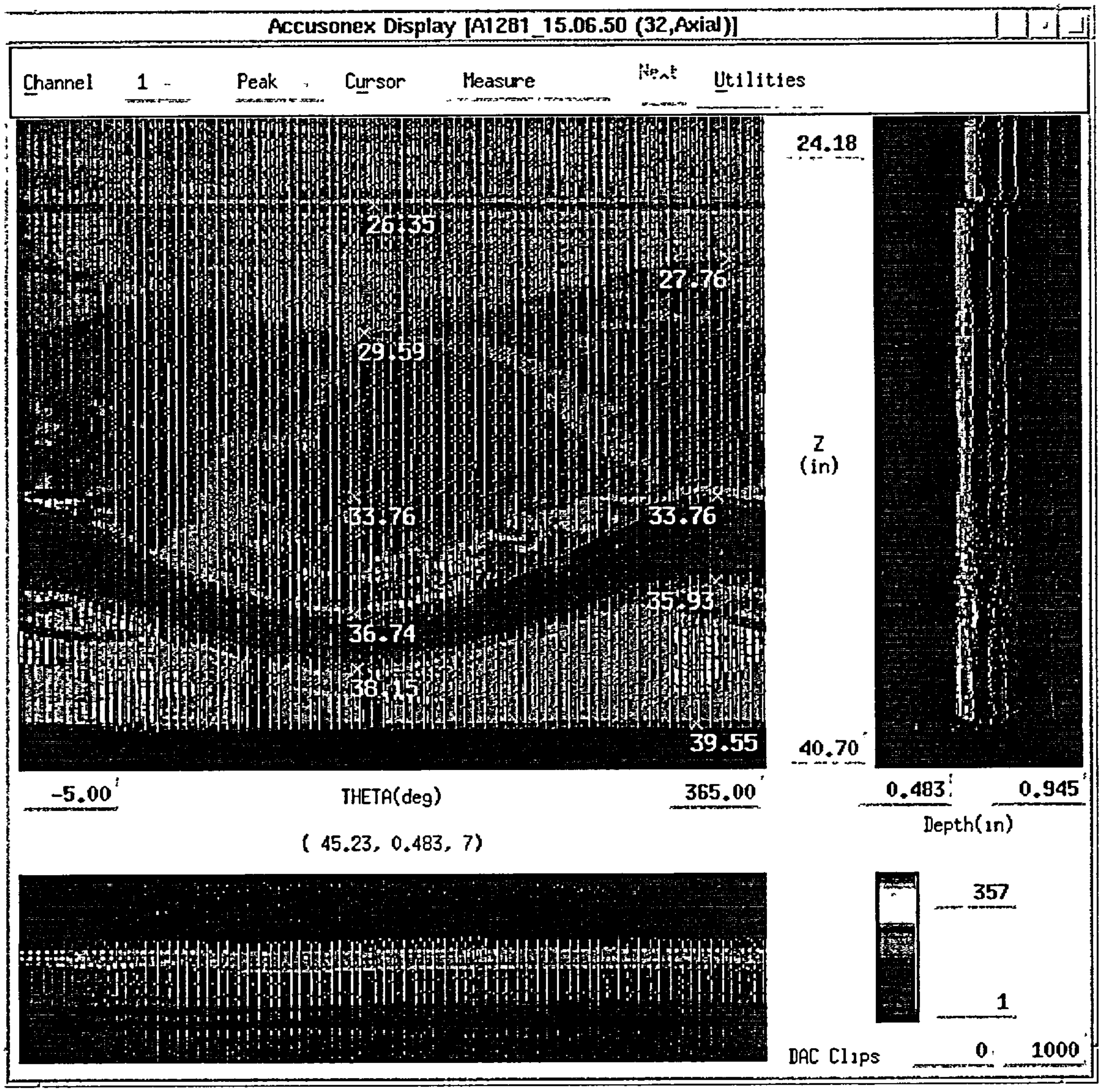

Accusonex Display [A1281_15.06.50 (32,Axial)]
Channel 1
Peak
Cursor
Measure
Next
Utilities
24.18
26.35
27.76
29.59
Z (in)
33.76
33.76
35.93
36.74
38.15
39.55
40.70
-5.00
THETA(deg)
365.00
0.483
0.945
Depth(in)
(45.23, 0.483, 7)
357
1
DAC Clips
0
1000

Figure 2

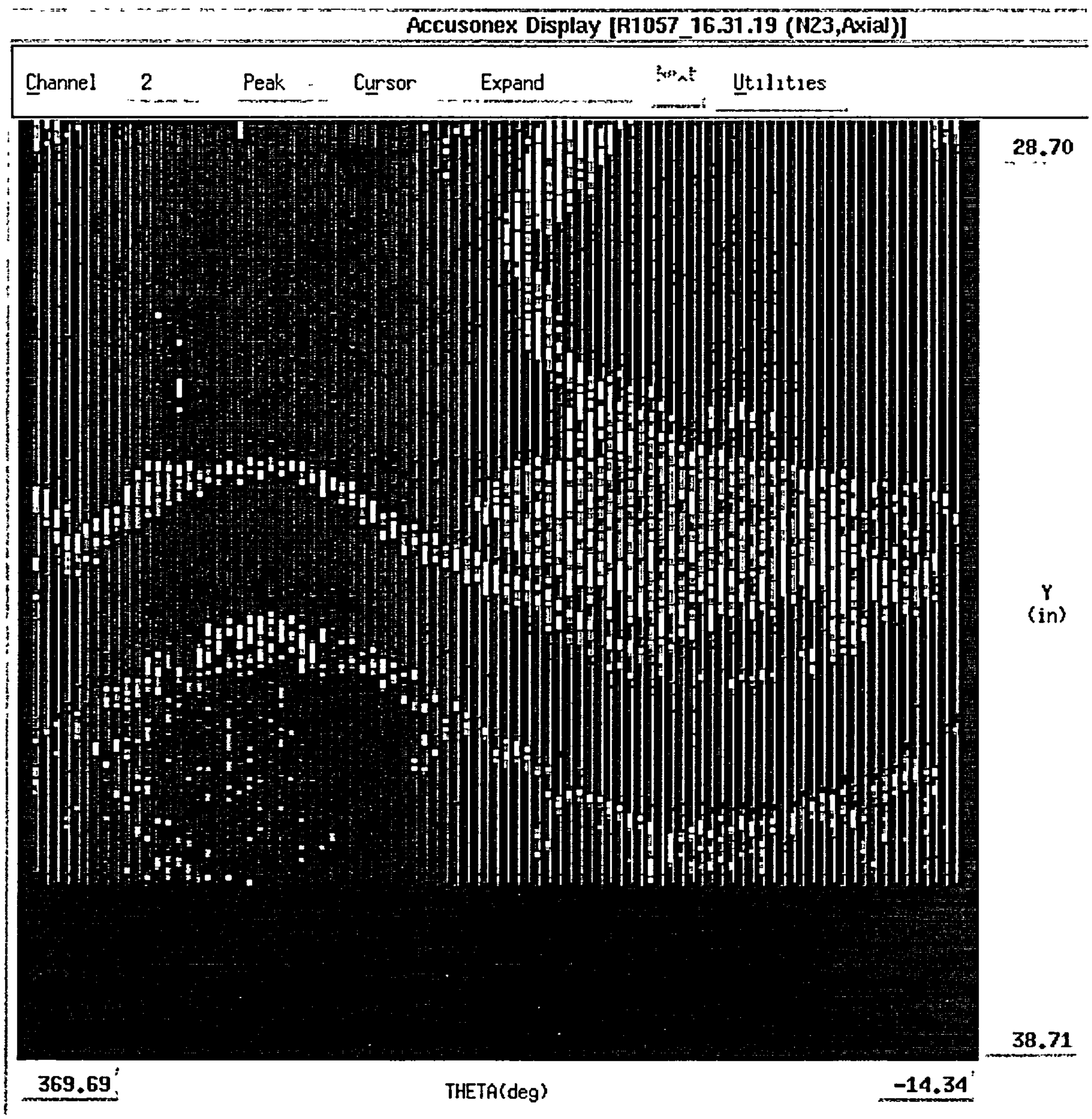
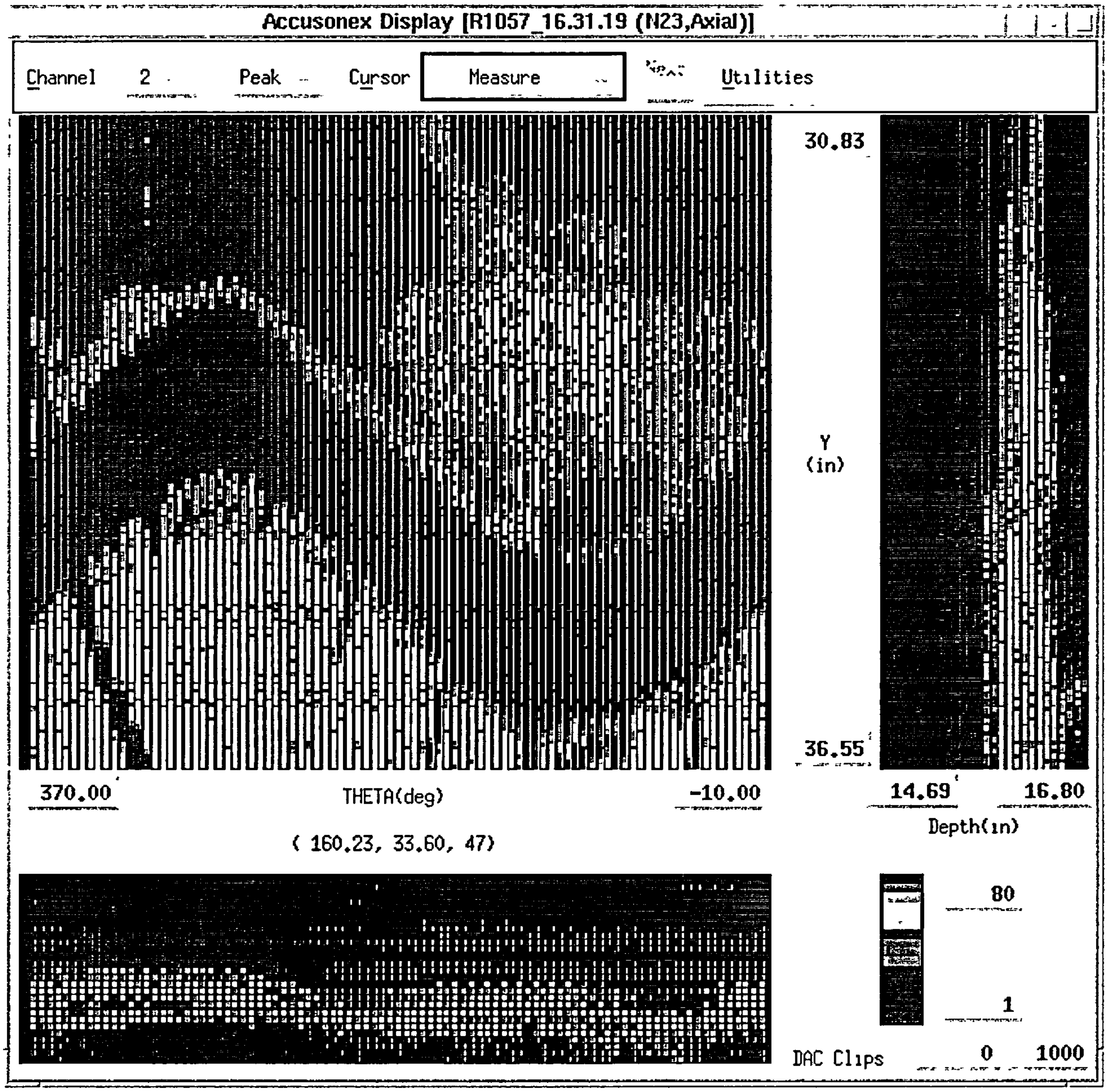

Accusonex Display [R1057_16.31.19 (N23,Axial)]
Channel
2
Peak
Cursor
Expand
Utilities
28.70
Y
(in)
38.71
369.69
THETA(deg)
-14.34

Figure 3



Accusonex Display [R1057_16.31.19 (N23,Axial)]
Channel
2
Peak
Cursor
Measure
Utilities
30.83
Y
(in)
36.55
370.00
THETA(deg)
-10.00
14.69
16.80
Depth(in)
(160.23, 33.60, 47)
80
1
DAC Clips
0
1000

Figure 4

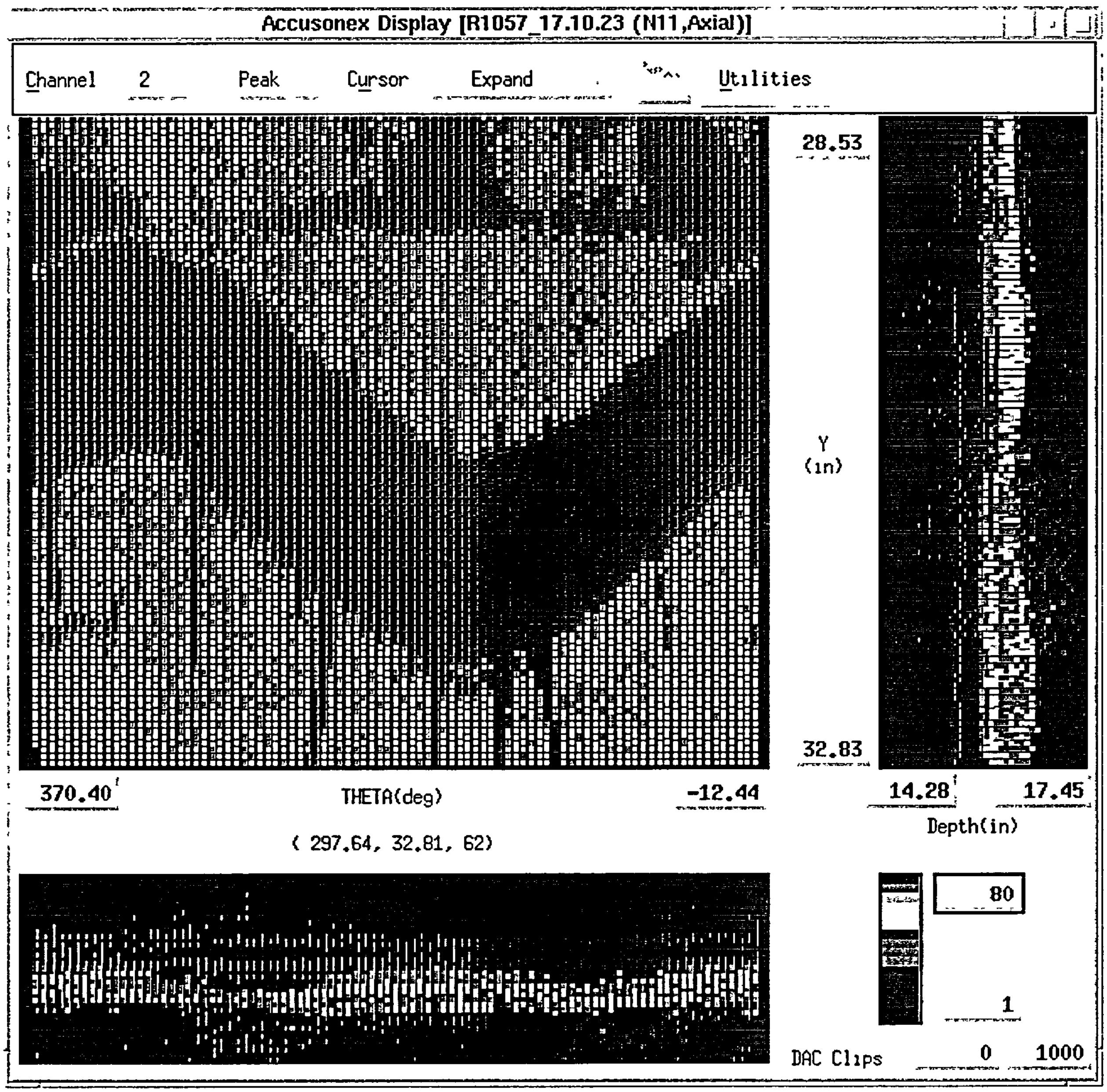
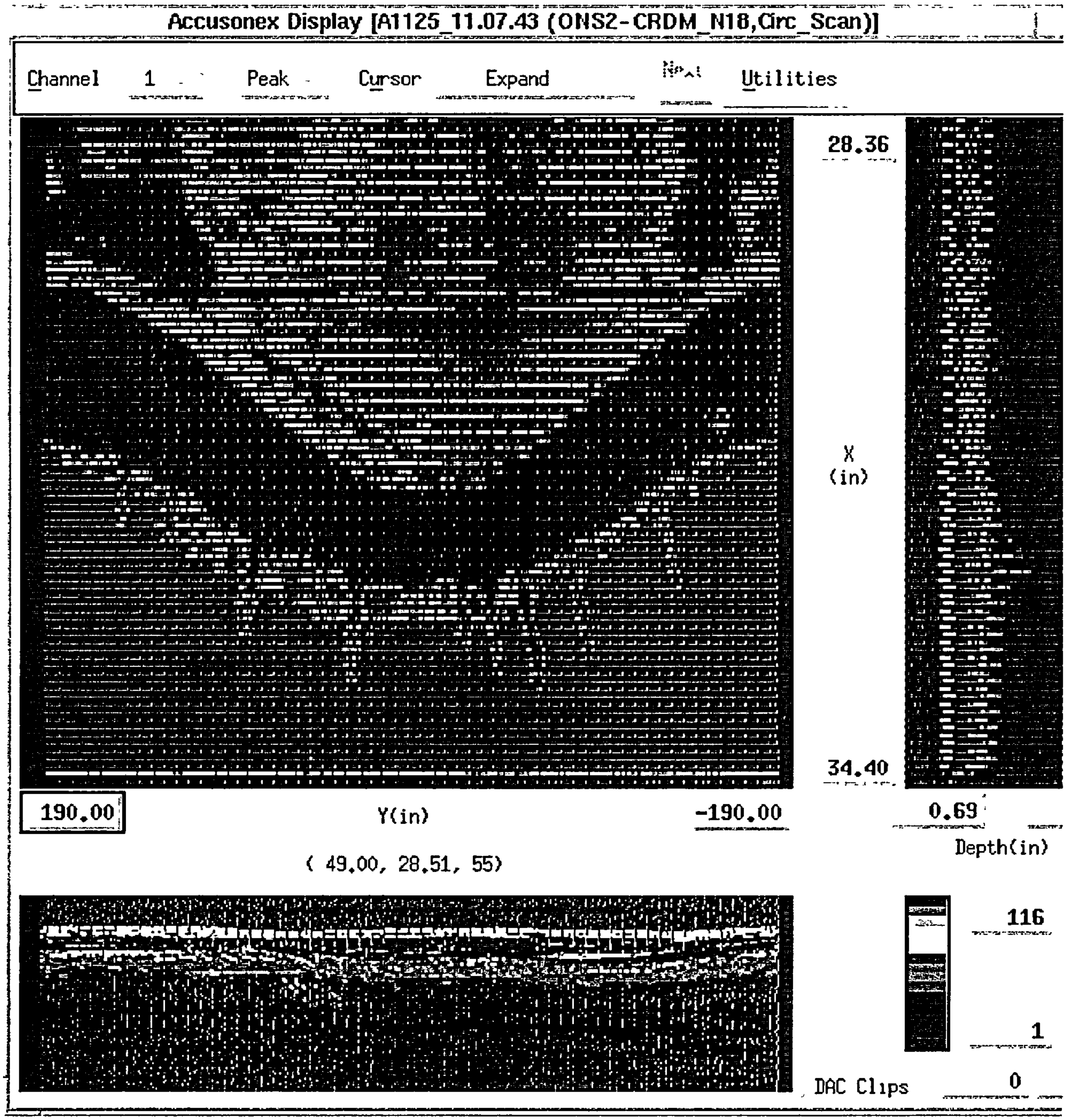

Accusonex Display [R1057_17.10.23 (N11,Axial)]
Channel
2
Peak
Cursor
Expand
Utilities
28.53
Y
(in)
32.83
370.40
THETA(deg)
-12.44
14.28
17.45
Depth(in)
(297.64, 32.81, 62)
80
1
DAC Clips
0
1000

Figure 5



Accusonex Display [A1125_11.07.43 (ONS2-CRDM_N18,Circ_Scan)]
Channel
1
Peak
Cursor
Expand
Utilities
28.36
X
(in)
34.40
190.00
Y(in)
-190.00
0.69
Depth(in)
(49.00, 28.51, 55)
116
1
DAC Clips
0

Figure 6

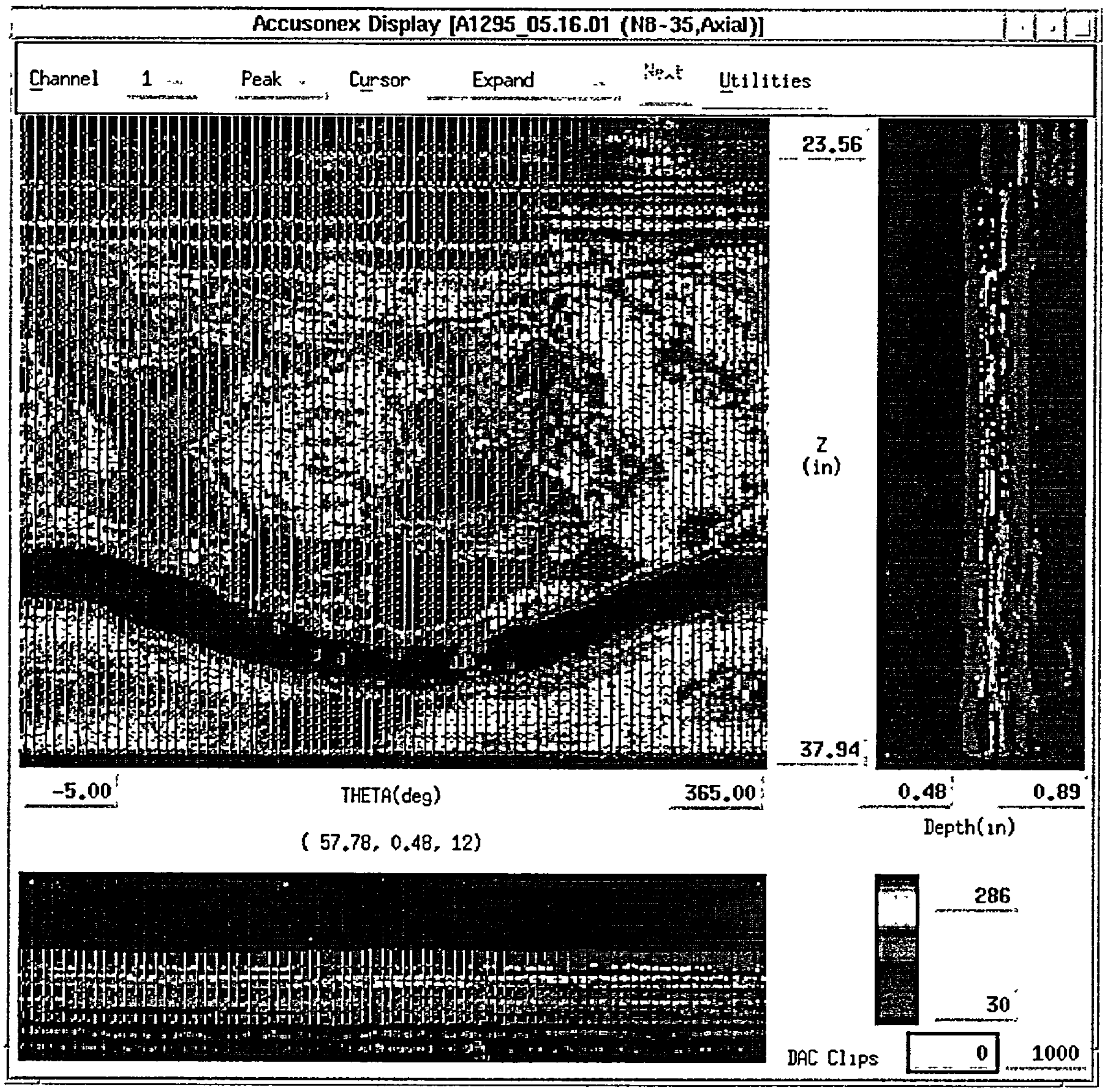

Accusonex Display [A1295_05.16.01 (N8-35,Axial)]
Channel
1
Peak
Cursor
Expand
Utilities
23.56
Z
(in)
37.94
-5.00
THETA(deg)
365.00
0.48
0.89
Depth(in)
(57.78, 0.48, 12)
286
30
DAC Clips
0
1000

Figure 7

In the following Figures, the quality of the illustrations is very poor when compared with the previous Figures. The preceding printouts are from the software program Accusonex while the following printouts are from the software program TomoScan. But even though the quality of the illustrations is poor, the areas of interest are still visible.

The illustration is rotated from the previous views. The bottom of the nozzle is now on the left side of the printout.

Even though the color scheme in Figure 8 has a light blue shade between the beige and green and also a light blue shade between green and dark blue on the color code bar, it is obvious that there are no leak paths or areas of high energy reflection in the interference fit, (which now appears on the right side of the illustration).

In Figure 9, there is an area above the weld and below the interference fit that displays an area of high energy reflection. The leak path through the interference fit is also visible. Although no cracks were detected with the ultrasonic flaw detection technique, a liquid penetrant test of the weld did produce an indication that turned out to be a through wall leak in the weld.

Figure 10 also depicts a leak path through the interference fit on a nozzle that contained a crack in the weld that was not detected with the ultrasonic flaw detection technique.

Conclusion

The above review, of the empirical data collected, demonstrates that if the subject examination technique is refined to focus on the amount of acoustic energy reflected from the external surface or interface of the Inconnel tube, and utilized in conjunction with conventional ultrasonic flaw detection techniques, the technique could aid the industry in the location of leaking RVHPs.

In order to refine this technique, a standard display format needs to be developed which optimizes and proceduralizes color ranges, scanning ranges, and detection criteria.

The benefit of using the information gathered from an examination of the interference fit, above the J-groove weld, is that it provides a reliable substitute, or alternate examination method, for a bare head visual inspection currently utilized for the detection of leaking RVHPs. This alternate examination could be utilized when access for a visual is limited or not available.

References

1. Memo Number MTACONFIG-01-324, entitled "Inspection of the Unit 2 Reactor Vessel Closure Head Penetrations", M Stark to T. Petit

2. Metals Handbook, Ninth Edition, Volume 17, Nondestructive Evaluation and Quality Control

3. Illustrations obtained from FTI Database

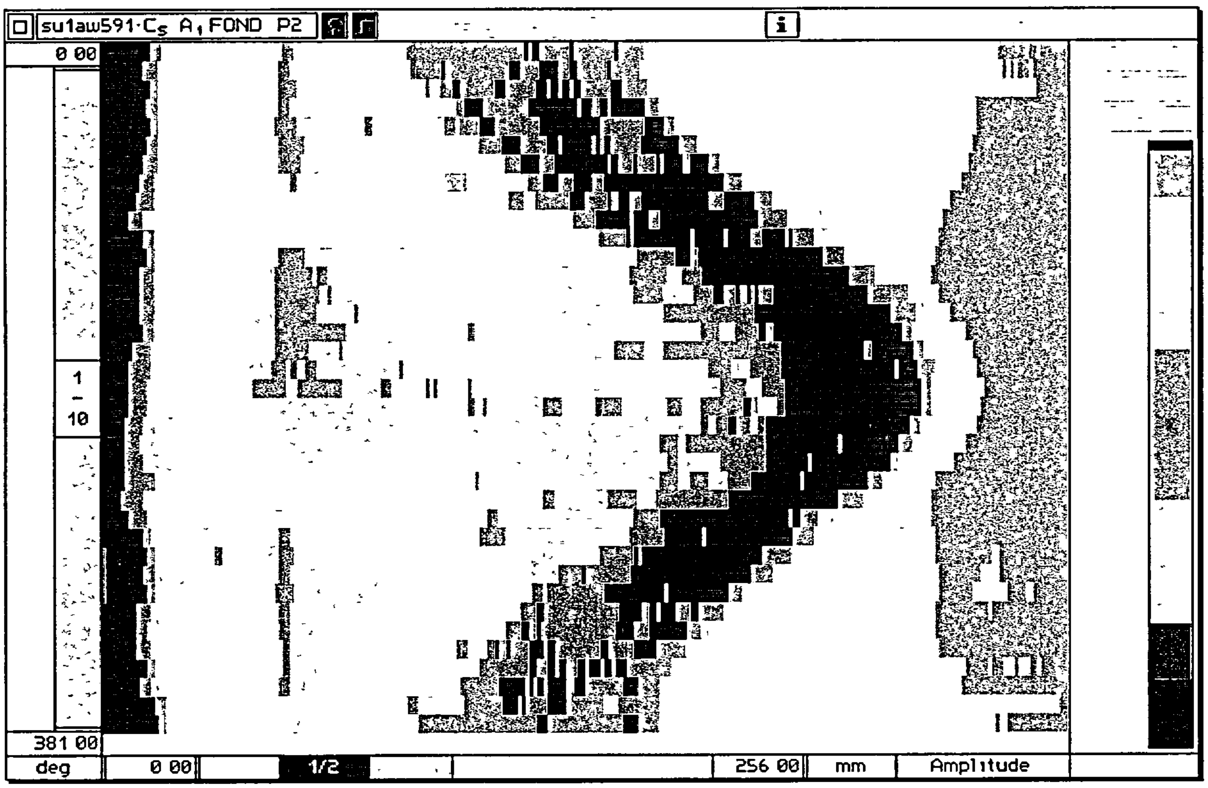

su1aw591·C5 A1 FOND P2
0 00
1
10
381 00
deg
0 00
1/2
256 00
mm
Amplitude

Figure 8

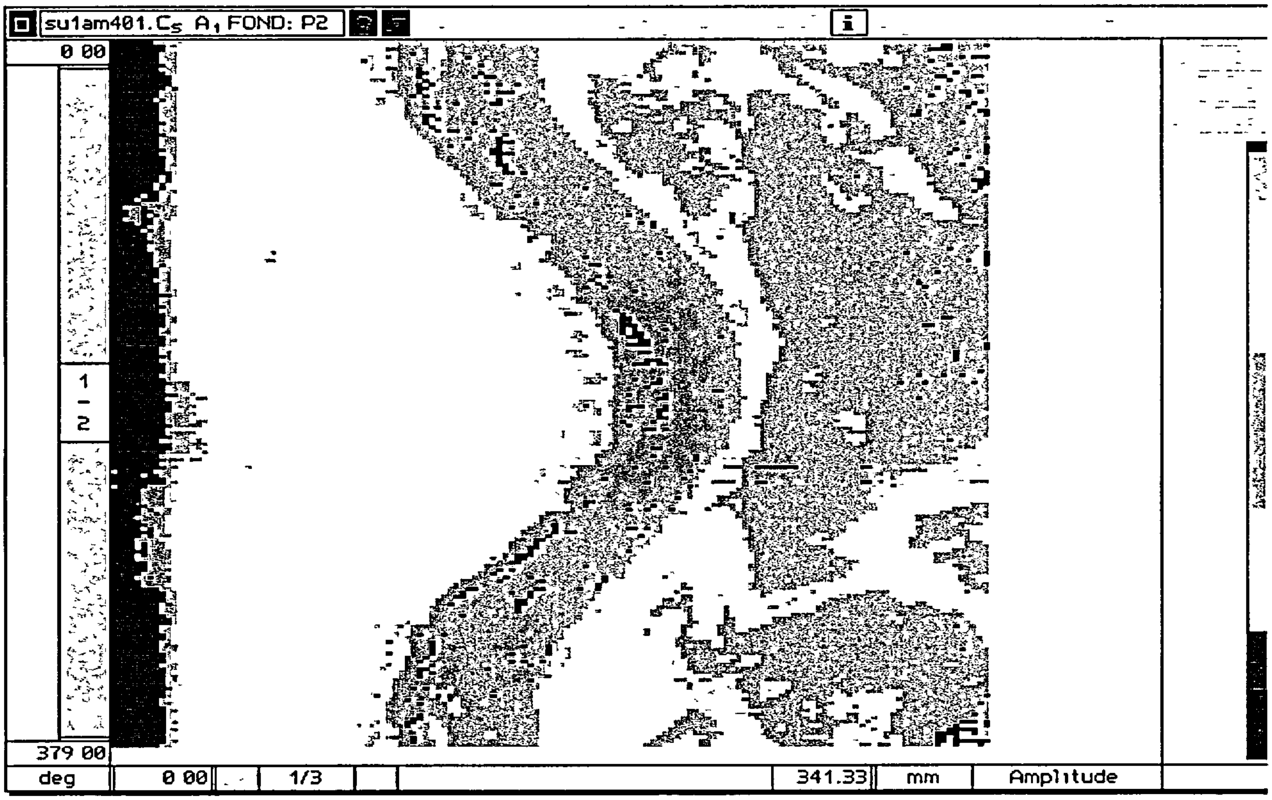

su1am401.Cs A1 FOND: P2
0 00
1
2
379 00
deg
0 00
1/3
341.33
mm
Amplitude

Figure 9

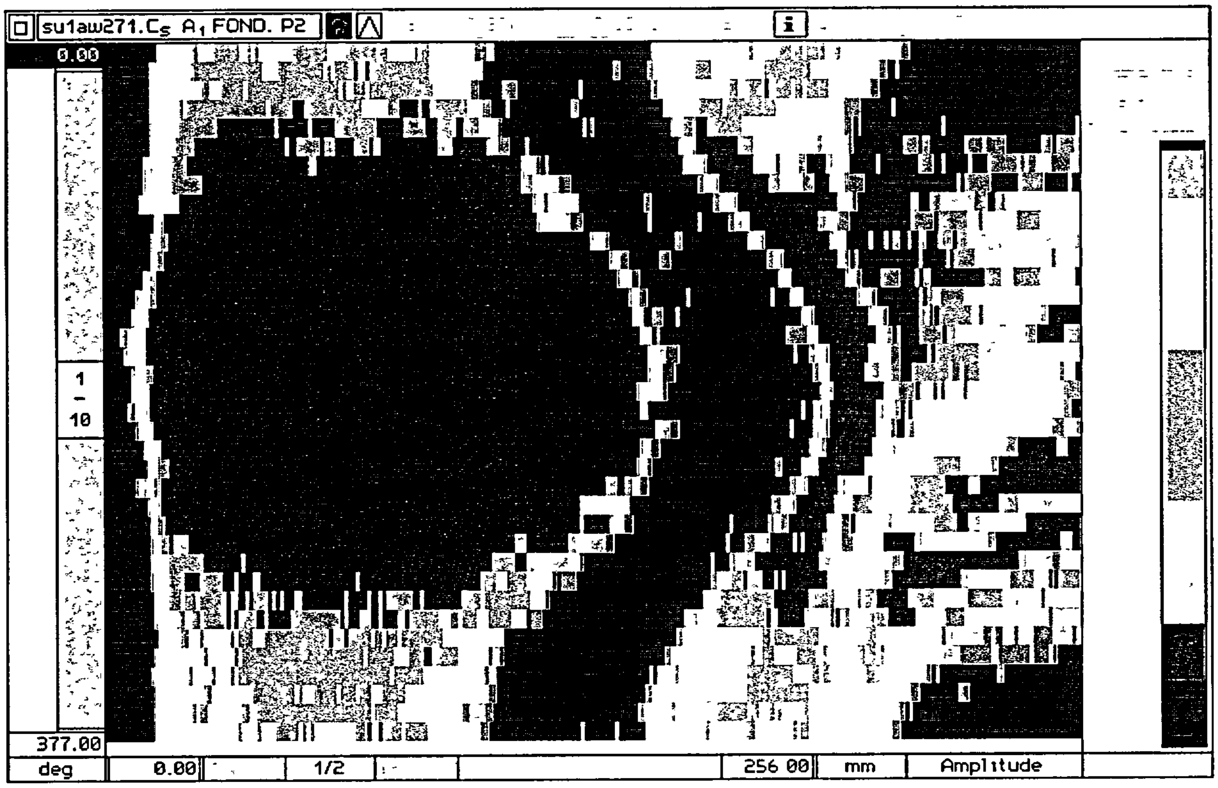


Figure 10

cc: (additional distribution)