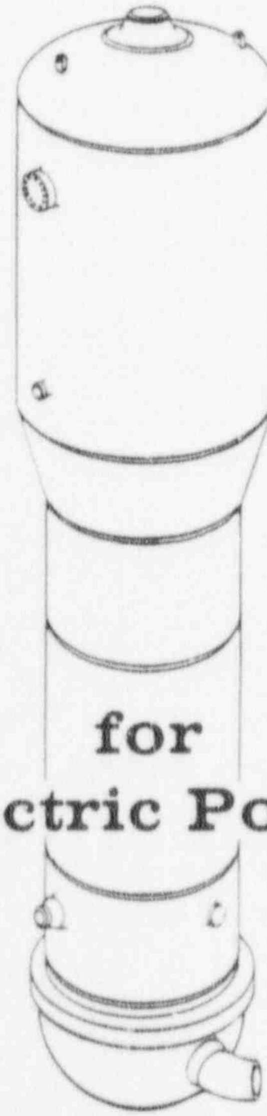
STEAM GENERATOR CREVICE FLOW TEST



for
Wisconsin Electric Power Company

Test Report
TR-ESE-411

POWER
SYSTEMS
COMBUSTION ENGINEERING, INC

8103090384

LEGAL NOTICE

COMBUSTION ENGINEERING

DEVELOPMENT DEPARTMENT

TEST REPORT

STEAM GENERATOR TUBESHEET CREVICE FLOW TEST

FOR

WISCONSIN ELECTRIC POWER COMPANY

CONTRACT NUMBER

14980

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The information contained in this document has been reviewed and satisfies the applicable items contained on Checklist No. 4 of the QADM.

Reviewer H. N. Guenon

Date Jan. 15, 1981

The information contained in this report No. TR-ESE-411 is certified to be an accurate account of information obtained by performance of the tests, inspections or other objectives described herein.

Certified by: C M [signature] Date: 1-15-81

Laboratory Manager

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1.0 INTRODUCTION

The Point Beach Nuclear Plant Unit 1 steam generators have experienced intergranular attack of the tubes in the tubesheet crevice area. A test program was undertaken to evaluate the potential rate of secondary leakage through simulated defective steam generator tubes in the tubesheet crevice.

This report details the testing which was performed to determine the secondary to primary leakage rate through tubes with simulated defects at various locations within the tubesheet crevice. All tests were performed with a nominal secondary side pressure of 1000 psig.

2.0 SUMMARY

The following summarizes the results of tests completed to determine flow characteristics through defective steam generator tubes during a postulated loss of primary pressure accident.

1. Nineteen tests were completed on samples having defects ranging from a .01 inch diameter hole to a .01" by 3 inch long slit.
2. The maximum steady state secondary to primary flow of 1460 lb/hr. was obtained with the .01 inch by 1/2 inch defect.
3. Defects greater than 1/2 inch long were found to reduce in size during test due to external pressure which caused deformation of the tube.
4. Flow is affected by primary side back pressure. Increasing the back pressure close to the saturation pressure resulted in a maximum flow that was almost twice as large as that obtained under maximum differential pressure.

5. Small defects yielded the maximum flow per unit area. Values ranged from 930,000 lbs. per hour per square inch for the .01 inch diameter hole to 46,000 lbs. per hour per square inch for the largest defect area tested.
6. An instrument error analysis showed that all tests were run with the test water entering the simulated tubesheet crevice in the liquid subcooled state.
7. Defects located 12 inches to 18 inches below the top of the tubesheet have leakage rates approximately 30% less than those located 5/8 inches below the top of the tubesheet.

3.0 DETAILS OF TEST HARDWARE

3.1 Test Facility Setup

The test facility is shown in Figure 1 and was assembled utilizing a 70 gallon autoclave with a nitrogen overpressure to provide a source of demineralized water at 550°F and a pressure of 1065 psig.

The system piping was 3/4 inch stainless steel tubing. Connectors and valves were 3/4 inch Swagelok. The discharge valve was a 1 1/2 inch fast-acting valve connected to an atomospheric drain line.

3.2 Instrumentation

All instrumentation was calibrated prior to and at the completion of the test. Instrumentation error analysis and calibration data are included as Appendix B.

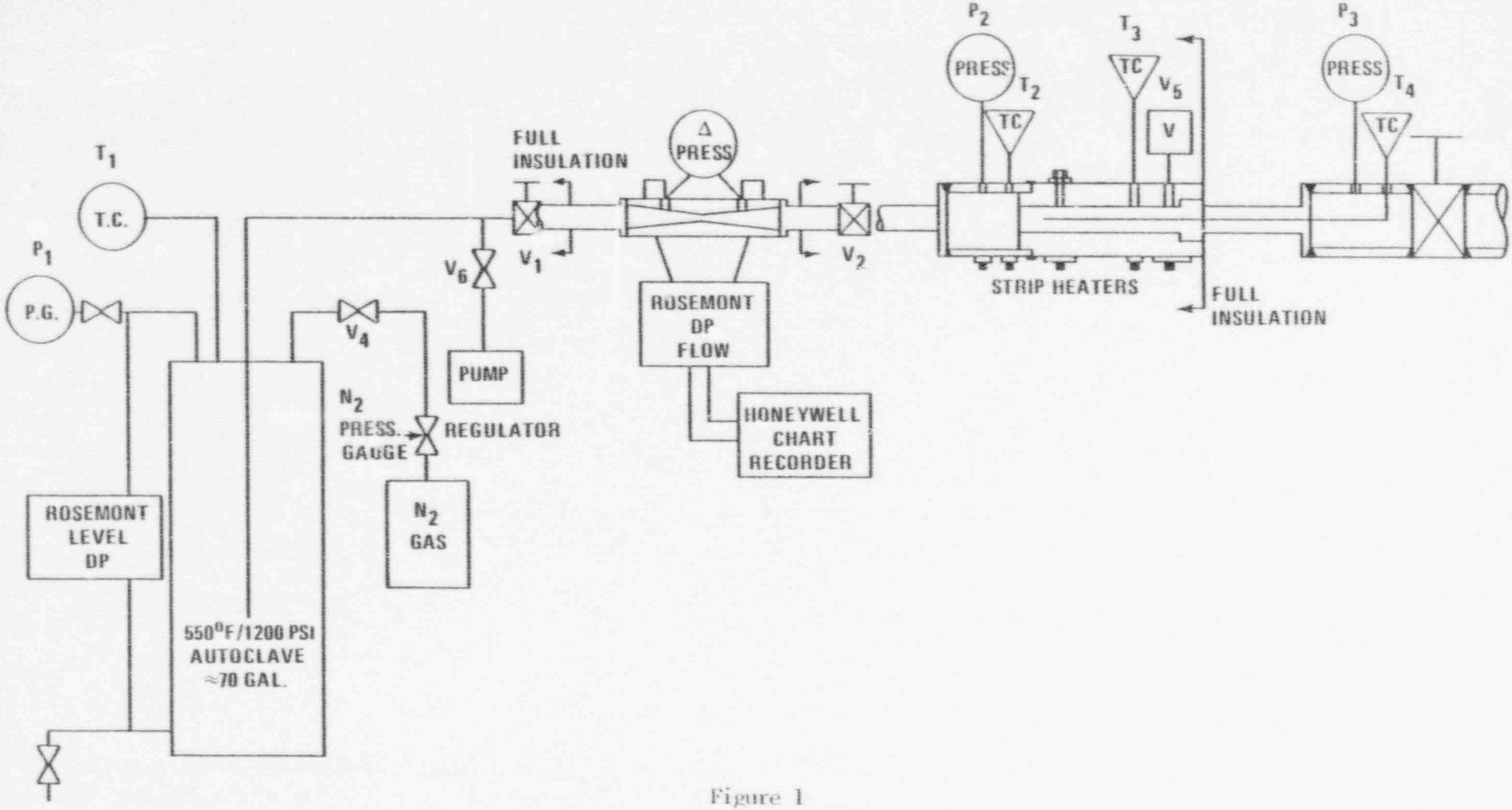


Figure 1

TEST FACILITY SETUP

3.2.1 Pressure Gages

Pressure gages were installed in the autoclave (P_1), tubesheet inlet (P_2) and upstream of the discharge valve (P_3).

3.2.2 Thermocouples

Thermocouples were installed in the autoclave (T_1), tubesheet inlet (T_2), tubesheet I.D. (T_3), and inside the tube adjacent to the defect (T_4). The thermocouples were connected to a digital readout.

3.2.3 Flow

A Meriam ΔP gage was connected to a Flow-Dyne venturi flow meter with a 0.1985 inch throat diameter. Connected in parallel to the venturi was a Rosemont ΔP Transmitter and a Honeywell 1508A visicorder. This system provided both a visual and permanent record of flow.

For backup flow data, the autoclave level was monitored. The level was measured using a Rosemont ΔP transmitter connected to a meter. Using a stopwatch and the level indication, the flow per unit time could be established.

As the level instrumentation had been calibrated at $68^{\circ}F$, the calculation in Appendix C was used to determine the $550^{\circ}F$ flow rate. Flow rates for the 0.010 inch hole defect were obtained solely by the autoclave level vs. time method.

3.3 Test Section

A 2 1/2 inch diameter carbon steel round was gun drilled to 0.892 ± .001 inches I.D. to simulate the tubesheet (Figure 2). Instrument taps and a vent tap were drilled perpendicular to the I.D. In addition, a tube deflection device was installed to deflect the test tube against the tubesheet I.D. to provide the maximum clearance area at the tube defect.

Eight strip heaters (of 250 watts each) were utilized to provide heat to the test section and inlet plenum. The test section temperature was stabilized at 600°F prior to initiation of the blowdown.

3.4 Test Specimens

The simulated steam generator tubes (Figures 15 through 22) were fabricated from 7/8 inch O.D. 316 stainless steel welded seam tubing. The tubes were cut to 24" in length and a plug welded into one end; they were then centerless ground to 0.872 ± .001 inches. Tube defects, with the exception of the 0.040 inch hole (3A) and the 0.010 X .500 inch slit (2A), were installed using Electron Discharge machining.

The tubes were installed in the test section (tubesheet) using Swagelok fittings. Defect positioning within the tubesheet crevice was measured to ± 1/16 inches.

4.0 DISCUSSION

4.1 Testing

The test tubes were installed in the simulated tubesheet and

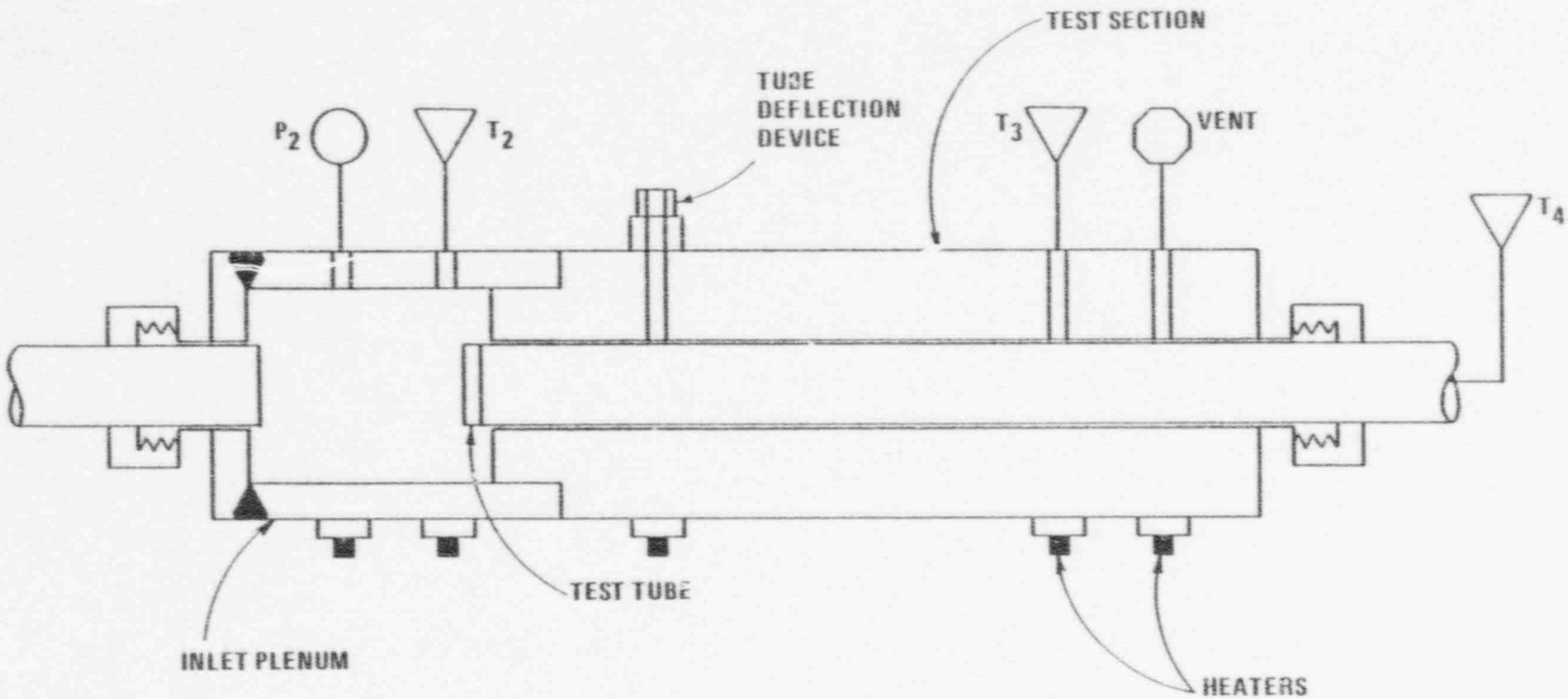


Figure 2

TEST SECTION INSTRUMENTATION
(SIMULATED TUBESHEET)

the defect location fixed. The tube was deflected to contact the tubesheet opposite the defect to allow maximum flow area at the defect. The system was heated and pressurized from the autoclave through the specimen tube up to the discharge valve. Upon reaching test conditions, the system was rapidly depressurized by opening the discharge valve. Temperature, flow and pressure were recorded before, during, and after blowdown.

An instrument error analysis (Appendix B) showed that all tests were run with the test water entering the simulated tubesheet crevice in the liquid subcooled state.

The testing was performed in accordance with Test Procedure 00000-ESE-298, "Wisconsin Electric Power Steam Generator Tubesheet Crevice Test", (Appendix A).

4.2 Observations

A total of 19 blowdown tests were performed using 9 tubes with various defects. Tests 1 through 12 and 17 through 19 were performed with the defect located 5/8 in. from the top of the tubesheet. Tests 13 through 16 were performed with the defect located 12 and 18 inches into the tubesheet. Flows with the defect located at these levels were, respectively, 590 and 500 lbs. per hour less than those with the defect located 5/8 in. into the tubesheet. See Figure 12. Flow rates for the other defects are displayed in Figures 5 through 11.

The flow rates during the initial ten seconds of each test were higher than those after test stabilization although significantly higher (50-100% higher) only for the first two (2) seconds. This corresponded to a freely discharging submerged flow condition as the valve was being opened and the back pressure in the test section was being reduced to atmospheric pressure. As the internal tube back pressure decreased and vaporization across the defect was established, flow rates stabilized at significantly lower values.

Tube deformation at the simulated defect was noted in most of the tubes after test. Tube S/N 4A defect was measured prior to installation at .010 x 1.00 inches. The tube was then installed and brought to test conditions (550°F 1075 psig) and stabilized for 30 minutes. The I.D. of the tube was not depressurized, thus no differential pressure was established. The tube was cooled and reinspected. No change in tube diameter or defect area was noted. The tube was then tested normally, after which test measurements disclosed a reduction in the defect area of about .005 in^2 due to tube deformation during flow testing. It was thus verified that the defect reduction was due to the external pressure caused by the depressurization rather than thermal effects.

Figure 15 and Table 1 provide a correlation of the stabilized flow per unit area versus defect area after test. A trend seems to be established that the larger defects have lower flow per unit area than the small defects.

The measured flow rates and the defect size effect can be correlated by equations for critical flow through orifices. These correlations are provided in Appendix D. For initially subcooled water, Zaloudek (Ref. 1) found that a choking condition occurs at the orifice throat corresponding to the situation when the local pressure reaches the saturation pressure. This is referred to as upstream choking which is characterized by flow consisting of a liquid core surrounded by a vapor annulus. The flow through the orifice remains constant even with further decreases in the back pressure.

This critical flow, G_1, is given by:

$$G_1 = C_1 \sqrt{2\ gc\ \rho_1\ (P_{upstream} - P_{sat.})} \qquad (1)$$

where C_1 is a coefficient of discharge, ρ_1 is saturated water density, $P_{upstream}$ is pressure upstream of orifice, and $P_{sat.}$ is saturation pressure at subcooled liquid temperature.

For highly metastable flow, the superheated liquid does not have time to flash and establish thermodynamic equilibrium. In this instance, the liquid flashes downstream of the orifice leading to a second critical flow situation. The value of this critical flow is determined from the data of Burnell as,

$$G_2 = \sqrt{2gc\ \rho_1 \left[P_{ups.} - (1-C_2)\ P_{sat.}\right]} \qquad (2)$$

where C_2 is a function of the surface tension.

Comparison of the measured flow rates with the predicted values by Eqs. 1 and 2 (Appendix D) showed that the flow rates for the smaller size defects corresponded to G_2 and those of the large defects corresponded to G_1 . It is thus apparent that with the smaller flow areas (0.010" hole up to 0.10" x 0.50" slit), surface tension has a strong effect in suppressing flashing and metastable conditions are more apt to occur. Conversely, thermodynamic equilibrium is reached with the larger flow areas. The agreement between predicted and measured values is close (± 15 to ± 27 percent) except for the 0.010" hole and the longest slits.

Increasing the upstream pressure for Tube 2A (Runs 3 & 5) created only a small increase in flow (< 1% increase). This trend is also predicted by Eq. 2; a much larger increase is predicted by Eq. 1. This supports the conclusion of downstream choking for this tube.

Figure 13 shows the effect of back pressure on flow for Tube 5A. In this test, stabilized flow conditions were first established with the back pressure set at atmospheric conditions. The isolation valve was then slowly closed to increase the back pressure. When the back pressure reached a value in the vicinity of the saturation pressure (1003 psia), the flow reached a maximum, a factor 1.8 greater than stabilized flow rate, after which, with further increase in back pressure, the flow decreased to zero corresponding to a decreasing differential pressure as in single phase flow. Due to the difficulty of obtaining steady values of flow under high back pressures, the flow versus back pressure data of Figure 13 represent quasi-steady state values. However, the maximum flow reached can be compared to the maximum theoretically possible. Since Eq. 1 applies for Tube 5A, increasing the back pressure would propagate this pressure increase back towards the orifice and cause the local static pressure to exceed the saturation pressure. Consequently, the choking condition would be removed, and the flow would be increased by the increase of the discharge coefficient to the single phase value (i.e., o.62 to 1.0 or a factor of 1.6). This provides an explanation of the increase in flow rate.

Two test runs were made to assess the effect of tube clearance within the simulated tubesheet. Runs 18 and 19, using the .01 by .5 inch long defect located 5/8 inches from the top, were placed undeflected in the test section. Leakage rates were generally lower than those obtained with the maximum clearance runs but only by a small percentage, approximately 3%. Since other parameters, such as inlet temperature and pressure have a much larger effect, it is concluded that tube excentricity within the clearances tested does not significantly affect the leakage rates reported.

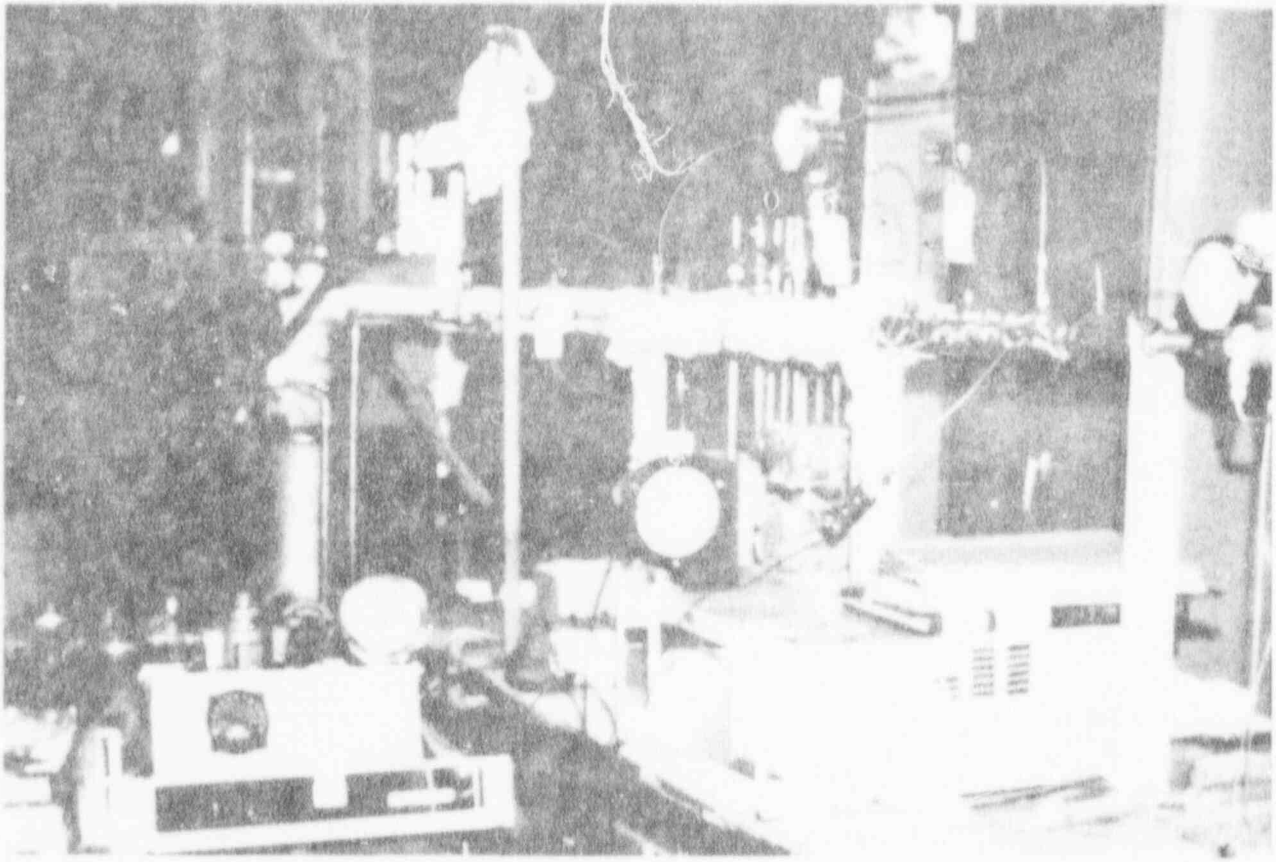
The test simulated a single tube and the adjacent tubesheet material. In an operational situation, unless adjacent tubes were also leaking, a larger heat source would be available thus maintaining a higher discharge/tubesheet temperature. This would tend to decrease the tube leak rate.

5.0 CONCLUSIONS

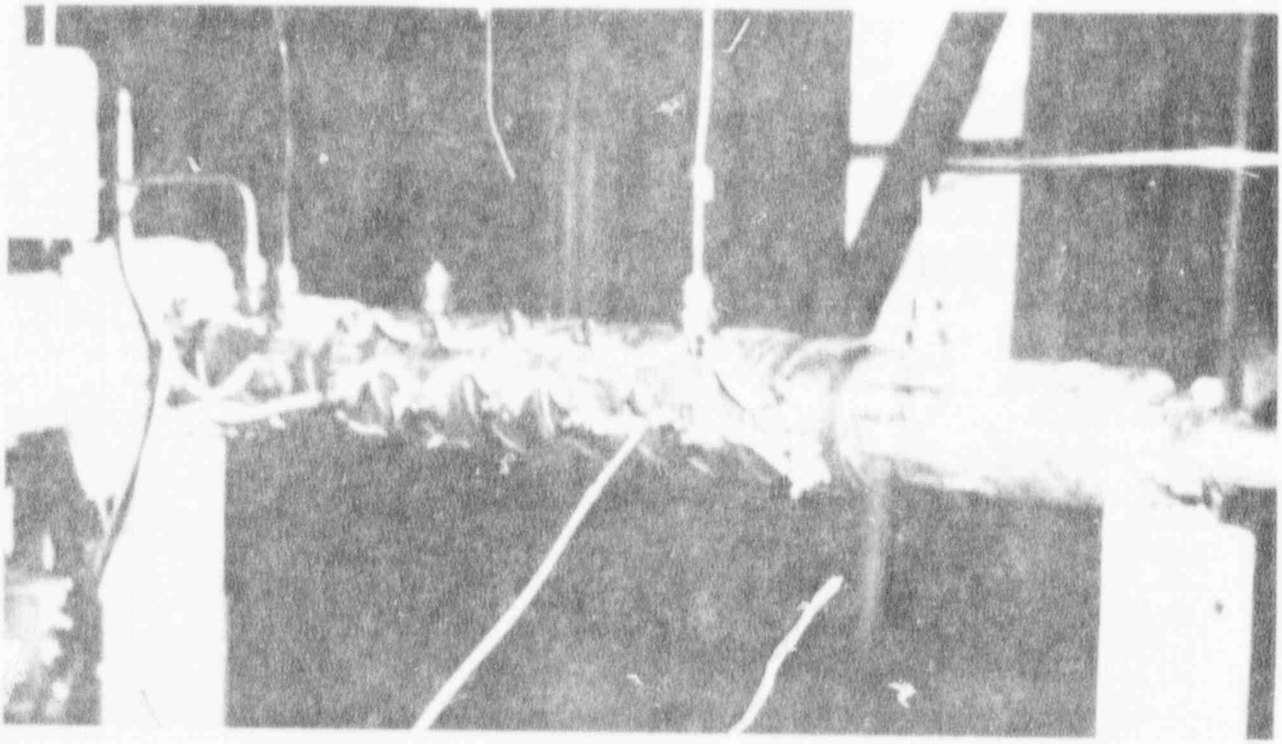
Based on the test data, it can be seen that the smaller defects yield larger leak rates per unit area. The maximum leak rate per unit area was obtained with the .01 inch diameter hole which yielded about 930,000 lbs. per hour per square inch. The measured leak rates can be correlated to previous data for critical flow in orifices based on upstream choking for the larger defect areas and downstream choking for the smaller defect areas.

An increased leak rate was observed when the simulated steam generator tube was internally pressurized to near saturation pressure of the water. The magnitude of this increase for large defects was twice that found while discharging at maximum ΔP.

With large defects, 12 inches to 18 inches from the top of the tubesheet, leak rates were reduced as much as 30%. Concentricity of the tube within the tubesheet crevice had minimal effect.



STEAM GENERATOR CREVICE LEAK RATE TEST FACILITY
FIGURE NO. 3



TEST SECTION - INSULATION REMOVED
FIGURE NO. 4

Table 1

TUBE		DEFECT		PRESSURE		TEMPERATURE		LEAK RATE				MINIMUM DEFECT WIDTH AFTER TEST	DEFECT AREA (IN^2)
RUN NO.	SERIAL NO.	SIZE (IN)	LOCATION	P_1	P_2	T_1	T_2	AUTOCLAVE † GPM	AUTOCLAVE † LB/HR	CALCULATED †† GPM F_1	CALCULATED †† LB/HR		
1	2A	.010 x .500	5/8"	1075	1050	541	219	3.5	1300	3.8	1390	.0115"	.00595
2	2A	.010 x .500	5/8"	1050	1025	534	222	3.8	1400	3.9	1420	.0115"	.00595
3	2A	.010 x .500	5/8"	1160	1125	546	217	3.6	1325	4.1	1500	.0115"	.00595
4	2A	.010 x .500	5/8"	1080	1050	541	242	3.3	1225	3.7	1370	.0115"	.00595
5	2A	.010 x .500	5/8"	1075	1040	547	241	4.0	1475	3.7	1370	.0115"	.00595
6	2A	.010 x .500	5/8"	1050	1025	545	242	4.0	1475	3.5	1280	.0115"	.00595
7	3A	.040 Dia.	1/2"	1100	1060	541	214	.9	325	1.0	360	.040"	.00133
8	4A	.010 x 1.00	5/8"	1125	1090	543	220	1.3	475	1.6	580	.005"	.00625
9	4A	.010 x 1.00	5/8"	1100	1075	542	219	1.3	475	1.5	540	.005"	.00625
10	5A	.010 x 2.00	5/8"	1090	1050	546	244	1.4	525	1.8	670	.006"	.01419
11	5A	.010 x 2.00	5/8"	1100	1060	547	225	1.6	600	1.7	640	.006"	.01419
12	6A	.010 x 3.00	5/8"	1080	1050	547	238	2.1	775	2.3	840	.007"	.02861
13	8A	.010 x .500	12"	1090	1050	546	241	2.9	1075	2.6	970	.008"	.00486
14	8A	.010 x .500	12"	1090	1050	547	252	2.6	975	2.6	970	.008"	.00486
15	9A	.010 x .500	18"	1090	1050	545	242	2.1	775	2.4	880	.009"	.00556
16	9A	.010 x .500	18"	1090	1070	547	241	2.2	825	2.3	840	.009"	.00556
17	7A	.010 Dia.	5/8"	1100	1070	520	214	.1	37	—	—	.010"	3.96×10^{-5}
18*	2A	.010 x .500	5/8"	1100	1040	547	250	3.3	1225	3.6	1330	.0115"	.00595
19*	2A	.010 x .500	5/8"	1090	1050	548	248	3.4	1250	3.6	1330	.0115"	.00595

* Tube not deflected within tubesheet

† Rounded to nearest 25-lb. increments (Run #17 - actual no.)

†† Rounded to nearest 10-lb. increments

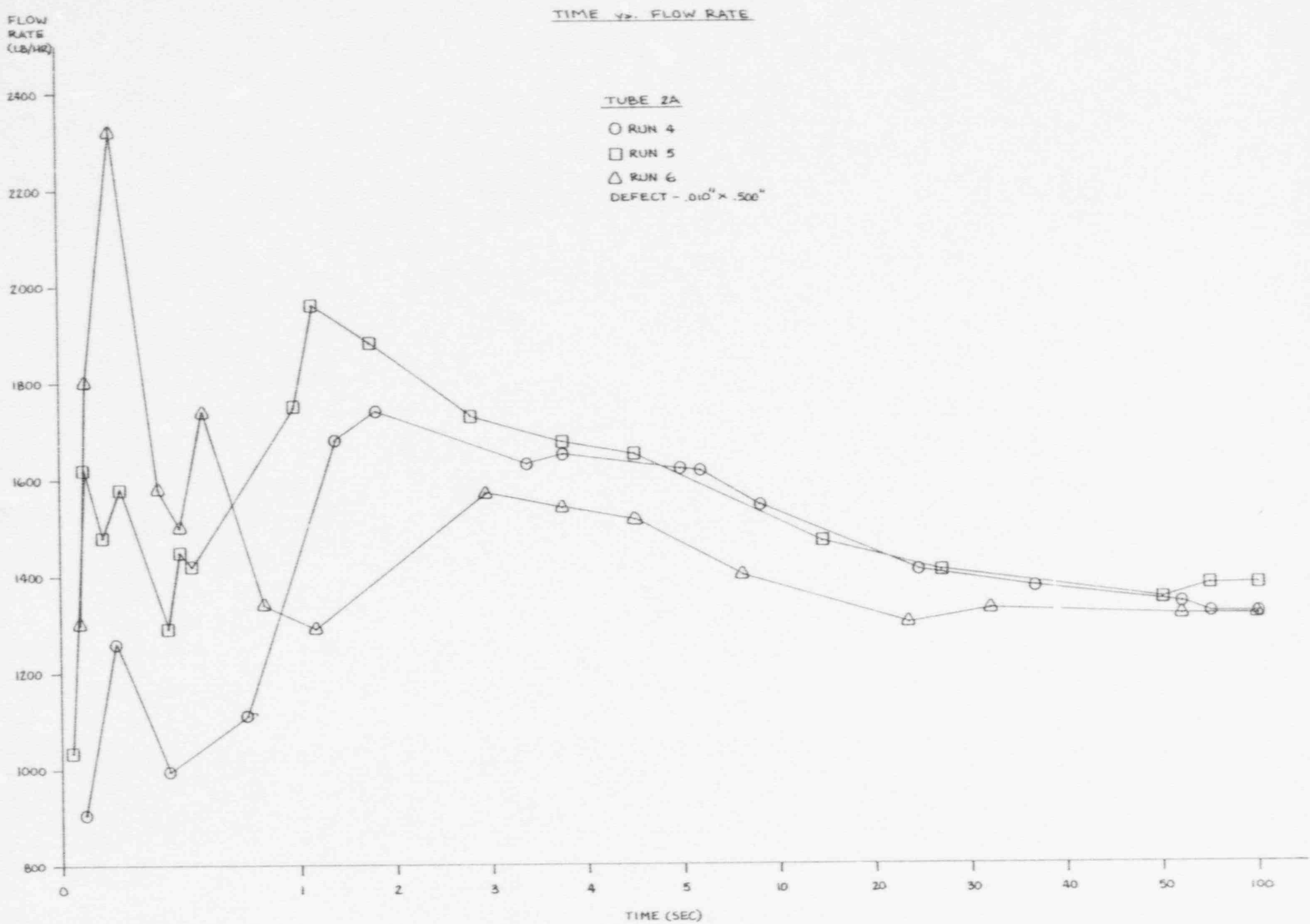

TIME vs. FLOW RATE
FLOW RATE (LB/HR)
2400
2200
2000
1800
1600
1400
1200
1000
800
TUBE 2A
○ RUN 4
□ RUN 5
△ RUN 6
DEFECT - .010" × .500"
0
1
2
3
4
5
10
20
30
40
50
100
TIME (SEC)

Figure 5

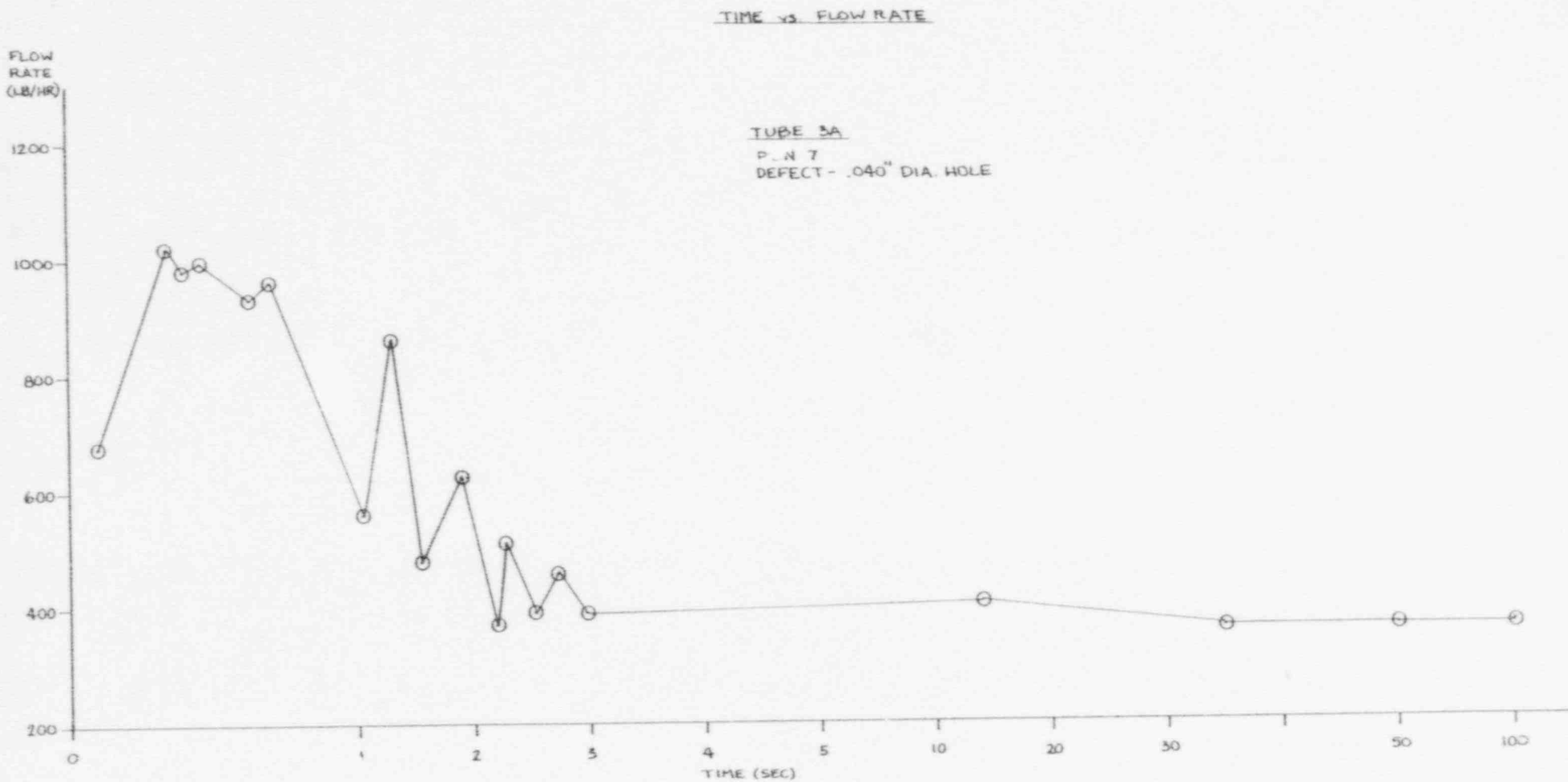

TIME vs. FLOW RATE
FLOW RATE (LB/HR)
1200
1000
800
600
400
200
TUBE 3A
P. N 7
DEFECT - .040" DIA. HOLE
0
1
2
3
4
5
10
20
30
50
100
TIME (SEC)

Figure 6

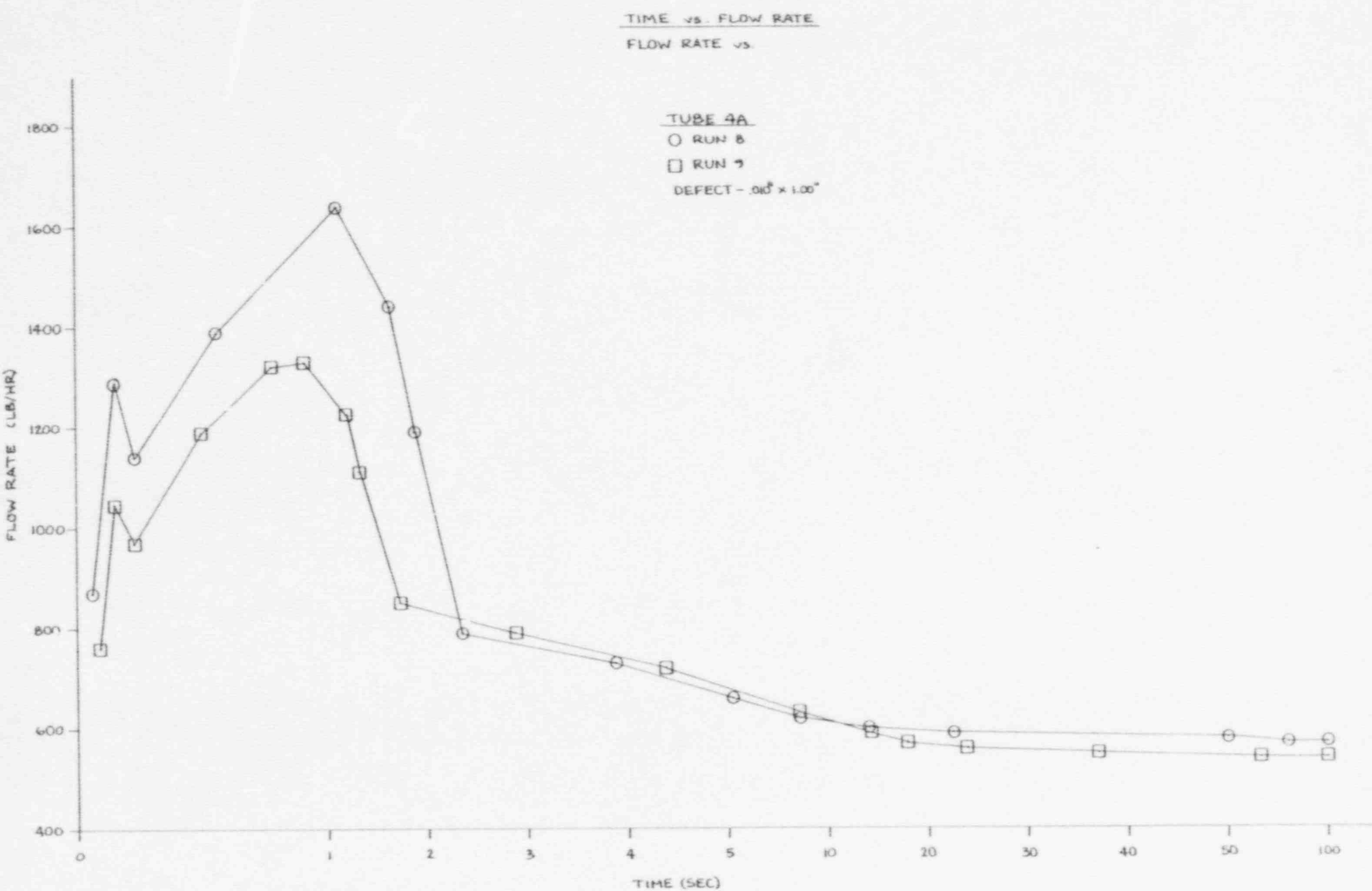
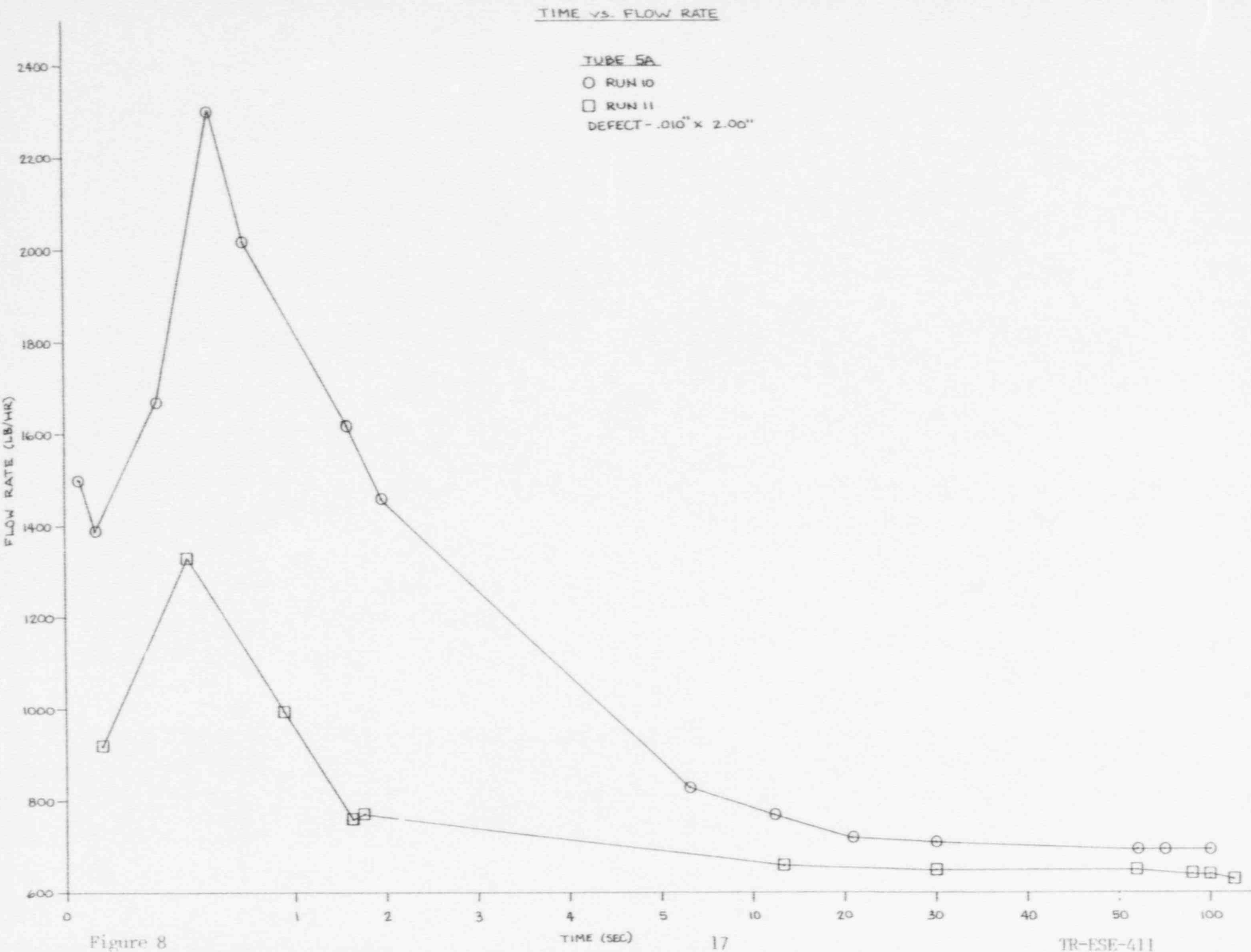

TIME vs. FLOW RATE
FLOW RATE vs.
TUBE 4A
○ RUN 8
□ RUN 9
DEFECT - .010" x 1.00"
FLOW RATE (LB/HR)
1800
1600
1400
1200
1000
800
600
400
0
1
2
3
4
5
10
20
30
40
50
100
TIME (SEC)

Figure 7



TIME vs. FLOW RATE
TUBE 5A
○ RUN 10
□ RUN 11
DEFECT - .010" x 2.00"
FLOW RATE (LB/HR)
2400
2200
2000
1800
1600
1400
1200
1000
800
600
0
1
2
3
4
5
10
20
30
40
50
100
TIME (SEC)

Figure 8

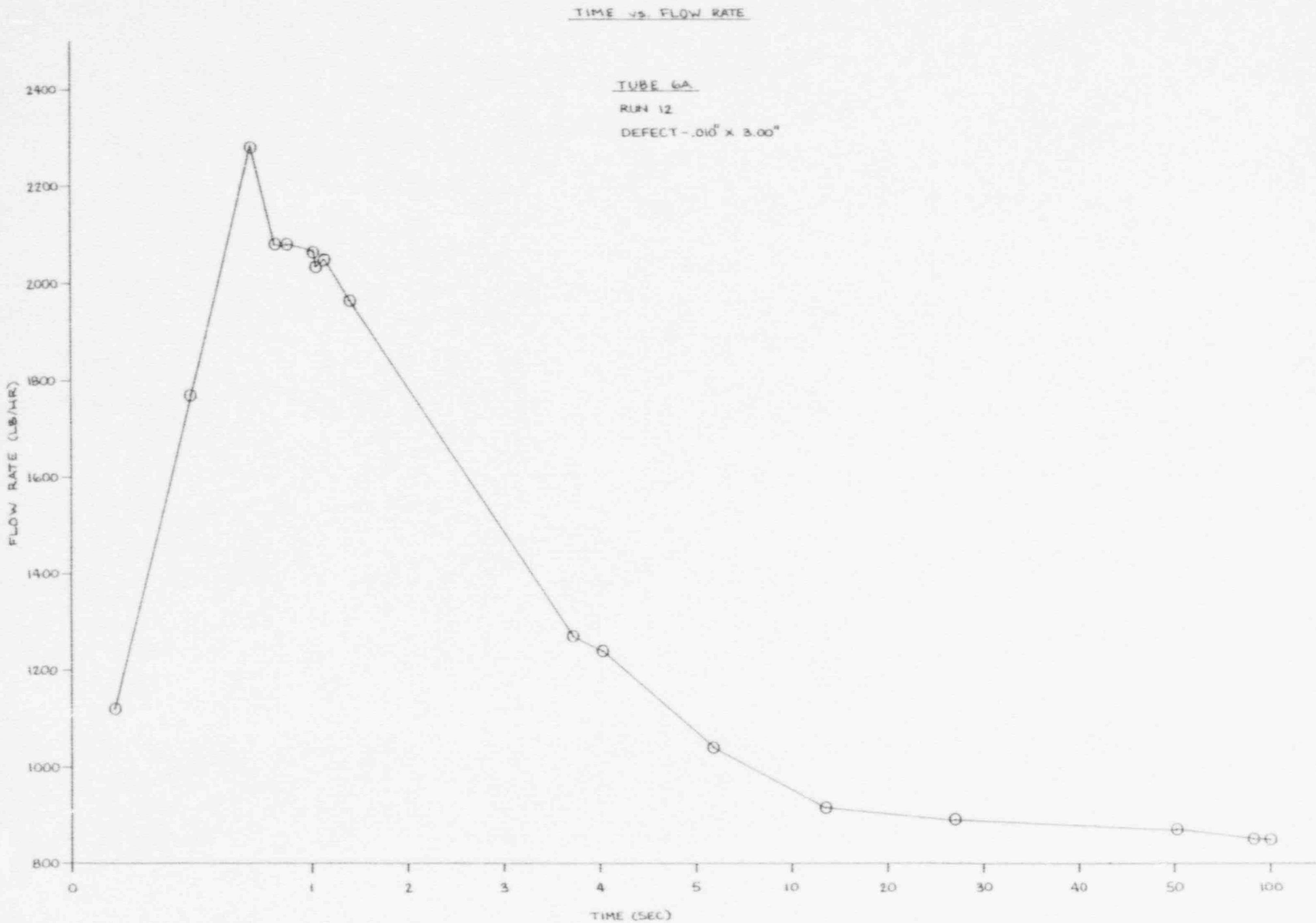

TIME vs. FLOW RATE
TUBE 6A
RUN 12
DEFECT - .010" x 3.00"
FLOW RATE (LB/HR)
2400
2200
2000
1800
1600
1400
1200
1000
800
0
1
2
3
4
5
10
20
30
40
50
100
TIME (SEC)

Figure 9

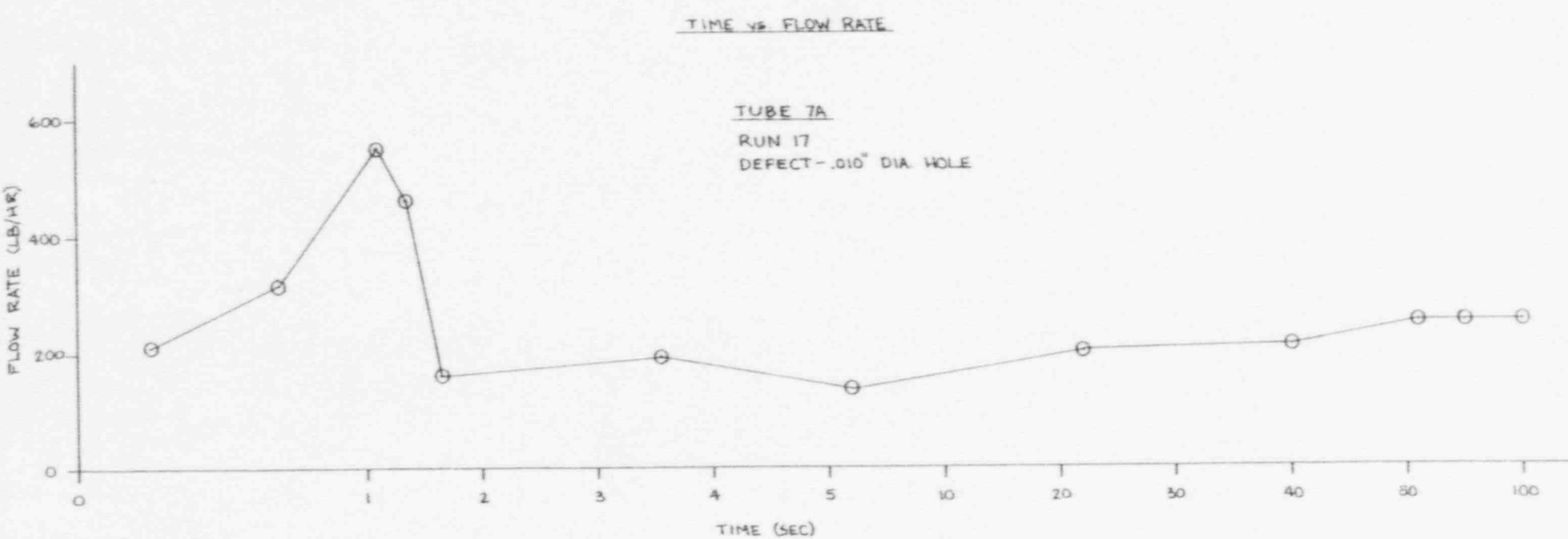

TIME vs. FLOW RATE
TUBE 7A
RUN 17
DEFECT - .010" DIA. HOLE
FLOW RATE (LB/HR)
600
400
200
0
0
1
2
3
4
5
10
20
30
40
80
100
TIME (SEC)

Figure 10

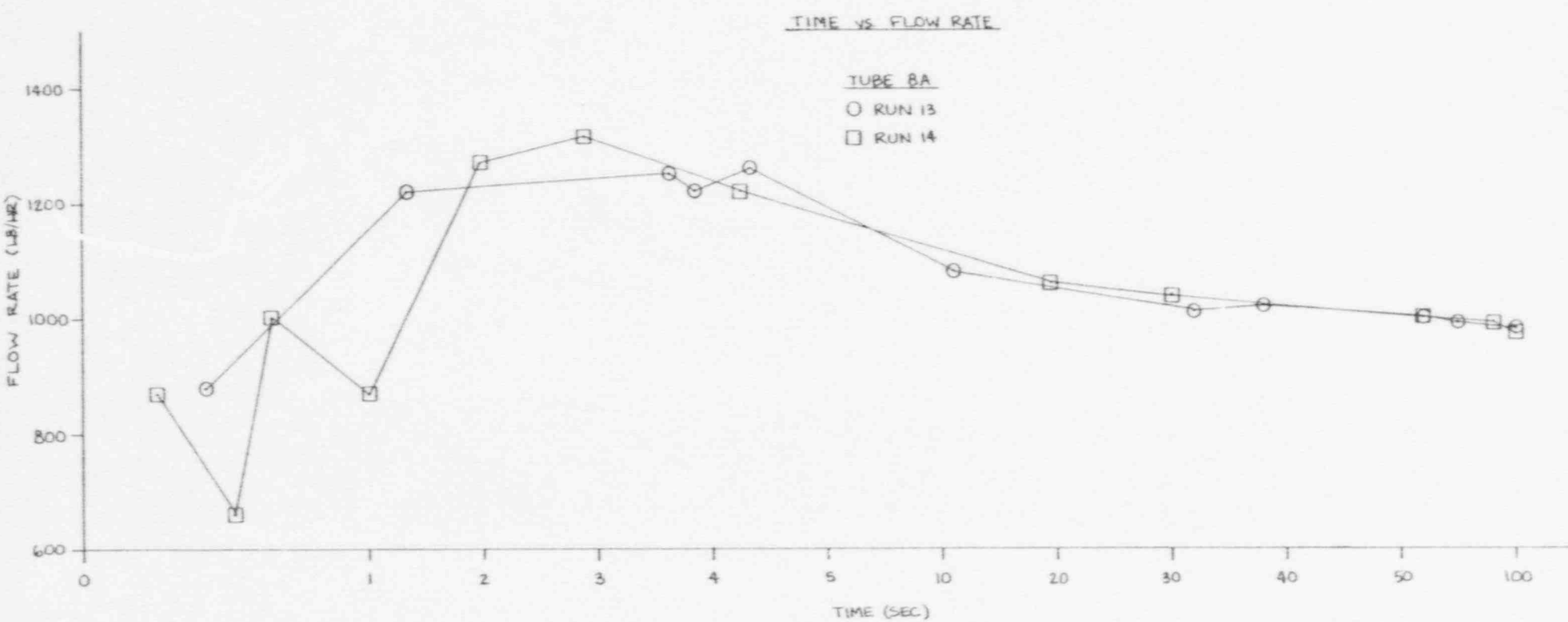
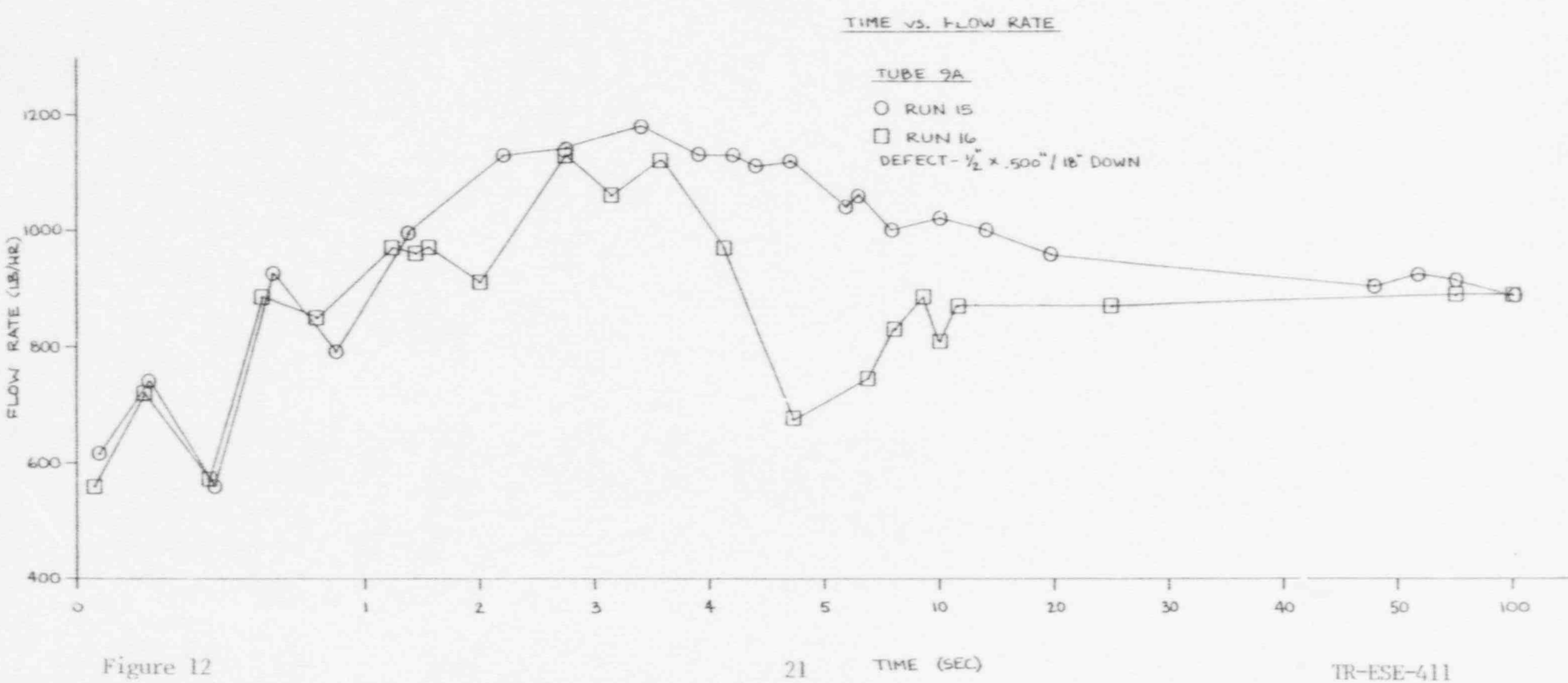

TIME vs FLOW RATE
TUBE 8A
○ RUN 13
□ RUN 14
FLOW RATE (LB/HR)
1400
1200
1000
800
600
0
1
2
3
4
5
10
20
30
40
50
100
TIME (SEC)

Figure 11



TIME vs. FLOW RATE
TUBE 9A
O RUN 15
□ RUN 16
DEFECT - ½" x .500" / 18" DOWN
FLOW RATE (LB/HR)
1200
1000
800
600
400
0
1
2
3
4
5
10
20
30
40
50
100
TIME (SEC)

Figure 12

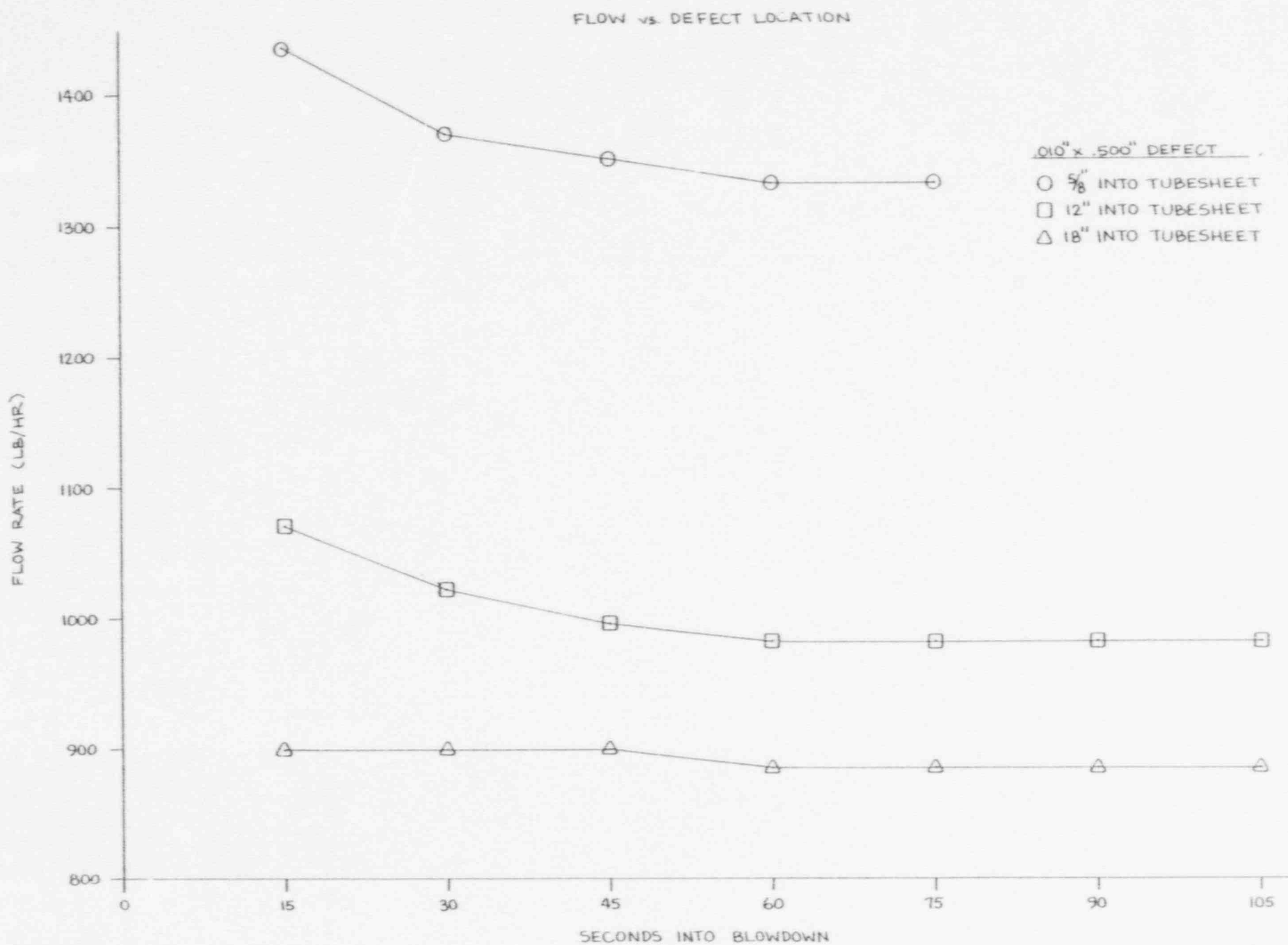
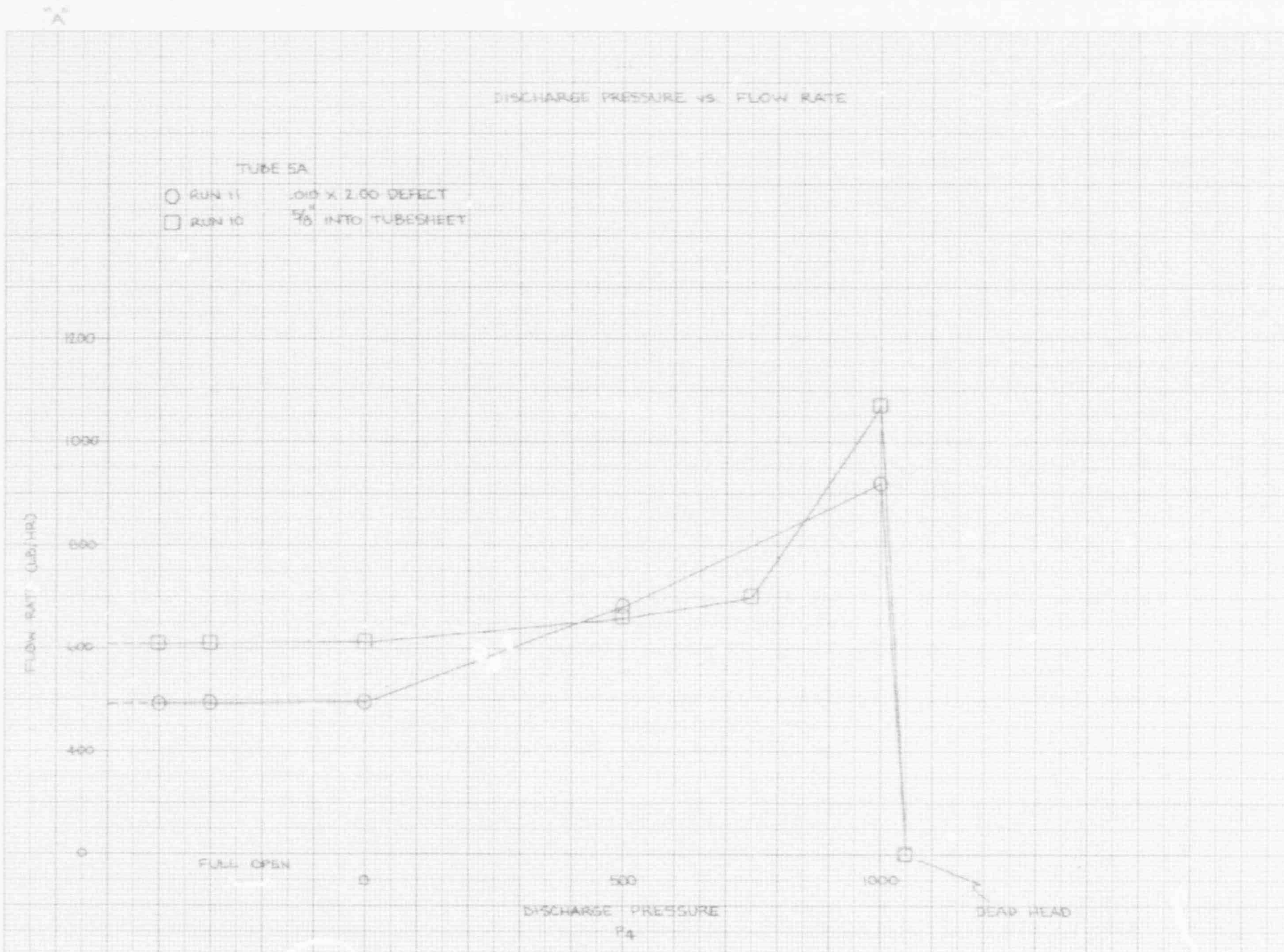

FLOW vs. DEFECT LOCATION
.010" x .500" DEFECT
○ 5/8" INTO TUBESHEET
□ 12" INTO TUBESHEET
△ 18" INTO TUBESHEET
FLOW RATE (LB/HR.)
1400
1300
1200
1100
1000
900
800
0
15
30
45
60
75
90
105
SECONDS INTO BLOWDOWN

Figure 13



"A"
DISCHARGE PRESSURE vs. FLOW RATE
TUBE 5A
RUN 11
RUN 10
.010 x 2.00 DEFECT
5/8" INTO TUBESHEET
FLOW RATE (LB/HR)
FULL OPEN
0
500
1000
DISCHARGE PRESSURE
P4
DEAD HEAD

Figure 14

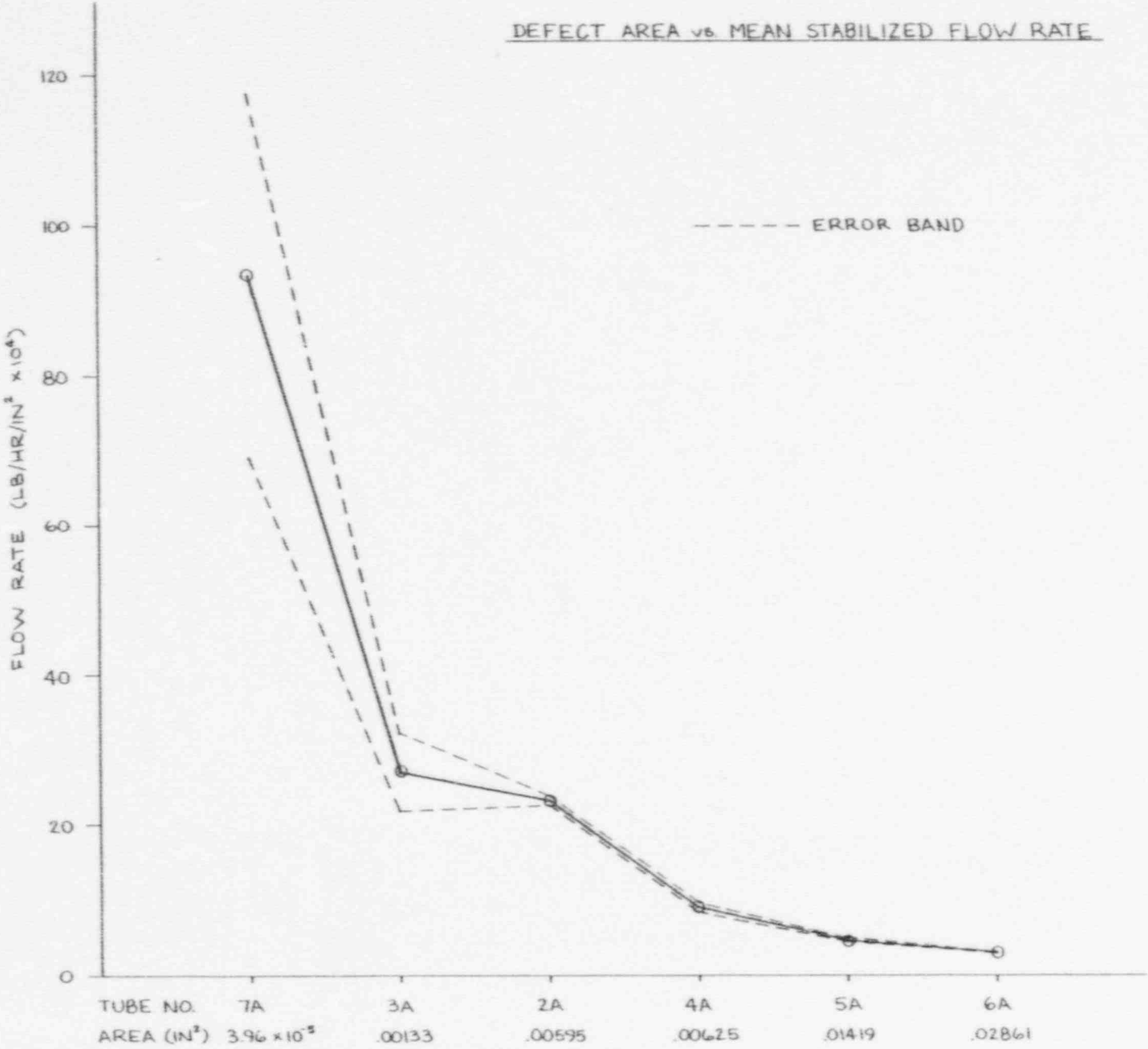
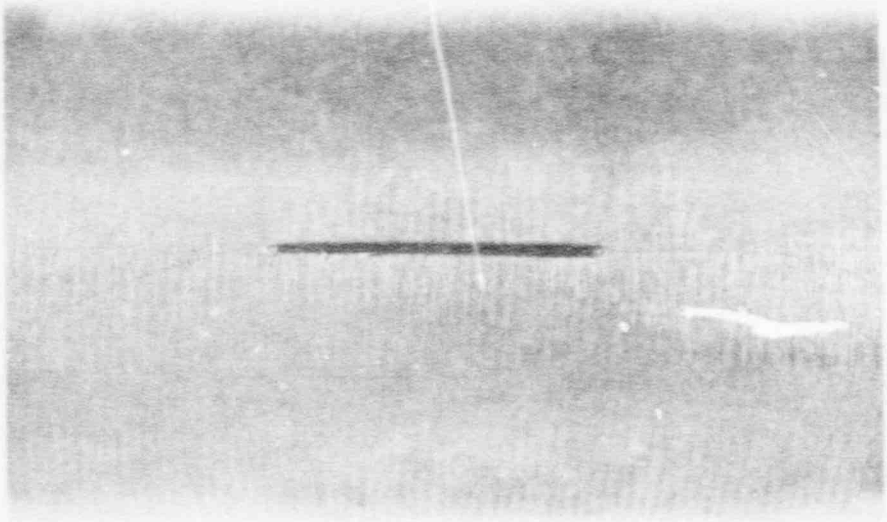

DEFECT AREA vs. MEAN STABILIZED FLOW RATE
ERROR BAND
FLOW RATE (LB/HR/IN² x 10⁴)
120
100
80
60
40
20
0
TUBE NO. 7A 3A 2A 4A 5A 6A
AREA (IN²) 3.96 x 10⁻⁵ .00133 .00595 .00625 .01419 .02861

Figure 15

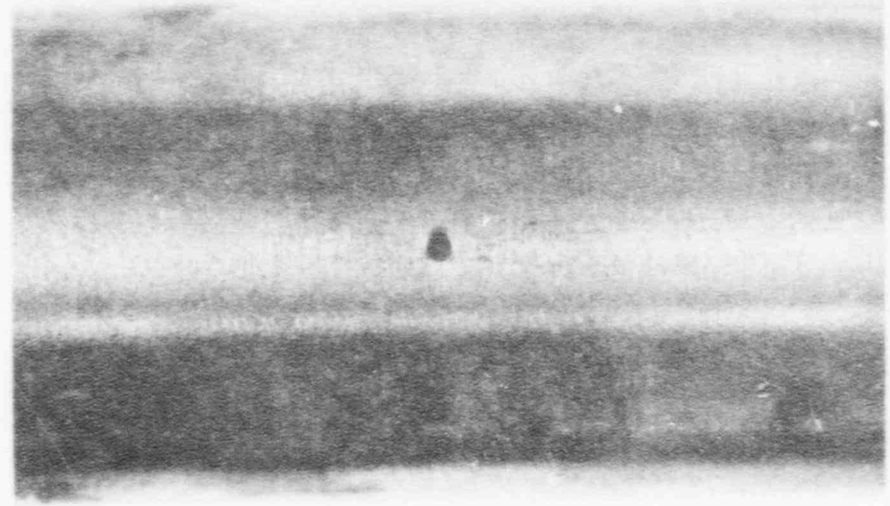
FIGURE NO. 16



TUBE NO. 2A

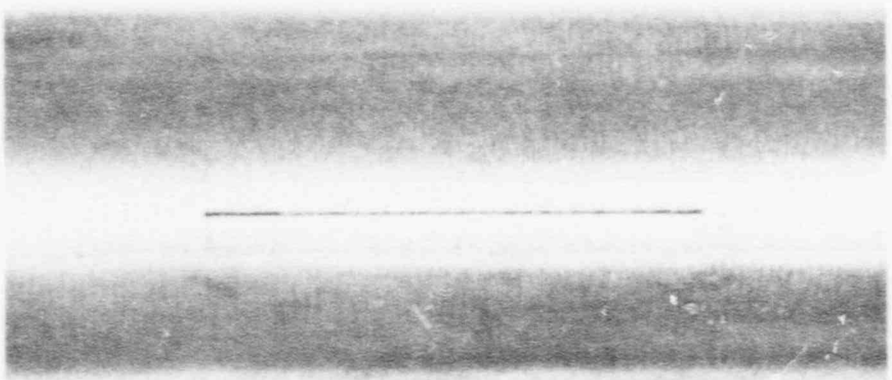
.010" x .500" DEFECT/5/8" INTO TUBESHEET

FIGURE NO. 17



TUBE NO. 3A

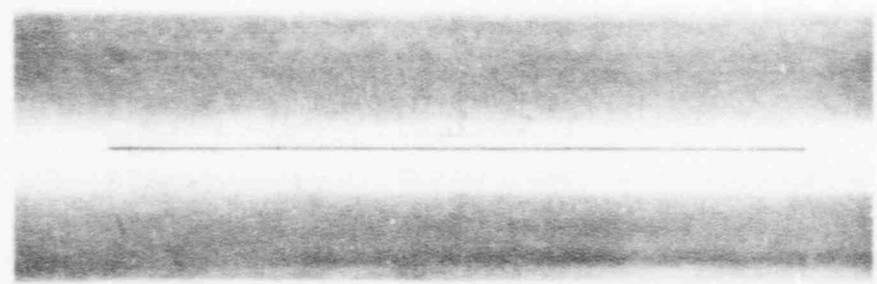
.040" DIA. HOLE/1/2" INTO TUBESHEET



TUBE NO. 4A

.010" x 1.00" DEFECT/5/8" INTO TUBESHEET

FIGURE NO. 18

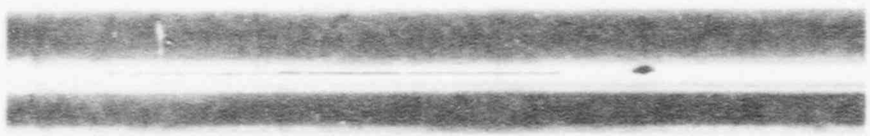


TUBE NO. 5A

.010" x 2.00" DEFECT/5/8" INTO TUBESHEET

FIGURE NO. 19

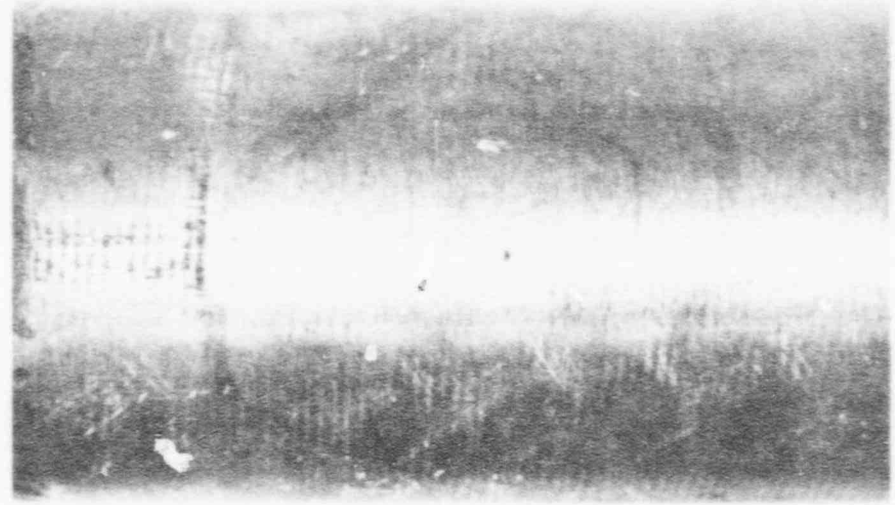
FIGURE NO. 20



TUBE NO. 6A

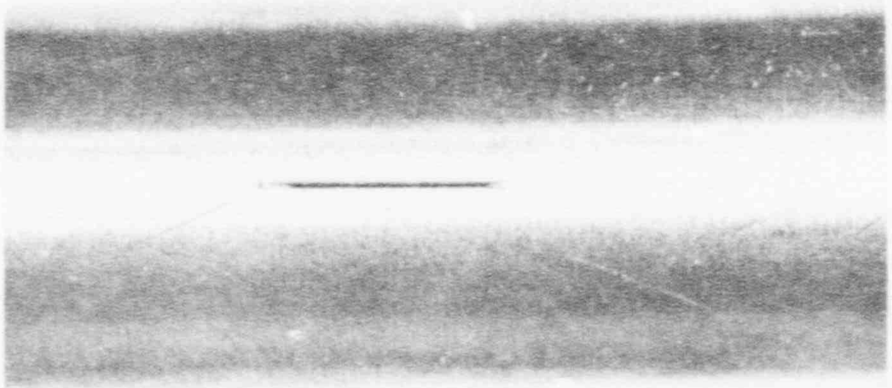
.010" X 3.00" DEFECT/5/8" INTO TUBESHEET

FIGURE NO. 21



TUBE NO. 7A

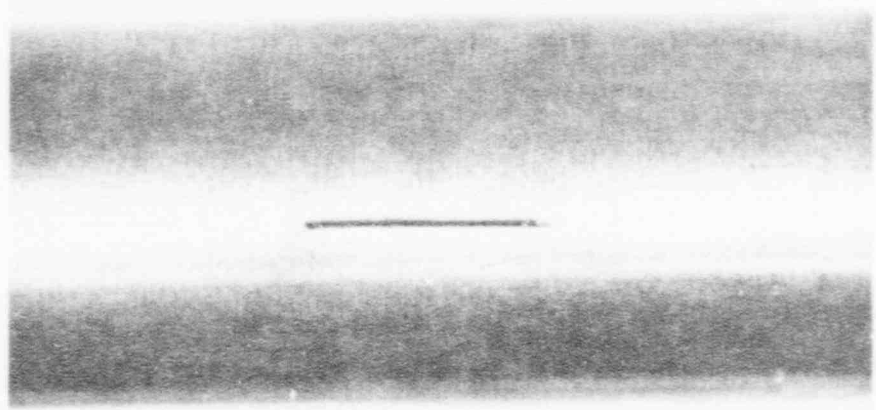
.010" .1A HOLE/5/8" INTO TUBESHEET



TUBE NO. 8A

.010" X .500" DEFECT/12" INTO TUBESHEET

FIGURE NO. 22



TUBE NO. 9A

.010" X .500" DEFECT/18" INTO TUBESHEET

FIGURE NO. 23

STEAM GENERATOR CREVICE
FLOW TEST

APPENDIX A

TEST PROCEDURE

COMBUSTION ENGINEERING

DEVELOPMENT DEPARTMENT

TEST PROCEDURE

WISCONSIN ELECTRIC POWER STEAM GENERATOR
TUBESHEET CREVICE FLOW TEST

PO #593⁵⁷

PREPARED BY: M P Chaplin
M. P. Chaplin

REVIEWED BY: C W Ruos
Supervisor

APPROVED BY: J. E. Schuler
Lab. Manager

APPROVED BY: Gary Frieling
Gary Frieling

DOCUMENT NO.: 00000-ESE-298

DATE OF ISSUE: 8/25/80

1.0 OBJECTIVE

This procedure details tests to evaluate the potential rate of secondary leakage through simulated defective steam generator tubes in the event of a LOCA. The test section reflects the Point Beach Steam Generator Design in the support plate region.

2.0 TEST HARDWARE DESCRIPTION

The tests will be performed using a 70 gal. autocalve to provide fluid at the pressure and temperature required.

The test section, Figure 1, will be connected to the autoclave with insulated 3/4 tubing. A venturi will be located upstream of the test section for flow measurement, in addition, a fluid level indicator will be connected to the autoclave for volumetric comparison.

2.1 Test Section

The test section will consist of a 2" diameter carbon steel round, with a 0.892 ± .002 hole through the center to simulate the tubesheet. Attached to the tubesheet is a 4" section of 1 1/2" sch: 80 pipe which will provide a test fluid reservoir having pressure and temperature measurement capability adjacent to the tube being tested.

Strip heaters and a fluid bleed are provided to maintain a test section temperature of 600 ± 10^{o}F prior to testing.*

Pressure gages and thermocouples will be provided at the tube sheet inlet and upstream of the 1 1/2" discharge valve. An additional TC will be located in the tubesheet adjacent to the test tube.

* To be adjusted per cognizant engineer.

2.2 Test Specimens

The test specimens will be fabricated from 7/8 O.D. x .049 wall welded tubing type 316. The tubes will be secured to the test section with swagelok fittings. Maximum tube to tubesheet excentricity will be maintained during testing using a rod against the tube downstream of the tube defect (except for bottom defect). Eight 24" long tube sections will be fabricated with the top end plugged containing the following defects.

Location	Defect
1. 1" from plug	.010 diameter hole
2. 1" from plug	.010 x .250 Lg slit (.040 dia. hole)
3. 1" from plug	.010 x .500 Lg slit
4. 1" from plug	.010 x 1.00 Lg slit
5. 1" from plug	.010 x 2.00 Lg slit
6. 1" from plug	.010 x 3.00 Lg slit
7. Center of tubesheet	To be determined later
8. Bottom of tubesheet	To be determined later

2.3 Test Conditions

Ideal test conditions at the entrance to the tubesheet are 550°F at 1025 psia. By overcharging the autoclave by approximately 100 psi and using a Nitrogen overpressure a pressure of 1100 ± 10 psig at 550 ± 5°F should be possible. However, tests will be performed to determine the correct autoclave pressure that yields the closest possible test tubesheet inlet temperature 550 ± and pressure 1065 ± 10 psig.

The N_2 will be applied just prior to initiation of the test. The autoclave will be degassified prior to each additional test.

3.0 QUALITY CONTROL

Testing shall be performed and controlled in accordance with the applicable sections of the C-E Quality Assurance of Design Manual.

3.1 Instrumentation

3.1.1 Temperature - Thermocouples and readout instrumentation shall be calibrated prior to the test program and upon completion of the test program.

3.1.2 Pressure - All pressure gages and Δ pressure transmitters shall be calibrated prior to the test program and upon completion of the test program.

3.1.3 All instrumentation shall be calibrated per the procedure for Control of Measuring and Test Equipment Procedure No. 0000 NLE-070.

3.1.4 Pressure gages, thermocouples, level indicators, flow meters and valves will be identified per Table 1.

3.2 Error Analysis

The test report will provide an error analysis based on instrument calibration.

3.3 Records

The original data sheets and copies of the procedure and report will be filed in the Nuclear Laboratories Building 2 Records Room.

4.0 TEST SETUP

4.1 Log S/N and tube defect on data sheet.

4.2 Log defect location from top of the tubesheet on data sheet.

4.3 Utilizing the push rod deflect the tube against the tubesheet opposite the defect. Log on data sheet.

4.4 Tighten the swagelok fitting on the tubesheet.

4.5 Install the discharge test section and tighten the swagelok fitting.

5.0 TEST PROCEDURE

5.1 Fill the autoclave to the 72" level with demineralized water.

5.2 Start autoclave and stabilize at 550°F 1065 psig.

Utilize the tubesheet vent for venting operations as required.

5.3 Energize tubesheet heaters.

5.4 By venting through the tubesheet vent and using the tubesheet heaters, stabilize the tubesheet at 600 ± 10°F at T-3 1065 psig at P_2.

5.5 Set N_2 regulator at 1150 psig. Based on initial results the test engineer may change the N_2 regulator pressure.

5.6 Open N_2 charge valve.

5.7 Read and log the following; P_1, P_2, P_3, L_1, T_1, T_2, T_3 T_4.

5.8 Open discharge valve.

5.9 Read and log the following while discharging; P_2, T_2, P_3, T_4, L_1, Flow F_2 and a change in autoclave level versus time.

5.10 Close discharge valve V_3.

5.11 Close N_2 charge valve V_4.

5.12 Read and log the following; P_1, P_2, P_3, L_1, T_1, T_2, T_3, T_4, L_1 .

5.13 Degasify autoclave for existing operating procedures.

5.14 Open charging Pump Valve V_6.

5.15 Log Gallons required to return to the autoclave level recorded in step 5.9.

5.16 If another test is scheduled, restabilize per step 5.4.

5.17 Sign data sheet.

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Table I

Pressure Gages

- P_1 Autoclave panel
- P_2 Test section inlet
- P_3 Test section discharge

Flow

- F_1 ΔPressure of venturi

Level

- L_1 Autoclave level, Δ pressure transmitter

Temperature

- T_1 Panel mounted autoclave temperature
- T_2 Test section inlet
- T_3 Tubesheet metal
- T_4 Test section discharge

Valves

- V_1 Upstream of venturi 3/4 swagelok
- V_2 Downstream of venturi 3/4 swagelok
- V_3 Discharge test section 2" gate
- V_4 N_2 regulator discharge
- V_5 Test section bleed
- V_6 Charge pump discharge

Tubesheet Crevice Leak Rate Test

Data Sheet

Step No.

4.1 Tube S/N______________ Defect Size_______________

4.2 Defect location______________

4.3 Tube deflected______________

5.5 Stabilized conditions

P_1____________psig L_1___________in H_2O T_1 _________ ^oF

P_2____________psig T_2 _________ ^oF

P_3____________psig T_3_________ ^oF

T_4_________ ^oF

5.9 Blowdown Readings

P_1___________psig T_2 ___________ ^oF F_1_________in H_2O

P_2__________ psig T_4____________ ^oF L_1_________in H_2O

P_3__________ psig

Blowdown time * Time ______min_______sec.

5.13 Stabilized Readings

P_1___________ psig T_1__________ ^oF L_1_________ in H_2O

P_2___________ psig T_2__________ ^oF

P_3____________psig T_3__________ ^oF

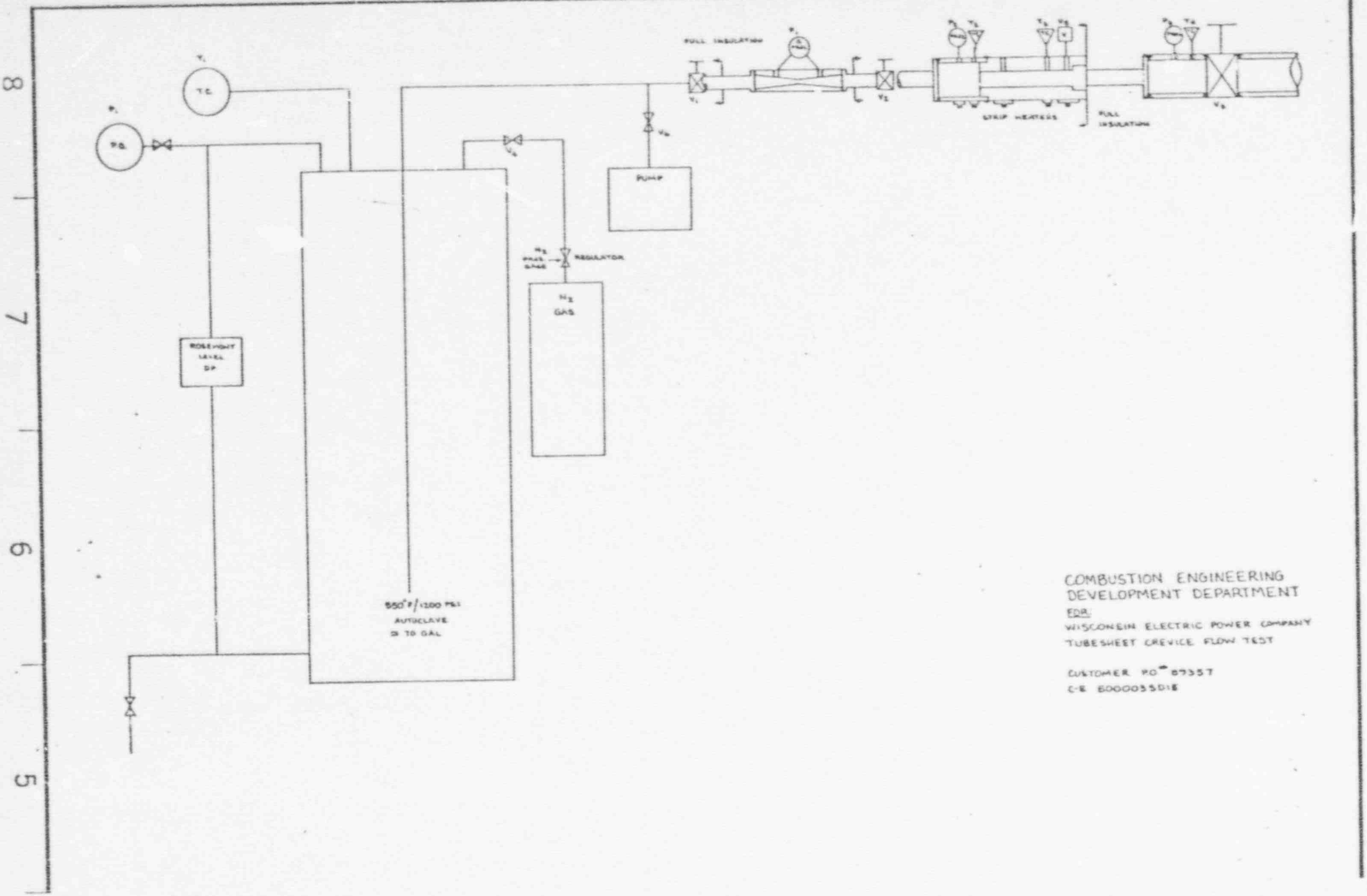
T_4__________ ^oF

5.14 Recharge autoclave ________________gal.

Technicians ______________________ date ____________

Engineer _________________________ date_____________

* Time between step 5.9 L_1 and 5.13 L_1.


T.C.
P.G.
ROSEMOUNT LEVEL DP
AUTOCLAVE
N2 GAS
REGULATOR
PUMP
FULL INSULATION
STRIP HEATERS
COMBUSTION ENGINEERING
DEVELOPMENT DEPARTMENT
FOR:
WISCONSIN ELECTRIC POWER COMPANY
TUBESHEET CREVICE FLOW TEST
CUSTOMER P.O.# 07357
C-E 6000035D18
8
7
6
5

STEAM GENERATOR CREVICE
FLOW TEST

APPENDIX B

INSTRUMENTATION
AND ERROR ANALYSIS

INSTRUMENT	MANUFACTURER	MODEL #	SERIAL #	CE #	RANGE	ACCURACY
Visicorder	Honeywell	1508A	15-4641	FL90	0-10 in/sec 0-80 in/sec	± 1% ± 4%
Flow Δ Press	Meriam	—	1124GR15991	EL457	0-600 in H_2O	± .5%
Press Gage P_3	Acco	2487	N/A	EL470	0-3000 psi	± 1%
Press Gage P_2	Acco	2487	N/A	EL469	0-3000 psi	± 1%
Press Gage P_1	U.S. Gage	—	N/A	EL468	0-3000 psi	± 1%
Temp T_1	Honeywell	—	504	N/A	0-1000 psi ^{o}F (J)	± 1%
Chart Recorder P_1	Honeywell	—	903827	EDL34	0-4000 psi	± 1%
Level L_1	Rosemont	11P6E22MB	L	N/A	150"	± 1%
Temp Recorder	Ircon	—	1398	EL432	-30 + 1600 ^{o}F	± 1%

APPENDIX B

ERROR ANALYSIS OF MEASURED QUANTITIES

1.) PRESSURE READINGS (P2)

SOURCE	UNCERTAINTY
a.) Calibration: ± 0.25% F.S. (3000 psig) (Standard gage)	± 7.5 psig
b.) Readability & Repeatability:* : 1/2 of 1 scale division	± 12.5 psig

*Repeatability or random error is usually much less than Readability.

Total pressure uncertainty by the second power law (See No. 4 this Appendix)

$$= \pm \sqrt{(7.5)^2 + (12.5)^2}$$

$= \pm 14.5$ psig (2 σ limits) or 95% confidence interval

The above uncertainty can be considered to be within 2 σ limits since these are provided by the manufacturer. For a higher confidence, 3 σ limits (99.7% confidence interval) may be chosen.

Total pressure uncertainty = $\frac{3}{2} \times 14.5 = 22$ psig (3 σ)

2.) TEMPERATURE READINGS (T2)

SOURCE	UNCERTAINTY
a.) Calibration	
Reference Temperature	± 0.18°F
Readout (0.015% of Readings)	± 0.08°F
b.) Readout (IRCON)	
Electronics (± 0.05% T ± 1.0°F)	± 1.3°F
Digital Indicator (least significant digit)	± 1.0°F

Total Temperature uncertainty = $\pm \sqrt{(0.18)^2 + (.08)^2 + (1.3)^2 + (1.0)^2}$

$= \pm 1.65°F$ (2 σ)

3.) CHECK FOR SUBCOOLED STATE OF UPSTREAM CONDITIONS

To ensure that subcooled conditions existed at the upstream conditions and thus, that flashing did not occur at the venturi flowmeter, the uncertainties in the measured upstream pressure and in the saturation pressure as determined by temperature measurement will be determined. The indicated pressure difference ($P_{2\,upstream} - P_{2\,sat.}$) should be larger than the algebraic sum of the absolute values of the uncertainties $|\delta P_{2\,upstream}| + |\delta P_{2\,sat.}|$.

From (1)

$\delta P_{2\,upstream} = \pm 22$ psig (3 σ)

From (2)

$\delta P_{2\,sat.} = \pm 1.65^{\circ}F \times 8$ psi/$^{\circ}F$

$= \pm 13.2$ psi (2 σ)
or ± 20 psi (3 σ)

where at 540°F $\delta P_{sat.}/^{\circ}F = 8$ psi/$^{\circ}$F

Thus $|\delta P_{2\,upstream}| + |\delta P_{2\,sat.}| = 22 + 20 = 42$ psi

Run	$T_{2\,corr.}$* (°F)	P_2sat. (Psia) based on $T_{2\,corr.}$	P_2 (ups) Psia	Diff (P_2ups. - P_2 sat.) Psi
1	540	963	1065	102
2	533	908	1040	132
3	545	1003	1140	137
4	540	963	1065	102
5	546	1012	1055	43
6	544	995	1040	45
7	540	963	1075	112
8	542	979	1105	126
9	541	971	1085	114
10	545	1003	1065	62
11	546	1012	1075	63
12	546	1012	1065	53
13	545	1003	1065	62
14	546	1012	1065	53
15	544	995	1065	70
16	546	1012	1085	73
17	519	806	1085	279
18	546	1012	1055	43
19	547	1020	1065	45

* T_2corr. is the indicated temperature T_2 corrected from calibration curve of the thermocouple. At ~ 540°F ($T_{2\,true} - T_{2\,indi}$) = −0.8°F

APPENDIX B

Since ($P_{2\,upstream} - P_{2\,sat.}$) > 42 psi in all runs, we can safely say that subcooled conditions occurred upstream of the crevice.

4.) FLOW MEASUREMENT (VENTURI)

Venturi Equation:

$$Q = 5.573 d^2 ce\ fa \left[2g \frac{\Delta P}{\rho}\right]^{1/2} \qquad \text{A-1}$$

or simplifying,

$$Q = C\left[2g\frac{\Delta P}{\rho}\right]^{1/2}$$

where Q - flow rate
C - a calibration constant
g - gravitational constant
ΔP - flowmeter reading (psi)
ρ - density of water

The Kline & McClintock Method of combining uncertainties using the second power law equation is the following:

If R is a function of n independent variables $R = R(V_1, V_2, \ldots V_n)$
Then the uncertainty in R is

$$W_R = \left[\left(\frac{\partial R}{\partial V_1}\delta V_1\right)^2 + \ldots \left(\frac{\partial R}{\partial V_n}\delta V_n\right)^2\right]^{1/2} \qquad \text{A-2}$$

Applying Eq. A-2 to A-1

$$\frac{W_Q}{Q} = \left[\left(\frac{\delta C}{C}\right)^2 + \left(\frac{1}{2}\frac{\delta\Delta P}{\Delta P}\right)^2 + \left(\frac{1}{2}\frac{\delta\rho}{\rho}\right)^2\right]^{1/2}$$

a.) Calibration Constant

From the manufacturer calibration const. uncertainty $\frac{\delta C}{C} = 2\% = .02$ (2σ)

b.) Δp readings

Instrument uncertainties (Meriam gauge)

Calibration: ± .025% F.S. (600-in H_2O) = 0.15-in H_2O

Readability & Repeatability, ± 1/2 of 1 division = 2.5-in H_2O

$$\Delta p_{uncertainty} = \sqrt{(0.15)^2 + (2.5)^2} = 2.5\text{-in-}H_2O \qquad (2\,\sigma)$$

c.) $\delta\rho$ uncertainty

$$\delta\rho \text{ for a } \Delta T = 1.65^{\circ}F = \frac{(46.59 - 45.96)}{10^{\circ}F}\ 16/_{ft^3} \times 1.65^{\circ}F$$

$$= 0.106\ \ 16_{s}/_{ft^3} \qquad (2\,\sigma)$$

$$\frac{\Delta\rho}{\rho} = \frac{0.106}{46.6} = 0.0022 \text{ or } 0.22\%$$

Summarizing for the different tube speciment, (except 7A) the flow uncertainties are:

Tube	ΔP venturi (nominal)	$\frac{\Delta\rho}{\rho}$	Total Uncertainty $^{W}Q/_{Q}$
2A	215-in-H_2O	1.16%	2.3%
3A	13	19.2%	19.2%
4A	35	7.2%	8%
5A	48	5.2%	5.6%
6A	75	3.3%	3.9%
8A	100	2.5%	3.2%
9A	83	3.0%	3.6%

APPENDIX B

5.) FLOW MEASUREMENT UNCERTAINTY BY LEVEL CHANGE METHOD

For Tube 7A, the flow rate was so low that more confidence was placed on the level change in the autoclave than on the venturi reading.

The flow was calculated by:

$$Q = \frac{(L_1 - L_2)\,\frac{\rho_{cold}}{\rho_{hot}} \times 0.4896\ \text{gal/in.}}{\Delta t\ (\text{min.})}$$

Then by Eq. A-1

$$\frac{WQ}{Q} = \left[\left(\frac{\delta L}{L}\right)^2 + \left(\frac{\delta \rho_{hot}}{\rho}\right)^2\right]^{1/2}$$

Level Monitor: Uncertainty

Calibration : 1/4% F.S. of 150-in. = 0.375" in-H_2O
Readability - Zero if scale marks are used.
Repeatability : 1/4% F.S. = 0.375 - in-H_2O

$$\frac{\delta L}{L} = \sqrt{(.0375)^2 + (.375)^2}$$

$$= 0.53''$$

Total Flow uncertainty for Tube 7A, Run 17

where $L_1 - L_2 = 2$ in.

$$\frac{W_Q}{Q} = \left[\left(\frac{0.53}{2.0}\right)^2 + (.002)^2\right]^{1/2}$$

$$= 0.26 \text{ or } 26\%$$

STEAM GENERATOR CREVICE
FLOW TEST

APPENDIX C

CALCULATIONS

APPENDIX C

1. Determine flow rate using autoclave level change.
   Level instrument L_1 calibrated at 68°F

Autoclave

12" dia. 144" high

$V = .7854\ d^2h$

$V = .7854\ (12^2)(144) = \underline{16286.05\ in^3}$

1 gal = 231 in^3 — Machinerys Handbook

$$\frac{16286.05\ in^3}{231^3 in} = \underline{70.5\ gal}$$

$$\frac{70.5\ gal}{144\ in.} = \underline{.4896\ gal/in.}$$

Autoclave Level = $\underline{\underline{.4896\ gal/in.}}$

Determine Flow rate in GPM using Autoclave Level change

Level - L_1

$$\frac{L_1\ stand - L_1\ stop\ (.4896\ gal/in)}{Test\ Time\ (sec)/60\ sec.} = gpm$$

Example: Tube 1A Run 8

L_1 start = 79 in. L_1 stop = 74 in. Test time 150 sec.

$$\frac{79 - 74\ (.4896)}{150/60} = \underline{\underline{.979\ gal/min}}$$

Convert gpm @ 68°F to gpm @ 550°F

$$\frac{Lb/Ft^3\ @\ 68^\circ F}{Lb/Ft^3\ @\ 550^\circ F} \qquad \frac{62.32\ Lb/Ft^3}{45.96\ Lb/Ft^3} = 1.36$$

Crane Tech Paper #410

1.36 x gpm @ 68°F = gpm @ 550°F

1.36(.979) = $\underline{\underline{1.33\ gpm}}$ @ 550°F

APPENDIX C

Convert gpm to Lb/Hr.

gpm x 60 x ft^3/gal x Lb/ft^3 = Lb/Hr

gpm x 60 x .134 ft^3/gal x 45.96 Lb/ft^3 = Lb/Hr — Crane Tech Paper #410

1.33(60)(.134)(45.96) = 491.5 Lb/Hr

Venturi Flow Meter

Mfg. Flowdyne

Throat = .1985 in.
Temp. = 550°F
Pressure = 1050 psi

Ref (1) Flow dyne Engineering Manual
(2) Annubar Flow Hdbk Dietrich Std.

(1) $Q = 5.573\ d^2\ c\ \ e\ f_a \left[\frac{2g\ \Delta P}{\rho}\right]^{1/2}$

C = Coefficient of Discharge (2)
E = Velocity of Approach (1)
f_a = Thermal Expansion Factor (2)
ρ = Density Lb/Ft^3 550°F
g = Gravitation Constant ft/sec^2
ΔP = Differential Press. in H_2O

C = for line size .195 to 2.5" dia 1.0
f_a = Thermal Expansion factor 536°F to 584°F 1.010

Example

$$Q = 5.573\ (.1985)^2\ (1.0)(1.010) \left[\frac{2(32.17)130.63}{45.935}\right]^{1/2}$$

$$Q = .2218 \left[\frac{2(32.17)130.63}{45.935}\right]^{1/2}$$

Q = 3.0 gpm

STEAM GENERATOR CREVICE
FLOW TEST

APPENDIX D

COMPARISON OF FLOW RATES

APPENDIX D

COMPARISON OF MEASURED AND PREDICTED FLOW RATES

Several investigators have observed two distinct types of critical flow of flashing water through orifices. The first type occurs with flashing at the orifice throat, termed upstream choking.

Zaloudek gives a relation for this critical flow (reported in L. S. Tong, Boiling Heat Transfer and Two-Phase Flow, J. Wiley, 1965 pp. 108-110.

$$G_1 = C_1 \sqrt{2g_c \rho_1 (P_{upstream} - P_{sat.})} \qquad \text{(critical flow for upstream choking)}$$

where G_1 = critical mass flux in lbm/hr-ft^2
C_1 = empirical constant, 0.61 - 0.64
g_c = gravitational const.
ρ_1 = saturated water density
$P_{upstream}$ = Pressure upstream of orifice
P_{sat} = saturation pressure at subcooled liquid temperature

A second type of critical flow occurs when the water in a metastable state exits the orifice and only then flashes. This is downstream choking. The equation of Barnell or Kinderman & Wales (Also reported by Tong).

$$G_2 = \sqrt{2g_c \rho_1 \; P_{upstream} - (1-C_2) \, P_{sat.upst.}}$$

where $C_2 = 0.284 \dfrac{\sigma \text{ for psat.upstream}}{\sigma \text{ for psat.} = 200 \text{ psia}}$

σ - surface tension
at psat = 1000 psia,
$C_2 = 0.20$

Table D-1

RUN	TUBE	$G_{corr.}$ * LB/HR-FT^2	$G_{Predicted}$ LB/HR-FT^2	COMMENTS Equation used	
1	2A	336 x 10^5	407 x 10^5	G_2	
2	2A	344	421	G_2	
3	2A	363	434	G_2	
4	2A	332	406	G_2	
5	2A	332	359	G_2	
6	2A	310	368	G_2	
7	3A	390	413	G_2	
8	4A	134	166	G_1	
9	4A	124	158	G_1	
10	5A	68	116	G_1	
11	5A	65	116	G_1	
12	6A	42	107	G_1	
13	8A	287	382	G_2	Effect of Long L/D Before Orifice (runs 13–16)
14	8A	287	384	G_2	
15	9A	228	387	G_2	
16	9A	218	391	G_2	
17	7A	1346	503	G_2	High Flow Rate Uncertainty
18	2A	322	369	G_2	
19	2A	322	372	G_2	

* $G_{measured}$ corrected for final flow area

STEAM GENERATOR CREVICE
FLOW TEST

APPENDIX E

DATA SHEETS

Tubesheet Crevice Leak Rate Test

Data Sheet

Step No.

4.1 Tube S/N 2A   Defect Size .010 x 1/2" Long

4.2 Defect location 5/2" Into Tube Sheet.

4.3 Tube deflected YES

5.5 Stabilized conditions

P_1 1150 psig	L_1 74 in H_2O (70)	T_1 550 °F
P_2 1150 psig		T_2 556 °F
P_3 1150 psig		T_3 582 °F
		T_4 423 °F

5.9 Blowdown Readings

P_1 1075 psig	T_2 541 °F	F_1 205 in H_2O
P_2 1050 psig	T_4 219 °F	L_1 60 in H_2O
P_3 0 psig		
Blowdown time	* Time 1 min 54 sec.	

5.13 Stabilized Readings (AFTER 10 MINUTES)

P_1 1150 psig	T_1 550 °F	L_1 59 in H_2O
P_2 1150 psig	T_2 502 °F	
P_3 1150 psig	T_3 408 °F	
	T_4 314 °F	

5.14 Recharge autoclave 5 gal.

Technicians John Falkowski date 8-26-80

Engineer MPChaplin date 8-26-80

* Time between step 5.9 L_1 and 5.13 L_1.

Test #1

Tubesheet Crevice Leak Rate Test

Data Sheet

Step No.

4.1 Tube S/N 2A Defect Size .010 x 1/2" Long

4.2 Defect location 5/8" Into Tube Sheet.

4.3 Tube deflected YES

5.5 Stabilized conditions

P_1 1100 psig L_1 72 (70) in H_2O T_1 540 °F

P_2 1100 psig T_2 564 °F

P_3 1075 psig T_3 588 °F

T_4 447 °F

5.9 Blowdown Readings

P_1 1050 psig T_2 534 °F F_1 215 in H_2O

P_2 1025 psig T_4 222 °F L_1 60 in H_2O

P_3 0 psig

Blowdown time   * Time 1 min 45 sec.

5.13 Stabilized Readings

(AFTER 5 MINUTES)

P_1 1125 psig T_1 540 °F L_1 59 in H_2O

P_2 1100 psig T_2 521 °F

P_3 1100 psig T_3 421 °F

T_4 316 °F

5.14 Recharge autoclave 5 gal.

Technicians John Falkowski date 8-26-80

Engineer M P Chapli date 8-26-80

* Time between step 5.9 L_1 and 5.13 L_1.

Test # 2

Tubesheet Crevice Leak Rate Test

Data Sheet

Step No.

4.1 Tube S/N 2A Defect Size .010 x 1/2" Long

4.2 Defect location 5/8" Into Tube sheet.

4.3 Tube deflected YES

5.5 Stabilized conditions

P_1 1200 psig | L_1 42 (42) in H_2O | T_1 550 °F
P_2 1175 psig | T_2 554 °F
P_3 1150 psig | T_3 574 °F
T_4 419 °F

5.9 Blowdown Readings

P_1 1160 psig | T_2 546 °F | F_1 238 in H_2O
P_2 1125 psig | T_4 217 °F | L_1 32 in H_2O
P_3 0 psig
Blowdown time | * Time 1 min 50 sec.

5.13 Stabilized Readings

(AFTER 1 MINUTE)
P_1 1175 psig | T_1 550 °F | L_1 31 in H_2O
P_2 1150 psig | T_2 561 °F
P_3 1140 psig | T_3 432 °F
T_4 339 °F

5.14 Recharge autoclave 5 gal.

Technicians John Falkowski date 8-26-80

Engineer M P Chaplin date 8-26-80

* Time between step 5.9 L_1 and 5.13 L_1.

Test # 3

Tubesheet Crevice Leak Rate Test

Data Sheet

Step No.

4.1 Tube S/N 2A Defect Size .010 x 1/2" Long

4.2 Defect location 5/8" Into Tube sheet.

4.3 Tube deflected YES

5.5 Stabilized conditions

P_1 1100 psig | L_1 82 (80) in H_2O | T_1 550 °F
P_2 1075 psig | T_2 573 °F
P_3 1070 psig | T_3 606 °F
T_4 551 °F

5.9 Blowdown Readings

P_1 1080 psig | T_2 547 °F | F_1 200 in H_2O
P_2 1050 psig | T_4 242 °F | L_1 75 in H_2O
P_3 0 psig

Blowdown time * Time 1 min 0 sec.

5.13 Stabilized Readings

(After 1 Minute)

P_1 1075 psig | T_1 550 °F | L_1 75 in H_2O
P_2 1050 psig | T_2 548 °F
P_3 1040 psig | T_3 429 °F
T_4 448 °F

5.14 Recharge autoclave 2½ gal.

Technicians John Falkowski date 8-29-80

Engineer M P Chaplin date 8-29-80

* Time between step 5.9 L_1 and 5.13 L_1.

Test # 4

Tubesheet Crevice Leak Rate Test

Data Sheet

Step No.

4.1 Tube S/N 2A   Defect Size .010 x 1/2" Long

4.2 Defect location 5/8" Into Tube Sheet.

4.3 Tube deflected YES

5.5 Stabilized conditions

P_1 1075 psig L_1 75 (73) in H_2O T_1 550 °F

P_2 1060 psig T_2 573 °F

P_3 1040 psig T_3 606 °F

T_4 550 °F

5.9 Blowdown Readings

P_1 1075 psig T_2 547 °F F_1 197 in H_2O

P_2 1040 psig T_4 241 °F L_1 67 in H_2O

P_3 0 psig

Blowdown time   * Time 1 min 0 sec.

5.13 Stabilized Readings (AFTER 1 MINUTE)

P_1 1075 psig T_1 550 °F L_1 67 in H_2O

P_2 1070 psig T_2 552 °F

P_3 1050 psig T_3 419 °F

T_4 446 °F

5.14 Recharge autoclave 2 1/2 gal.

Technicians John Falkowski date 8-29-80

Engineer M P Chaplin date 8-29-80

* Time between step 5.9 L_1 and 5.13 L_1.

Test # 5

Tubesheet Crevice Leak Rate Test

Data Sheet

Step No.

4.1 Tube S/N 2A   Defect Size .010 x 1/2" Long

4.2 Defect location 5/8" Into Tube sheet.

4.3 Tube deflected YES

5.5 Stabilized conditions

P_1 1050 psig L_1 63 (62) in H_2O T_1 550 °F

P_2 1035 psig T_2 580 °F

P_3 1010 psig T_3 604 °F

T_4 547 °F

5.9 Blowdown Readings

P_1 1050 psig T_2 545 °F F_1 175 in H_2O

P_2 1025 psig T_4 242 °F L_1 56 in H_2O

P_3 0 psig

Blowdown time   * Time 1 min 0 sec.

5.13 Stabilized Readings

(AFTER 1 MINUTE)

P_1 1050 psig T_1 550 °F L_1 56 in H_2O

P_2 1040 psig T_2 565 °F

P_3 1030 psig T_3 476 °F

T_4 480 °F

5.14 Recharge autoclave 2 1/2 gal.

Technicians John Falkowski date 8-27-80

Engineer MP Chaplin date 8-29-80

* Time between step 5.9 L_1 and 5.13 L_1.

Test # 6

Tubesheet Crevice Leak Rate Test

Data Sheet

Step No.

4.1 Tube S/N 3A Defect Size .040

4.2 Defect location 1/2" In To Tube Sheet

4.3 Tube deflected YES

5.5 Stabilized conditions

P_1 1100 psig

P_2 1080 psig

P_3 1060 psig

L_1 87 (86) in H_2O

T_1 550 °F

T_2 588 °F

T_3 579 °F

T_4 540 °F

5.9 Blowdown Readings

P_1 1100 psig

P_2 1060 psig

P_3 0 psig

Blowdown time

T_2 541 °F

T_4 214 °F

* Time 3 min 50 sec.

F_1 13 in H_2O

L_1 81 in H_2O

5.13 Stabilized Readings

P_1 1090 psig

P_2 1050 psig

P_3 1040 psig

T_1 550 °F

T_2 551 °F

T_3 384 °F

T_4 403 °F

L_1 80 in H_2O

5.14 Recharge autoclave 2 1/4 gal.

Technicians John Falkowski date 9-2-80

Engineer MP Chaplin date 9-2-80

* Time between step 5.9 L_1 and 5.13 L_1.

Test #7

Tubesheet Crevice Leak Rate Test

Data Sheet

Step No.

4.1 Tube S/N #4A Defect Size .010 x 1" Long

4.2 Defect location 5/8" Into Tube Sheet.

4.3 Tube deflected YES

5.5 Stabilized conditions

P_1 1150 psig L_1 80 (79) in H_2O T_1 550 °F

P_2 1135 psig T_2 555 °F

P_3 1130 psig T_3 607 °F

T_4 560 °F

5.9 Blowdown Readings

P_1 1125 psig T_2 543 °F F_1 35 in H_2O

P_2 1090 psig T_4 220 °F L_1 74 in H_2O

P_3 0 psig

Blowdown time * Time 2 min 30 sec.

5.13 Stabilized Readings

P_1 1150 psig T_1 550 °F L_1 72 in H_2O

P_2 1140 psig T_2 554 °F

P_3 1130 psig T_3 331 °F

T_4 490 °F

5.14 Recharge autoclave 2½ gal.

Technicians John Falkowski date 9-2-80

Engineer MPChaplin date 9-2-80

* Time between step 5.9 L_1 and 5.13 L_1.

Test #8

Tubesheet Crevice Leak Rate Test

Data Sheet

Step No.

4.1 Tube S/N #4A   Defect Size .010 x 1" Long

4.2 Defect location 5/8" Into tube sheet.

4.3 Tube deflected YES

5.5 Stabilized conditions

P_1 1100 psig L_1 86 (85) in H_2O T_1 547 °F

P_2 1070 psig T_2 548 °F

P_3 1060 psig T_3 607 °F

T_4 553 °F

5.9 Blowdown Readings

P_1 1100 psig T_2 542 °F F_1 30 in H_2O

P_2 1075 psig T_4 219 °F L_1 80 in H_2O

P_3 0 psig

Blowdown time   * Time 2 min 37 sec.

5.13 Stabilized Readings

P_1 1090 psig T_1 547 °F L_1 80 in H_2O

P_2 1065 psig T_2 550 °F

P_3 1050 psig T_3 373 °F

T_4 420 °F

5.14 Recharge autoclave 2½ gal.

Technicians John Falkowski date 9-3-80

Engineer MD Chapl[illegible] date 9-3-80

* Time between step 5.9 L_1 and 5.13 L_1.

Test #9

Tubesheet Crevice Leak Rate Test

Data Sheet

Step No.

4.1 Tube S/N 5A Defect Size .010 x 2" Long

4.2 Defect location 5/8" Into Tube Sheet

4.3 Tube deflected YES

5.5 Stabilized conditions

P_1 1100 psig — L_1 81 (80) in H_2O — T_1 550 °F

P_2 1075 psig — T_2 550 °F

P_3 1060 psig — T_3 610 °F

T_4 541 °F

5.9 Blowdown Readings

P_1 1090 psig — T_2 546 °F — F_1 48 in H_2O

P_2 1050 psig — T_4 244 °F — L_1 75 in H_2O

P_3 0 psig

Blowdown time — * Time 2 min 25 sec.

5.13 Stabilized Readings

P_1 1100 psig — T_1 550 °F — L_1 73 in H_2O

P_2 1060 psig — T_2 554 °F

P_3 1050 psig — T_3 497 °F

T_4 541 °F

5.14 Recharge autoclave 2½ gal.

Technicians John Falkowski date 9-3-80

Engineer MP Chapl[illegible] date 9-3-80

* Time between step 5.9 L_1 and 5.13 L_1.

Test 10

Tubesheet Crevice Leak Rate Test

Data Sheet

Step No.

4.1 Tube S/N 5A Defect Size .010 x 2" Long

4.2 Defect location 5/8" In To Tube sheet.

4.3 Tube deflected YES

5.5 Stabilized conditions

P_1 1100 psig — L_1 72 / 69 in H_2O — T_1 550 °F

P_2 1080 psig — T_2 550 °F

P_3 1075 psig — T_3 611 °F

T_4 544 °F

5.9 Blowdown Readings

P_1 1100 psig — T_2 547 °F — F_1 43 in H_2O

P_2 1060 psig — T_4 225 °F — L_1 64 in H_2O

P_3 0 psig

Blowdown time — * Time 2 min 06 sec.

5.13 Stabilized Readings

P_1 1100 psig — T_1 550 °F — L_1 63 in H_2O

P_2 1060 psig — T_2 552 °F

P_3 1050 psig — T_3 488 °F

T_4 524 °F

5.14 Recharge autoclave 2½ gal.

Technicians John Falkowski date 9-3-80

Engineer MP Chaplin date 9-3-80

* Time between step 5.9 L_1 and 5.13 L_1.

Test 11

Tubesheet Crevice Leak Rate Test

Data Sheet

Step No.

4.1 Tube S/N 69 Defect Size .010 x 3" Long

4.2 Defect location 5/8" Into Tube Sheet

4.3 Tube deflected YES

5.5 Stabilized conditions

P_1 1100 psig L_1 82 (80) in H_2O T_1 553 °F

P_2 1080 psig T_2 551 °F

P_3 1075 psig T_3 621 °F

T_4 554 °F

5.9 Blowdown Readings

P_1 1080 psig T_2 547 °F F_1 75 in H_2O

P_2 1050 psig T_4 238 °F L_1 75 in H_2O

P_3 0 psig

Blowdown time * Time 1 min 33 sec.

5.13 Stabilized Readings

P_1 1090 psig T_1 553 °F L_1 74 in H_2O

P_2 1080 psig T_2 552 °F

P_3 1070 psig T_3 430 °F

T_4 500 °F

5.14 Recharge autoclave 2½ gal.

Technicians John Falkowski date 9-4-80

Engineer WP Chapli date 9-4-80

* Time between step 5.9 L_1 and 5.13 L_1.

Test 12

Tubesheet Crevice Leak Rate Test

Data Sheet

Step No.

4.1 Tube S/N 8A Defect Size .010 X 1/2" Long

4.2 Defect location 12" Into Tube Sheet

4.3 Tube deflected YES

5.5 Stabilized conditions

P_1 1100 psig L_1 80 in H_2O (78) T_1 550 °F

P_2 1070 psig T_2 561 °F

P_3 1060 psig T_3 602 °F

T_4 550 °F

5.9 Blowdown Readings

P_1 1090 psig T_2 546 °F F_1 100 in H_2O

P_2 1050 psig T_4 241 °F L_1 73 in H_2O

P_3 0 psig

Blowdown time * Time 1 min 10 sec.

5.13 Stabilized Readings

P_1 1080 psig T_1 550 °F L_1 72 in H_2O

P_2 1040 psig T_2 562 °F

P_3 1030 psig T_3 554 °F

T_4 501 °F

5.14 Recharge autoclave 2 1/2 gal.

Technicians John Falkowski date 9-4-80

Engineer M P Chaplin date 9-4-80

* Time between step 5.9 L_1 and 5.13 L_1.

Test 13

Tubesheet Crevice Leak Rate Test

Data Sheet

Step No.

4.1 Tube S/N 8A Defect Size .010 x 1/2" Long

4.2 Defect location 12" Into Tube Sheet.

4.3 Tube deflected YES

5.5 Stabilized conditions

P_1 1100 psig L_1 72 (70) in H_2O T_1 550 °F

P_2 1070 psig T_2 558 °F

P_3 1060 psig T_3 601 °F

T_4 544 °F

5.9 Blowdown Readings

P_1 1090 psig T_2 547 °F F_1 100 in H_2O

P_2 1050 psig T_4 252 °F L_1 65 in H_2O

P_3 0 psig

Blowdown time * Time 1 min 16 sec.

5.13 Stabilized Readings L_1 64 in H_2O

P_1 1080 psig T_1 550 °F

P_2 1040 psig T_2 552 °F

P_3 1030 psig T_3 553 °F

T_4 490 °F

5.14 Recharge autoclave 2 1/2 gal.

Technicians John Falkowski date 9-4-80

Engineer MPChaplin date 9-4-80

* Time between step 5.9 L_1 and 5.13 L_1.

TEST 14

Tubesheet Crevice Leak Rate Test

Data Sheet

Step No.

4.1 Tube S/N 9A   Defect Size .010 x 1/2" Long

4.2 Defect location 18" Into Tube Sheet

4.3 Tube deflected YES

5.5 Stabilized conditions

P_1 1100 psig L_1 83 (82) in H_2O T_1 550 °F

P_2 1060 psig T_2 559 °F

P_3 1050 psig T_3 600 °F

T_4 548 °F

5.9 Blowdown Readings

P_1 1090 psig T_2 545 °F F_1 83 in H_2O

P_2 1050 psig T_4 242 °F L_1 77 in H_2O

P_3 0 psig

Blowdown time   * Time 1 min 34 sec.

5.13 Stabilized Readings

P_1 1080 psig T_1 550 °F L_1 76 in H_2O

P_2 1040 psig T_2 556 °F

P_3 1060 psig T_3 556 °F

T_4 530 °F

5.14 Recharge autoclave 2½ gal.

Technicians John Falkowski date 9-5-80

Engineer MP Chaplin date 9-5-80

* Time between step 5.9 L_1 and 5.13 L_1.

Test 15

Tubesheet Crevice Leak Rate Test

Data Sheet

Step No.

4.1 Tube S/N 9A Defect Size .010 x 1/2 Long

4.2 Defect location 18" Into Tube sheet

4.3 Tube deflected YES

5.5 Stabilized conditions

P_1 1100 psig — L_1 77 (75) in H_2O — T_1 550 °F

P_2 1080 psig — T_2 560 °F

P_3 1080 psig — T_3 603 °F

T_4 551 °F

5.9 Blowdown Readings

P_1 1090 psig — T_2 547 °F — F_1 75 in H_2O

P_2 1070 psig — T_4 241 °F — L_1 70 in H_2O

P_3 0 psig

Blowdown time — * Time 1 min 31 sec.

5.13 Stabilized Readings

P_1 1100 psig — T_1 550 °F — L_1 70 in H_2O

P_2 1070 psig — T_2 560 °F

P_3 1075 psig — T_3 566 °F

T_4 530 °F

5.14 Recharge autoclave 2 1/2 gal.

Technicians John Falkowski date 9-5-80

Engineer MP Chaplin date 9-5-80

* Time between step 5.9 L_1 and 5.13 L_1.

Test 16

Tubesheet Crevice Leak Rate Test

Data Sheet

Step No.

4.1 Tube S/N 7A   Defect Size .010 hole

4.2 Defect location 5/8" Into Tube sheet.

4.3 Tube deflected YES

5.5 Stabilized conditions

P_1 1100 psig L_1 83 in H_2O T_1 554 °F

82

P_2 1070 psig T_2 553 °F

P_3 1060 psig T_3 620 °F

T_4 546 °F

5.9 Blowdown Readings

P_1 1100 psig T_2 520 °F F_1 0 in H_2O

P_2 1070 psig T_4 214 °F L_1 80 in H_2O

P_3 0 psig

Blowdown time   * Time 14 min 25 sec.

5.13 Stabilized Readings

P_1 1100 psig T_1 554 °F L_1 80 in H_2O

P_2 1070 psig T_2 532 °F

P_3 1060 psig T_3 388 °F

T_4 400 °F

5.14 Recharge autoclave ______ gal.

Technicians John Falkowski date 9-8-80

Engineer M P Chaplin date 9-8-80

* Time between step 5.9 L_1 and 5.13 L_1.

Test 17

Tubesheet Crevice Leak Rate Test

Data Sheet

Step No.

4.1 Tube S/N 2A   Defect Size .010 x 1/2 Long

4.2 Defect location 5/8" Into Tube Sheet

4.3 Tube deflected NO

5.5 Stabilized conditions

P_1 1100 psig L_1 74 / 73 in H_2O T_1 554 °F

P_2 1060 psig T_2 561 °F

P_3 1050 psig T_3 612 °F

T_4 540 °F

5.9 Blowdown Readings

P_1 1090 psig T_2 547 °F F_1 190 in H_2O

P_2 1040 psig T_4 250 °F L_1 68 in H_2O

P_3 0 psig

Blowdown time   * Time 1 min 0 sec.

5.13 Stabilized Readings L_1 65 in H_2O

P_1 1075 psig T_1 554 °F

P_2 1030 psig T_2 550 °F

P_3 1020 psig T_3 463 °F

T_4 515 °F

5.14 Recharge autoclave 2½ gal.

Technicians John Falkowski date 9-9-80

Engineer MPChaplin date 9-9-80

* Time between step 5.9 L_1 and 5.13 L_1.

Test 18

Tubesheet Crevice Leak Rate Test

Data Sheet

Step No.

4.1 Tube S/N #2A Defect Size .010 x 1/2" Long

4.2 Defect location 5/8" Into Tube Sheet.

4.3 Tube deflected NO

5.5 Stabilized conditions

P_1 1100 psig — L_1 63 / 62 in H_2O — T_1 554 °F

P_2 1070 psig — T_2 558 °F

P_3 1060 psig — T_3 603 °F

T_4 540 °F

5.9 Blowdown Readings

P_1 1090 psig — T_2 548 °F — F_1 187 in H_2O

P_2 1050 psig — T_3 248 °F — L_1 57 in H_2O

P_3 0 psig

Blowdown time — * Time ____ min 58 sec.

5.13 Stabilized Readings

P_1 1080 psig — T_1 554 °F — L_1 55 in H_2O

P_2 1050 psig — T_2 557 °F

P_3 1040 psig — T_3 465 °F

T_4 461 °F

5.14 Recharge autoclave 2 1/2 gal.

Technicians John Falkowski date 9-9-80

Engineer M P Chaplin date 9-9-80

* Time between step 5.9 L_1 and 5.13 L_1.

Test 19