TD-MET-77-110

(Revised)

DEVELOPMENT OF IMPROVED ULTRASONIC TESTING TECHNIQUE FOR IN-SERVICE EXAMINATION OF CLADDING FLAWS IN STEAM GENERATOR CHANNEL HEADS

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SUMMARY

Experimental testing on notched test sections shows that crack depth definition for clad cracking surveillance purposes can be extended from the 3/8 inch limit to at least 3/4 inch. A 16° incident angle (37° shear in the material) technique produces an acceptable linear response from the 1/2, 5/8 and 3/4 inch deep notches in the channel head test section. A two (2) step procedure, one for the 1/8 - 3/8 inch depth range using a 20° incident angle, and another for the 1/2 - 3/4 inch range using a 16° incident angle, is proposed for the first-refueling-surveillance testing of the Indian Point #3 steam generator channel heads.

INTRODUCTION

The Materials Engineering Branch of the NRC, based on their review and evaluation[1] of the Consolidated Edison Report on Steam Generator Channel Head Cladding Surveillance has recommended revision of Section 10, "Proposed Action", of that report. The NRC recommendation was to continue development of the proposed technique to permit definition of deeper penetrations, i.e., deeper than the 3/8 inch proposed in the Con. Ed. report, of clad cracks into the base metal and, to incorporate the results of the extended development into the procedure to be used in the first-refueling-surveillance-examination of the Indian Point #3 channel heads. Definition to a total depth of at least 3/4 inch was recommended to cover the 0.250 inch maximum clad thickness found to date plus the approximate 0.4 inch critical flaw depth calculated for the cast carbon steel base metal.

An experimental testing program, based on notches in representative SA-216 WCC channel head test sections, was prepared in response to the NRC request. Guidelines for this extended test program were the same as those established for the earlier test program.[3,4] The goal of the extended program was a linear response from 1/2, 5/8 and 3/4 inch deep notches with a 1/16 inch definition or resolution capability, achieved either by (1) extending the present surveillance procedure, (2) modification of the present procedure or (3) development of a new procedure.

The test program, the results obtained, the test parameters, and the procedures needed to extend crack depth definition beyond the 3/8 inch maximum to at least 3/4 inch are described in this report.

TEST PROGRAM

ELOX notches of 1/2, 5/8 and 3/4 inch depth by 3/4 inch long were added to one of the notched (1/8, 1/4, 3/8 and 0.45 inch deep) clad channel head reference block sections used in the initial, 1/8-3/8 inch, test program. The added notches, as in the earlier program, were located in the surveillance region, See Figure 1, of the reference block. The notches were oriented parallel to the cladding beads and perpendicular to the clad surface to simulate the critical crack orientation and predicted direction of possible growth.

The notched test sample was examined using immersion techniques so that sound beam angles, transducer sizes and configurations, test frequencies, mode of propagation, etc. can be independently varied as needed to define test parameters. The sound beam in all cases was directed toward the "top" edge of the tapered channel head reference section, perpendicular to the

3/4 inch length of the notches to duplicate the scanning direction proposed for channel head surveillance purposes.

The experimental scanning of the notched test sample was conducted first using the 20° incident angle procedure[4] prescribed and successfully applied in the baseline examination of the IPP #3 channel heads. When a satisfactory linear response could not be achieved from the 1/2, 5/8, and 3/4 inch notches, the sample section was scanned using several beam angles above and below the incident 20° setting. The incident beam angles and the resulting refracted shear wave angles in the channel head material are listed in the following table.

Incident Angle (Through Water)	Refracted Angle (In Material)
*20°	48°
21°	51°
23°	58°
19°	45°
17°	39°
16°	37°
15°	34°

*The angle presently proposed for the 1/8-3/8 inch range of depths.

The results of the scanning conducted at the various incident angles are shown in the amplitude vs. notch depth plots in Figure 2. This method of presenting the test data shows in graphic fashion the response linearity attainable at each test angle and the interpolation or resolution available between the 1/8 inch notch depth increments. The amplitude values shown in the plotted results represent a general average of several (5 to 7) separate scans conducted at each incident angle setting.

DISCUSSION

The experimental scanning of the notched test sample was conducted first using the 20° incident angle procedure to determine to what extent the proposed procedure could be used in defining crack depth beyond the present 3/8 inch limit. The 20° test results confirmed the linear response from the 1/8, 1/4 and 3/8 and the 1/16 inch minimum definition or resolution capability that were developed in the original test program. The 20° incident angle also produced a linear response from the 1/2, 5/8 and 3/4 inch deep notches, however, the increase in response amplitude per 1/8 inch increment of notch depth was not considered sufficient for surveillance purposes. The 5% of screen height change per 1/8 inch increment of notch depth is less than the expected reading and instrument error of the test system; 12-15% of screen height is the smallest definable change in amplitude considered reliable for the proposed test system.

The test results show that a 16° incident angle with the same test parameters recommended for the 20° incident angle testing, will provide a linear response from the 1/2, 5/8, and 3/4 inch notches with a 1/16 inch minimum definition or resolution capability. A 16° NPT-61 flexible membrane "immersion/contact fixture" was mocked up for trial on the channel head test sections. Plotting the 1.0 MH_z, 16° incident angle, 37° shear wave, "fixture" test results from the 1/2, 5/8 and 3/4 inch notches as shown in Figure 3 shows the linear response and depth definition capability of the 16° test system. The Amplitude/Notch Depth plot for the 20° incident angle, 48° shear wave procedure is included in Figure 3 to show the crack depth definition capability of the test system over the 1/8-3/8 inch and 1/2-3/4 inch ranges of notch depth.

The inflection or non-linear response that occurs at 0.4"-0.45" in both the 20° and 16° amplitude vs. notch depth plots is a function of the 1/0 MH_z wave length which precludes 1/16" depth definition in the 3/8-1/2 inch range. A lower and less sensitive test frequency, for example, 0.5 MH_z, would shift the inflection to the critical 5/8 inch depth point.

CONCLUSIONS

1. The 1.0 MH_z, 20° incident angle - 48° shear wave technique previously proposed[3,4] produces a sufficiently linear response from the 1/8, 1/4 and 3/8 inch notches in channel head test sections for surveillance purposes.
2. The 1.0 MH_z, 16° incident angle - 37° shear wave technique described herein produces a sufficiently linear response from the 1/2, 5/8 and 3/4 inch notches in channel head test sections for surveillance purposes.
3. Notches exceeding 3/8 inch but less than 1/2 inch in depth can be indicated but the 1/16 inch definition is not available in the 3/8-1/2 inch range at the 1.0 MH_z test frequency used.
4. The 1/16 inch change in notch depth in the 1/8 - 3/8 inch range and in the 1/2 - 3/4 inch range is the minimum definable change available.

RECOMMENDATIONS

It is recommended that:

(1) A two step surveillance program be developed for the selected areas of the IPP #3 steam generator channel heads for in-service surveillance of clad cracking. Apply Step I which is the presently proposed 1.0 MH_z 20° incident angle (48° shear) technique to the selected areas for

comparison with the baseline data obtained in the pre-service examination and, for in-service surveillance through the 1/8-1/2 inch range. When change or growth approaching 3/8 inch is indicated, apply Step II, which is the 1.0 MH_z, 16° incident angle (37° shear) described in this report, to the affected areas for monitoring growth in the 1/2-3/4 inch range.

(2) The initially proposed 1/8-1/2 inch surveillance technique be modified to include the Step II 1/2-3/4 inch technique.

(3) A 1.0 MH_z, 16° +1° -0° incident angle flexible membrane immersion/contact search unit fixture be made up for use in the scanning or guidance fixture fabricated for the baseline and in-service surveillance program proposed for the IPP #3 steam generator channel heads.

(4) Flaw length be determined by the 1/8 inch depth end point indicated by the 20° incident angle, Step I technique.

BIBLIOGRAPHY

1. NRC Reference:

   Plant Name - Indian Point #3.

   Docket Number - 50-236

   Report Title - Technical Report On Steam Generator Channel Head Cladding

   Orig. Organization - Consolidated Edison Co.

2. MM-MPE-1872 "Proposed Program - Continued Development of Surveillance UT for Indian Point #3 Steam Generator Channel Heads".

3. TD-MET-75-080 "Evaluation of Cladding, Steam Generator Channel Heads, Consolidated Edison - Indian Point #3.

4. Supplement to TD-MET-75-080 "In-Service Examination Techniques For Surveillance of Cladding, Consolidated Edison IPP #3 Steam Generators".

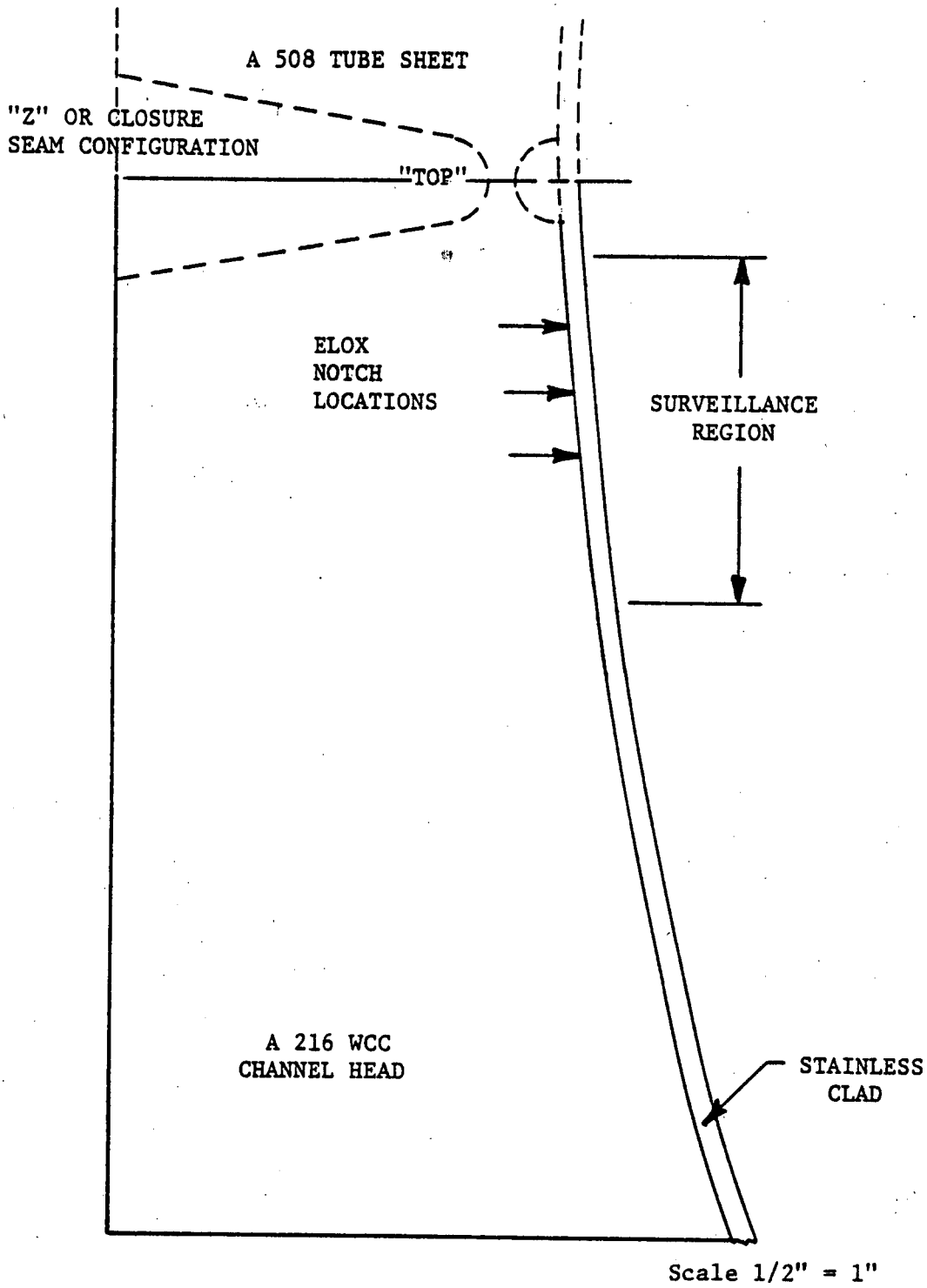


FIGURE 1. NOTCH LOCATIONS IN CHANNEL HEAD TEST SECTION

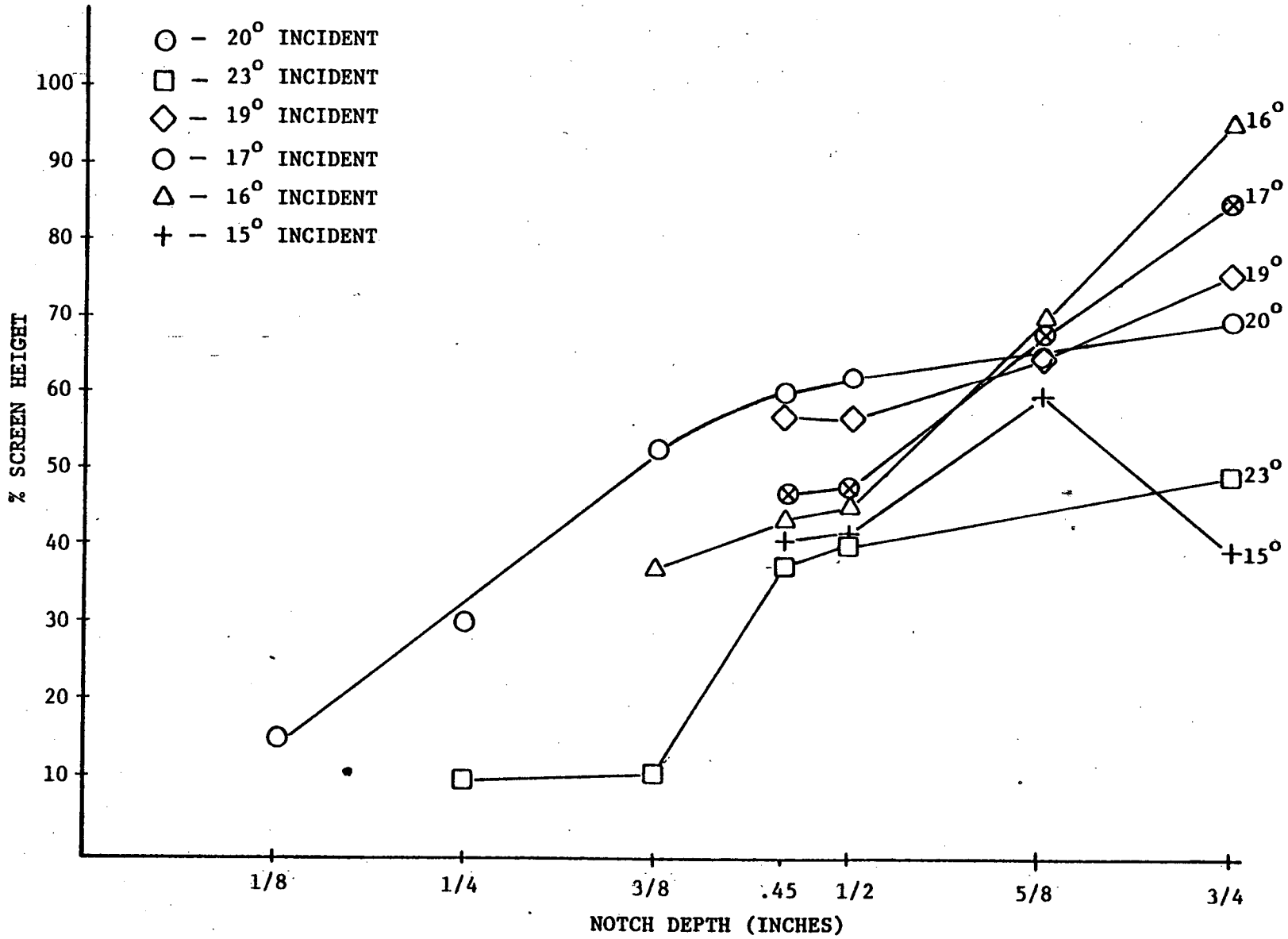


FIGURE 2. TEST RESULTS

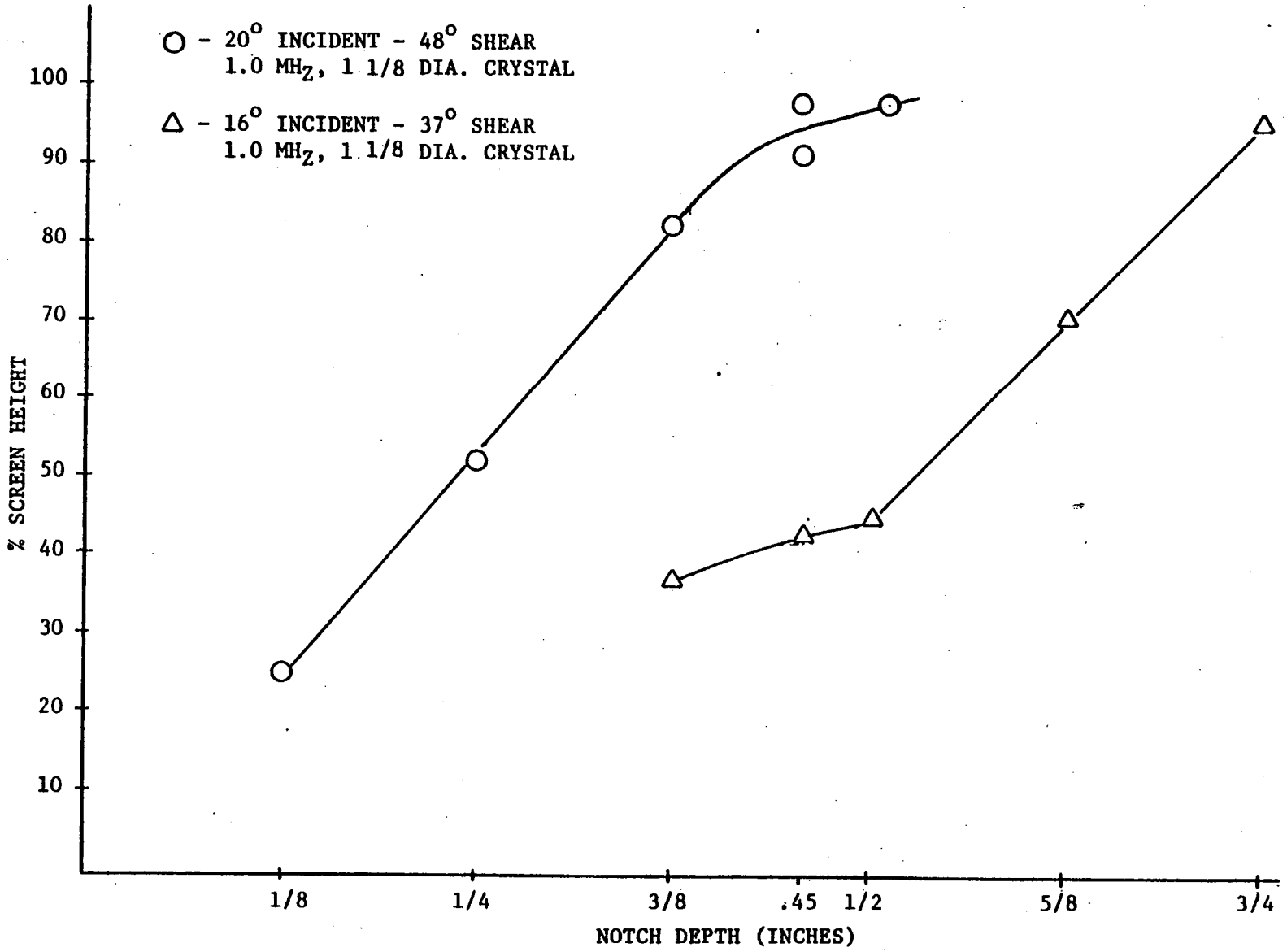


FIGURE 3. AMPLITUDE/NOTCH DEPTH PLOTS FOR 20° AND 16° INCIDENT ANGLES

ATTACHMENT III

(SECTION 6 OF WESTINGHOUSE TAMPA DIVISION REPORT TD-MET-75-080)

SECTION 6

ASME CODE COMPLIANCE AND STRUCTURAL APPRAISAL

The Boiler and Pressure Vessel Code, particularly Sections III and XI, has laterally given great attention to the discontinuities which exist in all real structures. There has been a consistent move to appraise defects such as lack of fusion, porosity, etc. in terms which are amenable to numerical evaluation and which avoid debates on semantics and definitions. Section XI of the Code is particularly advanced in this clarification and has published techniques which allow rational appraisals of defects, rather than the rules of thumb which are still common in many fabrication codes. In particular, Section XI recognizes that clad defects of the Indian Point type are common; it addresses techniques for their detection and then provides rote procedures for passing judgement upon the alternatives of repairing or not repairing the clad

Appendices I and II of this report illustrate these procedures.

Specifically:

Appendix I consists of a Flow Chart which diagrams the Code basis upon which the proposed course of action at the Indian Point Site is based.

Appendix II documents the Fracture Mechanics procedures recommended in Section XI for appraising flaw indications and lists the magnitudes of tolerable flaws.

Both Appendices illustrate compliance with the letter and spirit of Section XI and demonstrate the integrity of the proposed course of action.

APPENDIX I

COMPLIANCE FLOW CHART FOR ASME B&PV CODE, SECTION XI

ARTICLE IWB-3000
STANDARDS FOR EXAMINATION EVALUATIONS

IWB-3100 EVALUATION OF NONDESTRUCTIVE EXAMINATION RESULTS

IWB-3110 PRESERVICE EXAMINATIONS

IWB-3111 General

The preservice examinations performed to meet the requirements of IWB-2100 and conducted in accordance with the procedures of IWA-2200 shall be evaluated by comparing the examination results with the evaluation standards specified in Table IWB-3410. Acceptance of components for service shall be in accordance with IWB-3112 through IWB-3115.

IWB-3112 Acceptance

Components whose examination either confirms the absence of or reveals flaw indications that are not in excess of the standards listed in Table IWB-3410 shall be acceptable for service, provided the verified flaw indications are recorded in accordance with the requirements of IWA-6220 and I-6300 in terms of location, size, shape, orientation, and distribution within the component.

TABLE IWB-3410
EVALUATION STANDARDS

Examination Category	Component and Part Examined	Evaluation Standard
B-A	Welds in Reactor Vessel Belt-line Region	IWB-3510
B-B, B-C	Welds in Vessels, Vessel-to-Flange, Head-to-Flange	IWB-3511
B-D	Vessel Nozzles and Welds	IWB-3512
B-E-1	Welds in Vessel Penetrations	IWB-3513
B-F, B-J-1	Welds in Piping	IWB-3514
B-G-1	Bolting	IWB-3515
B-H, B-K-1	Supports—Components	IWB-3516
B-I-1, B-I-2	Interior Clad Surfaces	IWB-3517
B-L-1, B-M-1	Welds in Pumps and Valves	IWB-3518
B-L-2, B-M-2	Pump Casings and Valve Bodies	IWB-3519
B-N	Interior Surfaces and Internal Components of Reactor Vessels	IWB-3520

Revise IWB-3512.1 (d) to read:

(d) The size of allowable surface indications de ected within cladding shall be governed by the following standards:

(1) Inner surface indications not penetrati into base material are acceptable, except for noz inner corner radius indications; for any indicati at the inner corner radius, the depth "a" of dete indication shall be considered as equal to the no inal clad thickness, and compared with the stand of Table IWB-3512.1.

(2) For inner corner radius indications that penetrate into base material, the depth "a" of detected indication shall be considered equal to t sum of the nominal clad thickness and the penetration into base material.

(3) Inner surface indications at other than the inner corner radius of a nozzle, that penetrat through the cladding into the base material shall not exceed the limits of IWB-3512.1(a) except that the depth "a" of the indication shall be the total depth minus the nominal clad thickness.

Add IWB-3512.1(e):

(e) Subsurface indications in the base material o nozzle that are characterized as surface indicatio within the surface proximity limits specified in IWB-3310(b) shall not exceed the standards of IWB-3512.1(a) for subsurface indications.

TABLE IWB-3512.1
ALLOWABLE PLANAR INDICATIONS[1]

Material: SA-508 Class 2 and 3 Forgings that meet the requirements of NB-2331 and have specified minimum yield strengths of 50 ksi or less

Thickness Range, t: 3 in. and greater

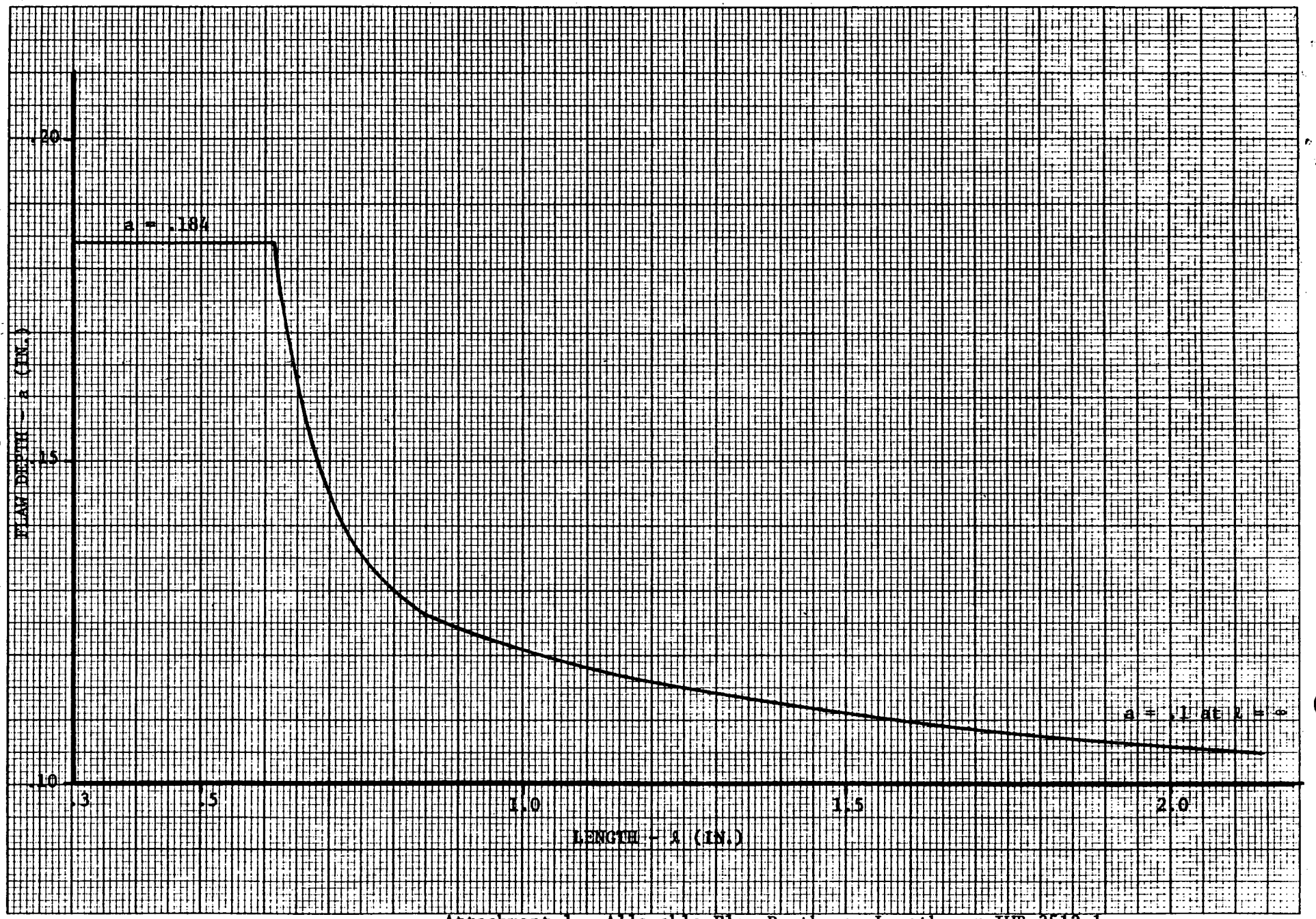
Aspect Ratio, a/ℓ[3]	Surface Indications, a/t,%[2]	Subsurface Indications, a/t,%[2,4]
0.	1.9	2.3
0.05	2.0	2.4
0.10	2.2	2.6
0.15	2.4	2.9
0.20	2.7	3.3
0.25	3.1	3.7
0.30	3.5	4.1
0.35	3.5	4.6
0.40	3.5	5.2
0.45	3.5	5.9
0.50	3.5	6.5
Inside Corner Radius	2.5	[redacted]

APPENDIX II

Per proposed revisions to Section XI, Para. IWB-3512.1(d)*, cladding indications that penetrate into base metal and stay within the limits of IWB-3512.1(a) are acceptable for preservice examinations. Although this subparagraph specifically relates to nozzles in pressure vessels, application of this same criterion to the existing areas of clad cracking is logical and technically sound. It must be noted also that in no instances were cracks found to penetrate into base material. Attached herein is a plot of the allowable crack depth and length variations for base metal flaws. It can be seen that .1 inch is the acceptable depth for an infinitely long crack. Assurance that no flaws ≥ .1 in. exist in the base metal will satisfy the proposed revisions of Section XI.

For inservice examinations, flaws with dimensions which fall above the attached curve must be evaluated by analysis as described in Section XI, Para. IWB-3600, to confirm structural adequacy of the component for continued service. Until that time when component loading histories and detected flaw geometries are available, any analytical effort per Para. IWB-3600 would be meaningless.

*Copy of proposed changes is included in flow chart of Appendix I.



Attachment 1 - Allowable Flaw Depth vs. Length per IWB-3512.1

ATTACHMENT IV

(WESTINGHOUSE TAMPA DIVISION REPORT WTD-SM-75-052)

REPORT PREVIOUSLY TRANSMITTED TO THE NRC BY THE
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WTD-SM-75-052

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FRACTURE MECHANICS EVALUATION OF CONSOLIDATED EDISON INDIAN POINT #3 STEAM GENERATOR CHANNEL HEADS

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