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SHUTTLE ACTIVE THERMAL CONTROL SYSTEM DEVELOPMENT TESTING

VOLUME VIII

TUBE ANOMALY INVESTIGATION

5 APRIL 1974

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VOUGHT SYSTEMS DIVISION
LTV AEROSPACE CORPORATION

SHUTTLE ACTIVE THERMAL CONTROL SYSTEM
DEVELOPMENT TESTING

VOLUME VIII

TUBE ANOMALY INVESTIGATION

Report No. T169-28

5 April 1974

Submitted by

VOUGHT SYSTEMS DIVISION
LTV Aerospace Corporation
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To

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Johnson Spacecraft Center
Houston, Texas

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FOREWORD

This volume is one of a series of reports describing the development tests conducted on a candidate Shuttle heat rejection system at the National Aeronautics and Space Administration - Johnson Space Center during the period from March to July 1973. The complete test series are reported in the following volumes:

Volume I	Overall Summary
Volume II	Modular Radiator System Tests
Volume III	Modular Radiator System Test Data Correlation With Thermal Model
Volume IV	Modular Radiator System Test Data
Volume V	Integrated Radiator/Expendable Cooling System Tests
Volume VI	Water Ejector Plume Tests
Volume VII	Improved Radiator Coating Adhesives Tests
Volume VIII	Tube Anomaly Investigation

The tests were conducted jointly by NASA and the Vought Systems Division of LTV Aerospace Corporation under Contract NAS9-10534. D. W. Morris of the NASA-JSC Crew Systems Division was the contract technical monitor. Mr. R. J. Tufte served as the VSD Project Engineer.

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1.0 SUMMARY

Vought Systems Division (VSD) of LTV Aerospace Corporation has produced and tested a Modular Radiator System projected for use on the Space Shuttle. During thermal-vacuum testing of the radiator panels at NASA/JSC Space Environmental Simulation Laboratory - Chamber A, leaks developed in the coolant fluid tubes containing the Freon 21 refrigerant.

An analysis of thermal-vacuum test conditions reveals that the test anomaly consisted of trapped Freon 21 fluid between frozen tube corners colder than the remainder of the panel. The trapped fluid expanded on further warming, causing high pressures to develop in the tubes. The pressure was sufficient to induce tube ruptures. Metallurgical analysis showed that concentric extrusion holes and heat treatment of the aluminum alloy to the -T6 condition would have prevented the ruptures. Thermal analysis indicates that attaching the tube corners to the radiator fin could eliminate the fluid trapping.

2.0 INTRODUCTION

During the concluding phase of a six-month thermal-vacuum test ruptures occurred in the coolant tubes* of the modular radiator panels containing Freon 21 (F-21).** Four tube ruptures on three panels (out of a total of seven panels in test) were noted during a thaw cycle following a two sided radiation condition (prime tube bypassed) to a liquid nitrogen sink temperature. The thermal up-ramp was 60°F/hour maximum. After a cold soak of some twelve hours with temperatures as low as -270°F measured, a recovery transient was started. Approximately 24 minutes into the thaw, tube 5 on panel 6 developed a leak. Tube 7 and possibly tube 9 of panel 5 began to leak some 34 minutes later. The thermal up-ramp was halted, but the thaw continued, causing tube 10 of panel 3 to rupture about 46 minutes after the initial leak was detected. The failure locations are diagrammed on the sketch in Figure 1. Note that all fractures occurred between the tube bends.

The modular radiator panels had an extensive test history in thermal-vacuum environments without mechanical problems. The radiator panels were given as many as seventeen cryogenic exposures in prior tests. A detailed analysis of panel instrumentation data revealed that three to six traps of liquid F-21 in coolant tubes by frozen F-21 at corner bends had occurred in previous exposures.

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* The coolant tube anomaly occurred on July 18, 1973 during Phase 3A testing of the subject contract. Phases 3A and 4 refer to segments of the overall radiator test program conducted under the subject contract.

** DuPont trademark for dichloro-fluoroethane

3.0 PURPOSE

The anomaly investigation was concentrated in three primary areas: analysis of the failed coolant tubes, inspection and test of remaining radiator hardware, and review prior and current test data for adverse thermal/pressure gradients.

The failure analysis of the coolant tubes determined mode of failure and metallurgical condition of the extruded 6063-T42 aluminum tubing. Electron fractography coupled with macroscopic examination was used to establish failure mode. Optical metallography revealed the microstructure of the alloy in both failed and unfailed areas. Examination for extrusion defects or inclusions was also made.

Measurements of unfailed coolant tubes were made to ascertain structural deformation. Mechanical properties of the aluminum extrusion were determined. Controlled freeze-thaw tests of F-21 in coolant tubes established if permanent distortion could be induced.

Correlations were established between previous thermal cycles and the current freeze-thaw conditions which contributed to the failures.

4.0 INVESTIGATION RESULTS

4.1 Metallurgical Failure Analysis

4.1.1 Background

Four coolant tubes from three modular radiator panels developed leaks during thermal-vacuum testing. The tubes were fabricated from as-extruded 6063-T42 aluminum alloy to the configuration shown in Figure 2. The four fracture locations and adjacent areas were sectioned from the panels and submitted for analysis.

4.1.2 Macroscopic Data

Location of the failures on radiator panels 3, 5 and 6 are shown in Figures 3, 4 and 5 respectively. The fracture locations were removed from the panels with surrounding metal intact as seen in Figure 6. A fractured and bulged area of tube 9, panel 5, with associated cracked and flaked paint is typical of each failure site, Figure 7.

A transverse section showing the double bore shotgun extrusion is seen in Figure 8. The lower tube was typically off center as-manufactured. The fracture followed the thin walled area of the tube at each failure location.

Considerable deformation at each of the failure sites was found; Figure 9 depicts the bulging noted in each tube. This indicates that catastrophic failure, i.e., leakage of F-21, was preceded by considerable yielding of the aluminum alloy tubing.

4.1.3 Microscopic Data

Fractographic examination with the scanning electron microscope (SEM) on each of the failure sites revealed a ductile tension mode of failure in every case. The primary topographic feature present was elongated dimples, see Figure 10, which indicates a tensile/shear mode of crack propagation. Indications of possible fatigue cracks originating on the inside diameter of tubes 7 and 9, panel 5 and tube 10, panel 3 were found during the SEM examination. A typical fractograph of an area containing the parallel striations associated with metal fatigue is illustrated in Figure 11. Such areas were patchy and scattered over the fracture surface, indicating that a dual crack propagation mode of fatigue - ductile tension was operative.

The microstructure of the extruded tubing appeared normal for 6063-T42 alloy in both failed and unfailed areas from each panel. The photomicrograph shown in Figure 12 was typical of all sites studied. The extrusion weld line was not related to the fracture locations as shown in Figure 13. No evidence of metallurgical defects was found during metallographic examination of the various specimens.

4.1.4 Mechanical Properties

The extruded tubing had Rockwell 15-T hardness values of 58.5 to 62.8 in areas adjacent to the fractures, normal for this alloy/temper aluminum. In a controlled test, as-extruded tubing was heat treated to Rockwell 15-T hardness ranging from 69.6 to 72.5, which is the hardness range for the -T6 temper for 6063 alloy.

Mechanical properties of the extruded tubing were determined in both longitudinal and transverse directions. Tensile specimen orientation and dimensions are shown in Figures 14 and 15. The results of the mechanical tests are given in Table 1. Considering the abnormal size of the test specimens, there was relatively little scatter in the data, with all specimens meeting the requirements for the -T42 condition.

4.1.5 Chemical Analysis

The chemistry of the extruded tubing was determined in the area of each fracture by atomic absorption spectroscopy. The results given in Table 2 confirm that the alloy met the requirements for 6063 in each case.

4.2 Tube Dimensions and Condition

Wall thickness in the coolant tubes was below the drawing requirement of 0.033 ± 0.005". A typical thickness in tube 5, see Figure 16, was 0.0165" in the thin wall area, decreasing to 0.013" adjacent to the fracture. The thick wall section of the tube measured between 0.023" - 0.024". As-received extrusions varied in wall thickness from 0.021" in the thin area to 0.029" on the opposite thick wall. This implies that yielding of the tube wall occurred remote from the fracture locations.

Physical inspection of the tubes on the various radiator panels revealed paint cracks concentrated on the outer seven (coldest) tubes. The results of this inspection are given in Appendix 1.

Freeze-thaw tests of F-21 in a sealed coolant tube, fourteen feet in length gave the dimensional changes detailed in Table 3. Expansion of 1.98% was induced in the tube by heating the center section into the F-21 liquid range while the ends remained frozen.

Coolant tube diameters on each of the seven modular radiator panels were expanded between the tube bends, particularly on the outer (colder) tubes. Plots of tube outside diameter vs location from the panel centerline are given in Appendix 2. These data were determined by micrometer measurement after removal of the paint. Dimensions on the coolant tubes on radiator panel serial #1, not in the Phase 3A and 4 test sequence, are included. These measurements revealed expanded tubes which resulted from the thermal-vacuum test, containing deep cold soaks, run on this panel in early 1972. Expanded tubes were, thus, not unique to the Phase 3A and 4 test sequence.

4.3 Stress Analysis

The data plotted in Figure 17 show that concentric walls in the coolant tubes cause considerably lower stress levels to be developed at a given temperature of Freon 21. In addition the heat treatment of 6063 to the -T6 condition raises the yield strength to the 33 - 36 ksi range at cryogenic temperatures. Maximum temperature differences of 35°F were measured between frozen corners and thawed tubes at mid-points. Assuming a concentric tube and a delta of 35°F from -211°F to -176°F, a stress of 26 ksi would be induced in the coolant tube by expansion of the F-21. This is below the yield strength of ca.33 ksi for 6063-T6, allowing a thaw under these conditions to leave the tube undamaged.

4.4 Thermal History

Figure 18 presents measured temperature data during the last freeze-thaw cycle in which the tube failed. This data indicates that the section between the tube corners thawed approximately 3 minutes before the corners. The fluid in this section thus underwent thermal expansion while constrained by the frozen corners. The trapped fluid was heated to approximately -180°F before the tube corners thawed and allowed the tube to flow. This demonstrates the postulated failure mechanism and indicates that thermally attaching the tube corners to the radiator fin to provide uniform heating of a frozen tube would prevent or reduce the trapping.

The radiator test panels have undergone extensive previous thermal vacuum testing including as many as 17 freeze thaw cycles. Panels 1 and 2 were tested in February of 1972, all eight panels were included in a checkout test in the VSD simulator in December 1972, and all eight panels were tested in the present Orbiter ATCS (Active Thermal Control System) Development Tests. Panel 1 was not included in the final two phases of this test.

Table 4 summarizes the thermal history data gathered for this investigation. The test results for each test were reviewed to determine the number of freeze-thaw cycles, the minimum temperature obtained during the cold soak, the number of fluid traps during the destagnation transient and the temperature difference between the tube corners and mid-point between the corners (an estimate of the severity of the trap). Individual panel instrumentation for all tests were rather extensive; however, temperature measurements on the tube corners were limited. Thus all traps on all tubes were not recorded. A detailed examination of the complete panel temperature map was used to estimate where traps could have occurred. The estimated c is included in Table 5.

The thermal history data of Table 4 indicates that the test conditions at the time of the failure were not significantly different from previous tests. The February 1972 single and two-panel tests were conducted with F-21 in the upper flow passage of the over/under tube configuration and subsequent tests had F-21 in only the lower flow passage. It is interesting to note that the thermal data indicated fluid trapping in the upper flow passage and the panel physical data of Appendix 1 indicates tube deformation in the suspected trapping area.

5.0 CONCLUSIONS

The test anomaly is understood. Frozen Freon 21 refrigerant is trapped between right angle tube bends which prevent thermal expansion as the Freon 21 between the bends is heated into the liquidus range. The pressure generated by the volume change to the liquid phase is sufficient to expand the coolant tubes used in the test.

Failure analysis shows that a ductile fracture occurred in the aluminum coolant tubes during thaw conditions following a deep cold soak.

Metallurgical condition and chemistry of the coolant tubes were normal for 6063-T42 aluminum.

Analysis indicates that concentric extrusion holes and heat treatment of the tubes to the -T6 condition would have prevented the test anomaly. Thermal analysis indicates that attaching the tube corners to the radiator fin could eliminate the fluid trapping.

TABLE I

MECHANICAL PROPERTIES OF EXTRUDED 6063 TUBING

	Fty, Ksi	Ftu, Ksi	El, %
LONGITUDINAL			
1 (2" gage length)	13.1	23.1	14
2	14.6	23.5	12
3	13.9	24.5	16
4	14.1	24.6	15
5	13.8	23.7	14
6	14.6	24.8	13
AVERAGE OF 6	14.0	24.0	14
TYPICAL 6063-T42	10.0	19.0	14
TRANSVERSE			
1 (1/2" gage length)	-	24.2	26*
2	-	24.2	24
3	-	23.3	18
4	-	23.2	20
5	-	23.2	18
6	-	24.0	24
7	-	23.6	22
8	-	23.9	22
9	-	23.1	20
10	-	23.9	20
11	-	23.8	20
AVERAGE OF 11		23.7	21

* Short gage length gives non-typical values

TABLE 2

CHEMICAL ANALYSIS OF COOLANT TUBES

SPECIMEN	% IRON	% CHROMIUM	% TITANIUM	% MAGNESIUM	% SILICON	% COPPER	% MANGANESE	% ZINC
Panel 6, Tube 5	0.27	0.03	0.03	0.54	0.50	0.01	0.00	0.03
Panel 3, Tube 10	0.24	0.05	0.03	0.53	0.55	0.01	0.00	0.03
Panel 5, Tube 7	0.24	0.04	0.01	0.52	0.61	0.01	0.00	0.03
Panel 5, Tube 9	0.26	0.04	0.04	0.52	0.60	0.01	0.00	0.03
As-Received, 1st Lot	0.21	0.03	0.03	0.53	0.51	0.03	0.00	0.02
As-Received, 2nd Lot	0.24	0.04	0.03	0.53	0.51	0.01	0.00	0.02
6063	0.35 max.	0.1	0.1	0.4 - 0.9	0.2-0.6	0.1	0.1	0.1
6061	0.7	0.04-0.35	0.15	0.8 - 1.2	0.4-0.8	0.15-0.4	0.15	0.25

TABLE 3

DIMENSIONAL CHANGES IN COOLANT TUBE AFTER CONTROLLED FREEZE-THAW TESTS

	DISTANCE FROM END FEET	TEMP AT END OF TEST °F	OUTSIDE DIAMETER BEFORE INCHES	OUTSIDE DIAMETER AFTER INCH
	0		.1920	.1920
		-325		
	1			.1920
	2	-325		.1930
	3			.1925
	3.5			.1940
HEATED SECTION	4	- 80		.1945
HEATED SECTION	5			.1948
HEATED SECTION	6	- 30		.1952
HEATED SECTION	7			.1955
HEATED SECTION	8	- 5		.1958 (MAX)
HEATED SECTION	9			.1952
HEATED SECTION	10	- 85		.1942
	11			.1920
	12			.1920
		-285		
	13			.1920
		-295		
	14		.1920	.1920

TABLE 4 TEST HISTORY AND DATA SUMMARY

PANEL NO.	FEB 1972 SINGLE PANEL TEST: NO FREEZES	APPX LOW TEMP.	NO TRANS.	AT MID	FEB 1972 TWO PANEL TEST: NO. FREEZES	APPX LOW TEMP	NO TRANS	AT MID	DEC 1972 EIGHT PANEL F/O TEST: NO FREEZES	APPX LOW TEMP	NO TRANS	AT MID
1	2	-270 [illegible]	7	NO DATA	5	-270 -280 -240 -270 -230	4	30 30 6 34 0	2	-220 -220	7	NO DATA
	1ST FREEZE HAD FREON IN LOWER TUBE WHILE UPPER TUBE FLOWED 2ND FREEZE HAD FREON IN UPPER ONLY.				FREON IN UPPER AND LOWER TUBE FOR 1ST FREEZE ONLY							
2					2	-220 -250	1	30	2	-220 -220	7	NO DATA
					FREON IN UPPER AND LOWER TUBE FOR 1ST FREEZE ONLY							
3									2	-240 -240	7	NO DATA
4									2	-240 -240	7	NO DATA
5									2	-240 -240	7	NO DATA
6									2	-230 -230	7	NO DATA
7									2	-270 -220	7	NO DATA
8									2	-220 -220	7	NO DATA

PANEL NO.	MARCH 1973 HRS TEST: NO. FREEZES	APPX LOW TEMP	NO TRANS	AT MID	MAY 1973 INTEGRATED SYSTEM TEST: NO. FREEZES	APPX LOW TEMP	NO TRANS.	AT MID	JULY 1973 COATINGS TEST: NO. FREEZES	APPX LOW TEMP	NO TRANS	AT MID	JULY 1973 NOZZLE AND ADDITIONAL COATINGS TESTS: NO FREEZES	APPX LOW TEMP	NO TRANS.	AT MID
1	1	-250	1	25	NO KNOWN FREEZE				NOT IN TEST				NOT IN TEST			
2	6	-215 -230 -215 -240 -230 -220	2	5 5					6	1 -230 2-5 -240 6 -240			2	1 -255 2 -256	7	NO DATA
3	3	-220 -250 -240	1	25					6	1-5 -240 6 -250			1	1 -250 2 -250	2	35 35
													TUBE 10 RUPTURE IN 2ND RECOVERY			
4	4	-230 -230 230 -270	1	10					6	1-5 -270 6 -230	7	NO DATA	1	1 -250 2 -260	7	NO DATA
5	5	-230 -220 -260 -240 -220	1	10 25 25					6	1 -220 2-6 -235 6 -240	1	35	2	1 -260 2 -270	1	30
													TUBE 7 RUPTURE IN 2ND RECOVERY			
6	5	-215 -230 -215 -260 -240	2	35 5					6	1-5 -275 6 -240	0		2	1 -250 2 -260	1	35
													TUBE 5 RUPTURE IN 2ND RECOVERY			
7	4	-215 [illegible] [illegible] [illegible]	1	10					6	1-5 -275 6 -240	1	18	2	1 -250 2 [illegible]	2	40 40
8	4	-215 -220 -260 -250	1	10					6	1-5 -275 6 -250	1	22	2	1 -260 2 -270	7	10

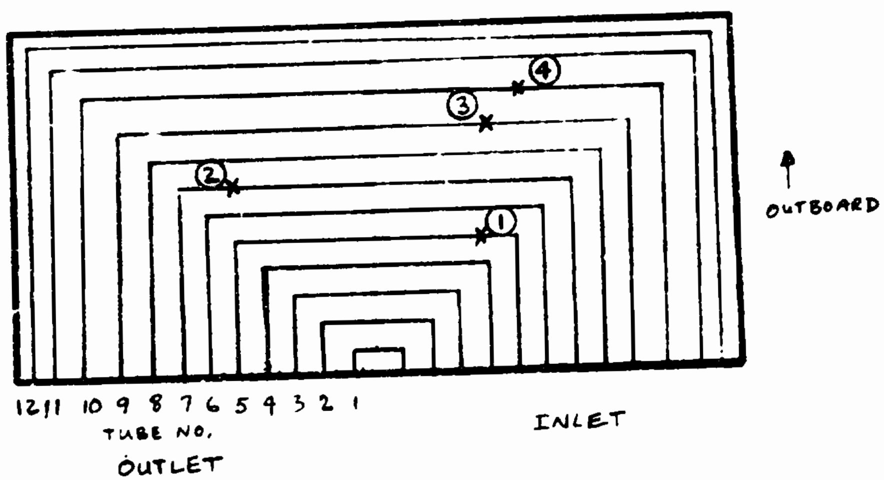
TABLE 5 SUMMARY OF PANEL FREEZE THAW HISTORY

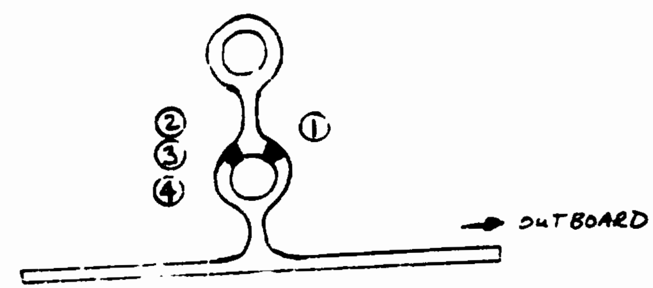
PANEL		NO. FREEZES	NO. TRAPS OBSERVED	NO. TRAPS ESTIMATED
1	Upper	7	4	6
	Lower	5	2	3
2	Upper	2	1	1
	Lower	17	2	4
3		13	3	3
4		14	1	3
5		15	5	6
6		15	3	4
7		14	4	4
8		14	3	3

FIGURE 1

ANOMALY DESCRIPTION

- 4 TUBES RUPTURED ON 3 DIFFERENT PANELS DURING RAPID WARM-UP FROM A COLD SOAK CONDITION



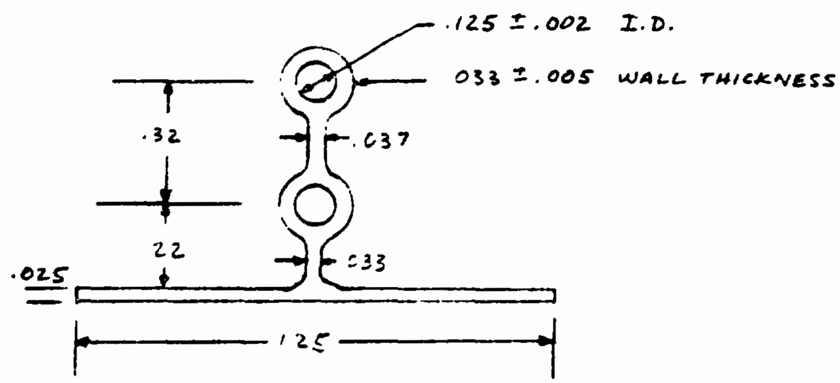


PANEL	TUBE	LOCATION
6	5	1
5	7 & 9	2 & 3
3	10	4

FIGURE 2

COOLANT TUBE CONFIGURATION

- PROTOTYPE TV TEST ARTICLE OF MIN. WEIGHT DESIGN
- EXTRUSION VENDOR SELECTED FOR MIN. LEAD TIME
- WELDABLE 6063 AL AS EXTRUDED
- TUBES NOT ATTACHED AT TUBE BENDS



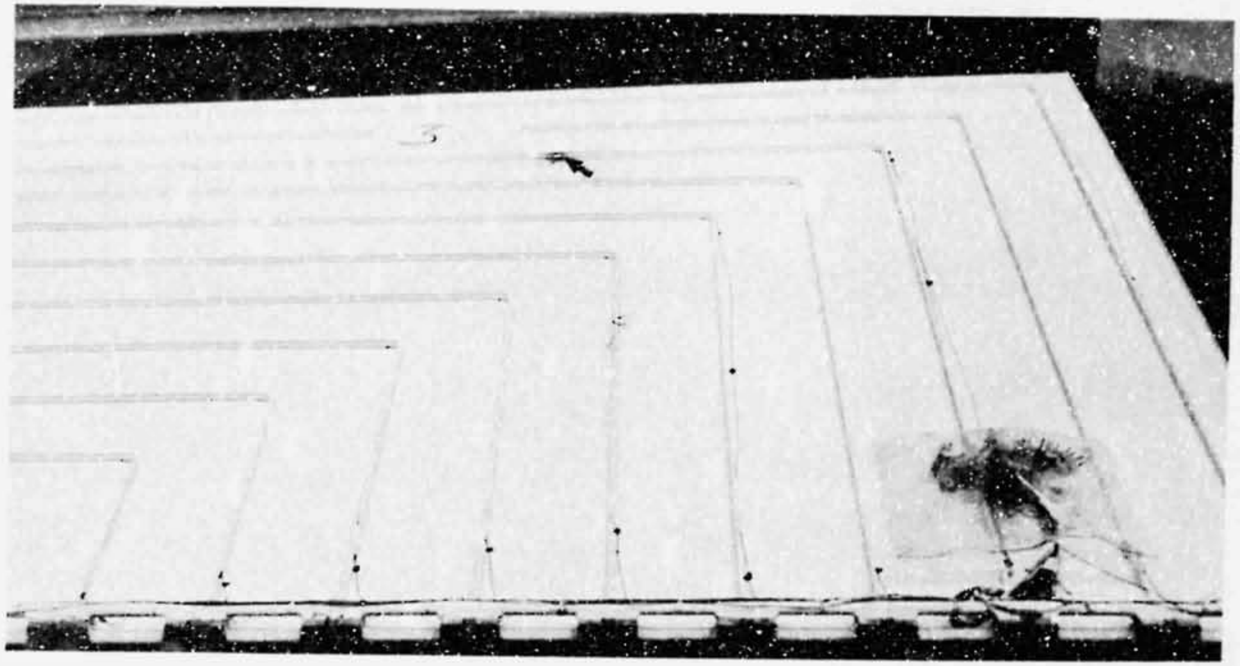


FIGURE 3

LOCATION OF FAILED TUBE 10, PANEL 3

FIGURE 4

LOCATION OF FAILED TUBES 7 AND 9, PANEL 5

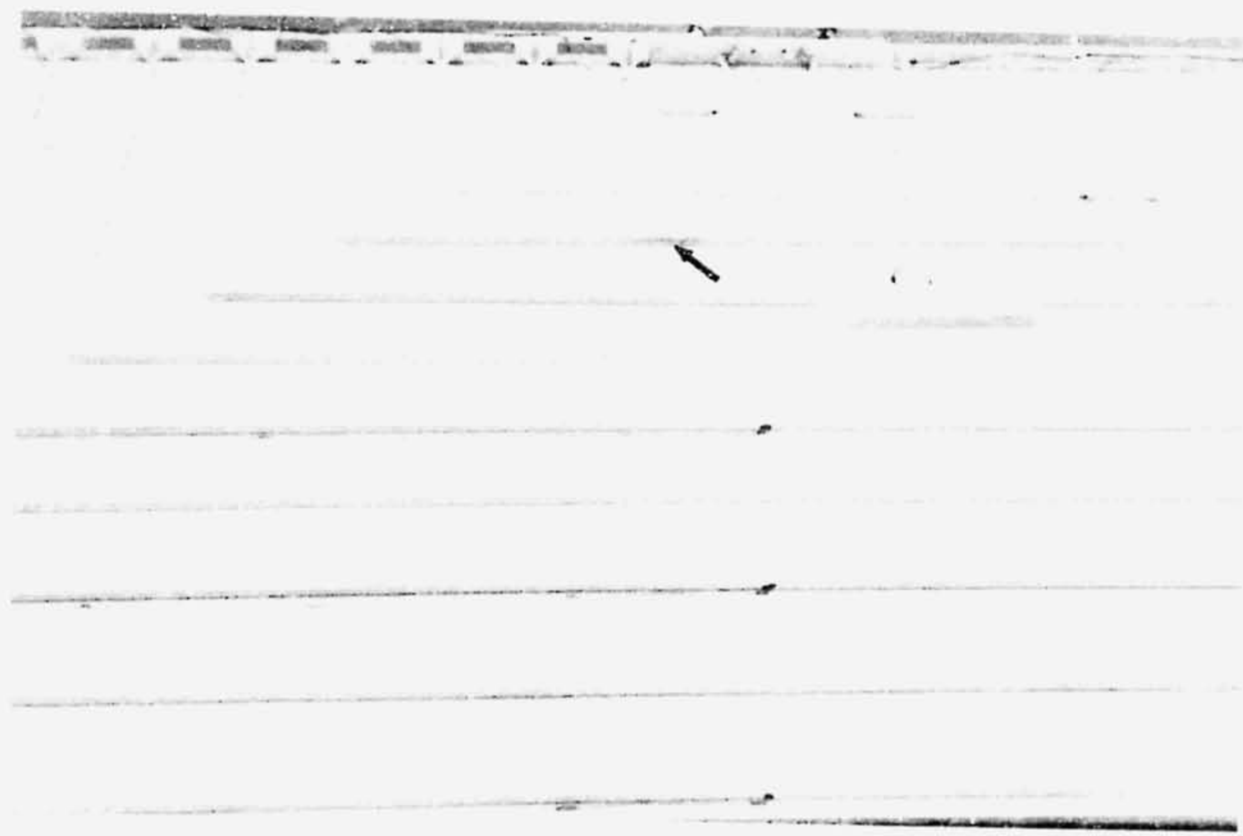


FIGURE 5

LOCATION OF FAILED TUBE 5, PANEL 6

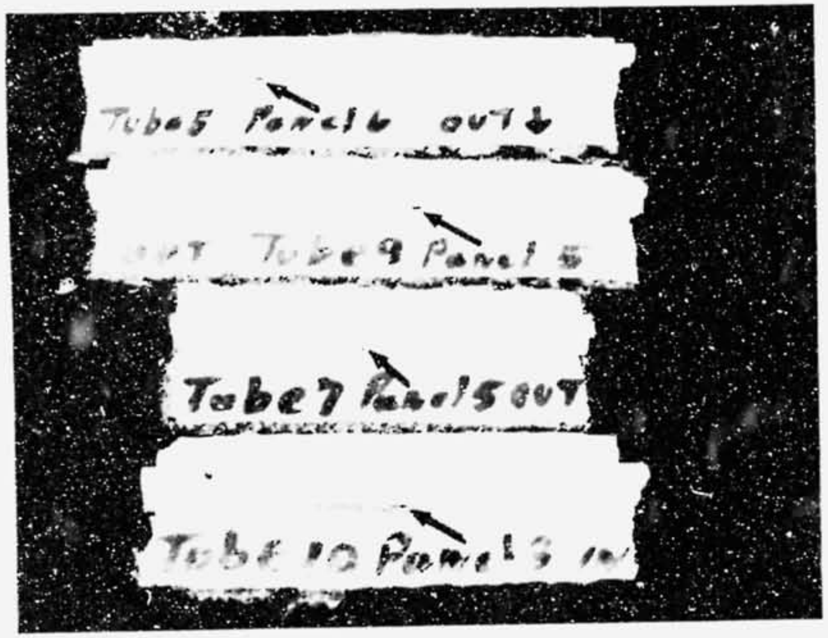


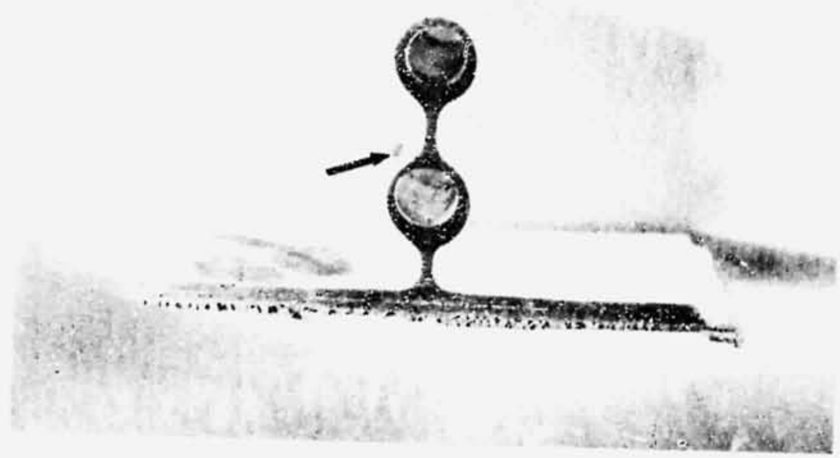
FIGURE 6

AS-RECEIVED COOLANT TUBES APPROXIMATELY 1/2X WITH FAILURE SITES DENOTED BY ARROWS

APPROXIMATELY 7X

FIGURE 7

PHOTOMACROGRAPH OF THE FRACTURE
SURFACE OF TUBE 9



APPROXIMATELY 2X

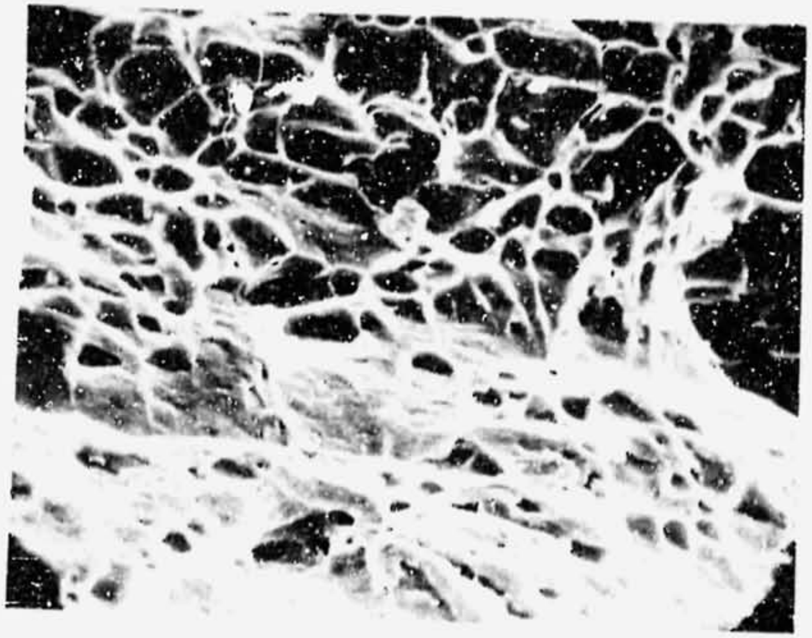
FIGURE 8

PHOTOMACROGRAPH OF EXTRUDED COOLANT TUBE WITH YIELDED THIN WALL ADJACENT TO FAILURE SITE, ARROW, OF TUBE 5

APPROXIMATELY 4X

FIGURE 9

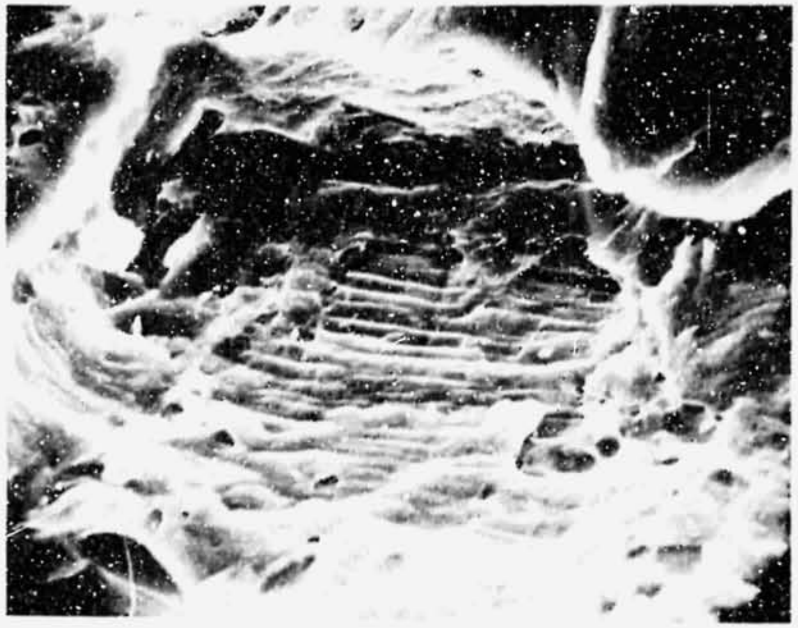
PHOTOMACROGRAPHS OF TUBES 5 AND 10 FRACTURE SURFACES AFTER OPENING
CRACK ORIGINS APPEAR TO BE FROM INSIDE DIAMETER
ARROWS DENOTE CRACK LOCATION



2000X

FIGURE 10

SEM FRACTOGRAPH SHOWING DIMPLE TENSION FAILURE
SCAN FROM INSIDE DIAMETER OF BULGED AREA OF TUBE 5



2000X

FIGURE 11

SEM FRACTOGRAPH OF FATIGUE STRIATION AREA FROM INSIDE DIAMETER OF TUBE 9

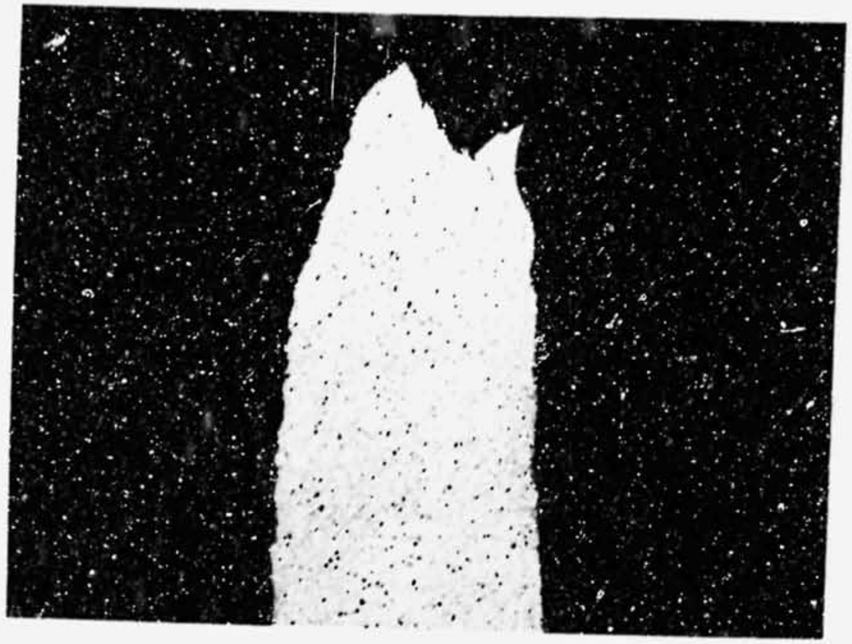
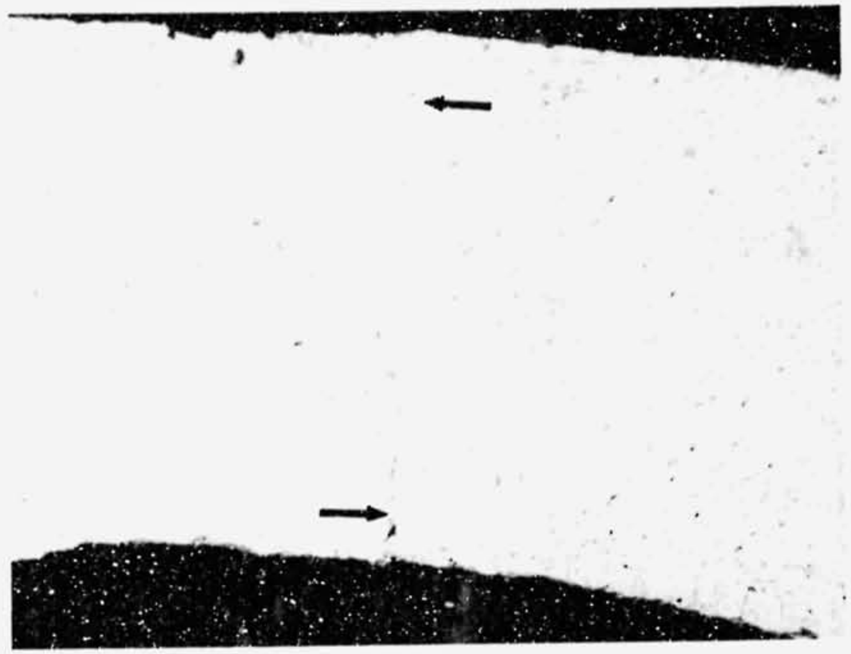


FIGURE 12

PHOTOMICROGRAPH OF SECTION THROUGH FAILURE ORIGIN OF TUBE 9 SHOWS NORMAL MICROSTRUCTURE
INSIDE DIAMETER AT RIGHT



FLICK'S ETCH 100X

FIGURE 13

EXTRUSION WELD LINE IN AS-RECEIVED TUBING
INTENTIONALLY OVERETCHED TO REVEAL WELD

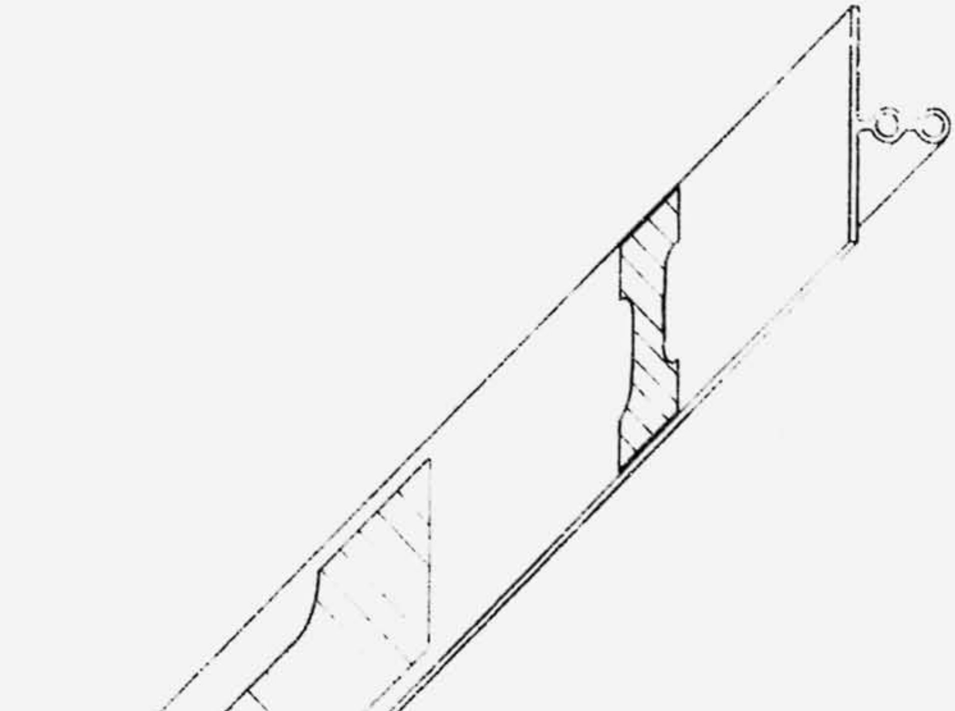
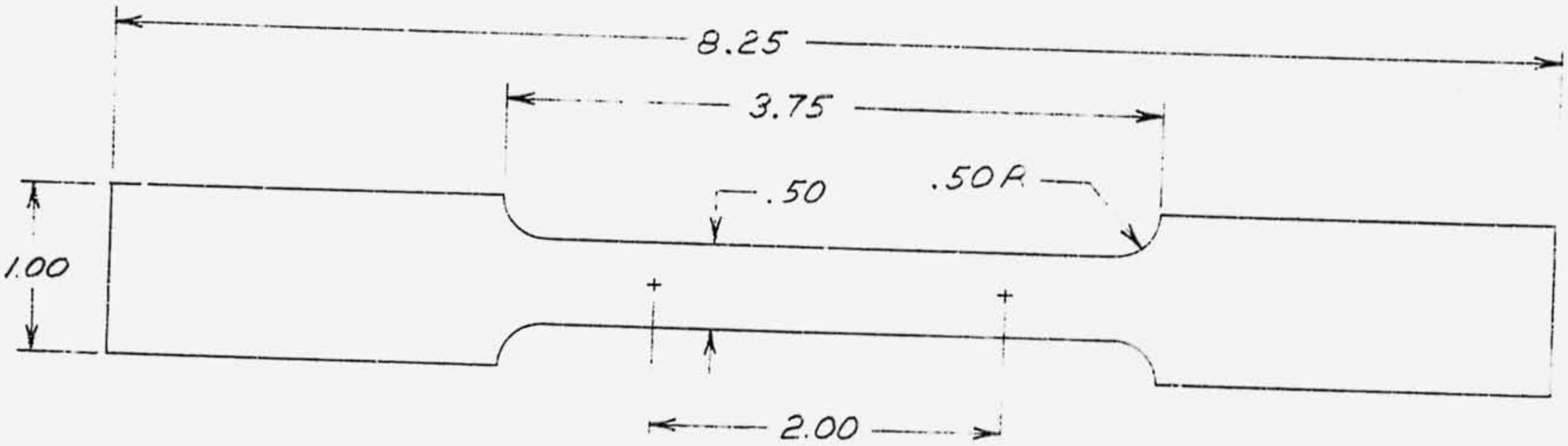
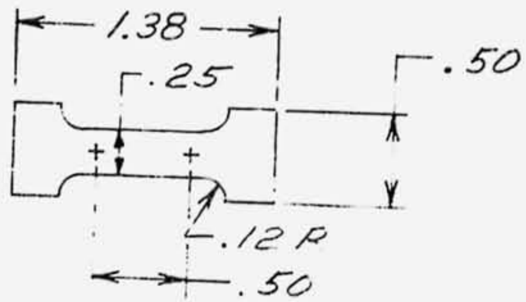


FIGURE 14
TENSILE SPECIMEN ORIENTATION



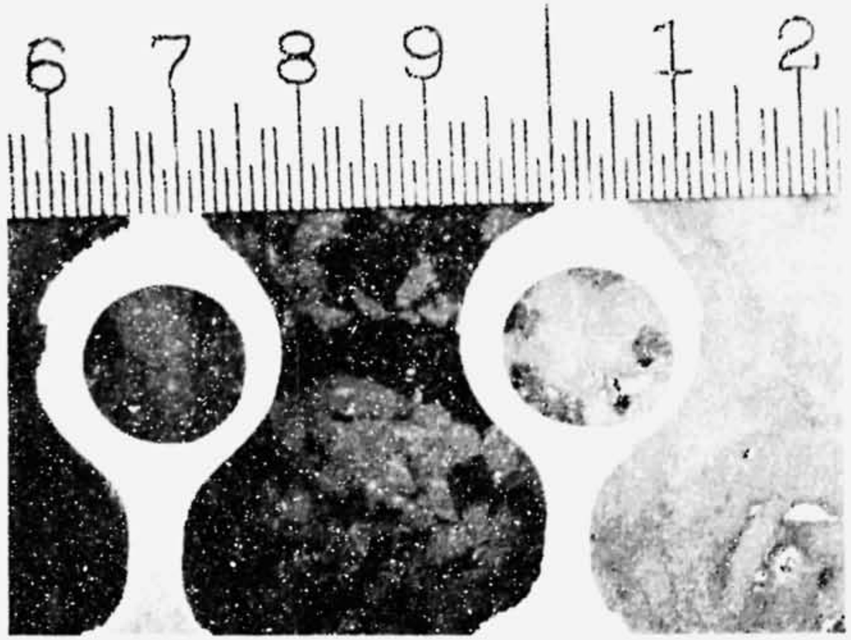
LONGITUDINAL TEST SPECIMEN



TRANSVERSE TEST SPECIMEN

FIGURE 15

TENSILE SPECIMENS FROM EXTRUDED COOLANT TUBE



APPROXIMATELY 7X

FIGURE 16

PHOTOMACROGRAPH OF TUBE 5, PANEL 6 ON INLET MANIFOLD SIDE, LEFT, AND ADJACENT TO FRACTURE, RIGHT

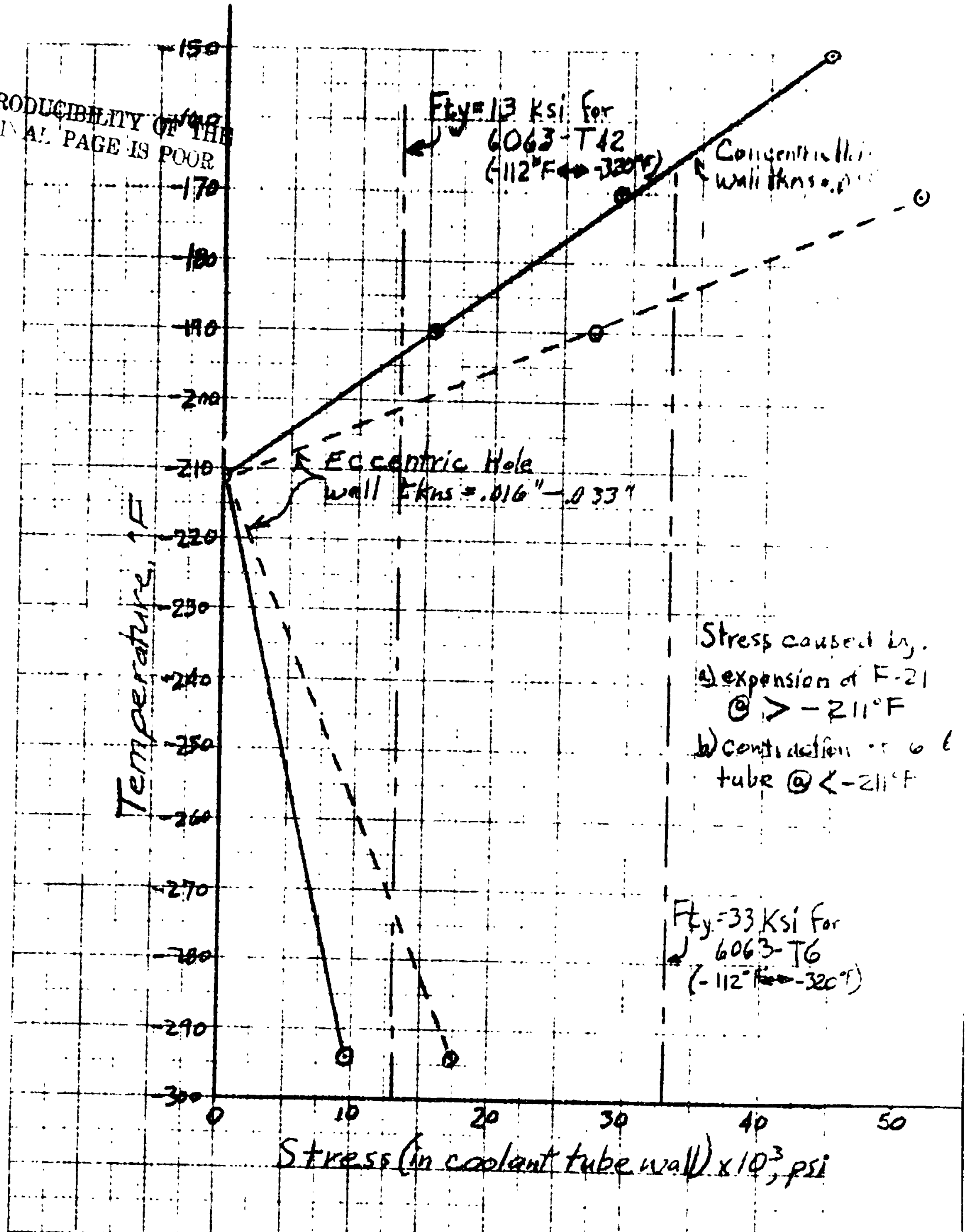


FIGURE 17

STRESS IN COOLANT TUBES VS TEMPERATURE

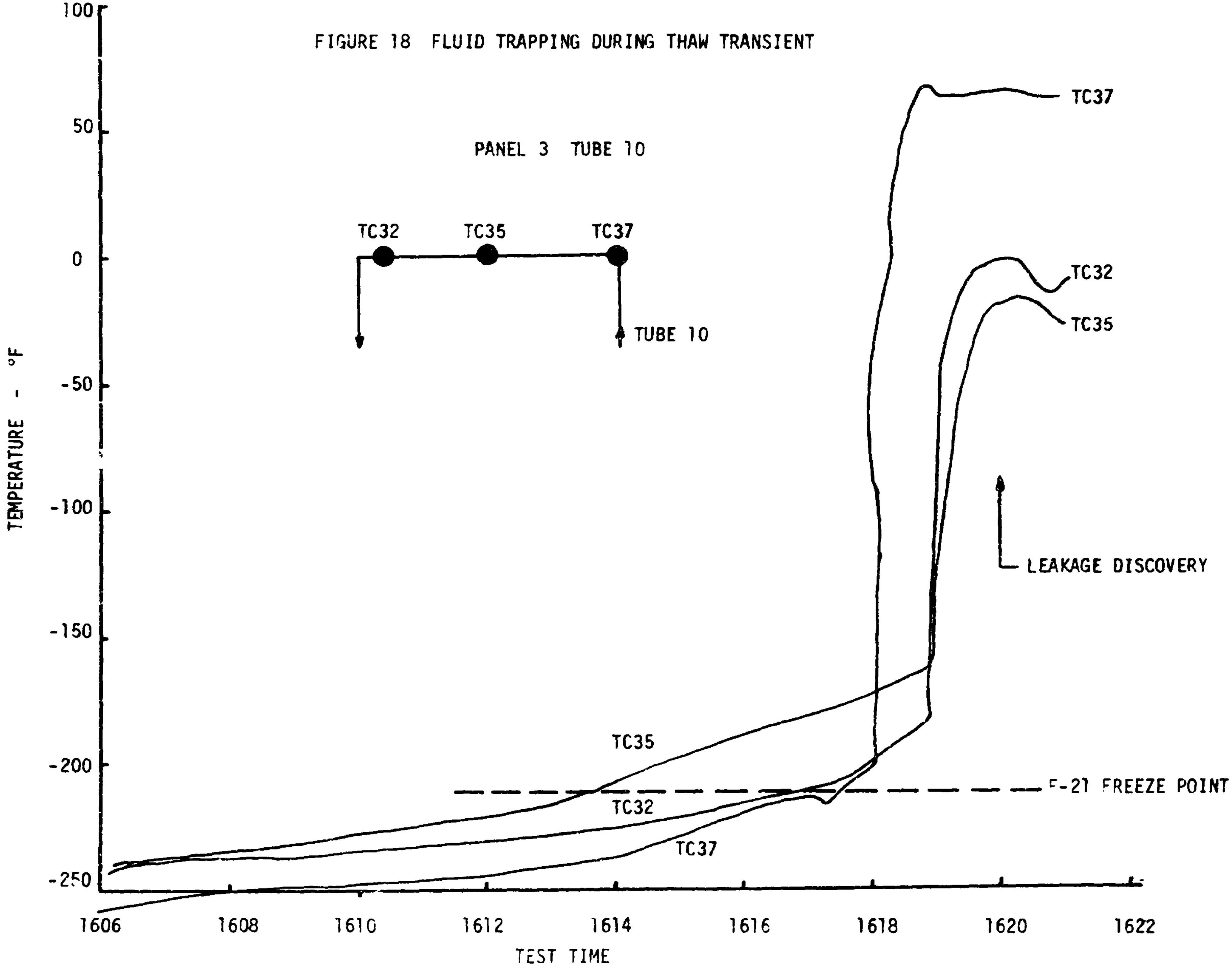


FIGURE 18 FLUID TRAPPING DURING THAW TRANSIENT

APPENDIX 1

PANEL PHYSICAL INSPECTION

PANEL PHYSICAL INSPECTION

PANEL 0001

Tube No.	Condition
1-10	No Cracks
11	Hairline, paint cracks 10 o'clock inboard upper and lower tubes, 2nd 20% of center section
12	No Cracks

PANEL 0002

Tube No.	Condition
1-4	No Cracks
5	Hairline, lower tube, 10 o'clock inside, center section.
6-12	Crack 10 o'clock inside and out, lower tube, center section. Inside worse than outside all cases, tube nine(9) worse than others. (Crack open perhaps .0001) stretch visible at crack tube 9 and 10

PANEL 0003 (Lower Tubes)

Tube No.	Condition
1-4	No Cracks
5	Paint crack nearly entire length center section inside at 9 o'clock
6-9	Paint cracks most of center section inside and outside at 10 o'clock
10	Paint cracks most of center section inside and outside at 10 o'clock, inside crack open near failure. Crack in outlet section, inside at 10 o'clock
11	Paint cracks most of center section, inside and out at 10 o'clock, worse on inside
12	Paint crack center section inside at 10 o'clock, and outlet section inside 10 o'clock. Crack in outlet section open, some stretch marks in aluminum

PANEL 0004 (Lower Tubes)

Tube No.	Condition
1-4	No Cracks
5	Paint crack center section inside at 10 o'clock
6-10	Paint cracks center section inside and outside at 10 o'clock
11-12	Paint cracks center section inside and out at 10 o'clock crack outlet section at 10 o'clock inside

PANEL 0005 (Lower Tubes)

1-3	No Cracks
4	Paint crack outside center section at 10 o'clock
5-6	Paint cracks inside outer section at 10 o'clock
7	Paint crack, stretch marks in aluminum outside center section at 10 o'clock
8	No paint cracks, but some stretch marks in aluminum in center section inside at 10 o'clock
9	Paint cracks inside and outside center section 10 o'clock stretch marks on outside
10	Hairline cracks inside and outside center section 10 o'clock, crack inside outlet section near manifold at 10 o clock
11	Hairline cracks inside and outside 10 o'clock center and outlet sections
12	Hairline cracks inside and outside 10 o'clock center section

PANEL 0006

1	No cracks
2	Hairline circumferential at bend into orifice block (upper)
3	" " " " " " " (both)
4	Same as (3) plus hairline in lower tube, 10 o'clock, outboard, center section
5	Same as (3) plus open crack and stretch marks lower tube 10 o'clock outboard, center section
6	Same as (3) plus hairline cracks 10 o'clock inboard and outboard lower tube, 1st 30% of center section

PANEL 0006 (Continued)

Tube No.	Condition
7	Same as (3) plus hairline crack lower tube outboard 10 o'clock center of center section
8	Same as (3) plus hairline cracks at lower tube 10 o'clock outboard center section
9	Same as (3) plus hairline in and outside 10 o'clock lower in inlet section, lessor but there in outlet section, crack both sides lower tube center section plus slight stretch at crack
10	Sames as (3) plus open crack inside 10 o'clock inlet section, open and hairline 10 o'clock inside center section, hairline inside 10 o'clock outlet section
11	Same as (3) plus hairline inside and outside 10 o'clock in inlet section, center section, very slight in outlet section
12	Same as (3) plus hairline inside and outside 10 o'clock entire length, worse in center section, least in outlet section

PANEL 0007 (Lower Tubes)

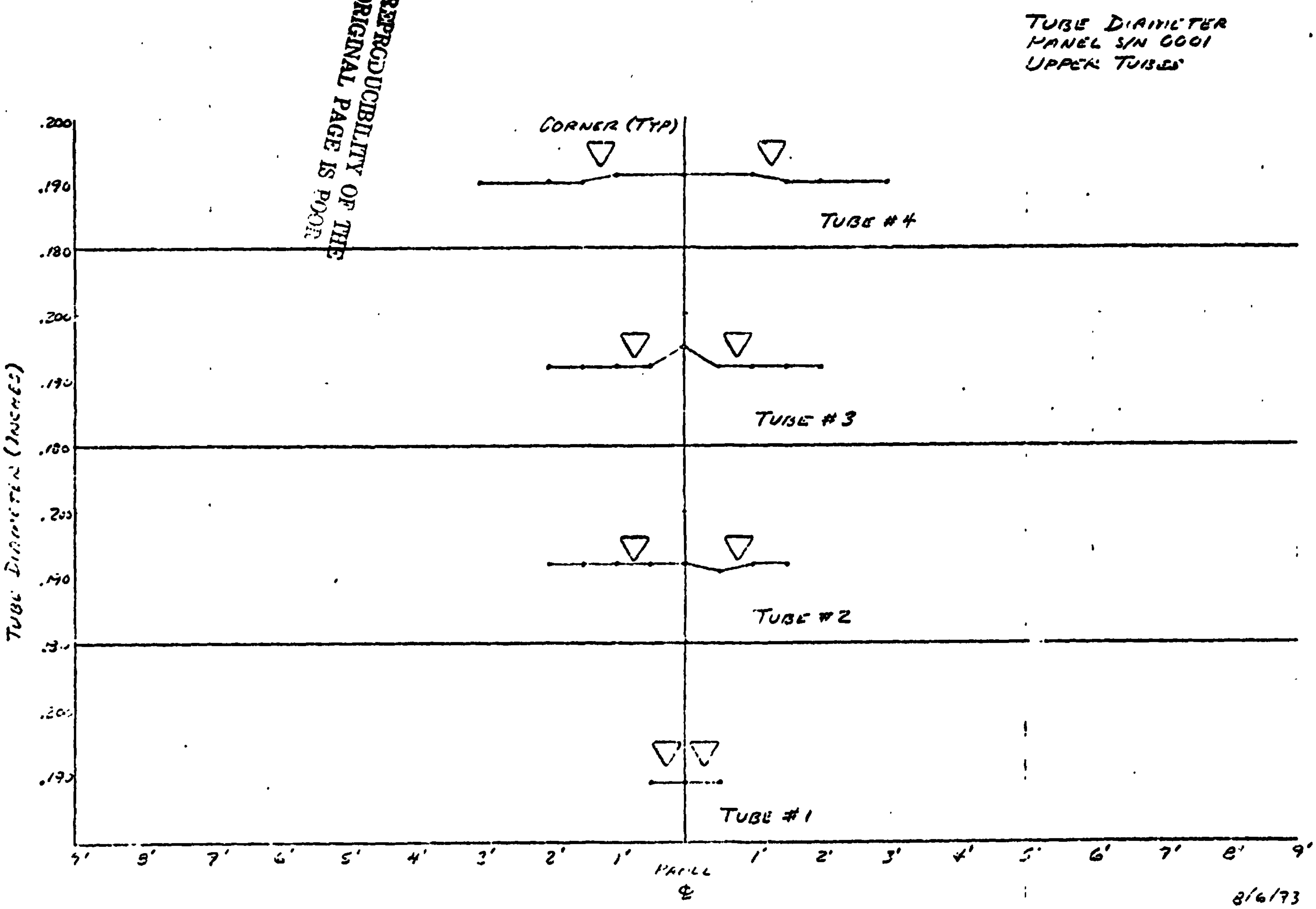
1-4	No Cracks
5	Paint crack center section inside 10 o'clock
6-12	Paint cracks (hairline) inside and out center section at 10 o'clock
	Tube 9 "damaged" on top, for 1/2 inch in inlet section (upper tube).

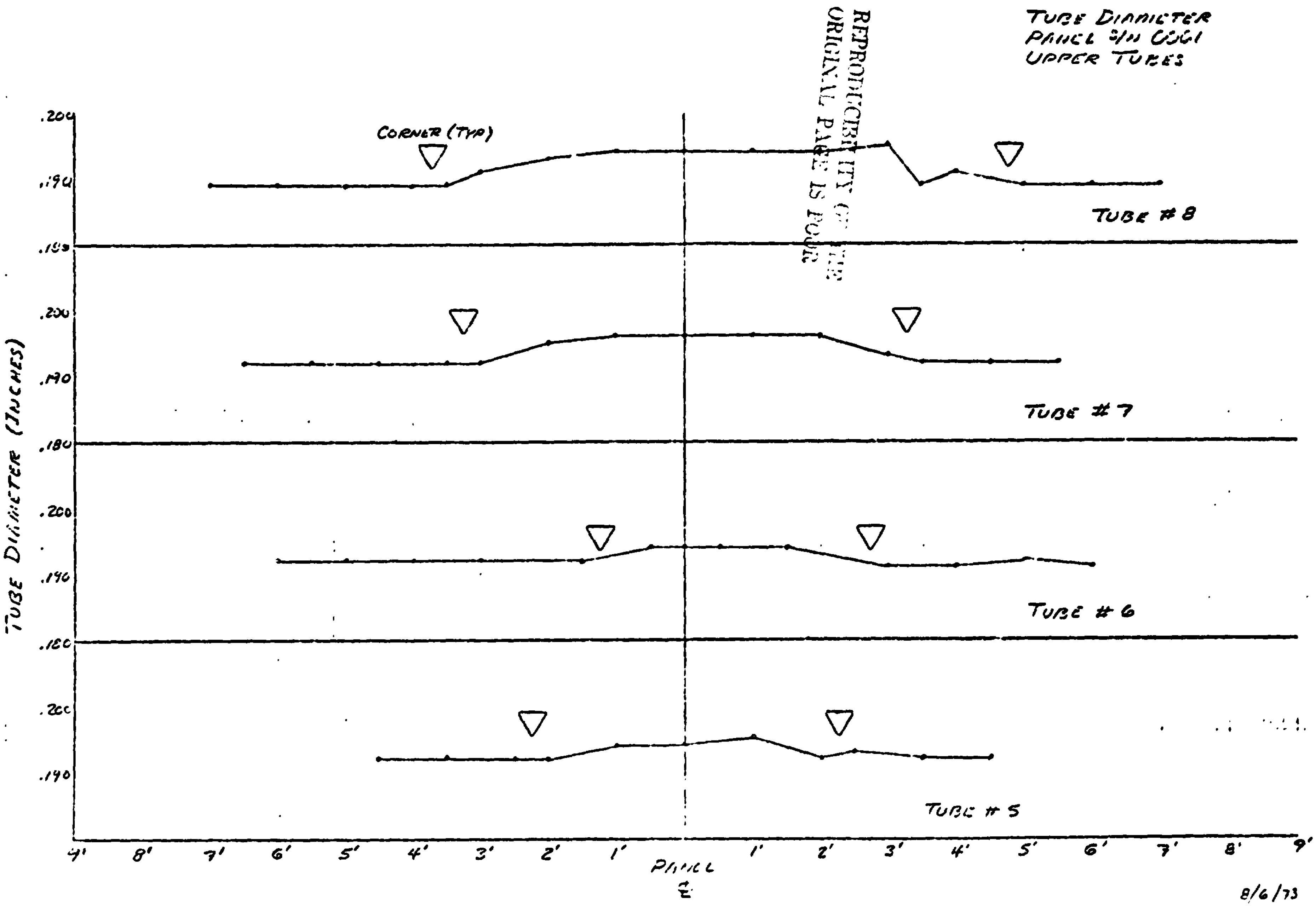
PANEL 0008 (Lower Tubes)

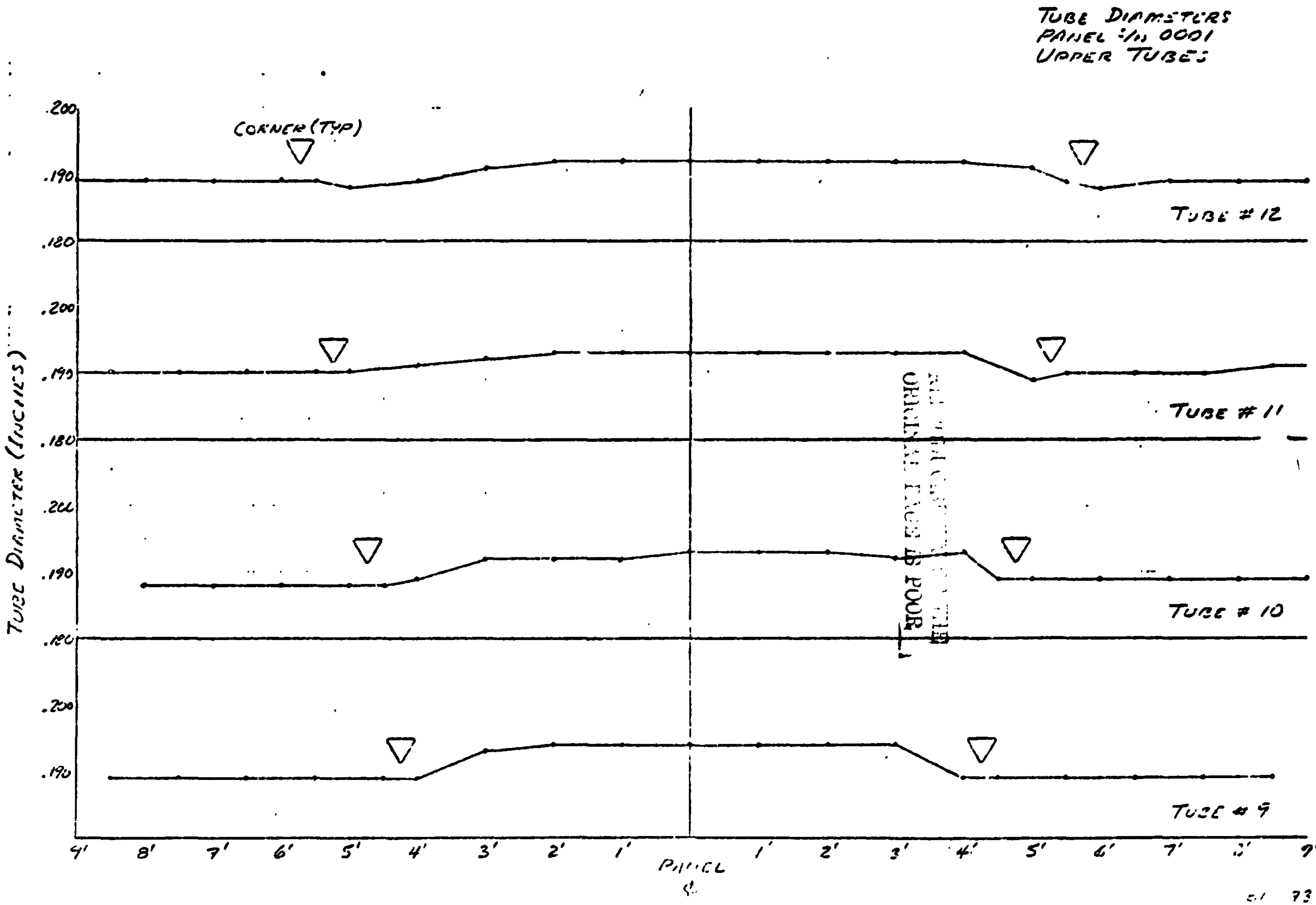
1-3	No Cracks
4	Paint crack inside center section 10 o'clock
5-8	Paint cracks inside and outside center section 10 o'clock
9	Paint crack outside center section 10 o'clock
10	Paint cracks inside and out center section 10 o'clock tube partially crushed by welding machine during fab at one spot in center section. Flow checked ok. Pronounced paint crack at this location approx. 11 o'clock (in radius at crush).
11-12	Hairline cracks inside and out center section 10 o'clock

APPENDIX 2

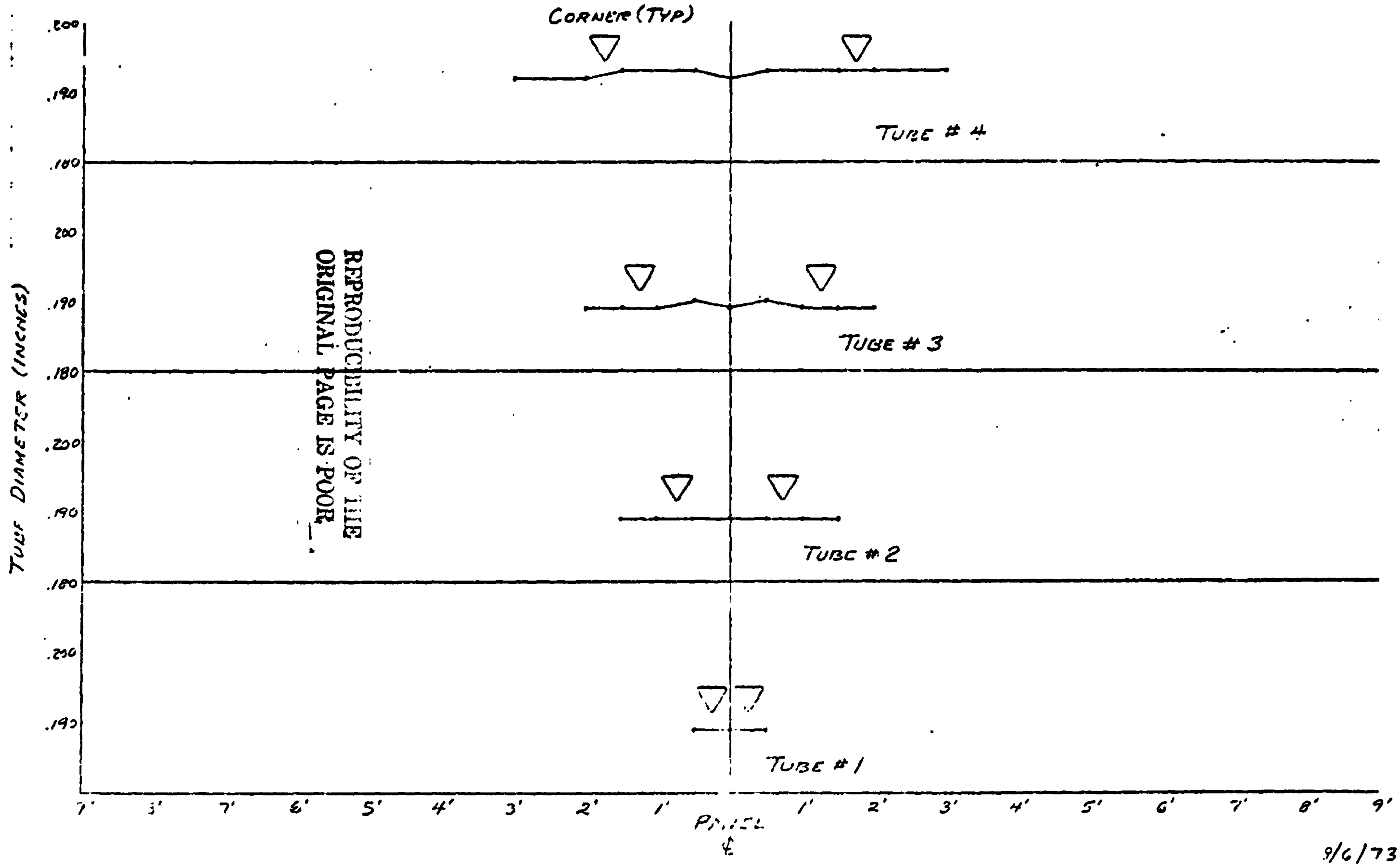
TUBE DIMENSIONS AFTER THERMAL VACUUM TESTS


TUBE DIAMETER
PANEL S/N 0001
UPPER TUBES
CORNER (TYP)
TUBE #4
TUBE #3
TUBE #2
TUBE #1
.200
.190
.180
.190
.180
.190
.190
TUBE DIAMETER (INCHES)
9'
8'
7'
6'
5'
4'
3'
2'
1'
PANEL
℄
1'
2'
3'
4'
5'
6'
7'
8'
9'
8/6/73

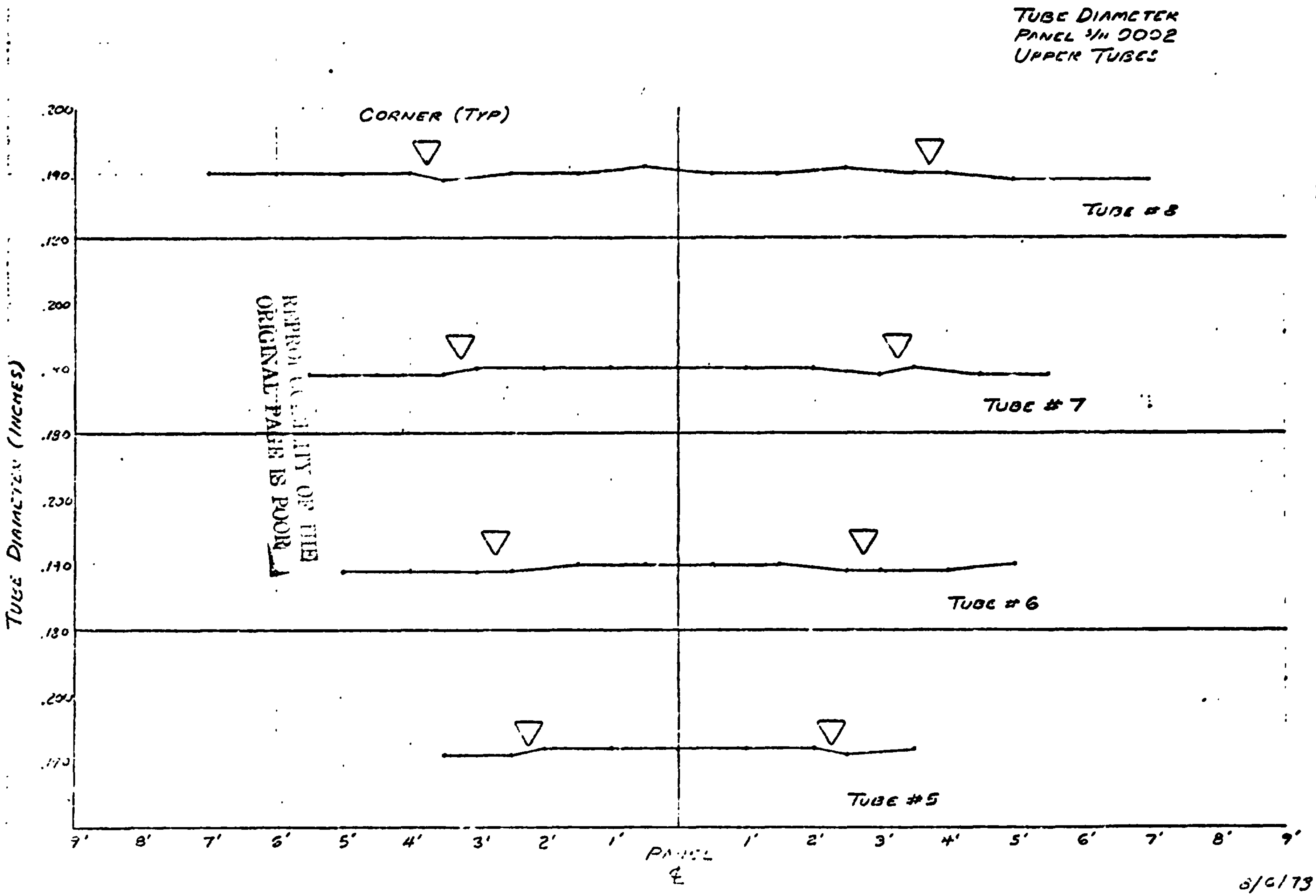

TUBE DIAMETER
PANEL S/N C0G1
UPPER TUBES
CORNER (TYP)
TUBE # 8
TUBE # 7
TUBE # 6
TUBE # 5
.200
.190
.180
TUBE DIAMETER (INCHES)
PANEL
℄
8/6/73

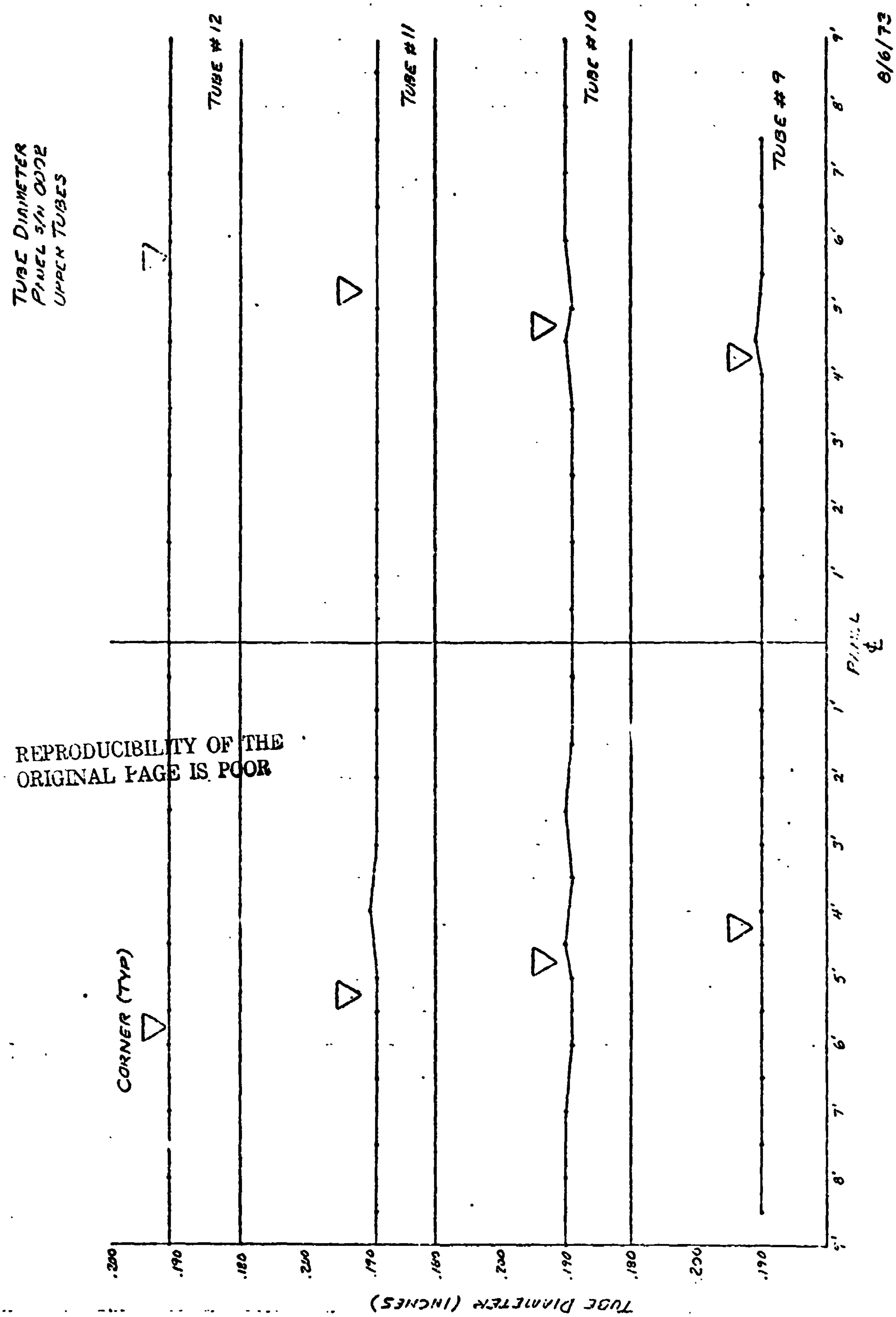

TUBE DIAMETERS
PANEL S/N 0001
UPPER TUBES
CORNER (TYP)
TUBE # 12
TUBE # 11
TUBE # 10
TUBE # 9
.200
.190
.180
TUBE DIAMETER (INCHES)
9'
8'
7'
6'
5'
4'
3'
2'
1'
PANEL ℄
ORIGINAL PAGE IS POOR

TUBE DIAMETER
PANEL S/N 0002
UPPER TUBES

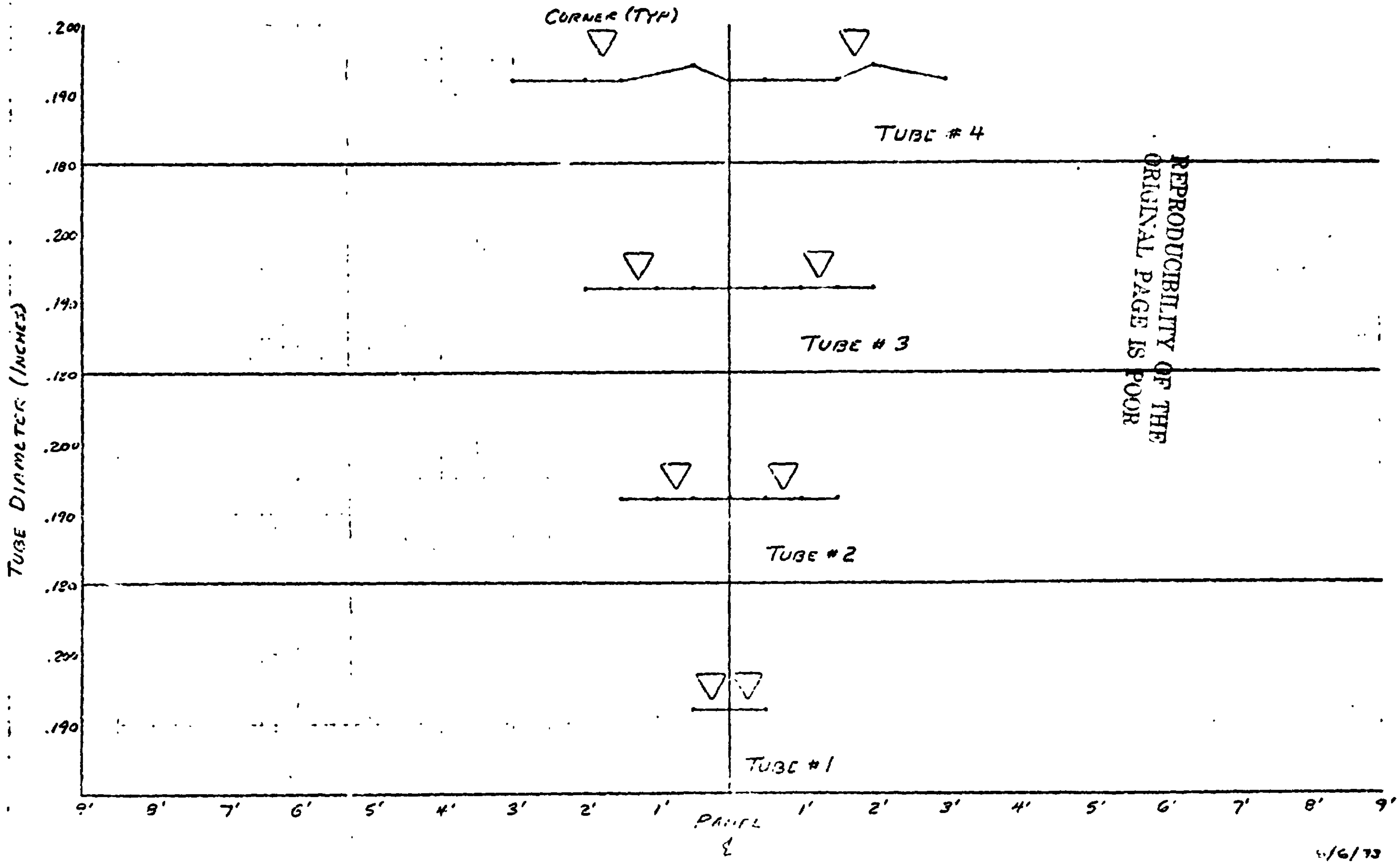


9/6/73

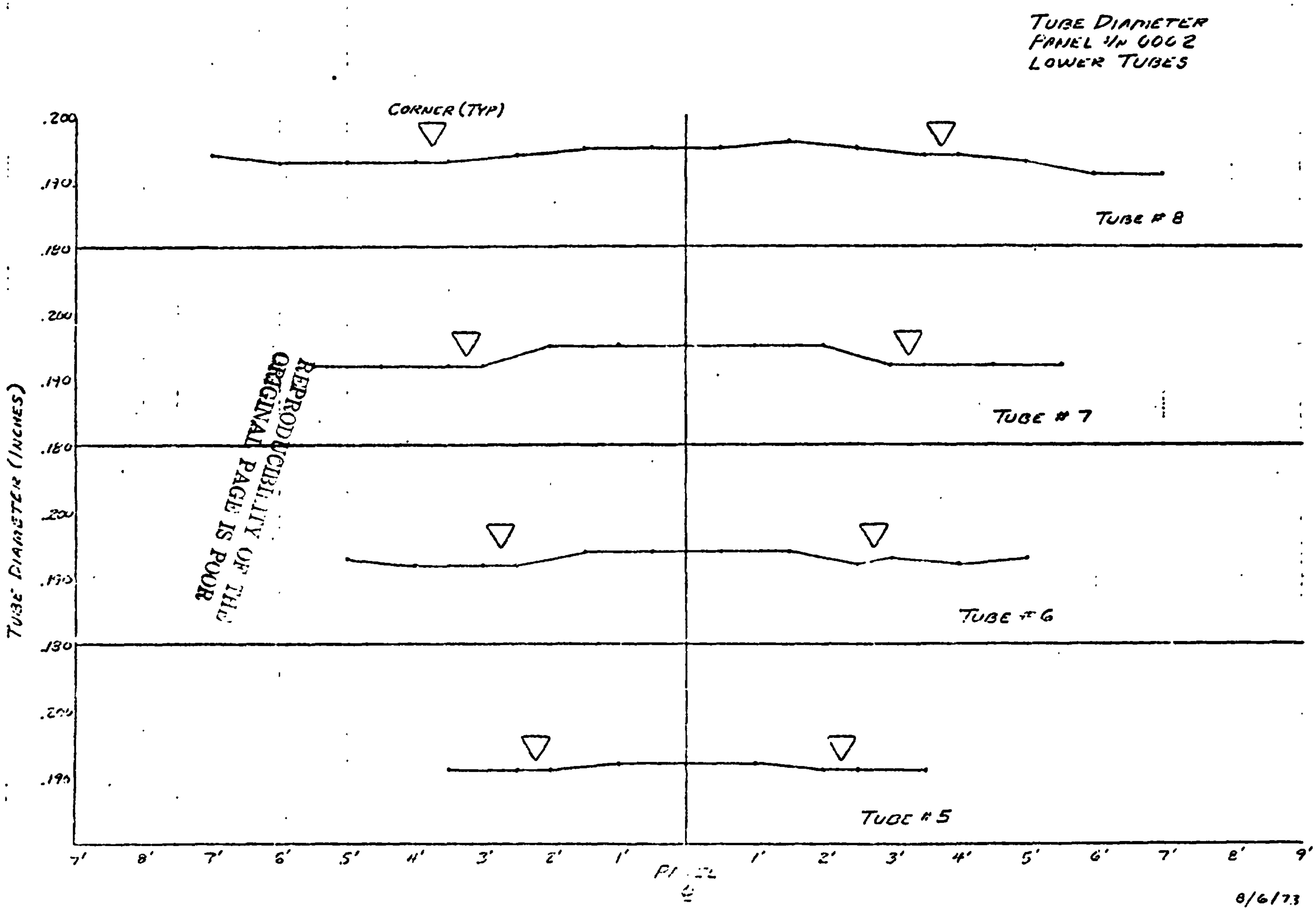

TUBE DIAMETER
PANEL 3/11 0002
UPPER TUBES
CORNER (TYP)
TUBE #8
TUBE #7
TUBE #6
TUBE #5
.200
.190
.120
.200
.180
.230
.140
.180
.170
TUBE DIAMETER (INCHES)
9' 8' 7' 6' 5' 4' 3' 2' 1'
PANEL ℄
1' 2' 3' 4' 5' 6' 7' 8' 9'
8/6/73


TUBE DIAMETER
PANEL S/N 0002
UPPER TUBES
TUBE #12
TUBE #11
TUBE #10
TUBE #9
8/6/73
CORNER (TYP)
PANEL ℄
TUBE DIAMETER (INCHES)

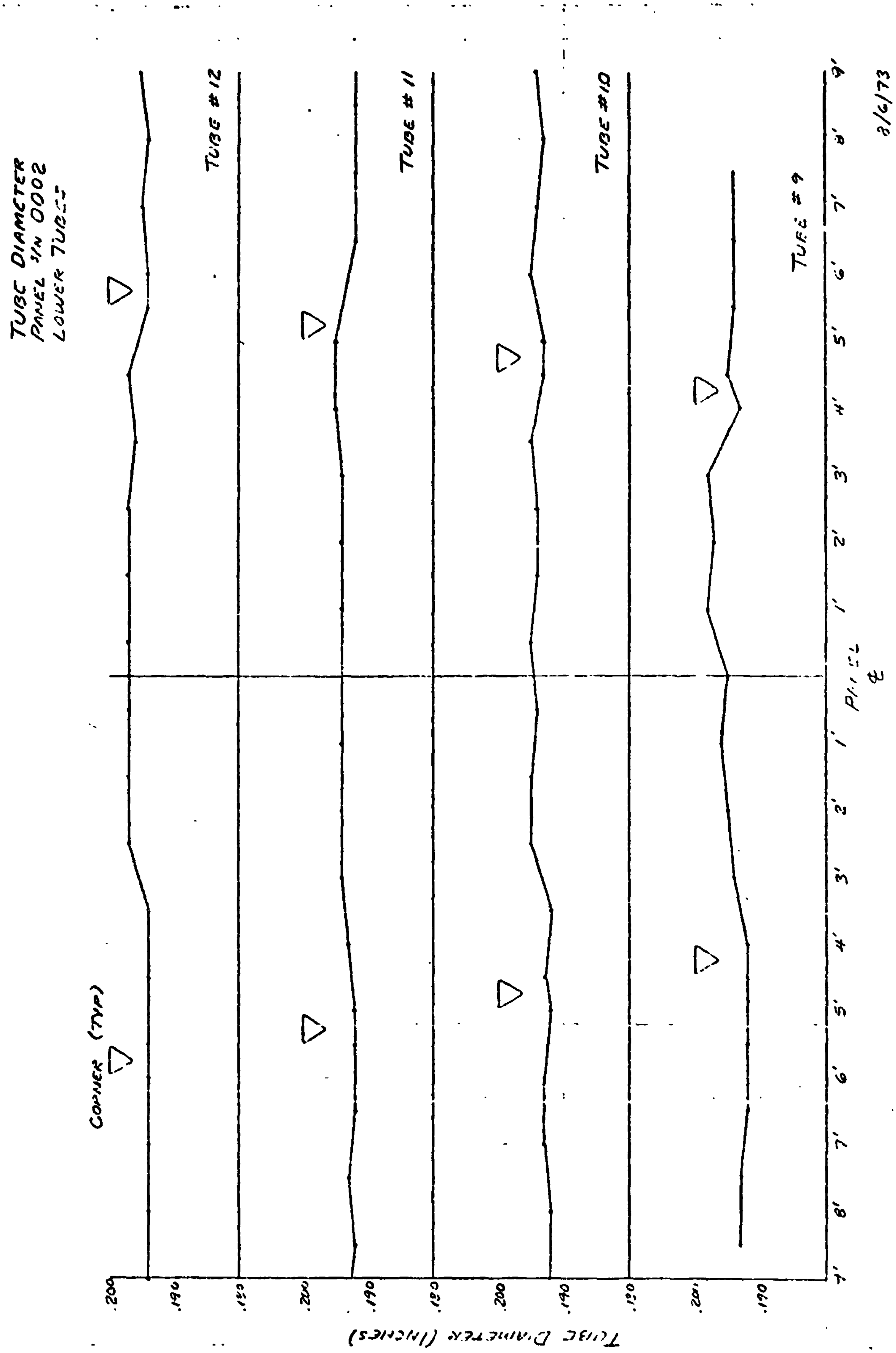
TUBE DIAMETER
PANEL 3/N COC L
LOWER TUBES

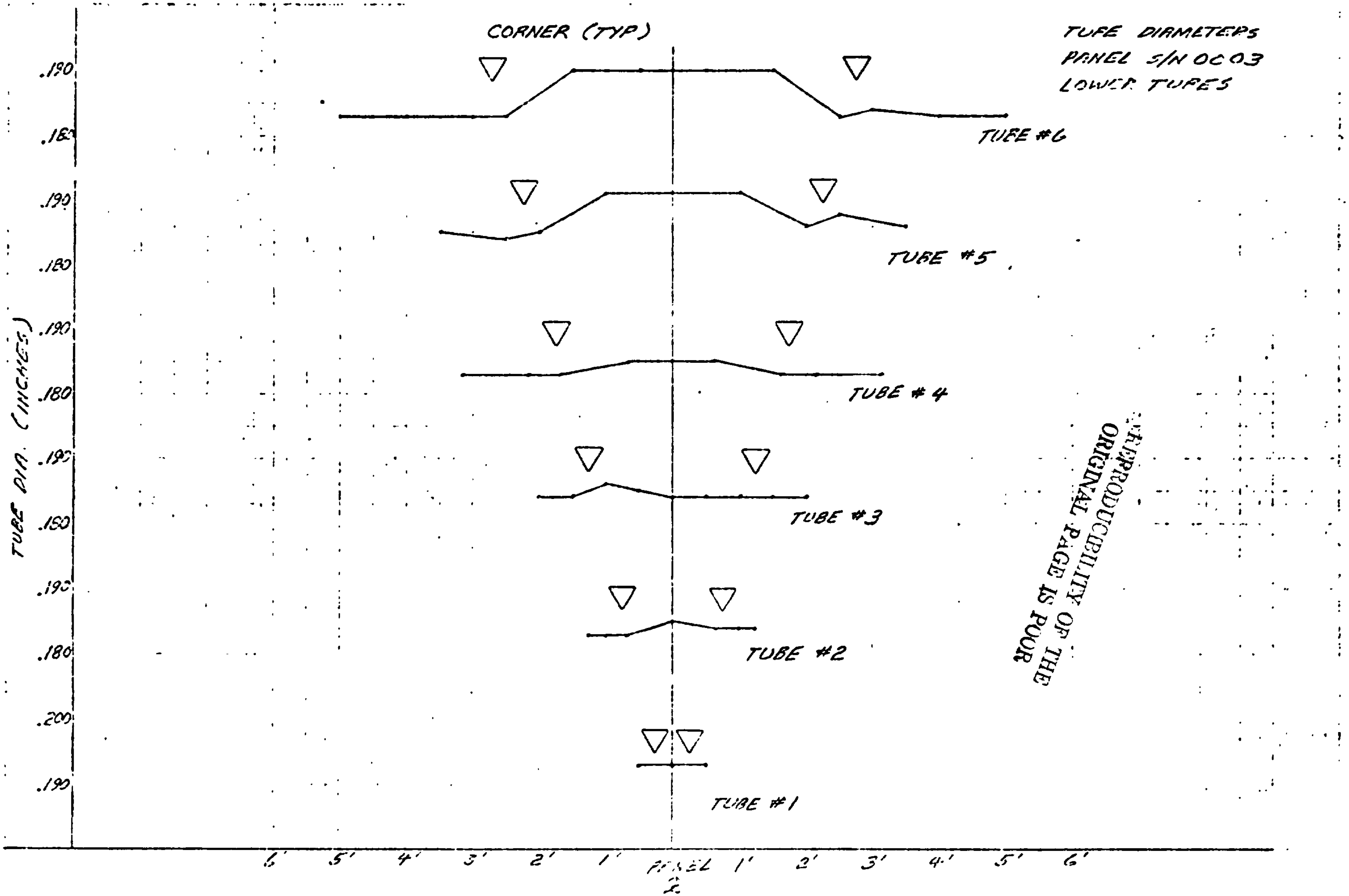


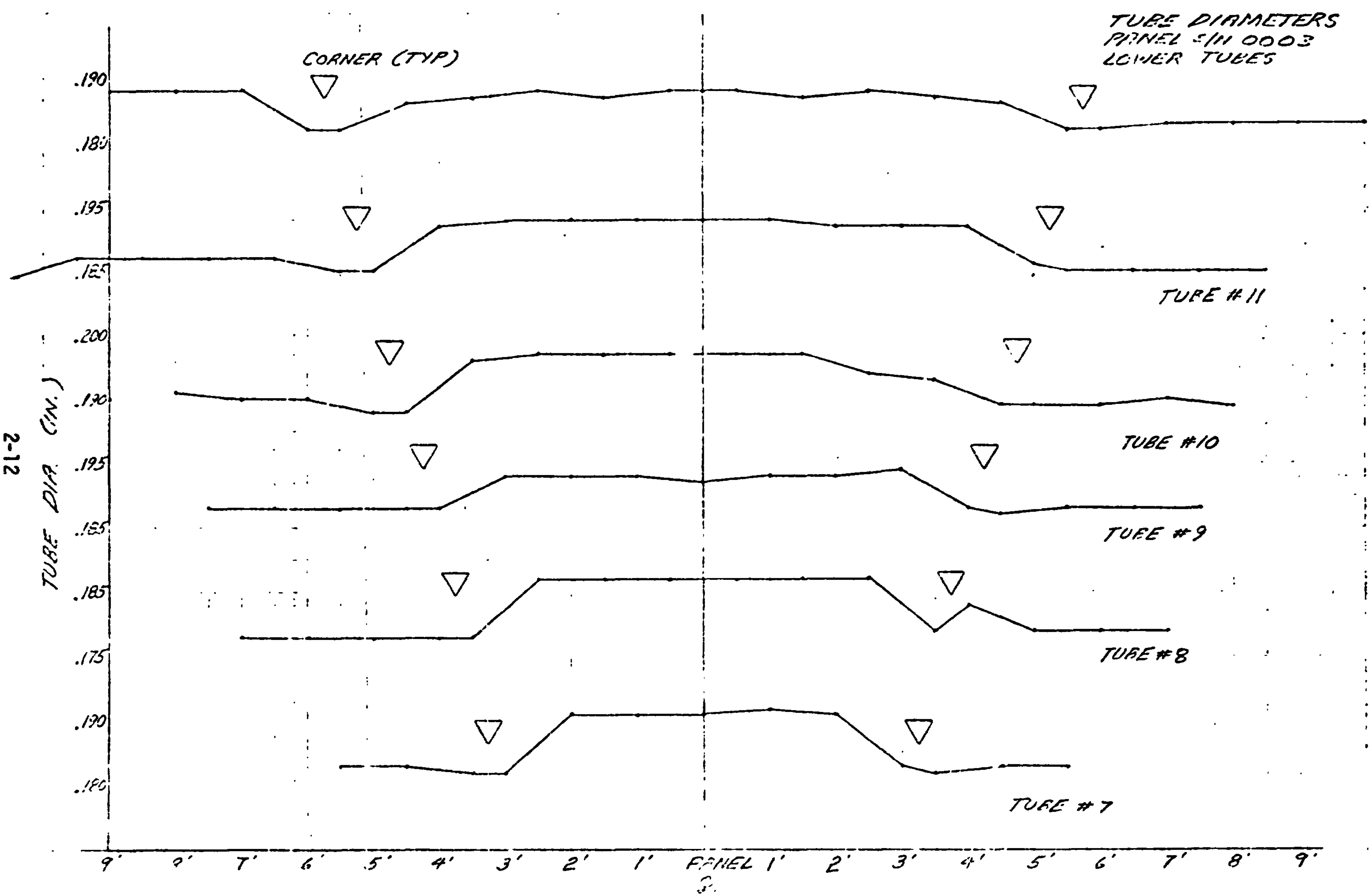
6/6/73



TUBE DIAMETER
PANEL 4/N 0002
LOWER TUBES
CORNER (TYP)
TUBE # 8
TUBE # 7
TUBE # 6
TUBE # 5
.200
.190
.180
.200
.190
.180
.200
.190
.180
.200
.190
TUBE DIAMETER (INCHES)
7'
8'
7'
6'
5'
4'
3'
2'
1'
1'
2'
3'
4'
5'
6'
7'
8'
9'
8/6/73


TUBE DIAMETER
PANEL S/N 0002
LOWER TUBES
TUBE # 12
TUBE # 11
TUBE #10
TUBE # 9
CORNER (TYP)
2/6/73
TUBE DIAMETER (INCHES)
.200
.190
.180
9'
8'
7'
6'
5'
4'
3'
2'
1'
PANEL ℄


TUBE DIAMETERS
PANEL S/N OC03
LOWER TUBES
CORNER (TYP)
TUBE #6
TUBE #5
TUBE #4
TUBE #3
TUBE #2
TUBE #1
TUBE DIA. (INCHES)
.190
.180
.200
6'
5'
4'
3'
2'
1'
PANEL ℄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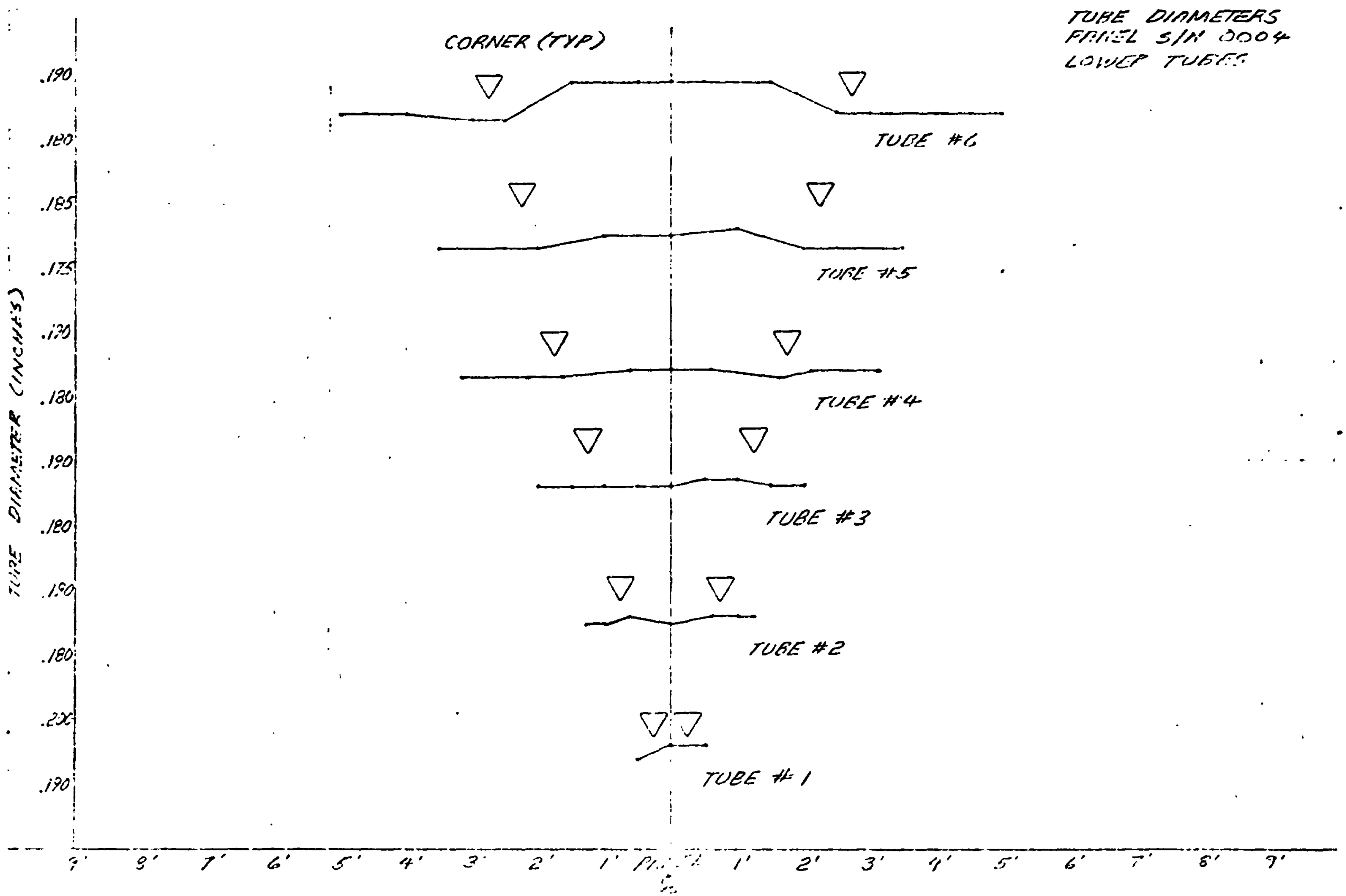
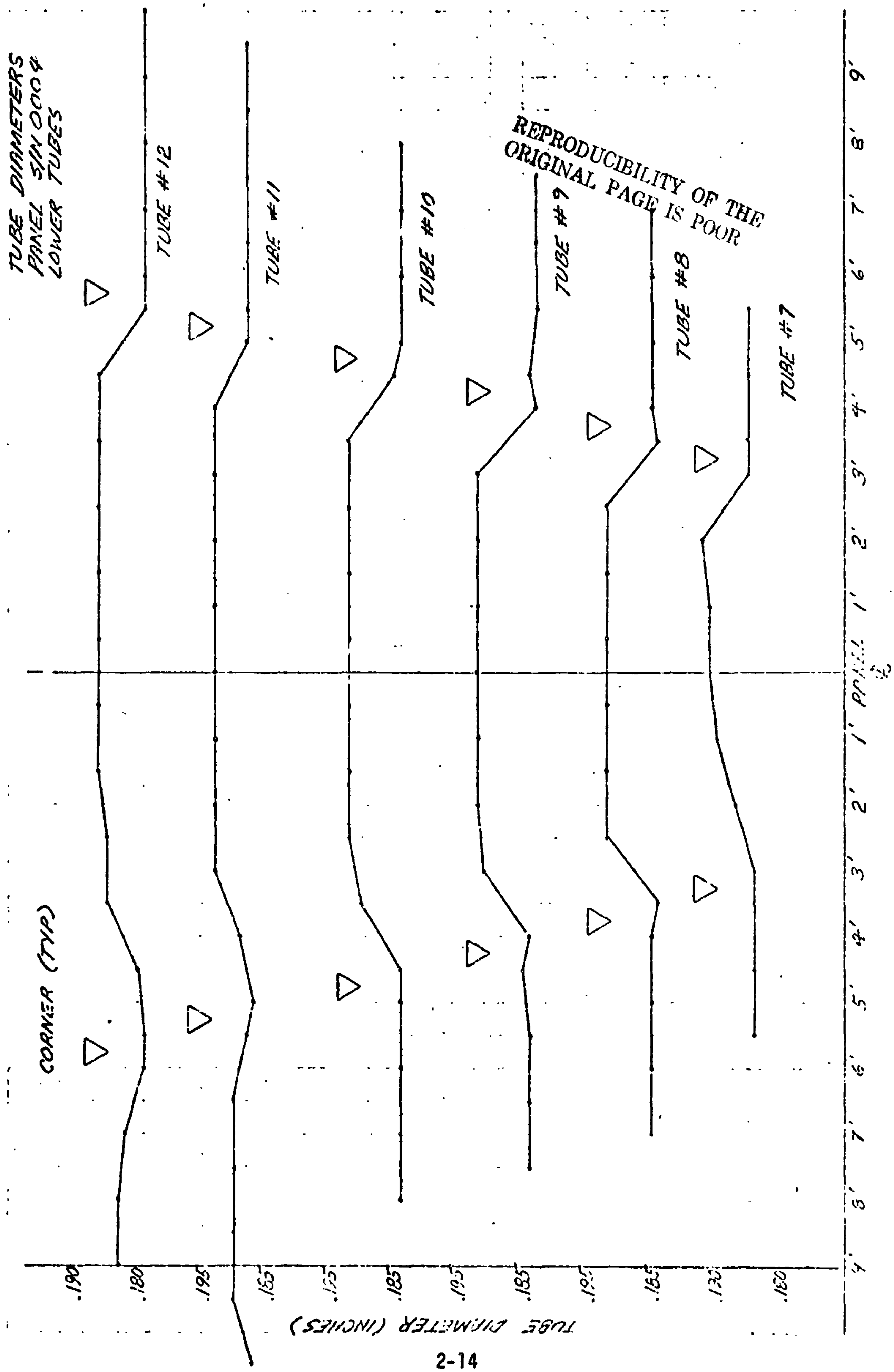
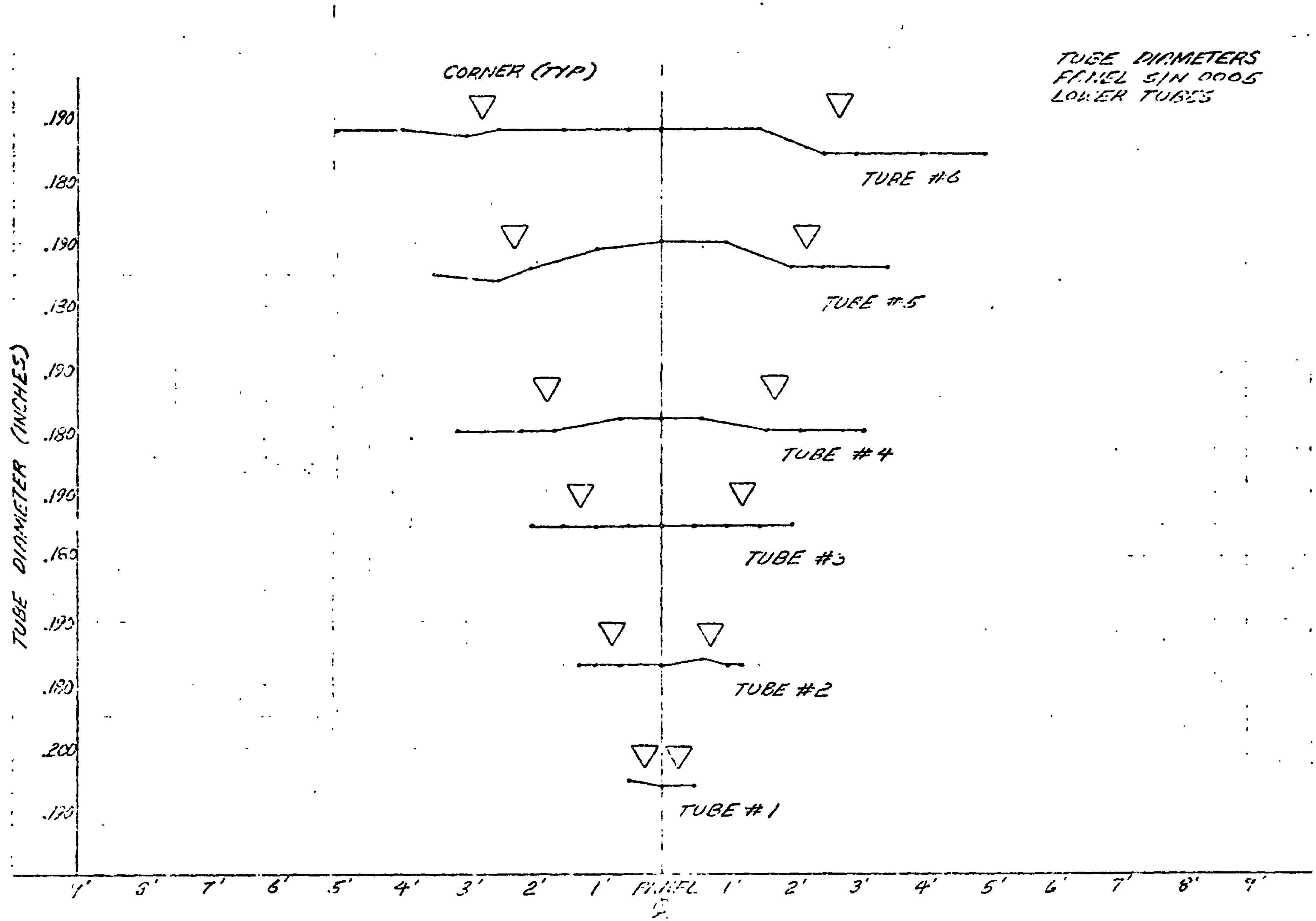
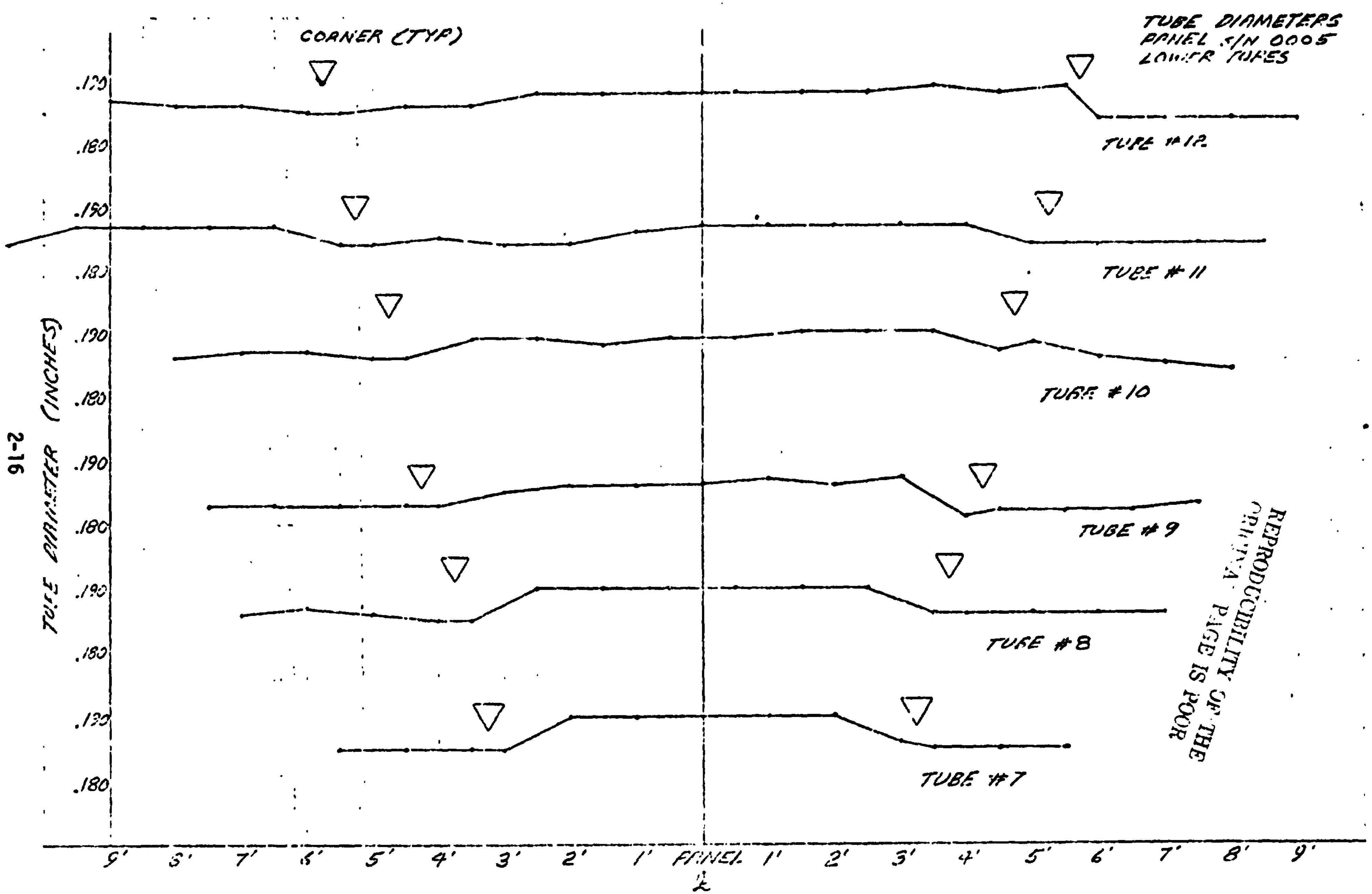
PANEL S/N 0003
LOWER TUBES
CORNER (TYP)
TUBE #11
TUBE #10
TUBE #9
TUBE #8
TUBE #7
TUBE DIA. (IN.)
PANEL


TUBE DIAMETERS
PANEL S/N 0004
LOWER TUBES
CORNER (TYP)
TUBE #6
TUBE #5
TUBE #4
TUBE #3
TUBE #2
TUBE #1
TUBE DIAMETER (INCHES)
.190
.180
.185
.175
.180
.190
.180
.190
.180
.200
.190
9'
8'
7'
6'
5'
4'
3'
2'
1'
1'
2'
3'
4'
5'
6'
7'
8'
9'



TUBE DIAMETERS
PANEL S/N 0004
LOWER TUBES
TUBE #12
TUBE #11
TUBE #10
TUBE #9
TUBE #8
TUBE #7
CORNER (TYP)
REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR
TUBE DIAMETER (INCHES)


TUBE DIAMETERS
PANEL S/N 0005
LOWER TUBES
CORNER (TYP)
TUBE #6
TUBE #5
TUBE #4
TUBE #3
TUBE #2
TUBE #1
TUBE DIAMETER (INCHES)
.190
.180
.200
.170
PANEL
1'
2'
3'
4'
5'
6'
7'
8'
9'


TUBE DIAMETERS
PANEL S/N 0005
LOWER TUBES
CORNER (TYP)
TUBE #12
TUBE #11
TUBE #10
TUBE #9
TUBE #8
TUBE #7
TUBE DIAMETER (INCHES)
.170
.180
.190
.180
.190
.180
.190
.180
.190
.180
.190
.180
9'
8'
7'
6'
5'
4'
3'
2'
1'
PANEL ℄
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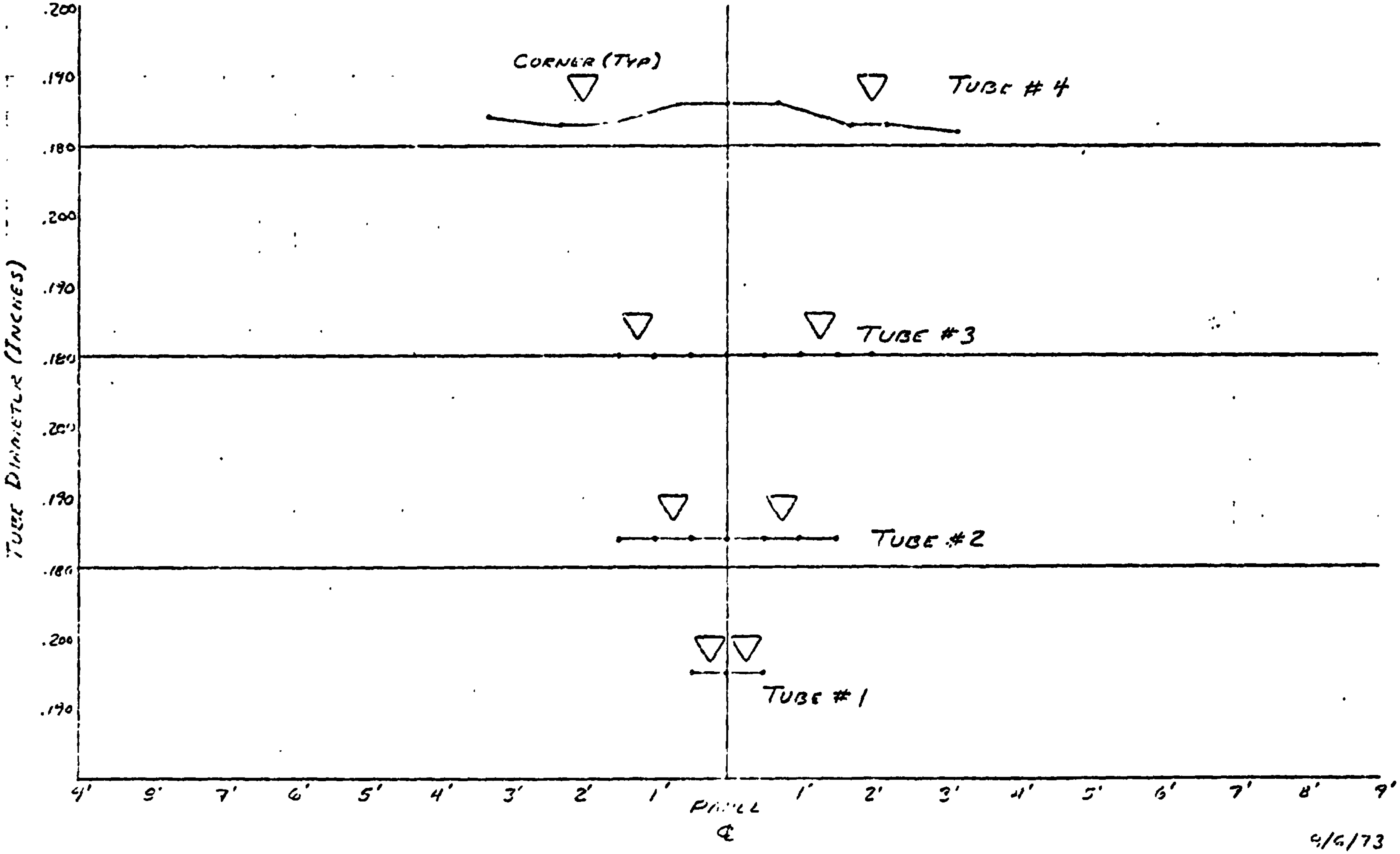
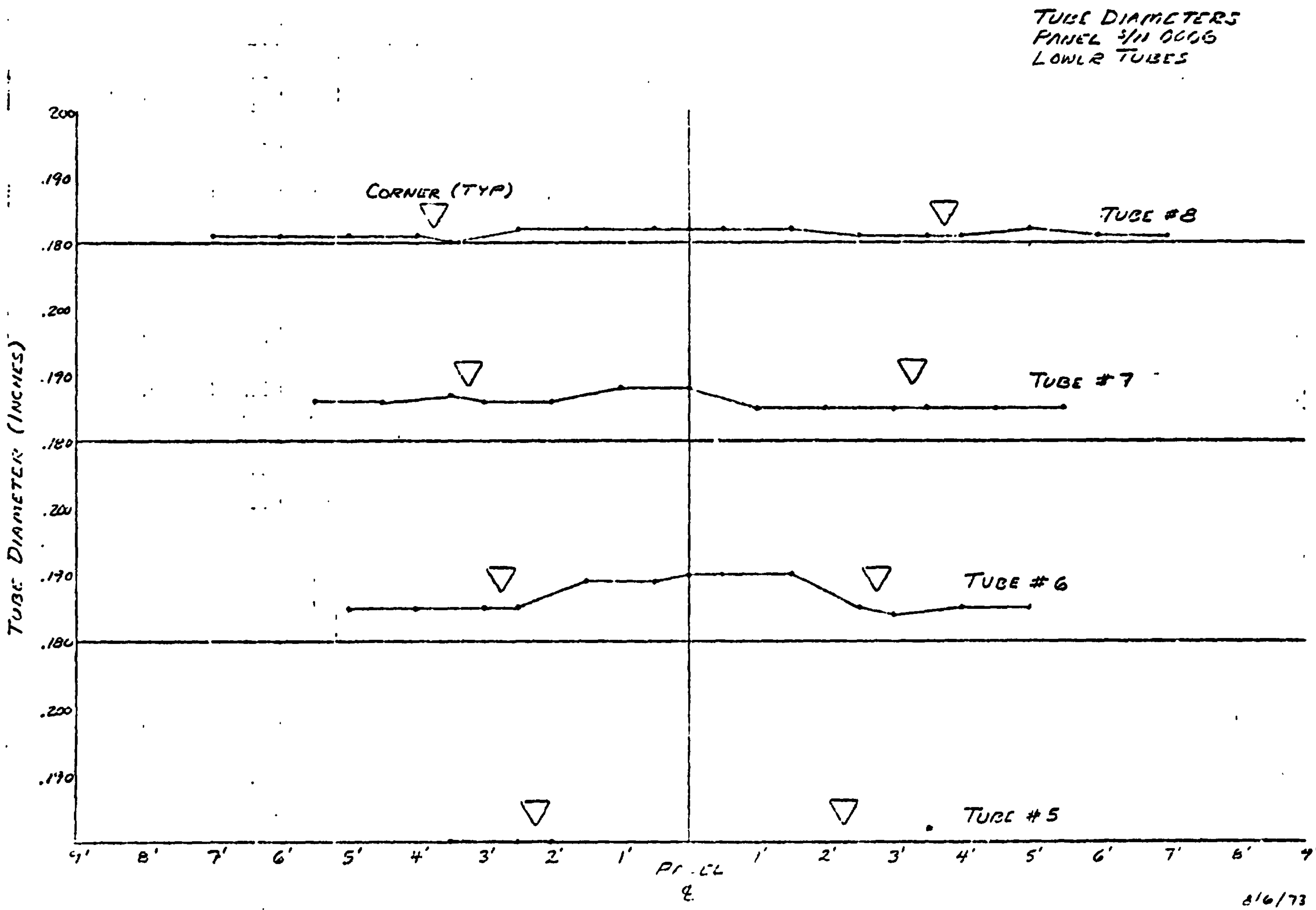
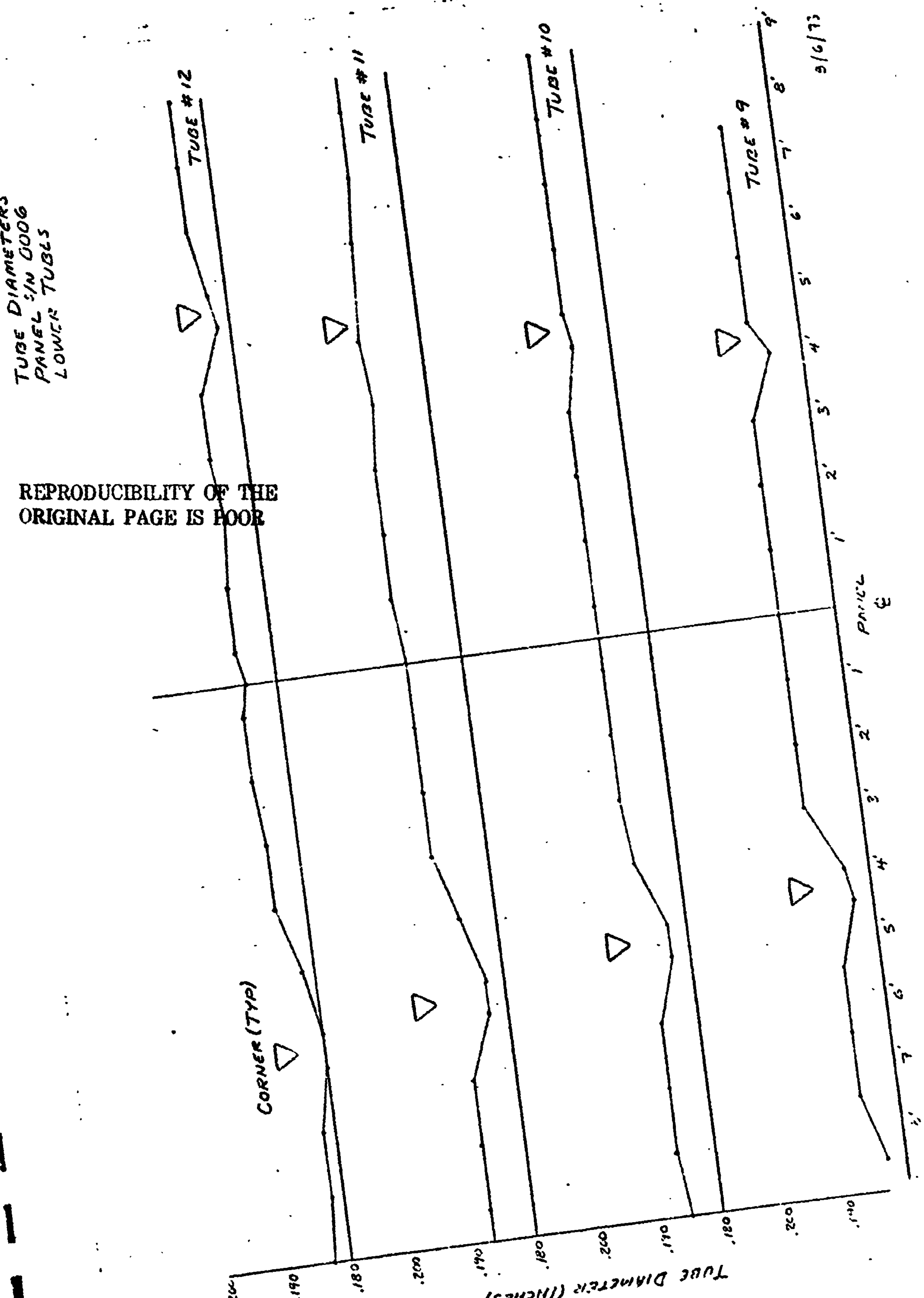
2'
3'
4'
5'
6'
7'
8'
9'

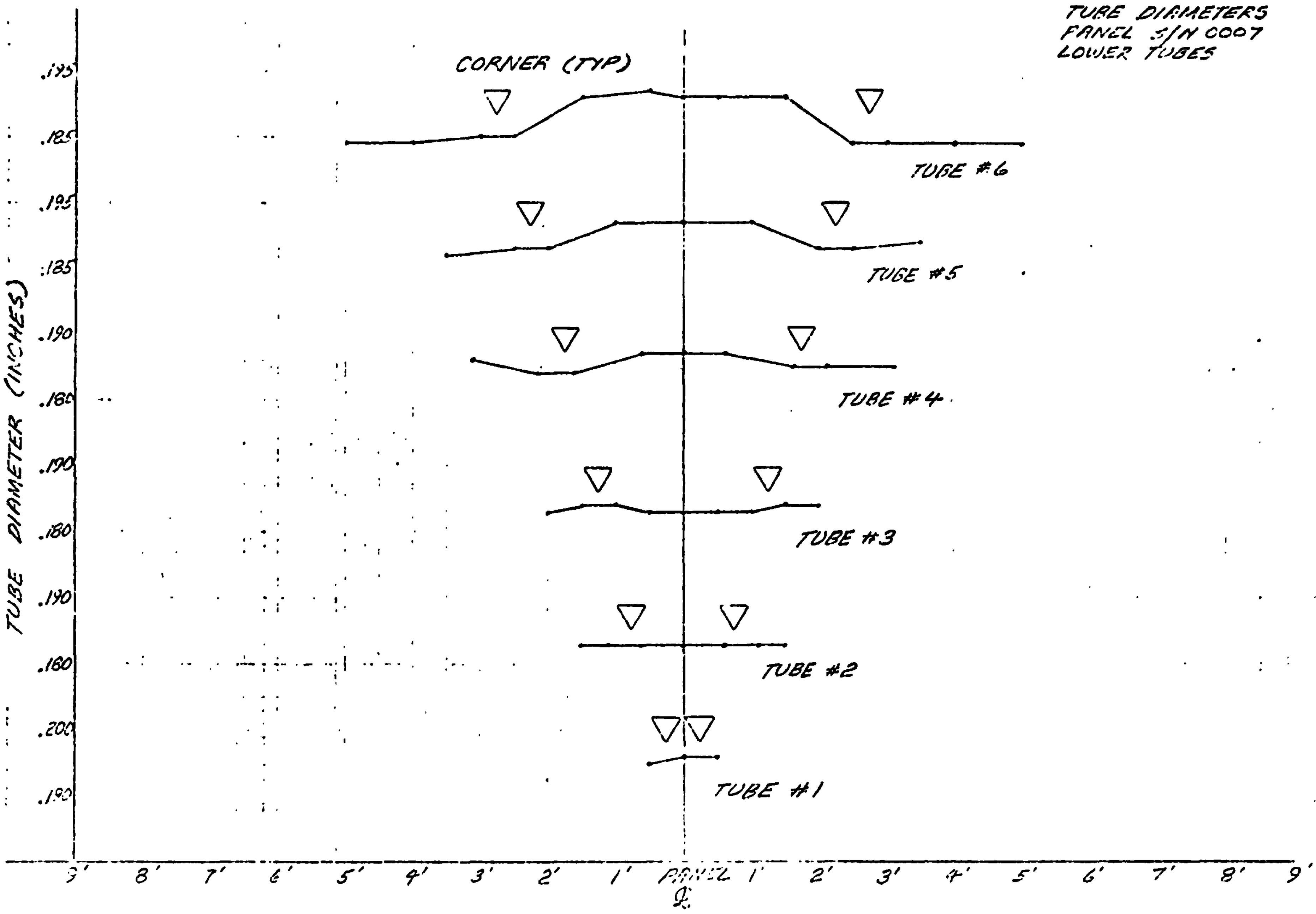
TUBE DIAMETERS
PANEL 3N OCC6
LOWER TUBES

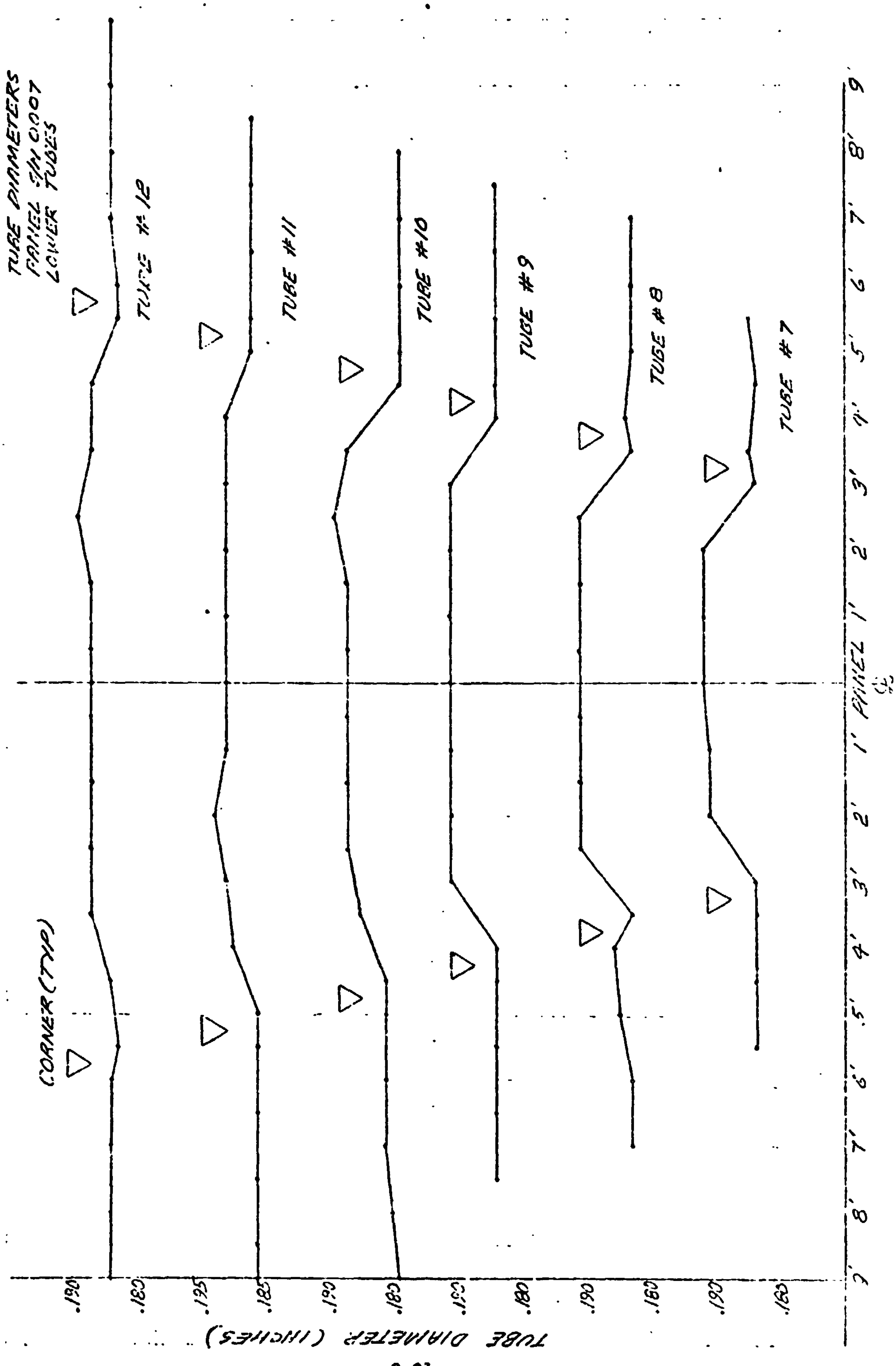



TUBE DIAMETERS
PANEL 3/11 0006
LOWER TUBES
CORNER (TYP)
TUBE #8
TUBE #7
TUBE #6
TUBE #5
TUBE DIAMETER (INCHES)
.200
.190
.180
9' 8' 7' 6' 5' 4' 3' 2' 1' PT. CL 1' 2' 3' 4' 5' 6' 7' 8' 9'
℄
8/6/73



REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR


TUBE DIAMETERS
PANEL S/N 0007
LOWER TUBES
CORNER (TYP)
TUBE #6
TUBE #5
TUBE #4
TUBE #3
TUBE #2
TUBE #1
TUBE DIAMETER (INCHES)
.195
.185
.195
.185
.190
.180
.190
.180
.190
.180
.200
.190
9'
8'
7'
6'
5'
4'
3'
2'
1'
PANEL ℄
1'
2'
3'
4'
5'
6'
7'
8'
9'


TUBE DIAMETERS
PANEL S/N 0007
LOWER TUBES
TUBE #12
TUBE #11
TUBE #10
TUBE #9
TUBE #8
TUBE #7
CORNER (TYP)
PANEL ℄
TUBE DIAMETER (INCHES)
.190
.180
.195
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.180
.190
.180
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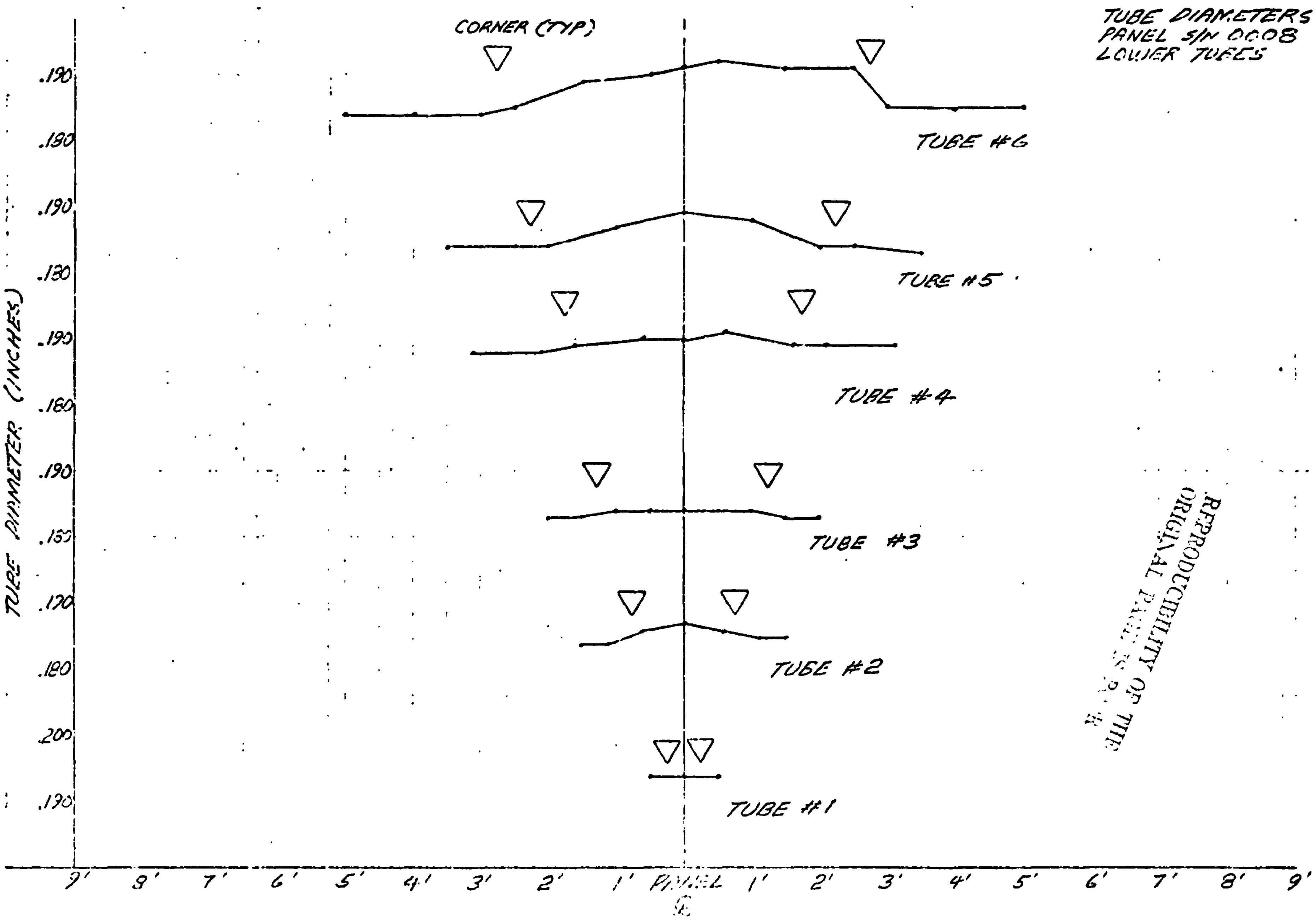
.180
9'
8'
7'
6'
5'
4'
3'
2'
1'
1'
2'
3'
4'
5'
6'
7'
8'
9'


TUBE DIAMETERS
PANEL S/N 0008
LOWER TUBES
CORNER (TYP)
TUBE #6
TUBE #5
TUBE #4
TUBE #3
TUBE #2
TUBE #1
TUBE DIAMETER (INCHES)
.190
.180
.190
.180
.190
.160
.190
.150
.170
.180
.200
.190
9'
8'
7'
6'
5'
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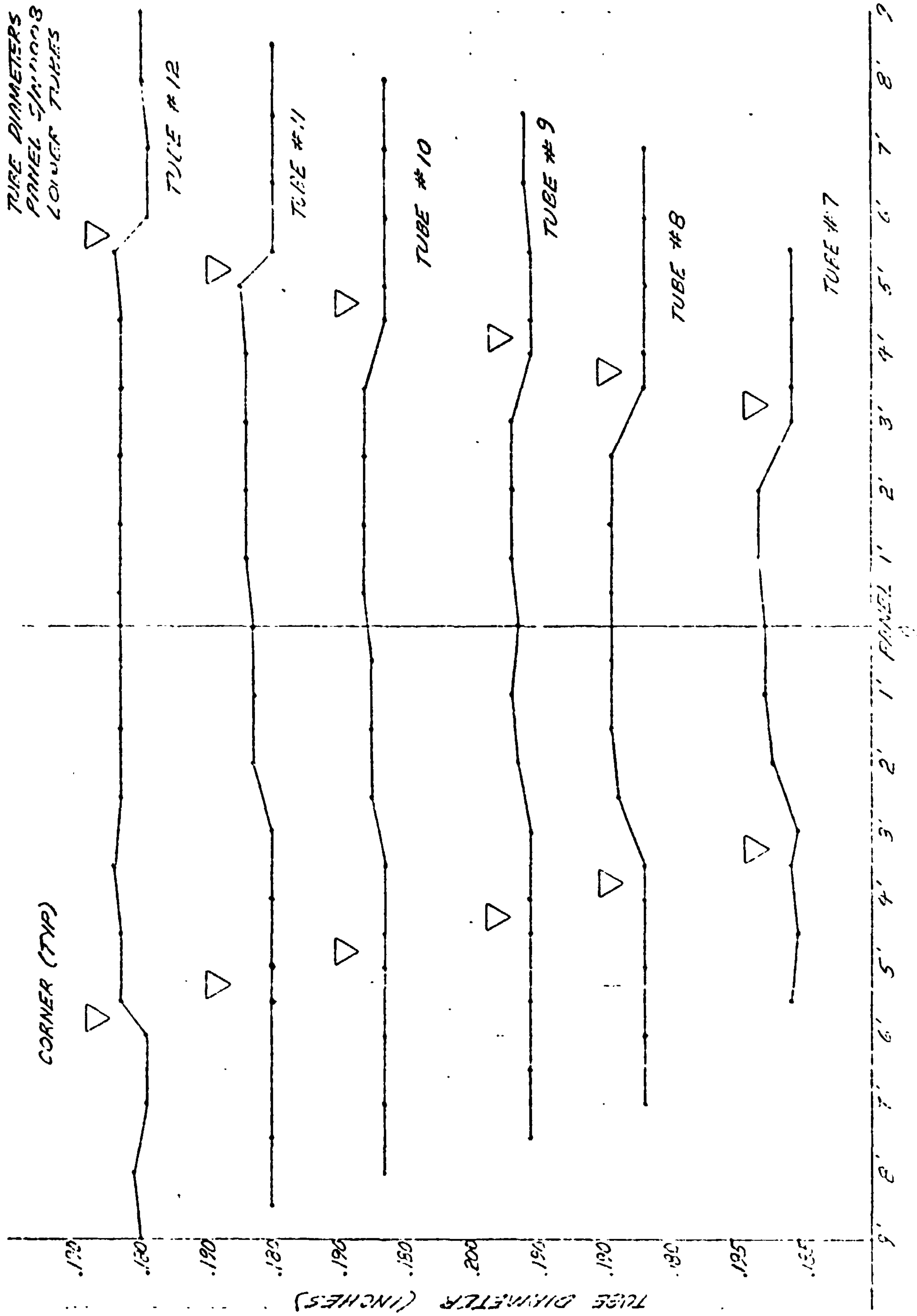
3'
2'
1'
PANEL
℄
1'
2'
3'
4'
5'
6'
7'
8'
9'


TUBE DIAMETERS
LOWER TUBES
TUBE #10
TUBE #9
TUBE #8
CORNER (TYP)
PANEL
TUBE DIAMETER (INCHES)
.190
.180
.200
.195