SCE MEETING WITH NRC

AUGUST 15, 1980

AGENDA

INTRODUCTION	SCE
PLANT STATUS	SCE
MECHANICAL PLUGS	W
DECONTAMINATION PROCESS STATUS	W
TUBE SLEEVING PROCESS UPDATE	W
ZONES TO BE SLEEVED	W
SUMMARY	SCE

PLANT STATUS

- RPC EDDY CURRENT TESTING COMPLETE

  SG A HOT LEG - 2315 TUBES TESTED

  SG A COLD LEG - 104 TUBES TESTED

  SG B HOT LEG - 1923 TUBES TESTED

  SG C HOT LEG - 2720 TUBES TESTED

- IN-SITU PRESSURE TESTS COMPLETE

  SG A - 22 TUBES (NON-LEAKERS)

  SG C - 5 TUBES (LEAKERS)

- TUBE PULLING COMPLETE

  SG A 9 TUBES HL/1 TUBE CL

  SG C 4 TUBES HL

- SLEEVING ZONES

- TUBE PLUGGING

- CHEMISTRY PROGRAM - IN DEVELOPMENT

- SITE PREPARATION FOR SLEEVING PROGRAM UNDERWAY

  DECONTAMINATION

  IN PLANT DEMONSTRATION SLEEVING

EXPANDED MECHANICAL PLUG

- PRESENTATION TO NRC APRIL, 1980
  - DESIGN
  - PROTOTYPE TESTING
  - PLANT INSTALLATION
- W REPORT TO NRC SCHEDULED FOR WEEK OF AUGUST 25, 1980

3/4" MECHANICAL PLUG STATUS

- O DESIGN DETAILS COMPLETED, CONFIRMED EVALUATION 7/8" PLUG
- O AUTOCLAVE TEST STARTED
- O MECHANICAL INSTALLATION CRITERIA ESTABLISHED
- O INSTALLATION TOOLS AVAILABLE
- O PLUGS BEING MANUFACTURED

ROLLED TUBE PLUG DESIGN CRITERIA

- THE PLUG SHOULD PREVENT TUBES FROM LEAKING
  ACCEPTABLE PLUG LEAK RATE = 10 DROPS/MIN (.00015 GPM)

- THE PLUG SHOULD BE STABLE AND WITHSTAND PRIMARY PRESSURES

  HYDROTEST PRESSURE = 3728 PSIG (150% DESIGN PRESSURE) THE PRESSURE IS TO BE CONSERVATIVELY APPLIED FROM WITHIN THE TUBE FORCING THE PLUG OUT.

- THE PLUG WHEN REMOVED SHOULD LEAVE THE TUBE INSIDE SURFACE SUITABLE FOR SLEEVING

- THE PLUG DESIGN SHOULD PERMIT REMOTE INSTALLATION AND REMOVAL

ROLLED TUBE PLUG
REMOTE INSTALLATION

- THE PLUG IS DESIGNED TO BE DELIVERED TO THE TUBE BY AIR PRESSURE AND TO STICK IN THE TUBE

- A SEMI-REMOTE MANIPULATOR WILL DIRECT THE AIR HOSE TO THE PROPER TUBE AND AFTER ALL ARE INSTALLED WILL EXPAND THE PLUGS.

- THIS OPERATION WILL MOST LIKELY TAKE PLACE PRIOR TO DECONTAMINATION

- FOLLOWING IS AN ESTIMATION OF THE RADIATION EXPOSURE ELIMINATED BY REMOTE INSTALLATION

$$\text{MAN-REM SAVINGS} = \frac{\text{500 PLUGS}}{\text{CHAMBER}} \; \frac{\text{6 CHAMBERS}}{\text{SCE}} \left[\frac{\text{0.5 MIN}}{\text{PLUG}} - \frac{\text{0.1 MIN}}{\text{PLUG}} \right] \frac{\text{HOUR}}{\text{60 MIN}} \; \frac{\text{10 REM}}{\text{HOUR}}$$

(0.5 MIN/PLUG: MANUAL RATE; 0.1 MIN/PLUG: REMOTE RATE)

$$= \text{200 MAN-REM}$$

ROLLED TUBE PLUG TEST RESULTS

- ALL THIRTY TEST SAMPLES HAVE BEEN PRESSURIZED AND PASSED THE HYDROTEST PRESSURE OF 3728 PSIG.

- THE HIGHEST LEAK RATE INITIATED AT 6600 PSIG AND WAS 9 DROPS/MIN (NO LEAKAGE OCCURED AT LOWER PRESSURE)

- THE LOWEST PRESSURE AT WHICH LEAKAGE WAS OBSERVED WAS 3500 PSIG. THE LEAK RATE WAS 0.03 DROP/MIN (1 DROP IN 30 MINUTES)

- ONLY ONE OF THIRTY SAMPLES LEAKED AT THE 3728 PSIG HYDROTEST ACCEPTANCE PRESSURE.

- HALF OF THE SAMPLES DID NOT LEAK OR MOVE WHEN SUBJECTED TO 7000 PSIG

- HALF OF THE SAMPLES WERE SUBJECTED TO THERMAL CYCLES PRIOR TO PRESSURE TESTING. (ROOM TEMPERATURE TO 650^{o}F FROM 2 TO 10 CYCLES)

- PLUGS ARE READILY REMOVABLE

ROLLED TUBE PLUG SCHEDULE

- 500 AVAILABLE BY 8/15
- MATERIAL FOR REMAINING 2500 ON HAND*
- EXPANDING TOOLS AVAILABLE
- 3 SEMI-REMOTE MANIPULATORS AVAILABLE BY 8/22
- PLUG REMOVAL EQUIPMENT AVAILABLE

*REMAINING PLUGS TO BE ORDERED WHEN NEEDED

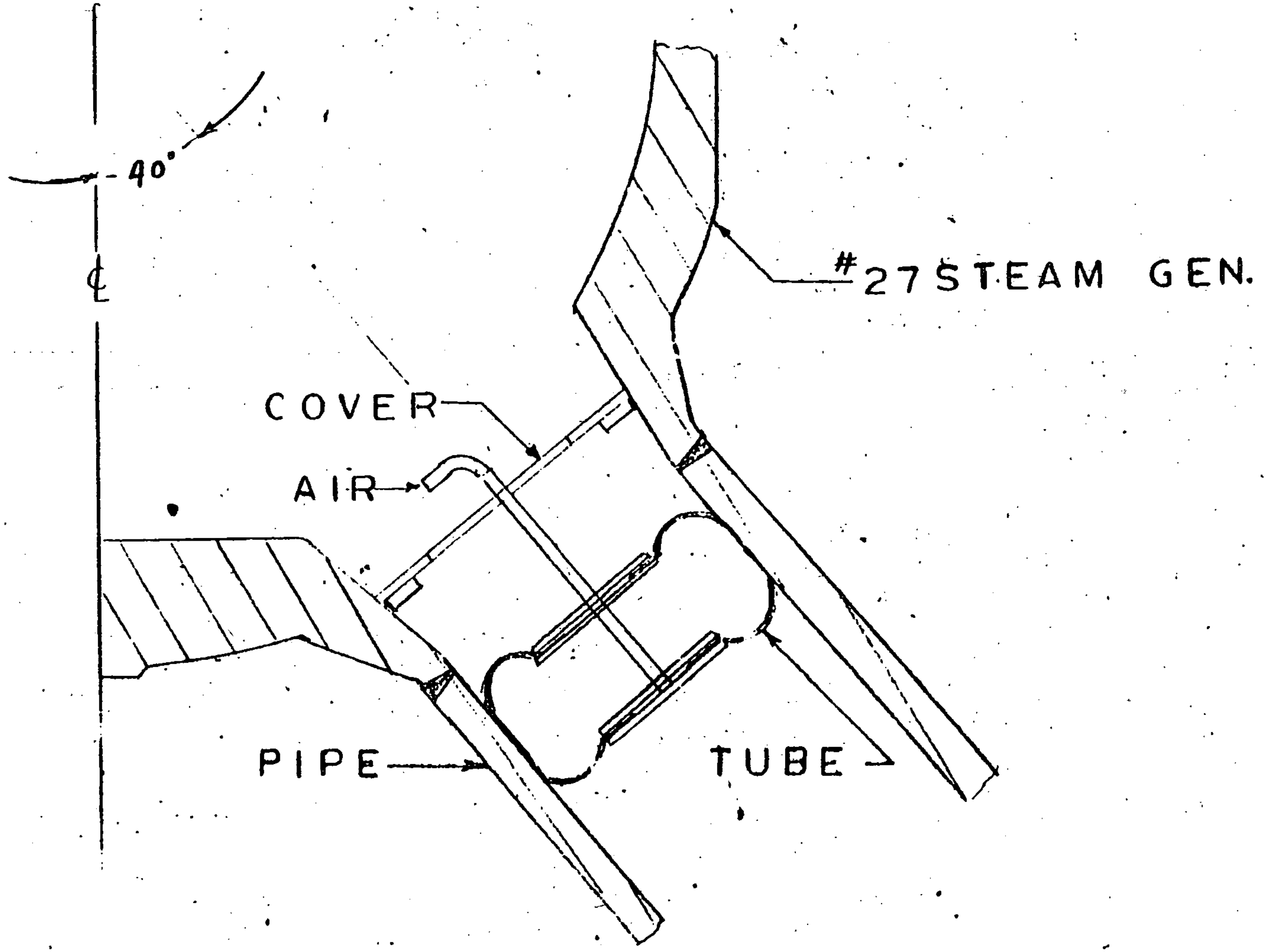
NOZZLE SEAL DESIGN FEATURES

CONCERN

- 0 WATER TIGHT BALLOON SEAL INFLATED IN R.C. PIPE (DROPS PER HOUR)

- 0 METAL NOZZLE COVER INSTALLED OVER NOZZLE AREA, PROVIDING SECOND SEAL LIMITING LEAK RATE

- 0 BALLOON SEAL MONITORED VIA PRESSURE GAGE OUTSIDE CHANNEL HEAD



NOZZLE SEAL ASSEMBLY

PIPE NOZZLE

CONCERN

O PIPE NOZZLE SEAL FAILURE

- CLOSED CYCLE DECON SYSTEM WITH 200 TO 300 GALLONS OF WATER

- REACTOR COOLANT SYSTEM SHUTDOWN CONDITION WILL ALLOW ADDITION OF UNBORATED WATER (50 PPM CHANGE)

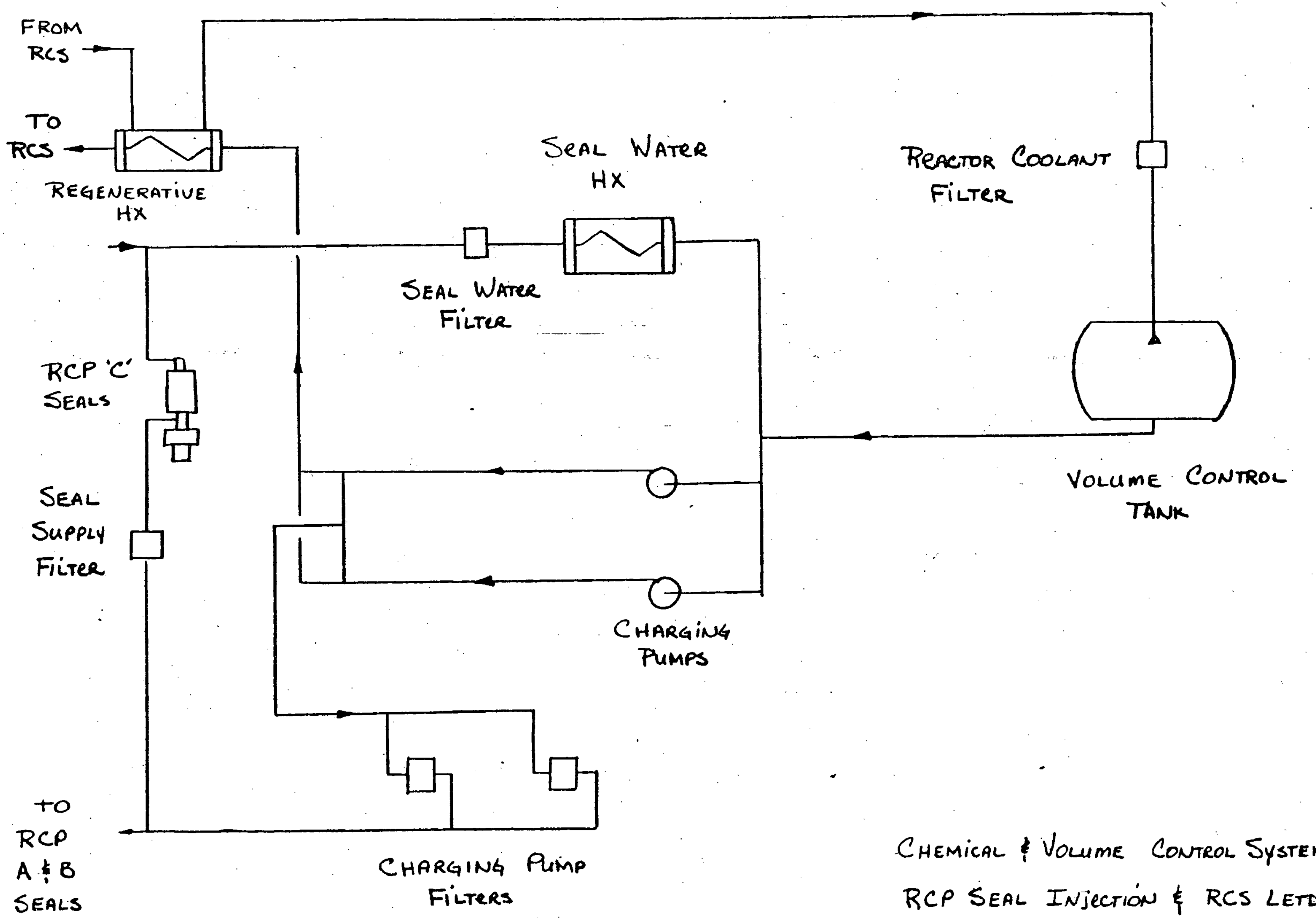
- R.C. SYSTEM AT 3410 PPM - TECHNICAL SPECIFICATION REQUIRES 2000 PPM MINIMUM

MAGNETITE ADDITION

CONCERN

O MAGNETITE GRIT ADDITION TO REACTOR COOLANT SYSTEM THRU FAILURE OF NOZZLE PLUG

- LIMITED VOLUME ACCESSIBLE TO R.C. SYSTEM WITH NOZZLE COVER IN PLACE - ESTIMATED 100/200 GRAMS
- 10 MICRONS OR GREATER PARTICULATES WILL BE FILTERED DURING CLEANUP OF REACTOR COOLANT SYSTEM AFTER SLEEVING VIA CVCS FILTERS, SEAL INJECTION FILTERS, ETC. (MAGNETITE IS 10 MICRONS OR GREATER)



CHEMICAL & VOLUME CONTROL SYSTEM

RCP SEAL INJECTION & RCS LETDOWN

SUMMARY OF MANWAY DIAPHRAM

DECON TEST

STEAM GENERATOR "A" COLD LEG

DATE	DIAPHRAM	S.G. BOWL SURFACE
1978	5 R	
AFTER MAGNITE DECON	50 MR	
INSTALLED 5-21-79	50 MR	2-3 R
REMOVED FOR INSPECTION 5-21-80	5 R	5 R

SUMMARY OF RADIATIONS LEVEL

IN "A" STEAM GENERATOR

BEFORE AND AFTER DECON

(5/72)

	STEAM GENERATOR A		STEAM GENERATOR B	
	HOT LEG	COLD LEG	HOT LEG	COLD LEG
BEFORE DECON 4/25/72				
Tubesheet	20-30	11-12	11	10
Channel Head	~~13~~	12	8	9
AFTER DECON 5/7/72				
Tubesheet	8	5	No Decon	
General Area	6	5		
AFTER OPERATION 11/5/74				
Tubesheet	25-35	10	13-14	10-11
Channel Head	15	13	15	10

OTHER OBSERVATIONS

1. Radiation levels in "A" steam generator hot leg was a factor of 2 higher than cold leg before decon, 4/25/72. (Hot leg, 20 R/Hr, Cold Leg 10 R/Hr.)
2. Hot leg levels were the same as cold leg shortly after decon, 10/17/72 about 10 R/Hr in both "A" and "B" steam generator.
3. Radiation levels in "A" steam generator, 11/4/74 were 35 R/Hr hot leg, 16 R/Hr cold leg. "B" steam generator levels were 13 R/Hr hot leg, 10 R/Hr cold leg.
4. "A" hot leg (4-3-80): 35 R/Hr
   "A" cold leg (4/3/80): 30 R/Hr
   "B" hot leg (4/3/80): 16 R/Hr
   "B" cold leg (4/3/80): 14 R/Hr
5. Al_2O_3 decon appear not to have increased levels significantly.

VERIFY ADEQUATE MECHANICAL PROPERTIES OF JOINT

ACTION REQUIRED	STATUS
1. Perform pressure tests.	Tests underway.
2. Perform collapse tests .	Tests underway.
3. Perform axial fatigue tests.	Tests underway.
4. Perform thermal and pressure cycling tests.	
a. Plant heat-up and shutdown transients.	Tests underway.
b. Plant load and unload transients.	Tests to start w/o Aug. 18.
5. Determine effect of brazing on tensile strength of tubing.	Completed.
6. Determine effect of flow induced vibration.	Analysis completed; indicates no problem.

VERIFY ADEQUATE CORROSION RESISTANCE OF JOINTS

ACTION REQUIRED	STATUS
1. Determine effect of brazing cycle on corrosion resistance of tube/sleeve.	Tests underway. Literature search completed.
2. Determine corrosion resistance of joints, including effect of residual flux.	Tests underway.
3. Determine effect of brazing cycle on diffusion of OD contaminants.	Tests to start Aug. 23, results anticipated Aug. 29.
4. Determine corrosion resistance of brazed assembly under operating conditions.	Model boiler tests to start Aug. 15.

ACCEPTANCE CRITERIA FOR [illegible]
QUALIFICATION TESTS OF SCE SLEEVING

	CRITERION	JUSTIFICATION
1.	Retain structural integrity (no burst) and leak tightness of tube/sleeve joint when internally pressurized at 4200 psi.	Maintain factor of safety of three over maximum operating ΔP, which is 1400 psi.
2.	Retain structural integrity (no collapse) and leak tightness of tube/sleeve joint when externally pressurized to 875 psi.	Prevent collapse under 1.25 times maximum secondary to primary pressure differential, which is 700 psi.
3.	Retain structural integrity and leak tightness of tube/sleeve joint after exposure to 150 cycles of plant heatup and cooldown transients.	Satisfy E-Spec 675161 requirement through 30 year operation.
4.	Retain structural integrity and leak tightness of tube/sleeve joint after exposure to 7500 cycles of simulated plant loading and unloading transients.	Satisfy E-Spec 675161 requirement through 30 year operation.
5.	Retain structural integrity and leak tightness after exposure at 600°F to 8500 cycles at maximum alternating axial loads anticipated.	Assure that joint can sustain operating cyclic loads.
6.	Tensile strength at 600°F of tube/sleeve joint shall not be less than minimum strength of tubing.	Satisfy ASME Section IX procedure qualification.
7.	Peel test shall not reveal defective areas greater than 30% of faying surface area.	Satisfy ASME Section IX procedure qualification.
8.	Sectioning test shall not reveal defects longer than 20% of length of overlap.	Satisfy ASME Section IX procedure qualification.

CRITERION	JUSTIFICATION
9. Ultimate strength of tube/sleeve assembly tested in tension at room temperature shall equal or exceed 80,000 psi.	Confirm that brazing has not reduced the minimum tensile strength of the tubing specified in SB 163.
10. Retain structural integrity of tube/sleeve assembly, with no evidence of excessive attack when exposed to accelerated corrosion tests in various primary and secondary environments.	Assure that the brazing cycle has not degraded the inherent corrosion resistance of the tubing such as to cause premature failure.
11. Demonstrated non-destructive test capability to (1) assure acceptable braze joints and (2) detect unacceptable defects in the tubing and sleeve in subsequent operation.	Satisfy Reg. Guide 1.83

MATERIAL AND CORROSION VERIFICATION

PROGRAM FOR BRAZED SLEEVES

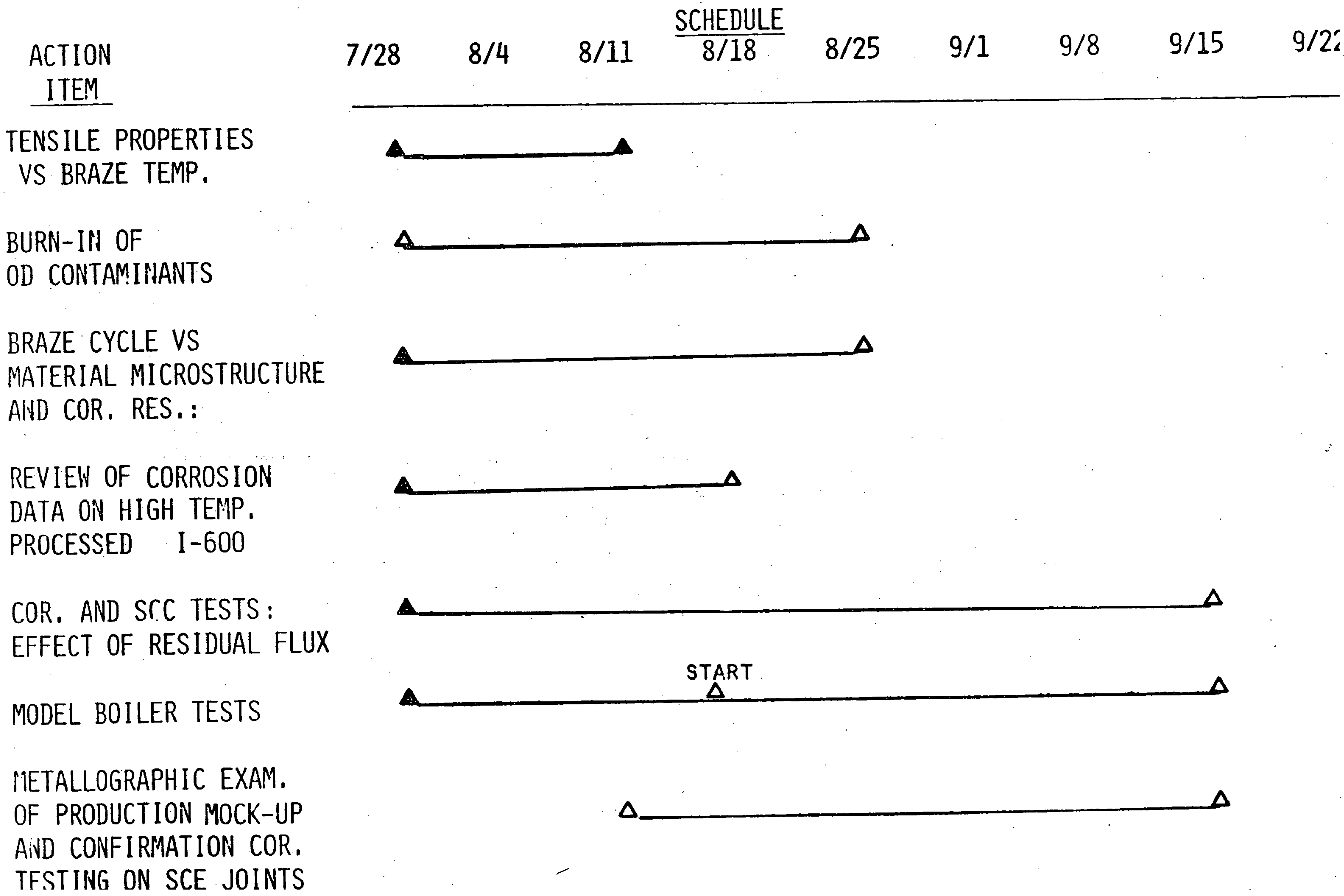


TABLE 1

TENSILE PROPERTIES OF INCONEL 600 AS A FUNCTION OF BRAZING TEMPERATURE

TEST PLAN

OBJECTIVE:

DETERMINE MECHANICAL PROPERTIES OF 3/4" OD INCONEL 600 STEAM GENERATOR TUBING FOLLOWING EXPOSURE TO HIGH TEMPERATURE BRAZING CYCLES.

APPROACH:

SUBJECT SINGLE TUBES TO BRAZING CYCLES WITH INCREASING PEAK TEMPERATURES FROM 1800° F TO 2250° F AT 50° F INTERVALS.

EVALUATION:

ROOM TEMPERATURE STRESS/STRAIN CURVES.

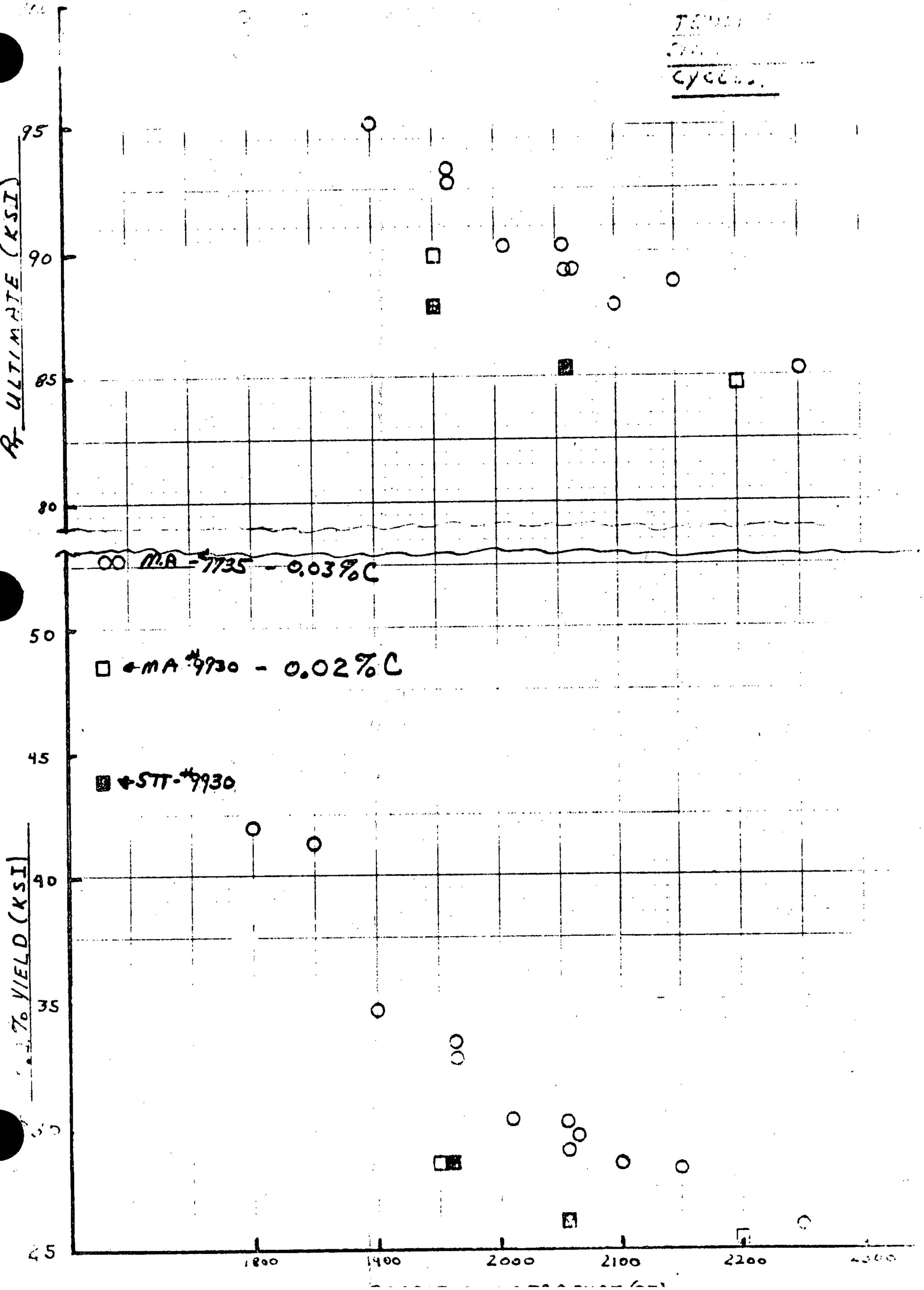
STATUS:

COMPLETE. ~~(FIGURE 1)~~

CONCLUSION:

THE 1950° F BRAZE CYCLE REDUCED THE ROOM TEMPERATURE YIELD STRENGTH BY 40% WHILE THE ULTIMATE WAS REDUCED BY 10%. FOR ALL BRAZE CYCLES TESTED THE ULTIMATE STRENGTH WAS 85 KSI OR GREATER.

FIGURE 1



ULTIMATE (KSI)
YIELD (KSI)
95
90
85
80
50
45
40
35
1800
2000
2100
2200
MA #7735 - 0.03%C
MA #9930 - 0.02%C
STT-#9930

TABLE 2

BURN-IN OF OD CONTAMINANTS

TEST PLAN

OBJECTIVE:

EVALUATE THE EXTENT OF DIFFUSION OF OD CONTAMINANTS DURING THE BRAZING CYCLE.

APPROACH:

CHARACTERIZE THE OD SURFACE CONTAMINANTS OBSERVED ON STEAM GENERATOR TUBES REMOVED FROM SCE USING MICROANALYTICAL TECHNIQUES. COMPARE THIS DISTRIBUTION WITH THAT OBSERVED FOLLOWING A SIMULATED HIGH TEMPERATURE BRAZING CYCLE.

REVIEW PREVIOUS LABORATORY RESULTS ON THE BURN-IN OF OD CONTAMINANT'S BOTH FROM THE EXTENT OF DIFFUSION AND THE EFFECT ON CORROSION AND SCG RESISTANCE.

- SIMULATED LABORATORY TESTS
- WELDING STUDIES

EVALUATION:

SEM/EDAX AND MICROPROBE ANALYSIS OF OD SURFACE BEFORE AND AFTER BRAZING CYCLE.

STATUS:

WORK TO BE COMPLETED WEEK OF AUGUST 25, 1980.

TABLE 3

EFFECT OF BRAZE CYCLE ON MATERIAL MICROSTRUCTURE AND SUBSEQUENT CORROSION RESISTANCE

TEST PLAN

OBJECTIVE:

EVALUATE THE MICROSTRUCTURAL RESPONSE AND SUBSEQUENT CORROSION AND SCC RESISTANCE OF BOTH MILL ANNEALED AND THERMAL TREATED INCONEL 600 STEAM GENERATOR TUBING EXPOSED TO BRAZING TEMPERATURES.

APPROACH:

SUBJECT TUBE/SLEEVE JOINTS TO BRAZE CYCLES AT PEAK TEMPERATURES OF 1850, 1950 AND 2050° F WITHOUT BRAZE METAL. RECORD HEATING AND COOLING RATES FOR LATER CORRELATION WITH METALLOGRAPHIC RESULTS.

EVALUATION:

- HARDNESS READINGS ALONG HEAT-AFFECTED-ZONE
- DETERMINE DEGREE AND EXTENT OF SENSITIZATION WITHIN HEAT-AFFECTED-ZONE USING MODIFIED HUEY AND REACTIVATION/ POLARIZATION TECHNIQUES.
- SELECT AREAS WITHIN HAZ FOR EXPOSURE TO 10% NaOH AT 600° F USING THE CONTROL POTENTIAL TEST TECHNIQUE (COMPARE RESULTS TO MILL ANNEALED AND STT DATA BASE).

STATUS:

IN PROGRESS - COMPLETION BY AUGUST 25, 1980.

TABLE 4

REVIEW OF EXISTING DATA ON THE MICROSTRUCTURAL CHANGES AND SUBSEQUENT CORROSION RESISTANCE OF INCONEL 600 TUBING EXPOSED TO TEMPERATURES BETWEEN 1850 - 1950° F

OBJECTIVE:

INVESTIGATE EXISTING DATA BASE AVAILABLE FOR DETERMINING THE CORROSION AND SCC RESISTANCE OF INCONEL 600 SUBJECTED TO ELEVATED TEMPERATURE (> 1800° F).

APPROACH:

REVIEW WESTINGHOUSE DATA AND DATA AVAILABLE IN THE PUBLIC DOMAIN.

RESULTS:

REFER TO TABLE 4-A.

STATUS:

WORK TO BE COMPLETED WEEK OF AUGUST 10, 1980.

TABLE 4-A

SCC DATA FOR HIGH TEMPERATURE (>1850° F) EXPOSED INCONEL 600

MATERIAL CONDITION	10% NaOH C-RINGS @ 650° F	10% NaOH + 10% CuO C-RINGS @ 600° F	PURE WATER U-BENDS @ 680° F
M.A.	SCC (1000 Hrs)	UNDER EVALUATION (1000 Hrs)	2-4 WEEKS CRACKING
1910° F	UNDER EVALUATION (1000 Hrs)	UNDER EVALUATION (1000 Hrs)	NC (8 WEEKS)

TABLE 5

CORROSION AND SCC EVALUATION OF BRAZED JOINTS

OBJECTIVE:

EVALUATE THE CORROSION AND SCC PERFORMANCE OF THE BRAZED AREA IN CAUSTIC, PRIMARY WATER AND HIGH TEMPERATURE WATER ENVIRONMENTS.

APPROACH:

- BRAZE JOINTS AT PEAK TEMPERATURES OF 1850, 1950, 2050° F.
- U-BEND EXPOSURE TO HIGH TEMPERATURE WATER AT 680° F.
- C-RING EXPOSURE TO OH^- AT 600°F/650°F.
- CAPSULE EXPOSURE TO PRIMARY WATER AT 650° F.

EVALUATION:

METALLOGRAPHIC EXAMINATION TO DETERMINE DEGREE AND EXTENT OF ATTACK.

STATUS:

TESTING UNDERWAY - COMPLETION WEEK OF SEPTEMBER 15, 1980.

TABLE 6

MODEL BOILER TESTS

TEST PLAN

OBJECTIVE:

- DETERMINE THE CORROSION AND SCC RESISTANCE OF THE BRAZED REGIONS FOR BOTH MILL ANNEALED AND THERMAL TREATED INCONEL 600 UNDER HEAT TRANSFER CONDITIONS.
- DETERMINE THE CONSEQUENCES OF LEAKAGE THROUGH THE OUTER TUBE AND SUBSEQUENT CONCENTRATION OF BULK WATER IMPURITIES IN THE SECONDARY-SIDE CREVICE BETWEEN THE TUBE AND SLEEVE.
- DETERMINE THE CONSEQUENCES OF RESIDUAL FLUX WITHIN THE PRIMARY-SIDE AND SECONDARY-SIDE CREVICES.

APPROACH:

SINGLE TUBE MODEL BOILER (2 TESTS)

TEST SET-UP:

REFER TO FIGURE 4

ENVIRONMENT:

- OH^- + Cl^-
- PHOSPHATE + Cl^-

STATUS:

START-UP WEEK OF AUGUST 10, 1980, COMPLETION WEEK OF SEPTEMBER 15, 1980.

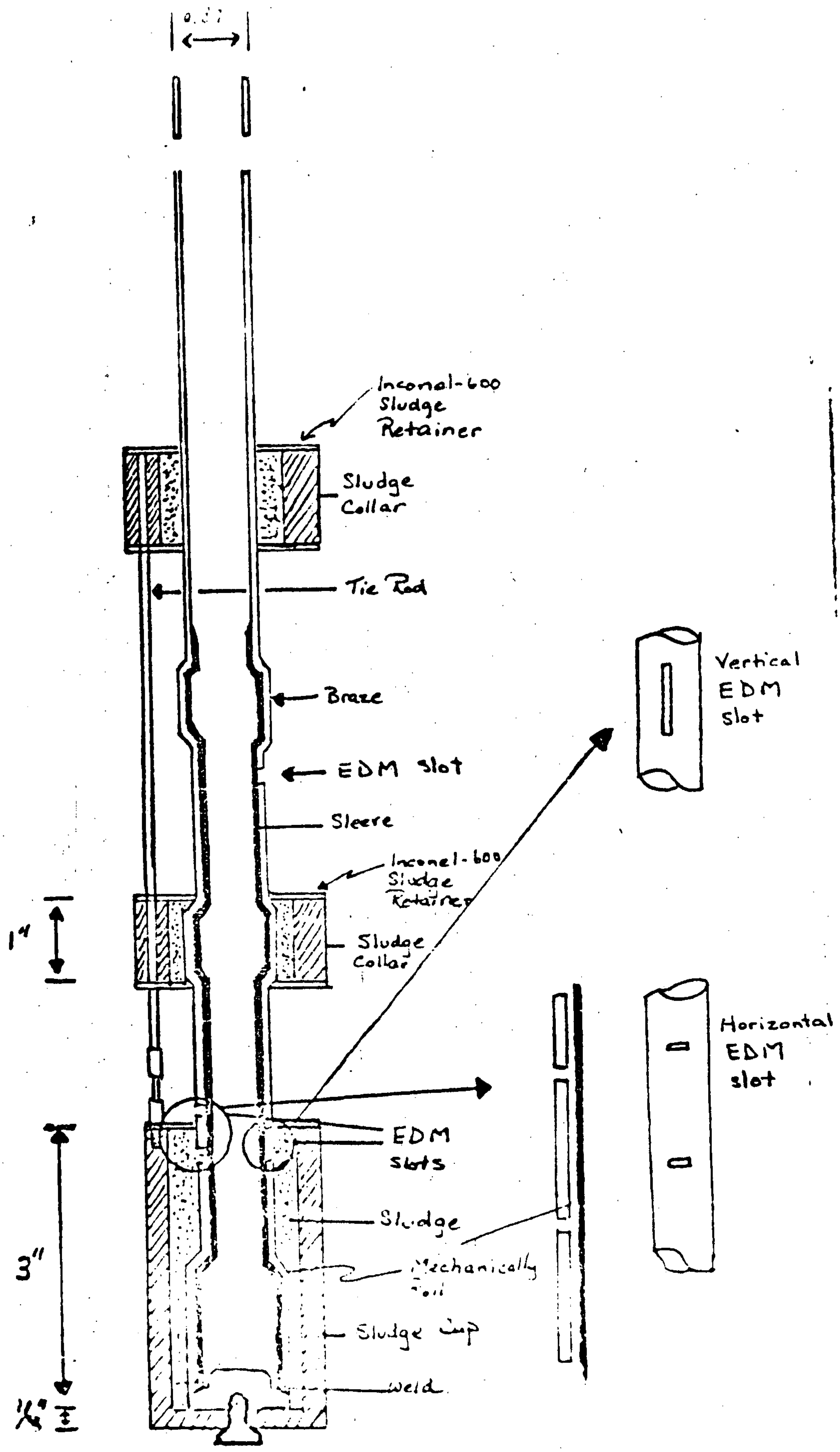


FIGURE 4
Schematic of Test Specimen

TABLE 7

METALLOGRAPHIC EXAMINATION OF MOCK-UP JOINTS AND CONFIRMATION CORROSION TESTING OF SCE JOINTS

OBJECTIVE:

CONDUCT SUFFICIENT METALLOGRAPHIC EXAMINATIONS, MECHANICAL AND CORROSION TESTS TO VERIFY SCE JOINTS.

APPROACH:

- METALLOGRAPHIC EXAMINATIONS OF A NUMBER OF MOCK-UP BRAZED JOINTS.
- SENSITIZATION AND CONTROL POTENTIAL TESTS.
- MECHANICAL PROPERTY TESTS AT 600/650°F

STATUS:

MOCK-UP FABRICATION UNDERWAY; TESTS TO BE COMPLETED BY SEPTEMBER 15, 1980.

POSTULATED MECHANISM OF OBSERVED CORROSION INDICATIONS

- TOP OF TUBESHEET INDICATIONS ASSOCIATED WITH THE ACCUMULATION OF CONCENTRATED CAUSTIC SOLUTION ON TOP OF TUBESHEET. (ACCUMULATION APPROXIMATELY ~1/4" HIGH).
- CAUSTIC FORMED BY SODIUM RETURNING TO SOLUTION IN A STEAM ENVIRONMENT IN SLUDGE, OR BY CONCENTRATION OF CAUSTIC IN BULK.
- CAUSTIC TRICKLES DOWN DURING OPERATION AND IS SUCKED DOWN DURING SHUTDOWN.
- CAUSTIC DOES NOT PENETRATE INTO MOST TUBESHEET CREVICES BECAUSE OF PLUGGING DURING EARLY PHOSPHATE OPERATION.
- CREVICES IN AREAS OF HIGHEST SLUDGE ACCUMULATION ALSO HAD SLUDGE DURING EARLIEST PHOSPHATE OPERATION. THEREFORE, PLUGGING OCCURRED IN SLUDGE ABOVE CREVICE. CAUSTIC CAN THEN PENETRATE UNPLUGGED CREVICES IN THESE LOCATIONS.

THERE ARE NO UNIQUE PRIMARY SIDE CONCERNS ASSOCIATED WITH THE SLEEVE

- SODIUM TETRABORATE FLUX CAN GO INTO SOLUTION IN CREVICE ABOVE ROLLED SECTION, FORMING CAUSTIC.
- CREVICE ABOVE ROLLED SECTION WILL INITIALLY BE OXYGENATED.
- CAUSTIC CONCENTRATION IN CREVICE WILL BE LIMITED TO <30% BY SOLUBILITY OF SODIUM TETRABORATE AND COMPETITION BETWEEN BORATE AND HYDROXIDE IONS.
- DIFFUSION CALCULATIONS INDICATE THAT ALL SODIUM TETRABORATE WILL GO INTO SOLUTION AND MAXIMUM CREVICE CONCENTRATION WILL BE REDUCED BELOW 1000 PPM WITHIN 100 HOURS OF HOT OPERATION.
- MAXIMUM OXYGEN CONCENTRATION IS 1221 PPM. 99% WILL DIFFUSE OUT OF CREVICE WITHIN 80 HOURS.

DOMINANT SECONDARY SIDE CORROSION IS ASSOCIATED WITH POTENTIAL ACCUMULATION OF SECONDARY SIDE CONTAMINANTS: NOT WITH DISSOLUTION OF FLUX MATERIAL

- IN THE ABSENCE OF A LEAK THROUGH THE ORIGINAL TUBE, SODIUM TETRABORATE WILL NOT GO INTO SOLUTION IN AN AIR ENVIRONMENT.
- IN THE PRESENCE OF A LEAK, ~50% CAUSTIC SOLUTION PLUS PERHAPS SOME STEAM WILL ENTER GAP BETWEEN SLEEVE AND TUBE.
- CREVICE IS LIKELY TO FILL WITH CAUSTIC SOLUTION TO AT LEAST LEVEL OF DEFECT.
- WICKING ACTION OF CAUSTIC MAY CAUSE WETTING OF ALL INTERNAL SURFACES OF CREVICE.
- CREVICE WILL BECOME FILLED WITH CAUSTIC SOLUTION AND/OR WATER UPON SHUTDOWN. WATER WILL BE BOILED OUT DURING SUBSEQUENT SHUTDOWNS.
- CREVICE MAY BECOME RICH IN CAUSTIC SOLUTION FOLLOWING SEVERAL START-UPS.

THERMALLY TREATED I-600 SLEEVE HAS SUPERIOR CORROSION RESISTANCE TO CAUSTIC ATTACK

- SCE attack is judged to be stress assisted intergranular attack, caused by concentrated caustic solutions.

- Attack occurs as general grain boundary dissolution (IGA) in absence of appreciable tensile stress, (and favored by increasing caustic concentrations and temperatures) or as discrete stress corrosion cracks (SCC) in presence of tensile stress (and favored by lower caustic concentrations).

- In either case, thermally treated Inconel 600 is superior to mill annealed material:

    - By a factor of 10 for SCC

    - By a factor of 4-5 for IGA

- Local region in HAZ of brazed joint may loose benefit of thermal treatment; the effect of this is being assessed in accelerated caustic tests.

- The benefit of a gold plate in the HAZ of the sleeve is being assessed.

TEST SPECIFICATION FOR SIMULATION OF PLANT HEATUP AND COOLDOWN AND LOADING AND UNLOADING TRANSIENTS

OBJECTIVE

EVALUATE EFFECTS WHICH PLANT NORMAL HEATUP & COOLDOWN AND LOADING & UNLOADING TRANSIENTS HAVE ON SEALING INTEGRITY OF JOINT. EFFECTS OF THESE TRANSIENTS WILL BE DETERMINED IN SEPARATE TESTS BUT THE SAME TEST SPECIMEN WILL BE USED IN BOTH TESTS.

TEST SPECIMEN

CONSISTS OF SHORT SECTION OF I-600 TT SLEEVE MATERIAL 0.620 IN. OD BRAZED 360° ALONG SPECIFIED AXIAL LENGTH OF INSIDE SURFACE OF SHORT SECTION OF I-600 MA TUBE MATERIAL 0.75 IN. OD.

FACILITY

HEATUP & COOLDOWN TEST: SPECIMEN PLACED IN PROTECTIVE CANNISTER INSIDE FURNACE - FIG. 2

LOADING & UNLOADING TEST: SYSTEM WILL IMPOSE CYCLICAL PRESSURE ON ANNULAR SPACE BETWEEN TUBE & SLEEVE. SLEEVE ID WILL BE PRESSURIZED - FIG. 3

TEST & CRITERIA

FIVE YEAR PERIOD OF CYCLES WILL BE IMPOSED:

- HEATUP & COOLDOWN: 125 CYCLES
- LOADING & UNLOADING: 7500 CYCLES

CRITERIA:

- JOINT MUST NOT LEAK FOR 10 MINUTES AT HYDRO TEST PRESSURE OF 3,720 PSI

STATUS

UNDERWAY.

TUBE-TO-SLEEVE BRAZED JOINT
PRESSURE COLLAPSE TEST

OBJECTIVE

EVALUATE EFFECTS WHICH A MULTIPLE OF SECONDARY SIDE DESIGN PRESSURE, WITH NO PRIMARY SIDE PRESSURE, HAS ON SEALING INTEGRITY OF JOINT. PRESSURE APPLIED TO ANNULUS BETWEEN SLEEVE AND TUBE.

TEST SPECIMEN

CONSISTS OF SHORT SECTION OF I-600 TT SLEEVE MATERIAL 0.620 IN. OD BRAZED 360° ALONG SPECIFIED AXIAL LENGTH OF INSIDE SURFACE OF SHORT SECTION OF I-600 MA TUBE MATERIAL 0.75 IN. OD - REF. FIG.

FACILITY

ROOM TEMP TEST: PRESSURIZING PUMP AND GAGE

ELEVATED TEMP TEST: FURNACE AND PROTECTIVE CANNISTER

TEST AND CRITERIA

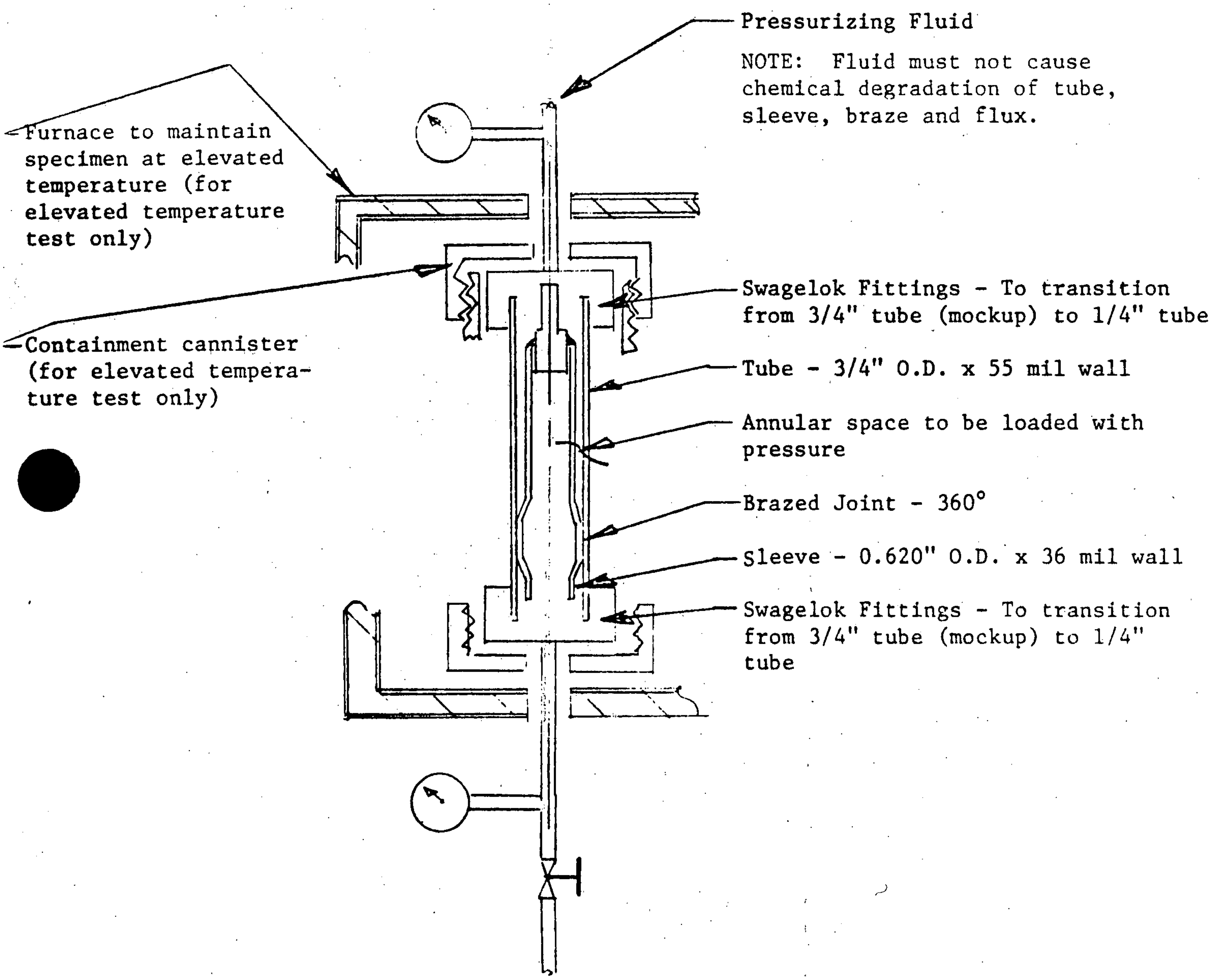
PRESSURE TO BE APPLIED TO ANNULUS BETWEEN TUBE AND SLEEVE TO BE 875 (1.25 TIMES SEC. SIDE PRESSURE OF 700 PSI). JOINT MUST BE LEAK TIGHT FOR 10 MINUTES UNDER HYDRO TEST AT 3,728 PSI BEFORE AND AFTER TEST.

STATUS

SPECIMENS PREPARED. TEST TO START 8/18/80.

TEST FACILITY FOR BRAZED TUBE JOINT

COLLAPSE-DUE-TO-PRESSURE TEST



TUBE-TO-SLEEVE BRAZED JOINT
PROOF PRESSURE TEST

OBJECTIVE

EVALUATE EFFECTS WHICH A MULTIPLE OF OPERATING PRIMARY-TO-SECONDARY DIFFERENTIAL PRESSURE HAS ON SEALING INTEGRITY OF JOINT.

TEST SPECIMEN

CONSISTS OF SHORT SECTION OF I-600 TT SLEEVE MATERIAL 0.620 IN. OD BRAZED 360° ALONG SPECIFIED AXIAL LENGTH OF INSIDE SURFACE OF SHORT SECTION OF I-600 MA TUBE MATERIAL 0.75 IN OD.

FACILITY

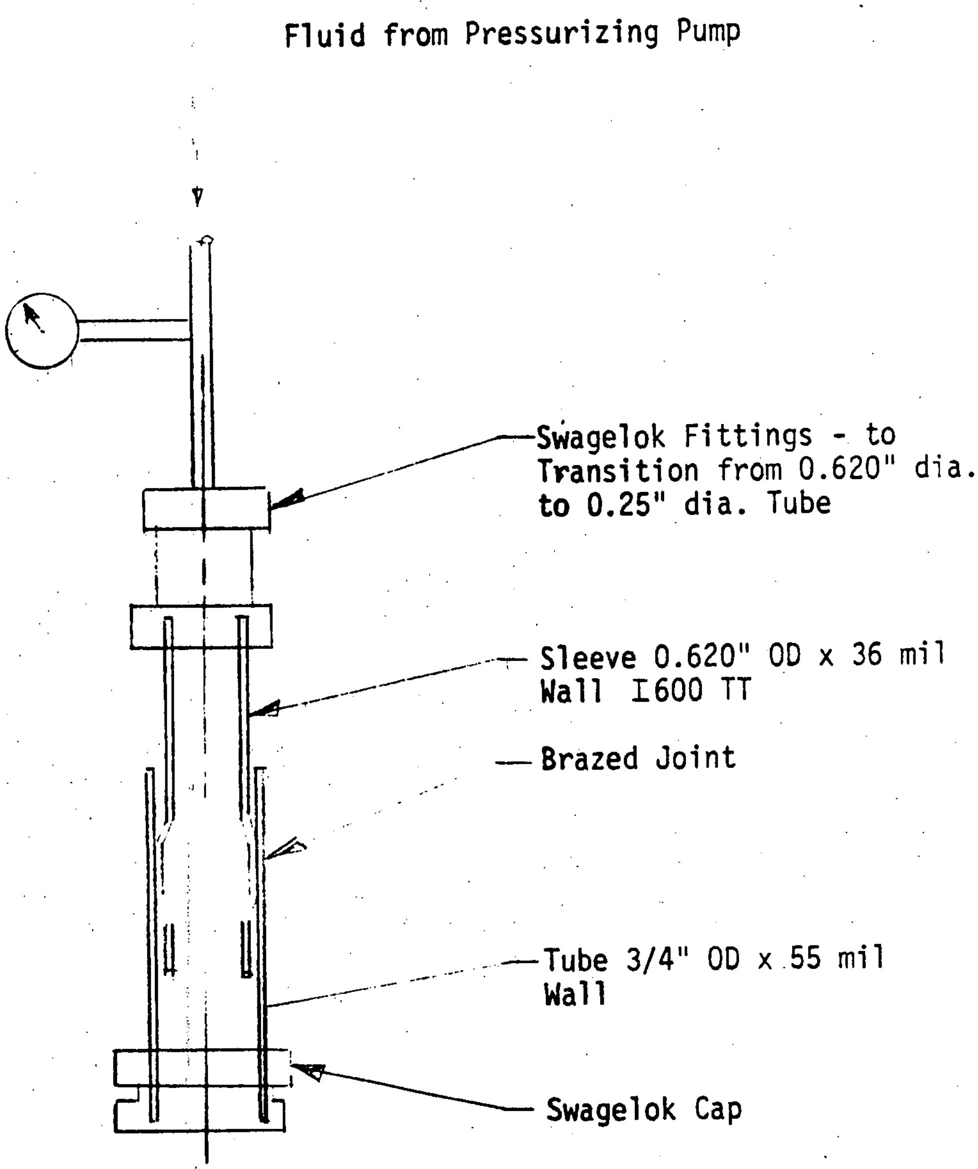
HYDRO TEST PUMP WITH PRESSURE GAGE - REF. FIG. 2

TEST AND CRITERION

PROOF PRESSURE TO BE 4,200 PSI, I.E., THREE TIMES THE MAXIMUM OPERATING PRIMARY-TO-SECONDARY DIFFERENTIAL PRESSURE. SPECIMEN AT ROOM TEMPERATURE. PRESSURE TO BE HELD FOR 10 MINUTES WITH NO LEAKS.

STATUS

SPECIMENS ARE PREPARED. TEST TO START 8/18/80.



Above-Tubesheet Tube-to-Sleeve Brazed Joint Test Specimen and Test Facility Configuration for Proof Pressure and Hydrostatic Leak Testing.

TUBE-TO-SLEEVE BRAZED JOINT
AXIAL SHEAR FATIGUE STRENGTH TEST

OBJECTIVE

EVALUATE EFFECTS OF THERMAL AND PRESSURE CYCLES ON THE SEALING INTEGRITY OF THE JOINT.

TEST SPECIMEN

CONSISTS OF SHORT SECTION OF I-600 TT SLEEVE MATERIAL 0.620 IN. OD BRAZED 360° ALONG SPECIFIED AXIAL LENGTH OF INSIDE SURFACE OF SHORT SECTION OF I-600 MA TUBE MATERIAL 0.75 IN. OD - REF. FIG.

FACILITY

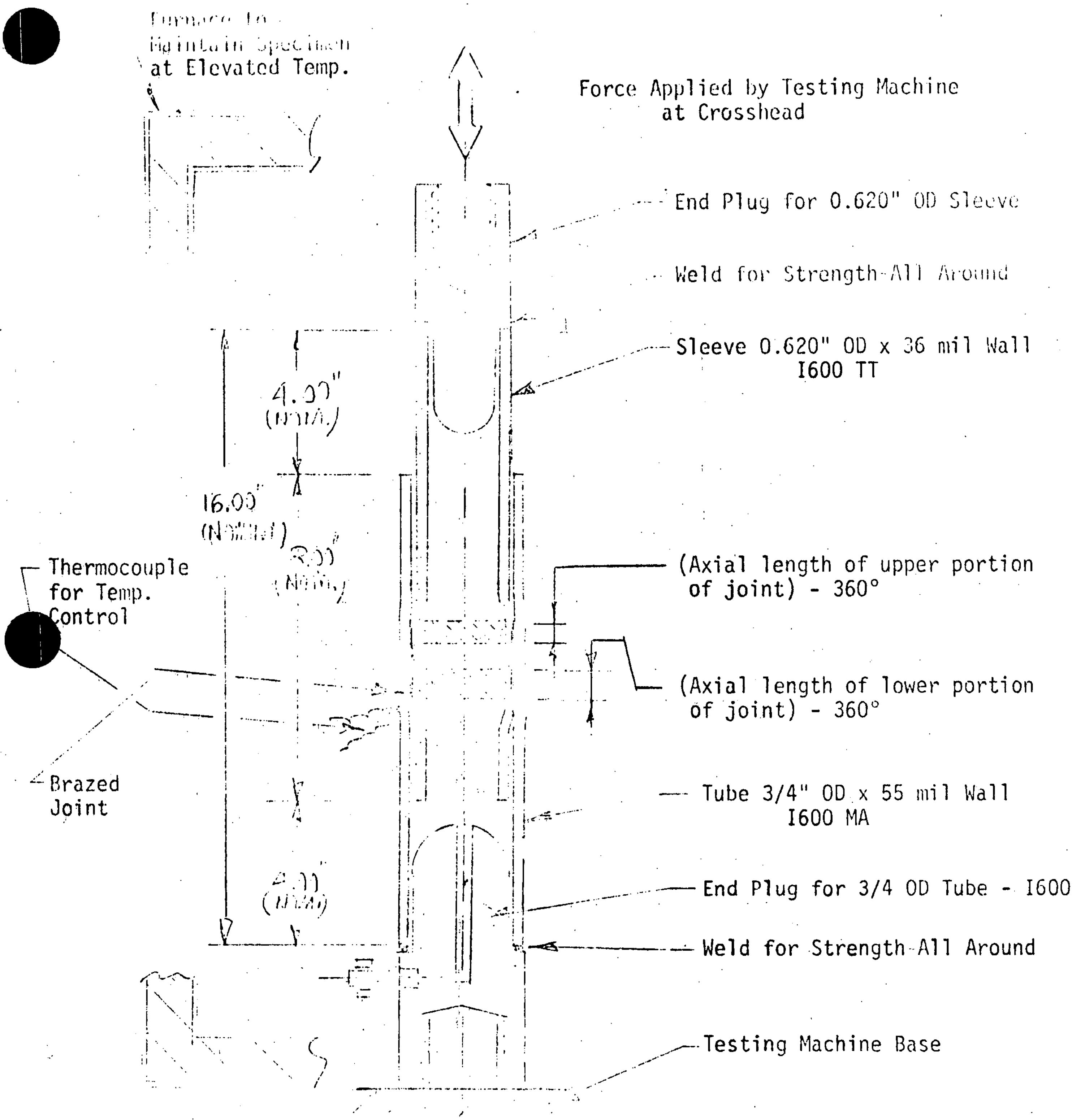
CONSISTS OF AMBIENT PRESSURE FURNACE WHICH ENCLOSES SPECIMENS. FATIGUE LOAD APPLIED BY TESTING MACHINE THROUGH END PLUGS MAINTAINS SPECIMEN AT 600°F ± 10°F.

TEST AND ACCEPTANCE CRITERIA

AXIAL LOAD TO BE ± 2,500 LB FOR 8,500 CYCLES, LOAD CONTROLLED. JOINT MUST BE LEAK TIGHT FOR 10 MINUTES UNDER HYDROSTATIC TEST AT 3,728 PSI BEFORE AND AFTER LOAD CYCLING.

STATUS

TEST UNDERWAY. 2,500 CYCLES NO FAILURES.



Test Configuration for Brazed Joint Axial Shear Fatigue Strength Testing

NDE OF SLEEVED TUBING

INSERVICE INSPECTION

BRAZE QUALITY

ISI

BRAZE QUALITY

REGIONS OF INTEREST

A. SLEEVE (TUBE)

B. TRANSITIONS

C. SLEEVE END

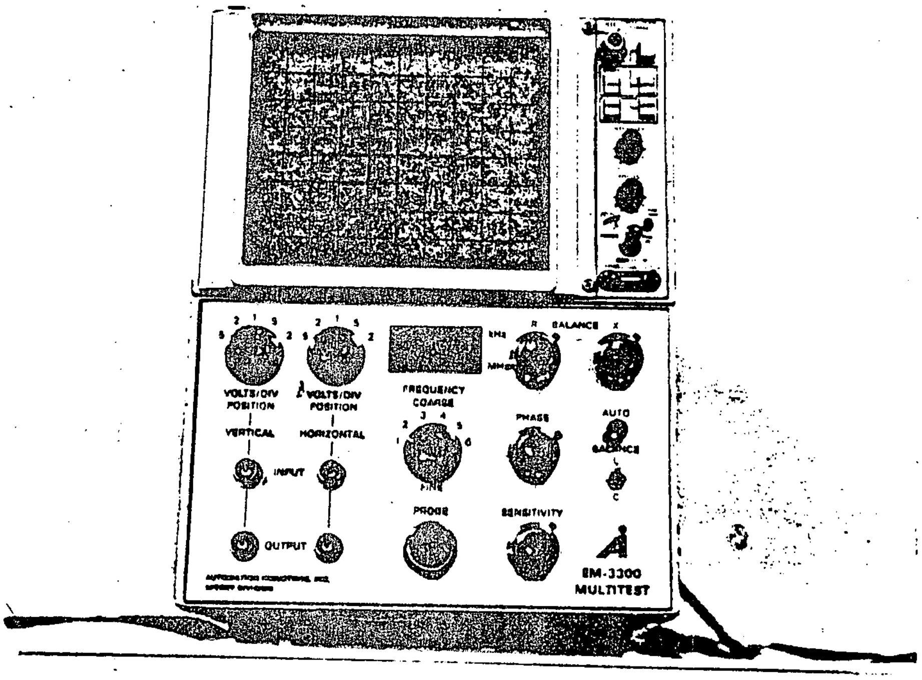
BRAZE PARAMETERS

A. EXTENT OF BRAZE

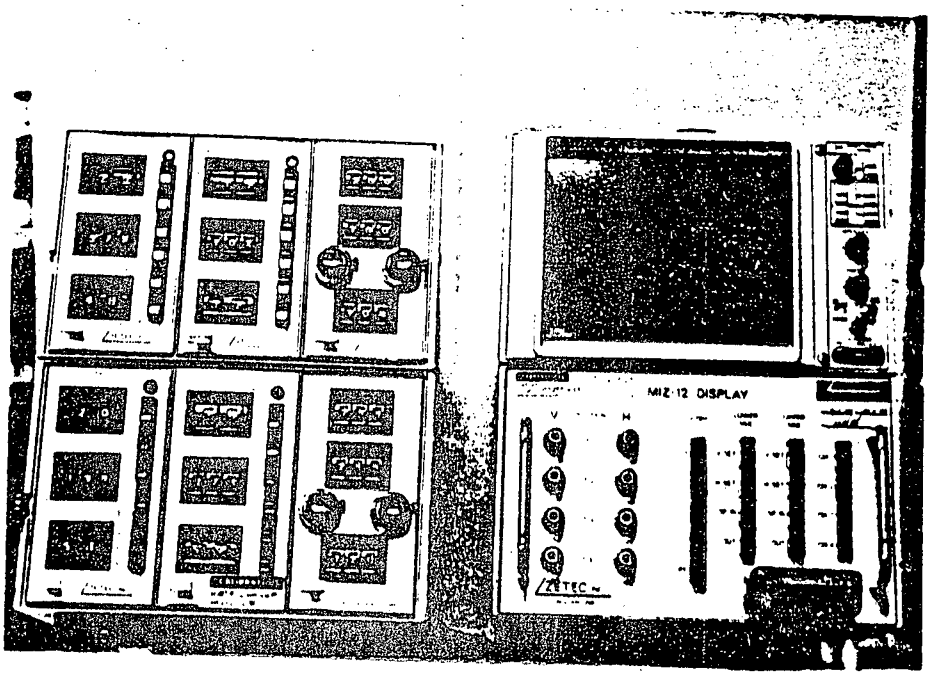
B. BRAZE WETTING

EDDY CURRENT INSTRUMENTATION

Single frequency



Multiple frequency



INSERVICE
INSPECTION
SUMMARY

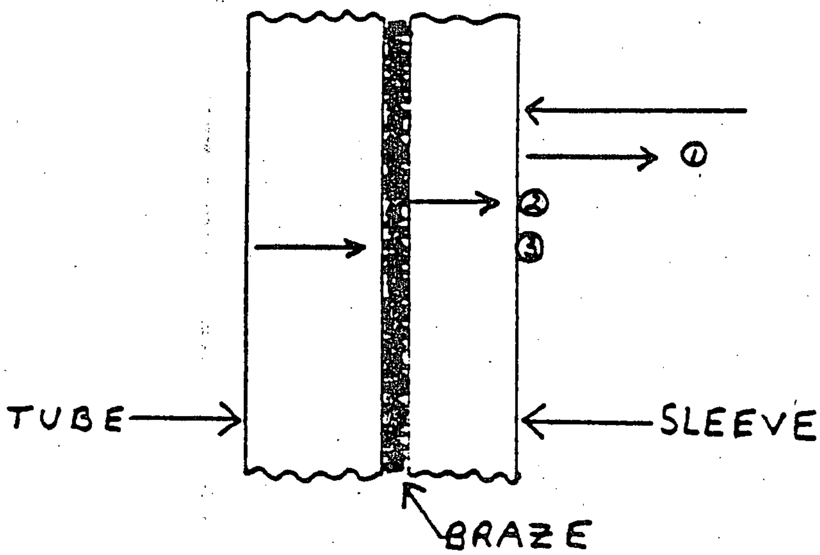
CONVENTIONAL EDDY CURRENT PROBES AND

MULTIFREQUENCY INSTRUMENTATION

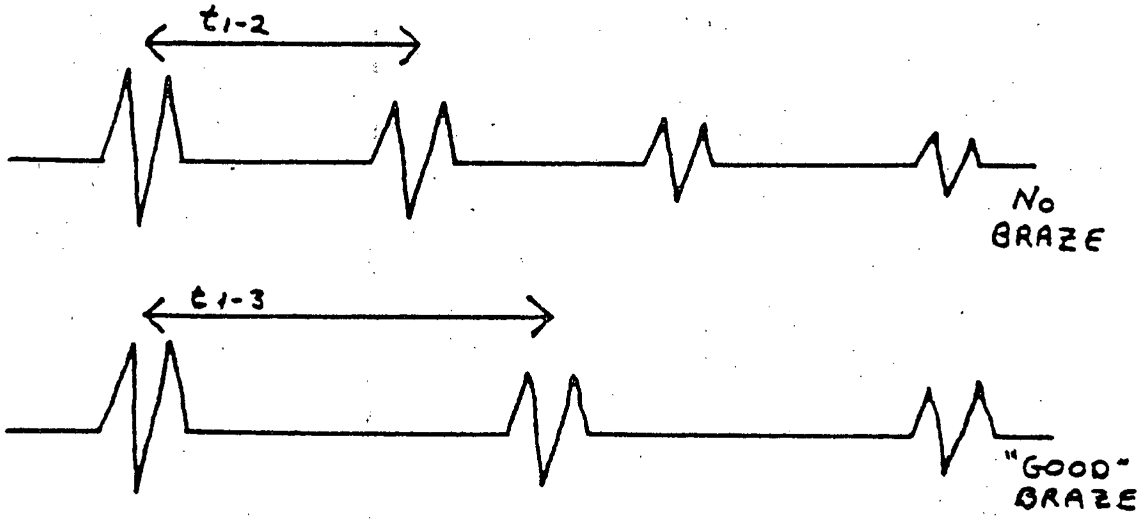
PROVIDE A VIABLE INSPECTION IN ALL

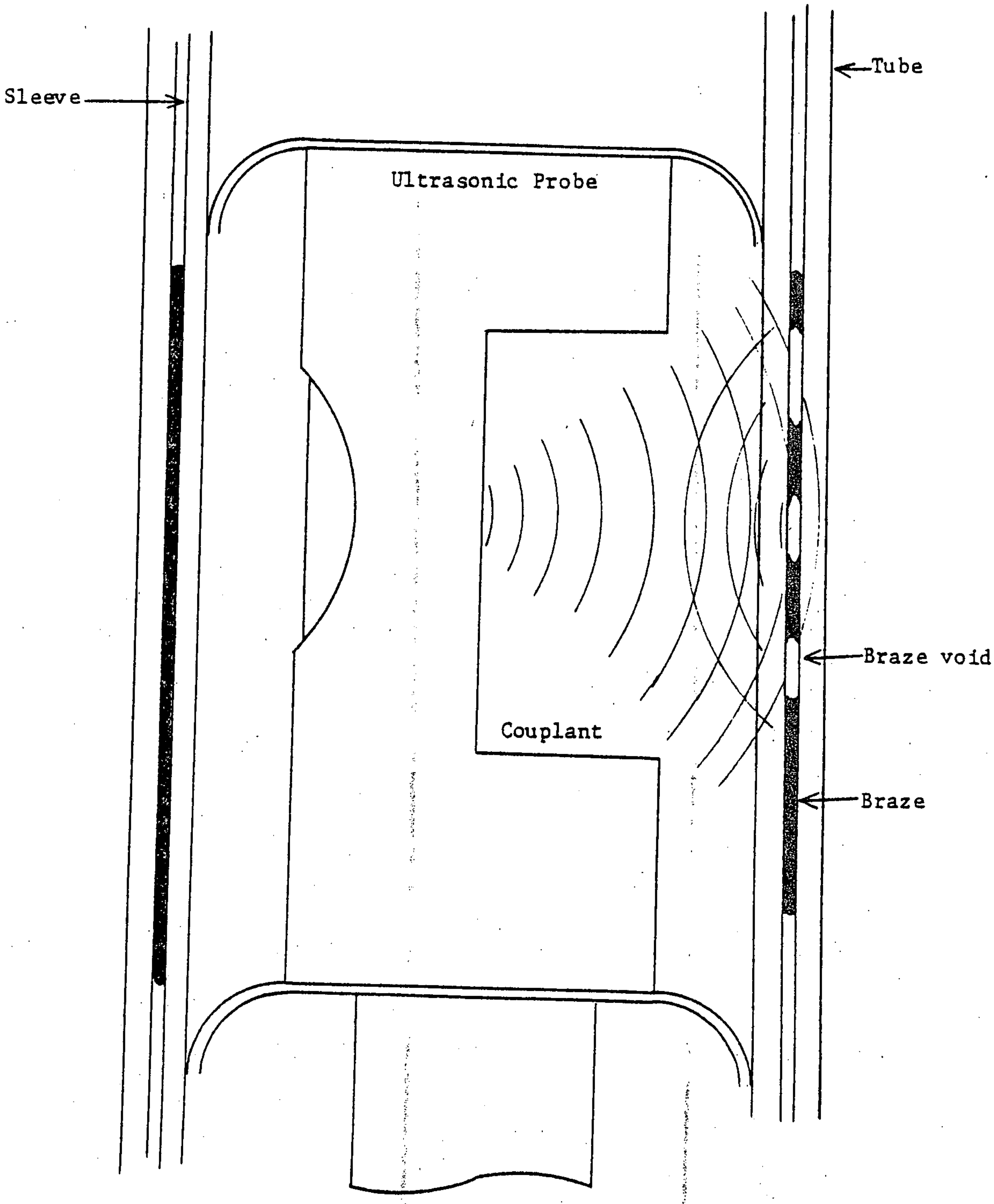
BUT THE BRAZE REGION

BRAZE U.T.



IDEALIZED WAVEFORMS

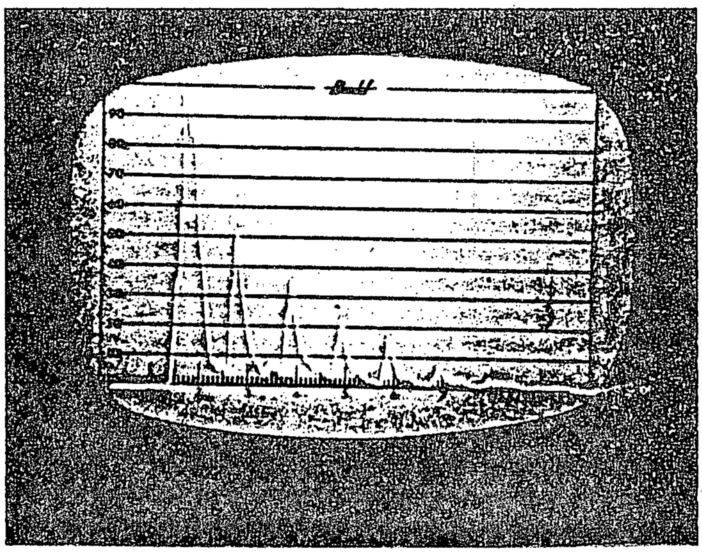




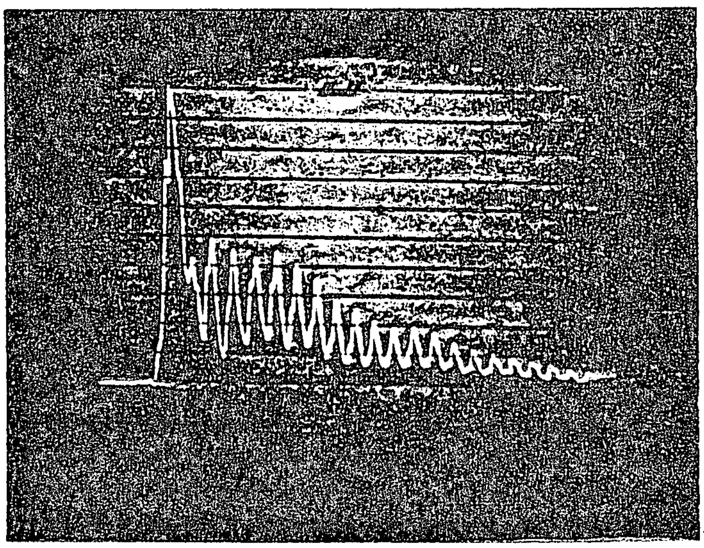
Sleeve
Tube
Ultrasonic Probe
Braze void
Couplant
Braze

ULTRASONIC RESPONSE
FROM BRAZE REGION

Good Braze



No-Braze



BRAZE QUALITY

SUMMARY

ULTRASONIC TECHNIQUES

PROVIDE A VIABLE MEANS OF

ASSURING BRAZE EXTENT

FUTURE DEVELOPMENT:

IMPROVED EDDY CURRENT INSPECTION OF BRAZE REGION

RECOMMENDATION:

BASE LINE EDDY CURRENT INSPECTION BE CONDUCTED WITH MAGNETICALLY BIASED EDDY CURRENT PROBES

8/14/80

SAN ONOFRE UNIT 1

SUPPORTING TECHNOLOGY

EDDY CURRENT DIAGNOSTICS (DDM)

--DEFINITION OF SLEEVING BOUNDARY
--APPARENT RATE OF CORROSION
--SLUDGE DISTRIBUTION MAPPING

METALLURGY OF TUBE SAMPLES (EPM)

--SUMMARY OF TUBES EMOVED AND REASONS
--CONDITION OF COLD LEG TUBES
--CRACK MORPHOLOGY OF HOT LEG TUBES
--DESCRIPTION OF BURST TEST OF TUBE SAMPLE 14-70
--CONDITION OF TUBES ABOVE TUBESHEET

CHEMISTRY PROGRAM (WDF)

--COLD AND HOT FLUSHES
--STARTUP CHEMISTRY CONTROL
--OPERATIONAL CONTROLS

TUBE PRESSURE TESTING (TT)

--SUMMARY OF TESTS
--WHOLE BUNDLE PRESSURE TESTS
--RESIDUAL STRENGTH

SUMMARY OF BASIS FOR SLEEVING BOUNDARY (WDF)

SAN ONOFRE UNIT #1

STEAM GENERATOR CHEMISTRY PROGRAM

OBJECTIVE

TO REMOVE CONTAMINANTS WHICH HAVE LED TO CORROSION OF THE STEAM GENERATOR TUBES. THESE CONTAMINANTS ARE CONTAINED WITHIN STEAM GENERATOR DEPOSITS AND SLUDGES.

PROGRAM CONTENT

COLD WATER SOAK
HOT WATER SOAK
CREVICE FLUSH
PLANT START UP

BACKGROUND

- REVIEW OF OPERATING PLANT CHEMISTRY SHOWS EVIDENCE OF FREE CAUSTIC PRESENT IN BULK WATER.
- ADDITION OF SODIUM HYDROXIDE FOR pH CONTROL WAS DISCONTINUED IN MID 1979.
- SHUTDOWN/START UP/POWER OPERATION CHEMISTRY CYCLED FROM LOW RATIO TO HIGH RATIO PHOSPHATES.
- PHOSPHATE INVENTORIES NOT REMOVED COMPLETELY DURING HIDEOUT RETURN SITUATIONS.
- CONDENSER LEAKAGE (LOW RATES) CONTINUED FOR A NUMBER OF WEEKS.
- MAKE UP WATER SOURCE CHANGED TO CITY WATER.

COLD WATER SOAK 70°F

RATIONALE — REVIEW OF PAST DATA SHOWS THAT EVEN AT COLD SHUTDOWN SIGNIFICANT RETURN OF PHOSPHATES EXPERIENCED. THIS SOAK WILL BE FIRST ATTEMPT TO REMOVE MORE ACCESSIBLE CONTAMINANTS.

PROCEDURE — FILL STEAM GENERATOR WITH PURE H_2O TO COVER TUBE BUNDLE.

SOAK FOR 24 HOURS (WITH CIRCULATION THROUGH HAND HOLES)

SAMPLE AND ANALYZE FOR pH, CONDUCTIVITY, SODIUM, PHOSPHATE, CHLORIDE, SILICA. ANALYZE LATER FOR SULFATE, POTASSIUM, MAGNESIUM, CALCIUM, IRON, COPPER, NICKEL, LEAD.

FOLLOW BUILD UP, WHEN CONCENTRATION PLATEAU REACHED, DRAIN AND SOAK AGAIN. IF NEW PLATEAU IS LESS THAN 10 - 15% OF ORIGINAL, DRAIN AND PROCEED TO HOT SOAK.

IF PLATEAU IS MORE, REPEAT SOAK.

HOT WATER SOAK 350 - 400°F

RATIONALE

LABORATORY DATA SHOWS THAT 300 - 400°F IS TEMPERATURE RANGE FOR OPTIMUM SOLUBILITY OF SODIUM PHOSPHATE. SOLUBILITY DROPS OFF WITH HIGHER TEMPERATURES. HIGHER TEMPERATURE IS MORE KINETICALLY FAVORABLE. EXPECT THIS SOAK TO HAVE GREATER PENETRATION THAN FIRST SOAK.

PROCEDURE

FILL STEAM GENERATOR WITH PURE H_2O (PLUS N_2 SPARGING) TO COVER TUBE BUNDLE.

HEAT TO 350 - 400°F USING PUMP HEAT.

SOAK FOR 24 HOURS (CONVECTION MIXING).

SAMPLE AND ANALYZE AS IN COLD SOAK.

FOLLOW CONCENTRATION INCREASE.

DRAIN 4 - 5 FEET FROM GENERATORS.

FEED AND BLEED TO 100TH DILUTION.

REFILL AND REHEAT. HOLD FOR AT LEAST 8 HOURS.

IF CONCENTRATION PLATEAU IS LESS THAN 10 - 15% OF ORIGINAL, COOL DOWN AND DRAIN. IF MORE, CONTINUE SOAK AND REPEAT.

CREVICE FLUSH WITH NITROGEN OVERPRESSURE AT 275 - 350°F

RATIONALE

COLD WATER SOAK AND HOT WATER SOAKS HAVE REMOVED READILY ACCESSIBLE CONTAMINANTS. THE CREVICE FLUSH WILL REMOVE THE CONTAMINANTS DEEP DOWN IN SLUDGE PILE AND IN TUBE-TUBESHEET CREVICES.

JAPANESE AND U.S. PLANT EXPERIENCE HAS SHOWN THAT SUCH A PROCEDURE WILL MOVE MATERIAL FROM RESTRICTED AREAS.

PROCEDURE

FILL STEAM GENERATOR TO TWO FEET ABOVE TOP OF SLUDGE PILE.

PRESSURIZE WITH N_2 TO 15 PSIG.

HEAT TO 275°F USING PUMP HEAT. (WITH CIRCULATION THROUGH HAND HOLES)

MONITOR CHEMISTRY AS IN SOAKS.

HOLD TEMPERATURE FOR MINIMUM OF ONE HOUR.

MONITOR CHEMISTRY.

DEPRESSURIZE BY OPENING STEAM DUMP VALVES.

REPRESSURIZE.

MONITOR CHEMISTRY.

REPEAT CYCLE.

FEED AND BLEED WHEN NECESSARY.

NEVER DRAIN LEVEL BELOW SLUDGE PILE.

CHEMISTRY CONTROL DURING HEATUP FOR RESTART

- FOLLOWING CREVICE FLUSH AND POSSIBLE SLUDGE LANCING, REFILL STEAM GENERATORS WITH PURE H_2O WITH N_2H_4.

- HEAT TO HOT STANDBY, APPLY MAXIMUM BLOWDOWN AND MONITOR CHEMISTRY, HOLD UNTIL BLOWDOWN CHEMISTRY IS STABILIZED FOR AT LEAST 24 HOURS (RESIDUAL Na/PO_4 RATIO TO BE <2.8)

- PROCEED TO 25% POWER. HOLD FOR CHEMISTRY STABILITY AS ABOVE. MONITOR TRANSPORT OF CONTAMINANTS AND CORROSION PRODUCTS FROM THE CONDENSATE/FEEDWATER SYSTEMS.

- IF NO HIGH RATIO PHOSPHATE HIDEOUT RETURN IS EXPERIENCED (PO_4 <2 PPM, Na/PO_4 <2.8), COMMENCE PO_4 INJECTION TO REACH PO_4 LEVEL OF 50 PPM AND Na/PO_4 = 2.3. HOLD FOR AT LEAST 24 HOURS.

  RAMP TO 50%, 75% AND 100% WITH AT LEAST 24 HOUR HOLDS TO MAINTAIN STABILITY.

  REDUCE PO_4 LEVEL TO 20 PPM WITH LIMITS OF 15 TO 30 PPM AND TARGET RATIO OF 2.4 (LIMITS 2.3 TO 2.6) DETERMINED USING THE MARCY/HALSTEAD RATIO.

CHEMISTRY CONTROL DURING HEATUP FOR RESTART (CONTINUED)

- IF HIGH RATIO PHOSPHATE HIDEOUT RETURN IS OBSERVED AT 25% POWER, CONTINUE BLOWDOWN AND HOLD FOR CHEMISTRY STABILITY FOR AT LEAST 24 HOURS.

  RAMP TO 50% POWER. IF NO HIGH RATIO PHOSPHATE HIDEOUT RETURN IS OBSERVED, COMMENCE ADDITION OF PHOSPHATE AS DESCRIBED ABOVE. IF HIGH RATIO PHOSPHATE IS EXPERIENCED, CONTINUE TO BLOWDOWN AND INCREASE POWER TO 75% TO ESTABLISH IF RETURN OCCURS THERE.

- ONCE STEAM GENERATOR IS UNDER 2.4 Na/PO_4, PO_4 = 20 PPM CONTROL, MAINTAIN CHEMISTRY FOLLOW ON 4 HOUR FREQUENCY.

- WHEN BLOWDOWN CHEMISTRY HAS STABILIZED FOR AT LEAST 24 HOURS, RETURN TO NORMAL ANALYTICAL SCHEDULE.

SUMMARY OF CONVENTIONAL EDDY CURRENT EXAMINATION

TYPE OF INDICATION (≥ 20%)	S/G A INLET	S/G A OUTLET	S/G B INLET	S/G B OUTLET	S/G C INLET	S/G C OUTLET	TOTAL ECI's ≥ 50%
At Anti-Vibration Bars							
Total (tubes)	148	-	215	-	209	-	
Pluggable (≥ 50%)	4	-	7	-	2	-	13
Above Tubesheet							
Total ECI's	415	629	148	96	245	39	
ECI's ≥ 50%	4	2	1	0	7	0	14
At Top Of Tubesheet							
Total ECI's	145	3	56	0	156	0	
ECI's ≥ 50%	128	0	52	0	148	0	328
Below Top Of Tubesheet							
Total ECI's	1	0	0	0	0	0	
ECI's ≥ 50%	1	0	0	0	0	0	1
Tube Support Plate Elevations							
Total ECI's	0	6	1	0	2	0	
ECI's ≥ 50%	0	0	0	0	0	0	0
Restricted Tubes							
Total Tubes	178	60	-	-	185	25	
Pluggable	0	2	0	0	2	0	
Other (1)	23	0			4		
Tubes Requiring Plugging	125	1	60	0	16		

(1) Tubes to be plugged because of tube pulling operations.

8/13/80
DDM

DIAGNOSTIC STUDIES

ROTATING PANCAKE COIL (RPC) EDDY CURRENT (EC) DATA STATISTICS - TOP OF TUBESHEET

a. SG/A Complete

HL - 2315 tubes

354 ≥ 50%

106 < 50% ≥ 20%

194 < 20%

CL - 104 tubes

4 ≥ 50%

0 < 50% ≥ 20%

3 < 20%

b. SG/B Data through 8/9/80

HL - 1923 tubes

159 ≥ 50% (+60 tubes plugged)

86 < 50% ≥ 20%

183 < 20%

c. SG/C Data through 8/9/80

HL - 2720 tubes

320 ≥ 50%

120 < 50% ≥ 20%

278 < 20%

SAN ONOFRE #1

EDDY CURRENT DATA CORRELATION

BOBBIN AND ROTATING PANCAKE COIL

Tubesheet entrance signal derived from 400 kHz channel of the bobbin probe data was qualitatively evaluated to determine populations of normal, distorted entries, dents and distorted dents.

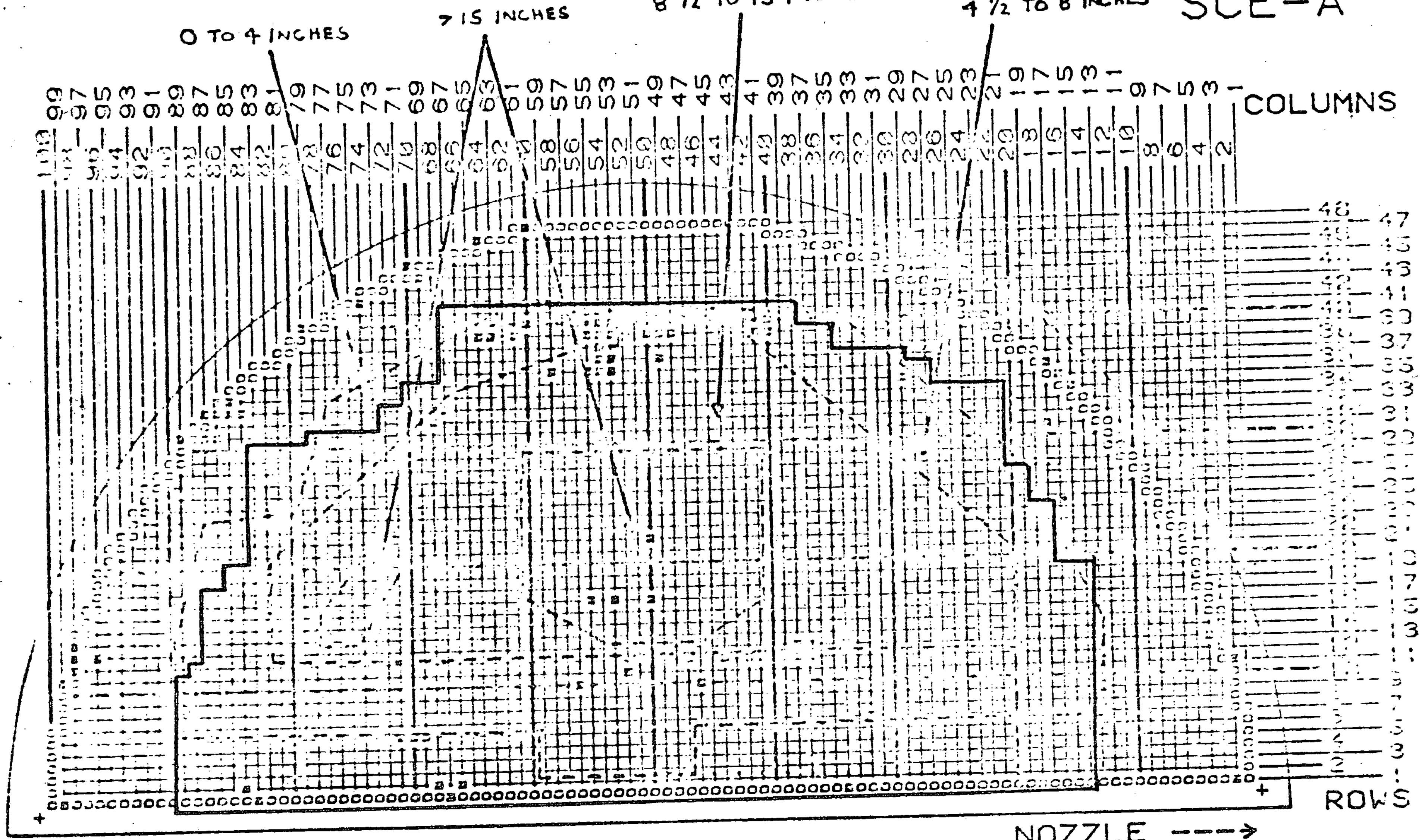
RPC results for SG/A have been compared with the bobbin probe results to establish whether RPC data is anticipated by bobbin signature.

RESULT

RPC findings, i.e. any detectable indication, are common to all categories of bobbin probe results.

SERIES 27

SCE-A



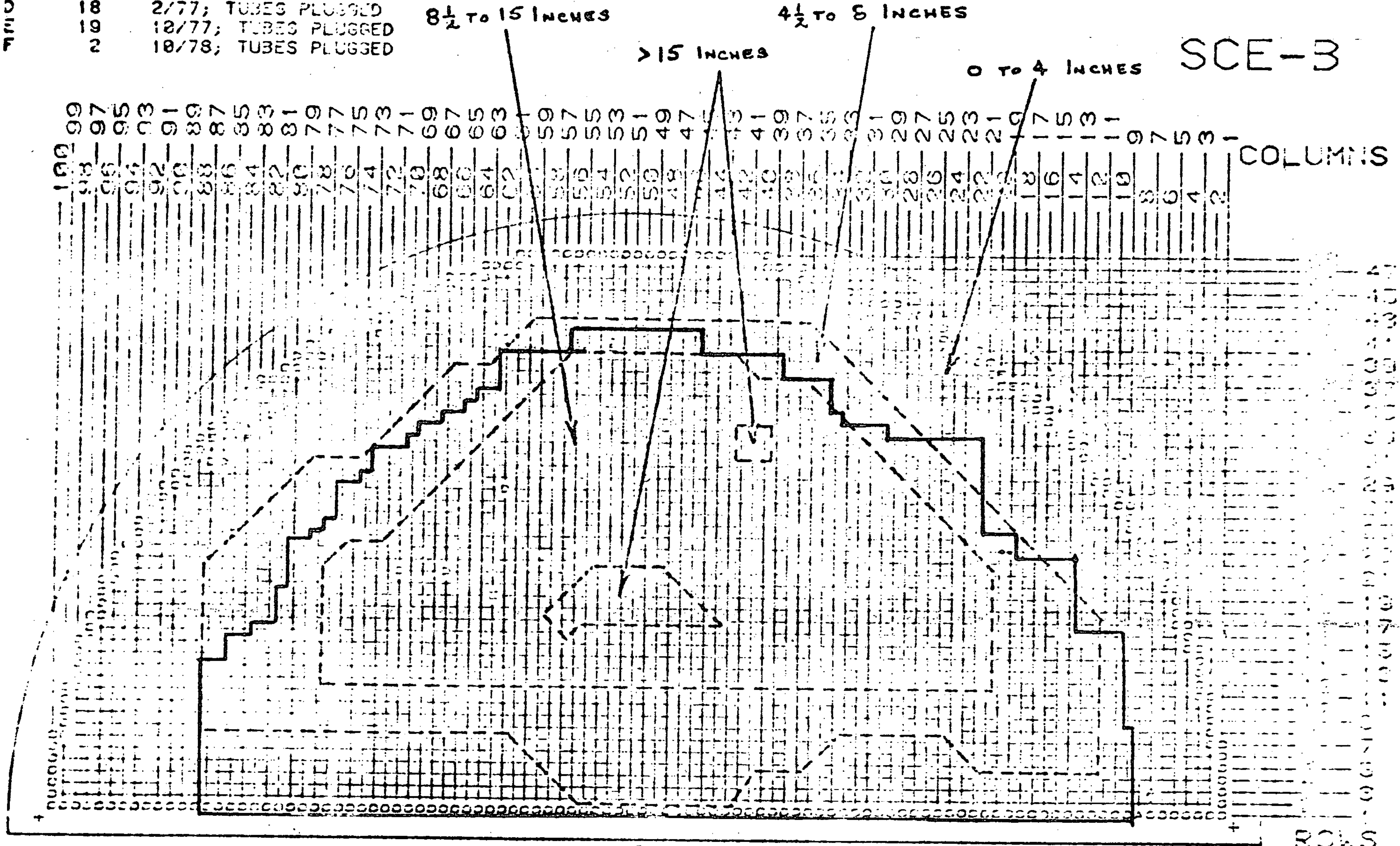
SLUDGE PROFILE
SCE
S/G A-INLET

2610 T
184 P
2426 Sleeves

A 4 73; TUBES PLUGGED
B 5 3; TUBES PLUGGED
C 2 4/75; TUBES PLUGGED
D 18 2/77; TUBES PLUGGED
E 19 10/77; TUBES PLUGGED
F 2 10/78; TUBES PLUGGED

SERIES 2

SCE-3



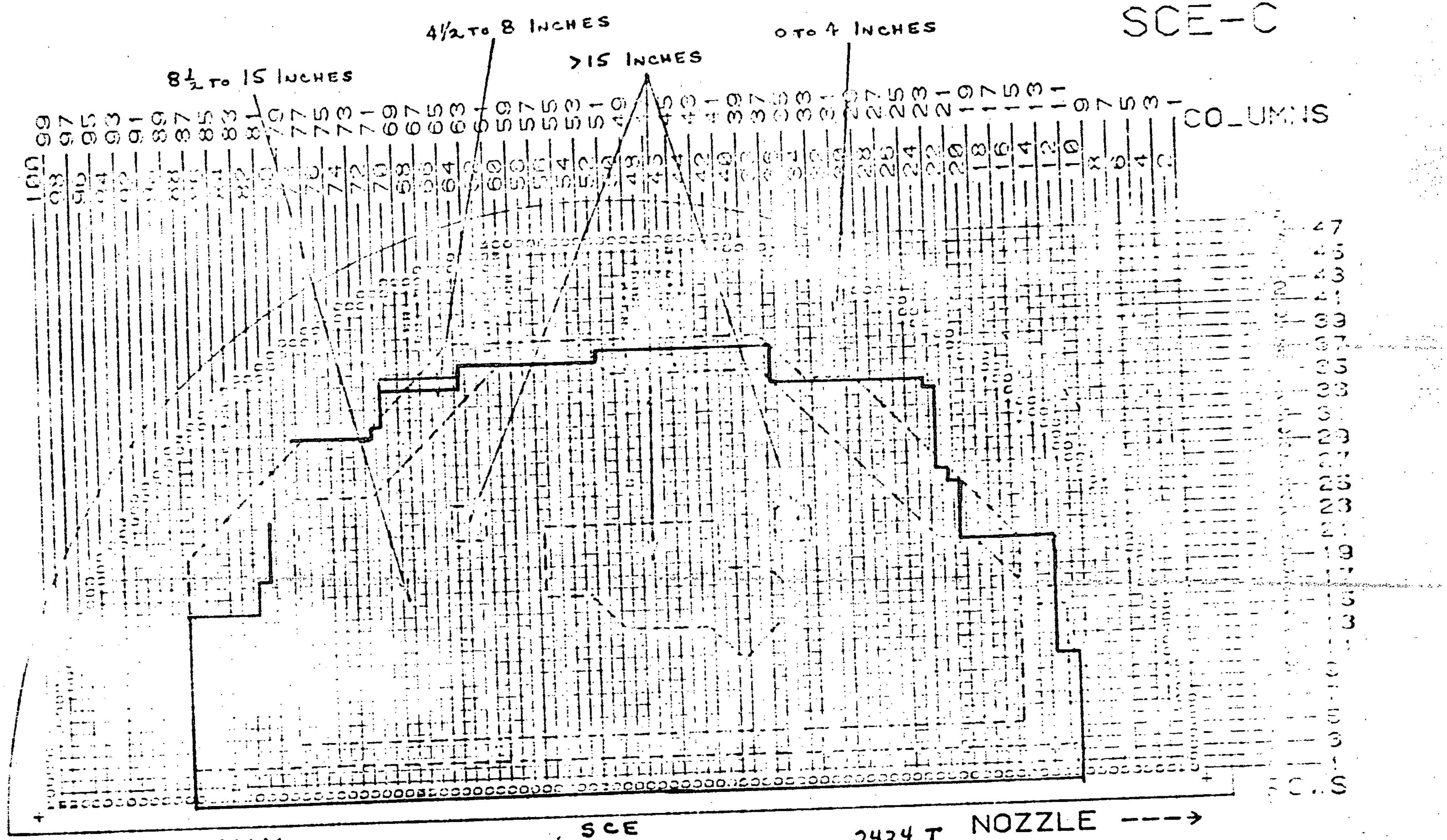
SCE
S/G B INLET
SLUDGE PROFILE

2418 T
- 13 P
2405 Sleeves

"

SERIES 2

SCE-C

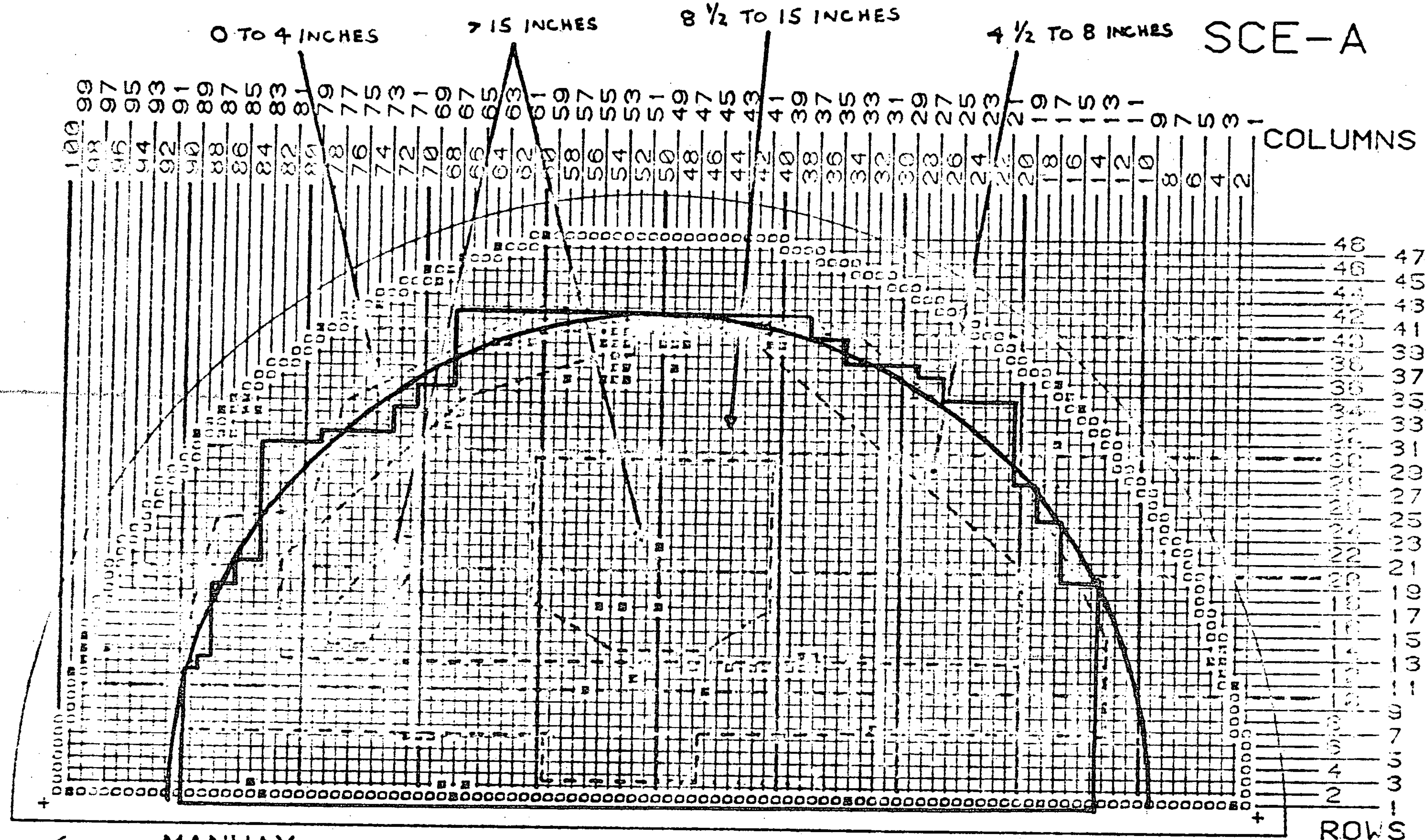


SCE
S/G C - INLET
SLUDGE PROFILE

2424 T
- 25 P
2399 Sleeves

SERIES

SCE-A



SLUDGE PROFILE

SCE

S/G A-INLET

SLEEVING BOUNDARY

SLEEVABLE ZONE

2610 T

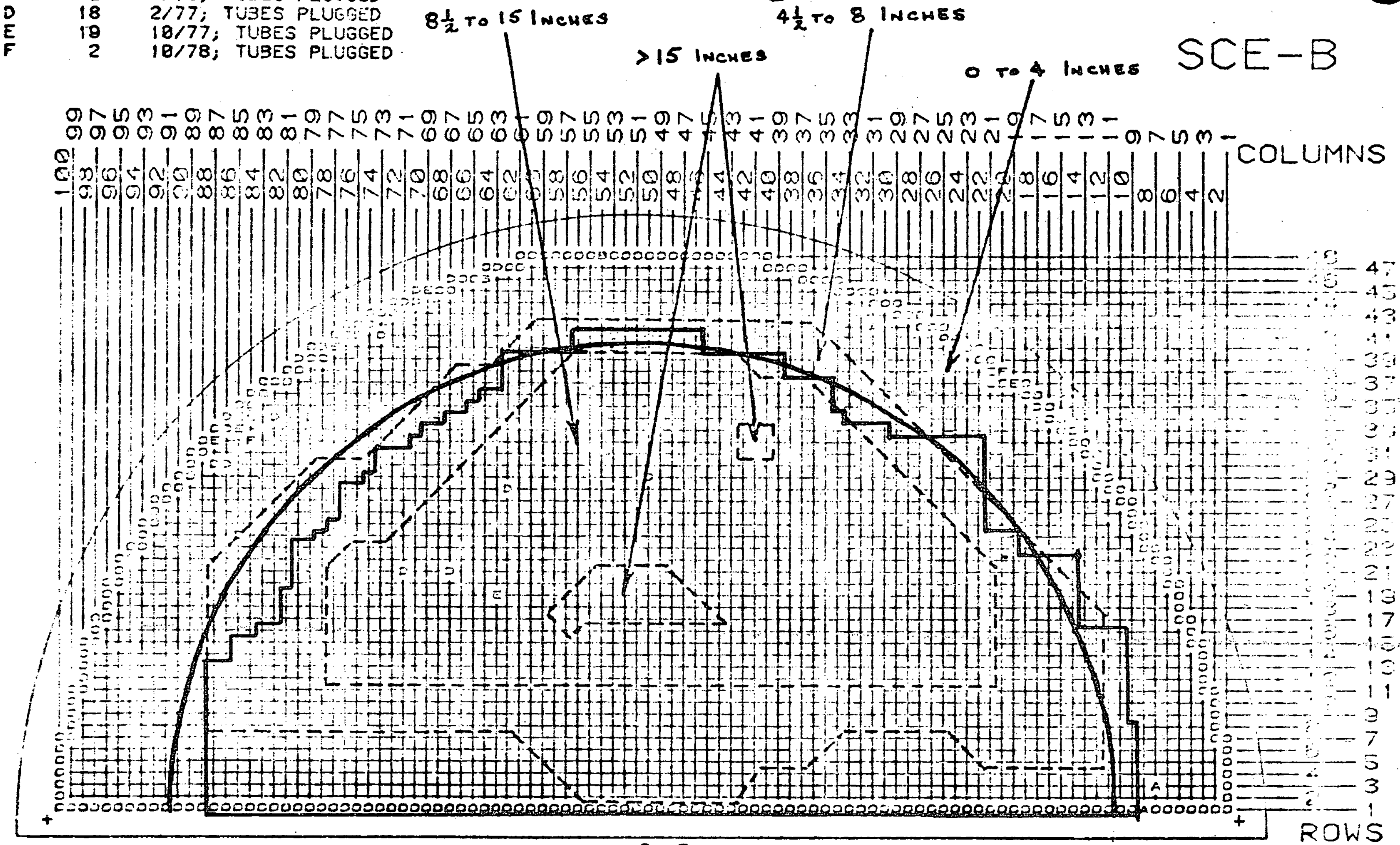
184 P

2426 Sleeves

A	4	70; TUBES PLUGGED
B	5	3; TUBES PLUGGED
C	2	4/75; TUBES PLUGGED
D	18	2/77; TUBES PLUGGED
E	19	10/77; TUBES PLUGGED
F	2	10/78; TUBES PLUGGED

SERIES 2

SCE-B



←--- MANWAY

NOZZLE --->

SCE
S/G B INLET

SLUDGE PROFILE

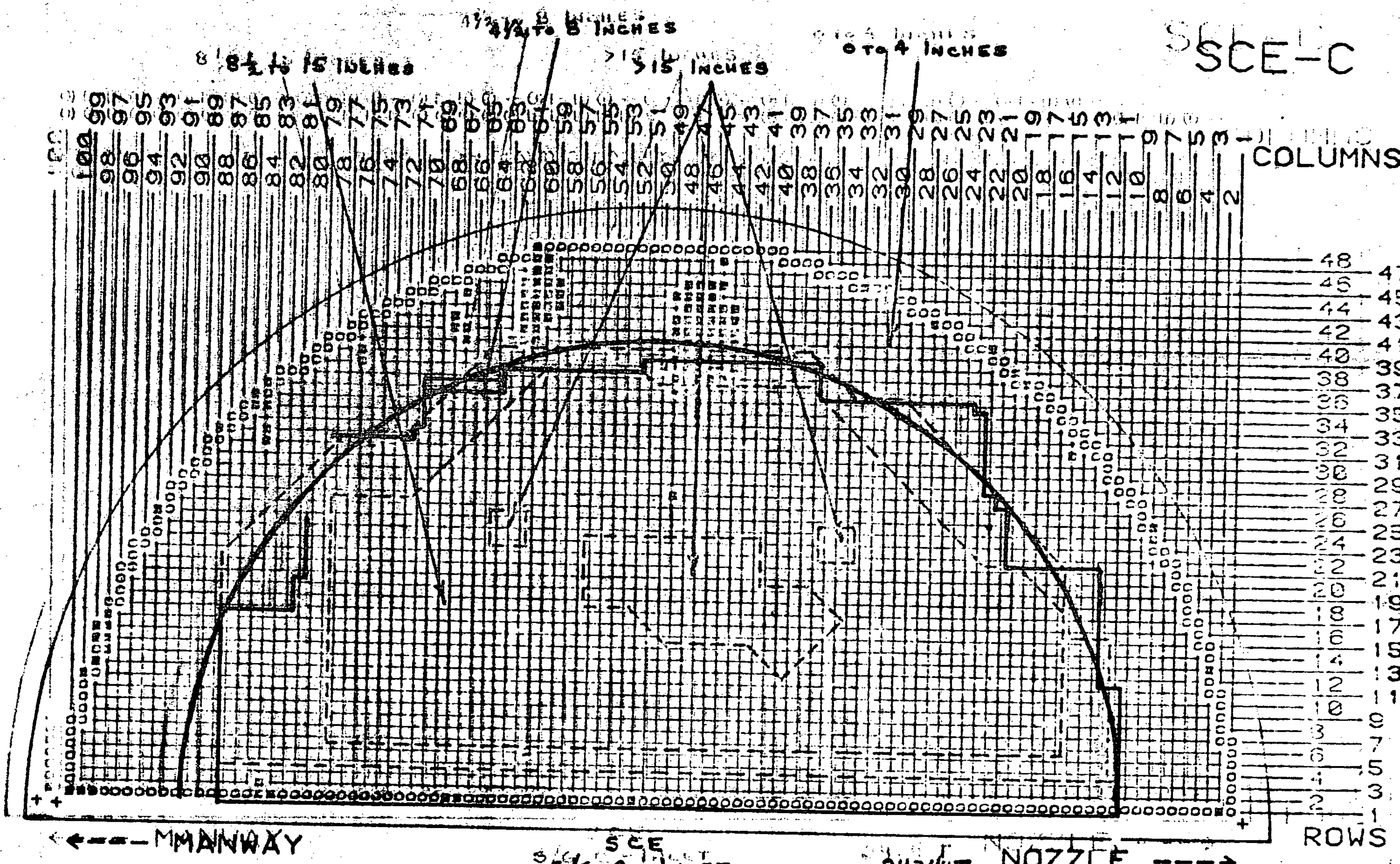
SLEEVING BOUNDARY

SLEEVABLE ZONE

2418 T
- 18 P
2405 Sleeves

SERIES 27

SCE-C



SCE
S/G C - INLET
- SLUDGE PROFILE -
- SLEEVING BOUNDARY -
- SLEEVABLE ZONE -

2424 T
- 25 P
2399 Sleeves

8/13/80

DDM

Sludge Inventory Considerations

a. Sludge lancing performed 4/80 prior to EC examinations.

	Inventory	%Removal	Residual
S/G A	77.2 gal.	57	33.2
S/G B	69.8 gal.	44	39.1
S/G C	62.8 gal.	46	33.9

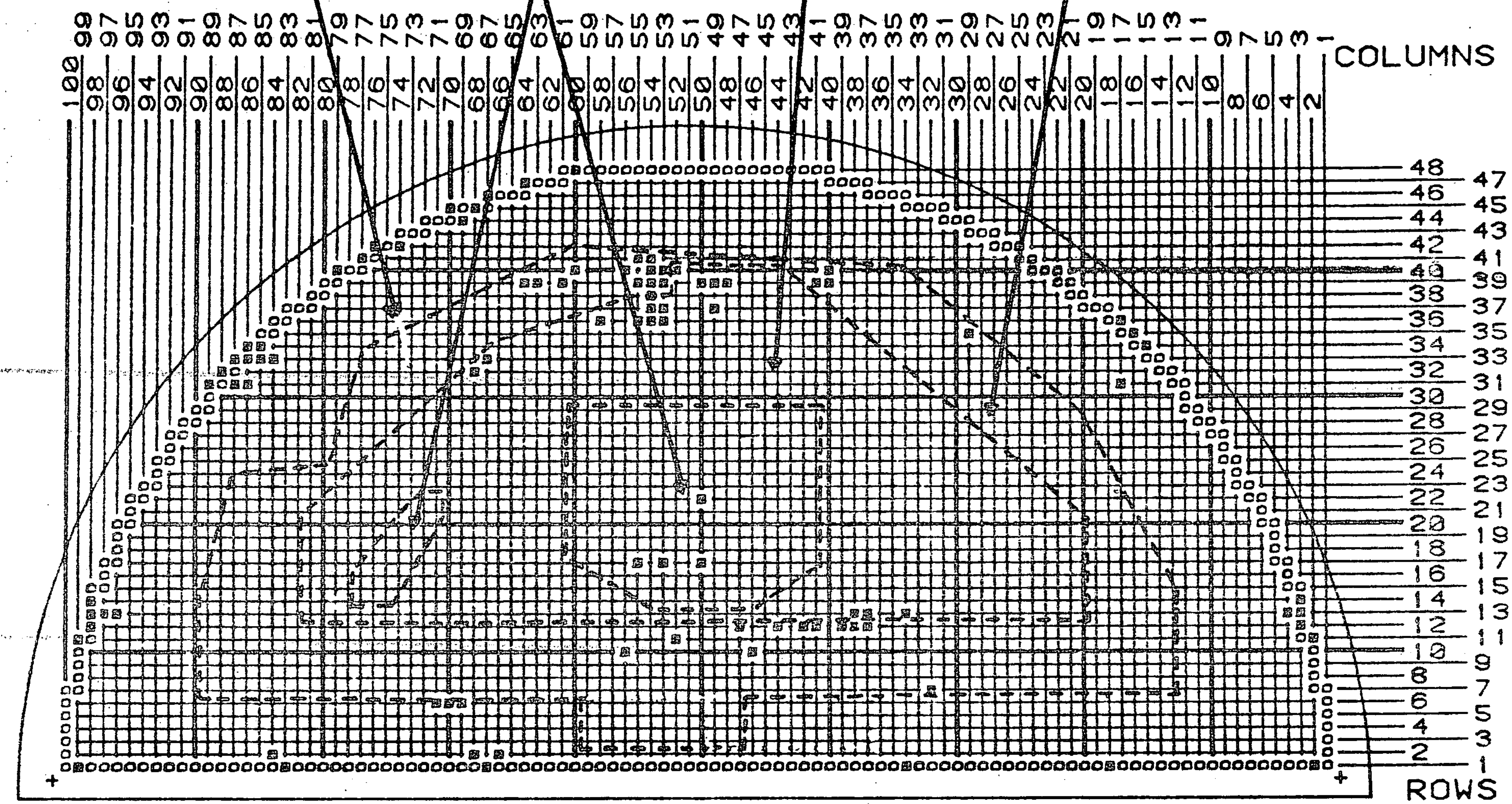
b. Results indicate 2 - 3" sludge uniformly across the tubesheet.

c. 100 kHz EC data indicates sludge up to approx. 23" in SG/A after lancing.

d. Sludge above the height of the float is not included in inventory Inventory value incorrect.

SERIES 27

SCE-A

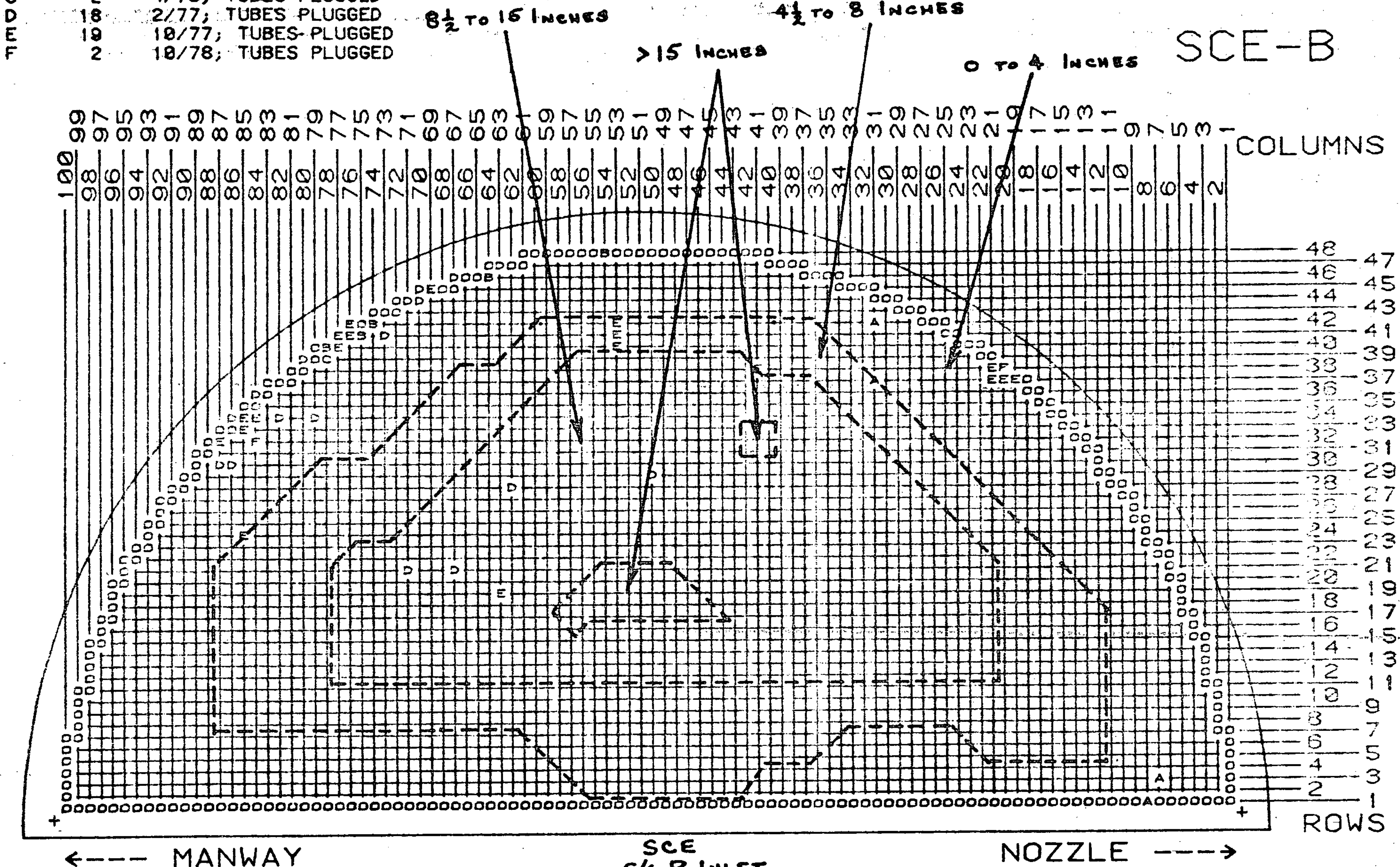


SLUDGE PROFILE

SERIES 2

SCE-B

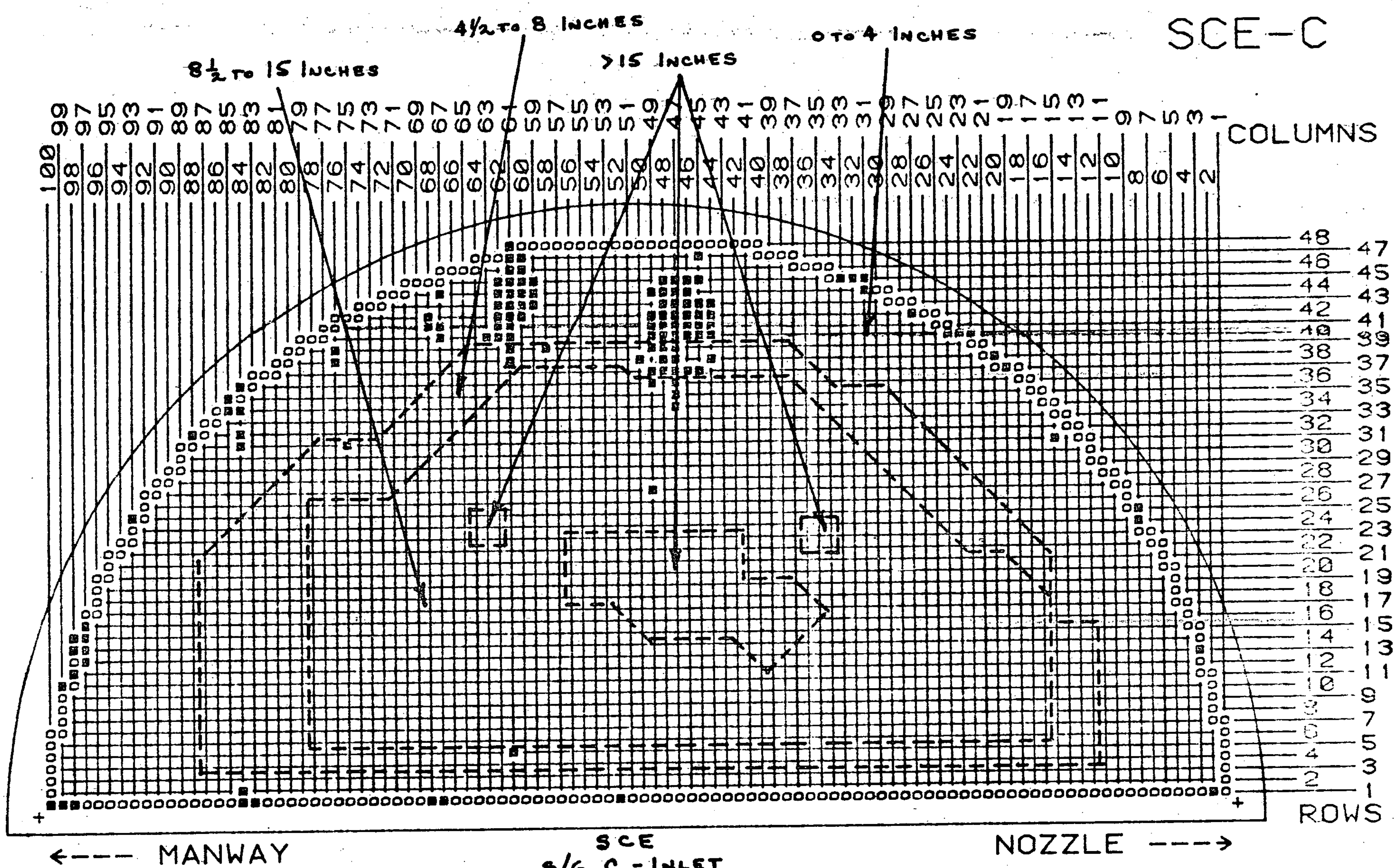
A	4	[illegible]/70; TUBES PLUGGED
B	5	[illegible]/73; TUBES PLUGGED
C	2	4/75; TUBES PLUGGED
D	18	2/77; TUBES PLUGGED
E	19	10/77; TUBES PLUGGED
F	2	10/78; TUBES PLUGGED



SCE
S/G B INLET

SLUDGE PROFILE

SCE-C



SCE
S/G C - INLET
SLUDGE PROFILE

San Onofre #1

Progression of Tube Degradation
at the Top of the Tubesheet

Tube Corrosion reported during the 1980 SG inspections was not a new or sudden occurrence.

- -1979 Leakers in SG/A
- -1976 Findings in SG/A

The chemical environment leading to a caustic condition was consistent over an extended period back to the early 1970's.

Review of prior EC data from tubes with deep indications in 1980 shows the presence of probable degradation in several prior inspections.

-Observable effects suggests degradation beyond 40% minimum.

-Sampling of tubes so characterized show 60-70% penetration 3-4 years ago; present values range from 80-100%.

Semi - quantitative estimate of progression of corrosion of less than 15% per year appears reasonable.

TUBE PRESSURE TESTS

SUMMARY OF TESTS

SLUDGE VS INSITU TESTS

WHOLE BUNDLE PRESSURE TEST

RESIDUAL STRENGTH OF TUBES

SUMMARY

SUMMARY OF TUBE PRESSURE TESTS

1. LEAKING TUBES

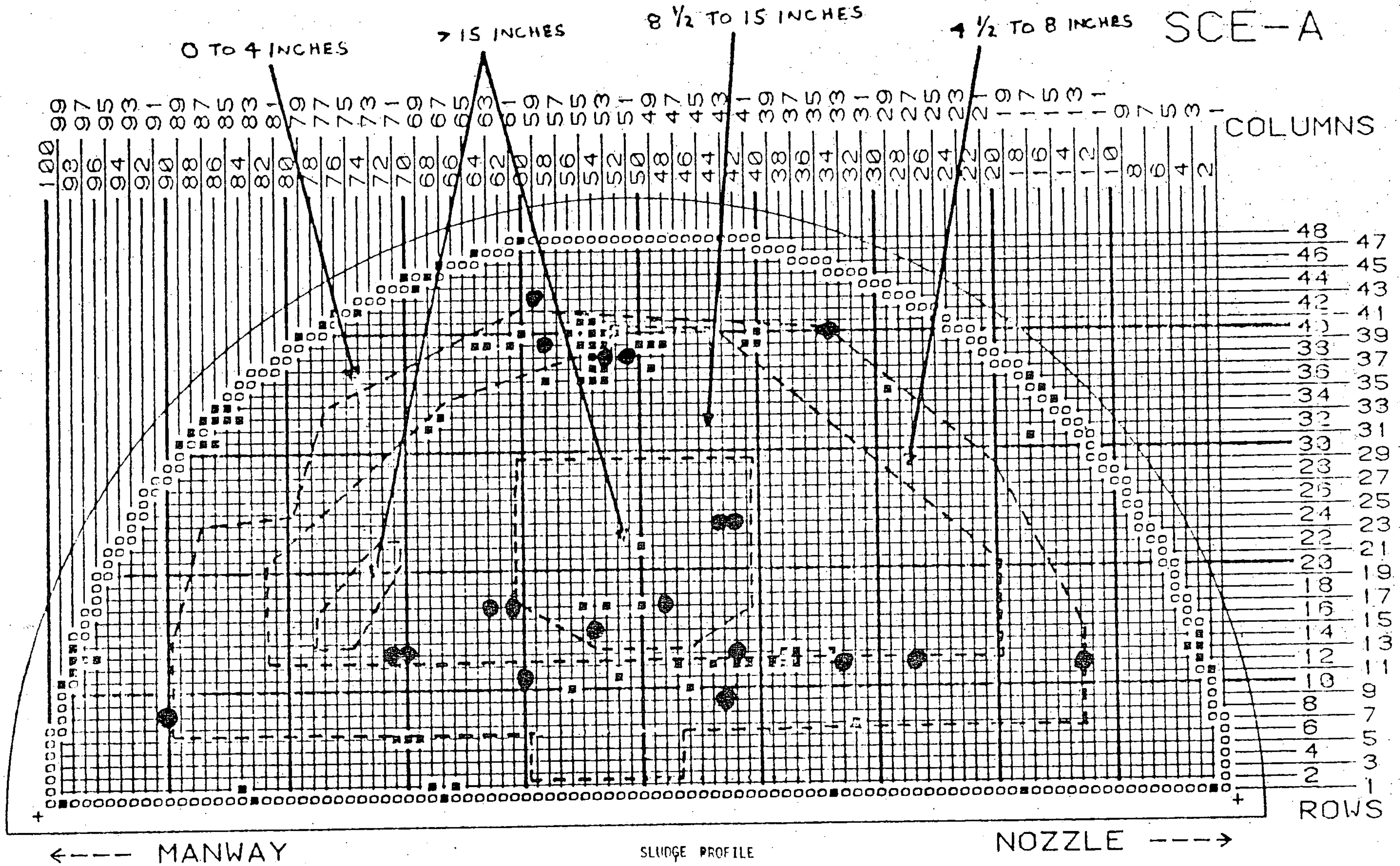
   --LEAKED AT STABLE RATE
   --SLUDGE MAY HAVE IMPEDED LEAK RATE
   --VISUAL INSPECTION SHOWED LARGE SEPARATION

2. BENCH TEST

   --50% CRACK OVER 180°
   --BURST AXIALLY AT 15,000 PSI
   --EXHIBITED FULL WALL STRENGTH

3. NON-LEAKING TUBES IN-SITU

   --NDD TO 97% CRACK BY RPC
   --NO MEASURED LEAKAGE AT 3000 PSI



SLUDGE PROFILE

WHOLE BUNDLE PRESSURE TEST

1. PERFORM SECONDARY & PRIMARY HYDRO

   --AFTER SLEEVING
   --PRIOR TO OPERATION
   --SECONDARY HYDRO AT ≈ 800 PSID
   --PRIMARY HYDRO AT ≈ 1900 PSID

2. HYDROTEST CONFIRMS INTEGRITY OF PRIMARY PRESSURE BOUNDARY

RESIDUAL STRENGTH OF TUBES

1. RESIDUAL STRENGTH OF TUBES IS SUFFICIENT TO WITHSTAND ACCIDENT LOADS

--CORROSION PROFILES INDICATE NON-UNIFORM CORROSION

--ANALYSIS OF CORROSION PROFILES INDICATES BURST STRENGTH >3000 PSI

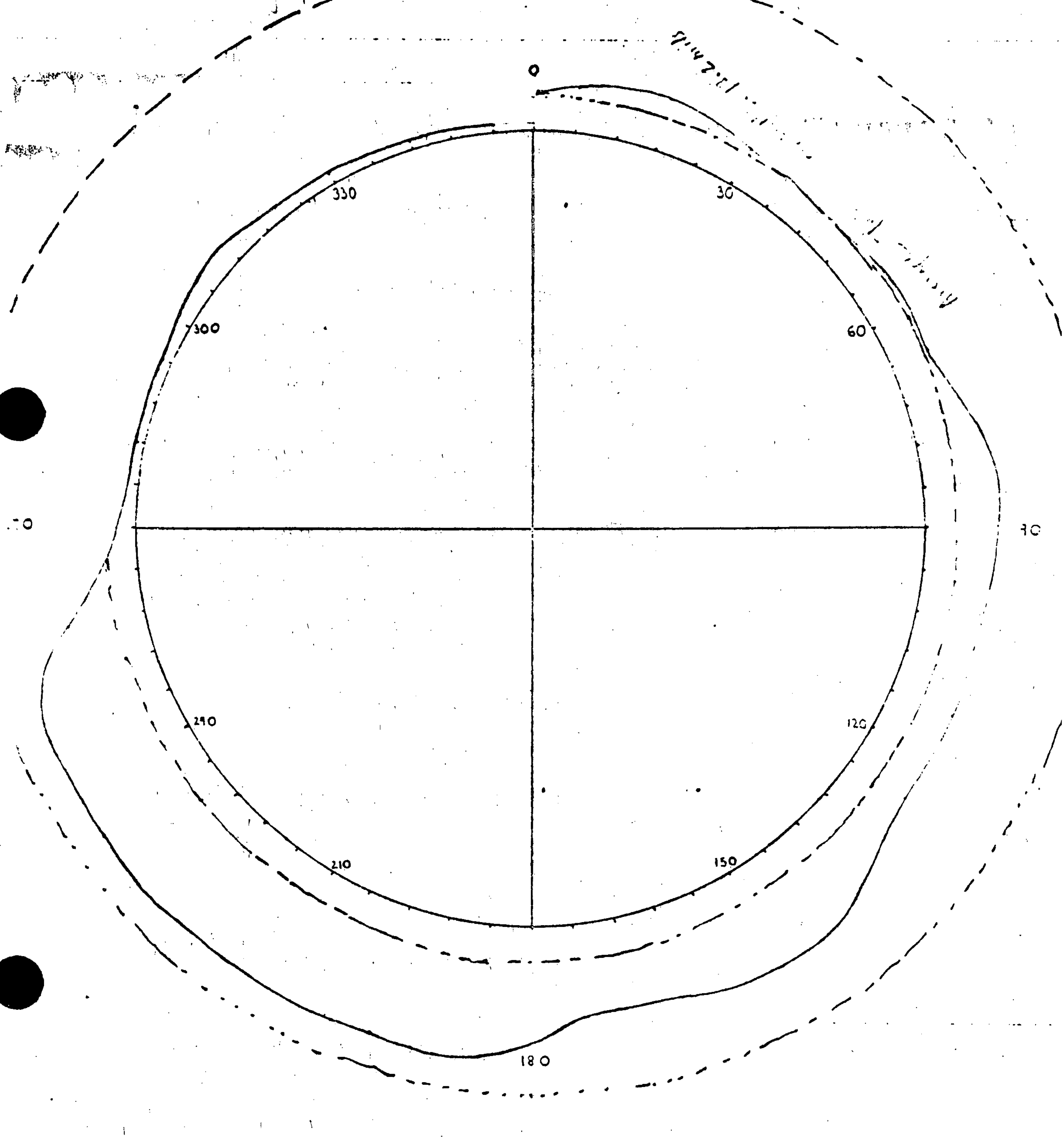
--PULLED TUBES SHOWED SIGNIFICANT DUCTILE TEARING

--ANALYSIS OF BURST PRESSURE VS ARC LENGTH OF CRACK SHOWS THAT A 90° ARC CRACK WITH 270° CORROSION TO 25% REMAINING WALL WILL WITHSTAND 3000 PSI WITHOUT BURST

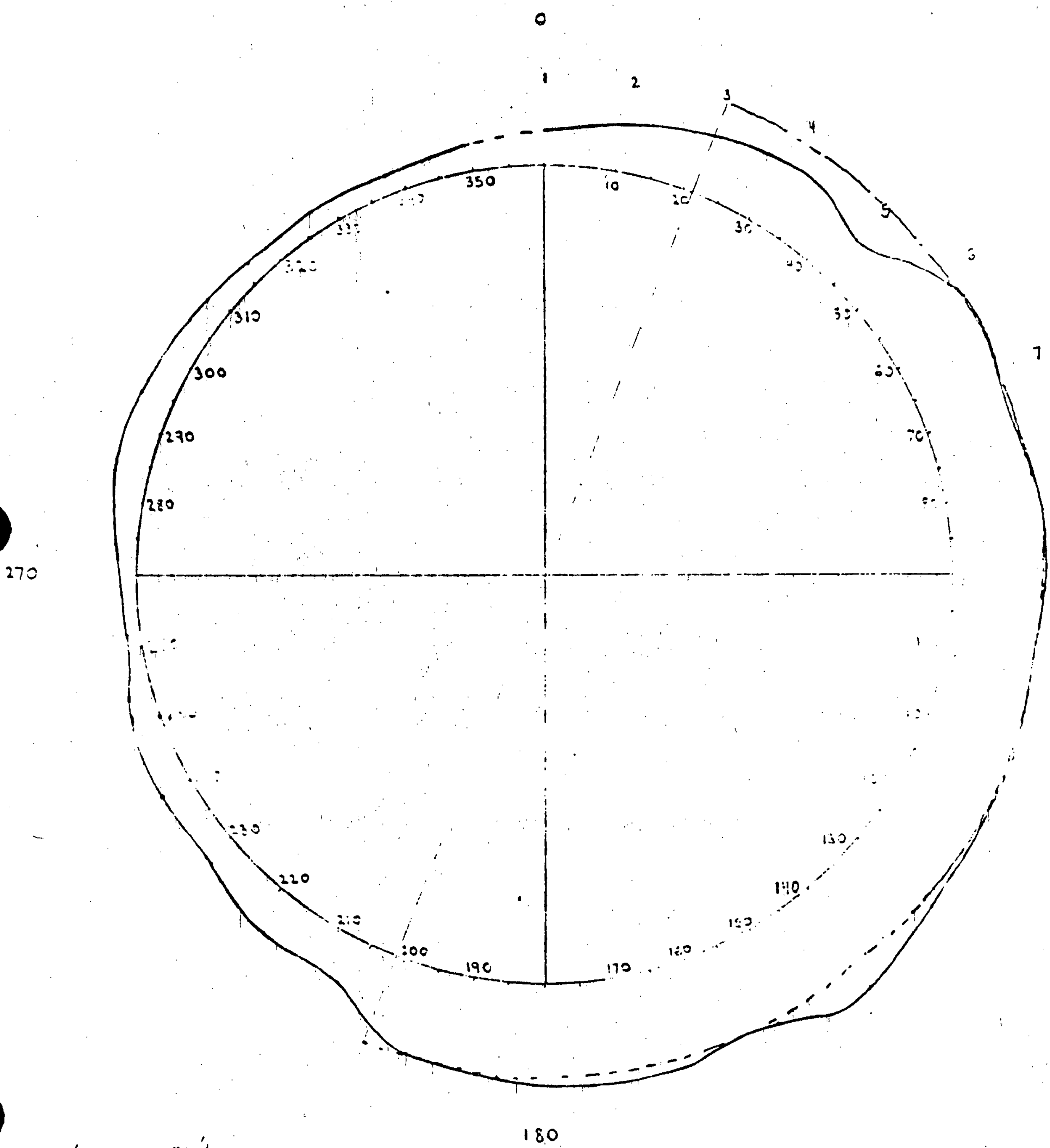
S.C.E. A24-71

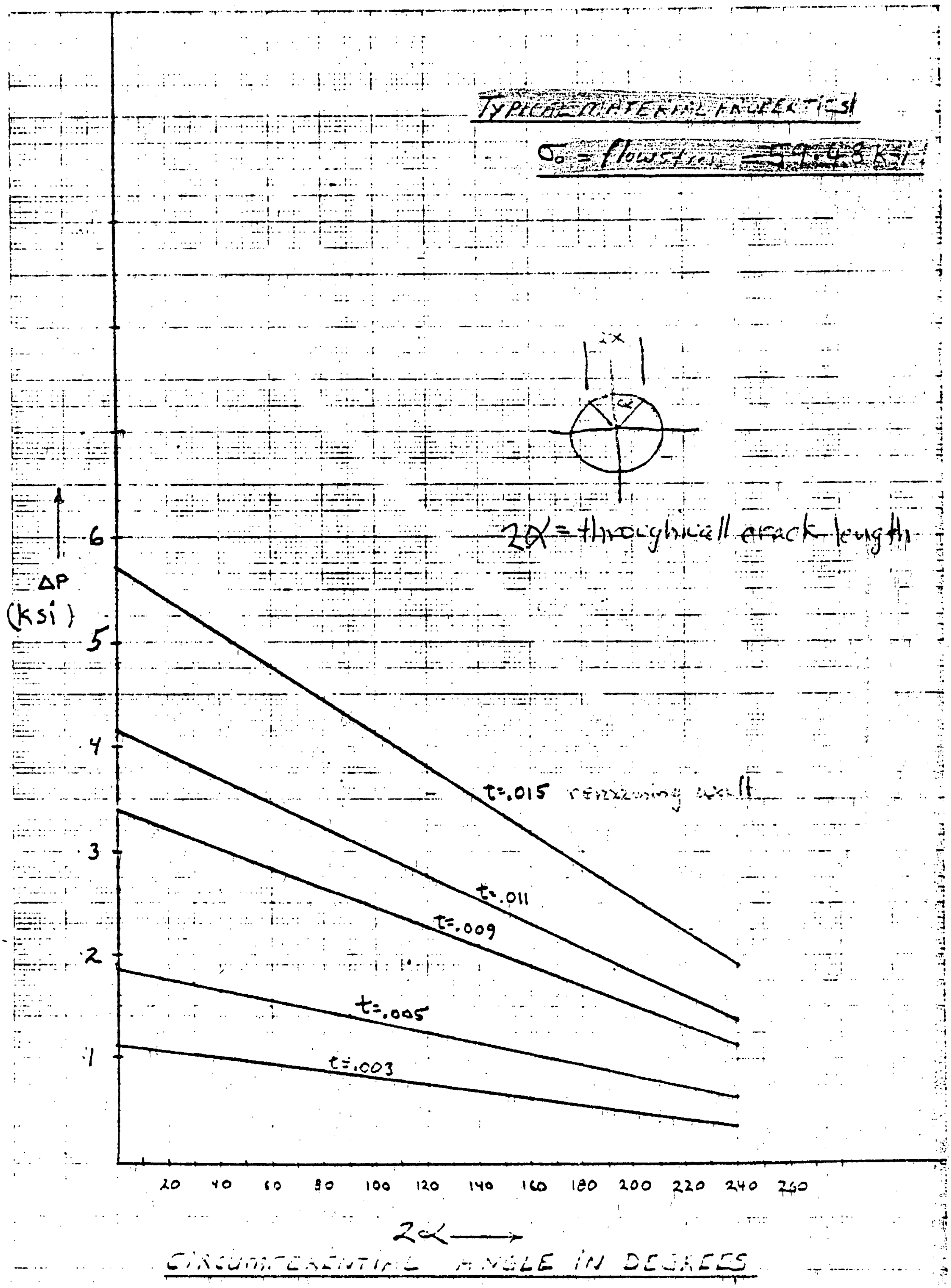
Outer scale: 1" on graph = .044"

Inner scale: 6" on graph = [illegible]"



SCE A31-28





TYPICAL MATERIAL PROPERTIES
σ_o = flowstress = 59.48 ksi
2α
2α = throughwall crack length
ΔP (ksi)
6
5
4
3
2
1
t=.015 remaining wall
t=.011
t=.009
t=.005
t=.003
20 40 60 80 100 120 140 160 180 200 220 240 260
2α
CIRCUMFERENTIAL ANGLE IN DEGREES

TUBE RESIDUAL STRENGTH

TUBE 14-70

BURST AT 15,000 PSI WITH 50% CORROSION OVER 180°
(NO SLUDGE)

TUBE 24-71

95% IGA - FRACTURED DURING PULL WITH SIGNIFICANT AREA OF DUCTILE MATERIAL - FRACTOGRAPHY ANALYSIS INDICATES BURST STRENGTH OF >3000 PSI

TUBE 31-28

70% IGA - FRACTURED DURING PULL WITH SIGNIFICANT AREA OF DUCTILE MATERIAL - FRACTOGRAPHY ANALYSIS INDICATES BURST STRENGTH OF >4000 PSI

SUMMARY OF TUBE PRESSURE TESTS

1. ALL TUBES HAVE SIGNIFICANT REMAINING RESIDUAL STRENGTH

2. LEAKING TUBES ARE EXPECTED TO EXHIBIT STABLE LEAKAGE

3. PRIMARY AND SECONDARY HYDROTEST WILL CONFIRM INTEGRITY OF UNSLEEVED TUBES

8/14/80

SUMMARY

BASIS FOR SLEEVING BOUNDARY

- WITHIN THE PERIPHERAL ZONE DEFINED, THERE ARE NO RPC INDICATIONS IN THE TUBES TESTED.

- TWO TUBES REMOVED NEAR ZONE BOUNDARY WITH NDD BY RPC WERE REMOVED WITHOUT FRACTURE AND SHOWED 20-30% PENETRATION (22-84, 23-84)

- IN-SITU PRESSURE TESTS OF TUBES IN PERIPHERAL ZONE SHOW NO LEAKAGE AT 3000 PSI
  - --22 TUBES WITH NDD TO 97% PENETRATION SHOWED NO LEAKAGE AT 3000 PSI

- TUBE 14-70 (50% CIRCUMFERENTIAL PENETRATION) BURST LONGITUDINALLY AT 15,000 PSI (~ VIRGIN TUBE STRENGTH)

- ADDITIONAL CONSIDERATIONS
  - --THERE WILL BE A PRIMARY-SECONDARY PRESSURE TEST AT 1900 PSI AFTER SLEEVING AS OVERALL STRUCTURAL INTEGRITY TEST.

  - --FOR TUBES THAT MAY CONTINUE TO UNDERGO CORROSION, METALLOGRAPHIC DATA INDICATES "LEAK BEFORE BREAK" APPLIES.

  - --CHEMISTRY PROGRAM IS EXPECTED TO REDUCE CORROSION PROCESS.