GPU Nuclear

TECHNICAL DATA REPORT

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BUDGET ACTIVITY NO. 123125	**PAGE** 1 **OF** 18
PROJECT: TMI-1 OTSG REPAIRS	**DEPARTMENT/SECTION** E&D/Mech. Comp.
	RELEASE DATE ______ **REVISION DATE** ______

DOCUMENT TITLE: Adequacy of TMI-1 OTSG Return to Service Safety Assessment After 1984 Technical Specification ECT Examination

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ABSTRACT:

Statement of the Problem

The safety assessment of the return to service of the TMI-1 OTSG's was made in 1983 (TR-008) and encompassed the examination, evaluation and repair of defects known up to that time and the prevention of reoccurrence. The 1984 technical specification eddy current examination reported further indications in both OTSG's.

Summary

The examinations done in 1984 have identified enhanced visibility of pre-existing indications on the threshold of detectability as the most probable and reasonable explanation for the new indications.

It was concluded that the corrosive failure mechanism identified in 1983 is still the correct description of what the OTSG's have undergone. The precautions taken to prevent reoccurrence have been adequately observed and are effective; no new material attack has occurred.

Conclusion

The safety assessment as originally performed in TR-008 remains valid and the 1984 inspection results neither call into question, nor invalidate, nor require a revision to the assessment.

1.0 INTRODUCTION

The safety assessment of the results of the TMI-1 OTSG repairs was originally done in Reference (1) and encompassed the examination, evaluation, and repair of the defects known up to the reports' release date and the subsequent testing and examination of those repairs. Recent examination in support of TMI-1 Technical Specification requirements in 1984 has uncovered additional indications. These indications may be generally characterized as follows (Ref. 3, page 23-24):

1. They are predominantly located within the outer periphery of both OTSG's. Some indications appear entirely across OTSG-1A; none of greater than 40% through wall penetration appear in the core region of OTSG-1B.

2. They are mostly (approximately 50%) in the upper tubesheet and (approximately 20%) in the 16th tube span area.

3. They predominantly exhibit voltages below 2 volts.

4. They are, in the majority, of less than 50% through-wall penetration.

5. They exhibit circumferential extent by 8 x 1 absolute ECT of predominantly 2 coils or less (90% of all indications).

This report reviews the 1983 evaluation for accuracy in light of the 1984 examination results. Discussion will center on the information contained in References 2 & 3 as it pertains to the logic and conclusions of Reference 1.

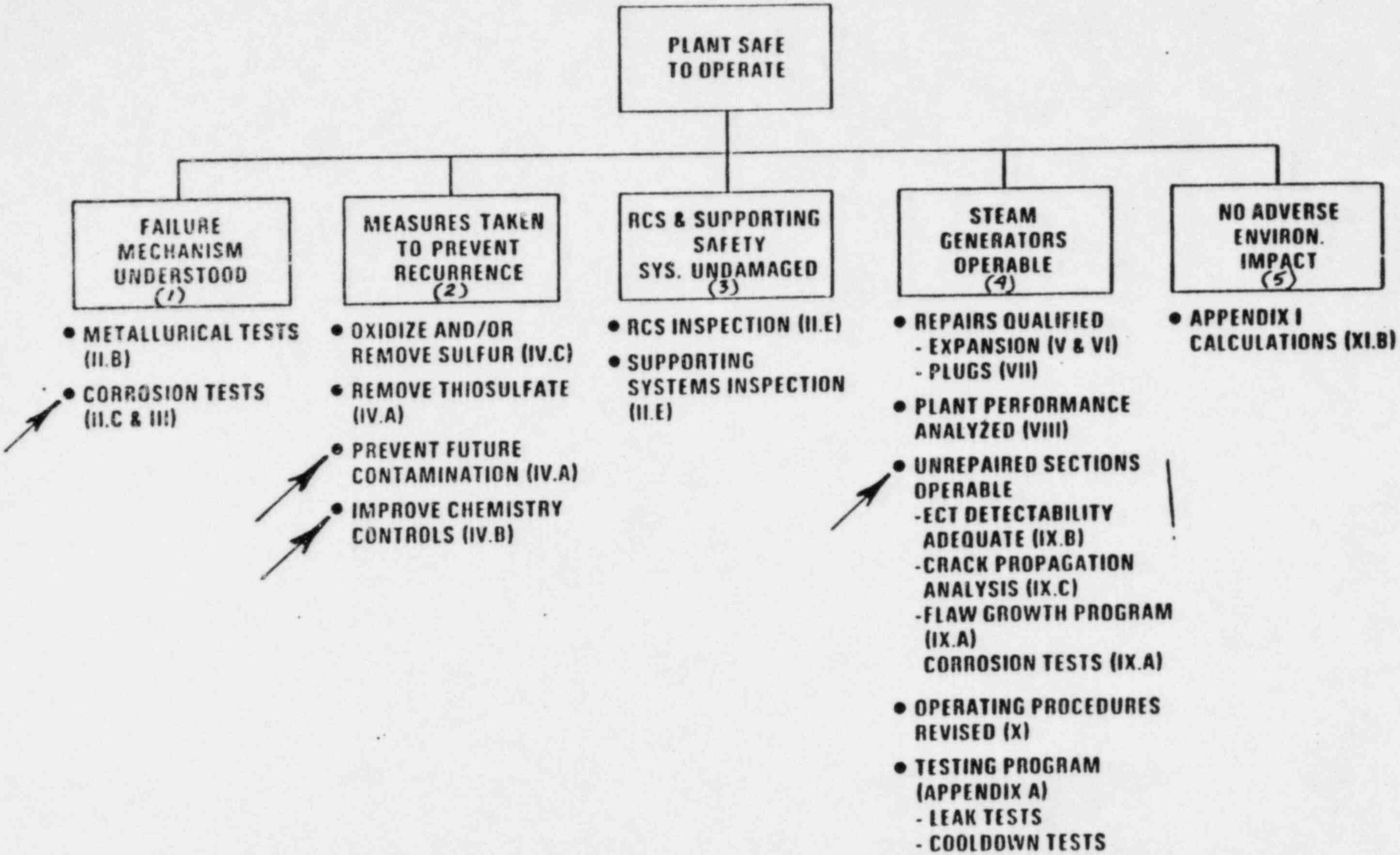
2.0 METHOD

The logic of the safety evaluation done in TR-008 is set forth in Section ID and describes the points to be demonstrated and assured by the repair program to allow OTSG return to service. This logic is graphically captured in Figure 1-7 (attached) and stated in ID (1) through (5) as follows (Ref. 1, Section ID, page 3):

"1. The failure mechanism is understood well enough to define the root cause of the steam generator damage;
2. Other components in the RCS and supporting safety systems were not visibly damaged by the failure mechanism;
3. The plant can be operated such that this failure mechanism is arrested and will not recur;
4. The Steam Generators can be repaired and operated within the design basis;

5. The plant can be operated with some tube leakage without adversely impacting the environment."

PLANT RETURN TO SERVICE SAFETY EVALUATION OVERVIEW



( ) - CORESPONDING PARAGRAPH NUMBERS ADDED

↗ - EMPHASIS ADDED

FIGURE I-7

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PAGE 3 OF 18
(from TR-008 REV 3)

The issues raised by the results of the 1984 inspection principally impact points (1), (2) and (4), specifically:

(1) Have the inspection results indicated the presence of a failure mechanism different than that set forth in TR-008?

(2) Have the steps taken under the assurance of preventing reoccurrence been followed accurately and proven effective?

(4) Has the confidence in ECT detectability been compromised by the discovery of new indications in the period Sept. 1982 to Jan. 1984 and has the lack of flaw growth and non-reoccurrence predicted by TR-008 been supplanted by the latest observations?

Each of these issues will be addressed in turn and the evidence to support or refute the positions set forth in TR-008 examined.

3.0 RESULTS

3.1 Issue (1): Failure Mechanism Identification

The discussion of failure mechanism is contained in Section II B and C and III in TR-008 (Ref. 1, Section IIB, 2g, page 11). Succinctly put, the OTSG tubing was found to have undergone intergranular stress-assisted cracking (IGSAC) producing predominantly circumferential cracking under the influences of a reduced sulphur species and axial stresses. In conjunction with cracking, intergranular attack (IGA) was observed. The cracking appeared to initiate and propagate in the presence of the thiosulphate agent, oxygen, and ambient temperatures.

Since the writing of TR-008, the results of the Long Term Corrosion Test (LTCT) have become available. The test followed conditions comparable to plant operation and confirmed that "in the absence of the intentionally added aggressive sulphur species, normal operations would not cause corrosion of TMI-1 OTSG tubing" (Ref. 2, Pg 12). Some IGA was noted in the LTCT samples that was not detectable by ECT (Ref. 2, page 12) most reasonably due to its superficial wall penetrations. Additionally, the ECT indications seen in 1982 were characterized as to voltage, percentage through-wall penetration, circumferential extent and spatial distribution. The comparison of recent ECT results with those of the 1982 examinations is accomplished in detail in Reference 3 (Section IVC, page 15). Here note was made that the amplitude and distribution of the total population of indications below the kinetic expansion zone appeared similar in 1982 and 1984, and both the through-wall penetration and the circumferential extent seen in 1984 were lower than those seen in 1982. For the smaller population of indications that are reported in 1984 but only seen on re-review of 1982 tapes, the amplitudes have generally increased while the through-wall penetration has not. This is indicative of newly reported but previously existing indications formerly below the threshold of reportability.

Hot Functional Testing (HFT) provided mechanical loading necessary to cause enhanced detectability, in degrees which varied according to the severity of loading. All tubes at each elevation saw flow loads both inside and out. Lateral loads due to buffeting and cross-flow were present at varying elevations, and heat-up and cool-down axial loads in excess of those generated by normal operations were experienced by all OTSG tubes. The axial load varies from a maximum on peripheral tubes to a minimum on core tubes; both the ISGAC defects found previously and the 1984 indications reflected this radial bias. The kinetic expansion (KE) process produced loads significant enough to enhance detectability as well. Additionally, larger IGA areas would be more susceptible to enhancement after mechanical loading, and smaller areas are structurally insignificant. Fourteen (14) tubes with no previous history of indications were identified in this 1984 ECT examination (Post - HFT) as having indications of over 40% through-wall penetration. A review of the 1983 ECT (Post - KE) tapes identified all 14 indications as marginally detectable but of low amplitude. One of the 14 indications could be seen in the review of the 1982 examination, which preceded both hot functional testing and kinetic expansion. The amplitude increase in these indications is demonstration of increased detectability with "...no trend of through-wall growth associated with this amplitude increase." (Ref. 3, page 46).

These observations and appreciations support the plausibility of enhanced visibility of pre-existing indications on the threshold of detectability as the most probable and reasonable explanation for the new indications. The failure mechanism identified in 1983 is still the correct description of what the OTSG's have undergone.

3.2 Issue (2): Prevention of Re-occurence

The steps to be taken to prevent the reoccurrence of the 1981 IGSAC incident were outlined in Reference 1, Section IV. These involved four areas: physical removal of the source of contamination, chemical removal of the existing contaminant, introduction of strict administrative controls on the use of other potential contaminants, and the revision of allowable RCS chemistry limits. The first two steps had been accomplished and were discussed in Reference 1.

The administration of the last two of these steps was reviewed for the period of time between 1982 and 1984. It was stated that a 95% adherence to the imposed limits was achieved; excursions were for brief periods and the environment remained protective (Ref. 2, pg. 16). It was therefore concluded that the adherence to the measures taken was adequate to prevent re-initiation of primary side corrosion.

The consideration of the ECT techniques used in 1982 to detect defects in the OTSG tubes is discussed in Reference 1, Section IX, as is the argument against recurring defects. Taking the last point first, the arguments against re-initiation are threefold:

"a) Cracking will not occur unless an active reduced species of sulfur is present and cracks in SG tubing will not propagate in the present chemical environment.
b) Sulfur induced cracking requires an oxidizing potential which does not exist under normal hot operating conditions.
c) Lithium hydroxide is an effective inhibitor of the cracking mechanism."

The results of both the short term corrosion tests (Reference 1, Section IIID) related in TR-008 and the Long Term Corrosion Tests (Ref. 2, pg. 11) bear out the accuracy of the original assessment.

Additional assurance of non-reoccurrence is obtained from the absence of flaw growth (Ref. 1, III) or the development of significant leaks since the 1982 inspections. The cracking mechanism is rapid, propagating up to 1 millimeter through-wall per day, and if the mechanism were still active the period of time past would have allowed the development of many severely leaking tubes. The bubble test of both OTSG's in Oct. 1984 showed 8 tubes in the lane area exhibiting minor leakage above the bottom of the kinetic expansion; the leakage was stopped by rolling the tubes. The leakage was via the kinetic expansion joint and in no way indicative of flaw growth in the tubes and as such had no safety impact. The most recent bubble test (3/11/85) showed no bubbling at all.

3.3 Issue (4) - Eddy Current Testing Limits of Detectability as It Impacts OTSG Operability

This leaves the question of why ECT found defects in 1984 that were not seen in 1982. Three possible classes of undetected defects were outlined in Reference 1 (IXC page 81):

"1) Local intergranular attack (IGA)

2) Below the detection limits of ECT

3) Detectable by ECT but missed through random error"

These causes were deemed to present no significant hazard because local shallow surface IGA results from the manufacturing process and is only 1-2 grains deep. Its long term behavior would be assessed by the Long Term Corrosion Testing. Additionally, small cracks below eddy current detectability will not propagate by chemical means in the absence of active corrodants and are far smaller than the crack size above which mechanical loading will cause propagation (Ref. 1 Section IXC page 82).

Taking the last point first, protection against randomly occurring failure to correctly read test results has been provided by Quality Assurance overview and the use of permanent magnetic tape records, allowing call-up and review of inspection results at any date. Additional protection is afforded by the GPUN practice of having a second data analyst separately review all tape records for missed or incorrectly analysed indications.

Subsequent to the release of TR-008 the observations obtained from the outcome of the Long Term Corrosion Tests and failure analysis are now seen to support the presence of local IGA which may not be visible to the standard .540 differential probe but have the potential to be exercised into visibility by mechanical loadings (Ref. 2, pg. 22). This presence is further suggested by the distribution of new indications (in tubes of higher mechanical loading) and the results of fiberscope observations in OTSG tubes in which rounded dark areas consistent with IGA in appearance were seen at locations where ECT reported indications (See Figures 3a and 3b).

The new indications can in fact be IGA that interacts with the ECT probe in a manner similar to IGSAC. This reflects the different geometries of IGA and IGSAC and the qualification method for ECT which employs constant width EDM slots more characteristic of IGSAC than IGA in as much as IGSAC implies significant depth of wall penetration for a given volume while IGA does not.

Consider the difference between IGSAC and IGA: Inter-Granular Stress-Assisted Cracking is characterized by sharp-edged, tight cracks running between metal grains and not visible optically prior to straining. It can be propagated under mechanical loading; the rate and threshold of this propagation has been determined in detail for the OTSG tubes and this knowledge was used to formulate the plugging and stabilizing criteria employed to determine which tubes must be removed from service, and how they shall be removed. Since circumferentially-oriented IGSAC posed the chief threat to the OTSG tubes, the examination methods were appropriately tailored to finding and measuring it accurately. Hence, ECT calibrations were done on electro-discharge machined slots in which the principal contributions to defect volumes were through-wall penetration and circumferential extent, not crack width.

Inter-Granular Attack, however, is characterized as roughly hemispherical pits penetrating as much as 50% of the tube wall, as seen in both the failure analysis (Ref. 8, Section IV, page 4, Fig. 17) and the Long Term Corrosion Test; the circumferential extent of an IGA pit of this size would be approximately .035". Two methods by which these pits of metal grains could become visible under mechanical loading were identified in Reference 2 (page 22) as:

"(1) Creation of a uneven grain boundary separation within the IGA islands as was seen in the LTCT...., or

(2) Disconnected grains dropping out and leaving pits."

It is important to note that this addresses the enhancement of visibility, and not propagation; the pit depth (to sound metal) remains the same. It has been demonstrated that IGA pits up to 83% through-wall do not significantly reduce tube burst strength (Ref. 4). Cracks originating in patches ("islands") of IGA would show no distinct orientation preference in the absence of loading and would not grow because the metal surrounding this IGA pit maintains its original ductility and would blunt the crack tip. Additionally, in the absence of an aggressive corrodant the pit will not grow chemically. Therefore tube damage done by IGA is already accomplished and is static; i remains only to evaluate the extent of that damage.

Nonetheless, for conservatism all 1984 indications have been dispositioned as if they were defects capable of active mechanical propagation in service (cracks). When this was done it could be seen that none of the defects individually challenged the Main Steam Line Break criteria for peripheral tubes. This is depicted on Figure 1 (a thru c), where the effects of through-wall penetration uncertainty and absolute ECT probe coil overlaps are used to show each defect as a probability area rather than a point. The indications plotted in Figure 1 (a thru c) include all the worst combinations of through-wall penetration and circumferential extent for single defects (See Table 1). These tubes have all been removed from service in 1985. Three tubes exhibited defects of large circumferential extent but lesser penetration: 3 coil signals coupled with 20-50% through-wall penetration, with one showing 76% through-wall but located within the upper tubesheet. These extreme cases are also plotted and they nonetheless did not approach the MSLB line for peripheral tubes. It should be noted that, minority extremes aside, the great majority of all 1984 ECT indications fall below or in the immediate vicinity of the limits of ECT detectability (See Figure 2).

It can be seen from Figure 1a-c that the maximum possible size characterization of several indications both extend above the ECT detectability curve and include areas above curve A. Areas above curve A represent crack sizes which will propagate through-wall in service. Nonetheless, assuming the worst confluence of events (1- the indication is truly at the maximum extent of its characterization range, and 2- the defect is a crack and not an IGA pit) there is still no unanticipated hazard. Degradation in this range will be by through-wall penetration before tube rupture (Leak Before Break) and OTSG leak detection systems and procedures will enable operators to deal with the leaking tubes safely.

Many of these defects were nonetheless used as justification for removal of a tube from service. This arose from considering these pits as behaving like cracks and therefore capable of propagative interaction. Additionally, circumferential extent was characterized solely by the maximum number of ECT probe coils signalling; no credit was taken for the overlap of coils (See Figure 1a thru c) whereby a defect only slightly larger than one-half of one-coil sensitivity would register as a two-coil defect. These are inherent conservatisms which should not be used to mask the actual appreciation of the comparatively benign nature of these defects.

4.0 CONCLUSION

To recapitulate, TR-008 postulated a failure mechanism, a plan to prevent reoccurrence, and an assurance of the detectability of potential flaws before they propagate to tube failure. The results of the 1984 inspections (Ref. 2 and 3) indicate no alternative failure mechanism, general adherence to preventative guidelines, and reassurance of flaw detectability. There is nothing in the 1984 inspection results which invalidates, calls into question, or necessitates a revision to TR-008.

5.0 REFERENCES

1) GPUN TR-008 Rev. 3, "Assessment of TMI-1 Plant Safety in Return to Service After Steam Generator Repair", T.M. Moran, 9/3/83.

2) GPUN TDR 638, "Evaluation of Eddy Current Indications Detected During TDR 1984 Tech. Spec. Inspection", J. A. Janiszewski, 1/11/85.

3) GPUN TDR 652, "Evaluation of the 1984 Tech. Spec. Inspection for TMI-1 OTSG" - G. Rhedrick.

4) NUREG 1063 - "Steam Generator Operating Experience Update, 1982 - 1983".

5) GPUN TDR 388, "Mechanical Integrity Analysis of TMI-1 OTSG Unplugged Tubes", S. D. Leshnoff, 5/11/83.

6) GPUN TDR 401, 'Task IV Report on Eddy Current Indications Found Subsequent to Kinetic Expansion of TMI-1 Steam Generator Tubes", G. Rhedrick, 4/8/83.

7) GPUN TDR 423 Rev. 1, "TMI Unit 1 OTSG Tubing Eddy Current Program Qualification", R. Barley, 3/15/84

8) A. K. Agrawal, W. N. Stiegelmeyer, and W. E. Berry, "Final Report on Failure Analysis of Inconel 600 Tubes from OTSG A and B of Three Mile Island Unit 1", Battalle Columbus Laboratories, June 30, 1982

9) GPUN TDR 642, "Qualification of Conversion Curve For Inner Diameter Discontinuties", M. T. Torborg, 1/24/85.

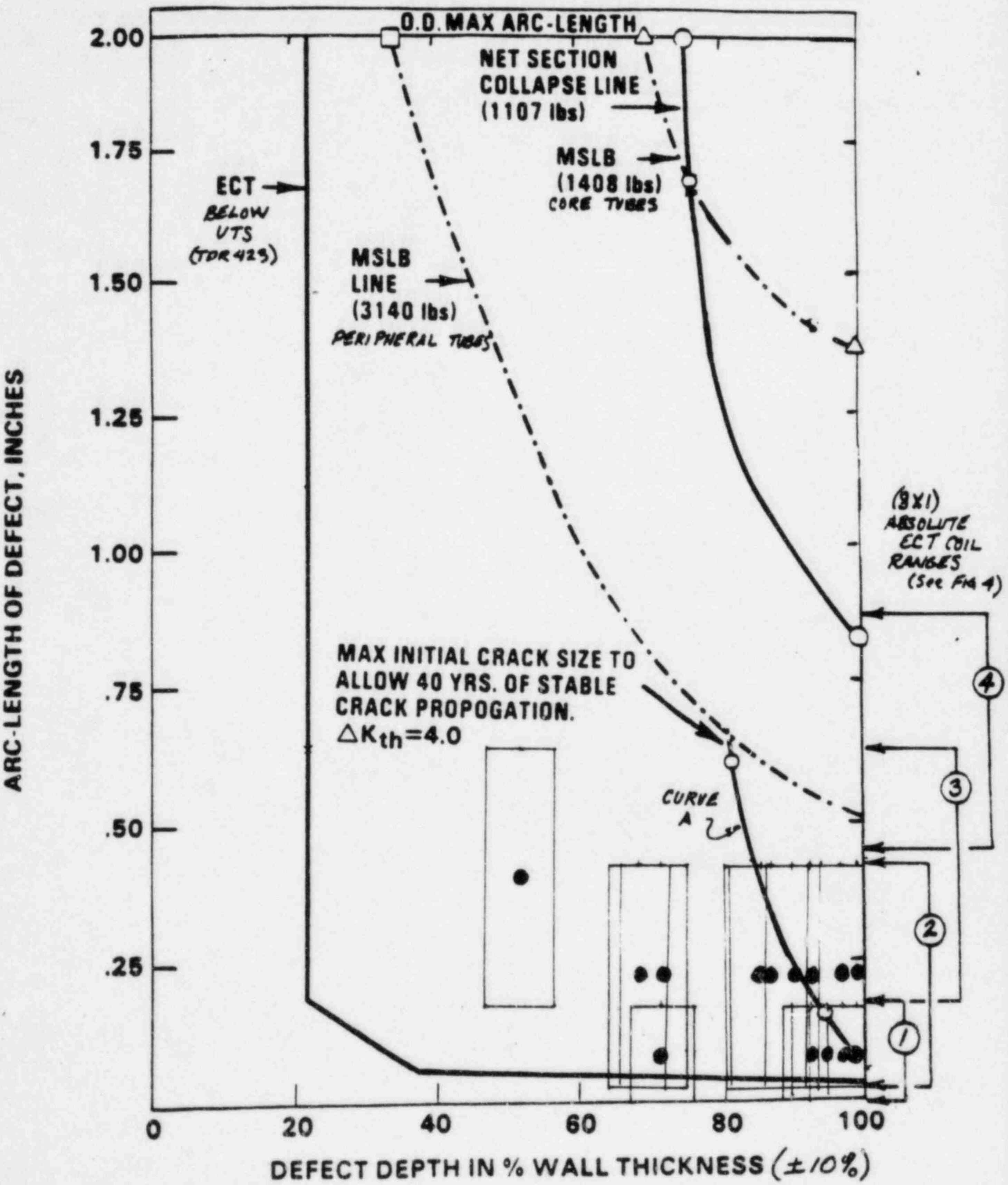
TABLE 1

Major 1984 ECT Indications

OTSG	ROW/TUBE	ELEVATION	% THRU-WALL (540SD)	COIL-CALL(S) (8X1 ABS)
A	2-13	15 + 17	97	2
A	9-1	9 + 11	97	2
A	12-4	15 + 11	87	2
A	13-2	06 - 9	90	2
A	15-3	US + 0	97	1
A	16-3	15 + 6	97	1
A	57-1	03 - 13	99	1
A	57-128	15 + 43	95	1
A	63-127	US + 2	90	2
A	92-5	US + 5	99	2
A	111-113	15 - 13	93	1
A	112-117	10 + 14	99	2
A	115-110	US - 4	90	2
A	115-114	11 + 2	93	2
A	117-2	13 + 04	99	1
A	120-106	15 + 0	97	2
A	127-97	14 + 07	97	1
A	133-2	15 + 31	93	1
A	134-72	15 + 13	99	1
A	135-1	US - 14	97	1
A	138-64	US - 03	92	2
A	139-65	US - 03	86	2
A	139-73	US + 01	97	2
A	142-1	07 - 11	93	2
A	142-50	US - 08	97	2
A	143-31	US - 03	97	1
A	147-4	15 + 27	98	2
A	147-45	US + 01	99	2
A	149-14	15 - 17	99	1
A	151-8	15 + 00	86	2
A	9-4	15 + 26	72	1
A	63-127	US - 1	76	2
A	64-126	US + 6	86	2
A	78-126	US - 4	69	2
A	96-125	US + 1	72	2
A	115-110	US + 3	90	2
B	65-1	15 + 32	72	2
B	88-5	US + 1.1	66	2
B	97-5	US + 0	76	3
A	147-4	15 + 22	98	2

FIGURE 1a

MAJOR INDICATIONS BELOW THE UTS LOWER FACE (±1")



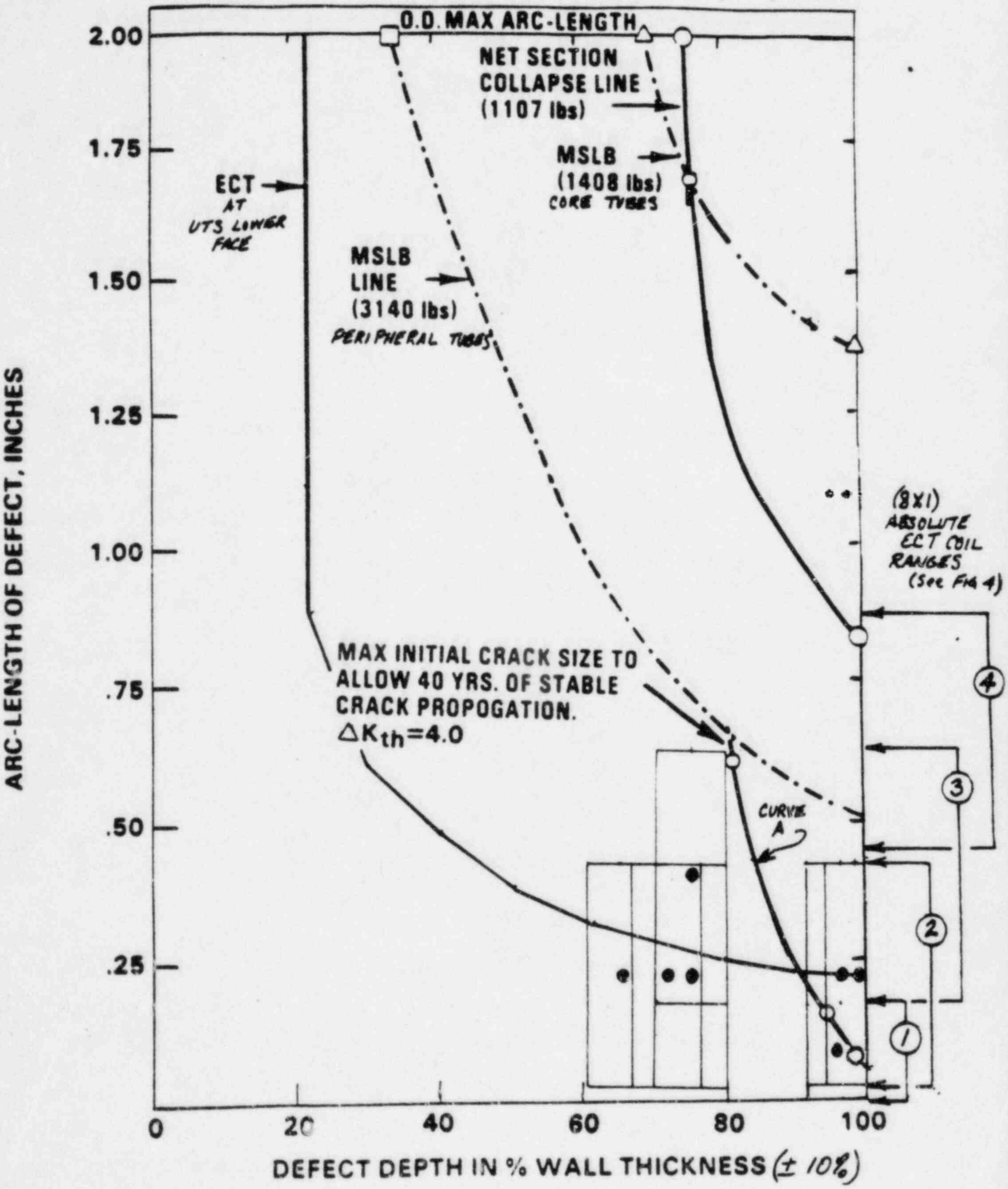
▯ - PROBABILITY AREA OF INDICATION (REF 9, APP D, PG D22)

● - MOST PROBABLE INDICATION CHARACTERIZATION

(from TDR 38 REV 1.)

FIGURE 1b

MAJOR INDICATIONS AT THE UTS LOWER FACE (±1")



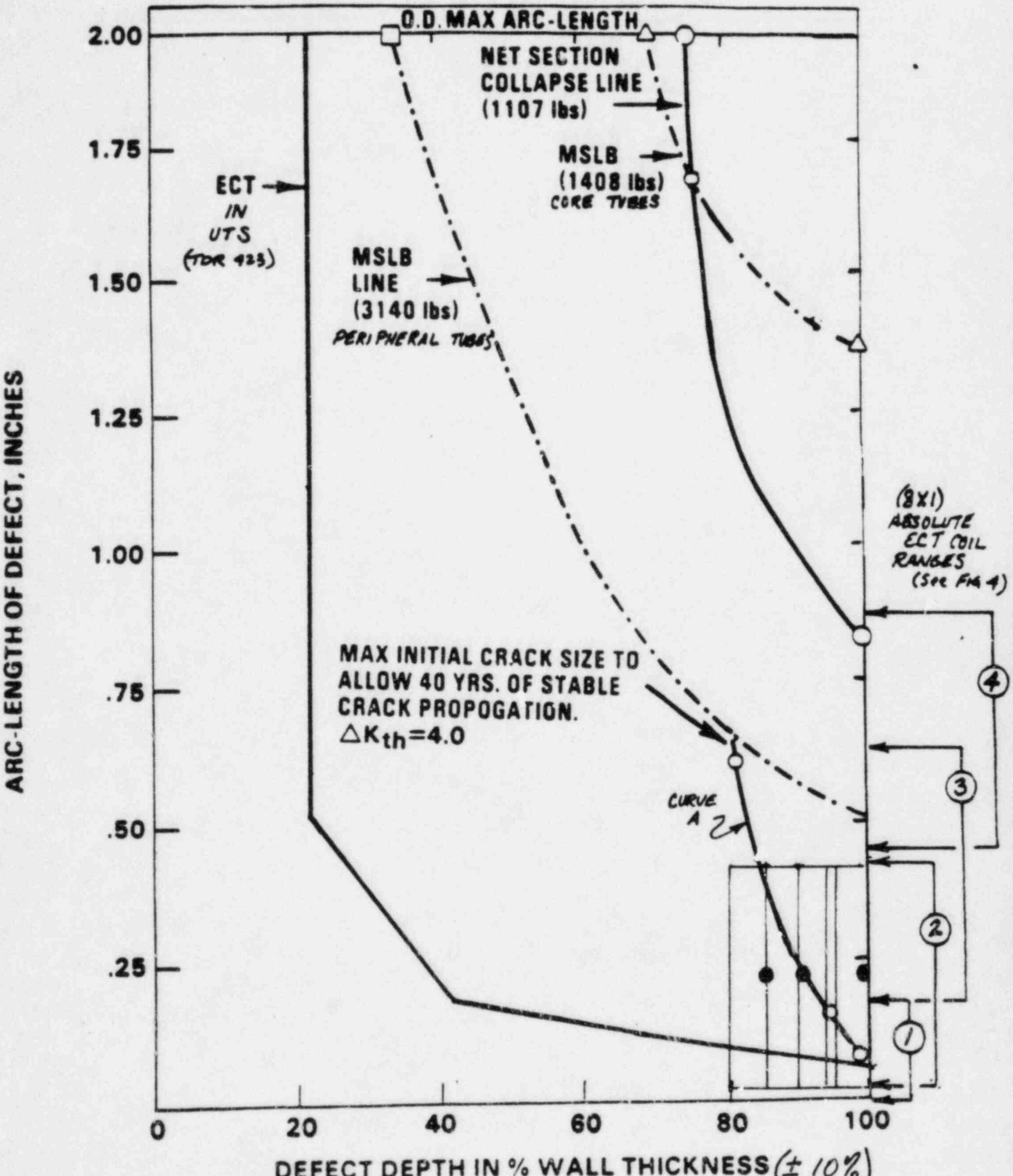
□ - PROBABILITY AREA OF INDICATION (REF 9, APP D, Pg D22)

● - MOST PROBABLE INDICATION CHARACTERIZATION

(from TDR ? REV:

FIGURE 1c

MAJOR INDICATIONS INSIDE THE UTS (± 1")



☐ - PROBABILITY AREA OF INDICATION (REF 9, APP. D, PG. D22)

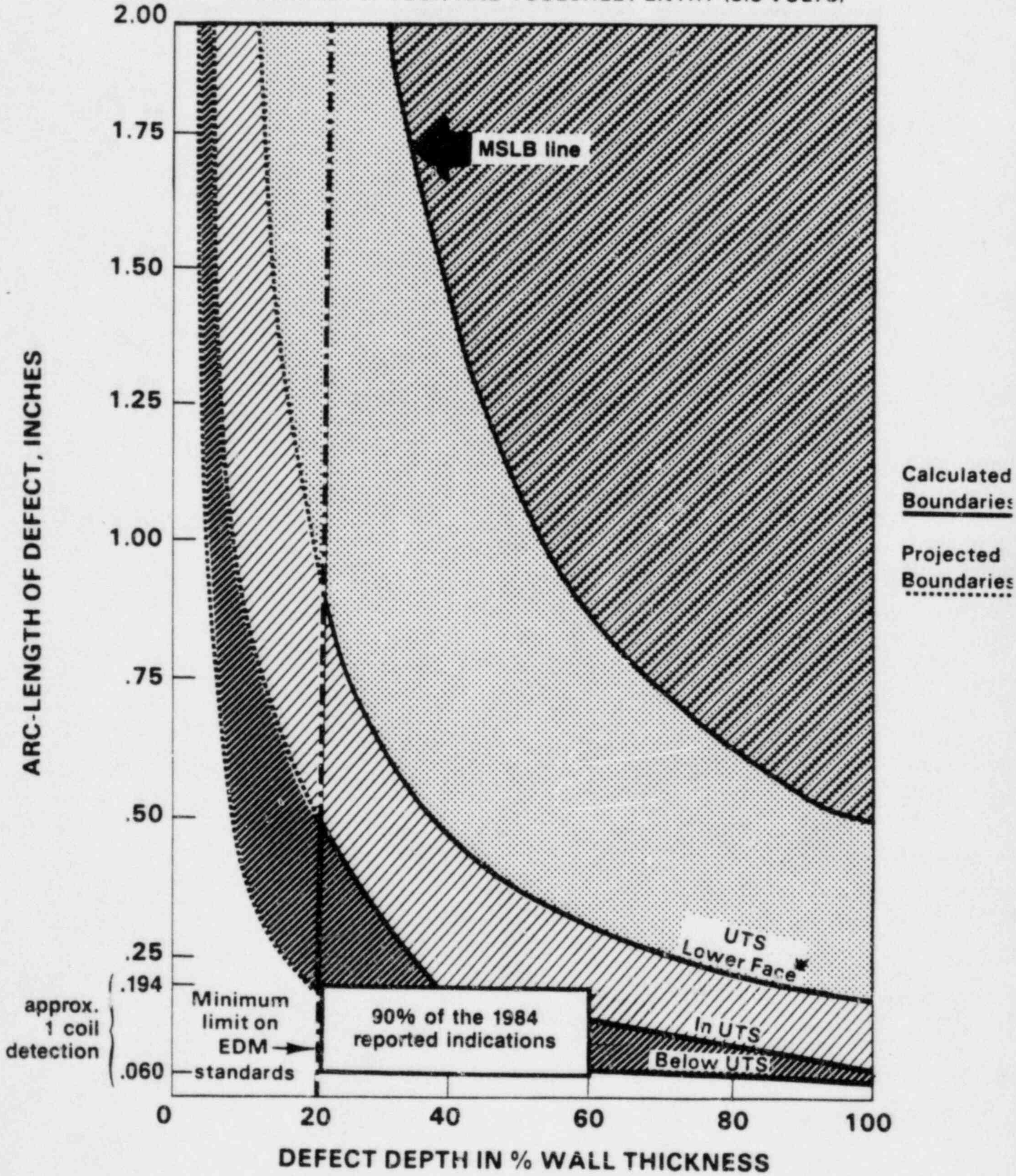
● - MOST PROBABLE INDICATION CHARACTERIZATION

(from TDR ?

FIGURE 2

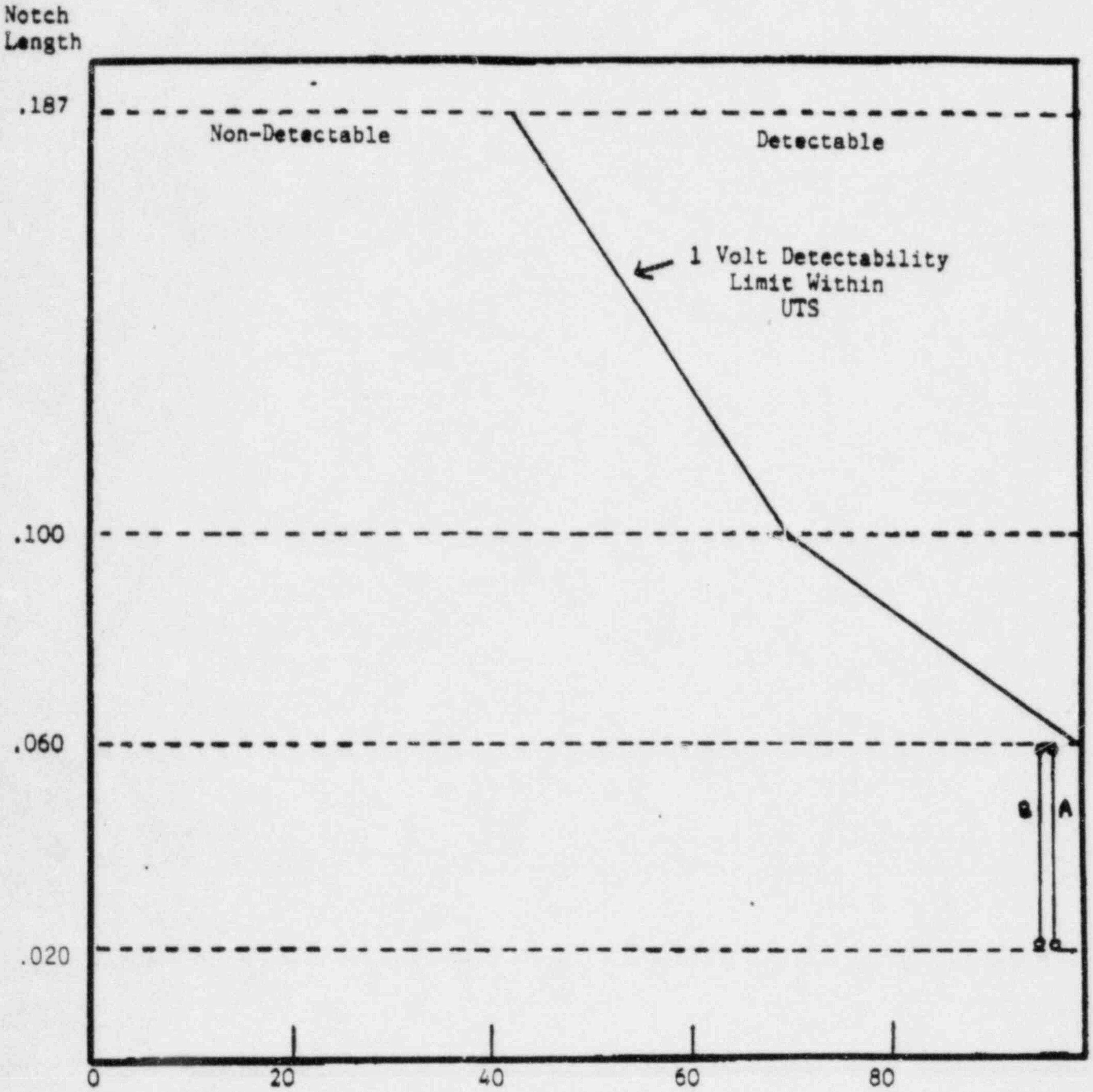
(WAS FIGURE 6 OF TDR 652)

ESTABLISHED MINIMUM SENSITIVITY FOR THE HIGH GAIN .540 S.D. EXAMINATIONS BELOW UPPER TUBESHEET (300 MV) WITHIN UPPER TUBESHEET (1 VOLT) AND TUBESHEET ENTRY (3.3 VOLTS)



*UTS + 0 ± ¼"

Figure 3a - Within - Tubesheet Fiberscope Indications Compared to Detectability Limit

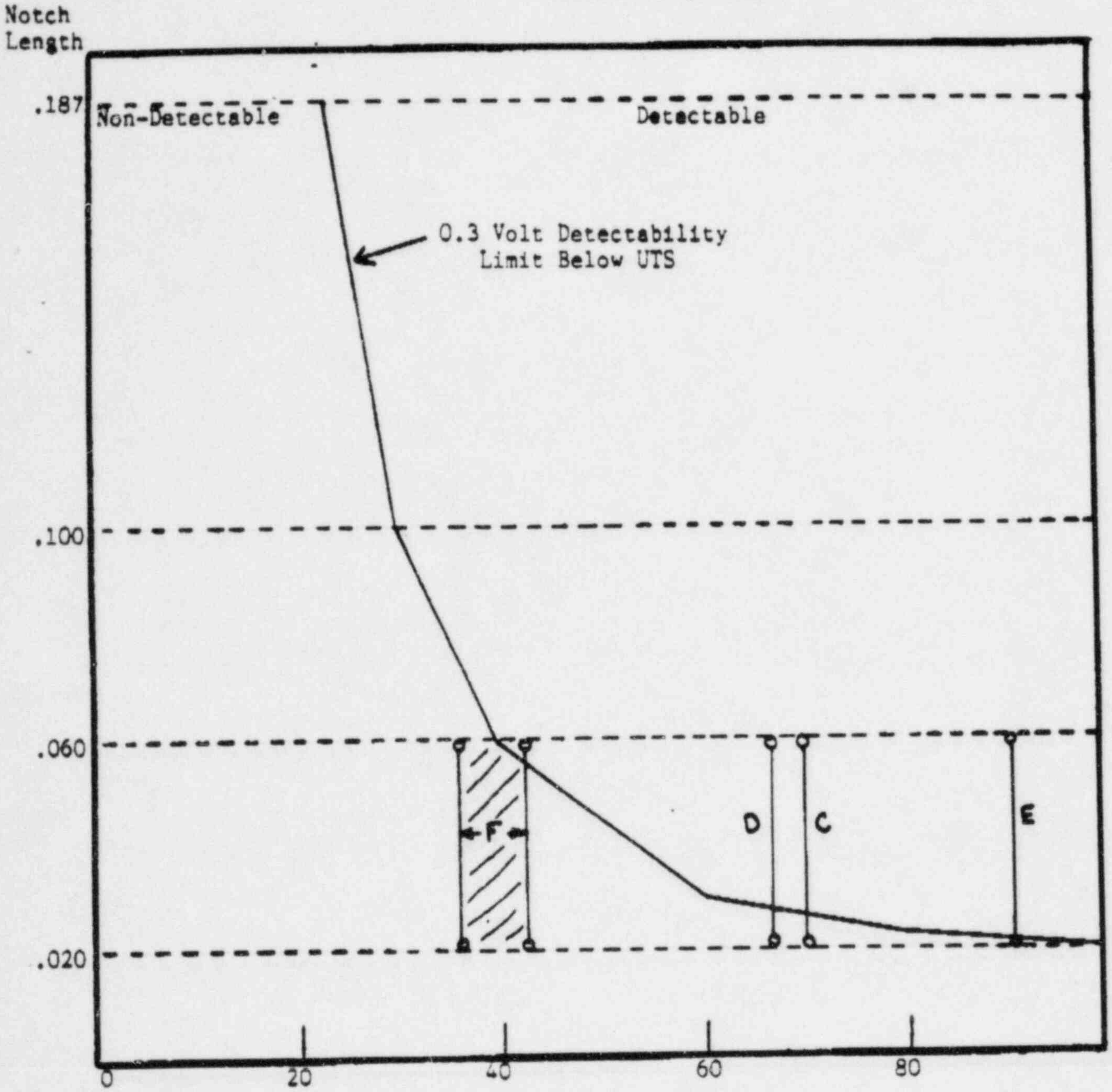


(BASED ON PRELIMINARY 1984 DATA)

Tube Identification

A   A-89-124
B   A-76-119

Figure 3b - Below - Tubesheet Fiberscope Indications Compared to Detectability Limit



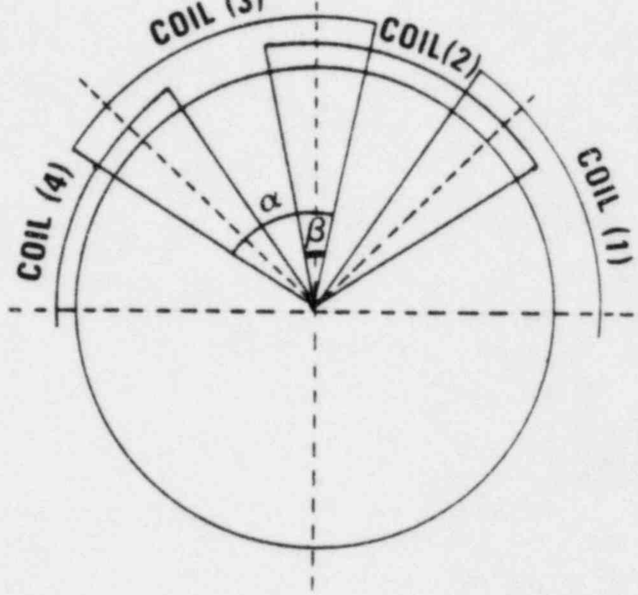
(BASED ON PRELIMINARY 1984 DATA)

Tube Identification

C	A-66-129
D	A-61-123
E	A-57-128
F	A-60-126

FIGURE 4
(WAS Figure B-1)

Tube OD	.625
Min. wall X (2)	.068
Tube ID	.557
Circumf ID	1.75
Coil dia.	.187
1 volt peak calibration	
.300 volt response	
50° coverage per coil	α
5° overlap	β



COILS	MAXIMUM		MINIMUM	
			Threshold of Detection	
1	< 40°	.194"		
2	< 85°	.413"	|5°|	.024"
3	<130°	.632"	> 45°	.219"
4	<175°	.851"	> 90°	.438"
5	<220°	1.07"	>135°	.656"
6	<265°	1.29"	>180°	.875"
7	<310°	1.51"	>225°	1.09"
8	360°	1.75"	>270°	1.31"

(BASED ON TESTING WITH .060" x 80% TW x .005" EDM NOTCH)