NUREG/CR-3562
PNL-4629

Steam Generator Tube Integrity Program Leak Rate Tests

Progress Report

Prepared by R. A. Clark, R. L. Bickford

Pacific Northwest Laboratory
Operated by
Battelle Memorial Institute

Prepared for
U.S. Nuclear Regulatory Commission

Availability of Reference Materials Cited in NRC Publications

Most documents cited in NRC publications will be available from one of the following sources:

1. The NRC Public Document Room, 1717 H Street, N.W.
   Washington, DC 20555
2. The NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission,
   Washington, DC 20555
3. The National Technical Information Service, Springfield, VA 22161

Although the listing that follows represents the majority of documents cited in NRC publications, it is not intended to be exhaustive.

Referenced documents available for inspection and copying for a fee from the NRC Public Document Room include NRC correspondence and internal NRC memoranda; NRC Office of Inspection and Enforcement bulletins, circulars, information notices, inspection and investigation notices; Licensee Event Reports; vendor reports and correspondence; Commission papers; and applicant and licensee documents and correspondence.

The following documents in the NUREG series are available for purchase from the NRC/GPO Sales Program: formal NRC staff and contractor reports, NRC-sponsored conference proceedings, and NRC booklets and brochures. Also available are Regulatory Guides, NRC regulations in the *Code of Federal Regulations*, and *Nuclear Regulatory Commission Issuances*.

Documents available from the National Technical Information Service include NUREG series reports and technical reports prepared by other federal agencies and reports prepared by the Atomic Energy Commission, forerunner agency to the Nuclear Regulatory Commission.

Documents available from public and special technical libraries include all open literature items, such as books, journal and periodical articles, and transactions. *Federal Register* notices, federal and state legislation, and congressional reports can usually be obtained from these libraries.

Documents such as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings are available for purchase from the organization sponsoring the publication cited.

Single copies of NRC draft reports are available free upon written request to the Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at the NRC Library, 7920 Norfolk Avenue, Bethesda, Maryland, and are available there for reference use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from the American National Standards Institute, 1430 Broadway, New York, NY 10018.

GPO Printed copy price: $4.50

NUREG/CR-3562
PNL-4629
R5

Steam Generator Tube Integrity Program Leak Rate Tests

Progress Report

Manuscript Completed: March 1983
Date Published: January 1984

Prepared by
R. A. Clark, R. L. Bickford

Pacific Northwest Laboratory
Richland, WA 99352

Prepared for
Division of Engineering Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
NRC FIN B2097

ABSTRACT

This interim report presents preliminary results on leak rate tests performed on through-wall defected Inconel 600 steam generator tubing. Tube defects included an EDM (electro-discharge machine) notch and IGSCC (intergranular stress corrosion cracks) of various lengths. Tests were conducted at PWR operating temperatures with leakage of hot water/steam into air. A number of IGSCC cracks were unstable under the experiment conditions of these initial tests, continuing to grow until system capacity limitations resulted in decreased pressure differential. However, initial testing also pointed to a need for reconfiguration of the test apparatus to sustain increased flow and, more importantly, alter the mode of control. The initial test configuration is based on flow control, with pressure differential across the specimen an independent variable. This often results in pressure increases too rapid to establish the initiation of crack instability. A reconfigured system based on pressure control with flow as an independent parameter is being recommended for future tests.

ABSTRACT

This interim report presents preliminary results on leak rate tests performed on through-wall defected Inconel 600 steam generator tubing. Tube defects included an EDM (electro-discharge machine) notch and IGSCC (intergranular stress corrosion cracks) of various lengths. Tests were conducted at PWR operating temperatures with leakage of hot water/steam into air. A number of IGSCC cracks were unstable under the experiment conditions of these initial tests, continuing to grow until system capacity limitations resulted in decreased pressure differential. However, initial testing also pointed to a need for reconfiguration of the test apparatus to sustain increased flow and, more importantly, alter the mode of control. The initial test configuration is based on flow control, with pressure differential across the specimen an independent variable. This often results in pressure increases too rapid to establish the initiation of crack instability. A reconfigured system based on pressure control with flow as an independent parameter is being recommended for future tests.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

INTRODUCTION

Leak rate testing of laboratory stress corrosion cracked Inconel 600 steam generator tube specimens is part of NRC research efforts concerning primary system integrity. The total matrix of proposed tests is shown in Table 1. This matrix is designed to evaluate potential leakage associated with cracks of different sizes and orientations. More importantly information is generated on what happens to the defect under an accident condition such as a main steam line break (MSLB) during which the pressure differential across the generator tubes is temporarily increased.

Stress corrosion cracked specimens are generated by the process described in Ref. 1. After being removed from the autoclave, they are cleaned and nondestructively tested by an eddy-current probe scan. If the SCC specimen meets the criteria for an acceptable leak test specimen as described in a later section of this paper, it is photographed and ultrasonically cleaned. The leak test is performed and the specimen is either photographed, in the case of a crack opening up, or eddy-current tested if the crack remained tight.

This paper includes a summary of test results to date, some problems encountered and corrective action taken. Detailed descriptions of each leak test performed including computer results and specimen photographs are provided.

SUMMARY OF LEAK TEST RESULTS TO DATE

Fifteen autoclave runs consisting of 59 specimens of .875" OD x .050" wall Inconel 600 tubing with a machined uniform thinned area were made in an effort to produce tight 90-100% through-wall SC cracks(1) suitable for leak testing. Of the 59 uniform thinned specimens autoclaved, 7 uniform thinned specimens were successfully cracked through-wall and were subsequently leak tested. Two additional unthinned tubes were also leak tested for a total of nine leak rate tests. Table 2 shows a list of the thinned specimens, along with their thinning parameters, NDE/visual results after autoclaving, and notations showing the specimens used for leak testing. The two unthinned tubes are described in Table 3 along with descriptions of each leak test performed to date.

(1) R. A. Clark and R. L. Burr. Technical Note: A Method for Controlled Stress Corrosion Cracking in Nonsensitized Inconel 600 Tubing. Corrosion. Vol. 36, No. 7, p. 382-383. July 1980.

TABLE 1. Leak Rate Test Matrix*

Uniform Thinning and Stress Corrosion Crack

Study 1/4", 1/2", 1", and 1-1/2" SCC with uniform thinning twice the crack length and of the following depths: 0%, 35-45%, 55-60%, 75-85%. (Number of tests = 16)

Long Through-Wall Cracks

Study 2" and 3" cracks with no uniform thinning. (Number of tests = 2)

0.625" x 0.034" Tubing

Spotcheck tubes with no thinning and varying crack lengths. (Number of tests = 4)

SCC Through-Wall Circumferential

Study circumferential cracks of 45°, 90°, 120°, 180°, 270°. (Number of tests = 5)

Leak in Simulated Tube Sheet Crevice

Test 1 SCC and multiple SCC with and without packing. (Number of tests = 4)

Leak Under Dent

Study tubes with 1/8" and 1/4" cracking on each side of support plate. (Number of tests = 2)

*0.875" x 0.050" tubing unless otherwise noted.

TABLE 2. Autoclaved Specimens and Visual/NDE Results to Date

Specimen Number	Percent of Wall Thinning	Length of Thinned Area (in.)	Visual/NDE Results
E-1	40	1	Burst
E02-4	60	2	One 90% through-wall crack (could not be seen by microscope)
E02-8	80	2	Burst
E02-10 (LT)*	40	1	100% through-wall crack
E03-10	40	1	No indications
E04-2	60	1	Burst
E04-6	80	1/2	No indications
E04-10 (LT)	40	1	Two indications - each 90%
E05-2	40	1/2	No indications
E05-6	60	2	Burst
E05-10 (LT)	60	2	100% through-wall crack
E06-4	80	1/2	No indications
E09-4	40	1/2	Through-wall crack near end plug
E09-6	80	1	Burst
E09-10	40	1/2	Burst
E10-2	80	1/2	No indications
E10-3	60	2	Burst
E10-5	80	1	Burst
E10-6	80	2	Burst
E10-7	40	1/2	No indications
E10-8	80	1/2	No indications
E13-0	40	2	No indications
E13-1 (LT)	40	1	100% through-wall crack and several shallow cracks
E13-5	40	2	One crack ~25% through-wall
E14-10	40	2	One crack ~60% through-wall
E15-4	40	1/2	No indications
E15-6	80	2	Burst
E15-10	60	2	Burst
B44-4	60	1	No indications

TABLE 2. (Continued)

Specimen Number	Percent of Wall Thinning	Length of Thinned Area (in.)	Visual/NDE Results
F01-8	60	1/2	One crack <50% through-wall
F04-6 (LT)*	60	2	One crack ~90% through-wall
F04-10 (LT)*	40	2	One crack ~90% through-wall
F07-2 (LT)	40	2	One crack ~90% through-wall
F07-6	40	1	Burst
F08-2	60	1	Burst
F08-4	40	2	No indications
F08-6	80	1	Burst
F12-1	40	1/2	No indications
F12-3	40	1/2	100% through-wall near end plug
F12-4	40	1/2	No indications
F12-5	60	1/2	No indications
F12-7	40	1	One crack <20% through-wall
F12-9	60	1	No indications
F63-4	40	1/2	No indications
L-1	40	1/2	Burst
L-2	60	1/2	Burst
L-3	80	1	Burst
L-4	80	1	No indications
L04-2	40	1/2	No indications
L11-8	60	1/2	No indications
L16-2	20	1/2	No indications
L16-4	40	1/2	No indications
L17-1	80	1/2	No indications
L17-2	40	1/2	Burst
L17-4	80	1/2	No indications
L17-6	20	1/2	No indications
L17-7	40	1/2	No indications
L17-8	60	1/2	No indications
L17-9	60	1/2	No indications

*Leak tested

TABLE 3.

E01-3

- Computer data: Figures 8, 9 and 10.
- After test photograph: Figure 35.
- Eddy current before test: 100% through-wall crack.
- Visual inspection: No thinning, 3/8" long crack in center of exposed area.
- Testing: Flow remained <2 gpm although pressure ranged between 2700 and 2500 psig. Test ran for slightly over 2 minutes.
- Test results: Major crack opened slightly and length increased to 1/2". No substantial crack growth noted on videotape.

E03-9

- Computer data: Figures 11, 12 and 13.
- After test photograph: Figure 36.
- Visual inspection: 1/2" long EDM notch.
- Testing: Pressure built up to 500 psi and flow remained at <2 gpm for first 50 seconds of test. Then pressure increased in steps to a maximum of ~1700 psi while flow increased in steps to 10 gpm.
- Test results: Notch bulged slightly at both edges.

E13-1

- Computer data: Figures 14, 15 and 16 - original test.
Figures 17, 18 and 19 - retest.
- After test photograph: Figure 37.
- Eddy current before test: 100% through-wall crack.
- Visual inspection: 1" long thinned area, 40% thinning (60% of wall remaining), major crack ~1/4" long and towards one side of thinned area, several small shallow cracks in same area.
- Testing: On the first run, the control panel indicated that hot water never got to the specimen (this problem and action taken are discussed previously in this paper). Flow remained at <2 gpm and pressure was ~2700 psi. Test terminated after 2 minutes due to water temperature problem. The retest was run after the specimen drain valve was installed in the line. The pressure on the specimen remained at 2500 psi and flow was <2 gpm for ~70 seconds. Specimen then burst and flow increased to 20 gpm and pressure decreased to ~600 psi. Test remained running for 80 seconds. Flow vs. pressure plot for this run shows a nice curve.
- Testing results: Tube burst; length of crack increased to 6/10".

TABLE 3. (Continued)

F07-2

- Computer data: Figures 20, 21 and 22.
- After test photograph: Figure 38.
- Eddy current before test: Major crack ~90% through-wall.
- Visual inspection: 2" long thinned area, 40% thinning (60% of wall remaining), crack ~3/8" long - started at very edge of thinned area.
- Testing: Flow remained at <2 gpm for 10 seconds then increased to 4 gpm until test was terminated. Pressure started out at ~2300 and decreased to ~1750 psi when 4 gpm flow started. Test lasted for 150 seconds.
- Test results: Length of crack grew to 6/10" and opened up slightly.

E05-10

- Computer data: No computer data due to computer problem developed after test initiation.
- After test photograph: Figure 39.
- Eddy current before test: One crack 100% through-wall.
- Visual inspection: 2" long thinned area, 60% thinning (40% of wall remaining), 7/16" long crack in center of thinned area.
- Testing: No computer results however instrument panel indicated pressure began at ~2500 psi and specimen burst immediately. Flow meter was pegged at 100% (20 gpm).
- Testing results: Specimen burst wide open over almost entire length of thinned area. Small amounts of crack growth could be seen on videotape before bursting occurred.

E04-10

- Computer data: Figures 23, 24 and 25.
- Before and after photographs: Figures 40 and 41.
- Eddy current before test: 90% through-wall - 2 indications.
- Visual inspection: 1" long thinned area, 40% thinned (60% of wall remaining) 1/2" long crack running towards one side of thinned area.
- Testing: Pressure was not applied to specimen until ~25 seconds into the test. Pressure started out then to be 1000 psi and flow increased from <2 gpm to 7 gpm. Test ran for 60 seconds after maximum flow.
- Test results: Crack opened up over its entire length but did not burst.

TABLE 3. (Continued)

F04-10

- Computer data: No computer data due to computer problem developed after test initiation.
- Before and after photographs: Figures 42 and 43.
- Eddy current before test: One crack 90% through-wall.
- Visual inspection: 2" long thinned area, 40% thinning, 1/2" crack in center of thinned area.
- Testing: All data was obtained from control panels. Pressure remained at 2400 psi and flow was <2 gpm for entire test. Test lasted 80 seconds.
- Test results: Crack opened up slightly but flow never increased over <2 gpm.

F04-6

- Computer data: Figures 26, 27 and 28.
- Before and after photographs: Figures 44 and 45.
- Eddy current before test: One crack 90-100% through-wall.
- Visual inspection: 2" long thinned area, 60% thinning, 1/2" crack in center of thinned area.
- Testing: Flow was increased in steps to a maximum of ~14 gpm. This flow was held for 30 seconds. Pressure was increased slowly to a maximum of 600 psi during maximum flow.
- Test results: Crack burst open but its length did not increase significantly.

E02-10

- Computer data: Figures 29, 30 and 31 - original test.
Figures 32, 33 and 34 - retest.
- Before and after photographs: Figures 46 and 47.
- Eddy current before test: One crack 100% through-wall.
- Visual inspection: One major crack and several branching cracks, 1" long thinned area, 40% thinning.
- Testing: Original test produced no results due to water temperature problem in specimen. Test was run for 5 minutes but temperature never increased substantially. This problem was remedied by installation of a specimen vent valve. The retest was run for 100 seconds. The flow was increased in steps to a maximum of 20 gpm. Pressure remained at ~200 psi for most of test.
- Testing results: Crack burst open. Length 3/4".

SPECIMEN FABRICATION PROBLEMS

For uniform thinned tubes, typically 30-40% of autoclaved specimens exhibit no detectable NDE indications and the remainder of the specimens exhibit varying depths of SC attack. Specimens with no NDE indications after one autoclave run have historically had a 70% chance of cracking if autoclaved again.

A heat of .875" OD x .050" wall Inconel 600 tubing, designated the L heat, is now being used for fabrication of leak rate specimens due to depletion of tubing from the B, E and F heats. Fifteen uniform thinned specimens from the L heat have been autoclaved. Four specimens burst and the remainder had no detectable NDE indications (results are shown in Table 2). Three specimens with no NDE indications were autoclaved a second time with no NDE results. For this heat of tubing, ~70% of the specimens exhibited no NDE indications (vs. 30-40% for previous heats of tubing) and no cracking occurred during a second autoclave run (vs. a 70% chance of cracking for previous heats).

Considering that machining stresses and resultant work hardening may be a contributing factor, a heat treatment of 1600°F for 30 minutes in an inert atmosphere with an air quench was devised for relieving the machining stresses. This was done after consulting with Huntington Alloys. Four uniform thinned specimens from the L heat were subjected to this heat treatment and autoclaved. Again, there were no detectable NDE indications in these tubes.

Two unthinned specimens from the L heat were autoclaved in an effort to determine if the method of thinning was a deterrent to initiating SCC. These specimens were run for a period exceeding 100 hours and had no NDE indications upon examination. Previous experience with other material heats has shown cracking within 24 hours.

We are presently continuing to autoclave specimens from this heat although it appears to be crack-resistant.

LEAK TEST PROBLEMS AND RESOLUTIONS

In the initial runs, the tube leak tests did not perform as expected, it was noted that specimen water temperatures were not rising to the expected level of 250-270°C. It was determined that these problems were a result of cool water left standing in the pressure line between the metering valve and the specimen. This problem was remedied by the addition of a drain line from the specimen and a specimen vent valve. In operation, this configuration allowed water of the proper operating temperature to pass beyond the specimen before valve closure and test initiation.

CLEANLINESS OF CRACKS

A stress corrosion cracked steam generator tubing specimen produced by autoclaving in a caustic solution[(1)] was subjected to SEM/EDX analysis to determine crack cleanliness of specimens used for leak rate testing. The specimen had a 60% through-wall SCC in a thinned area and was cleaned prior to SEM/EDX analysis using the same technique used for leak test specimens prior to leak testing - one half hour of ultrasonic cleaning in an alcohol/deionized water solution. The specimen was then compressed in a vise to open the crack and expose the interior for SEM/EDX analysis.

The crack interior was shown to have an Inconel 600 chemistry but with a slightly lower amount of nickel and a higher amount of aluminum (Figure 1). Figures 2 and 3 show SEM photographs of the crack interior at 200X and 1000X magnifications. An area closer to the crack mouth (Figure 4) showed an Inconel 600 chemistry with trace amounts of Al, Si, Cd, Sb (Figure 5) and a few small particles high in Si, Al, Ca and Fe with smaller amounts of K, Cr and Ni (Figure 6). Very few high Cu particles were found in the SEM/EDX scan indicating that excess Cu particles left on the specimen due to the cracking process are effectively removed during specimen cleaning. These high Cu and other impurity particles found in the crack during the analysis were small and few in number and very likely do not influence the crack propagation during the leak test.

DESCRIPTION OF LEAK RATE TESTS

The leak rate testing system is shown in Figure 7. A large autoclave serves as the hot water reservoir. Pressure is maintained in the autoclave by bleeding in a cover gas from high pressure accumulators as the autoclave blows down via a bottom penetration through the test specimen. The blow-down water passes through a high temperature flow meter to the specimen which is instrumented to measure internal pressure and temperature. Each test is started by first opening a vent valve on the specimen and allowing sufficient heated water to pass through the specimen to bring it to test temperature. The vent valve is then closed and specimen leakage is controlled by a metering valve. In concept the metering valve will enable several pressure differential versus flow data points to be taken. The metering valve is positioned and pressure in the specimen allowed to come to an equilibrium for the particular flow, then the metering valve opened further allowing a new equilibrium

[(1)] R. A. Clark and R. L. Burr. Technical Note: A Method for Controlled Stress Corrosion Cracking in Nonsensitized Inconel 600 Tubing. Corrosion. Vol. 36, No. 7, p. 382-383. July 1980.

x = 3, Ref micro B-24,801
Specimen P-5076 (#1 CRACKed TuBe)
General scan of cracked area
0-10.2 KV; 20 ev/ch; 10 sec. count
FS: 4096

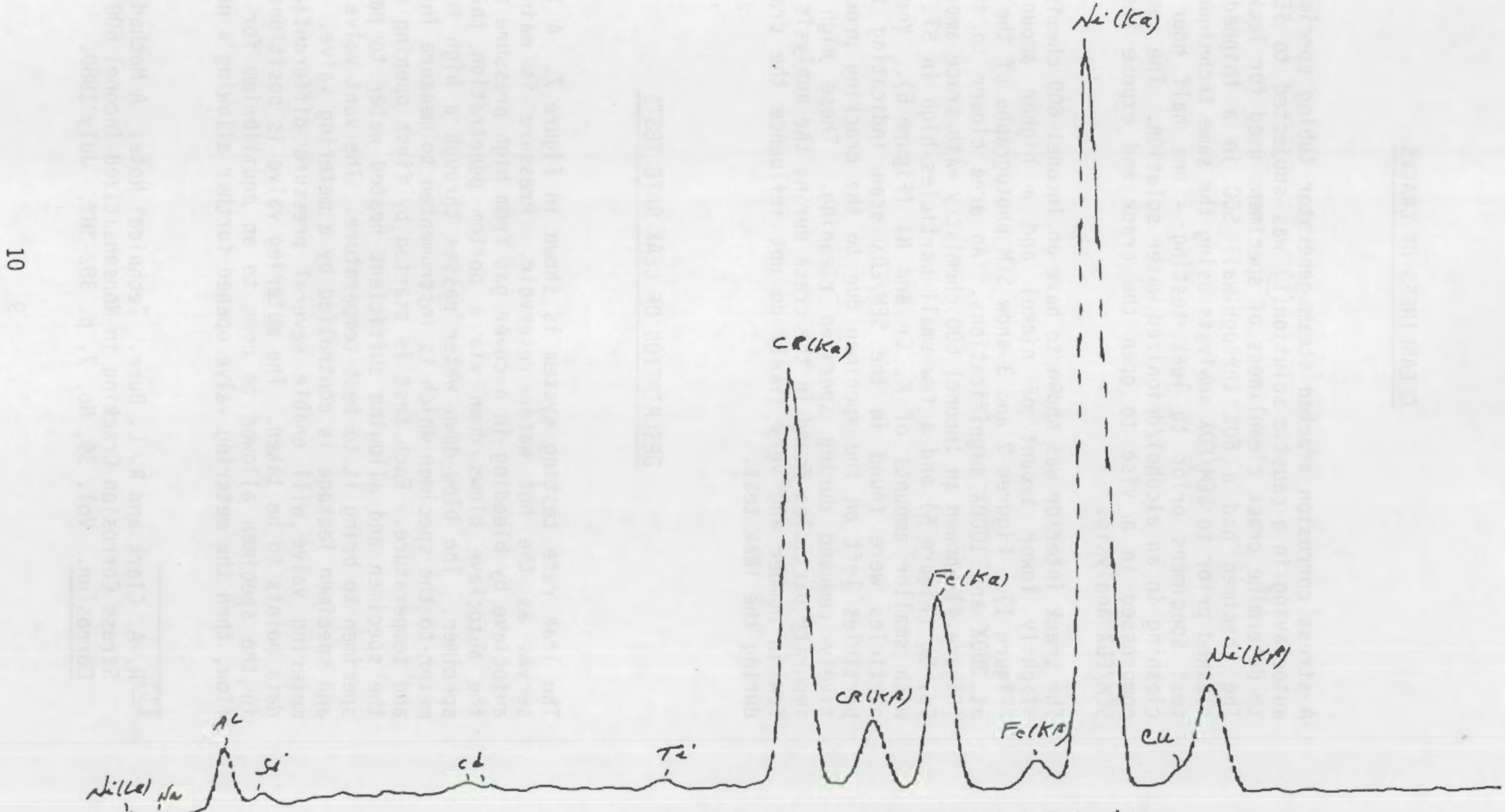


FIGURE 1. EDX Analysis of Typical Stress Corrosion Crack Interior

FIGURE 2. SEM Photograph Looking Oown into Crack Mouth Showing Crack Interior

FIGURE 3. SEM Photograph - Close-up View of Interior Section Seen in Figure 2

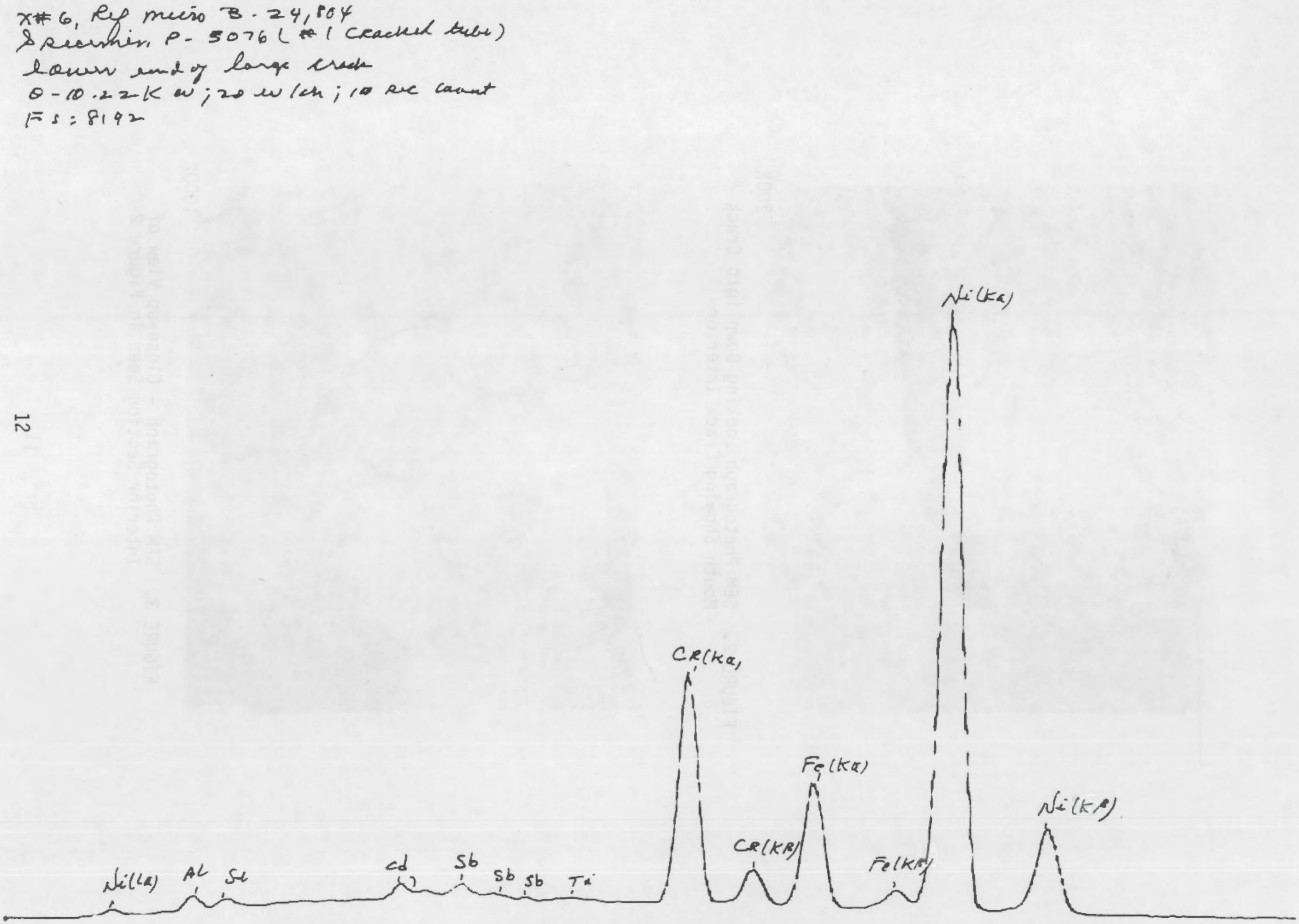


FIGURE 4. EDX Analysis of Area Near Crack Mouth Showing Trace Amounts of Al, Si, Cd, & Sb

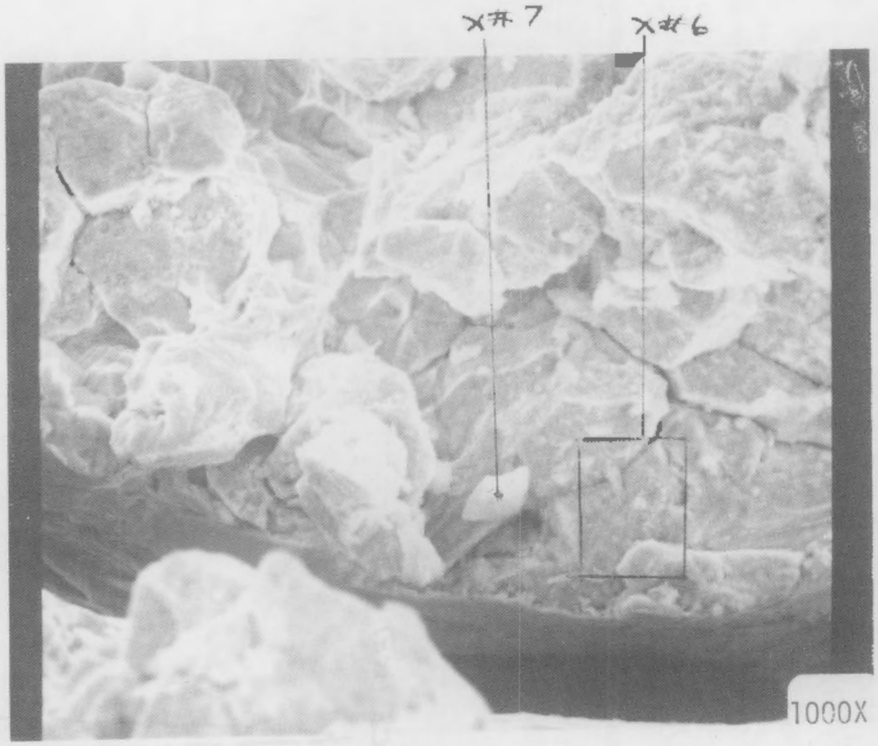


FIGURE 5. SEM Photograph of Area Near Crack Mouth.
Impurity Particles Can be Seen.

X#7, Ref micro B-24,884
Specimen P-5076 (#1 Cracked Tube)
Particle on fracture face
0-10.22 Kev; 20 ev/cm; 100 sec count
FS = 4096

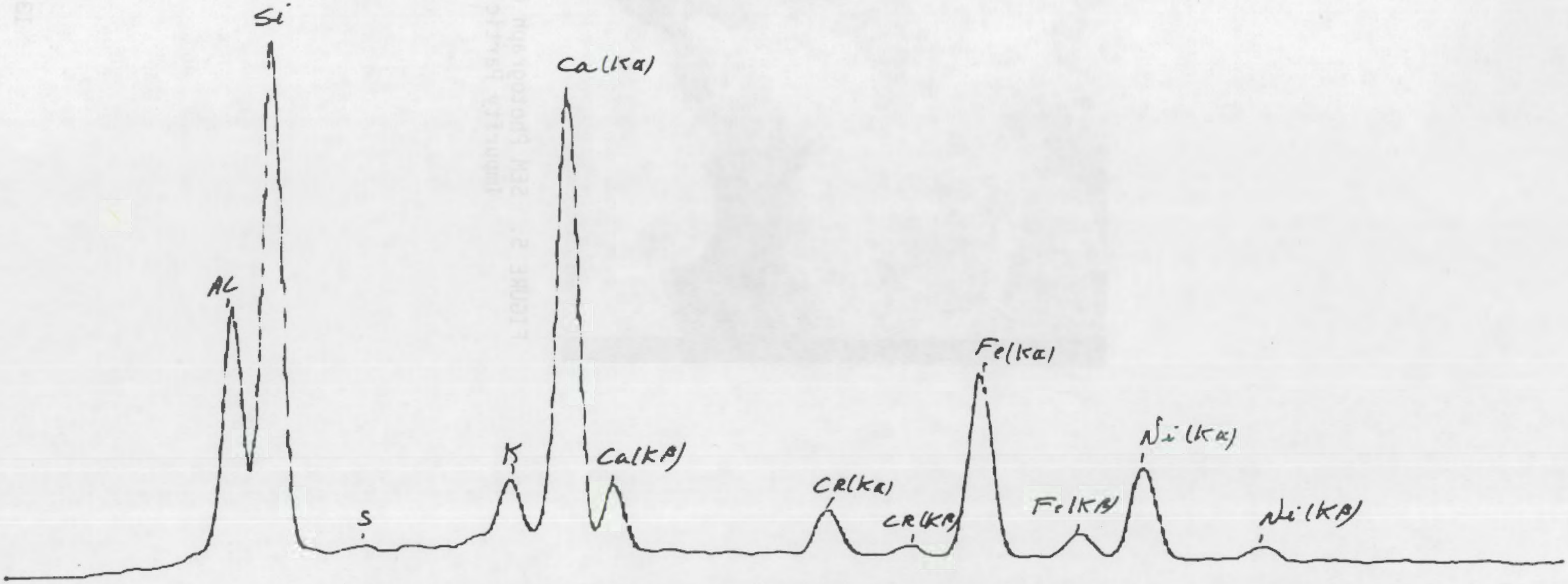


FIGURE 6. EDX Analysis of Impurity Particle Seen in Figure 5

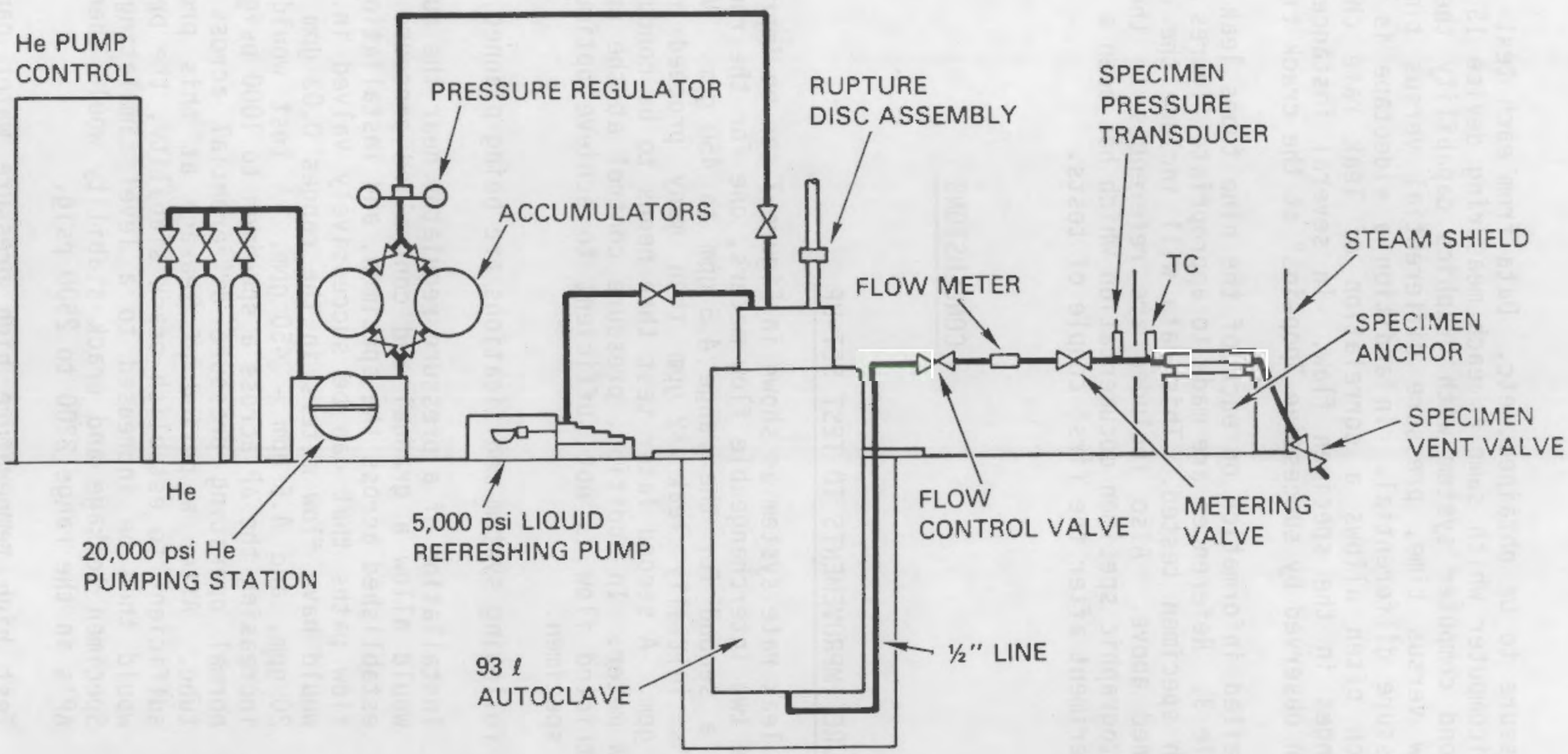


FIGURE 7. Schematic of Leak Rate Test Set-up

pressure to be obtained, etc. Data from each test is acquired using a minicomputer which samples each measuring device 15 times a second. A second computer system with graphics capability then creates plots of flow versus time, pressure differential versus time and flow versus pressure differential. In addition a videotape is taken of each test which often allows a correlation of leak rate changes with visible changes in the specimen flaw. In several instances crack growth has been observed by successive "pop-ins" at the crack tip.

Detailed information on each of the nine tubes leak tested is given in Table 3. References are made to appropriate figures containing data for each specimen tested. This data will include the computer plots mentioned above. Also included are references to the before and after photographic specimen documentation which has been a routine part of the experiment after the first couple of tests.

CONCLUSIONS

FUTURE IMPROVEMENTS TO TEST SET-UP

The leak rate system as shown in Figure 7 can be improved. Currently we have two interchangeable flow meters, one for the range 2 gpm to 20 gpm and a second for the range 4.5 gpm to 450 gpm. Virtually all tight SCC's initially leak <2 gpm then many proceed rapidly to leakage >20 gpm. A second later test then needs to be conducted using the high flow meter. In addition, pressure control at the specimen by means of restricted flow is not sufficient to achieve optimum information from the specimen.

The following system modifications are being planned.

- Installation of a pressure regulator near the autoclave source that would allow a gradual and controlled pressure differential to be established across the specimen, and installation of three parallel flow paths that can be successively valved in. These flow paths would have flow meters in the ranges 0.03 gpm - 3.0 gpm, 2 gpm - 20 gpm, and 4.5 gpm - 450 gpm. A test would be run by slowly increasing the ΔP across a specimen to 1000 psig, approximating the normal operating pressure differential across a steam generator tube. After a period of leakage at this pressure differential sufficient to establish crack stability, the pressure differential would then be increased to a level simulating a MSLB condition. Specimen leakage and crack stability would then be determined for ΔP's in the range 2200 to 2500 psig.

- Test high temperature high pressure water capacity needs to be expanded to run longer tests for evaluation of crack stability.

- A larger capacity blower will be installed to keep the camera lens path clear of steam.

TEST MATRIX SUGGESTIONS

Experience with the tests run to date suggests some redirection. First the method used to produce localized stress corrosion cracks in tube samples does not appear to be capable of producing 100% through-wall cracks longer than 1" without deformation in the sample. This is probably due to crack growth aspect ratios leading to through-wall failures at smaller crack lengths. On the other hand crack growth behavior in 1" long and shorter cracks suggests there is no real benefit in testing the longer cracks. It appears that 1" long and shorter through-wall stress corrosion cracks are not stable at a pressure differential of 2500 psig across a .875" OD x .050" wall steam generator tube. We propose limiting the test matrix for uniform thinned specimens to 1/4", 1/2" and 1" long SCC with 40%, 60% and 80% thinning in an area twice the crack length.

The testing concept that we propose to be of most interest would involve a through-wall crack that at $\Delta P \cong 1000$ psig leaked $\leq .2$ gpm and was stable. We would then gradually increase ΔP to 2250 psig and evaluate crack growth and leak rate behavior. This would provide input into possible consequences associated with code acceptable leaks in the event of a main steam line break (MSLB).

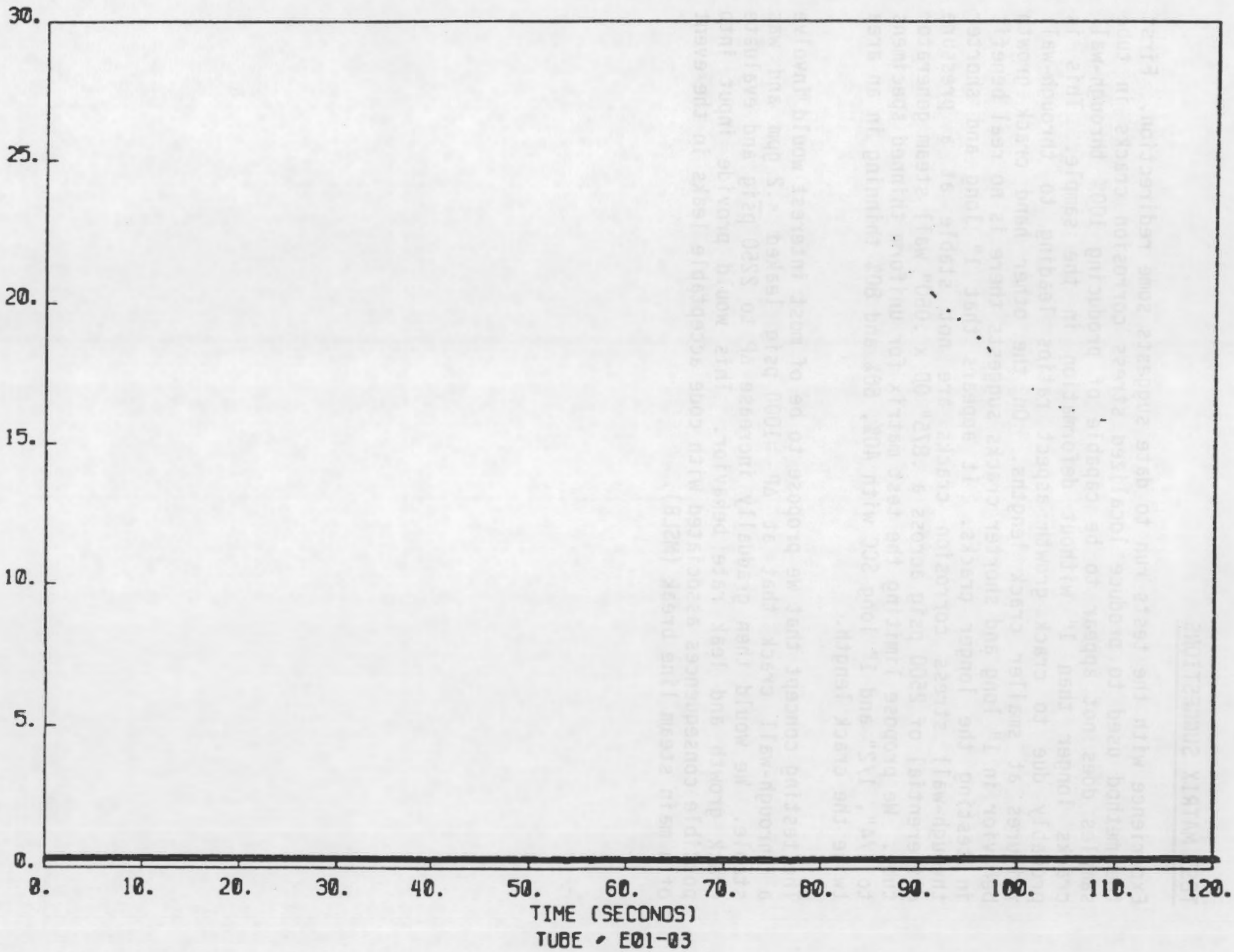

FLOW (GPM)
30.
25.
20.
15.
10.
5.
0.
0.
10.
20.
30.
40.
50.
60.
70.
80.
90.
100.
110.
120.
TIME (SECONDS)
TUBE - E01-03

FIGURE 8

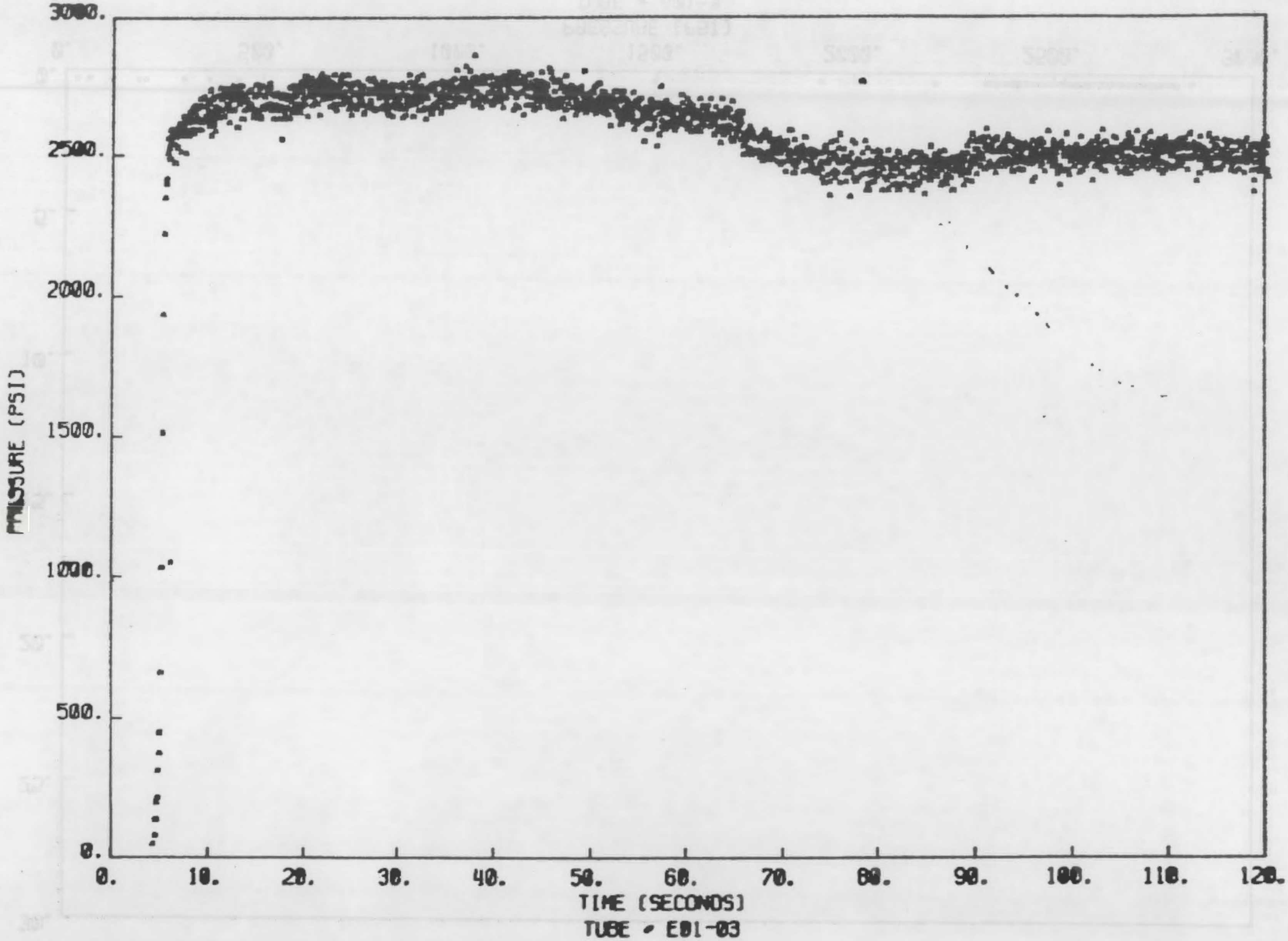

3000.
2500.
2000.
1500.
1000.
500.
0.
PRESSURE (PSI)
0.
10.
20.
30.
40.
50.
60.
70.
80.
90.
100.
110.
120.
TIME (SECONDS)
TUBE - E01-03

FIGURE 9

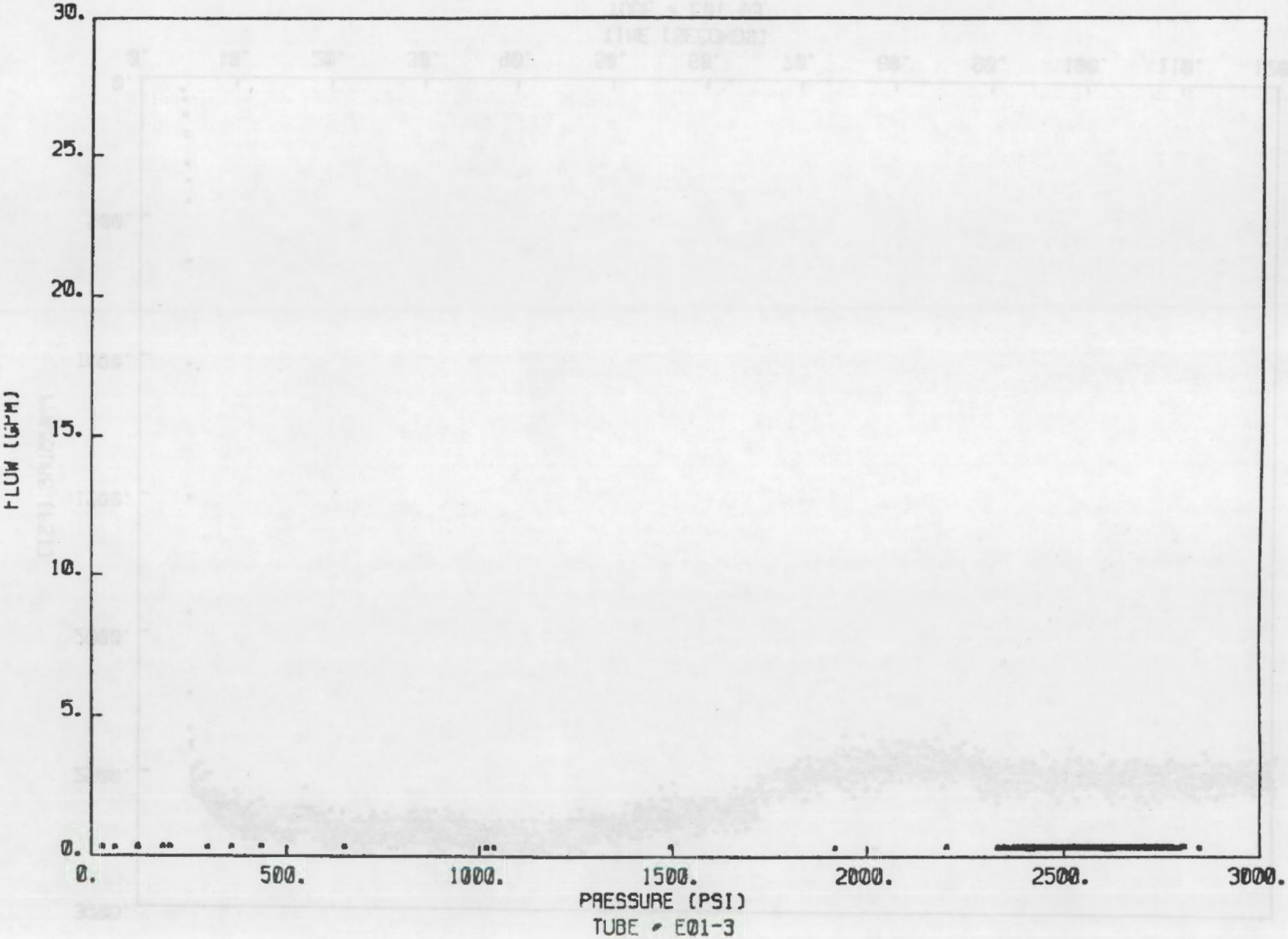

30.
25.
20.
15.
10.
5.
0.
FLOW (GPM)
0.
500.
1000.
1500.
2000.
2500.
3000.
PRESSURE (PSI)
TUBE • E01-3

FIGURE 10

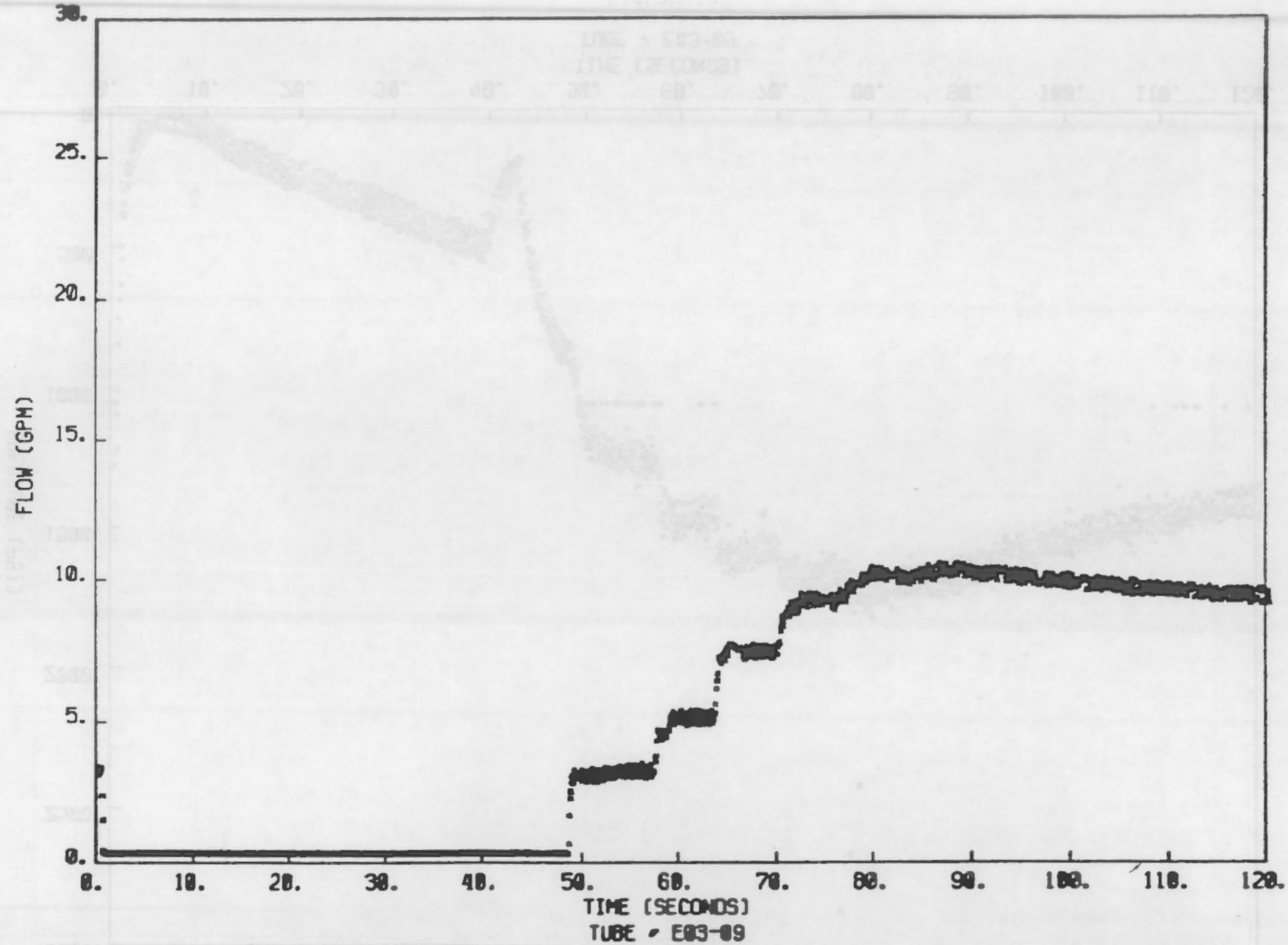

30.
25.
20.
15.
10.
5.
0.
FLOW (GPM)
0.
10.
20.
30.
40.
50.
60.
70.
80.
90.
100.
110.
120.
TIME (SECONDS)
TUBE # E03-09

FIGURE 11

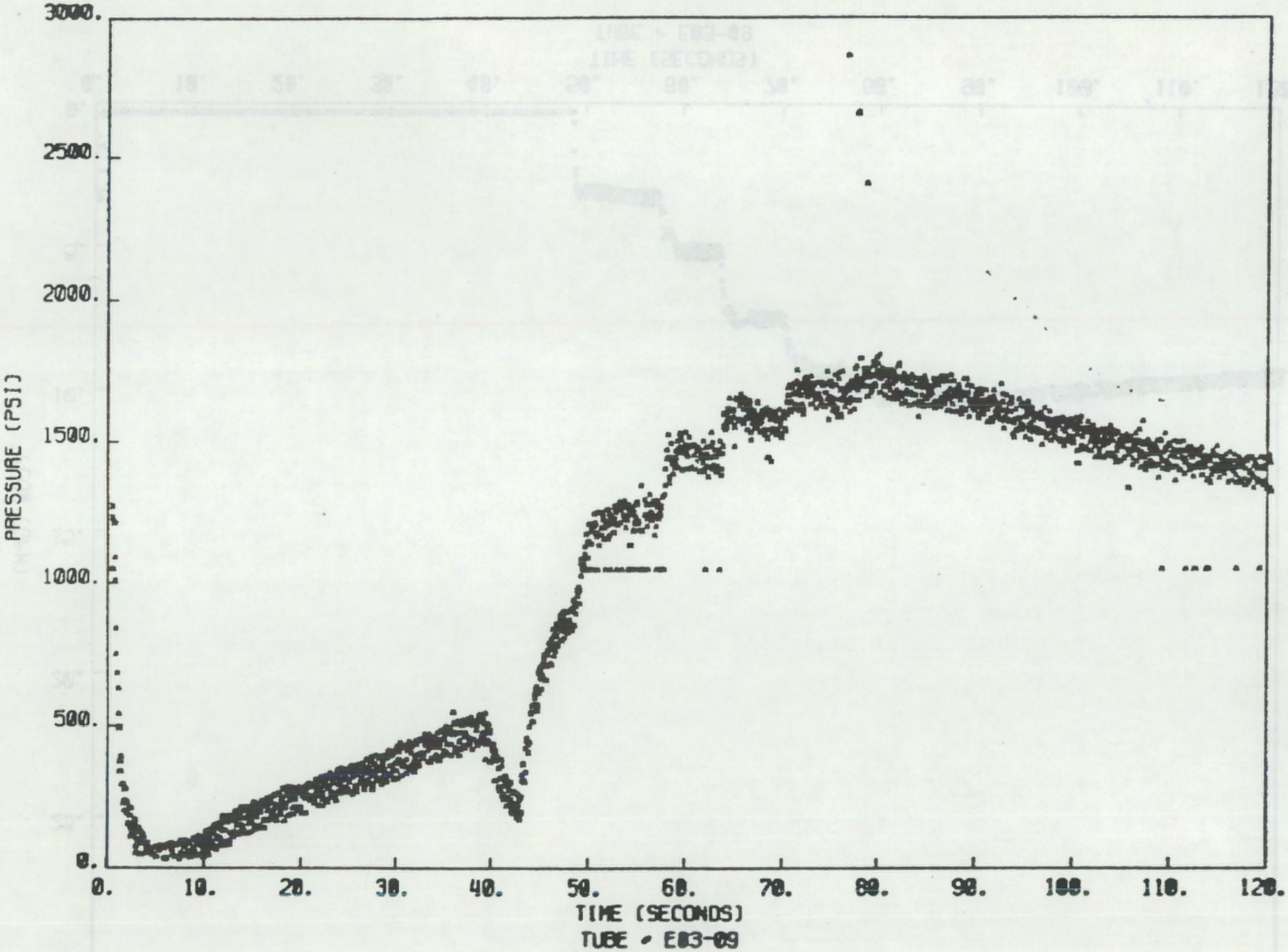

3000.
2500.
2000.
1500.
1000.
500.
0.
PRESSURE (PSI)
0.
10.
20.
30.
40.
50.
60.
70.
80.
90.
100.
110.
120.
TIME (SECONDS)
TUBE • E03-09

FIGURE 12

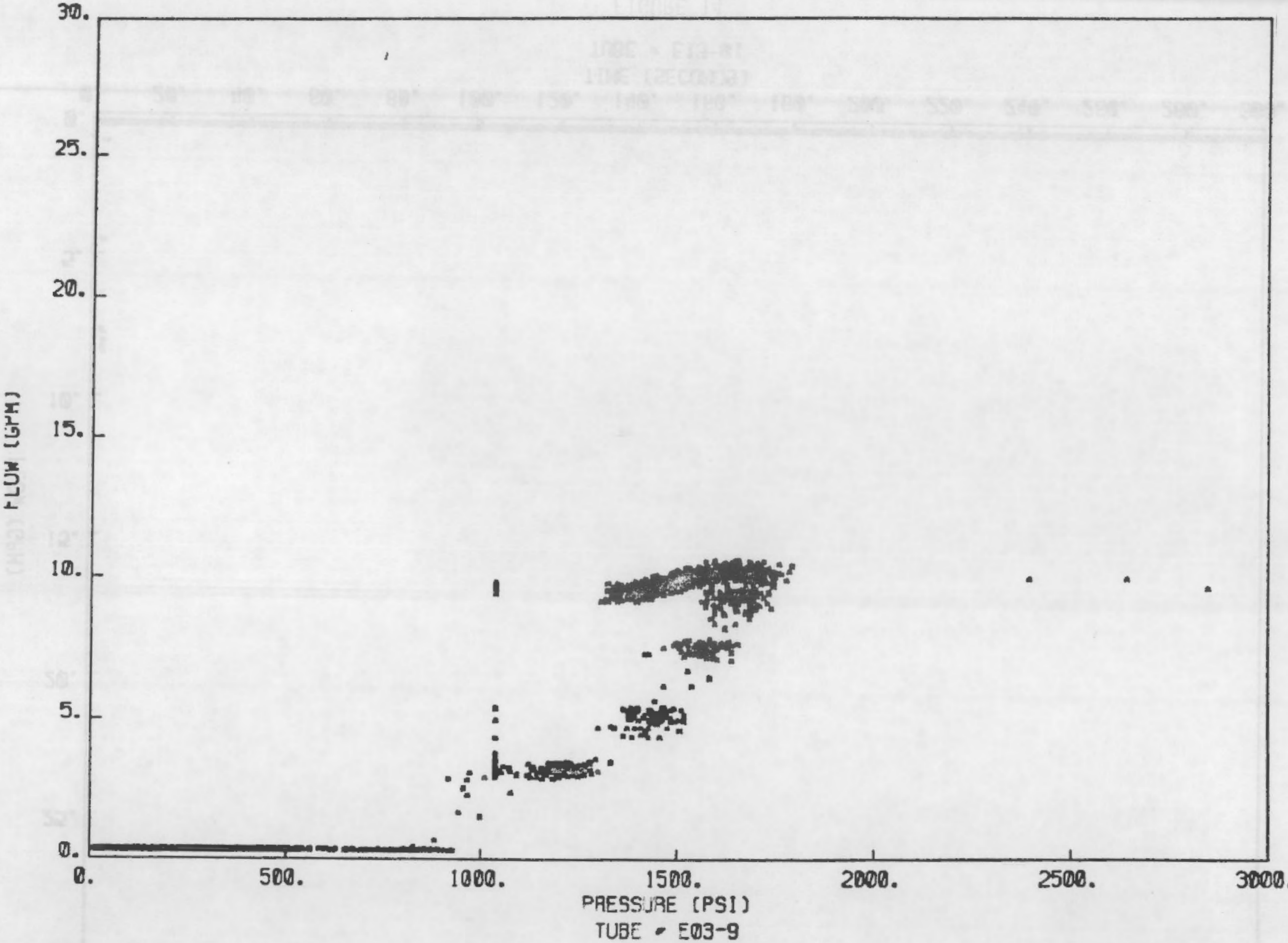
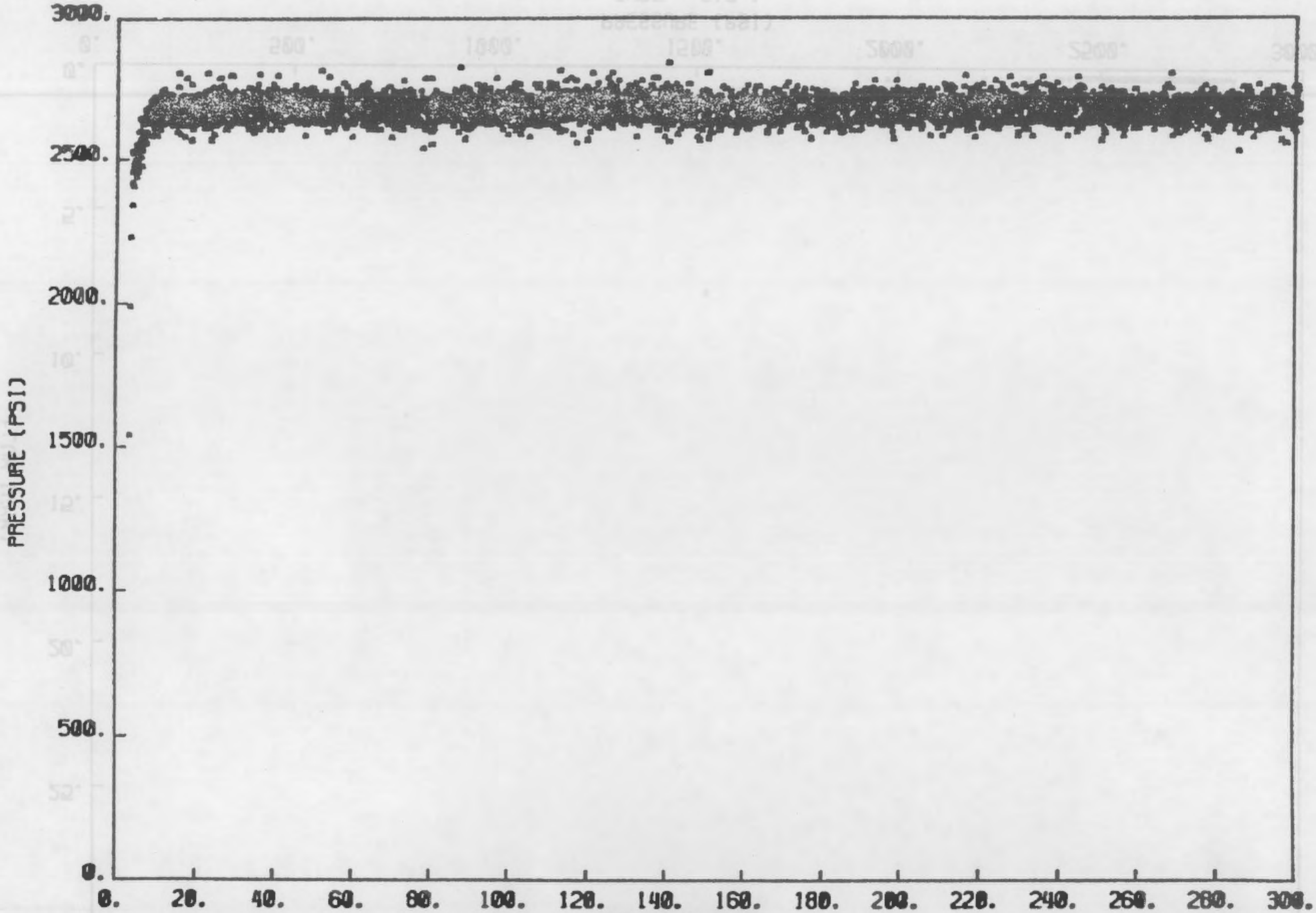

30.
25.
20.
15.
10.
5.
0.
FLOW (GPM)
0.
500.
1000.
1500.
2000.
2500.
3000.
PRESSURE (PSI)
TUBE - E03-9

FIGURE 13



TUBE • E13-01

FIGURE 15

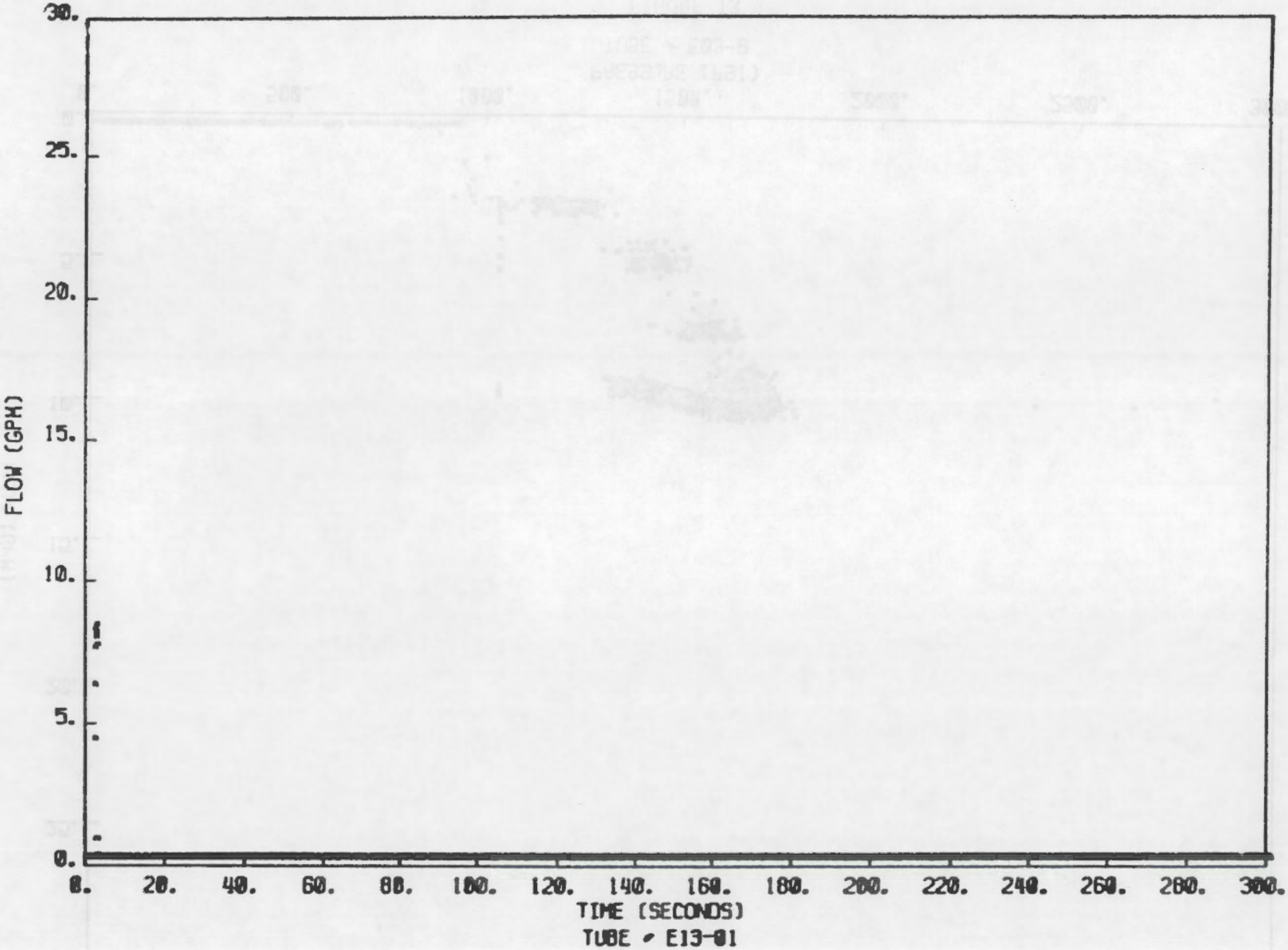
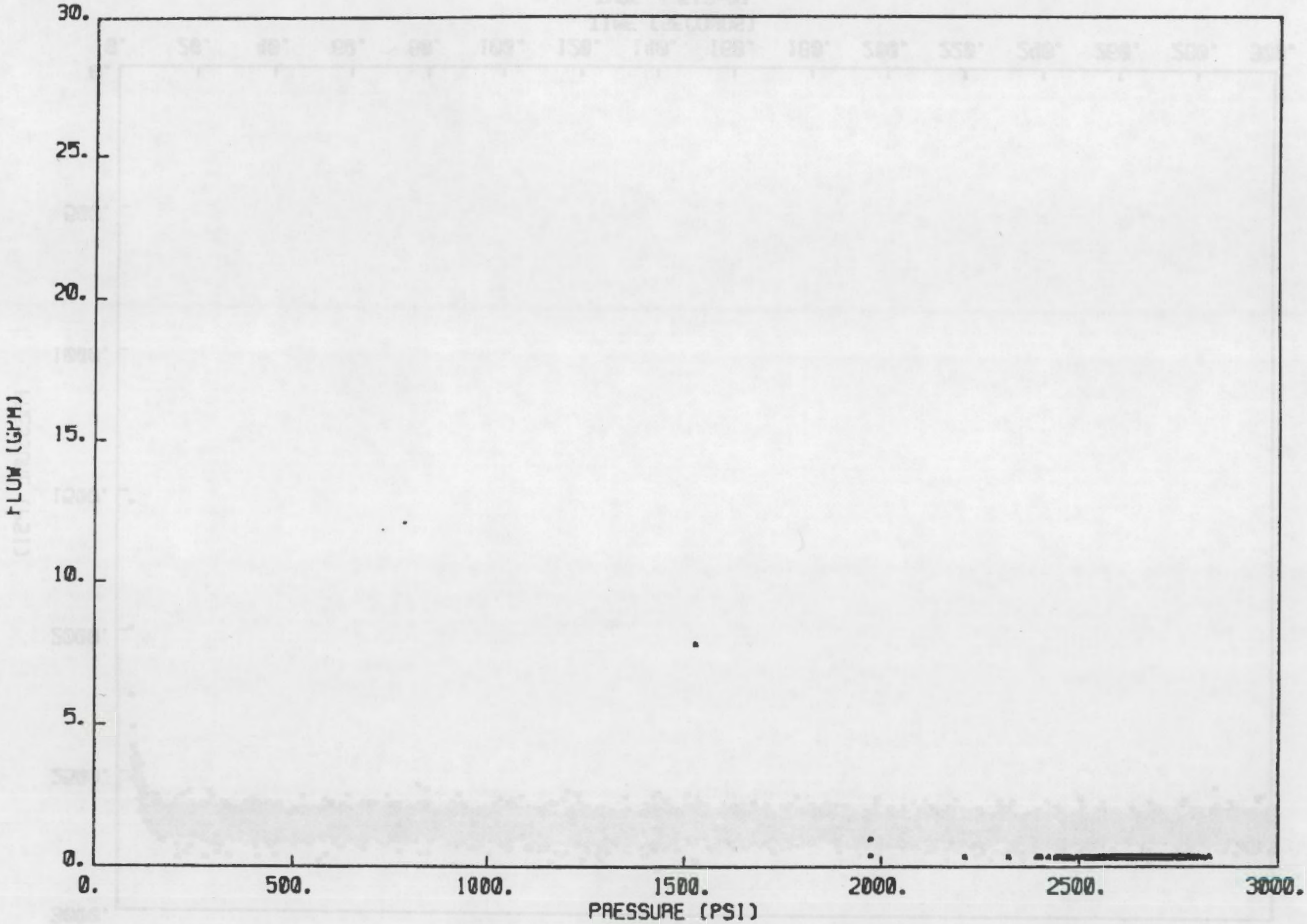

FLOW (GPM)
30.
25.
20.
15.
10.
5.
0.
0.
20.
40.
60.
80.
100.
120.
140.
160.
180.
200.
220.
240.
260.
280.
300.
TIME (SECONDS)
TUBE / E13-01

FIGURE 14



TUBE - E13-1

FIGURE 16

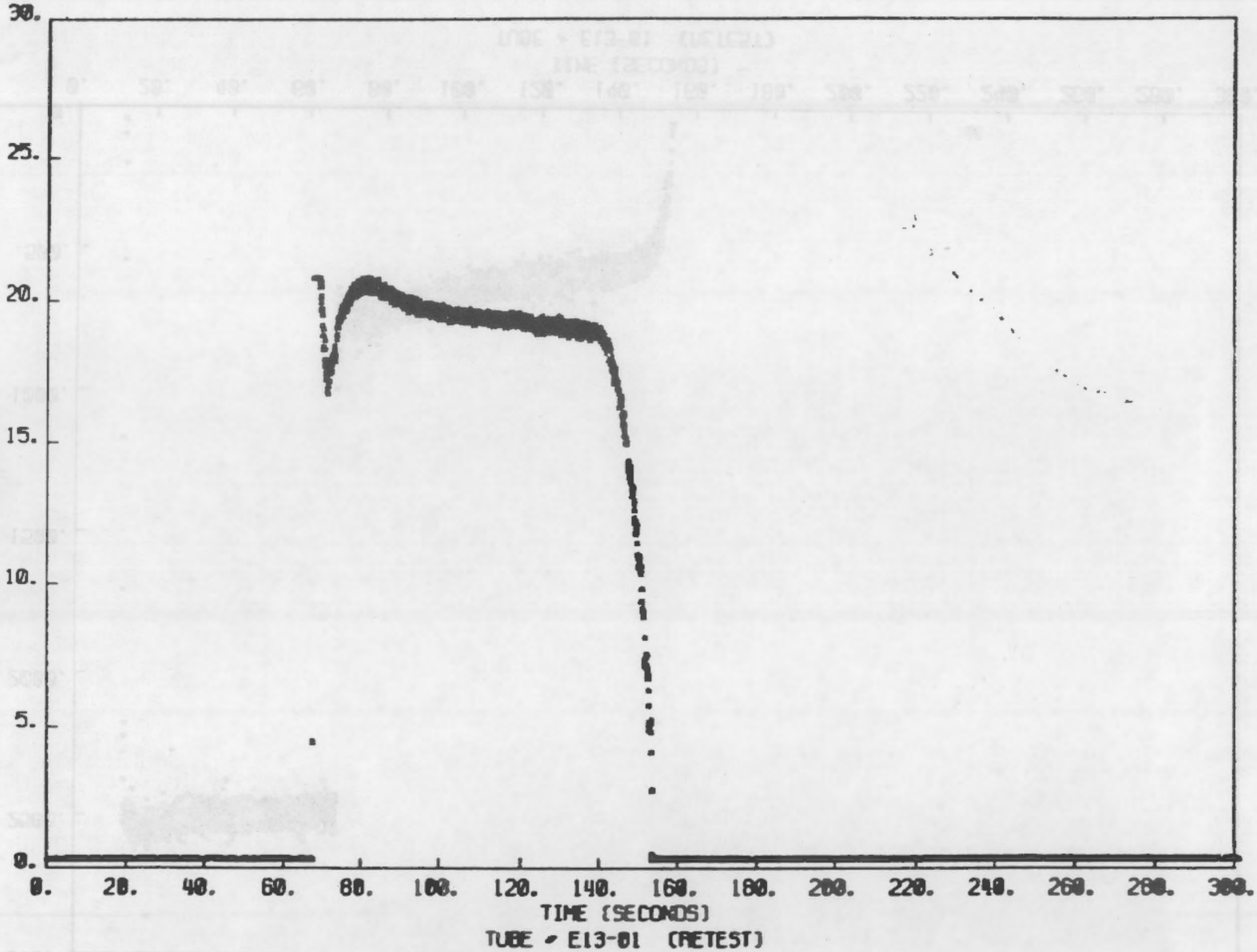

30.
25.
20.
15.
10.
5.
0.
FLOW (GPM)
0.
20.
40.
60.
80.
100.
120.
140.
160.
180.
200.
220.
240.
260.
280.
300.
TIME (SECONDS)
TUBE - E13-01 (RETEST)

FIGURE 17

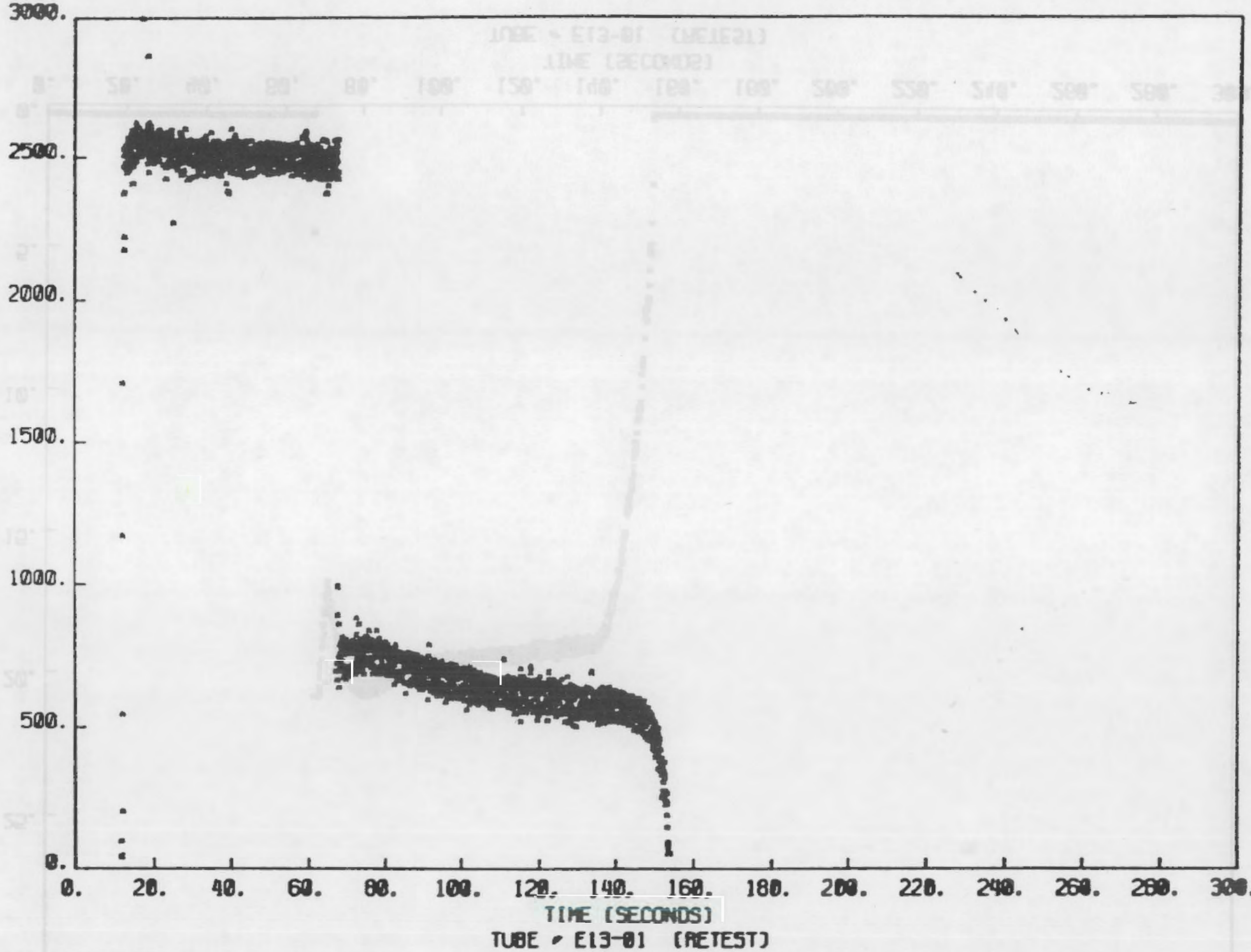
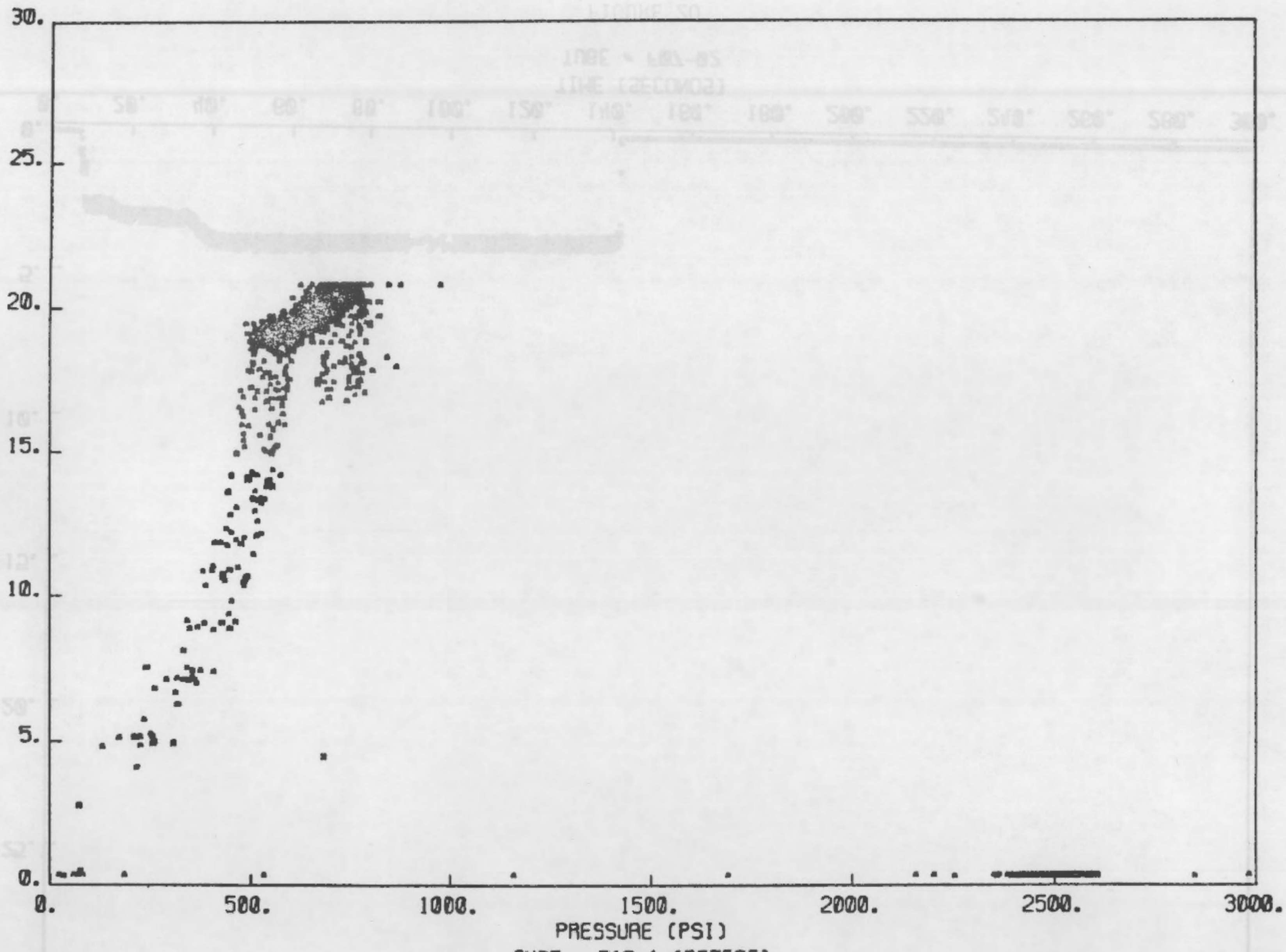

3000.
2500.
2000.
1500.
1000.
500.
0.
PRESSURE (PSI)
0.
20.
40.
60.
80.
100.
120.
140.
160.
180.
200.
220.
240.
260.
280.
300.
TIME (SECONDS)
TUBE # E13-01 (RETEST)

FIGURE 18



TUBE # E13-1 (RETEST)

FIGURE 19

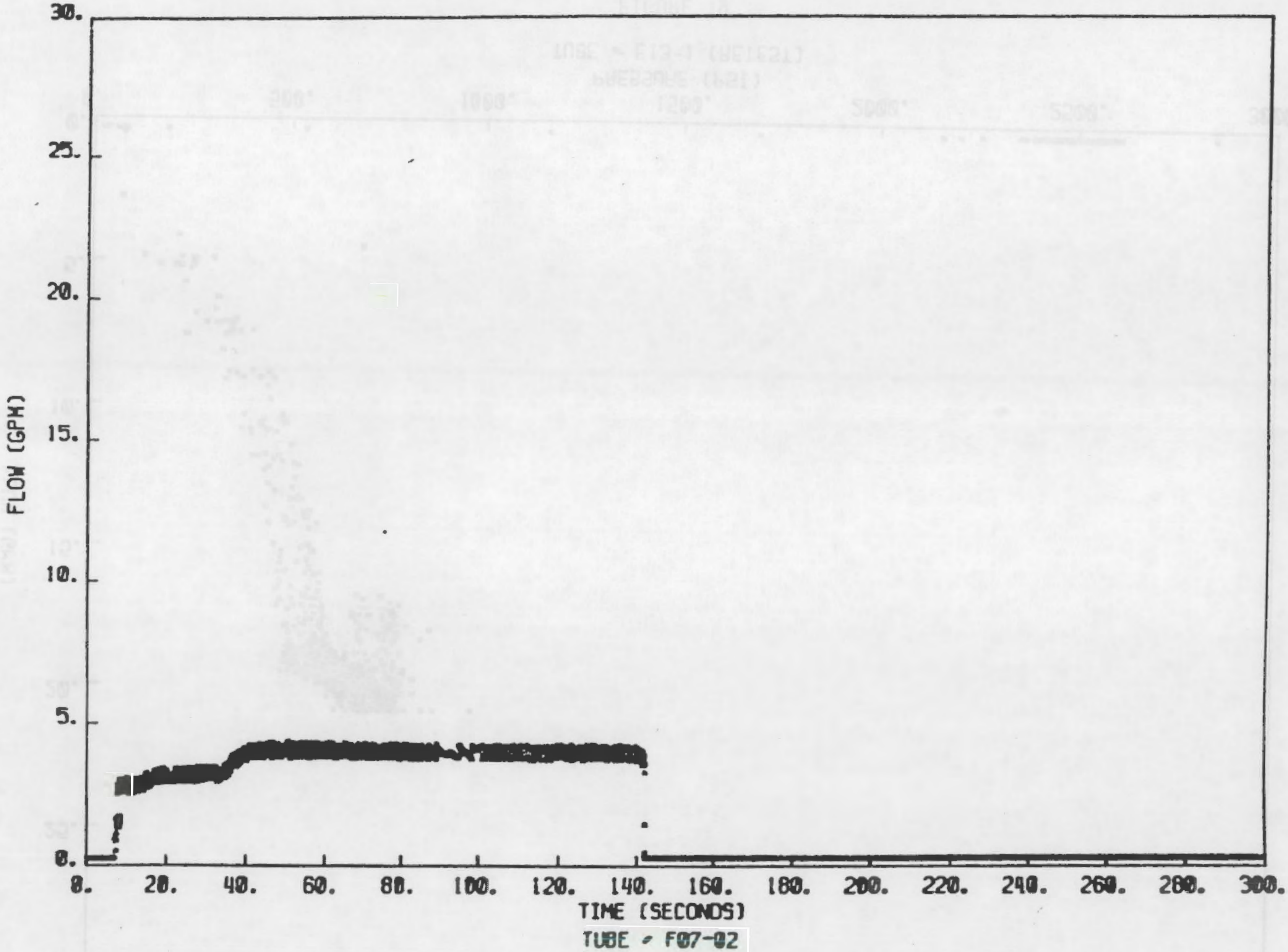

FLOW (GPM)
30.
25.
20.
15.
10.
5.
0.
0.
20.
40.
60.
80.
100.
120.
140.
160.
180.
200.
220.
240.
260.
280.
300.
TIME (SECONDS)
TUBE - F07-02

FIGURE 20

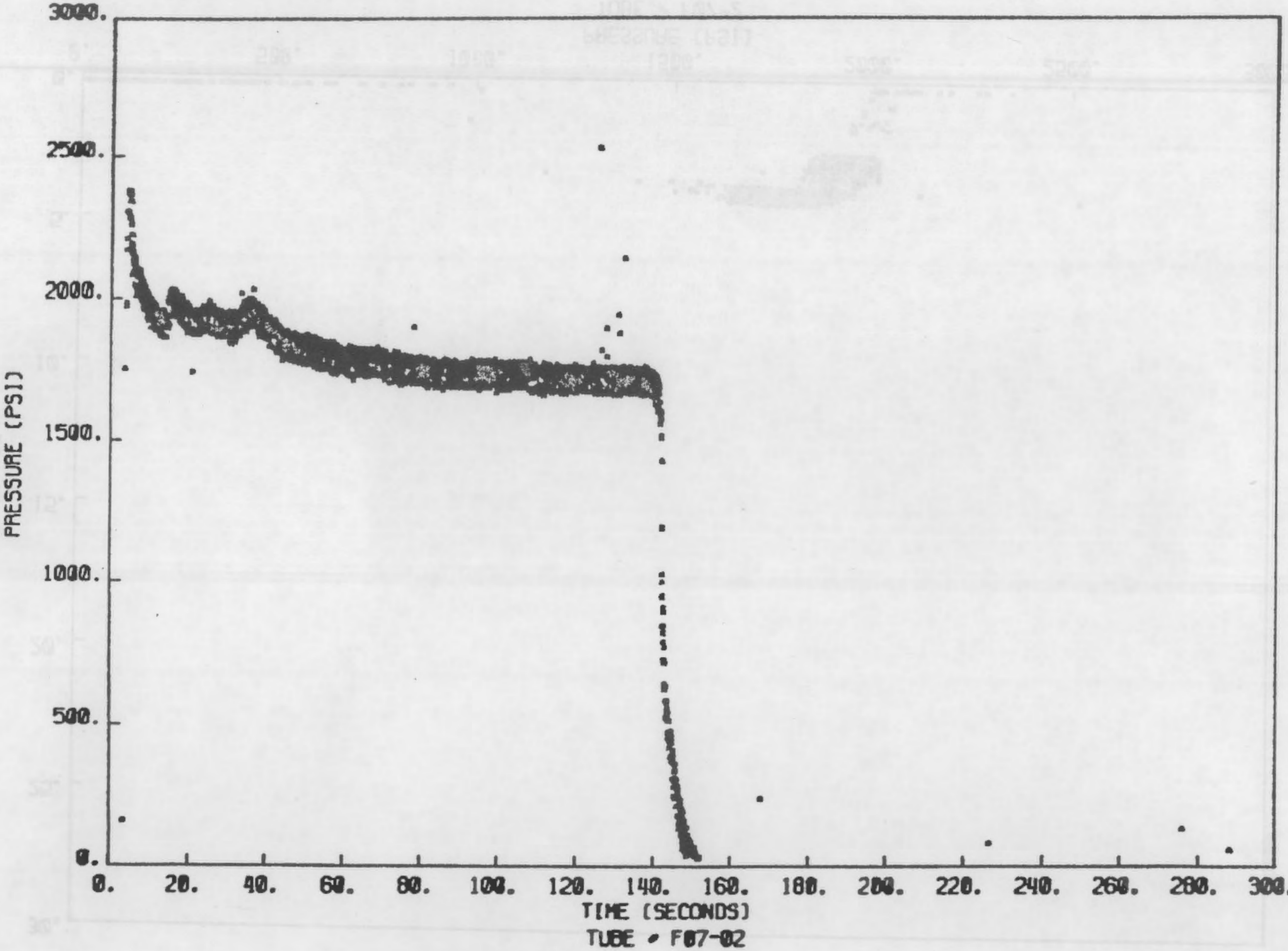
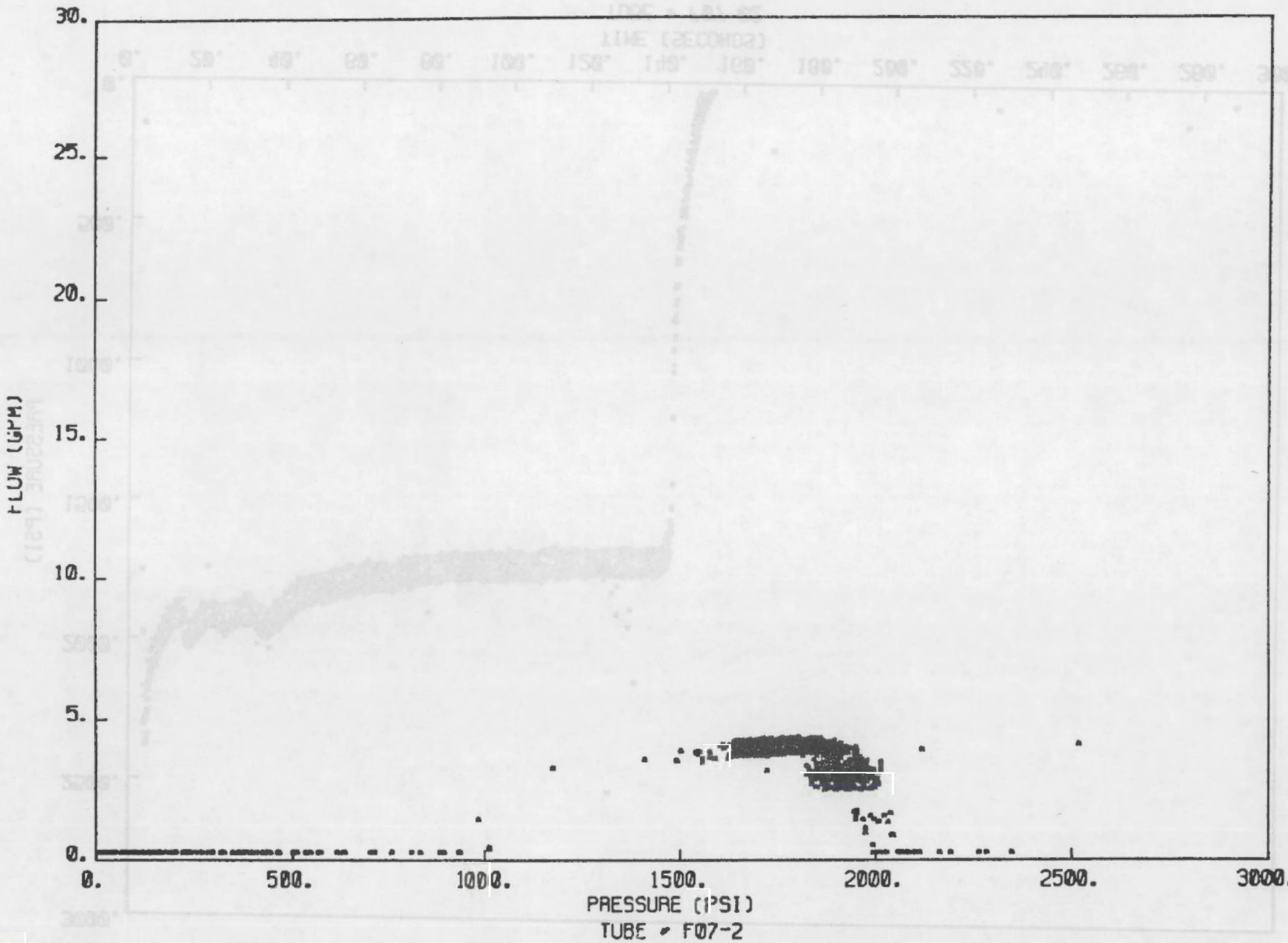

3000.
2500.
2000.
1500.
1000.
500.
0.
PRESSURE (PSI)
0.
20.
40.
60.
80.
100.
120.
140.
160.
180.
200.
220.
240.
260.
280.
300.
TIME (SECONDS)
TUBE • F07-02

FIGURE 21



30.
25.
20.
15.
10.
5.
0.
FLOW (GPM)
0.
500.
1000.
1500.
2000.
2500.
3000.
PRESSURE (PSI)
TUBE # F07-2

FIGURE 22

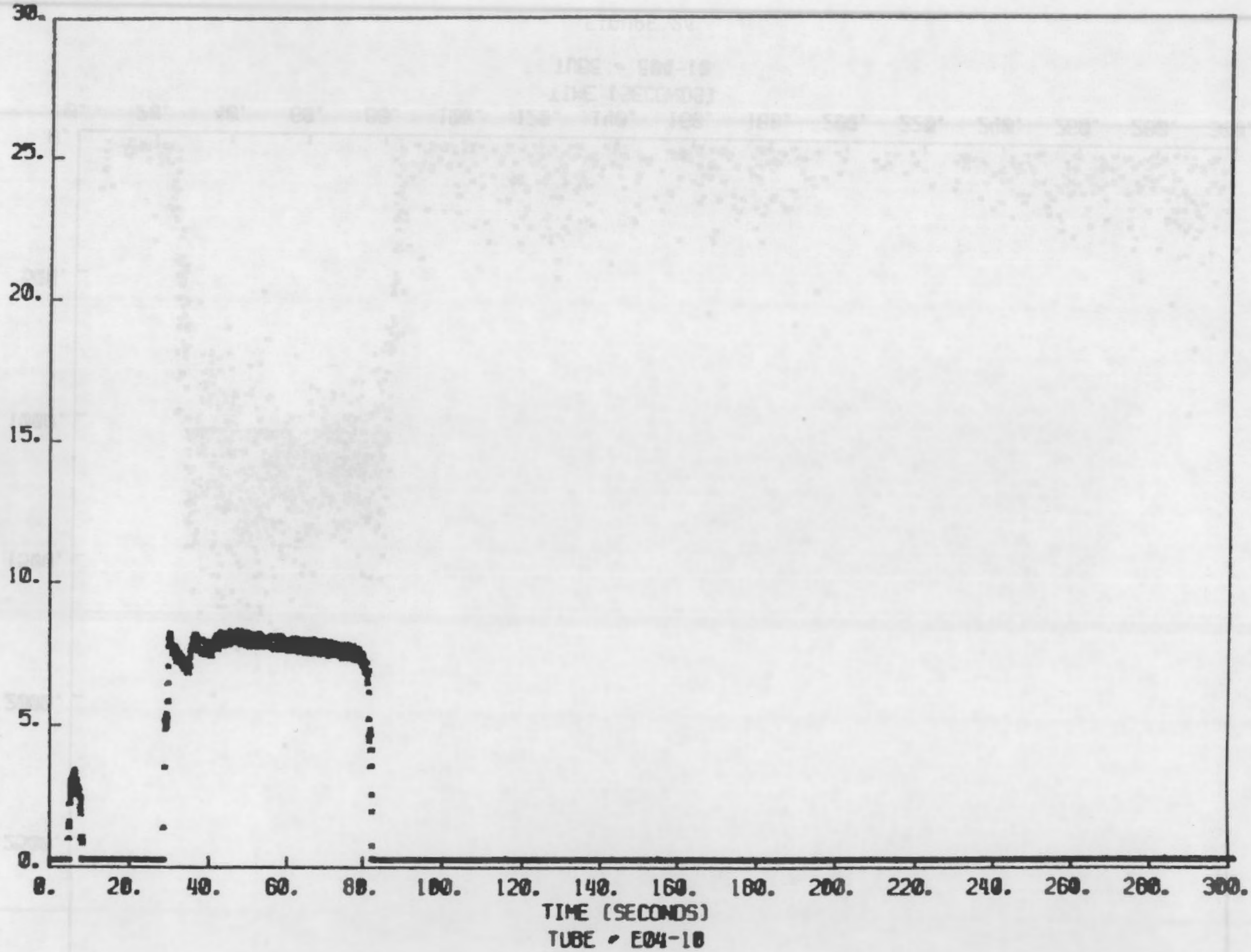
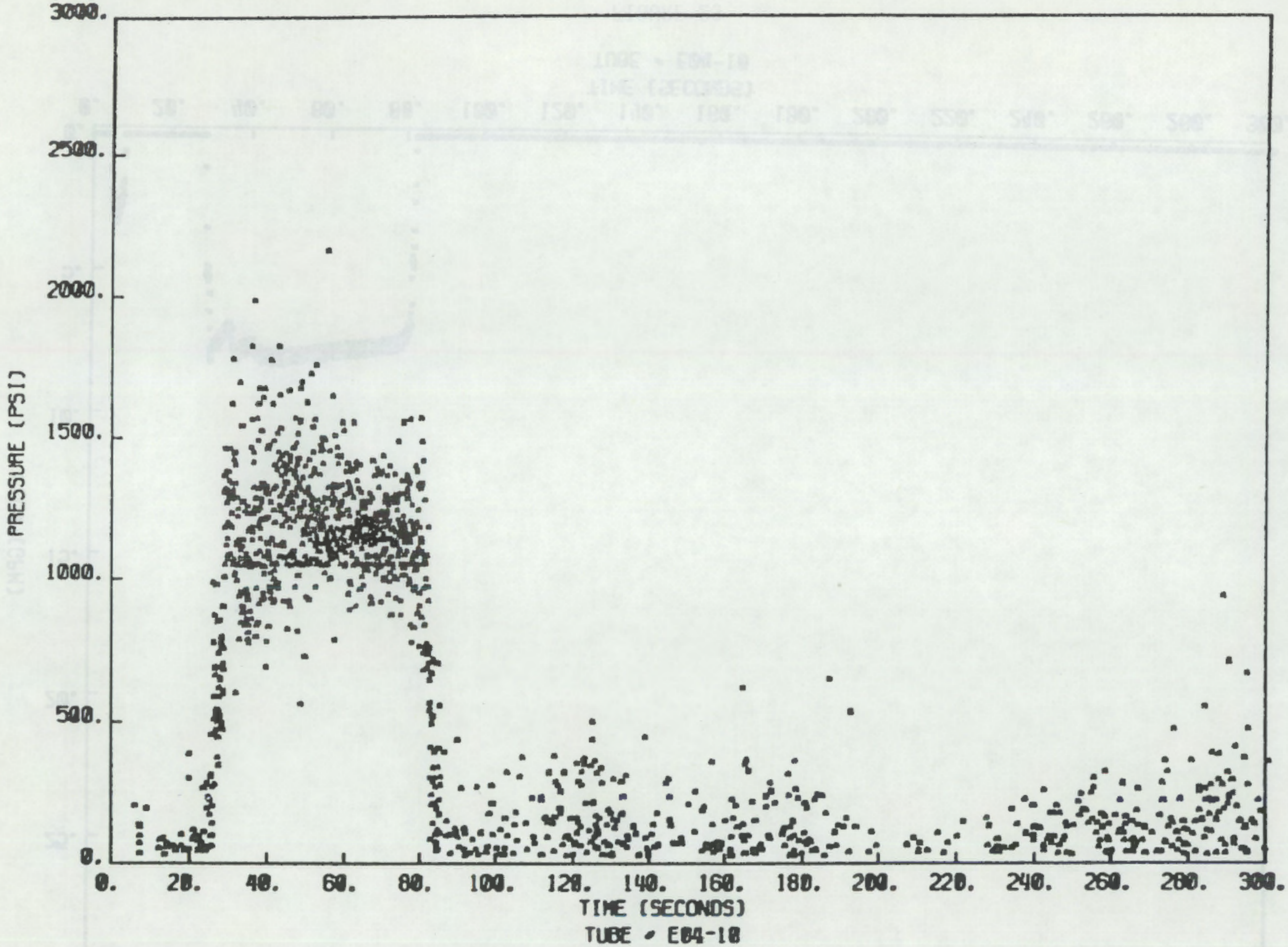

30.
25.
20.
15.
10.
5.
0.
FLOW (GPM)
0.
20.
40.
60.
80.
100.
120.
140.
160.
180.
200.
220.
240.
260.
280.
300.
TIME (SECONDS)
TUBE - E04-10

FIGURE 23



3000.
2500.
2000.
1500.
1000.
500.
0.
PRESSURE (PSI)
0.
20.
40.
60.
80.
100.
120.
140.
160.
180.
200.
220.
240.
260.
280.
300.
TIME (SECONDS)
TUBE # E04-10

FIGURE 24

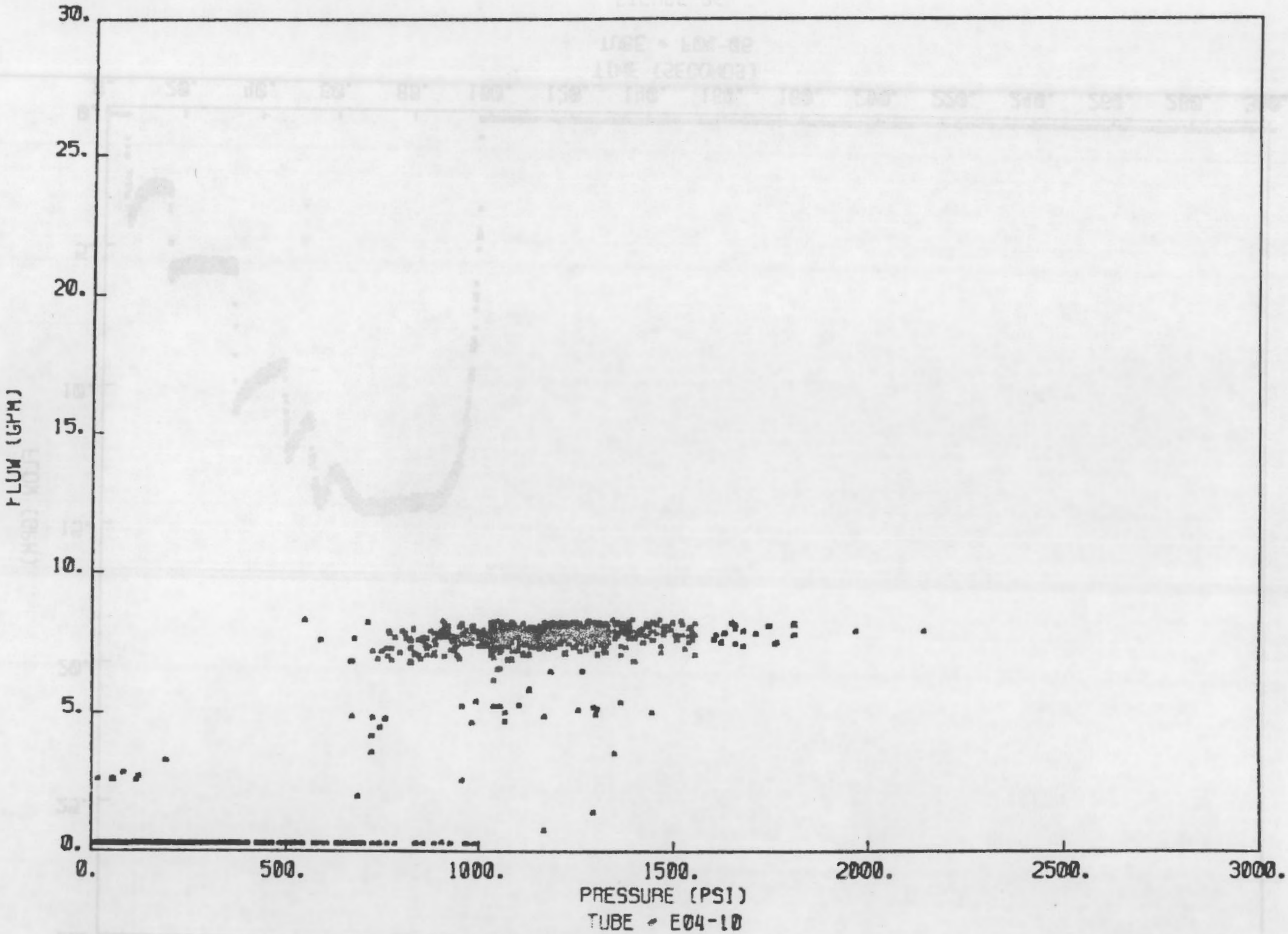

30.
25.
20.
15.
10.
5.
0.
FLOW (GPM)
0.
500.
1000.
1500.
2000.
2500.
3000.
PRESSURE (PSI)
TUBE - E04-10

FIGURE 25

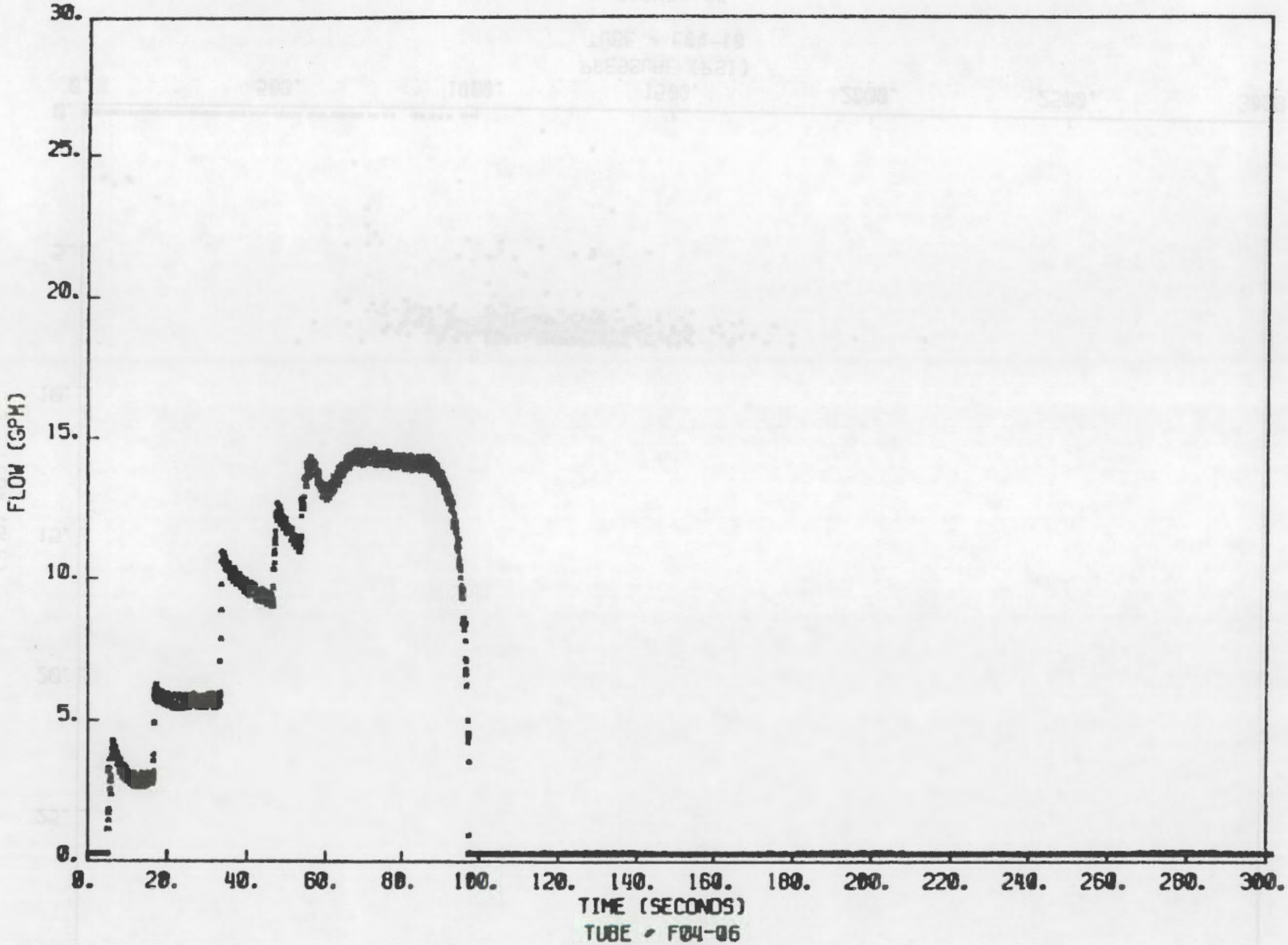

30.
25.
20.
15.
10.
5.
0.
FLOW (GPM)
0.
20.
40.
60.
80.
100.
120.
140.
160.
180.
200.
220.
240.
260.
280.
300.
TIME (SECONDS)
TUBE ⋆ F04-06

FIGURE 26

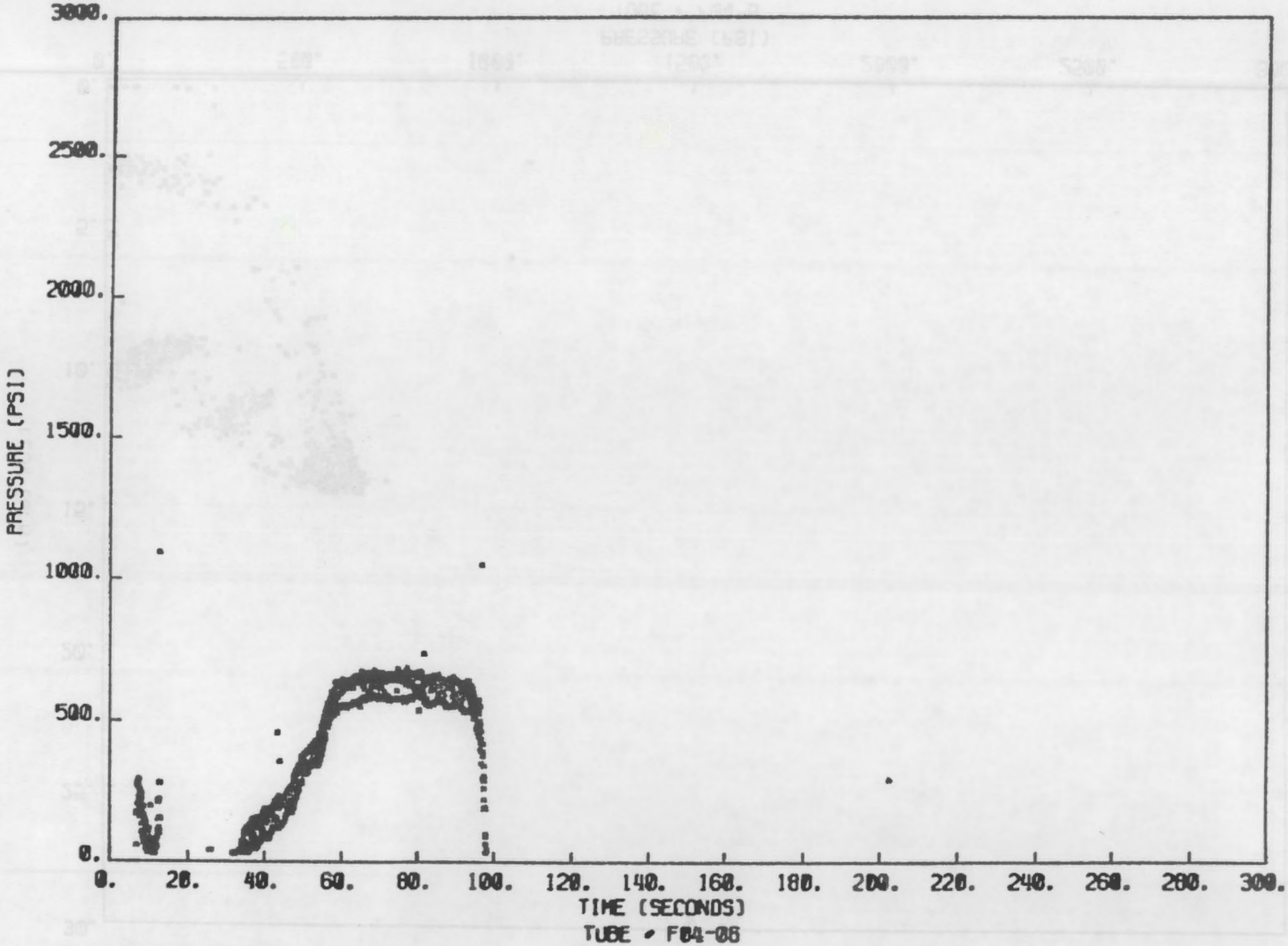

3000.
2500.
2000.
1500.
1000.
500.
0.
PRESSURE (PSI)
0.
20.
40.
60.
80.
100.
120.
140.
160.
180.
200.
220.
240.
260.
280.
300.
TIME (SECONDS)
TUBE • F04-06

FIGURE 27

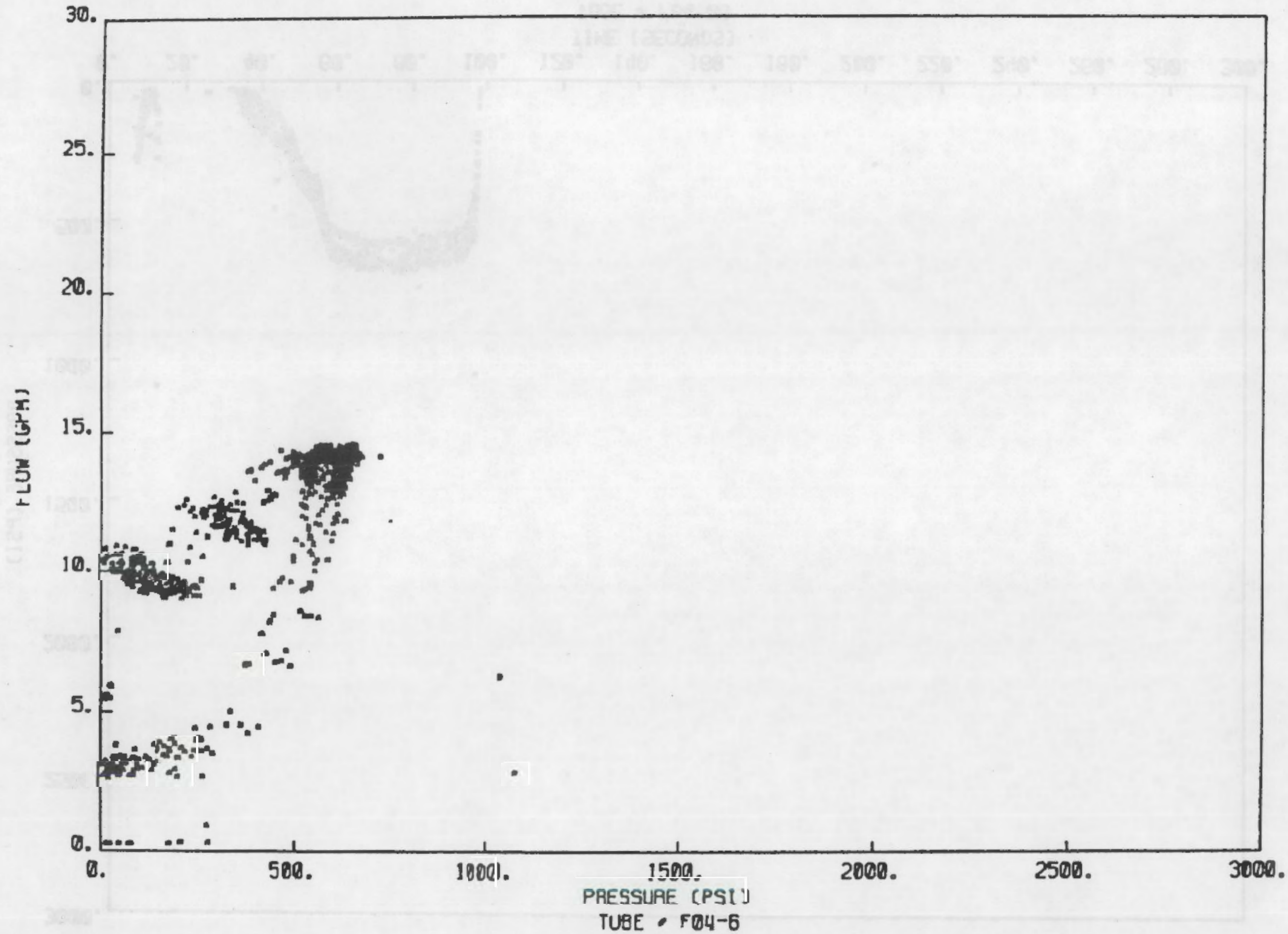

30.
25.
20.
15.
10.
5.
0.
FLOW (GPM)
0.
500.
1000.
1500.
2000.
2500.
3000.
PRESSURE (PSI)
TUBE # F04-6

FIGURE 28

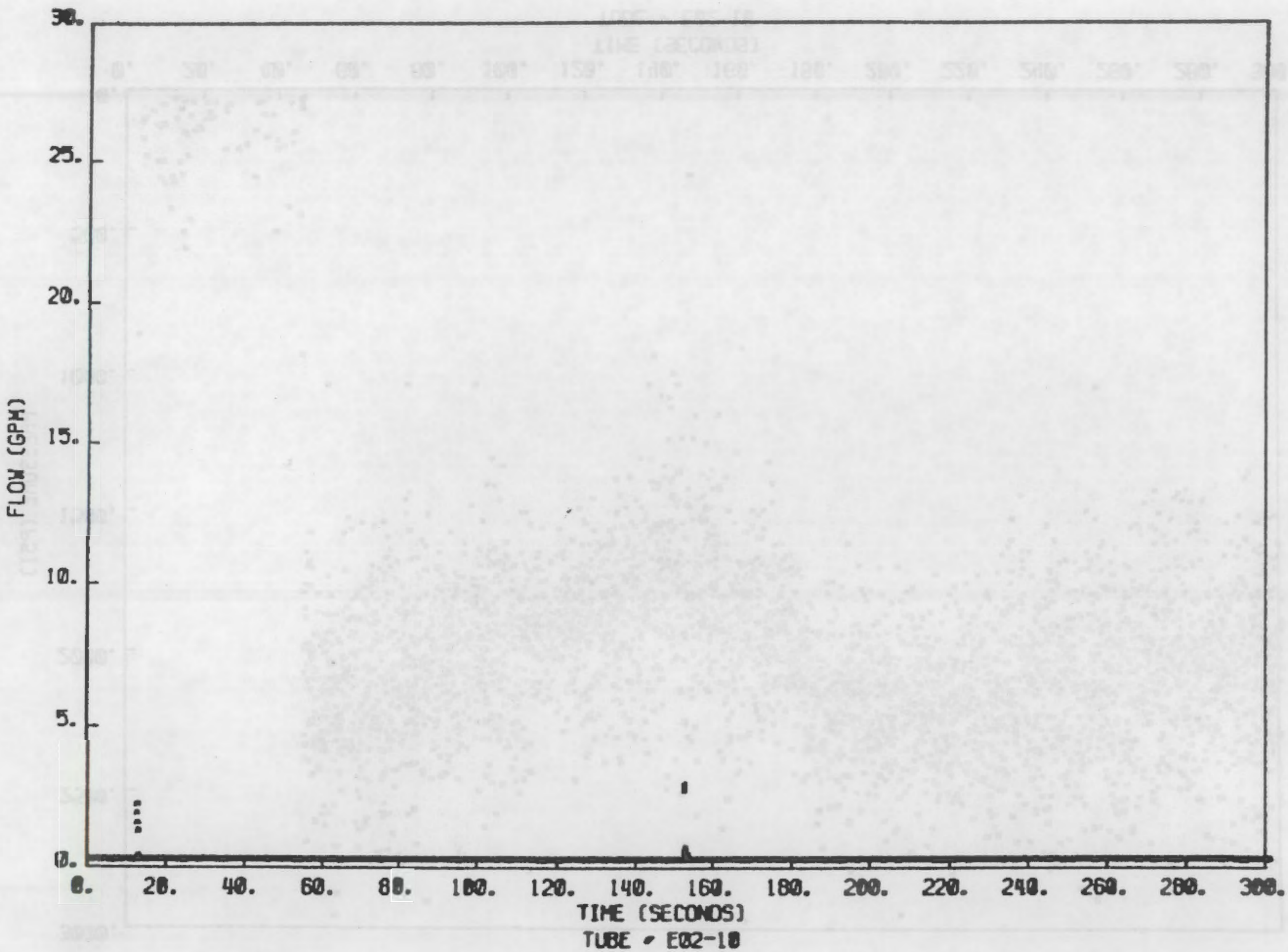

30.
25.
20.
15.
10.
5.
0.
FLOW (GPM)
0.
20.
40.
60.
80.
100.
120.
140.
160.
180.
200.
220.
240.
260.
280.
300.
TIME (SECONDS)
TUBE # E02-10

FIGURE 29

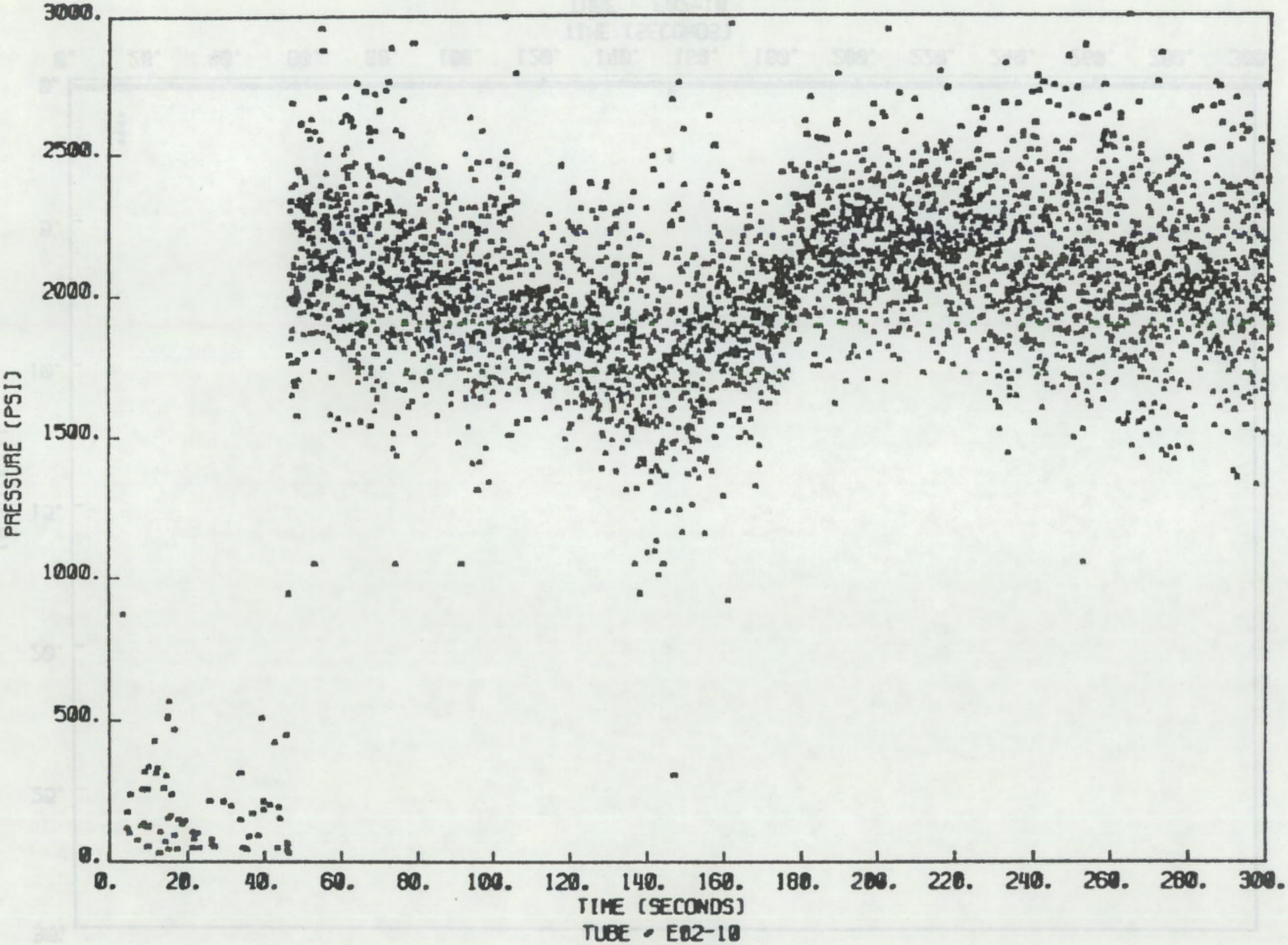

3000.
2500.
2000.
1500.
1000.
500.
0.
PRESSURE (PSI)
0.
20.
40.
60.
80.
100.
120.
140.
160.
180.
200.
220.
240.
260.
280.
300.
TIME (SECONDS)
TUBE # E02-10

FIGURE 30

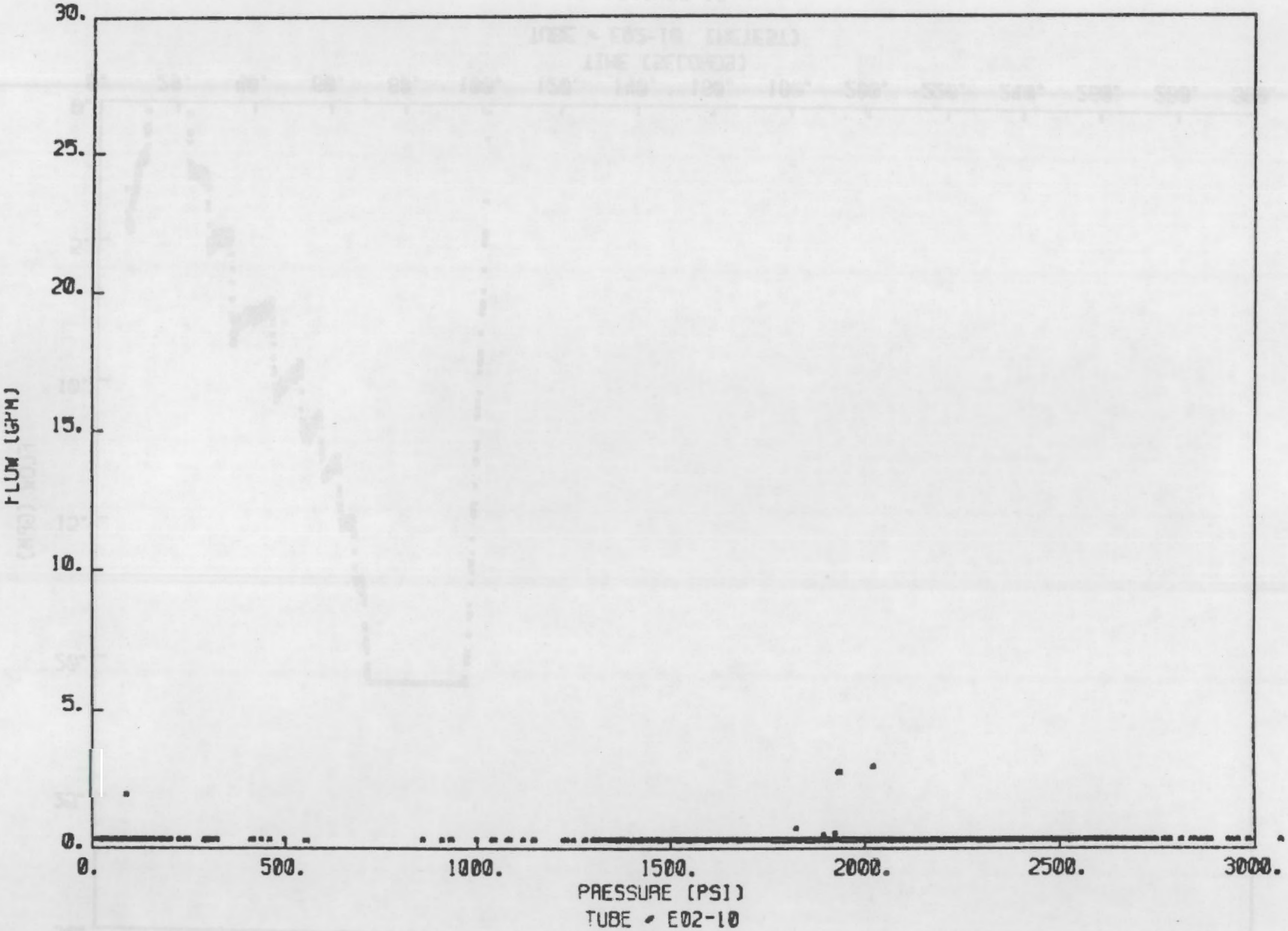
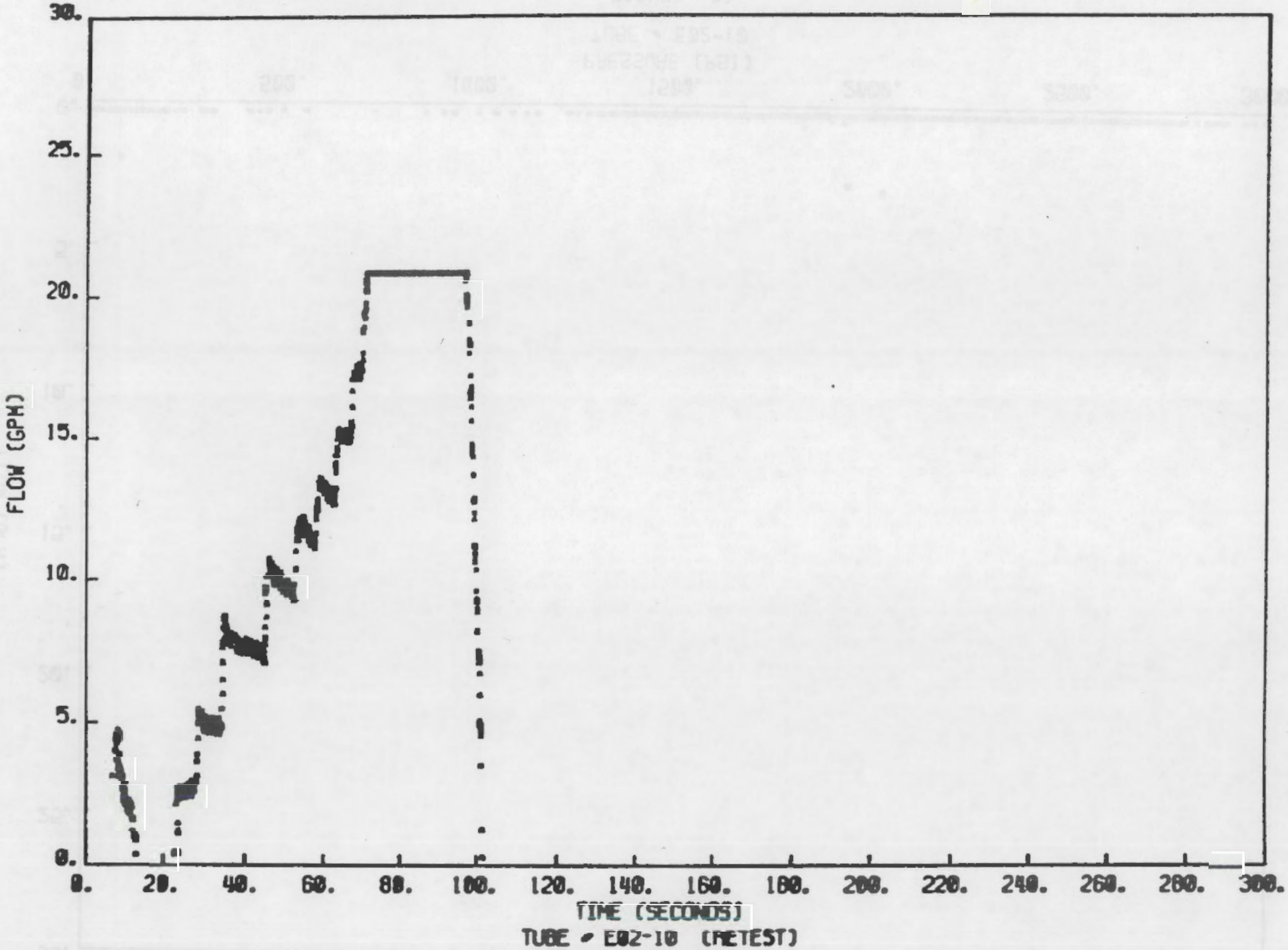

30.
25.
20.
15.
10.
5.
0.
FLOW (GPM)
0.
500.
1000.
1500.
2000.
2500.
3000.
PRESSURE (PSI)
TUBE • E02-10

FIGURE 31



30.
25.
20.
15.
10.
5.
0.
FLOW (GPM)
0.
20.
40.
60.
80.
100.
120.
140.
160.
180.
200.
220.
240.
260.
280.
300.
TIME (SECONDS)
TUBE # E02-10 (RETEST)

FIGURE 32

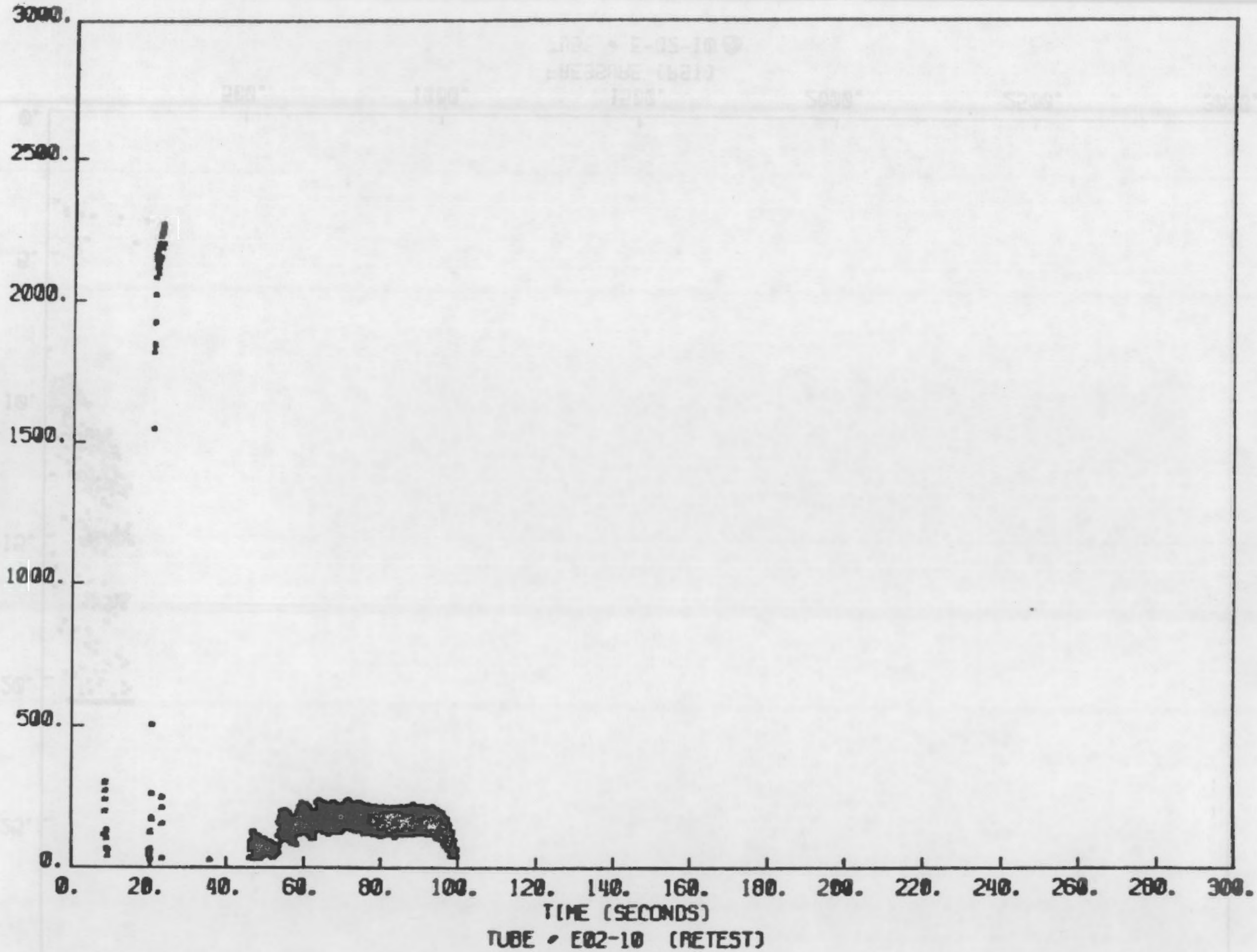
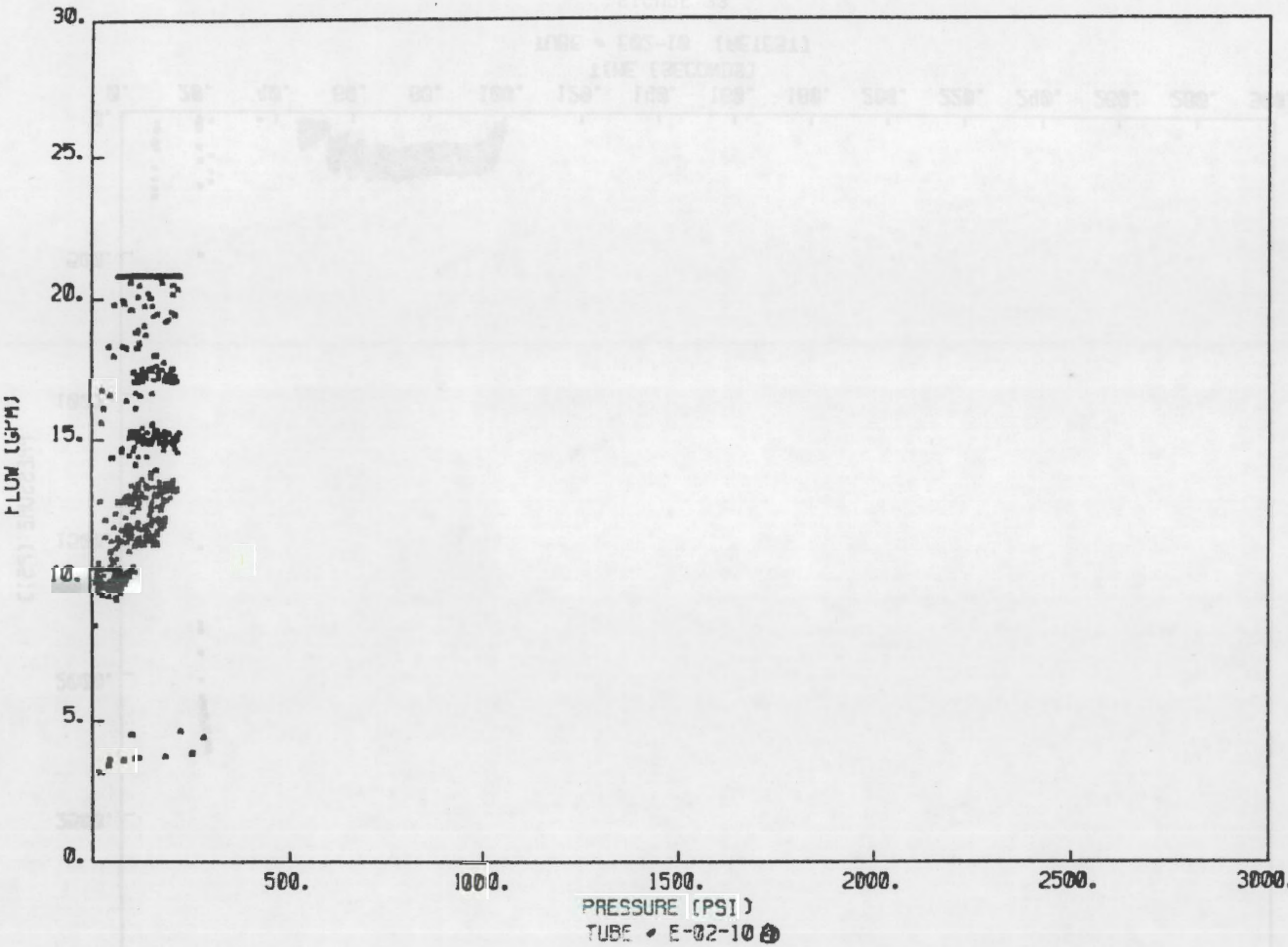

3000.
2500.
2000.
1500.
1000.
500.
0.
PRESSURE (PSI)
0.
20.
40.
60.
80.
100.
120.
140.
160.
180.
200.
220.
240.
260.
280.
300.
TIME (SECONDS)
TUBE # E02-10 (RETEST)

FIGURE 33



30.
25.
20.
15.
10.
5.
0.
FLOW (GPM)
500.
1000.
1500.
2000.
2500.
3000.
PRESSURE (PSI)
TUBE # E-02-10

FIGURE 34

FIGURE 35. After Test Photograph of Specimen E01-3

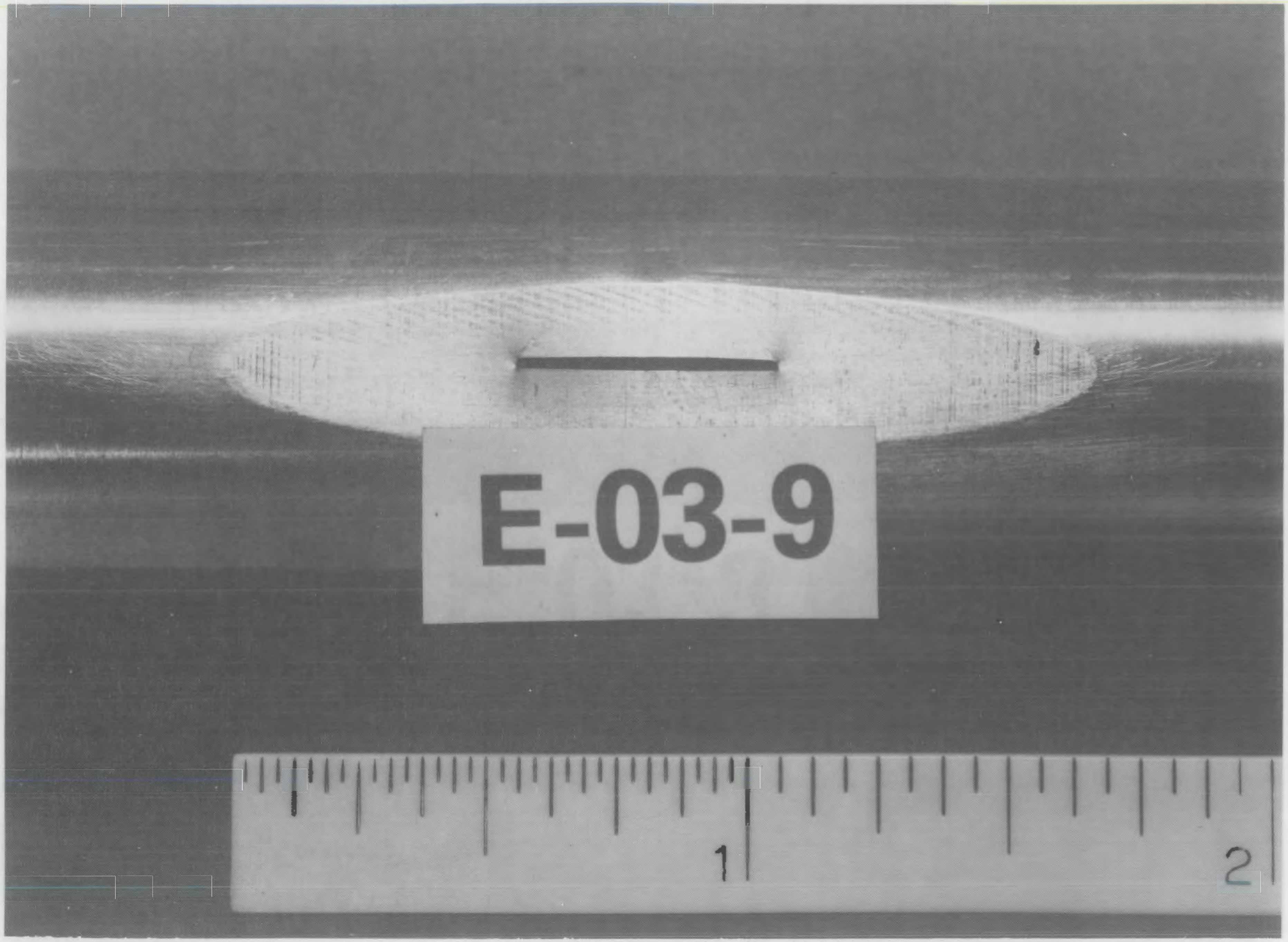


FIGURE 36. After Test Photograph of Specimen E03-9

FIGURE 37. After Test Photograph of Specimen E13-1

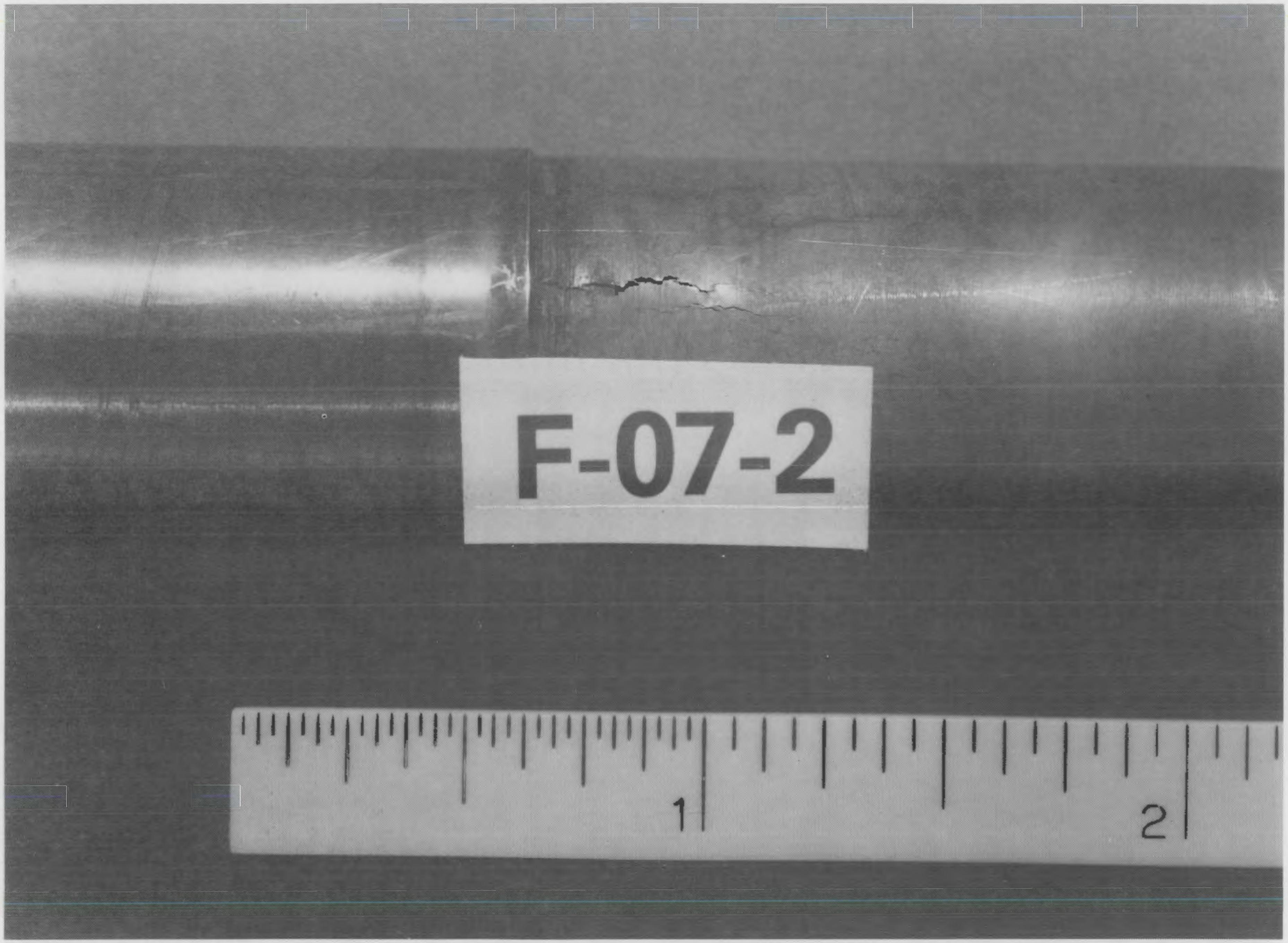


FIGURE 38. After Test Photograph of Specimen F-07-2

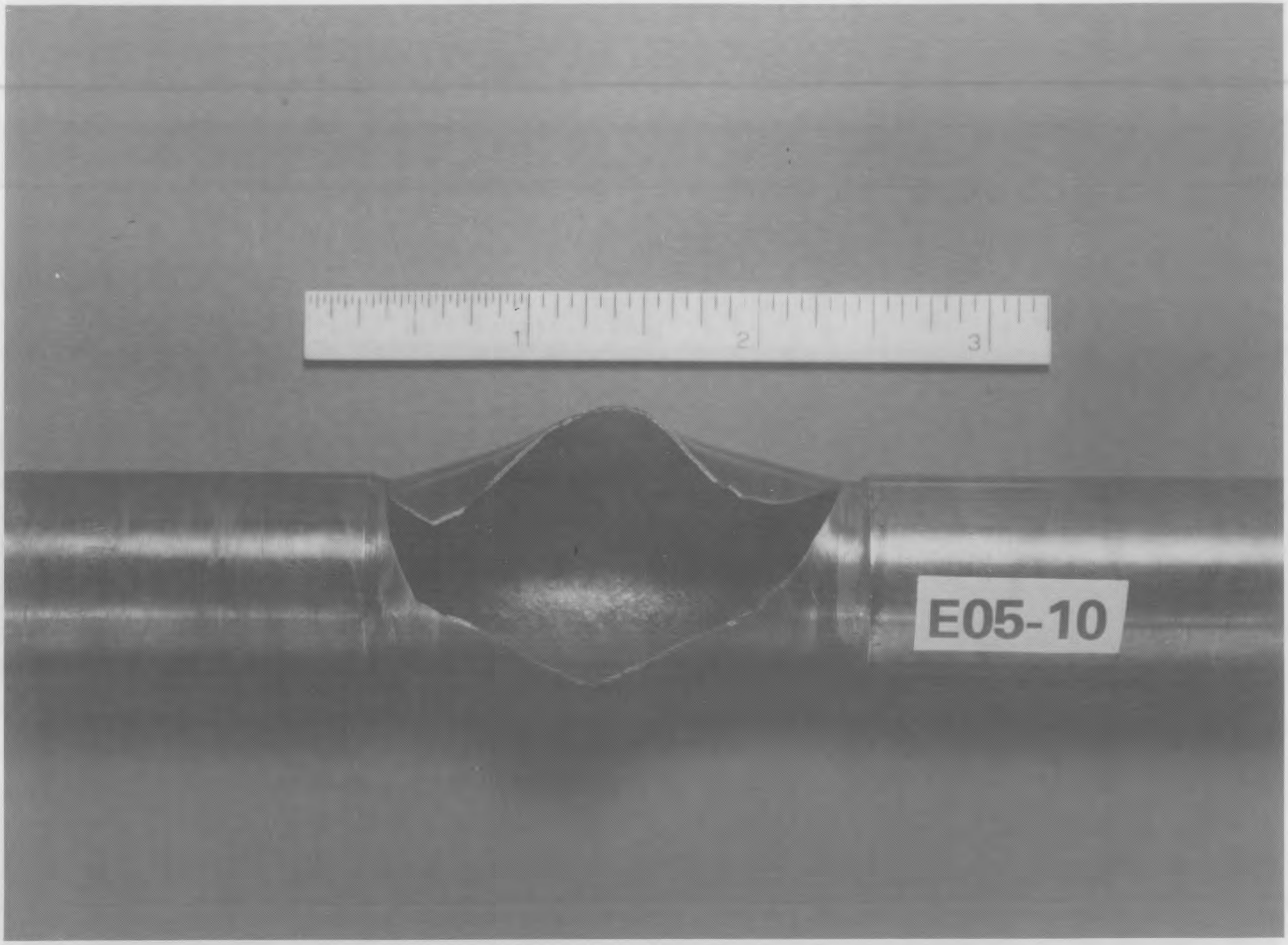


FIGURE 39. After Test Photograph of Specimen E05-10

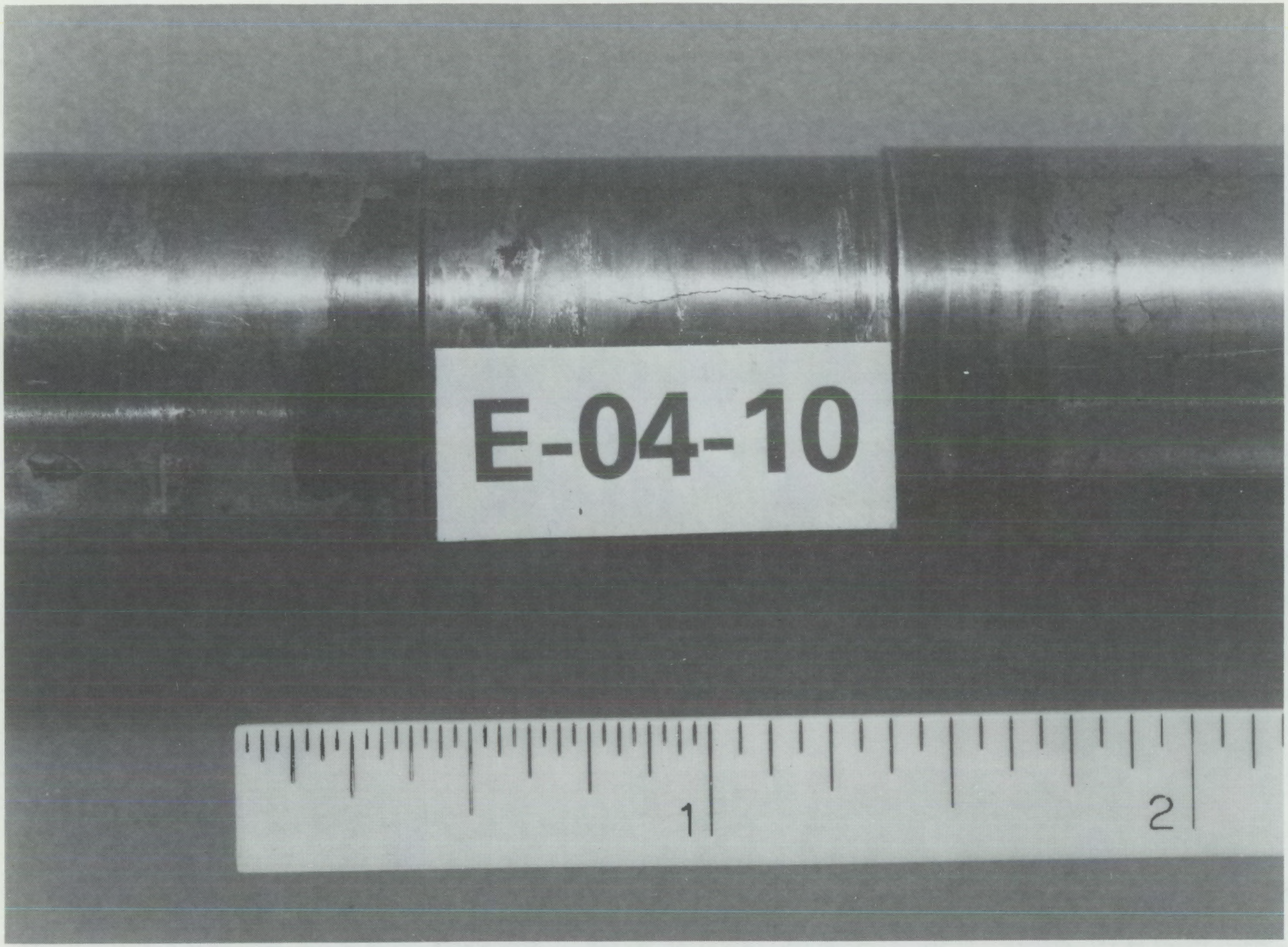


FIGURE 40. Before Test Photograph of Specimen E-04-10

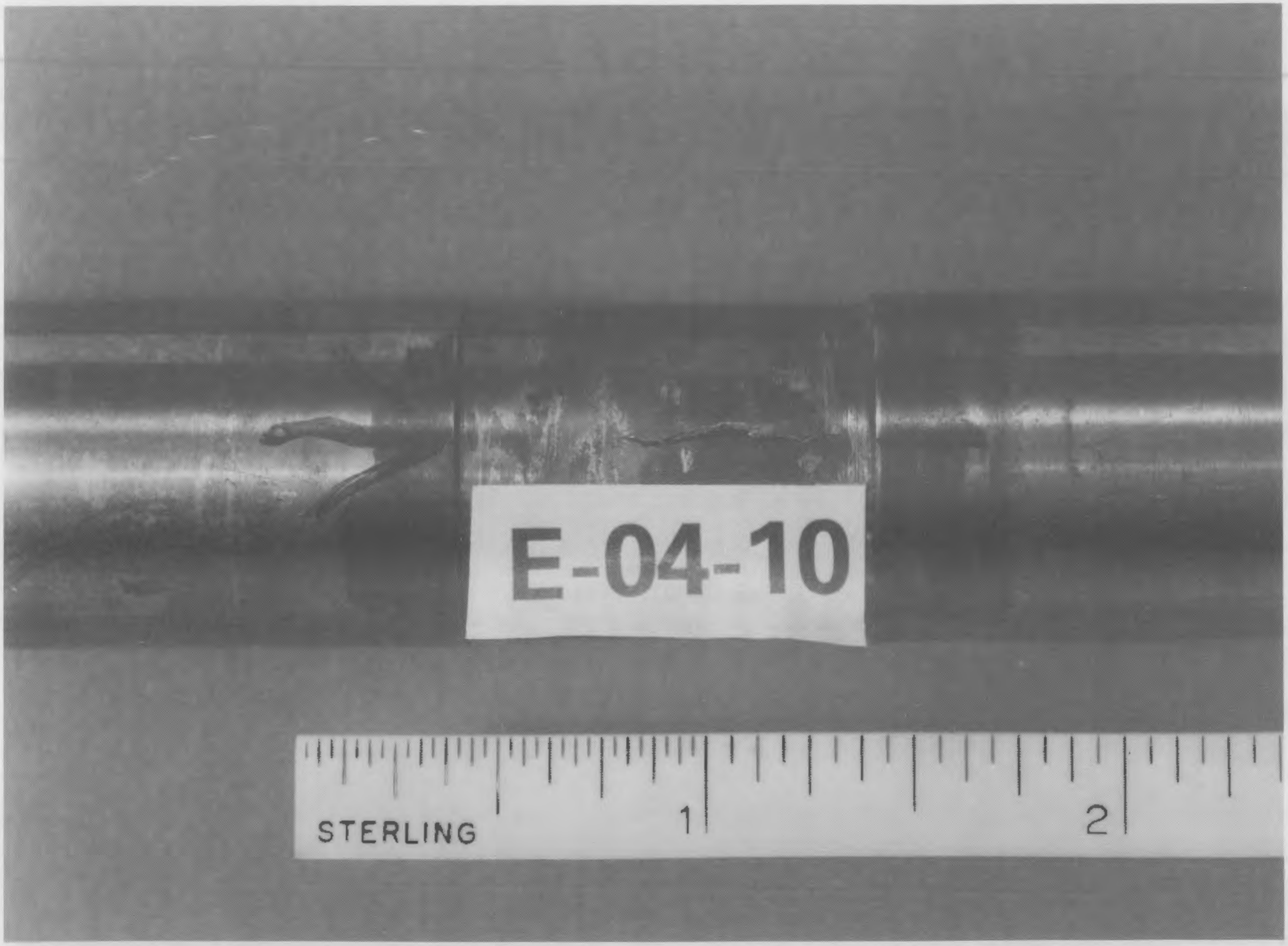


FIGURE 41. After Test Photograph of Specimen E04-10

FIGURE 42. Before Test Photograph of Specimen F04-10

FIGURE 43. After Test Photograph of Specimen F04-10

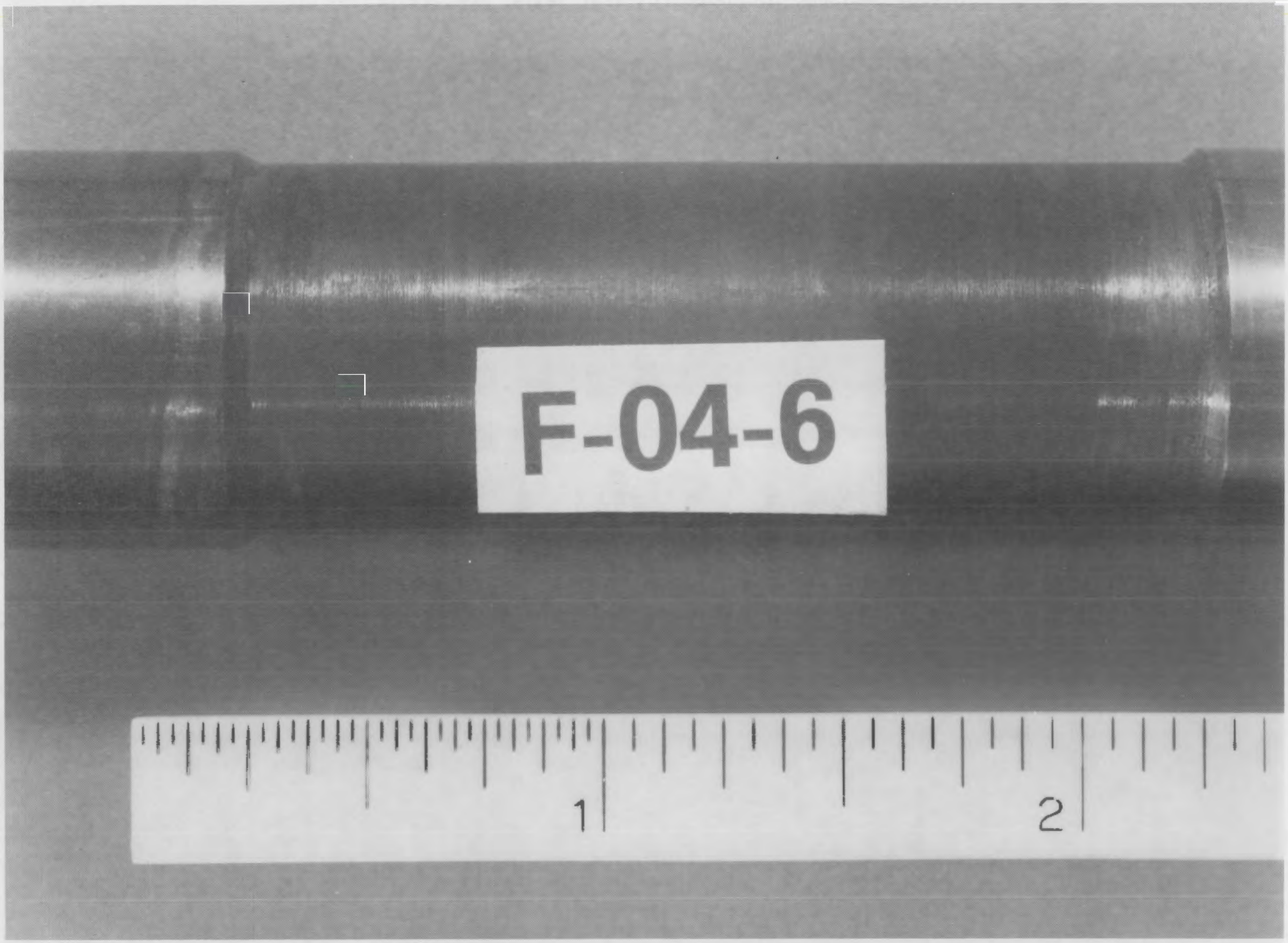


FIGURE 44. Before Test Photograph of Speciemen F04-6

FIGURE 45. After Test Photograph of Specimen F04-6

FIGURE 46. Before Test Photograph of Specimen E02-10

FIGURE 47. After Test Photograph of Specimen E02-10

DISTRIBUTION

No. of Copies

OFFSITE

U.S. Nuclear Regulatory Commission
Division of Technical Information & Document Control
7920 Norfolk Avenue
Bethesda, MD 20014

Dr. Joseph Muscara
Materials Engineering Branch
Division of Engineering Technology
Nuclear Regulatory Commission
M/S 1130 SS
Washington, DC 20555

Dr. B. D. Liaw
Materials Engineering Branch
Division of Engineering Technology
Nuclear Regulatory Commission
M/S 1130 SS
Washington, DC 20555

Dr. C. McCracken
Nuclear Regulatory Commission
M/S P-302
Phillips Bldg.
Washington, DC 20555

3 Mr. J. A. Mundis
Electric Power Research Institute
3412 Hillview Avenue
P.O. Box 10412
Palo Alto, CA 94303

5 Mr. H. S. McKay
Virginia Electric Power Co.
The Electric Bldg.
P.O. Box 564
Richmond, VA 23204

No. of Copies

Foreign

3 Dr. J. L. Campan
Department Manager
Water Reactor Service
C.E.A./Caderache B.P.N. 01
13115 Saint-Paul-Lez-Durance
FRANCE

3 Mr. M. Oishi, Manager
Steam Generator Project NUPEC
No. 2 Akiyama Bldg., 6-2, 3-Chome
Toranomon, Minatoku, Tokyo 105
JAPAN

4 Dr. R. De Santis
R&D Manager
Ansaldo DBGV
Viale Sarca 336
Milano, ITALY 20126

ONSITE

50 Pacific Northwest Laboratory

R. A. Clark (43)
Publishing Coordination (2)
Technical Information (5)

NRC FORM 335 (11-81)

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER (Assigned by DDC)
NUREG/CR-3562
PNL-4629

4. TITLE AND SUBTITLE (Add Volume No., if appropriate)
Steam Generator Tube Integrity Program
Leak Rate Tests - Progress Report

2. (Leave blank)

3. RECIPIENT'S ACCESSION NO.

7. AUTHOR(S)
R. A. Clark R. L. Bickford

5. DATE REPORT COMPLETED
MONTH: March | YEAR: 1983

9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Pacific Northwest Laboratory
P.O. Box 999
Richland, WA 99352

DATE REPORT ISSUED
MONTH: January | YEAR: 1984

6. (Leave blank)

8. (Leave blank)

12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Division of Engineering Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

10. PROJECT/TASK/WORK UNIT NO.

11. FIN NO.
B2097

13. TYPE OF REPORT
Topical

PERIOD COVERED (Inclusive dates)
1981-1982

15. SUPPLEMENTARY NOTES

14. (Leave blank)

16. ABSTRACT (200 words or less)
This interim report presents preliminary results on leak rate tests performed on through-wall defected Inconel 600 steam generator tubing. Tube defects included an EDM (electro-discharge machine) notch and IGSCC (intergranular stress corrosion cracks) of various lengths. Tests were conducted at PWR operating temperatures with leakage of hot water/steam into air. A number of IGSCC cracks were unstable under the experiment conditions of these initial tests, continuing to grow until system capacity limitations resulted in decreased pressure differential. However, initial testing also pointed to a need for reconfiguration of the test apparatus to sustain increased flow and, more importantly, alter the mode of control. The initial test configuration is based on flow control, with pressure differential across the specimen an independent variable. This often results in pressure increases too rapid to establish the initiation of crack instability. A reconfigured system based on pressure control with flow as an independent parameter is being recommended for future tests.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

Steam Generators
Inconel 600 tubing
Leak Rate

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT
Unlimited

19. SECURITY CLASS (This report)
Unclassified

21. NO. OF PAGES

20. SECURITY CLASS (This page)
Unclassified

22. PRICE
$