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J. Phillip Bayne
Executive Vice President
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February 9, 1984
JPN-84-10

Director of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Attention: Mr. Domenic B. Vassallo, Chief
Operating Reactors Branch No. 2
Division of Licensing

Subject: James A. FitzPatrick Nuclear Power Plant
Docket No. 50-333
Induction Heating Stress Improvement (IHSI)

References: 1) NYPA letter, C.A. McNeill to T.E. Murley, dated July 22, 1983 (JAFP-83-0769).

Dear Sir:

During a short outage scheduled for early March of this year, a demonstration of Induction Heating Stress Improvement (IHSI) will be performed at the James A. FitzPatrick Nuclear Power Plant. This outage is tentatively planned to start on March 2 and to end on March 12, 1984.

As presently planned, the IHSI process will be applied to eleven (11) welds in the reactor water recirculation system. Table 1 lists the number, type of joint, pipe diameter, stress rule index, carbon content and EPRI Damage Index for the affected welds. These welds are identified on Figures 1 and 2 which are simplified isometrics of the FitzPatrick recirculation system. The stress rule indices and carbon contents have been factored into the EPRI Damage Index calculations along with variables such as post-weld grinding and plant thermal cycles to give a quantitative measure of possible future IGSCC. The welds were selected on the basis of equipment accessibility and their future susceptibility to IGSCC.

The object of this proposed demonstration is two-fold: to obtain plant specific information on the effect of IHSI on possible pre-existing IGSCC; and to evaluate the usefulness of IHSI as a plant-wide IGSCC countermeasure. It is also expected to reduce the susceptibility to IGSCC of some of the most vulnerable welds. The first goal is a direct result of the experiences other operating plants have had with IHSI. That is, post-IHSI ultrasonic testing revealed suspected IGSCC indications that were previously not detected or were evaluated as weld/joint geometry.

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A pre-IHSI and post-IHSI ultrasonic examination will be performed on the sample welds. It is planned that both of these inspections will be executed by the same technicians using the same equipment and procedures. In this way any changes in ultrasonic indications will be more clearly defined and interpreted.

Because the sample is heavily weighted towards welds most susceptible to IGSCC, and in light of the extensive inspections performed during last summer's refueling outage, it is the Authority's view that in the event of discovery of IGSCC indications, additional inspections would not need to be performed during this outage. Any indications of IGSCC will be evaluated for impact on piping structural integrity and, if required, will be repaired. Discovery of IGSCC during the examinations performed during this March's outage will be considered in selecting the sample size for inspection during the next refueling outage, scheduled for early spring of 1985.

One of the welds selected for treatment by IHSI is the distribution manifold end cap in which IGSCC was discovered as reported in Reference 1. Attached is an analysis performed by Structural Integrity Associates to determine the impact of IHSI on this weld. This analysis indicates that no crack propagation is expected to occur during the induction heating of the pipe, and that the tip of such a crack would experience a negative or compressive stress for a depth of up to 70% of the wall. Note that the depth of this crack was determined to be no more than 20% of the pipe wall, which, even if doubled for conservatism, is well below that depth at which residual stresses become tensile. Performing IHSI on this weld will help clarify the effects of IHSI on the ultrasonic detectability of pipe cracks while enhancing the resistance of this particular welded joint to future crack growth. Finally, if this demonstration of IHSI confirms the feasibility for full scale application to the large diameter stainless steel piping, implementation would be tentatively scheduled for September, 1984.

If you have any questions, please contact Mr. J. A. Gray, Jr. of my staff.

Very truly yours,

C.M. Wilverding

for J.P. Bayne
Executive Vice President
Nuclear Generation

cc: Office of the Resident Inspector
U.S Nuclear Regulatory Commission
P.O. Box 136
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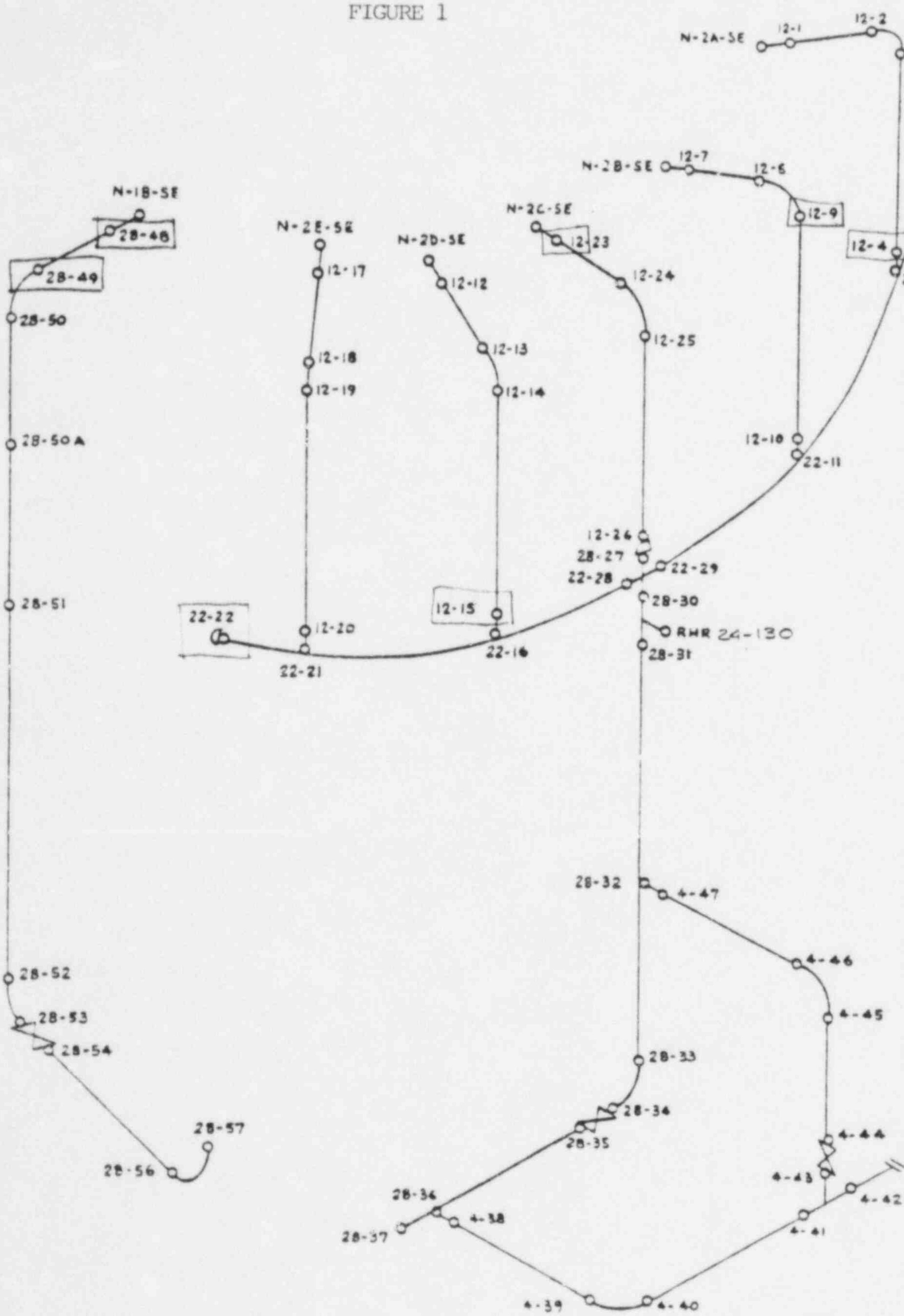
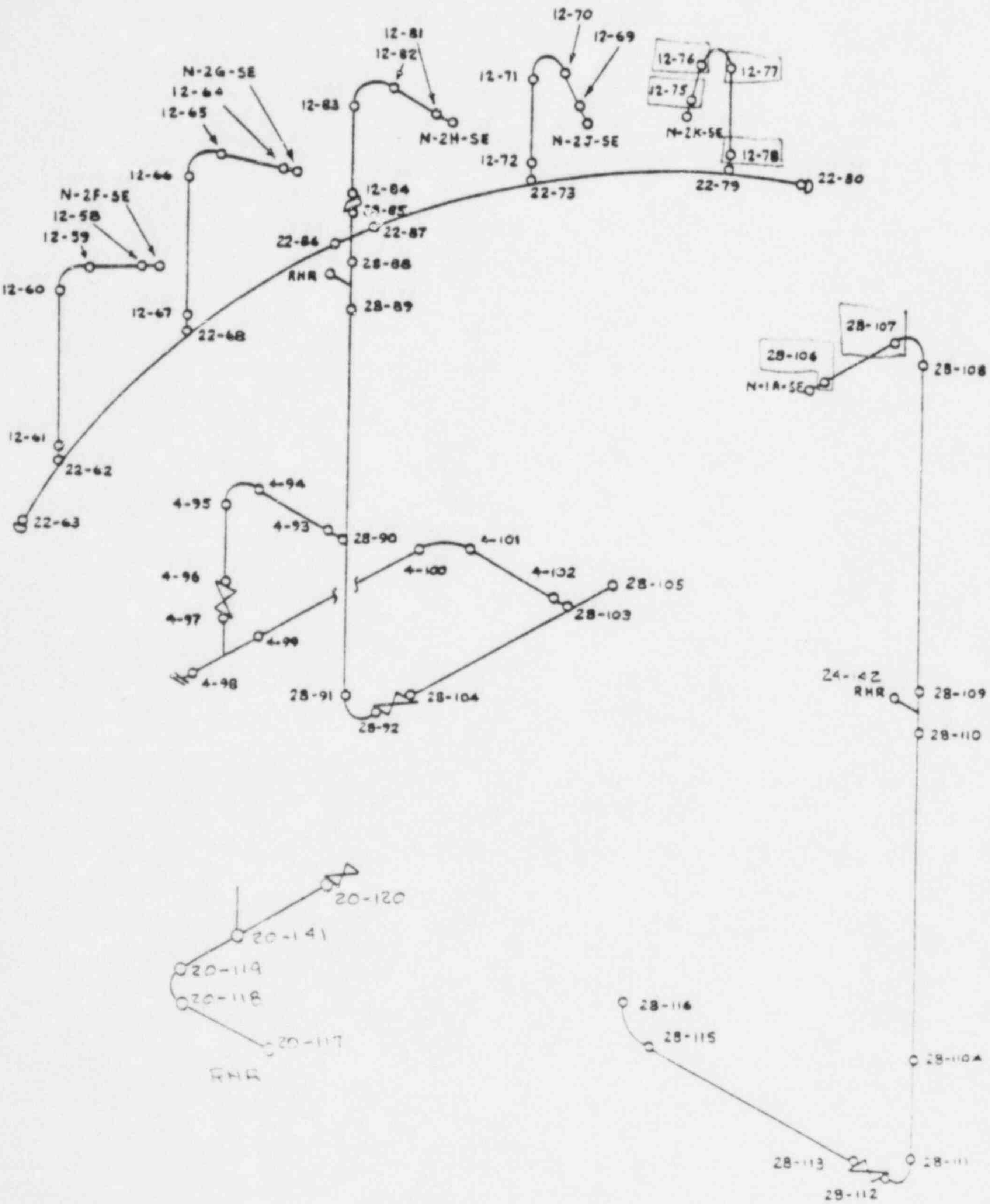
FIGURE 1



ISOMETRIC OF RECIRCULATION SYSTEM - LOOP A

NOTE: ABBREVIATED ISI WELD NUMBERS

FIGURE 2



ISOMETRIC OF RECIRCULATION SYSTEM - LOOP B

NOTE: ABBREVIATED ISI WELD NUMBERS

TABLE 1

Weld No.	Joint Type	Nominal Pipe Diameter	C%	Stress Rule Index	EPRI Damage Index [2]
12-4	Sweepolet-pipe	12"	.070	1.88	2.13
12-9 [1]	Pipe-elbow	12"	.070	1.53	1.13
12-15	Sweepolet-pipe	12"	.050	2.02	3.16
12-23 [1]	Pipe-safe-end	12"	.044	1.59	1.22
12-75	Pipe-safe-end	12"	.057	1.53	1.14
12-76	Pipe-elbow	12"	.079	1.84	2.03
12-77	Pipe-elbow	12"	.070	1.67	1.41
11-78	Sweepolet-pipe	12"	.044	2.28	1.04
22-22	Pipe-end cap	22"	.079	0.98	0.95
28-48	Pipe-safe-end	28"	.058	1.06	0.87
28-49	Pipe-elbow	28"	.053	1.36	1.15
28-106	Pipe-safe-end	28"	.051	1.06	0.69
28-107	Pipe-elbow	28"	0.52	1.31	0.80

1) Alternate welds to be substituted in case of accessibility problems.
2) Values after seven years of operation.

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December 22, 1983
PCR-83-054

Mr. David Sancic
New York State Power Authority
123 Main Street
White Plains, New York 10601

Subject: IMPACT OF IHSI ON POTENTIALLY CRACKED PIPE WELDS AT FITZPATRICK

Dear Dave:

This letter report addresses several questions you raised regarding the upcoming IHSI sampling program planned at Fitzpatrick. The questions arise due to the fact that IHSI will be performed on one weld with a known, IGSCC-like UT indication, and several welds which, although not called out to be cracked in the recent UT examination program, did contain some "geometric" indications, and were identified as potentially susceptable to IGSCC by the Structural Integrity (SI) Associates damage index evaluation (Reference 1). This report summarizes a substantial body of data (References 2 and 3) which exists on the impact of IHSI on cracked or potentially cracked welds, and addresses it to three potential concerns at Fitzpatrick:

1. To what extent will the IHSI residual stress improvement be realized in welds which are already cracked?

2. What will be the effect of IHSI on predicted IGSCC crack growth, (such as that reported for end cap weld 22-02-2-22 in Reference 4)?

3. Is there any potential for propagation of existing cracks during the IHSI process?

Details of the SI review in each of these areas are presented below. In summary, the preponderance of analytical and experimental data, both in the U.S. and Japan suggest that IHSI is effective in producing a deep, compressive residual stress field in the vicinity of existing IGSCC in pipe welds. Incorporating this residual stress field into fracture mechanics based IGSCC crack propagation analyses (such as Reference 4) results in highly compressive stress intensity factors, even for crack depths of up to 60 or 70 percent of the wall thickness, from which it can be concluded that

IHSI treatment of existing IGSCC should promote crack arrest under operating condition loads. Finally, analytical as well as destructive metallographic evaluations have confirmed that no crack extension occurs during an IHSI treatment. Some data have shown, however, that changes in UT amplitude can occur either as a result of operational variables or changes in UT reflectivity as a result of the IHSI process. It is noteworthy, however, that where such UT reflectivity changes have been observed in the laboratory, they were not due to physical growth of the defects, but rather were due to a change in crack tightness or acuity, such that it produced a UT signal change.

RESIDUAL STRESS IMPROVEMENT

The effect of pre-existing defects on IHSI residual stress improvement was studied by both analytical modelling and experimental measurements (X-ray, strain gage and magnesium chloride) as reported in section 5.1 of Reference 2. Results of the analytical modelling are summarized in Figure 1. This plot shows through-wall axial residual stress distributions in a 26-inch diameter pipe as a function of crack depth (a/t) for a pre-existing 360° crack. The plot shows that the magnitude of compressive stress and the depth or the compressive zone actually increase with crack depth for depths up to 40 percent of the wall thickness. Experimental confirmation of this analytical prediction is illustrated by Figure 2, which is typical of many such strain gage residual stress measurements reported in Reference 2. This plot represents data on a 4-inch pipe weld which was precracked by the pipe test technique and then given an IHSI treatment. The strain gage residual stress measurements were also borne out by surface residual stress measurements on pre-cracked pipe using X-ray defraction and boiling magnesium chloride techniques. The later tests were particularly noteworthy in that they produced transgranular cracking TGSCC on the outside surface of the pipe, in which tension is predicted after IHSI, but none on the inside surface (see Figure 3).

Analytical modelling performedin Japan (Reference 3) for 12 inch diameter pipe, precracked up to 25 percent of the wall thickness yielded essentially identical results as the GE 26 inch pipe results discussed above (see Figure 4). IHI also performed magnesium chloride testing of a pipe with an EDM notch in the weld HAZ, both with and without IHSI treatment. As illustrated in Figure 5, cracking at the notch was experienced with no IHSI, but not at the IHSI treated notch.

The above analytical and experimental results confirm that IHSI is effective in producing compressive residual stresses even in the presence of pre-existing IGSCC in a pipe weld.

EFFECT ON PREDICTED IGSCC CRACK GROWTH

GE used the above analytical residual stress data as input to a fracture mechanics formulation to determine crack tip stress intensity factor as a function of crack depth. The results, for a 26 inch diameter pipe, are illustrated in Figure 6. The predicted stress intensity factor is increasingly negative for crack depths up to 60% of the wall thickness. This result should be sufficient to counteract any positive stress intensity factor

data due to applied loading, and effectively negate any further propragation of the crack.

SI has incorporated an expected post IHSI residual stress pattern into our crack growth analysis of the Fitzpatrick end cap weld 22-02-2-22 (Reference 4). The results, illustrated in Figures 7 and 8, are similar to the GE results described above. The crack tip stress intensity factor for residual and applied stress is negative for crack depths up to 70% of the wall indicating no crack growth. Thus a substantial improvement is predicted over the pre-IHSI crack growth results of Reference 4.

Finally, experimental crack growth data on pre-cracked, IHSI treated pipe obtained using pipe test methodology are reported in Reference 2. These data indicate a slight improvement in time to failure versus non-IHSI treated pipe (See Figure 9), but the degree of improvement is not nearly as dramatic as that predicted by the above analyses. The reason for this apparent discrepancy is that the pipe test methodology is not a good one for testing residual stress improvements such as IHSI. Pipe tests are loaded significantly above expected service loads to accelerate the cracking phenomenon, and the subsequent yielding overwhelms any apparent benefit of IHSI. In order for pipe tests to adequately represent IHSI, they must be conducted at lower loads, which results in much longer failure times in non-IHSI treated piping, and extremely long (bordering on impractical) test times to demonstrate factors of improvement associated with IHSI.

It is thus concluded, based on analytical results, that IHSI of pipes containing pre-existing IGSCC, should promote crack arrest, and that the GE pipe test data, although not substantiating the magnitude of this claim, does not contradict it.

CRACK PROPAGATION DURING IHSI

Extensive analysis and testing, both in the U.S. and Japan have been conducted which demonstrates that the IHSI process in itself does not propagate pre-existing defects. The elastic plastic residual stress analysis reported in Reference 2 was further examined to determine the maximum strain excursion in the innermost vicinity of the crack-tip. The resulting stress-strain history is illustrated in Figure 10. This figure does not exhibit nearly enough strain to produce ductile tearing or other forms of crack extension in a material as inherently tough as 304 stainless steel. Similar analytical work conducted by IHI in Japan [Reference 3] demonstrates that the maximum crack-tip opening displacement [CTOD] during the IHSI process is well below the critical CTOD value for crack extension.

These analytical results are borne out by extensive destructive metallurgical examinations of pipe test specimens reported in Reference 2. In these tests, specimens were pre-cracked, IHSI treated, then destructively examined. Metallurgical examination of several such specimens showed no evidence of crack propagation in any mode other than intergranular stress corrosion,

which is positive evidence that IHSI did not propagate the pre-existing cracks in these specimens. An interesting by-product of these experiments, however, is the fact that IHSI did appear to change the UT reflectivity of the cracks in some cases. This phenomenon is illustrated by Figure 11 in which there was a substantial increase in UT amplitude (> 40% of full screen height) in a precracked weldment before and after IHSI. GE did extensive investigations of UT operational variables, crack morphology, and actual crack size of these specimens from which they concluded that the IHSI process, while not causing any physical crack growth, may affect the crack tightness and acuity such that it will produce a UT signal change.

I hope that the above information satisfies your licensing/internal review needs for the upcoming IHSI outage. Please call if you have any questions on it or need our assistance on any other aspect of the job.

Very truly yours,

Peter C. Riccardella

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encl.

List of References

1. Structural Integrity Associates Report No. SIR-83-005, Revision 0 "A Damage Model Based Cost/Benefit Alternatives at the Evaluation of IGSCC Remedy/Repair alternatives at the James A. Fitzpatrick Nuclear Power Plant," September, 1983.

2. EPRI Report NP-3375, "Induction heating Stress Improvement", Prepared by General Electric Co , EPRI Project Manager A.T. Giannuzzi, November, 1983.

3. EPRI Report NP-81-4-LD, "Residual Stress Imporvement by Means of Induction Heating," Prepared by Ishikawajima- Harima Heavy Industries Co.,Japan, EPRI Project Manager A. J. Giannuzzi, March, 1981.

4. Structural Integrity Associates Report No. SIR-83-002, Revision 2, "Fracture Mechanics Evaluation of observed flaw indication in 22-inch pipe to end cap weld 22-02-2-22, JAMES A. Fitzpatrick Nuclear Power Plant", August, 1983.

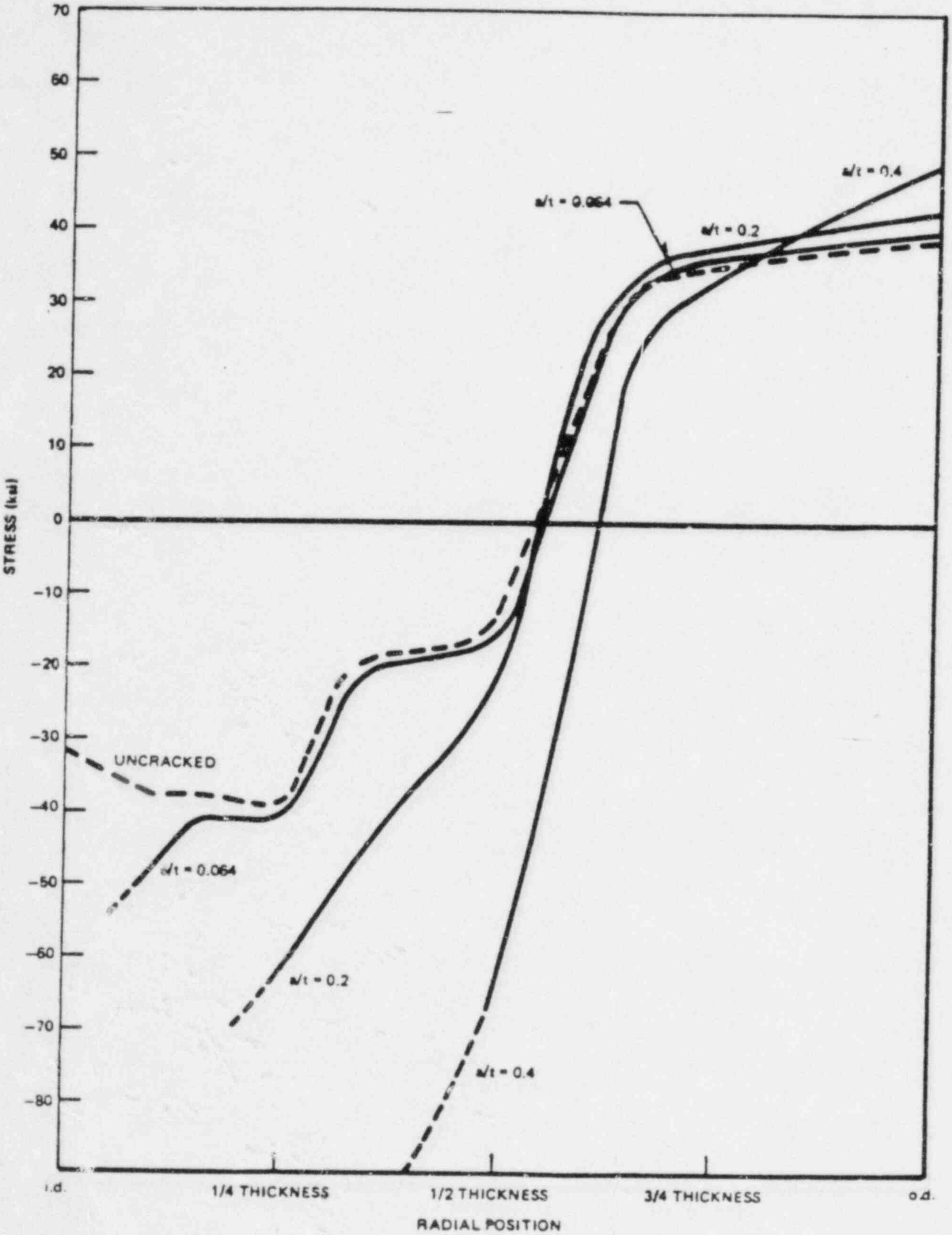

Figure 1 IHSI Through-Wall Axial Stress Distribution at Weld Center Line for Preexisting Cracks (From GE Analysis of Reference 2)

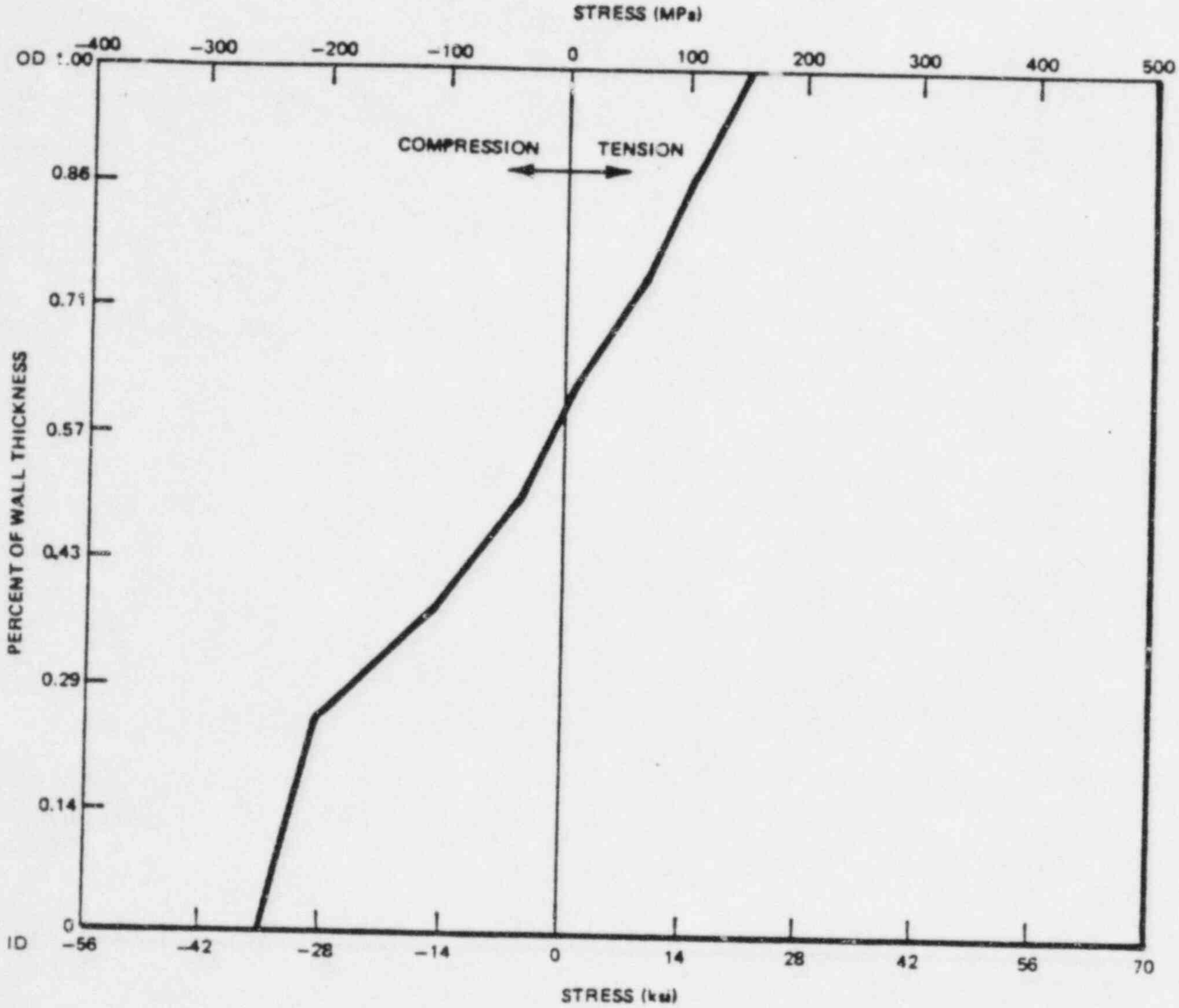

Figure 2. Through Wall Axial Residual Stress Distribution for Specimen RS-06 Joint E. Pre-Cracked Plus IHSI-279.5° Azimuth, 1.52 mm (0.06 Inches) From Weld Fusion Line (Strain Gage Measurements from Reference 2)

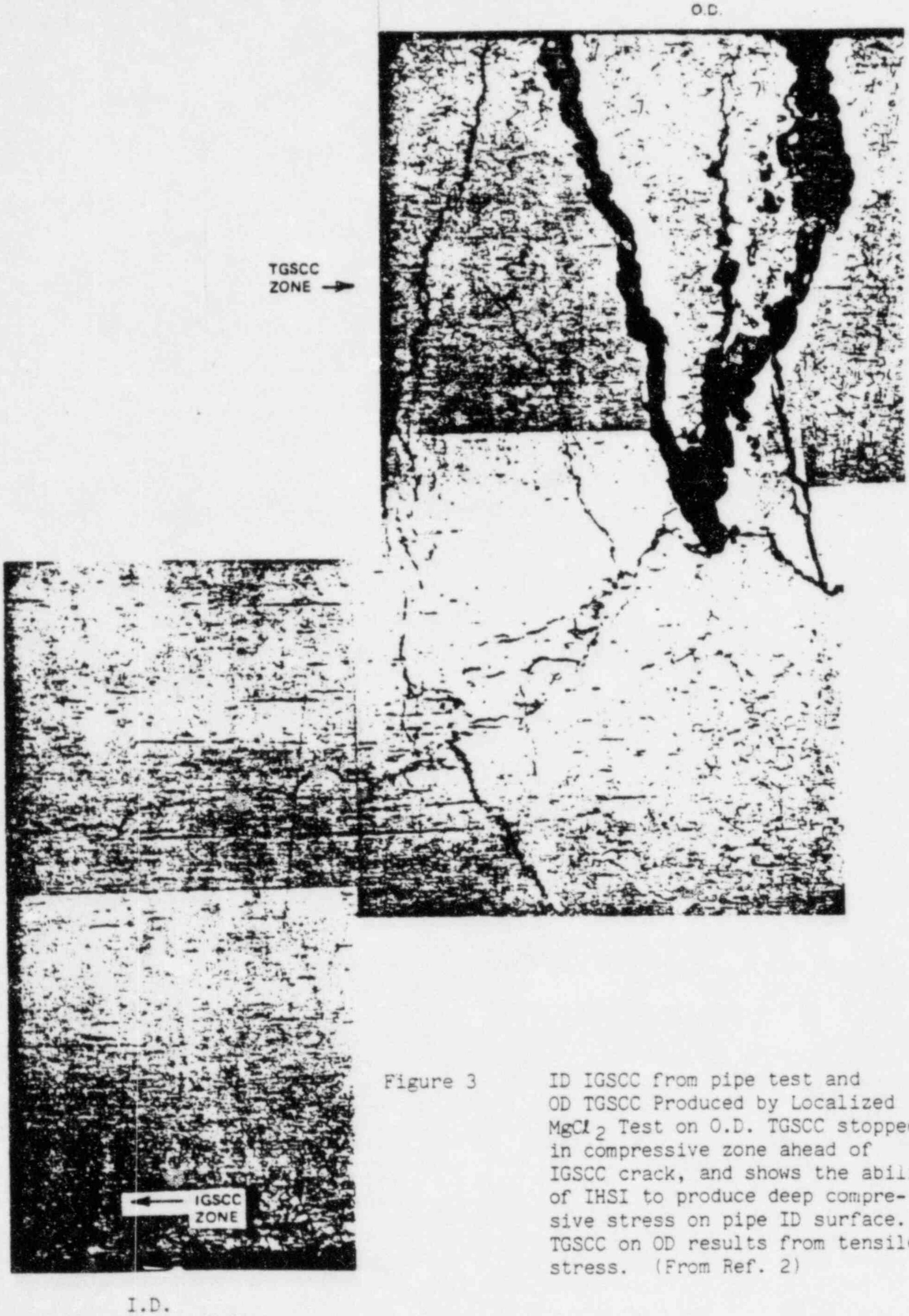

Figure 3 ID IGSCC from pipe test and OD TGSCC Produced by Localized $MgCl_2$ Test on O.D. TGSCC stopped in compressive zone ahead of IGSCC crack, and shows the ability of IHSI to produce deep compresive stress on pipe ID surface. TGSCC on OD results from tensile stress. (From Ref. 2)

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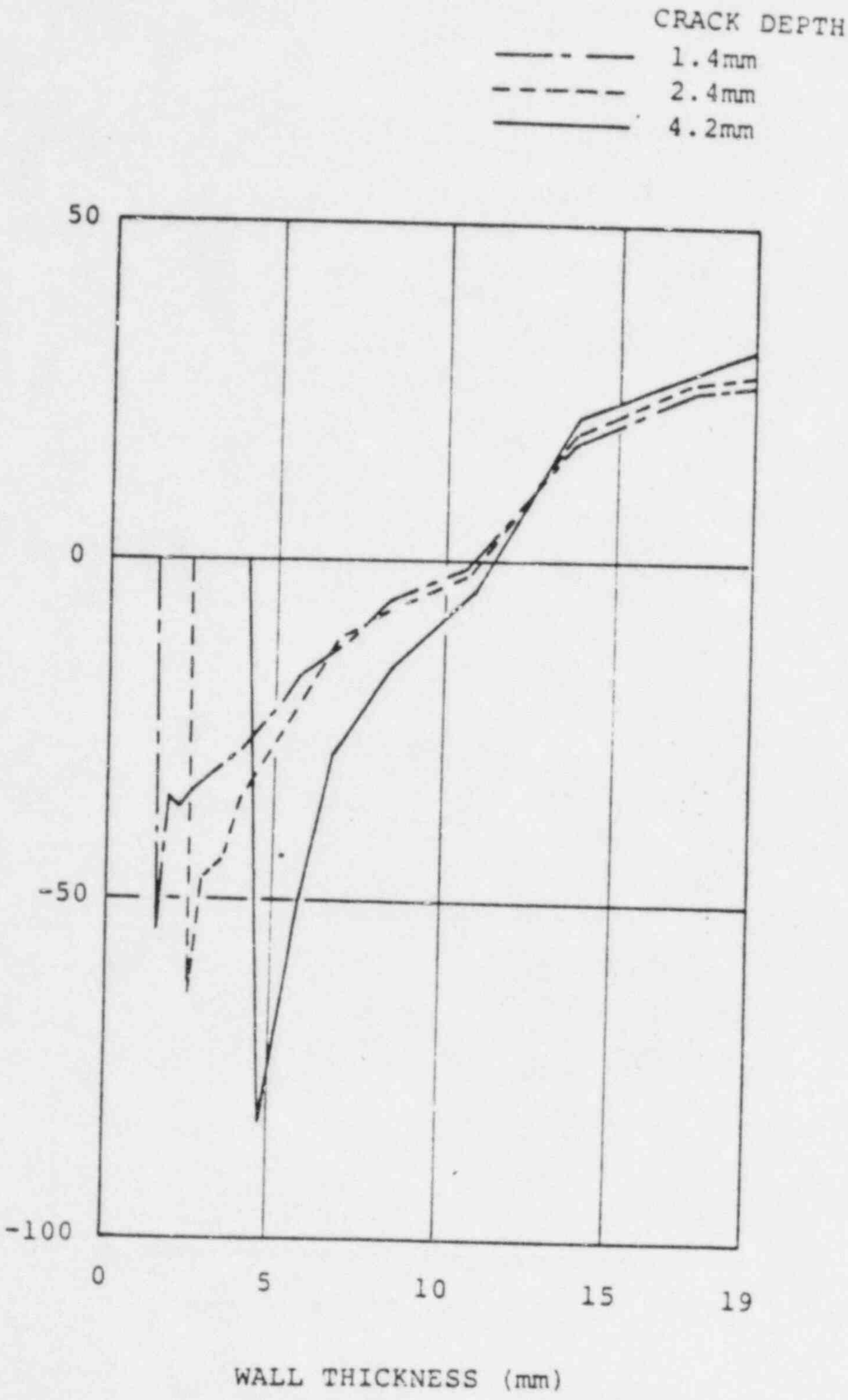

Figure 4 Calculated residual stress through the thickness of 12 in. pipe with a flaw (Reference 3)

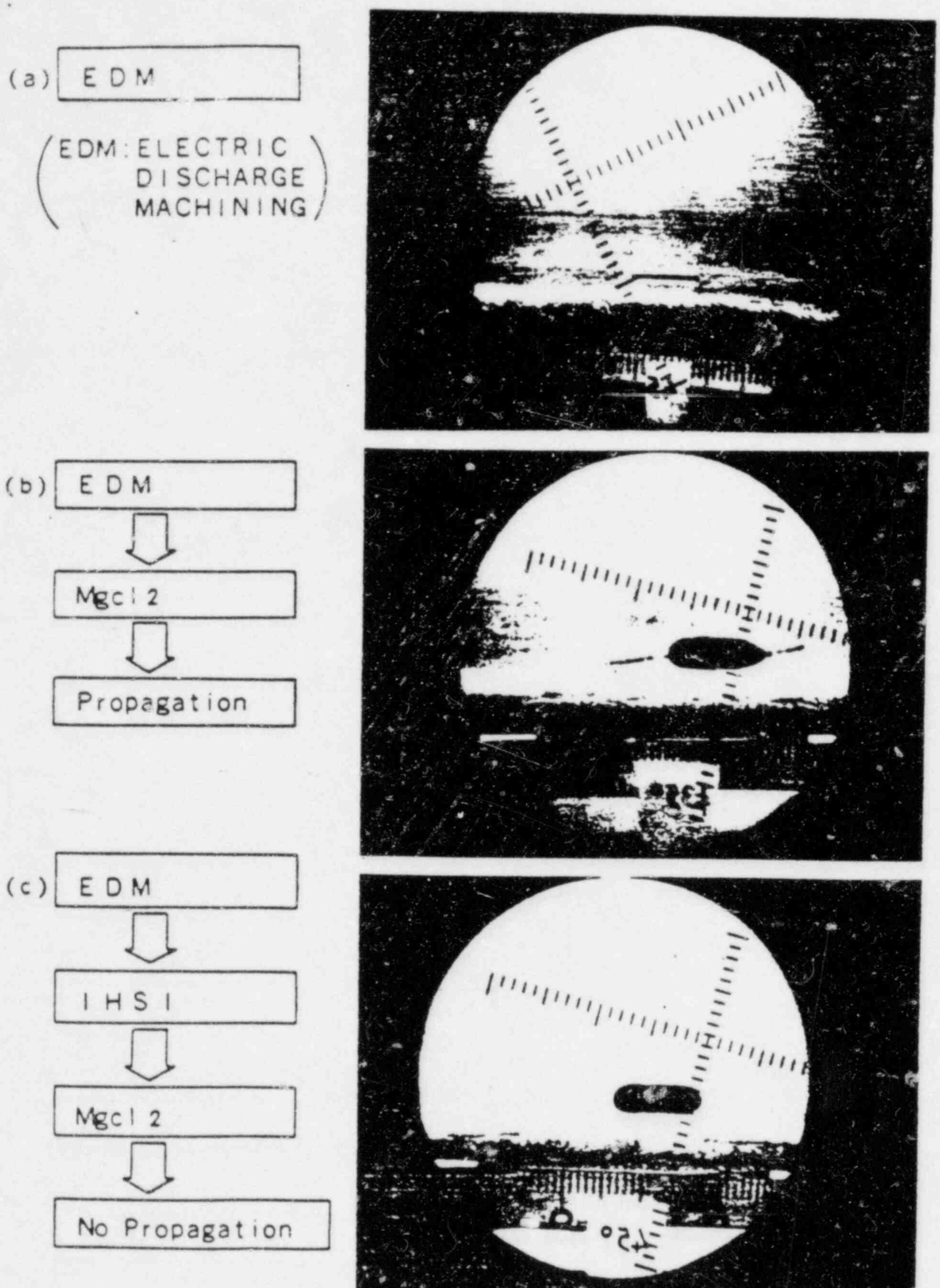

Figure 5. Japanese Experiment Showing IHSI Residual Stress Improvement in Pre-Notched Pipe (Reference 3)

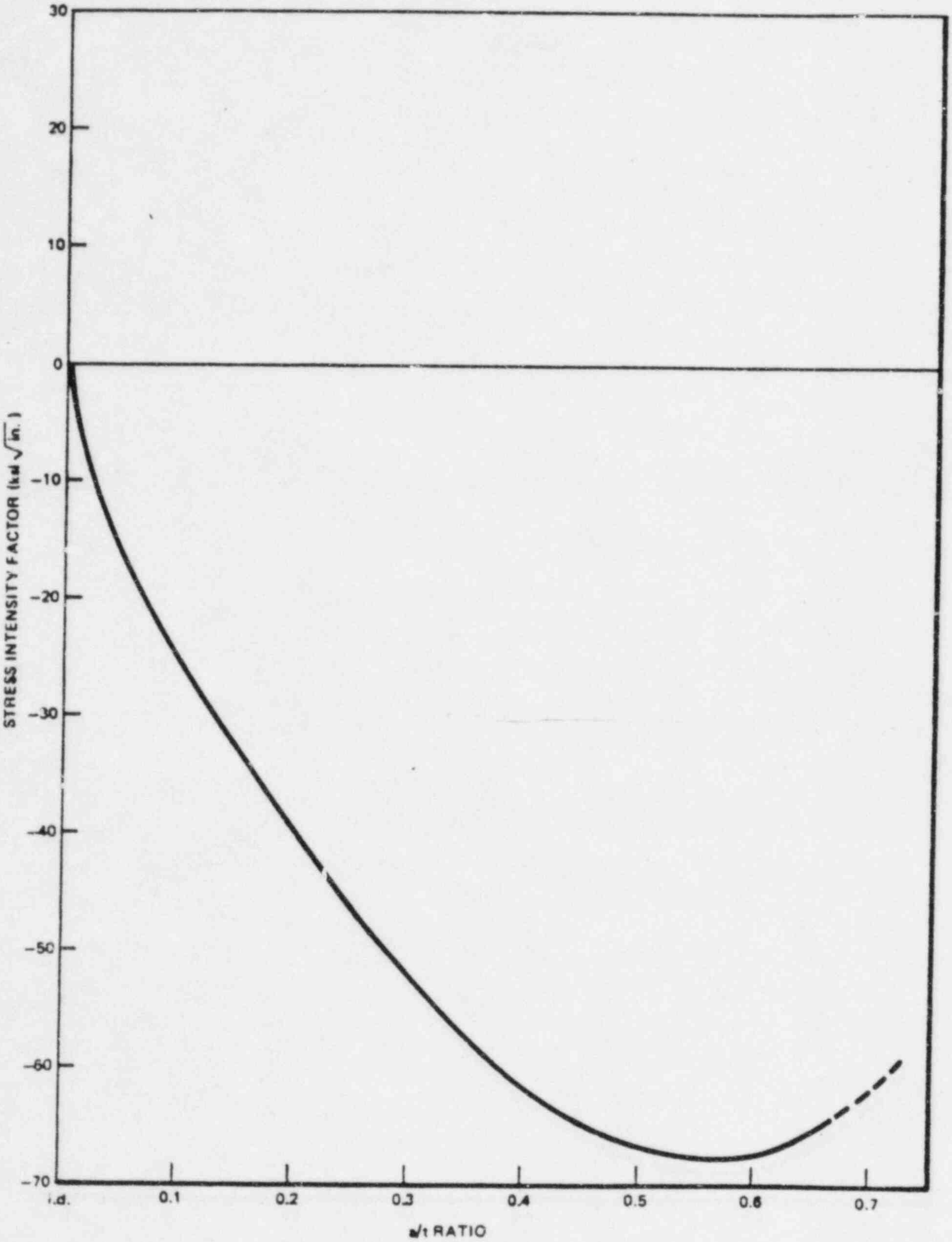

Figure 6 Stress Intensity Factor vs. Crack Depth (a/t ratio) for Pipe Subjected to IHSI (From GE Analysis of 26 Inch Diameter Pipe - Reference 2)

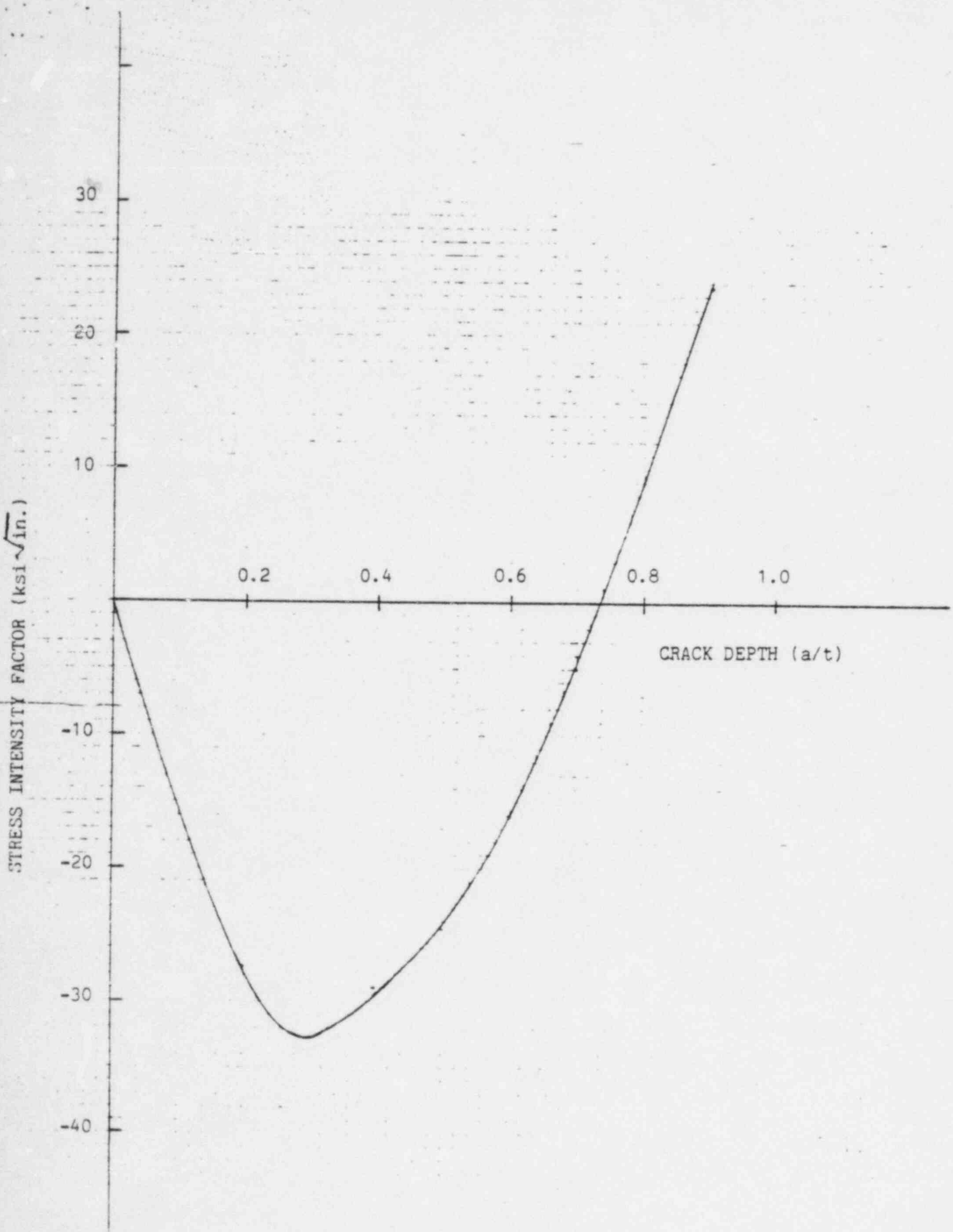

Figure 7. Crack-Tip Stress Intensity Factor Vs. Crack Depth for Fitzpatrick 22 Inch Pipe to End Cap Weld Subject to IHSI (SI Analysis)

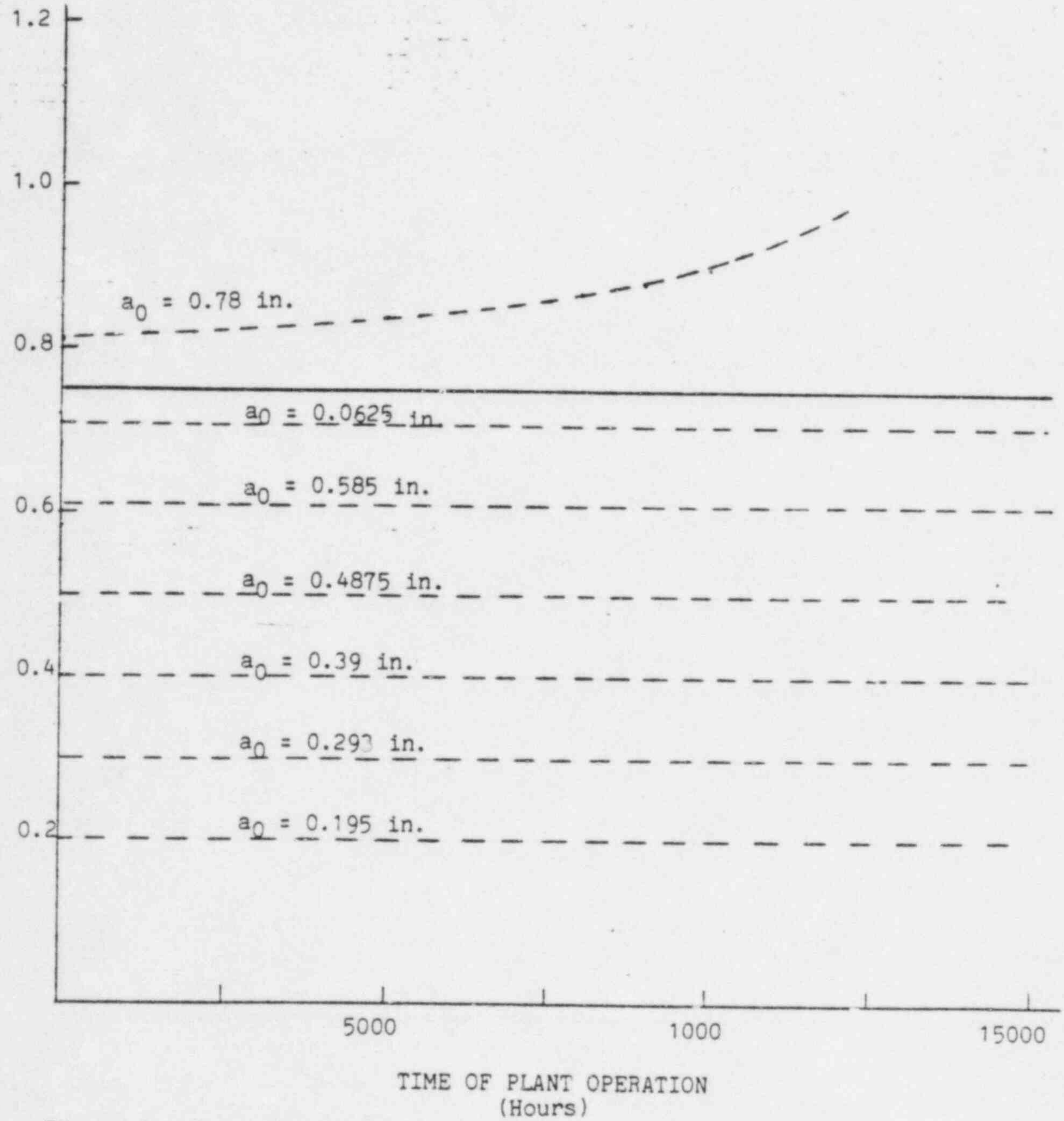

Figure 8. Predicted Crack Growth Rates With IHSI For Fitzpatrick 22 Inch Pipe-To-End Cap Weld (SI Analysis)

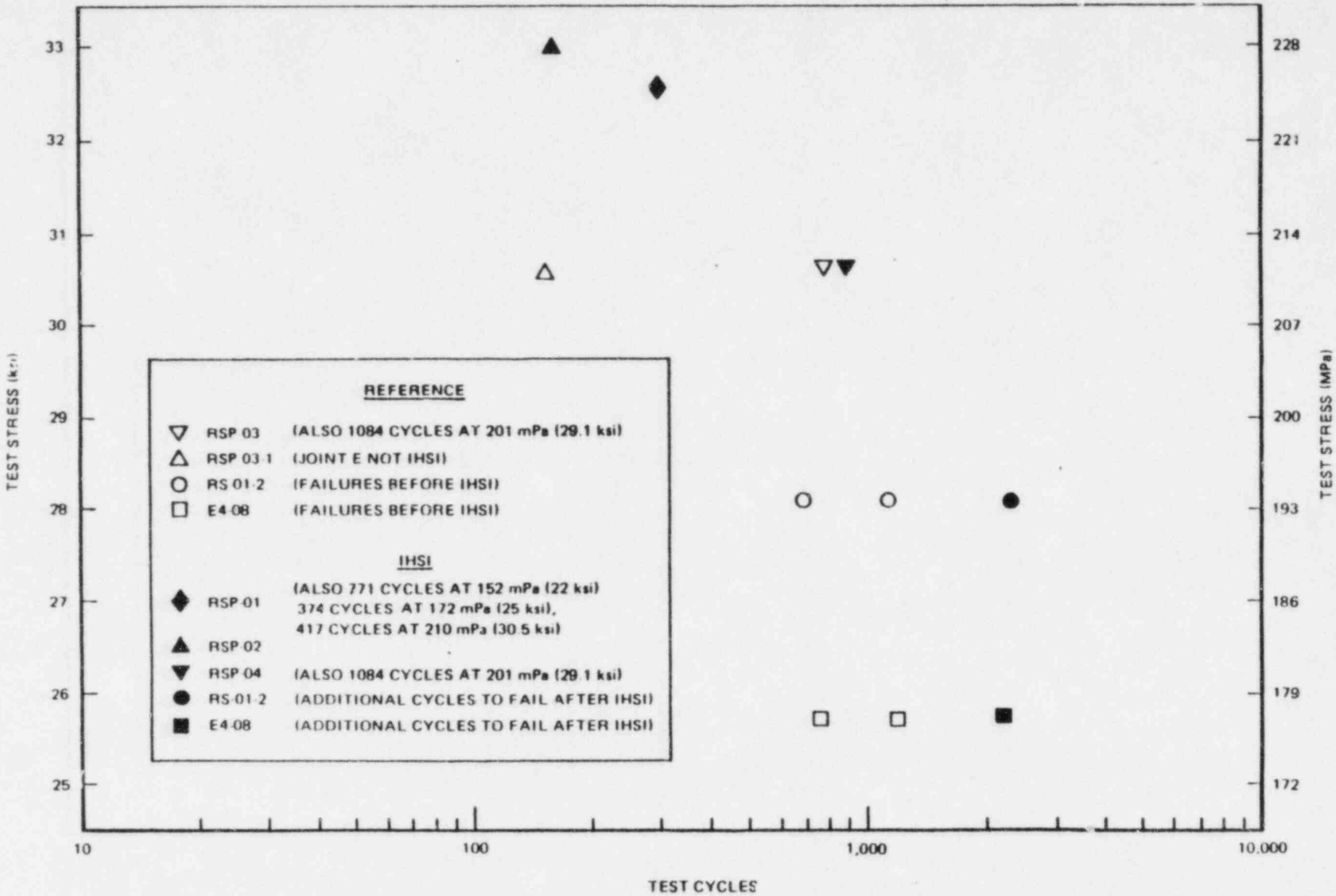

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Figure 9. Results of Precracked Pipe Testing of Four Inch Diameter Pipe Welds Before and After IHSI (From Reference 2)

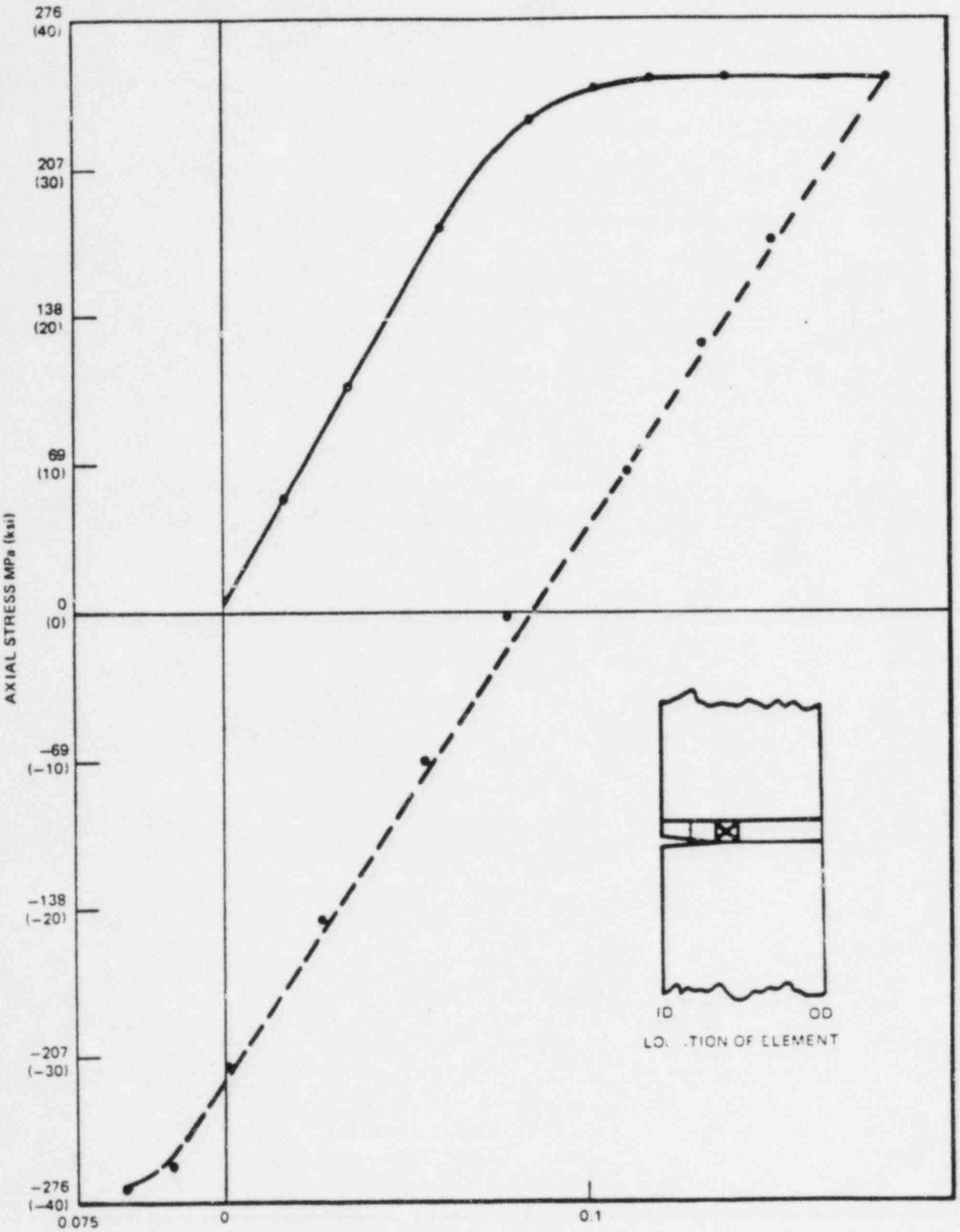

Figure 10. Axial Stress-Strain History in Vicinity of Crack-Tip During IHSI (From Finite Element Analysis of Reference 2)

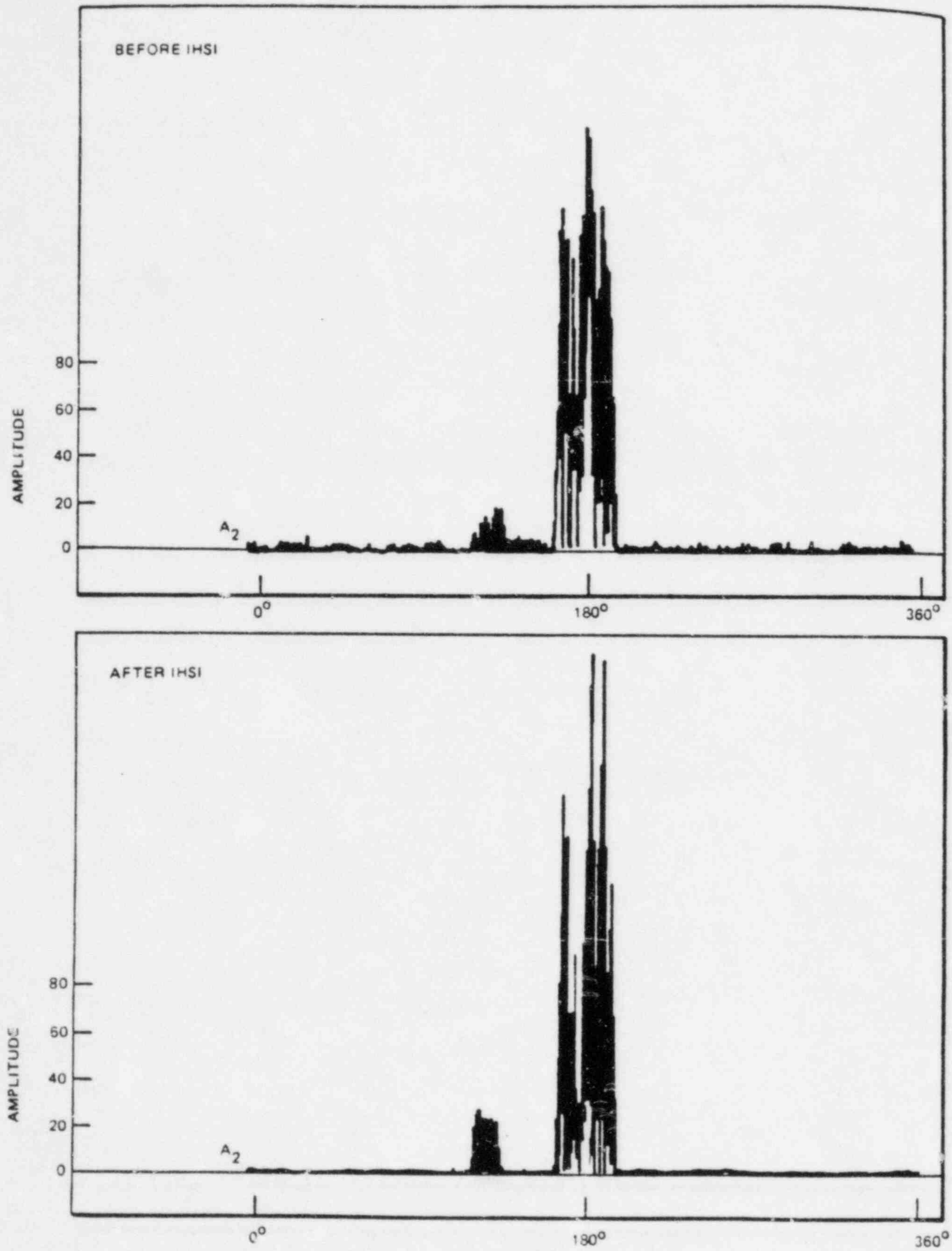

Figure 11 UT Amplitude Versus Azimuth for Specimen RS-01-2 Before and After IHSI as Recorded by Same Operator. Small changes in amplitude do not represent crack growth. (From Reference 2)