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Water Spray Suppression of Fully-Developed Wood Crib Fires in a Compartment

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U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Fire Research
Gaithersburg, MD 20899

June 1988

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U.S. DEPARTMENT OF COMMERCE, C. William Verity, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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Wood Crib Fires in a Compartment

James Milke, David Evans, Warren Hayes, Jr.*

Abstract

A series of five experiments examining the effects of a simulated fire fighting water spray introduced into a fully-developed compartment fire were conducted for the Federal Emergency Management Agency by the Center for Fire Research at the National Bureau of Standards per Interagency Agreement (EMW-E-1239) Task Order 4A. Data from these tests were intended to be used as a check of predicted results from the Mission Research Corporation Fire Demand Model. The results illustrate the dynamics of compartment fire suppression using water sprays.

1.0 Introduction

A series of five experiments examining the effects of a simulated fire fighting water spray introduced into a fully-developed compartment fire were conducted for the Federal Emergency Management Agency by the Center for Fire Research at the National Bureau of Standards per Interagency Agreement (EMW-E-1239 Task Order 4A). Data from these tests were intended to be used as a check of predicted results from the Mission Research Corporation Fire Demand Model.[1] The results illustrate the dynamics of compartment fire suppression using water sprays. This report is reproduced in two parts. Part 1 contains a description of the experiments and summary of results including graphical presentations of data. This report contains a description of the experiments and summary of results including graphical presentations of data.

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[1] Pietrzak, L.M., Johnson, G.A., and J. Ball, "A Physically Based Fire Suppression Computer Simulation for Post-Flashover Compartment Fires", Mission Research Corporation, Santa Barbara, CA, June 1984.

* Retired

2.0 Experimental Parameters

The experimental parameters can be grouped into three categories: compartment, fuel, and water spray application. In these tests only the water spray drop size and flow rate were varied. The compartment geometry, wood crib fuel array, ignition method, and conditions to start water spray extinguishment were not varied. A full list of test parameters is provided in Table 1.

Total water spray flow rate and median volumetric droplet diameter were varied by choice of nozzle and operating pressure. The water flow rate and median volumetric droplet diameter for tests 2 through 5 are presented in Table 2 (no water was applied in Test 1). In each of the water spray tests, extinguishment was begun one minute after the top thermocouple in the room doorway reached a temperature of 478°C. This temperature in the doorway correlated with the beginning of the nearly steady burning rate of the wood crib in the room. Plan and elevation views of the room are provided in Figures 1 and 2, indicating the location of the cribs, water spray nozzle and measurement equipment.

2.1 Compartment Parameters

The compartment had inside dimensions of 2.44 m x 3.66 m x 2.44 m (height) with one ventilation opening (i.e. a doorway) measuring 0.44 m by 1.51 m (height). The wall, ceiling and floor were lined with a 0.019 m layer of

Marinite I.* The Marinite panels were simply laid over a concrete slab floor. For the ceiling, the Marinite panels were attached to steel channels with a nominal 2 inch layer of Kaowool* insulation placed above the channels. For the walls, the Marinite panels were placed on steel channels attached to a concrete masonry block wall. This produced an air gap 0.0365 m wide between the marinite and concrete. The compartment doorway size was chosen to produce an air regulated, fully-developed compartment fire, when the wood crib fuel was burned.

2.2 Fuel Parameters

The fuel consisted of 7 clear white pine cribs, 10 layers in height and 3 sticks per layer. The crib was designed to have the free burning rate fuel-surface controlled and the fire duration of sufficient length to provide a long period for extinguishment studies unaffected by fuel depletion.

2.3 Water Spray Parameters

Several sizes of Bete* spiral, 60°, full cone nozzles were operated at selected pressures and were used to provide a particular flow rate and

*Certain commercial equipment, instruments, or materials are identified in this paper in order to adequately specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

medium volumetric droplet diameter for the spray. Flow rates and drop sizes were chosen to provide a range of extinguishment results. The water spray nozzle was located in the plane of the doorway, approximately 0.3 m from the floor, pointed in an upward direction at an angle of 15° above the horizontal axis. The water spray nozzle was rotated in a somewhat elliptic pattern (major axis (horizontal) 0.27 m, minor axis (vertical) 0.12 m) at a frequency of one cycle per second in a counter clockwise direction in an attempt to represent the action of firefighters.

A Bete Droplet Analysis System* was used to obtain droplet size distributions for the water spray nozzles. The Bete Droplet Analysis System consists of a strobe, camera and computer, as illustrated in Figure 3. The strobe and camera are positioned to obtain the droplet size distribution at a desired position within the water spray cone. Since the droplet size distribution is known to be a function of position in the cone, measurements must be taken at numerous positions to obtain a comprehensive representation of the droplet size distribution within the water spray cone. To reduce the number of measurements to be conducted to a reasonable level, the water spray pattern was assumed to be axisymmetric. A distance of 1.52 m was selected as the vertical distance of the nozzle to the analyzer strobe and camera as the droplets appeared to be well dispersed at this distance, and 1.52 m was the distance between the water spray nozzle and the front face of the wood cribs in the fire tests. Thus, measurements of droplet size distribution were only necessary at various radii at the selected height to characterize the spray.

Radial measurements started at the inner edge of the overall spray cone and continued in two inch increments to the observed outer edge of the water spray cone.

The analysis of data by the system is performed in accordance with ASTM E799-81, "Standard Practice for Data Criteria and Processing for Liquid Drop Size Analysis."[2] Using a spatial sampling technique, the system accumulates drop size data from a sufficient number of frames such that the tolerable fractional error (the ratio of the volume of the largest drop in the sample to the cumulative volume of all the drops) is less than a selected value. For the purpose of this project a maximum tolerable fractional error of 0.05 was selected. The number of frames necessary to reduce this error to at least this value was observed to vary for each nozzle and radial position. The sampling time, which is proportional to number of frames exposed, was maintained constant for all radial positions measured in a single nozzle spray. This is a necessary condition so that separate radial measurements can be combined to obtain an overall average for the nozzle. The sampling time for each nozzle was selected such that an adequate number of frames were included to obtain a tolerable fractional error of less than 0.05 at all radial positions.

The smallest droplet recorded in the measurements had a diameter of 31.4 microns or 2 pixels on the monitor which displays in focus a measurement volume of 4 mm by 5 mm by 32 mm depth. Droplets on the border of the

---

[2] American Society for Testing and Materials, "Standard Practice for Data Criteria and Processing for Liquid Drop Size Analysis", E 799, ASTM, 1981.

measurement field were excluded. Only droplets within the measurement volume (in focus) were counted. The manufacturer's data reduction program parameter slope was set at 4.0 and 6.0 for 1 pixel and 50 pixel droplets, respectively. The two slopes are used to increase the ability of the system to view both large and small droplets as being "in focus."

The cumulative distributions of water droplet diameters for the selected radial sample positions obtained for each of the spray nozzles are presented in Tables 3-6. Histograms of the cumulative distributions for each nozzle are presented in Figures 4-11.

3.0 Instrumentation

The instrumentation was designed to characterize the thermophysical aspects of the compartment fire. The number of temperature probes was selected for the experiments to ensure adequate characterization of the temperature distributions of the compartment gases and interior surfaces. Two oxygen probes were installed in the room, one in the upper and one in the lower portion of the room to measure oxygen vitiation in the room. A pressure probe was installed 0.61 m above the floor to help determine gas flow rates in and out of the room. Finally, mass loss of the cribs was monitored by a load cell.

A detailed description of the test instrumentation is presented in Table 7 in terms of the physical parameter being measured and the symbol and abbreviations used for each on diagrams and in test data listings. Each measurement position is shown in Figures 1 and 2.

4.0 Temperature Measurements

Thermocouples in Figures 1 and 2 are designated by the suffixes 'ST' and 'T'. The 'ST' designation is for the thermocouples used to measure the surface temperature of the compartment walls, ceiling and floor. These thermocouples were installed in a groove in the surface of the wall lining material. So that a portion of the junction bead was flush with the surface a caulking layer no more than 1.0 mm thick was then applied over the thermocouple to secure the thermocouple as well as shield it from radiation effects.

The 'T' designation for the thermocouple sensors refers to the aspirated probes. Aspirated probes were used to obtain a valid measure of the gas temperature, without being influenced by radiation effects. The tube in which the thermocouple was housed was custom designed for these test with two objectives in mind:

a) To provide shielding, and sufficient gas velocity flowing past the thermocouple bead to minimize radiation effects on the gas temperature measurement.

b) To provide shielding and a gas velocity that was insufficient to carry water droplets to the thermocouple bead.

Normally aspirated probes are designed with the thermocouple bead located in a straight, constant internal diameter tube. This type of probe was examined in the laboratory and found to draw water spray into the tube with a tube gas flow velocity of 7 m/s.

The final design of the tip of the aspirated probe is shown in Figure 12. The large diameter at the open end of the probe tip resulted in a low velocity which eliminated the drawing of water spray into the tube, the small diameter around the thermocouple produced the high 7 m/s gas flow velocity necessary to minimize radiation effects. The final tip design included a ceramic tube to anchor the thermocouple beam in the aspirated probe tip. In addition, radiation heating of the aspirated tube tip was reduced by wrapping the tip with reflective aluminum foil prior to each test.

4.1 Weight Loss Measurement

Weight loss of the cribs was measured by a water cooled, insulated load platform. A thermocouple was placed close to the load cell to observe any temperature variation. The weight loss measurement apparatus is shown in Figure 13. The purpose of the design of the apparatus was to avoid weight measurement of water not impinging on the cribs which could accumulate on the load platform. A box was formed of 12.7 mm thick Marinite I panels to shield the load platform with the crib basket frame placed through holes in the box to rest on the load platform.

5.0 Test Procedure

A water flow rate and median volume diameter droplet size for each test was selected, based on discussions with Dr. Larry Pietrzak, to assure the data would be useful for evaluation of the Fire Demand Model.[1] The appropriate nozzle to deliver the desired flow rate and droplet size was installed in an apparatus referred to as the iron firefighter (see Figure 14). This device designed and constructed to rotate the nozzle in an elliptic pattern at a rate of 1.0 cps. to mimic the action of fire fighters and provide a broader distribution of spray in the compartment.

Of the four tests in which water was applied, two tests were performed with "large" droplets and two with "small" water spray droplets, i.e. median volumetric droplet diameters of approximately 0.6 mm and 0.5 mm respectively. In each of the tests with a specific median volumetric droplet diameter, different flow rates were used.

The wood cribs were conditioned at 23°C, 39% RH for at least 48 hours prior to the test until the moisture content stabilized. The weight and moisture content of the cribs used in the five tests are given in Table 8. Immediately prior to the test, the cribs were placed in the burn compartment, on the crib weighing basket. A container with 50 ml of heptane was placed under each crib (but separated from the weight measurement system).

Ignition of the seven cribs was achieved by igniting the heptane in each container. This ignition process was done in less than 1 minute so that ignition of the cribs was almost simultaneous.

In test 1 the cribs were allowed to burn until they were completely consumed, without any water applied. This test was used to examine the fire development in the compartment and to determine the time available for water spray extinguishment studies before the fire would extinguishment naturally. In tests 2-5, water was applied 60 seconds after the gas temperature exiting at the top of the doorway (as measured by the uppermost aspirated thermocouple just outside the doorway, number 20 in Figure 2) achieved 478°C. This criterion identified a specific point in the fire development, in test 1 in which no water was applied, at 8 minutes after ignition when the crib weight loss rate history reached a steady value sustained for nearly 5 minutes until fuel depletion caused the weight loss rate to decrease. This criterion used to start extinguishment should be independent of the ignition process. Water was applied in each of the four tests until all water was emptied from the 340ℓ (90 gallon) storage tank.

Data was collected for each measurement device approximately every four seconds. In addition, video tape records of each test were made.

6.0 Test Results

Each measurement device is identified by a data recording channel number and abbreviation for type of measurement device, as defined in Table 7. Graphs are provided in Figures 15-29 of the pressure, oxygen concentration, mass loss and mass loss rate history for the five tests.

The lower edge of the upper layer was defined for calculating gas temperature averages as the position of the lowest thermocouple among 27 through 41 which measured a Celsius temperature numerically at least twice that of the lowest thermocouple, number 41, see Figure 2. The average temperature in each layer was calculated as a simple numerical average of measured temperatures from those thermocouples 27 through 41 within each layer.

Graphs of the illustrative mean temperature in the upper and lower layers, and interface height are shown in Figures 30-39.

7.0 Summary

A series of five tests were conducted to examine the effect of water spray on a fully-developed compartment fire. One test was conducted without the application of water as a "control", two tests were performed applying a water spray with "small" droplets (0.5 mm median volumetric diameter), and two tests with "large" droplets (0.6 mm median volumetric diameter). For each pair of tests with a particular median drop size, the visual effect of the water spray was most pronounced using the greater water flow rate, and was visually not apparent in the other test with the lesser flow rate.

8.0 Acknowledgements

The authors wish to acknowledge the insight and constructive critique of the experimental plans provided by Jim Quintiere. In addition, the effort of R. Zile, W. Bailey and colleagues in preparing the room, constructing equipment, setting up the instrumentation, and assisting in the conduct of the tests at the NBS fire test facility in Building 205 should be recognized. Special thanks are extended to L. Buffington for characterizing the water spray nozzles and C. Thompson for preparing the typed manuscript.

Table 1. Compartment and Fuel Parameters

COMPARTMENT DESCRIPTION	
Room Height	2.44 m
Floor Area	2.44 m x 3.66 m = 8.93 m^2
Area of Walls and Ceiling	37.72m^2
Door Area	0.67 m^2
Door Height	1.51 m
Wall Material	Marinite I
Wall Thickness	1.9 cm
Wall Properties	
Thermal conductivity	0.12 W/m °K
Specific Heat	1.25 kJ/kg °K
Density	738 kg/m^3
FUEL DESCRIPTION	
Fuel Type	White Pine Wood Crib
Crib Geometry	
Square Stick Thickness	4.0 cm
Stick Length	26.0 cm
Spacing Between Sticks	7.0 cm
Number Sticks per Layer	3
Number of Layers	10
Number of Cribs	7
Fuel Surface Area	7.59 m^2
Fuel Surface Area Exposed to Water	16%
Heat of Combustion	4440 kcal/kg
Fuel Density	370 kg/m^3
WATER APPLICATION DESCRIPTION	
Distance of Nozzle from Vent	0.0 m
Cone Angle of Hose Stream	60°
Sweep time to cover Compartment	2 sec
Volume Median Drop diameter	see Table 2
Flow Rate of Water	see Table 2

Table 2. Water Spray Parameters

Test	Drop Size (mm)	kPa(psi)	ℓ/s	$(\ell/s\text{-}m^2)x10^2$	Manufacturer's Nozzle Code
1	Free Burn (no extinguishment)				
2	0.627	123 (18)	0.46	5.2	TF 16NN
3	0.491	372 (54)	0.44	4.9	TF 12NN
4	0.595	117 (17)	0.35	3.9	TF 14NN
5	0.482	276 (40)	0.26	2.9	TF 10NN

Table 3. Cumulative Distribution of Droplets, Nozzle TF16NN, Test 2

```
COMPOSITE REPORT                          NOZZLE: TF 16 NN
TEST DATE        1/16/85                  TEST METHOD:   PLANE
TESTS INCLUDED:     118   121  122  123  124  125  126
SPRAY DIRECTION           VERTICAL
PRESSURE                  18.0 PSI
CENTERLINE COORDINATE     60.00 INCHES
RADIAL COORDINATE         14.00 -  26.00 INCHES
DISTANCE FROM NOZZLE      61.61 -  65.39 INCHES
AZIMUTHAL ANGLE           13.1 - 23.4  DEG
CYLINDRICAL ANGLE          270  DEG
```

DIAMETER (MICRONS)	DROPS	% OCCURRENCE	% SURFACE AREA	% VOLUME	CUM % VOLUME	CLASS CHECK
25.1 - 31.6	620	13.42	0.12	0.01	0.01	0.000
31.6 - 39.8	374	8.10	0.11	0.01	0.01	0.000
39.8 - 50.1	225	4.87	0.09	0.01	0.02	0.000
50.1 - 63.1	124	2.68	0.08	0.01	0.03	0.000
63.1 - 79.4	142	3.07	0.15	0.02	0.05	0.000
79.4 - 100.0	259	5.61	0.42	0.07	0.12	0.000
100.0 - 125.9	282	6.11	0.74	0.15	0.27	0.000
125.9 - 158.5	317	6.86	1.30	0.33	0.60	0.000
158.5 - 199.5	286	6.19	1.83	0.58	1.17	0.001
199.5 - 251.2	228	4.94	2.33	0.93	2.10	0.001
251.2 - 316.2	219	4.74	3.56	1.79	3.89	0.002
316.2 - 398.1	376	8.14	9.97	6.41	10.31	0.007
398.1 - 501.2	483	10.46	19.72	15.73	26.04	0.018
501.2 - 631.0	400	8.66	25.13	24.88	50.92	0.029
631.0 - 794.3	198	4.29	19.70	24.56	75.48	0.028
794.3 - 1000.0	68	1.47	10.34	15.91	91.39	0.018
1000.0 - 1258.9	17	0.37	4.07	7.85	99.24	0.009
1258.9 - 1584.9	1	0.02	0.34	0.76	100.00	0.001
	4619.	100.00	100.00	100.00	100.00	

AVERAGE DIAMETERS (MICRONS) :

```
ARITHMETIC MEAN =   241.54           MAXIMUM DIAMETER =  1287.00
SURFACE MEAN =      326.62           MINIMUM DIAMETER =     31.40
VOLUME MEAN =       392.22           TOTAL DROPS IN SAMPLE =   4619.
SAUTER MEAN =       565.56           TOTAL OUT OF FOCUS =       560
WEIGHT MEAN =       652.27           TOTAL FRAMES IN SAMPLE =  3543
VOLUME MEDIAN =     627.02           AVE. DROPS PER FRAME =    1.30
SAMPLE SIZE CHECK =  0.01            DEVIATION =  0.0[illegible]

RELATIVE SPAN - (  981.73 -   395.28)/  627.02  =   0.94
```

Table 4. Cumulative Distribution of Droplets, Nozzle TF12NN, Test 3

```
COMPOSITE REPORT                                 NOZZLE: TF 12 NN
TEST DATE       1/16/85                          TEST METHOD:    PLANE
TESTS INCLUDED:      94    95  127   97  128  129  130  131
SPRAY DIRECTION            VERTICAL
PRESSURE                   54.0 PSI
CENTERLINE COORDINATE      60.00 INCHES
RADIAL COORDINATE          16.00 -  30.00 INCHES
DISTANCE FROM NOZZLE       62.09 -  67.08 INCHES
AZIMUTHAL ANGLE            14.9 - 26.5  DEG
CYLINDRICAL ANGLE           270  DEG
```

DIAMETER (MICRONS)	DROPS	% OCCURRENCE	% SURFACE AREA	% VOLUME	CUM % VOLUME	CLASS CHECK
25.1 - 31.6	473	9.13	0.13	0.01	0.01	0.000
31.6 - 39.8	384	7.41	0.15	0.01	0.02	0.000
39.8 - 50.1	410	7.92	0.24	0.03	0.05	0.000
50.1 - 63.1	549	10.60	0.50	0.06	0.11	0.000
63.1 - 79.4	447	8.63	0.62	0.10	0.21	0.000
79.4 - 100.0	445	8.59	0.96	0.19	0.40	0.000
100.0 - 125.9	266	5.14	0.91	0.23	0.62	0.000
125.9 - 158.5	180	3.48	0.98	0.31	0.93	0.000
158.5 - 199.5	129	2.49	1.10	0.43	1.37	0.000
199.5 - 251.2	153	2.95	2.11	1.06	2.42	0.001
251.2 - 316.2	235	4.54	5.23	3.32	5.74	0.004
316.2 - 398.1	452	8.73	15.95	12.76	18.50	0.015
398.1 - 501.2	689	13.30	37.14	36.71	55.21	0.043
501.2 - 631.0	300	5.79	24.92	30.56	85.77	0.035
631.0 - 794.3	62	1.20	8.04	12.32	98.09	0.014
794.3 - 1000.0	5	0.10	1.01	1.91	100.00	0.002
	5179.	100.00	100.00	100.00	100.00	

```
   AVERAGE DIAMETERS  (MICRONS) :

ARITHMETIC MEAN =   190.64           MAXIMUM DIAMETER =    997.62
SURFACE MEAN =      266.69           MINIMUM DIAMETER =     31.40
VOLUME MEAN =       313.41           TOTAL DROPS IN SAMPLE =   5179.
SAUTER MEAN =       453.90           TOTAL OUT OF FOCUS =        234
WEIGHT MEAN =       499.10           TOTAL FRAMES IN SAMPLE =  3775
VOLUME MEDIAN =     490.84           AVE. DROPS PER FRAME =     1.37
SAMPLE SIZE CHECK =  0.00            DEVIATION =  0.60

RELATIVE SPAN = (  685.9[illegible] -   352.71)/  490.84  =   0.68
```

Table 5. Cumulative Distribution of Droplets, Nozzle TF14NN, Test 4

COMPOSITE REPORT NOZZLE: TF 14 NN
TEST DATE 1/16/85 TEST METHOD: PLANE
TESTS INCLUDED: 112 113 114 115 116
SPRAY DIRECTION VERTICAL
PRESSURE 17.0 PSI
CENTERLINE COORDINATE 60.00 INCHES
RADIAL COORDINATE 18.00 - 26.00 INCHES
DISTANCE FROM NOZZLE 62.64 - 65.39 INCHES
AZIMUTHAL ANGLE 16.6 - 23.4 DEG
CYLINDRICAL ANGLE 270 DEG

DIAMETER (MICRONS)	DROPS	% OCCURRENCE	% SURFACE AREA	% VOLUME	CUM % VOLUME	CLASS CHECK
25.1 - 31.6	208	7.72	0.06	0.00	0.00	0.000
31.6 - 39.8	107	3.97	0.05	0.00	0.01	0.000
39.8 - 50.1	55	2.04	0.03	0.00	0.01	0.000
50.1 - 63.1	61	2.27	0.06	0.01	0.02	0.000
63.1 - 79.4	75	2.78	0.11	0.02	0.03	0.000
79.4 - 100.0	124	4.60	0.29	0.05	0.08	0.000
100.0 - 125.9	166	6.16	0.65	0.14	0.22	0.000
125.9 - 158.5	195	7.24	1.16	0.30	0.52	0.000
158.5 - 199.5	211	7.84	2.01	0.67	1.19	0.001
199.5 - 251.2	154	5.72	2.31	0.96	2.15	0.001
251.2 - 316.2	184	6.83	4.53	2.42	4.57	0.003
316.2 - 398.1	322	11.96	12.53	8.38	12.95	0.010
398.1 - 501.2	449	16.67	26.76	22.17	35.12	0.025
501.2 - 631.0	227	8.43	20.68	21.18	56.30	0.024
631.0 - 794.3	99	3.68	14.45	18.74	75.04	0.021
794.3 - 1000.0	47	1.75	10.99	18.01	93.05	0.021
1000.0 - 1258.9	7	0.26	2.28	4.39	97.44	0.005
1258.9 - 1584.9	2	0.07	1.05	2.56	100.00	0.003
	2693.	100.00	100.00	100.00	100.00	

AVERAGE DIAMETERS (MICRONS) :

ARITHMETIC MEAN = 284.17
SURFACE MEAN = 352.26
VOLUME MEAN = 406.72
SAUTER MEAN = 542.20
WEIGHT MEAN = 632.85
VOLUME MEDIAN = 595.48
SAMPLE SIZE CHECK = 0.01

MAXIMUM DIAMETER = 1347.83
MINIMUM DIAMETER = 31.40
TOTAL DROPS IN SAMPLE = 2693.
TOTAL OUT OF FOCUS = 72
TOTAL FRAMES IN SAMPLE = 2262
AVE. DROPS PER FRAME = 1.19
DEVIATION = 0.52

RELATIVE SPAN = (964.95 - 376.03)/ 595.48 = 0.99

Table 6. Cumulative Distribution of Droplets, Nozzle TF10NN, Test 5

COMPOSITE REPORT — NOZZLE: TF 10 NN
TEST DATE 1/16/85 — TEST METHOD: PLANE
TESTS INCLUDED: 86 87 106 107 108 109 110 111
SPRAY DIRECTION VERTICAL
PRESSURE 40.0 PSI
CENTERLINE COORDINATE 60.00 INCHES
RADIAL COORDINATE 14.00 - 28.00 INCHES
DISTANCE FROM NOZZLE 61.60 - 66.21 INCHES
AZIMUTHAL ANGLE 13.1 - 25.0 DEG
CYLINDRICAL ANGLE 270 DEG

DIAMETER (MICRONS)	DROPS	% OCCURRENCE	% SURFACE AREA	% VOLUME	CUM % VOLUME	CLASS CHECK
25.1 - 31.6	191	5.11	0.05	0.00	0.00	0.000
31.6 - 39.8	140	3.74	0.05	0.00	0.01	0.000
39.8 - 50.1	143	3.82	0.08	0.01	0.02	0.000
50.1 - 63.1	197	5.27	0.18	0.02	0.04	0.000
63.1 - 79.4	186	4.97	0.25	0.04	0.08	0.000
79.4 - 100.0	210	5.62	0.44	0.09	0.17	0.000
100.0 - 125.9	177	4.73	0.60	0.15	0.32	0.000
125.9 - 158.5	116	3.10	0.61	0.19	0.52	0.000
158.5 - 199.5	139	3.72	1.17	0.47	0.99	0.001
199.5 - 251.2	236	6.31	3.15	1.59	2.58	0.002
251.2 - 316.2	401	10.72	8.68	5.60	8.18	0.006
316.2 - 398.1	696	18.61	23.75	19.24	27.42	0.022
398.1 - 501.2	563	15.06	29.12	29.04	56.46	0.033
501.2 - 631.0	267	7.14	21.61	26.96	83.43	0.031
631.0 - 794.3	68	1.82	8.52	13.23	96.66	0.015
794.3 - 1000.0	9	0.24	1.74	3.34	100.00	0.004
	3739.	100.00	100.00	100.00	100.00	

AVERAGE DIAMETERS (MICRONS) :

ARITHMETIC MEAN = 264.89
SURFACE MEAN = 318.30
VOLUME MEAN = 356.35
SAUTER MEAN = 446.62
WEIGHT MEAN = 492.94
VOLUME MEDIAN = 482.14
SAMPLE SIZE CHECK = 0.01

MAXIMUM DIAMETER = 953.06
MINIMUM DIAMETER = 31.40
TOTAL DROPS IN SAMPLE = 3739
TOTAL OUT OF FOCUS = [illegible]14
TOTAL FRAMES IN SAMPLE = [illegible]
AVE. DROPS PER FRAME = 1.50
DEVIATION = [illegible].45

RELATIVE SPAN = (710.45 - 328.53)/ 482.14 = 0.79

Table 7 Description of Instrumentation

Channel	Acronym	Description	Units	Location
16	PR	Differential Pressure	Inches H_2O	Rear of side wall, 2 ft. above floor
17	OX	Oxygen Concentration	Percent by Volume	Rear wall, 2 ft. below ceiling
18	OX	Oxygen Concentration	Percent by Volume	Rear wall, 2 ft. above floor
19	MS	Mass of Cribs	kg	Under crib assembly
20	GT	Gas Temperature	°C	Doorway
21	GT	Gas Temperature	°C	Doorway
22	GT	Gas Temperature	°C	Doorway
23	GT	Gas Temperature	°C	Doorway
24	GT	Gas Temperature	°C	Doorway
25	GT	Gas Temperature	°C	Doorway
26	GT	Gas Temperature	°C	Doorway
27	GT	Gas Temperature	°C	Room Center
28	GT	Gas Temperature	°C	Room Center
29	GT	Gas Temperature	°C	Room Center
30	GT	Gas Temperature	°C	Room Center
31	GT	Gas Temperature	°C	Room Center
32	GT	Gas Temperature	°C	Room Center
33	GT	Gas Temperature	°C	Room Center
34	GT	Gas Temperature	°C	Room Center
35	GT	Gas Temperature	°C	Room Center
36	GT	Gas Temperature	°C	Room Center
37	GT	Gas Temperature	°C	Room Center
38	GT	Gas Temperature	°C	Room Center
39	GT	Gas Temperature	°C	Room Center
40	GT	Gas Temperature	°C	Room Center
41	GT	Gas Temperature	°C	Room Center
42	ST	Surface Temperature	°C	Rear Wall
43	ST	Surface Temperature	°C	Rear Wall
44	ST	Surface Temperature	°C	Rear Wall
45	ST	Surface Temperature	°C	Left Wall
46	ST	Surface Temperature	°C	Left Wall
47	ST	Surface Temperature	°C	Left Wall
48	ST	Surface Temperature	°C	Front Wall
49	ST	Surface Temperature	°C	Front Wall
50	ST	Surface Temperature	°C	Front Wall
51	ST	Surface Temperature	°C	Right Wall
52	ST	Surface Temperature	°C	Right Wall
53	ST	Surface Temperature	°C	Right Wall
54	ST	Surface Temperature	°C	Ceiling
55	ST	Surface Temperature	°C	Ceiling
56	ST	Surface Temperature	°C	Ceiling
57	ST	Surface Temperature	°C	Floor
58	ST	Surface Temperature	°C	Floor
59	ST	Surface Temperature	°C	Floor

Table 8 Fuel Mass Data For Tests

Test #	Crib Mass (kg)	Crib Moisture Content (%)	Total Fuel Mass (kg)	Fuel Load* (kg/m^2)	Total Residual Fuel Mass (kg)
1	5.72	7.5	40.27	4.51	0
	5.62	8.3			
	5.76	8.0			
	6.03	7.8			
	5.53	8.2			
	6.12	7.8			
	5.49	8.2			
2	5.72	8.2	38.42	4.30	11.80
	5.61	8.5			
	5.39	7.5			
	5.17	9.3			
	5.66	9.5			
	5.59	9.5			
	5.28	8.0			
3	5.51	9.1	39.37	4.41	12.16
	5.86	9.0			
	5.62	9.0			
	5.62	8.5			
	5.15	9.1			
	5.82	8.6			
	5.79	9.2			
4	5.38	8.3	37.78	4.23	4.54
	5.60	9.2			
	5.51	9.0			
	5.42	7.2			
	5.55	7.2			
	5.67	9.5			
	5.65	8.0			
5	5.86	7.8	40.51	4.54	4.57
	6.09	8.4			
	5.70	8.0			
	5.89	8.8			
	5.41	8.8			
	5.86	8.5			
	5.70	8.5			

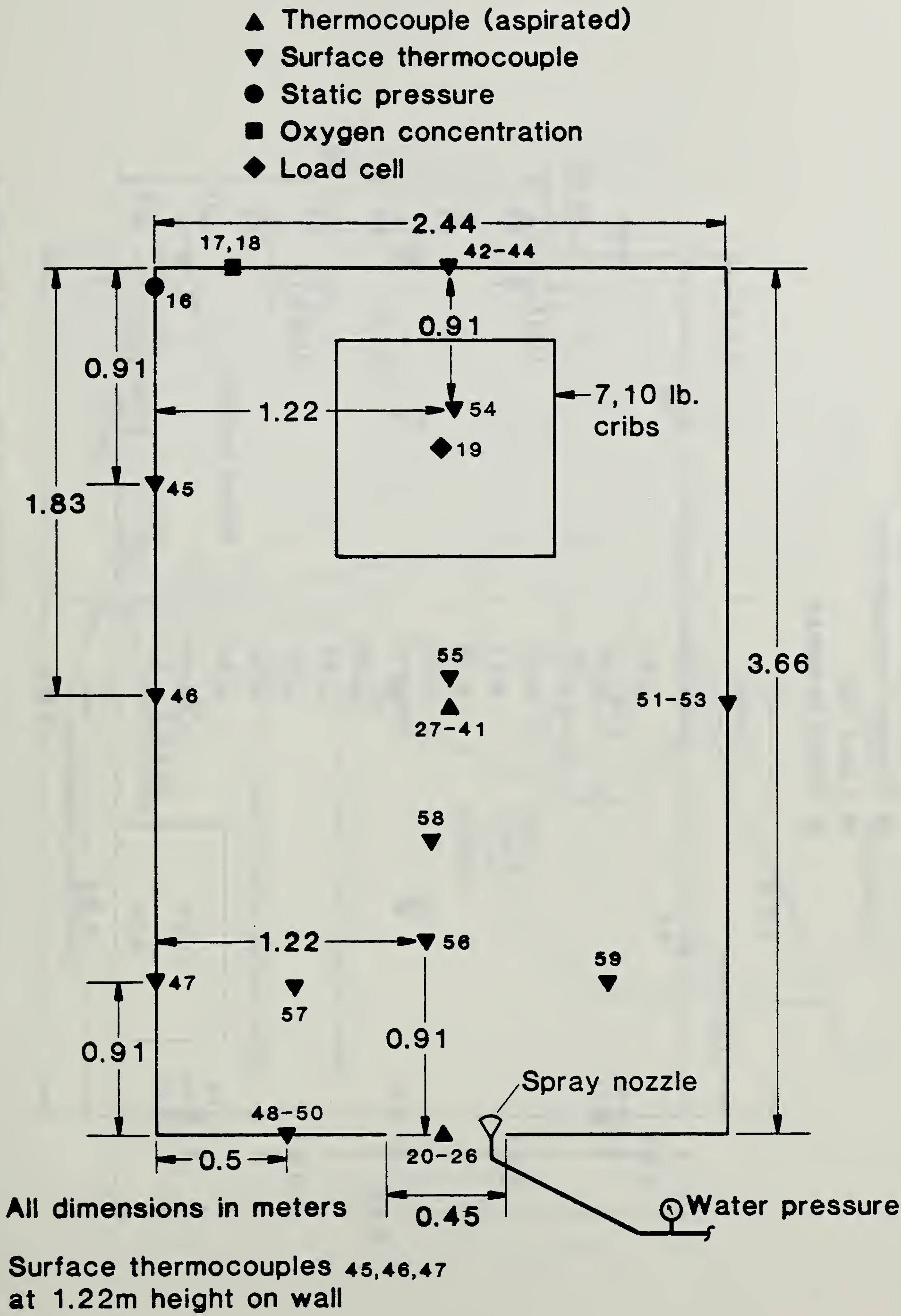


Figure 1. Plan View of Test Room and Instrumentation

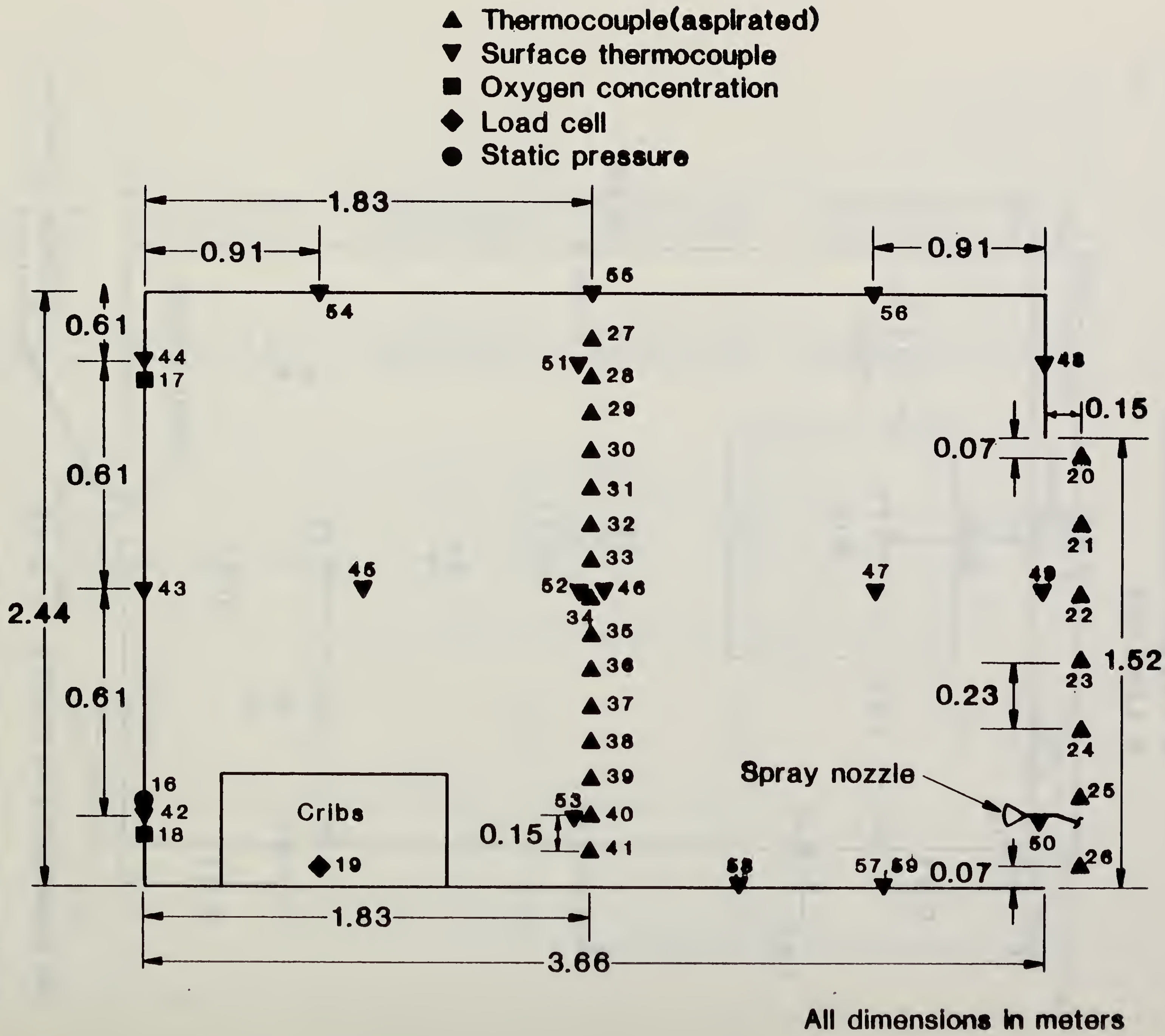


Figure 2. Elevation View of Test Room and Instrumentation

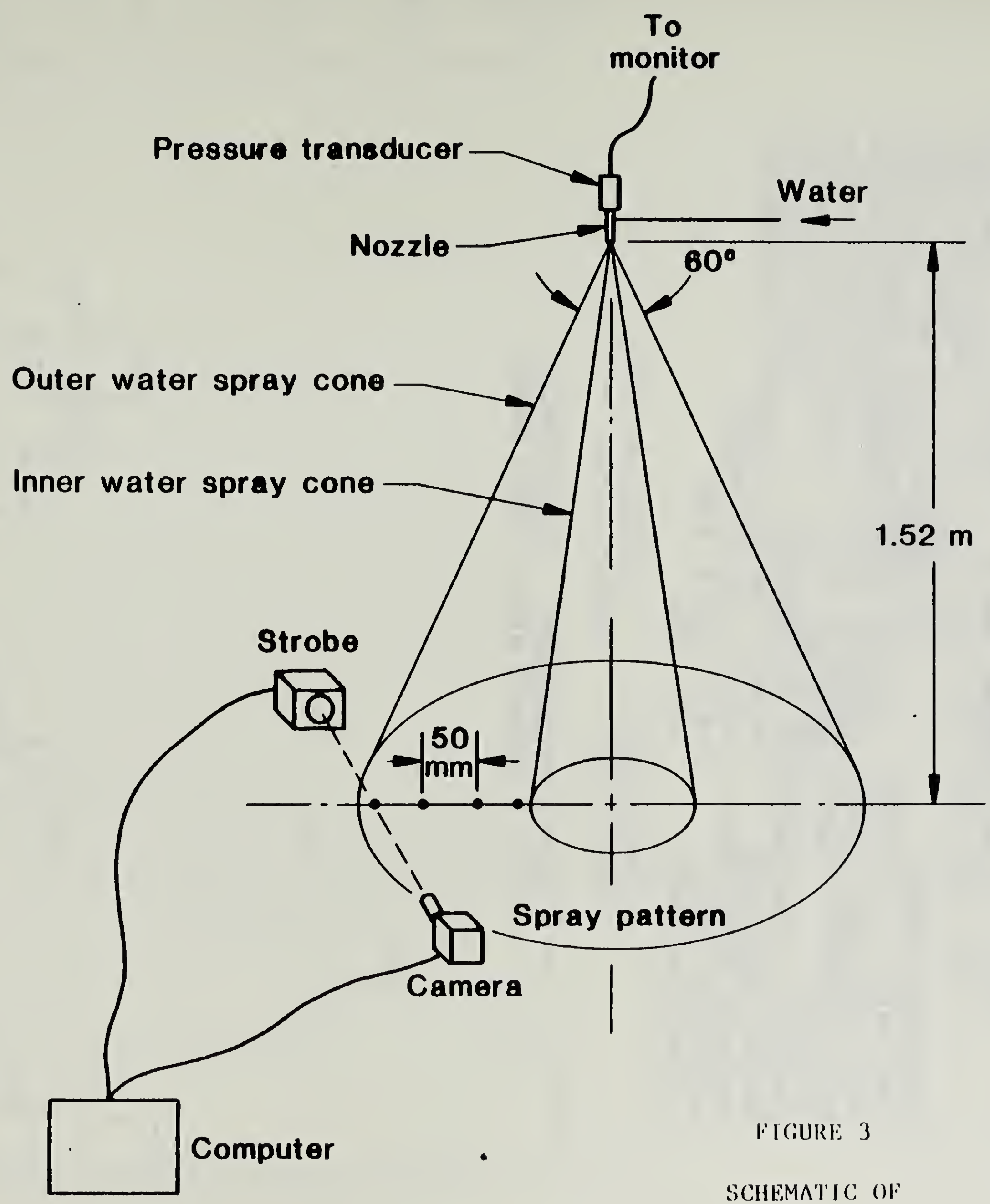


FIGURE 3

SCHEMATIC OF

DROPLET ANALYZER SYSTEM

Figure 4. Histogram of Droplet Diameter by Percent Volume and Cumulative Volume, Nozzle TF16NN, Test 2

COMPOSITE REPORT — NOZZLE: TF 16 NN
TEST DATE 1/16/85 — TEST METHOD: PLANE
TESTS INCLUDED: 118 121 122 123 124 125 126
SPRAY DIRECTION VERTICAL
PRESSURE 18.0 PSI
CENTERLINE COORDINATE 60.00 INCHES
RADIAL COORDINATE 14.00 - 26.00 INCHES
DISTANCE FROM NOZZLE 61.61 - 65.39 INCHES
AZIMUTHAL ANGLE 13.1 - 23.4 DEG
CYLINDRICAL ANGLE 270 DEG

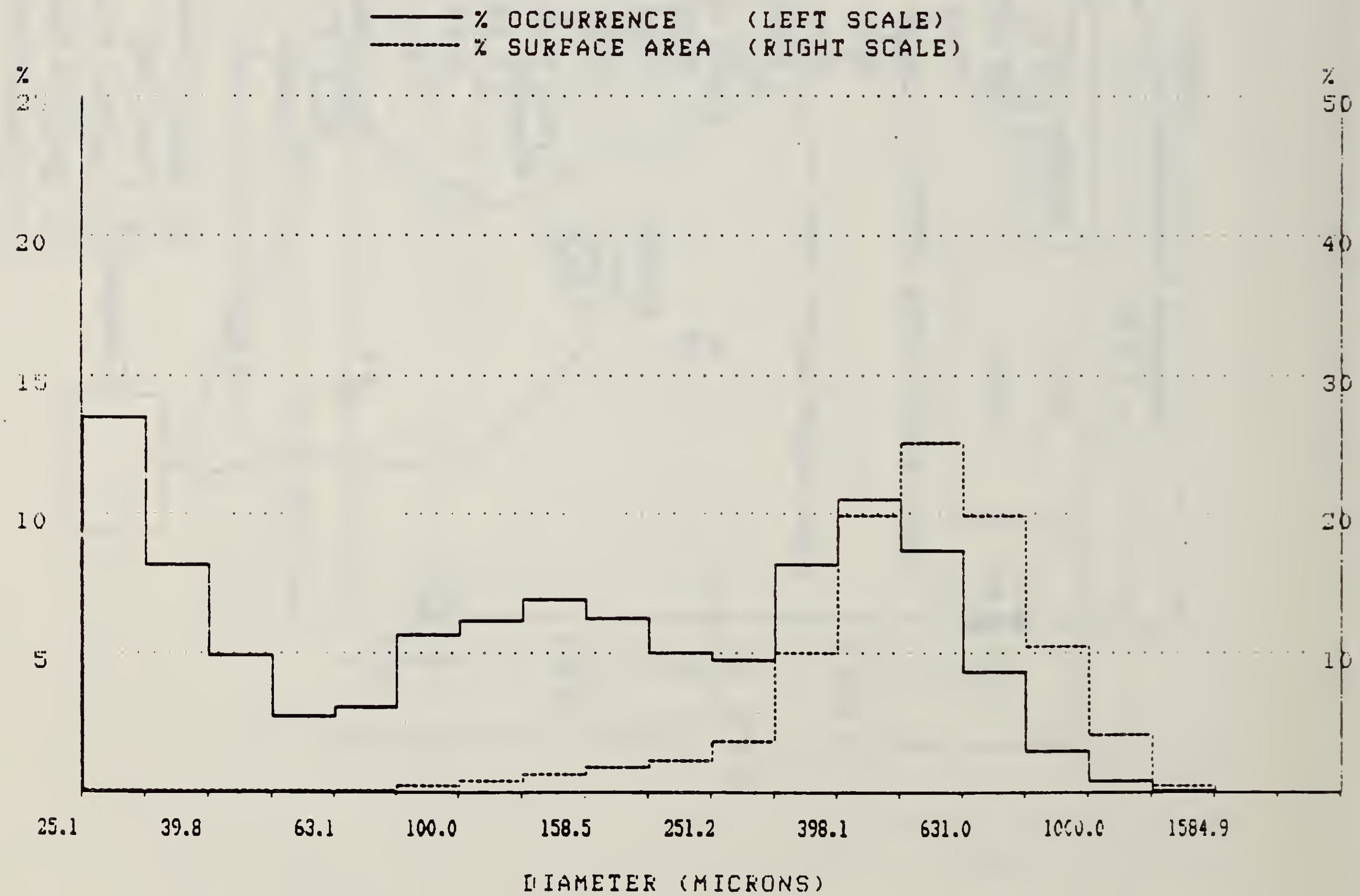


Figure 5. Histogram of Droplet Diameter by Percent Occurrence and Surface Area, Nozzle TF16NN, Test 2

```
COMPOSITE REPORT                                NOZZLE: TF 16 NN
TEST DATE      1/16/85                          TEST METHOD:   PLANE
TESTS INCLUDED:    118   121  122  123  124  125  126
SPRAY DIRECTION          VERTICAL
PRESSURE                 18.0 PSI
CENTERLINE COORDINATE    60.00 INCHES
RADIAL COORDINATE        14.00 -  26.00 INCHES
DISTANCE FROM NOZZLE     61.61 -  65.39 INCHES
AZIMUTHAL ANGLE          13.1 - 23.4  DEG
CYLINDRICAL ANGLE         270  DEG
```

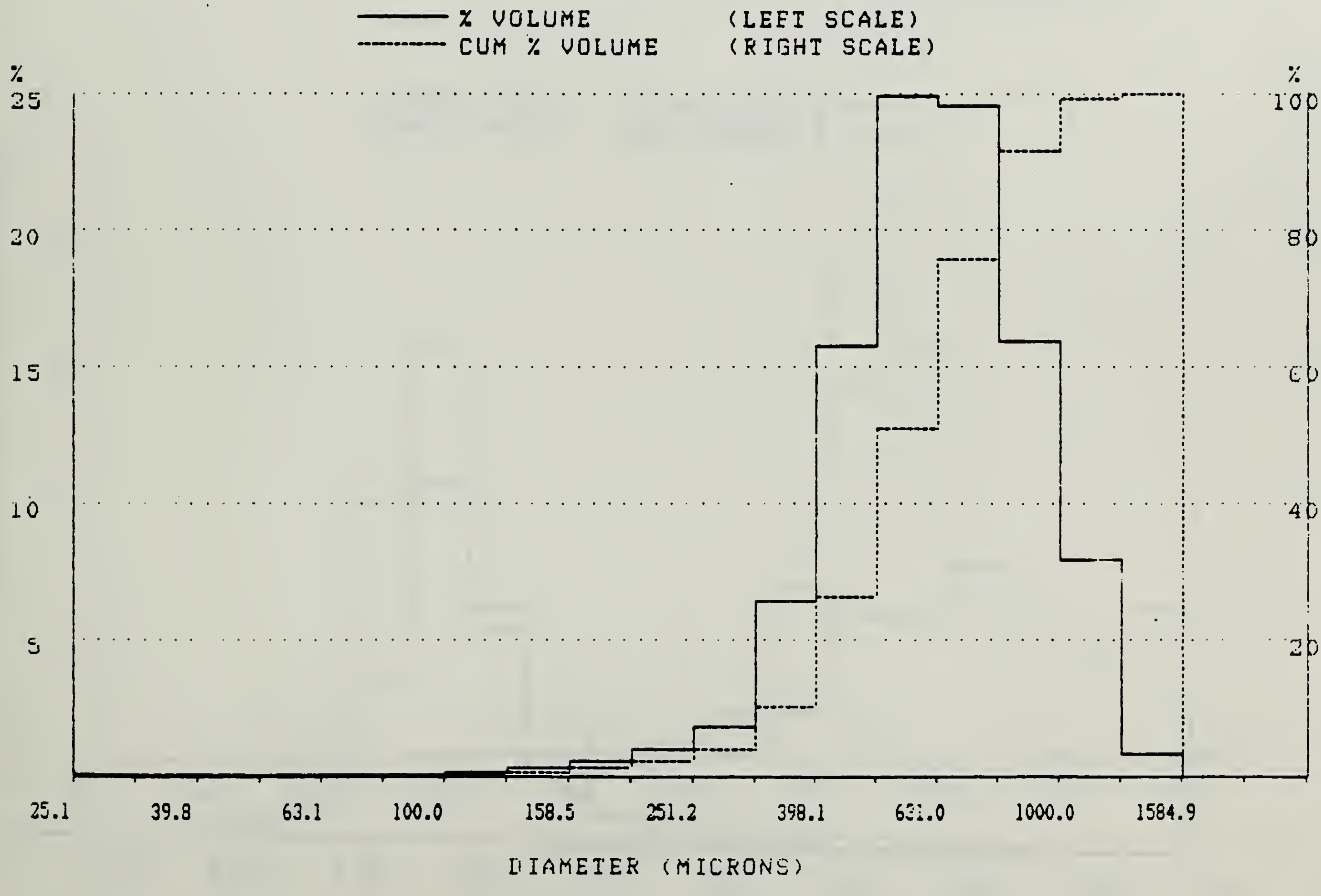


Figure 6. Histogram of Droplet Diameter by Percent Volume and Cumulative Volume, Nozzle TF12NN, Test 3

COMPOSITE REPORT				NOZZLE: TF 12 NN						
TEST DATE	1/16/85			TEST METHOD:	PLANE					
TESTS INCLUDED:	94	95	127	97	128	129	130	131		
SPRAY DIRECTION	VERTICAL									
PRESSURE	54.0 PSI									
CENTERLINE COORDINATE	60.00 INCHES									
RADIAL COORDINATE	16.00 - 30.00 INCHES									
DISTANCE FROM NOZZLE	62.09 - 67.08 INCHES									
AZIMUTHAL ANGLE	14.9 - 26.5 DEG									
CYLINDRICAL ANGLE	270 DEG									

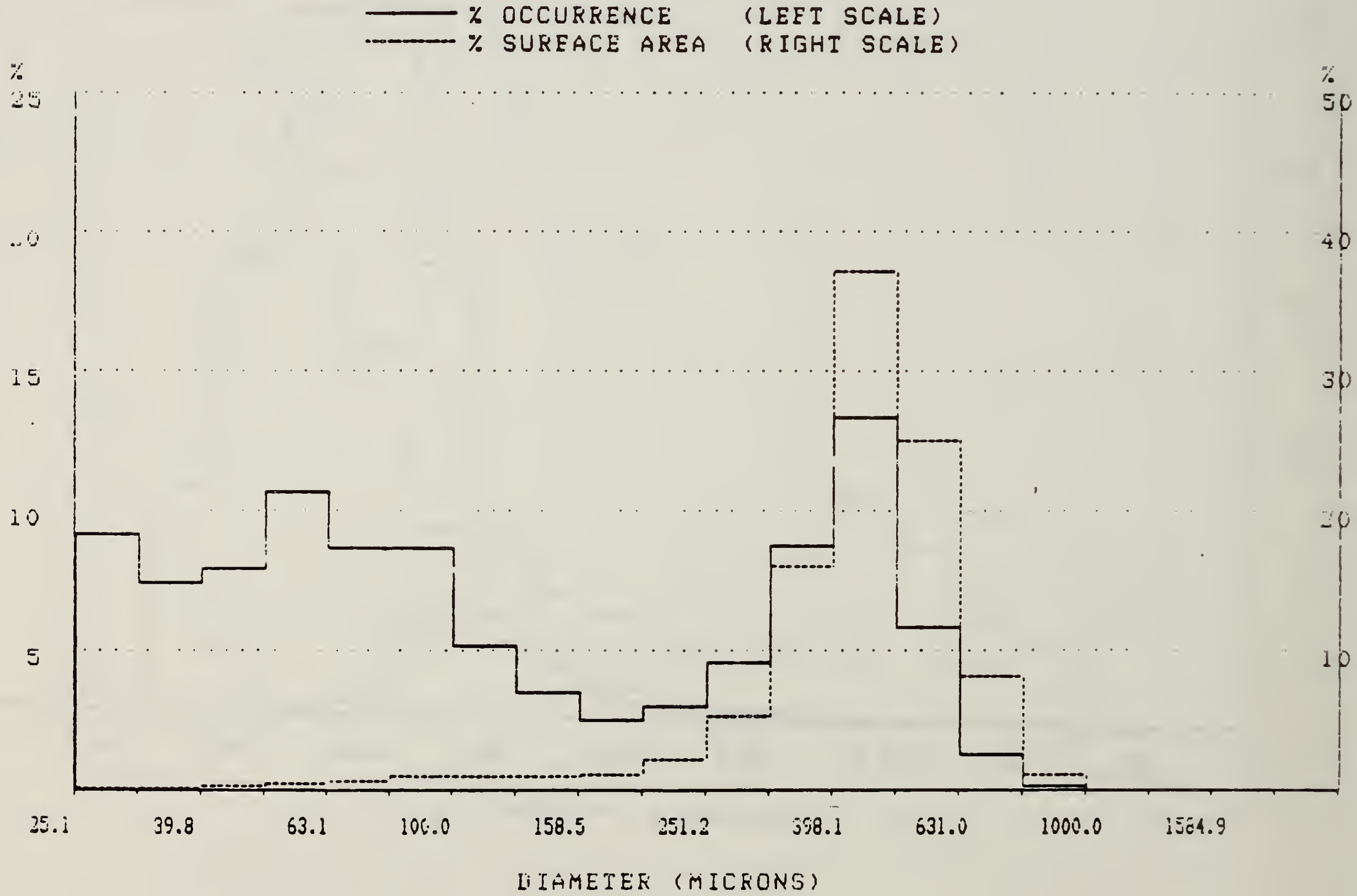


Figure 7. Histogram of Droplet Diameter by Percent Occurrence and Surface Area, Nozzle TF12NN, Test 3

```
COMPOSITE REPORT                              NOZZLE: TF 12 NN
TEST DATE        1/16/85                      TEST METHOD:    PLANE
TESTS INCLUDED:       94    95   127    97   128   129   130   131
SPRAY DIRECTION            VERTICAL
PRESSURE                   54.0 PSI
CENTERLINE COORDINATE      60.00 INCHES
RADIAL COORDINATE          16.00 -   30.00 INCHES
DISTANCE FROM NOZZLE       62.09 -   67.08 INCHES
AZIMUTHAL ANGLE            14.9 - 26.5   DEG
CYLINDRICAL ANGLE           270   DEG
```

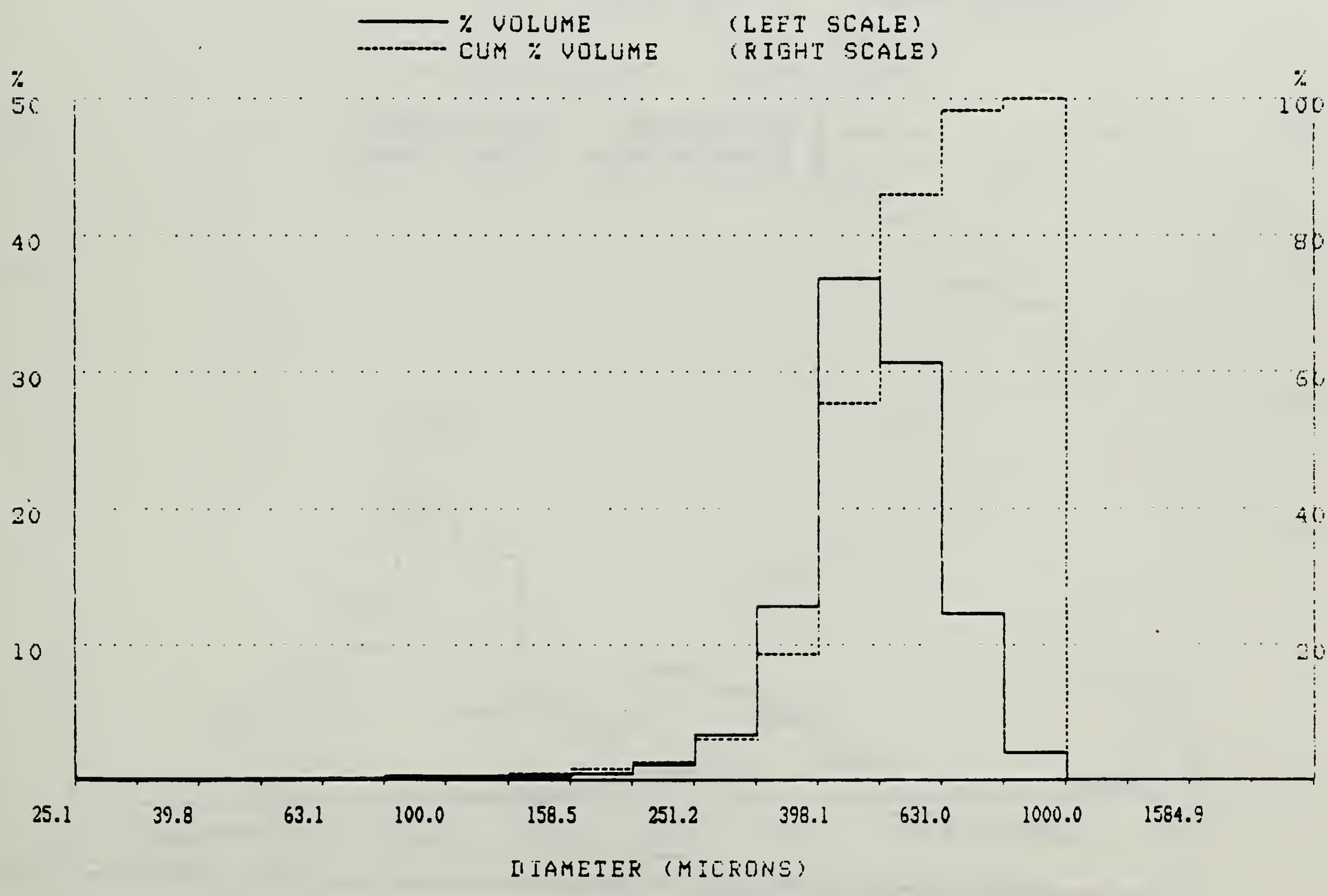


Figure 8. Histogram of Droplet Diameter by Percent Volume and Cumulative Volume, Nozzle TF14NN, Test 4.

```
COMPOSITE REPORT                               NOZZLE: TF 14 NN
TEST DATE       1/16/85                        TEST METHOD:    PLANE
TESTS INCLUDED:     112   113   114   115   116
SPRAY DIRECTION           VERTICAL
PRESSURE                  17.0 PSI
CENTERLINE COORDINATE     60.00 INCHES
RADIAL COORDINATE         18.00 -   26.00 INCHES
DISTANCE FROM NOZZLE      62.64 -   65.39 INCHES
AZIMUTHAL ANGLE           16.6 - 23.4   DEG
CYLINDRICAL ANGLE          270   DEG
```

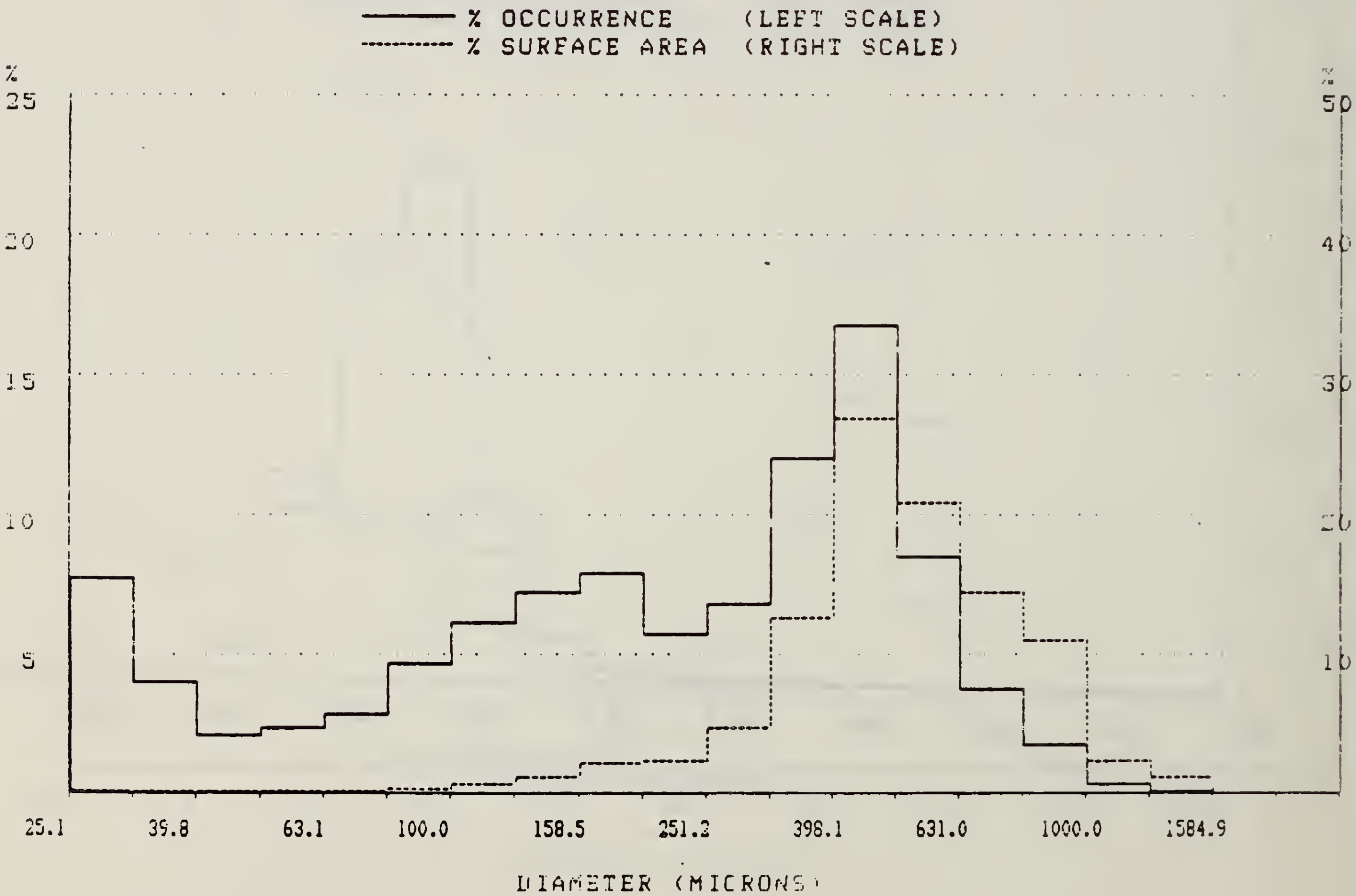


Figure 9. Histogram of Droplet Diameter by Percent Occurrence and Surface Area, Nozzle TF14NN, Test 4

```
COMPOSITE REPORT                          NOZZLE: TF 14 NN
TEST DATE      1/16/85                    TEST METHOD:    PLANE
TESTS INCLUDED:     112   113   114   115   116
SPRAY DIRECTION           VERTICAL
PRESSURE                  17.0 PSI
CENTERLINE COORDINATE     60.00 INCHES
RADIAL COORDINATE         18.00 -   26.00 INCHES
DISTANCE FROM NOZZLE      62.64 -   65.39 INCHES
AZIMUTHAL ANGLE           16.6 - 23.4   DEG
CYLINDRICAL ANGLE          270   DEG
```

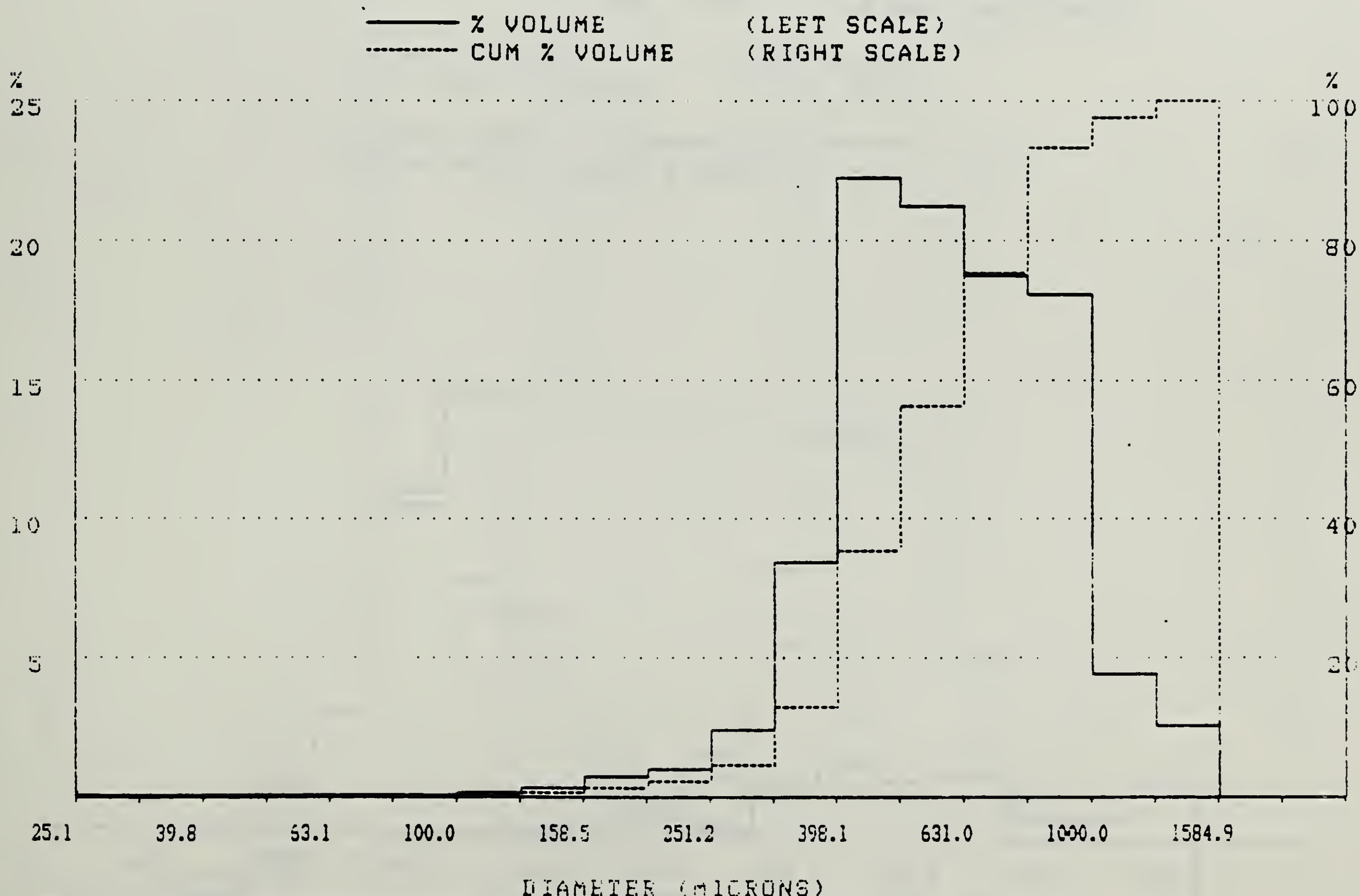


Figure 10. Histogram of Droplet Diameter by Percent Volume and Cumulative Volume, Nozzle TF10NN, Test 5.

```
COMPOSITE REPORT                              NOZZLE: TF 10 NN
TEST DATE        1/16/85                      TEST METHOD:    PLANE
TESTS INCLUDED:      86    87  106  107  108  109  110  111
SPRAY DIRECTION          VERTICAL
PRESSURE                 40.0 PSI
CENTERLINE COORDINATE    60.00 INCHES
RADIAL COORDINATE        14.00 -  28.00 INCHES
DISTANCE FROM NOZZLE     61.60 -  66.21 INCHES
AZIMUTHAL ANGLE          13.1 - 25.0  DEG
CYLINDRICAL ANGLE         270  DEG
```

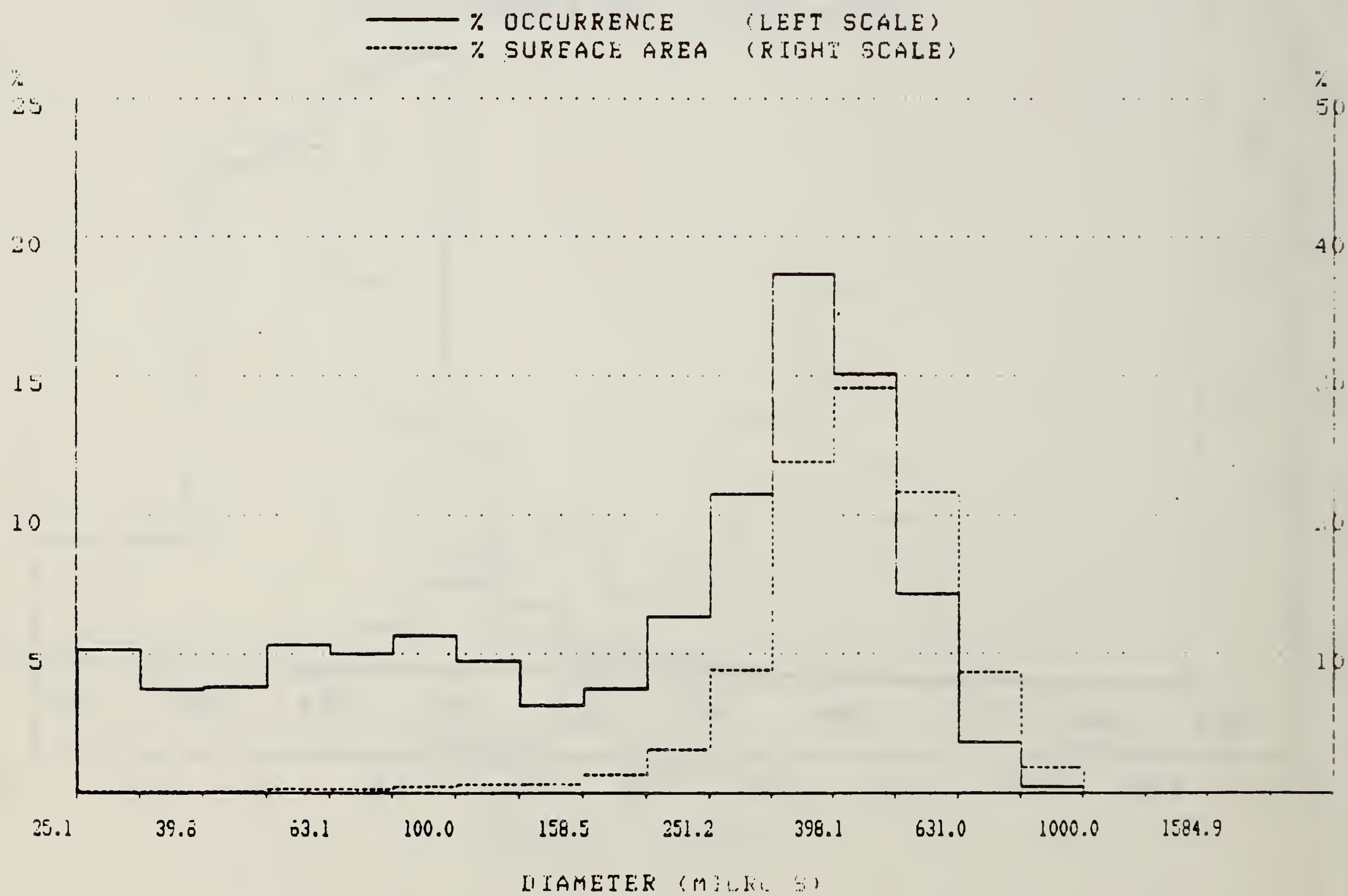
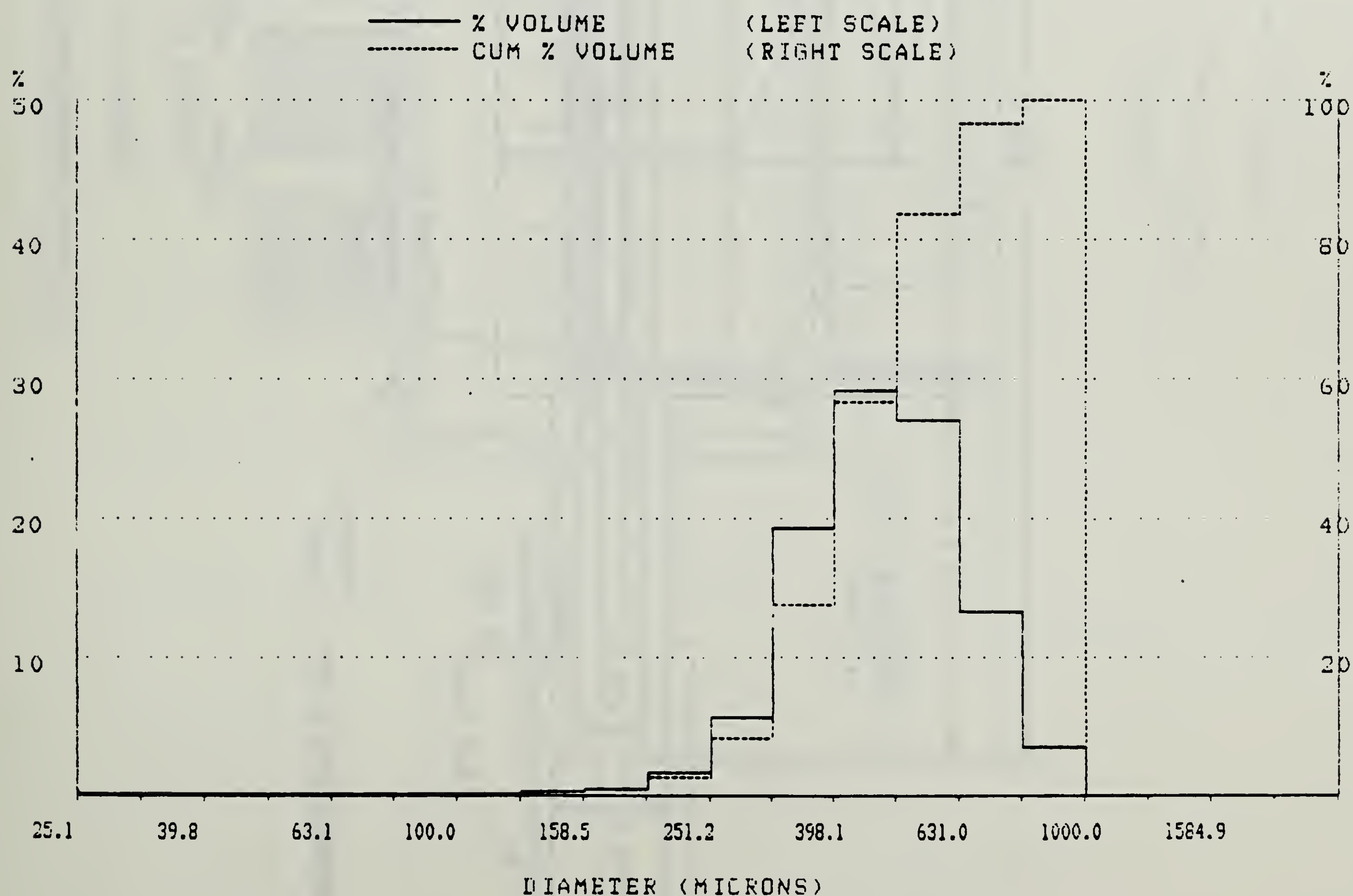


Figure 11. Histogram of Droplet Diameter by Percent Occurrence and Surface Area, Nozzle TF10NN, Test 5

COMPOSITE REPORT NOZZLE: TF 10 NN
TEST DATE 1/16/85 TEST METHOD: PLANE
TESTS INCLUDED: 86 87 106 107 108 109 110 111
SPRAY DIRECTION VERTICAL
PRESSURE 40.0 PSI
CENTERLINE COORDINATE 60.00 INCHES
RADIAL COORDINATE 14.00 - 28.00 INCHES
DISTANCE FROM NOZZLE 61.60 - 66.21 INCHES
AZIMUTHAL ANGLE 13.1 - 25.0 DEG
CYLINDRICAL ANGLE 270 DEG



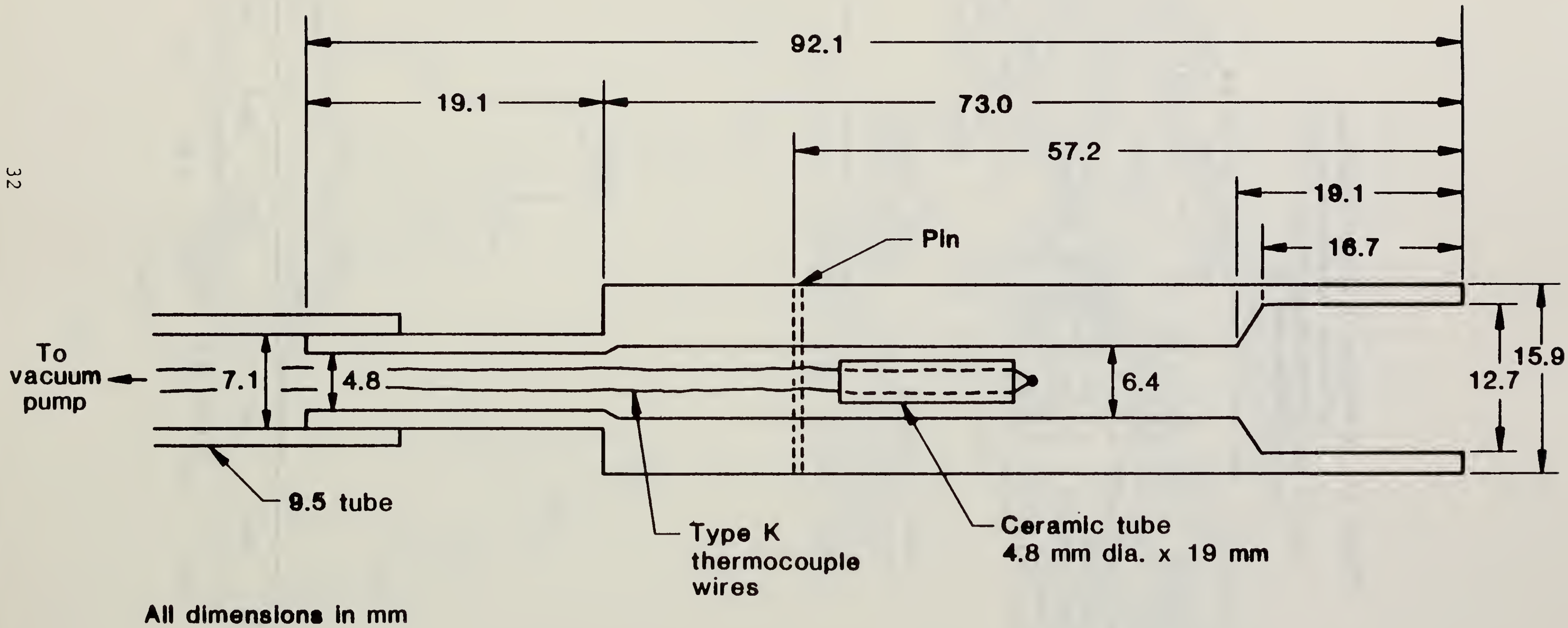


FIGURE 12

SCHEMATIC OF

ASPIRATED THERMOCOUPLE PROBE TIP

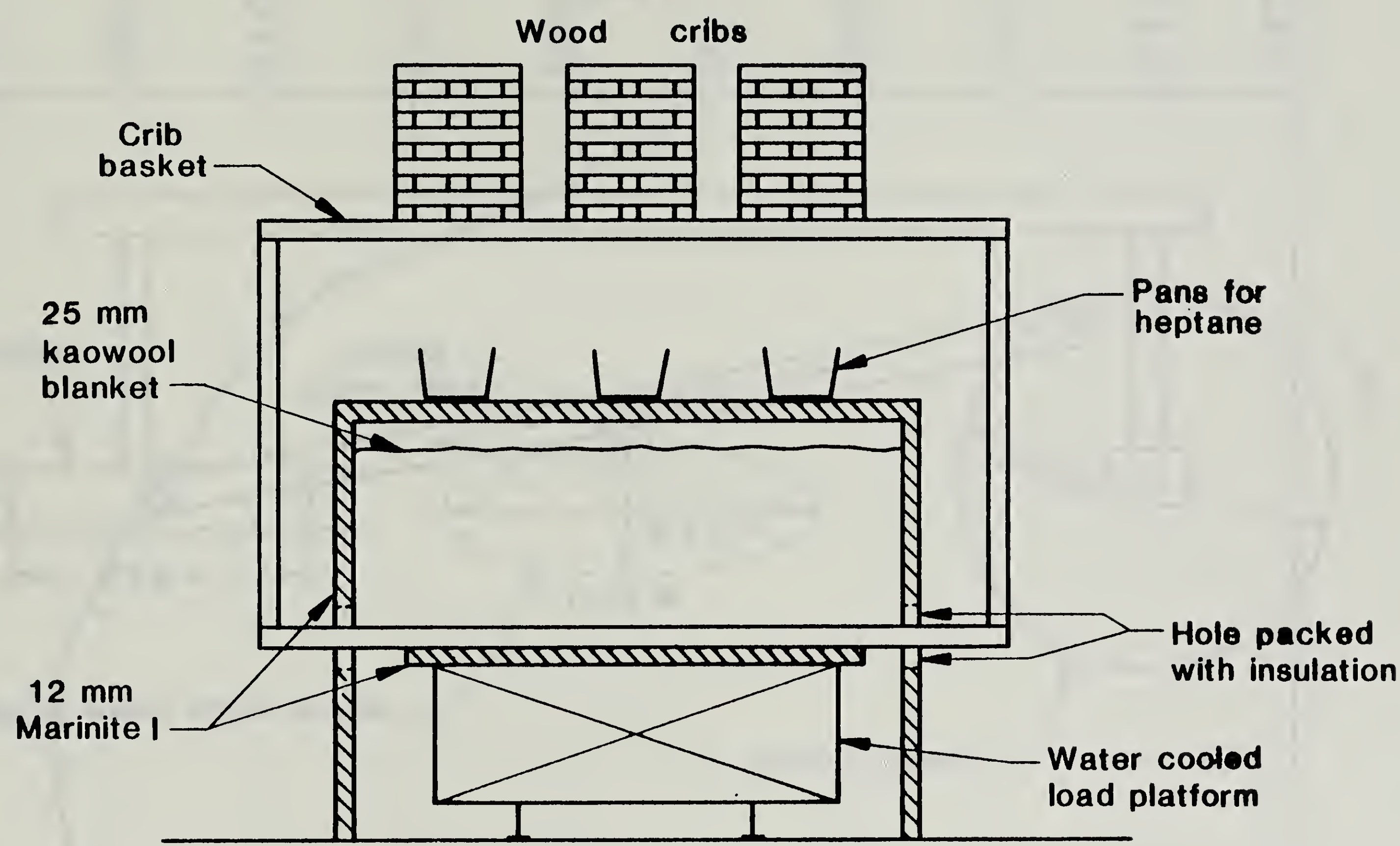


FIGURE 13

SCHEMATIC OF MASS LOSS

INSTRUMENTATION

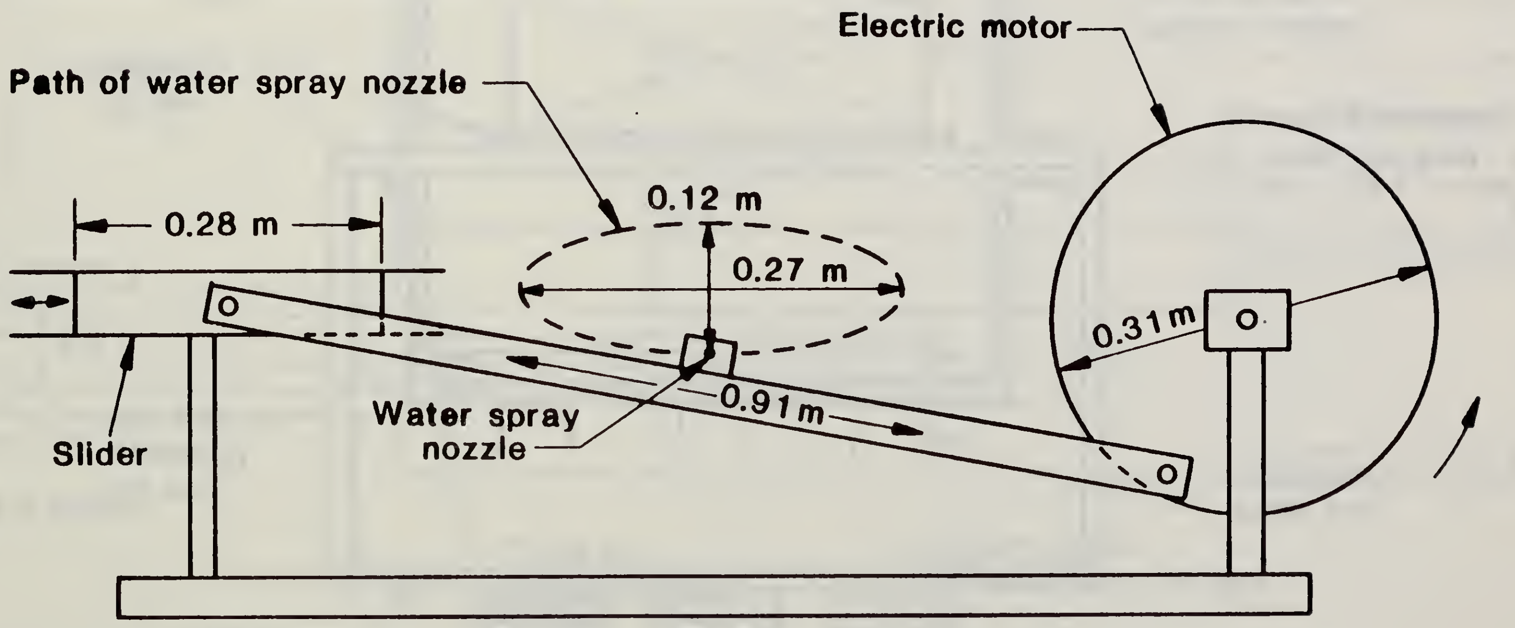


FIGURE 14

SCHEMATIC OF

IRON FIRE FIGHTER

Figure 15. Static Room Gauge Pressure

Test Number 1

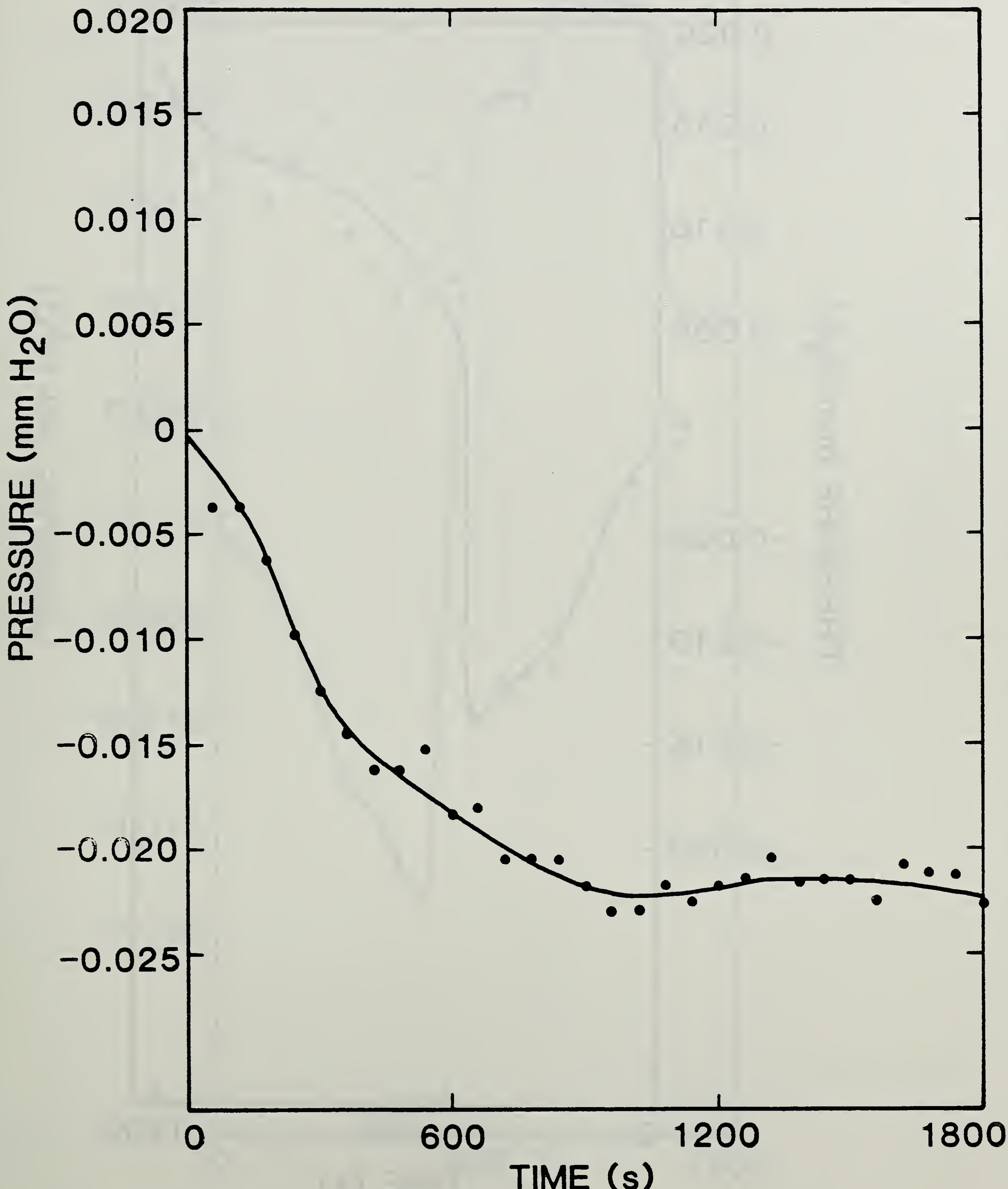


Figure 16. Static Room Gauge Pressure
Test Number 2

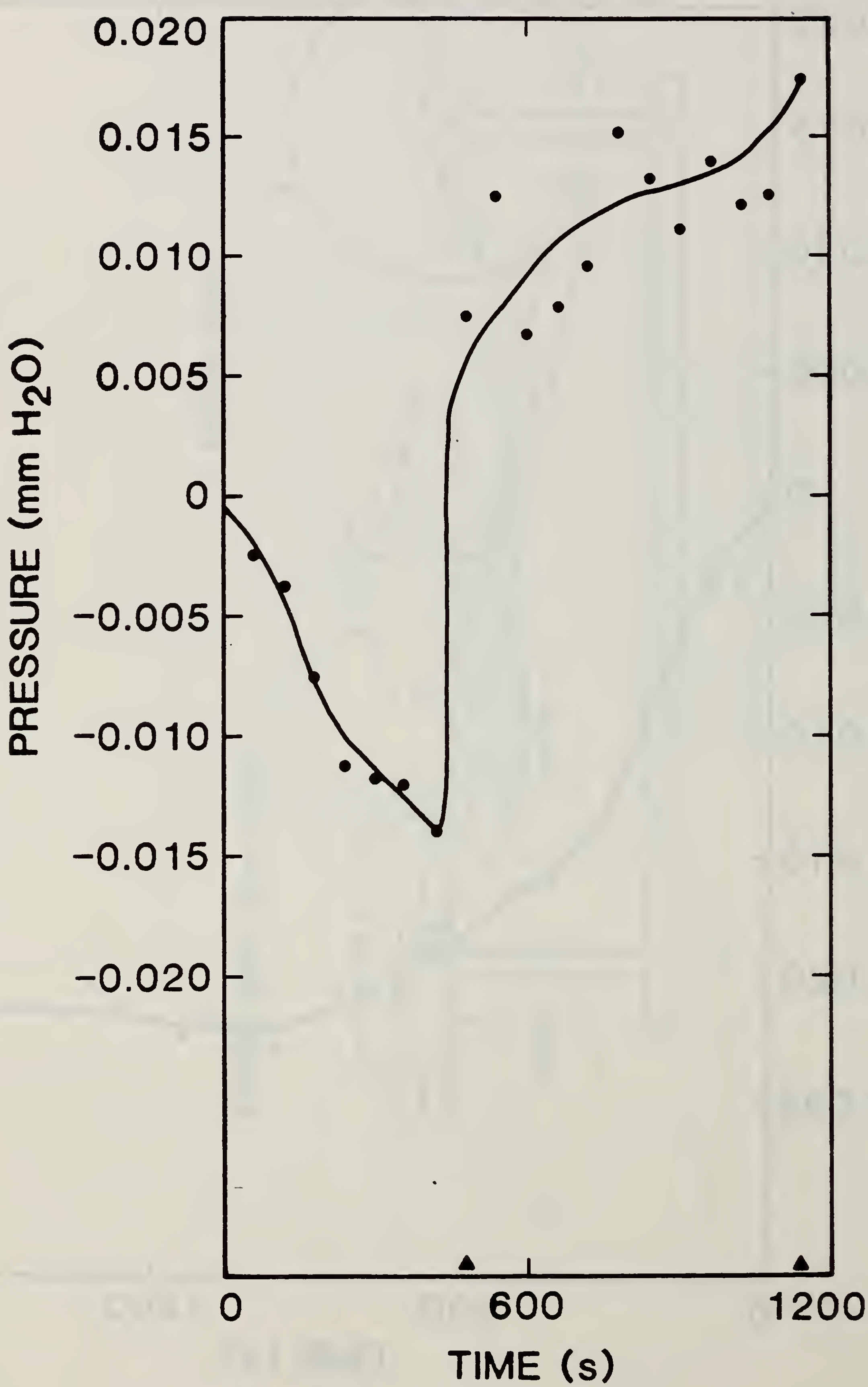


Figure 17. Static Room Gauge Pressure

Test Number 3

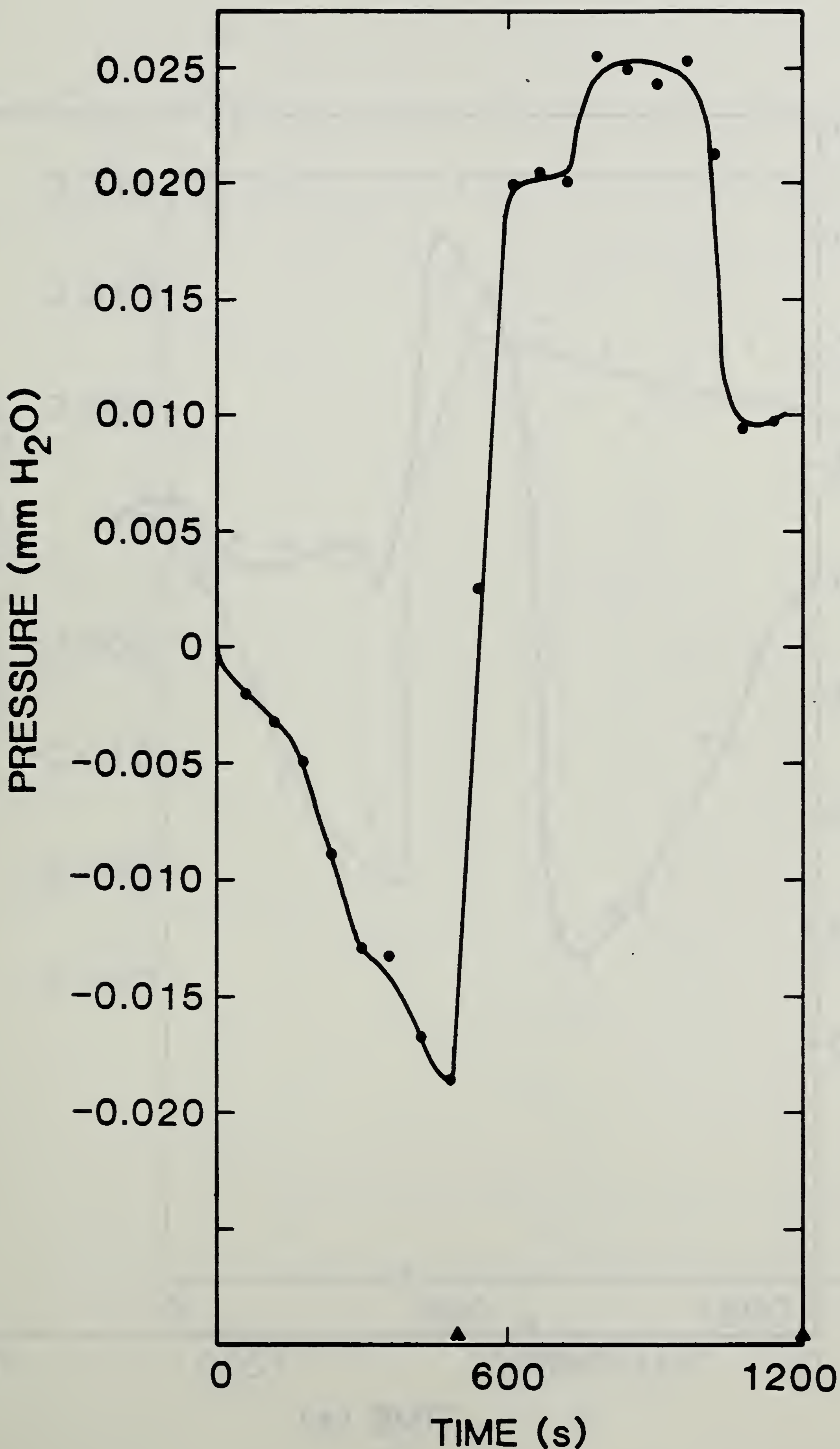
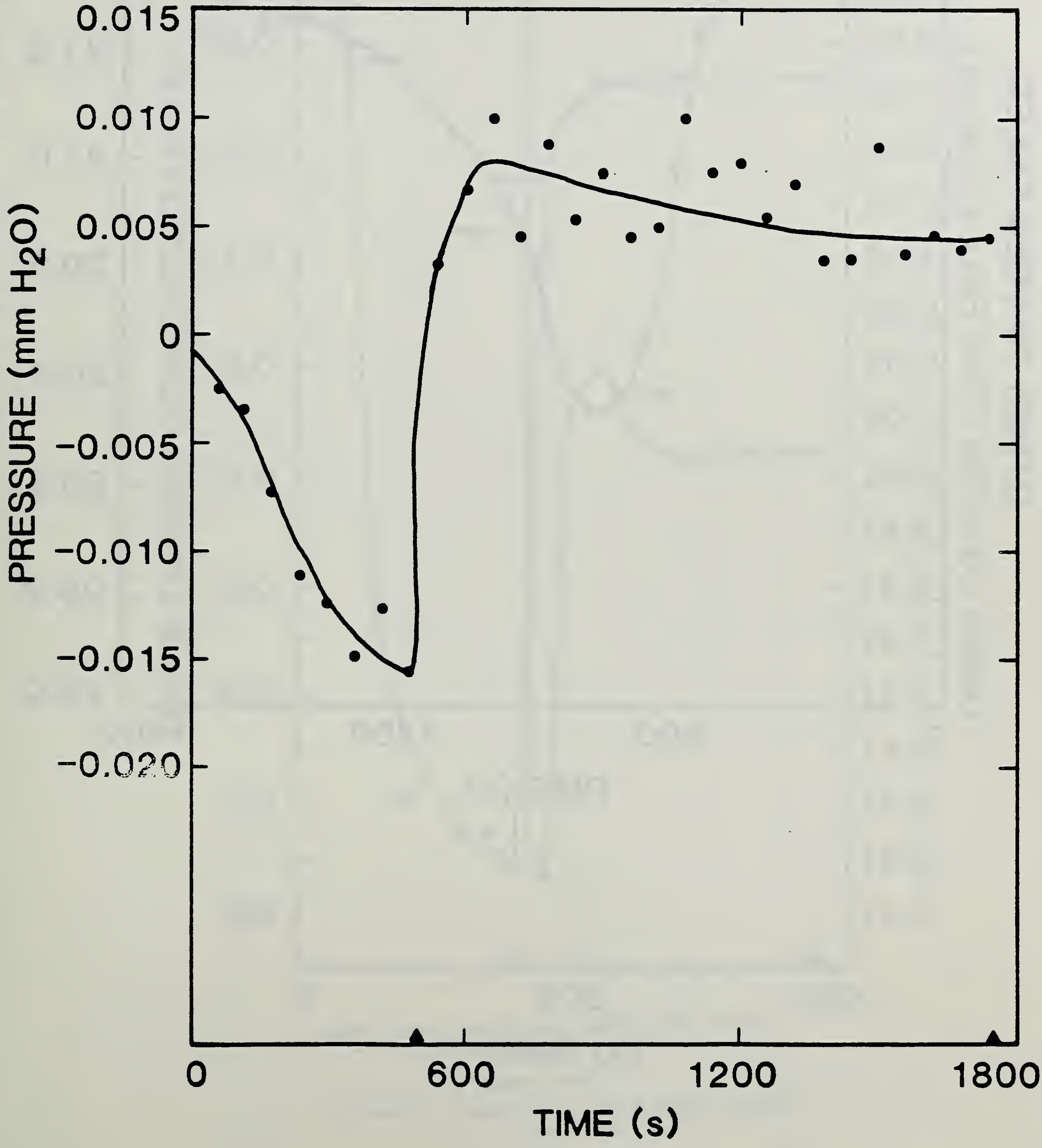


Figure 18. Static Room Gauge Pressure

Test Number 4

Figure 19. Static Room Gauge Pressure
Test Number 5



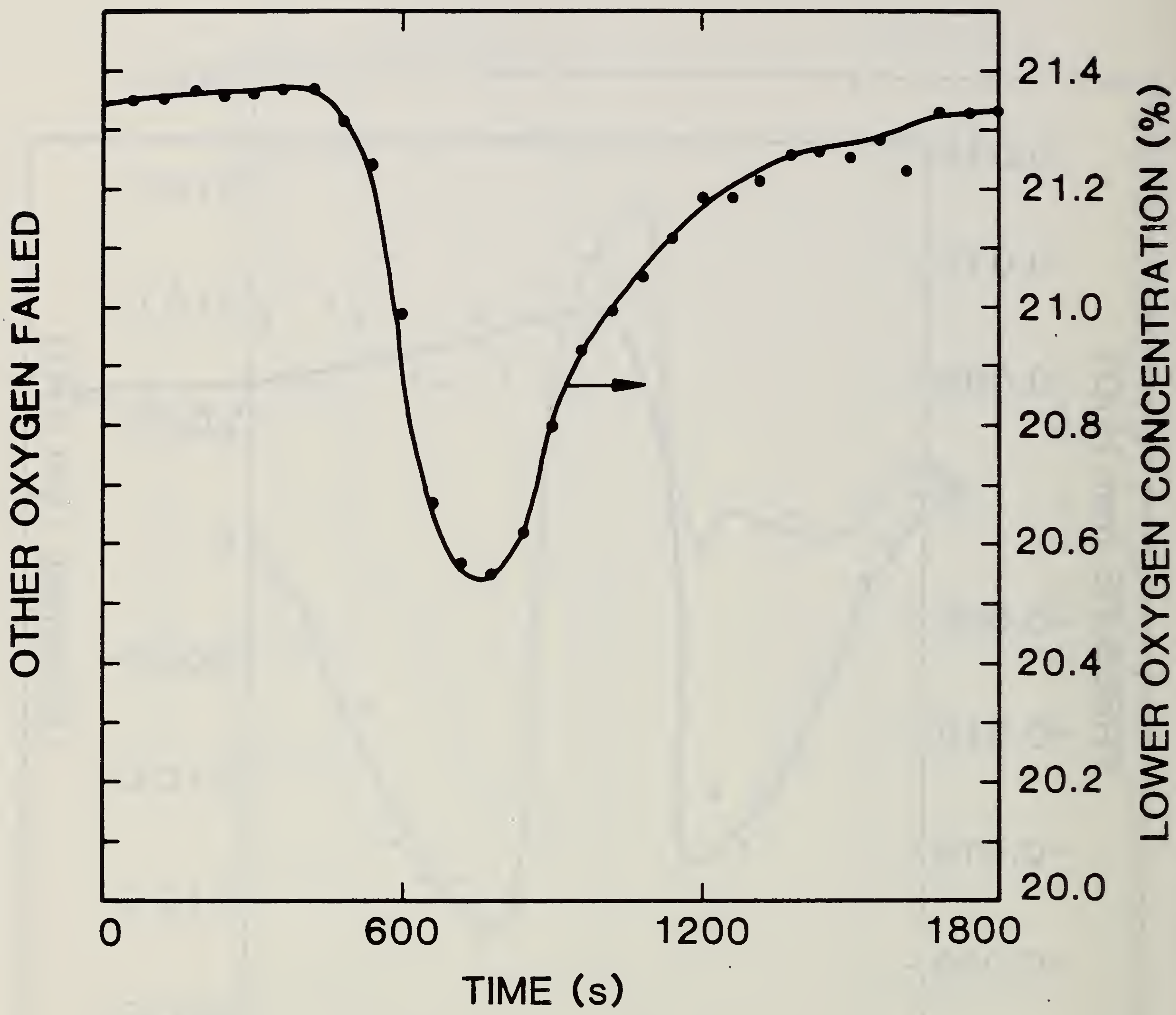


Figure 20. Upper and Lower Layer Oxygen Concentration

Test Number 1

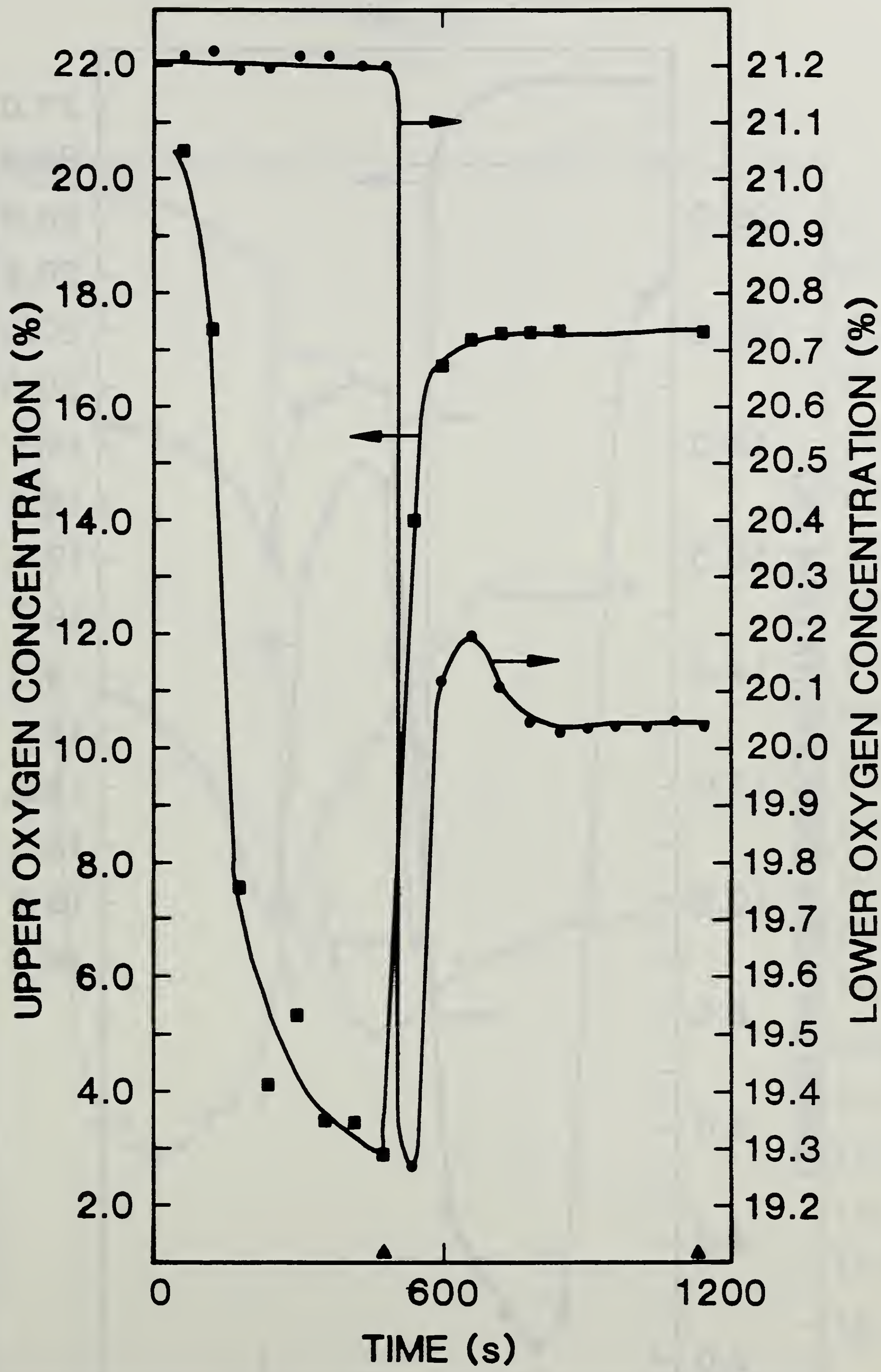


Figure 21. Upper and Lower Layer Oxygen Concentration

Test Number 2

Figure 22. Upper and Lower Layer Oxygen Concentration

Test Number 3

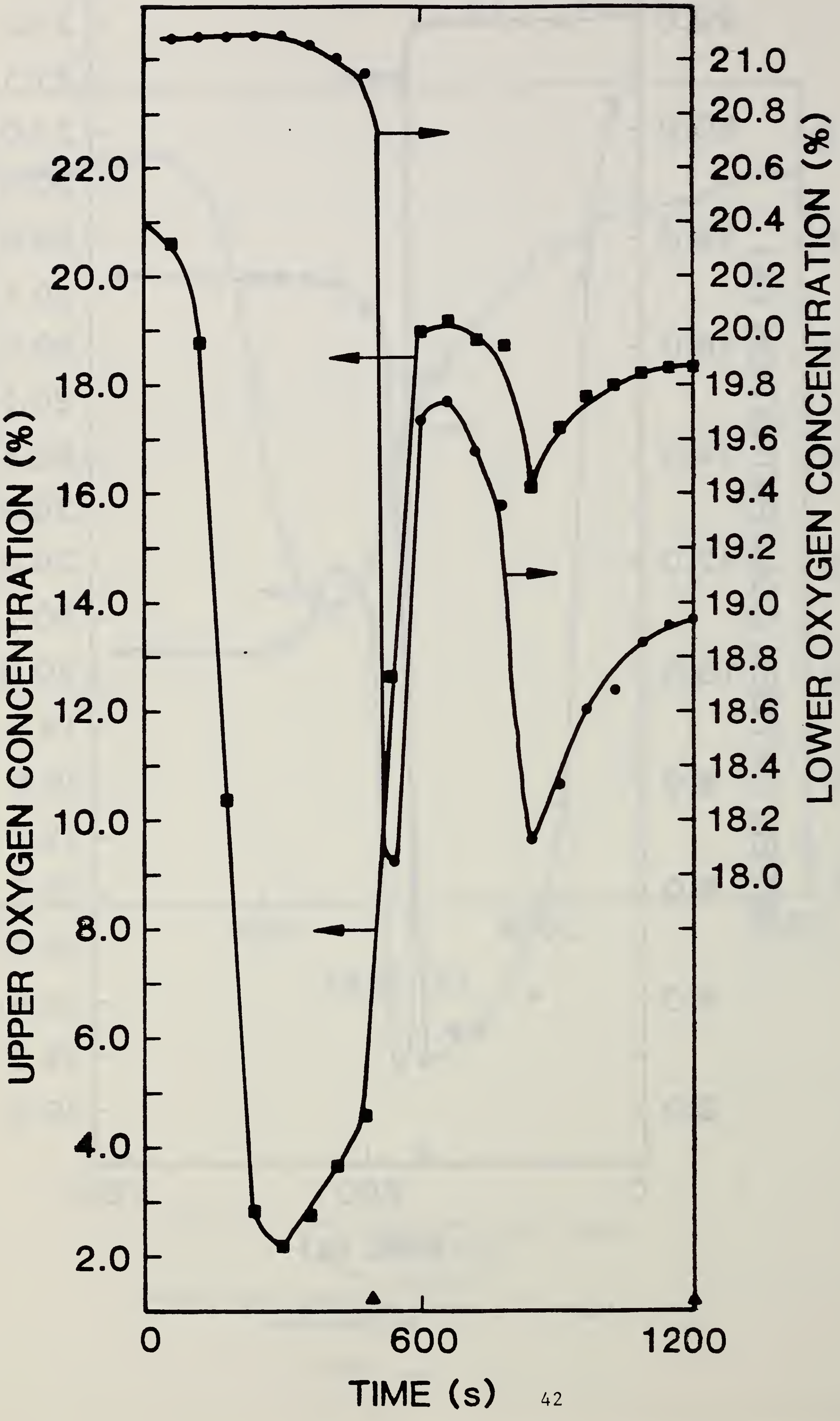


Figure 23. Upper and Lower Layer Oxygen Concentration

Test Number 4

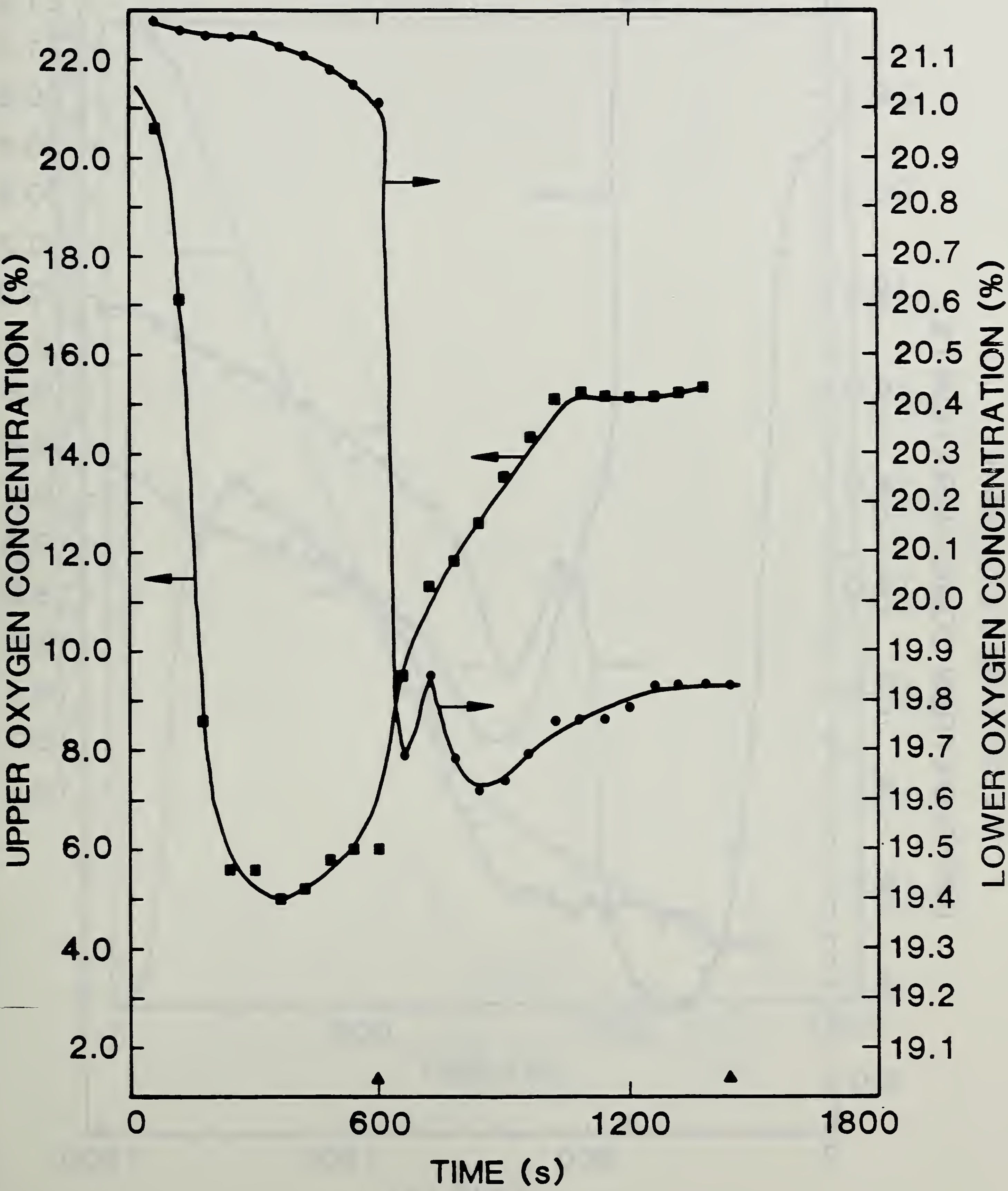


Figure 24. Upper and Lower Layer Oxygen Concentration

Test Number 5

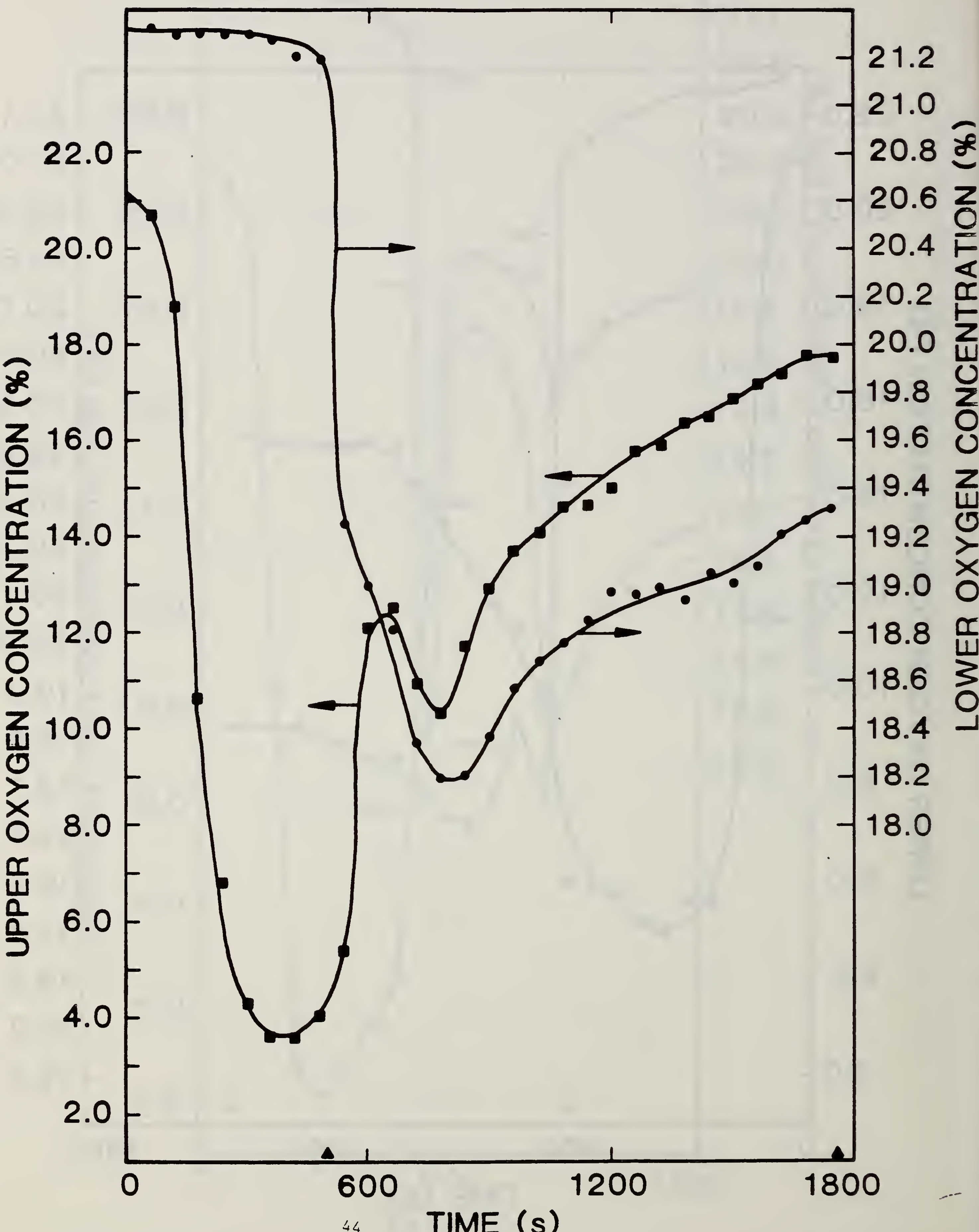


Figure 25. Fuel Mass and Mass Loss Rate

Test Number 1

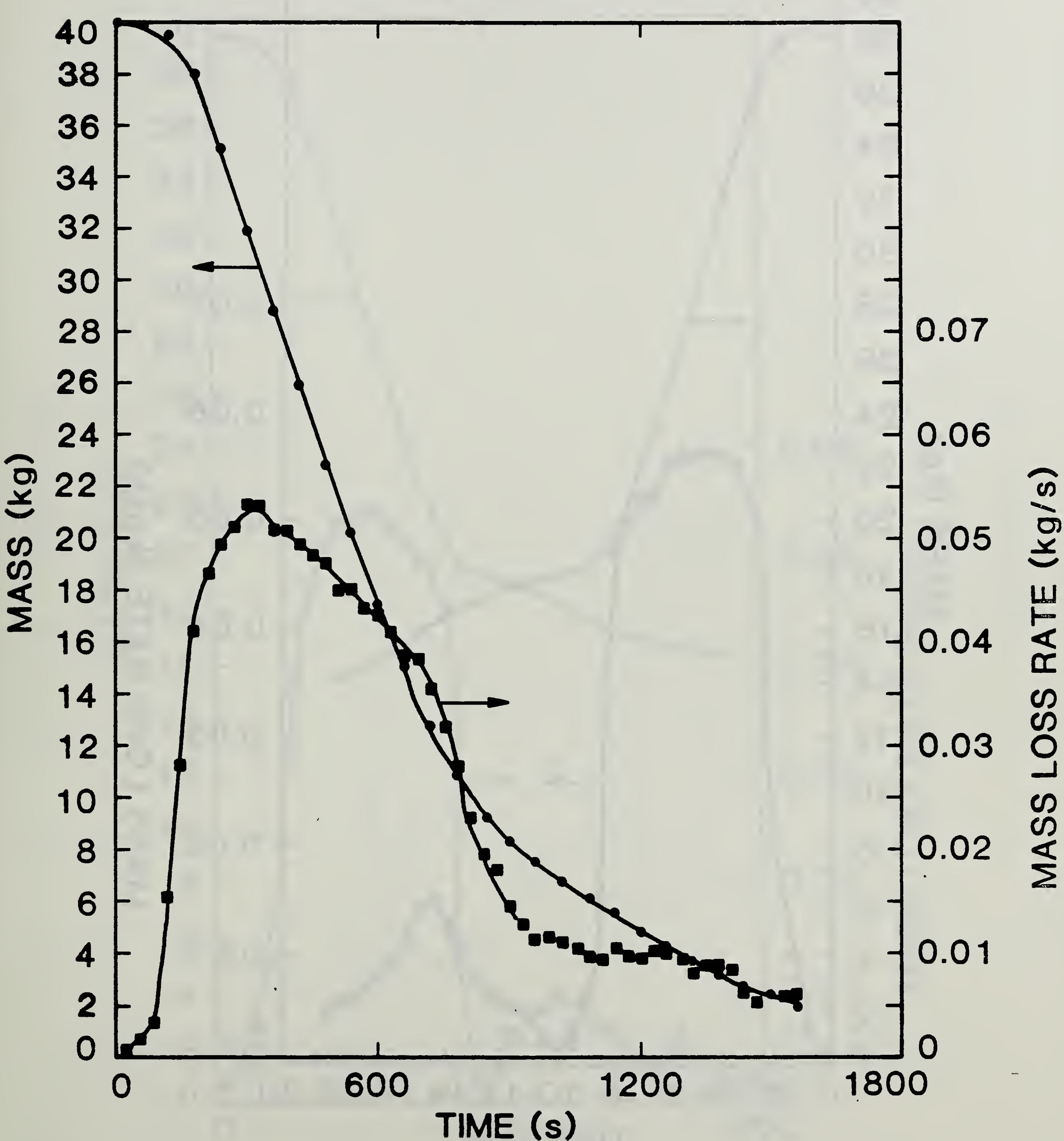


Figure 26. Fuel Mass and Mass Loss Rate
Test Number 2

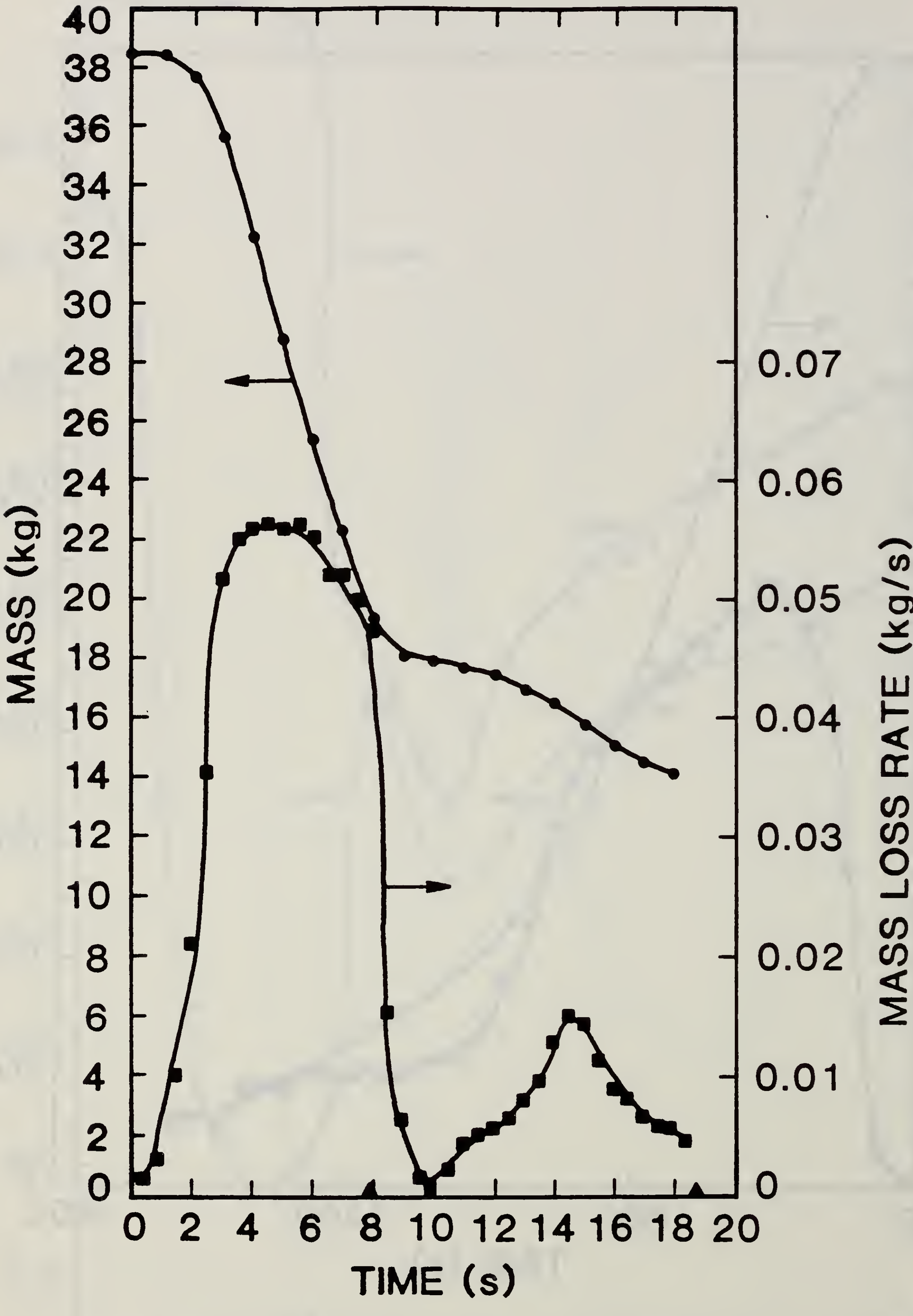


Figure 27. Fuel Mass and Mass Loss Rate

Test Number 3

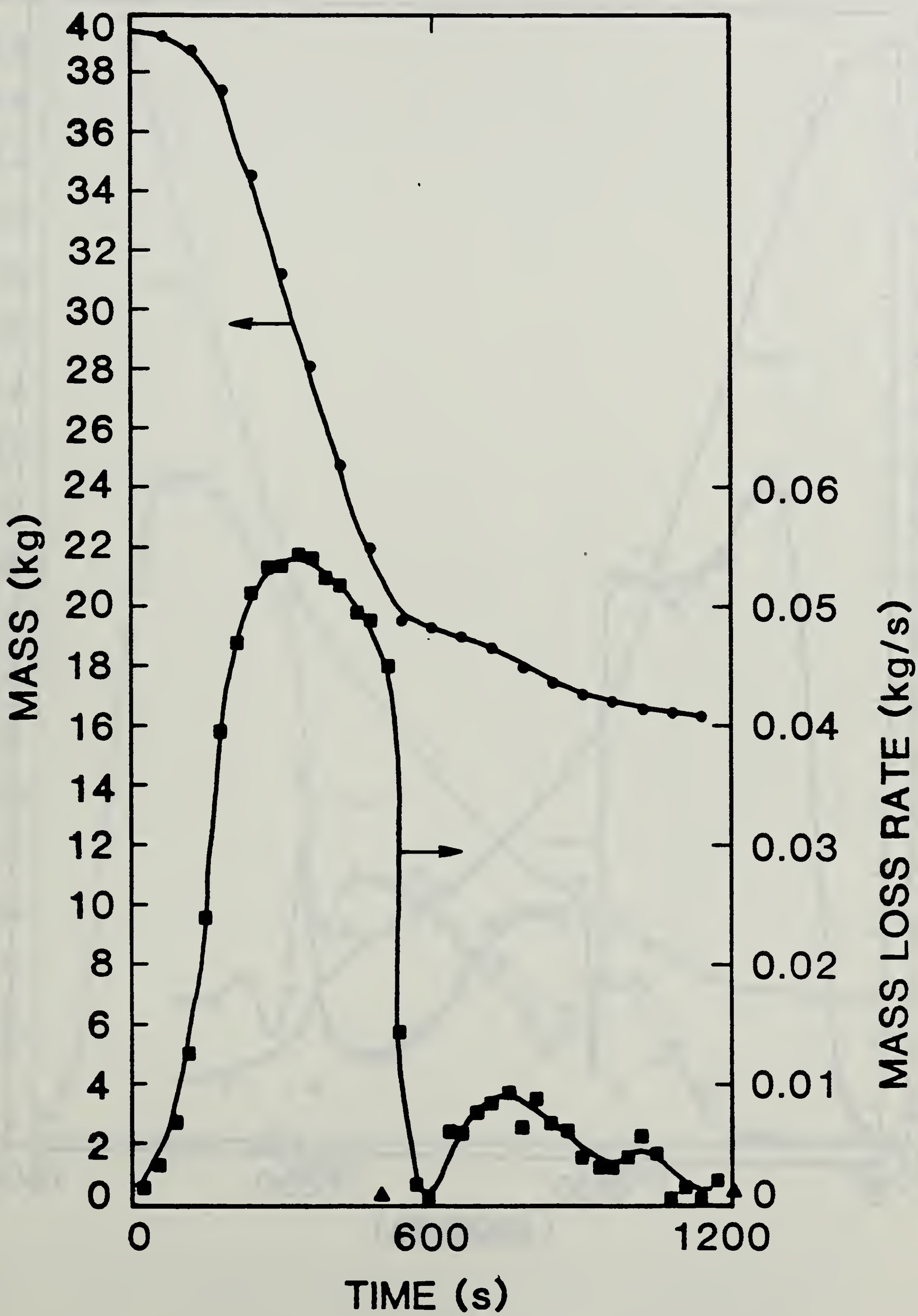


Figure 28. Fuel Mass and Mass Loss Rate

Test Number 4

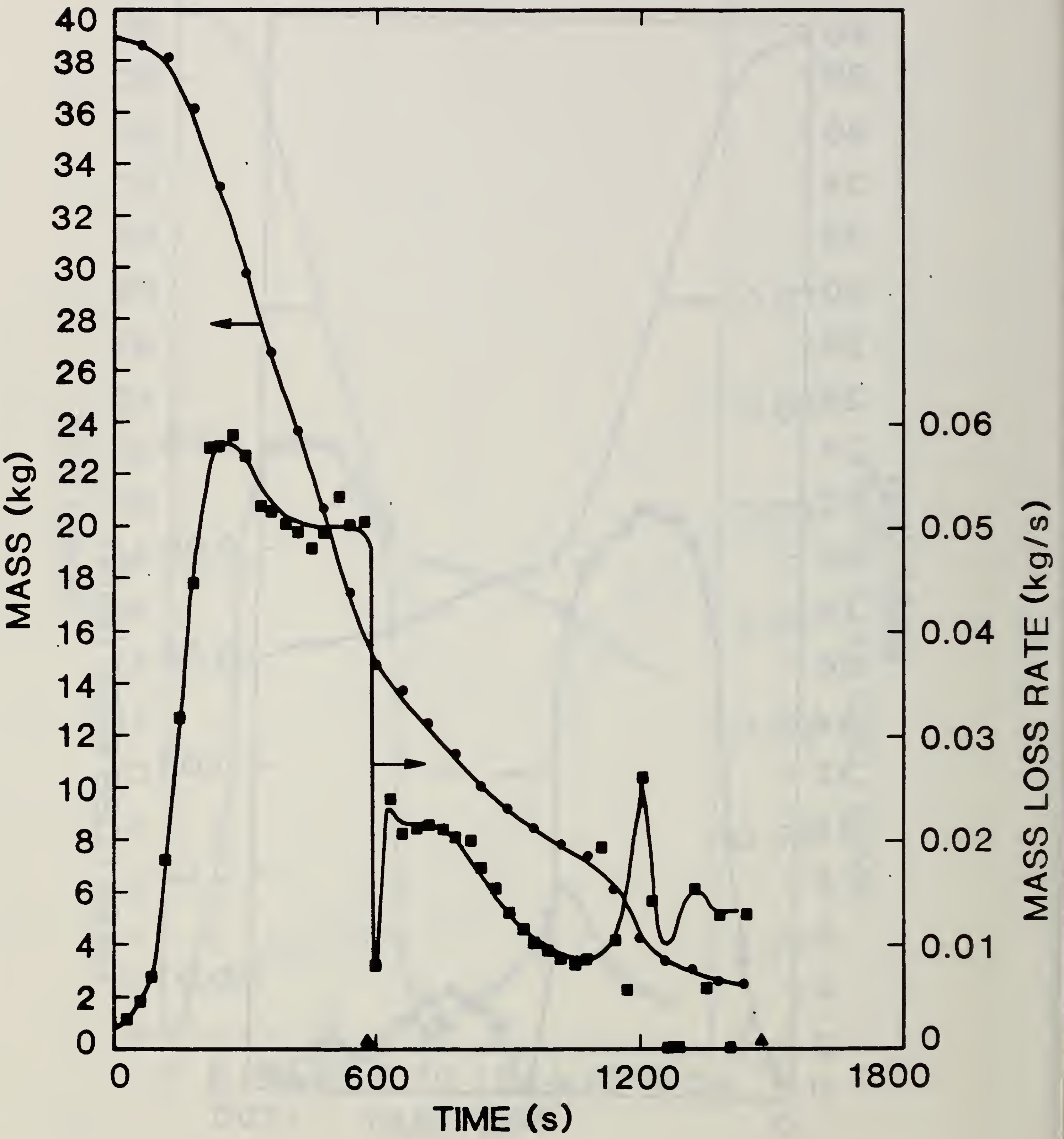


Figure 29. Fuel Mass and Mass Loss Rate

Test Number 5

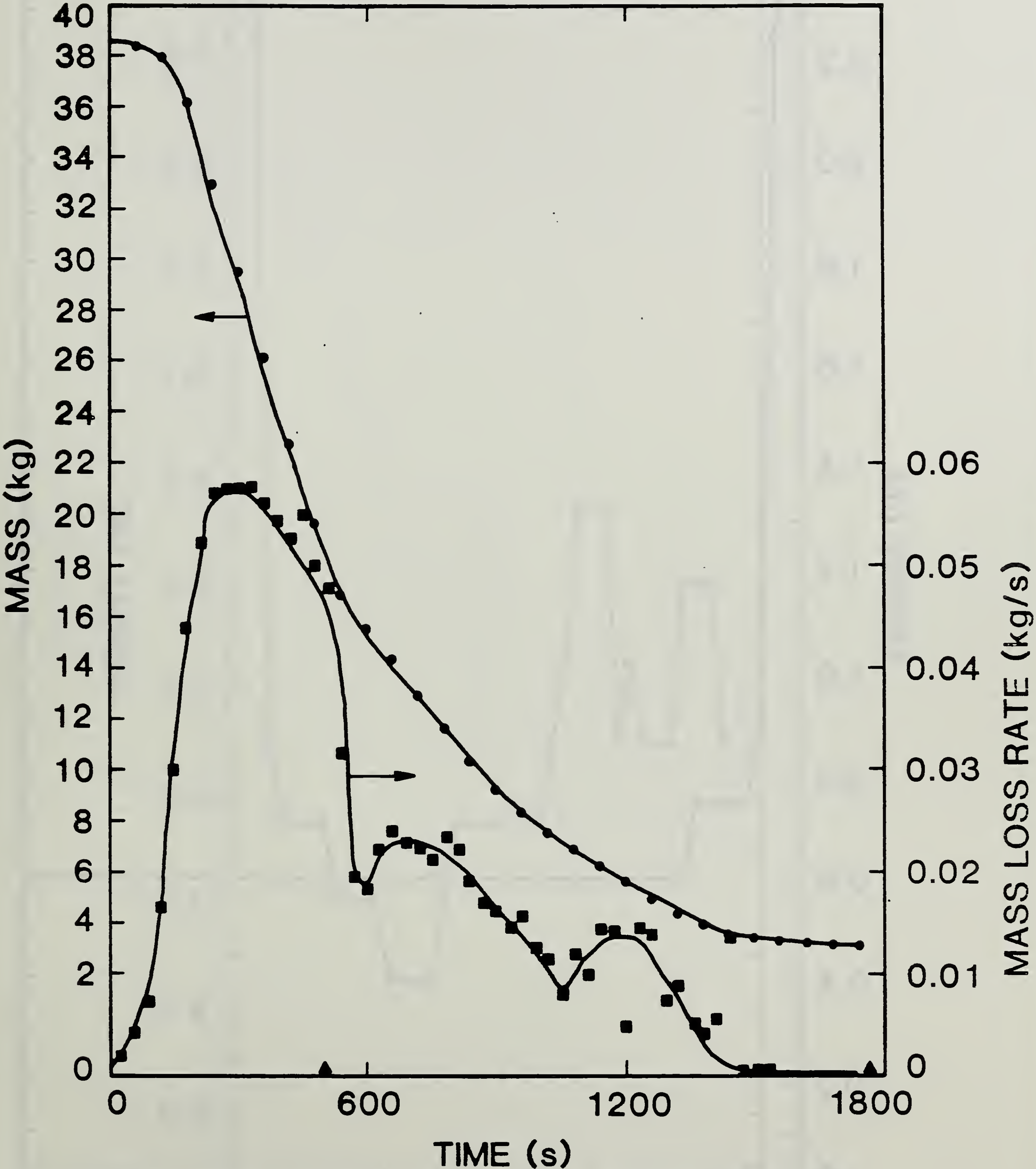


Figure 30. Depth of Lower Layer
Test Number 1

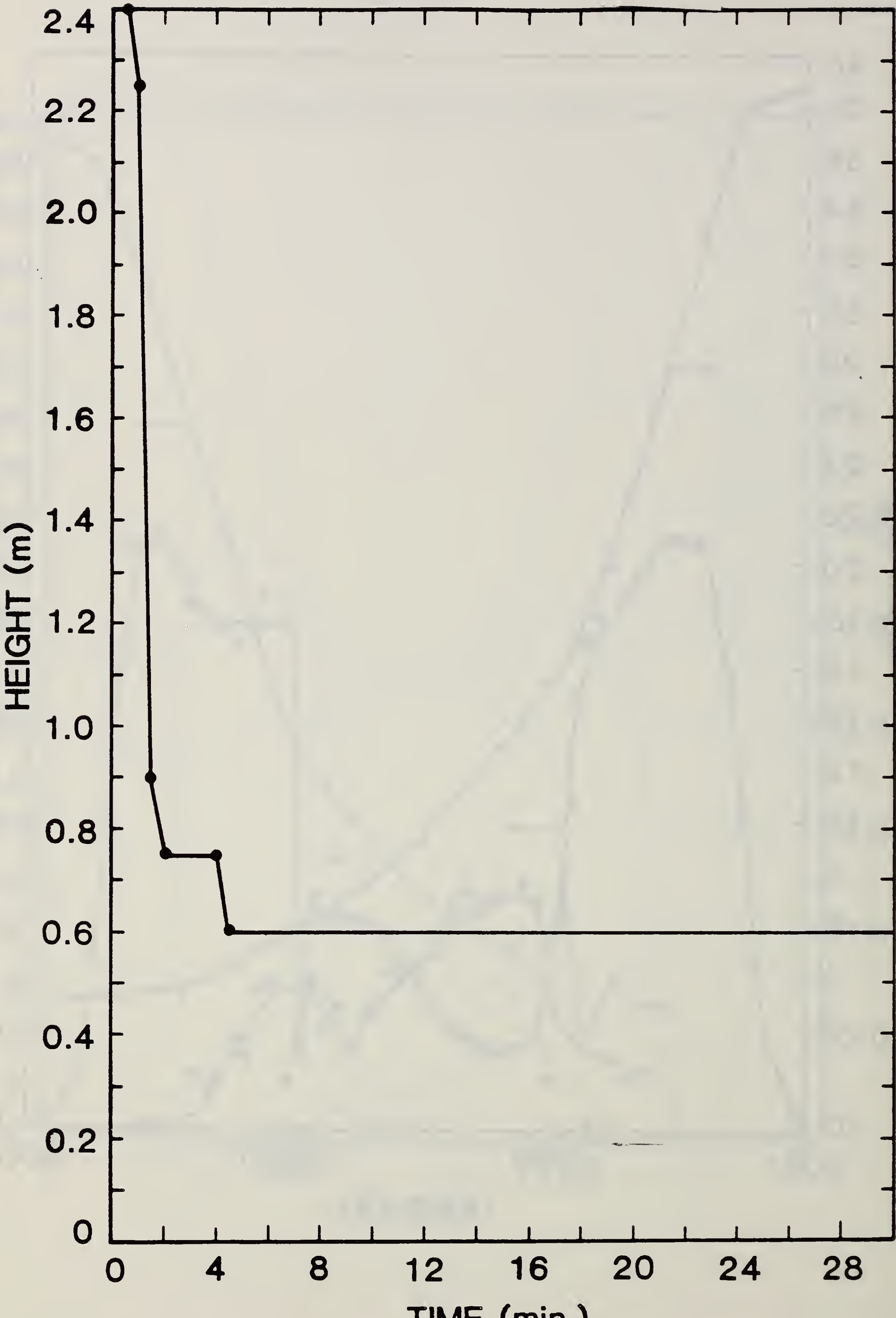


Figure 31. Depth of Lower Layer
Test Number 2

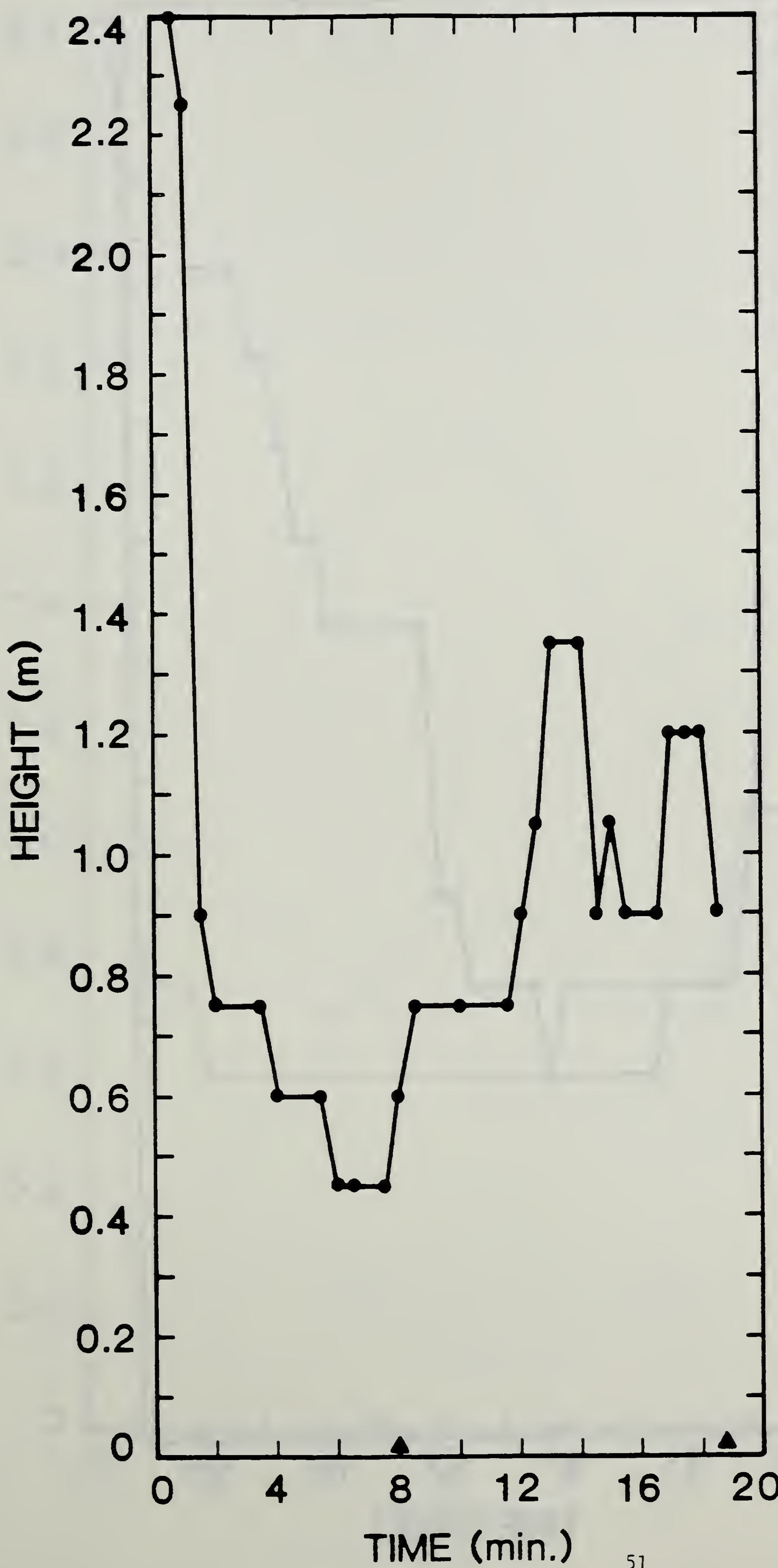


Figure 32. Depth of Lower Layer
Test Number 3

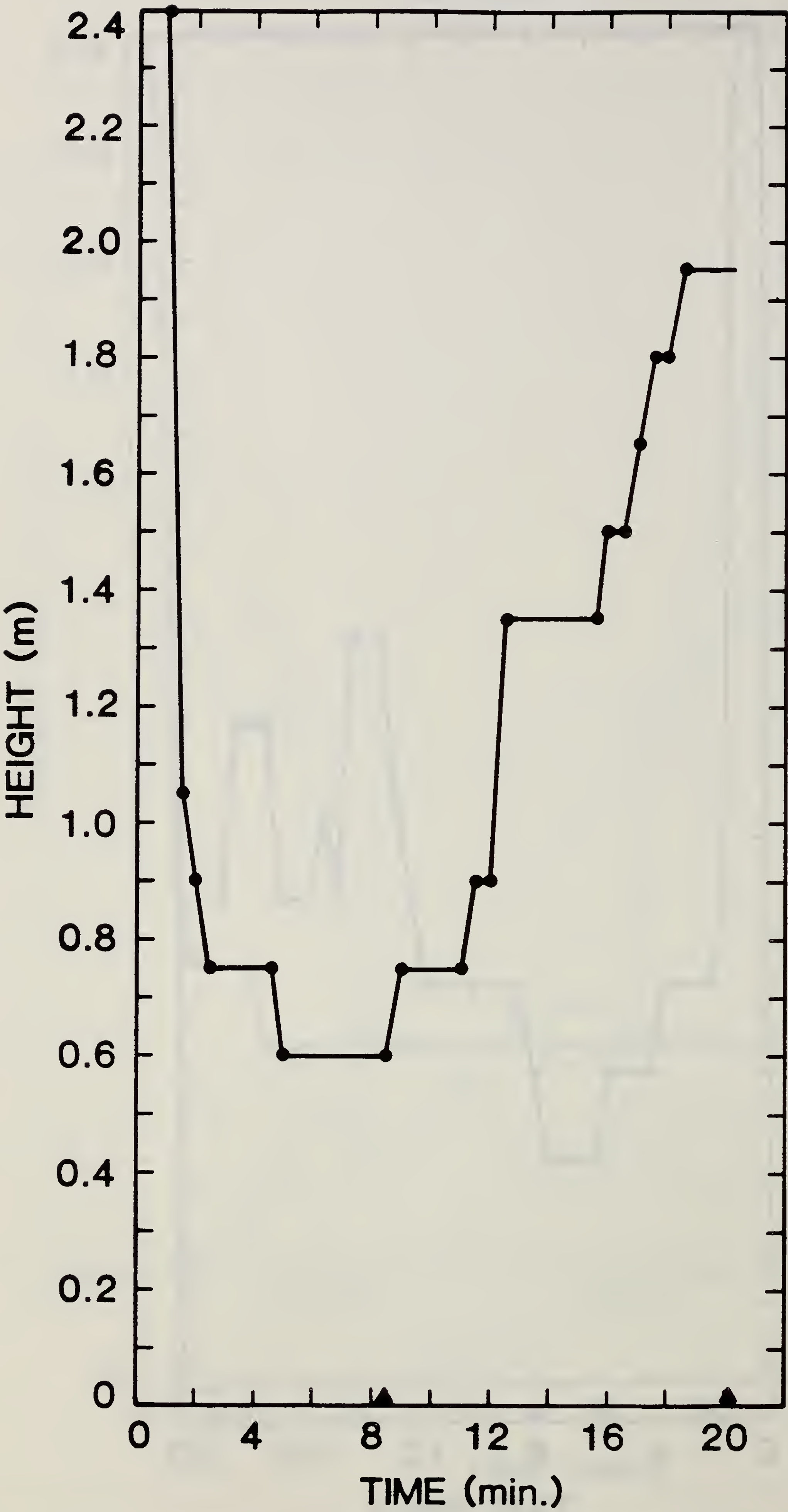


Figure 33. Depth of Lower Layer
Test Number 4

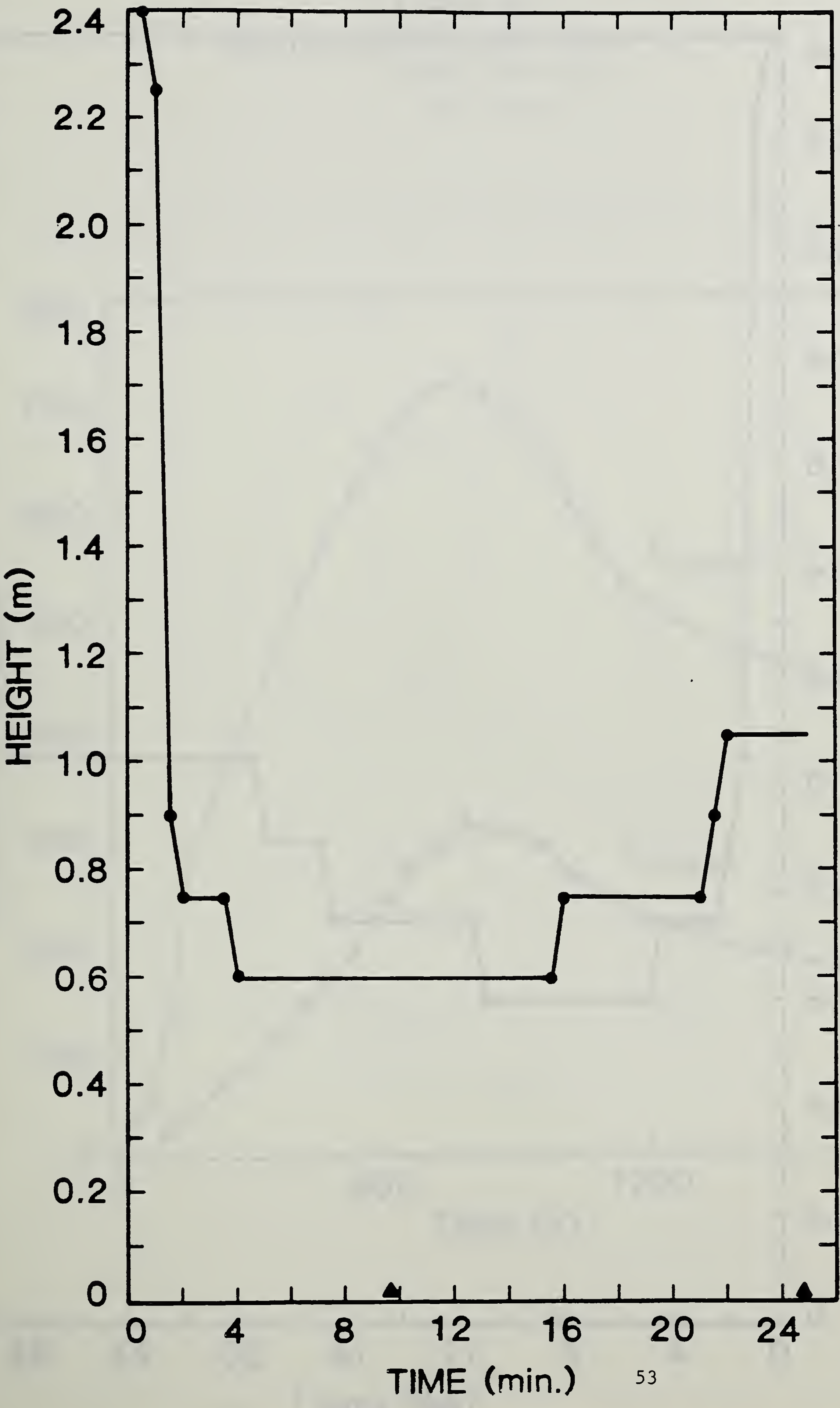


Figure 34. Depth of Lower Layer

Test Number 5

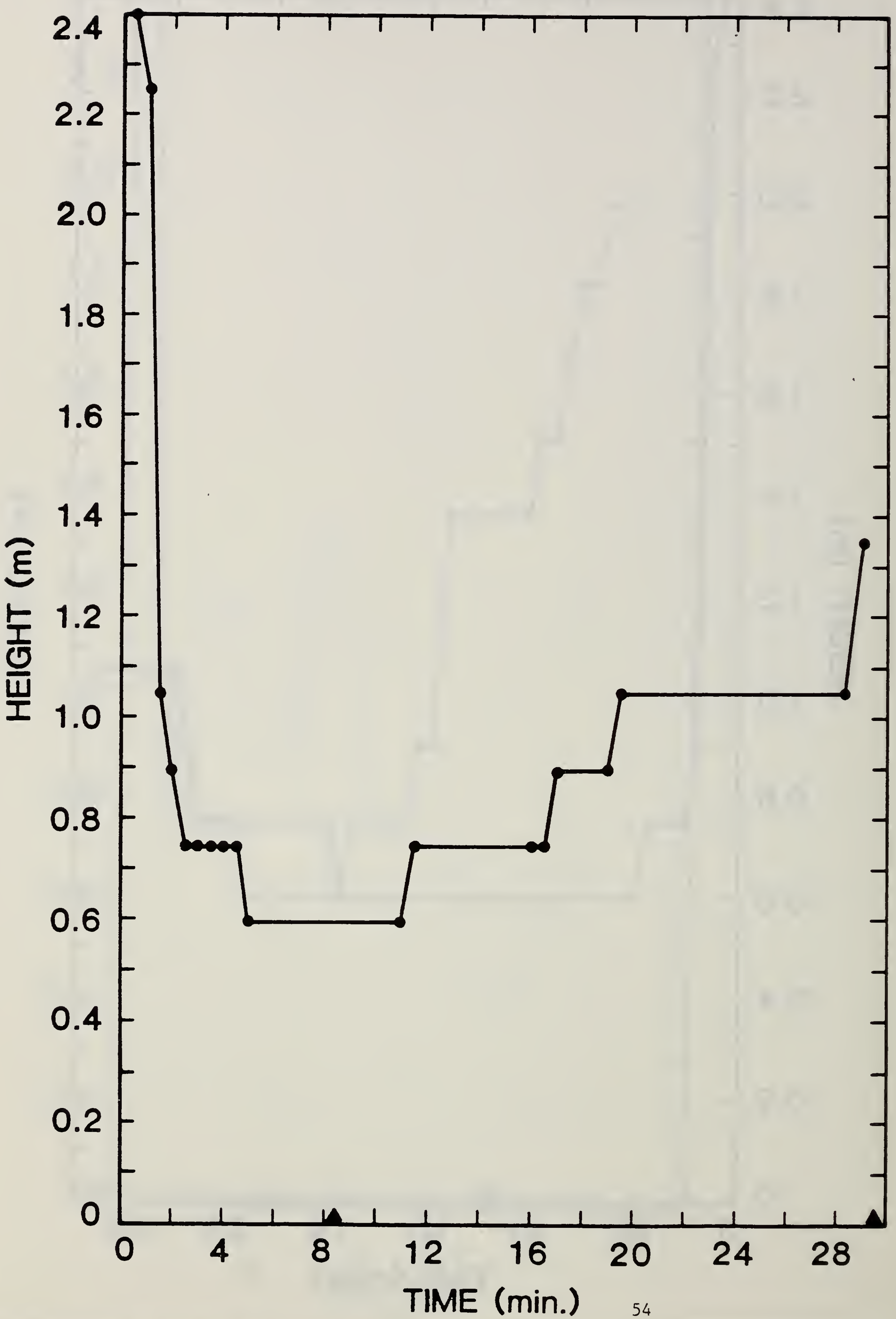


Figure 35. Upper and Lower Layer
Average Temperature

Test Number 1

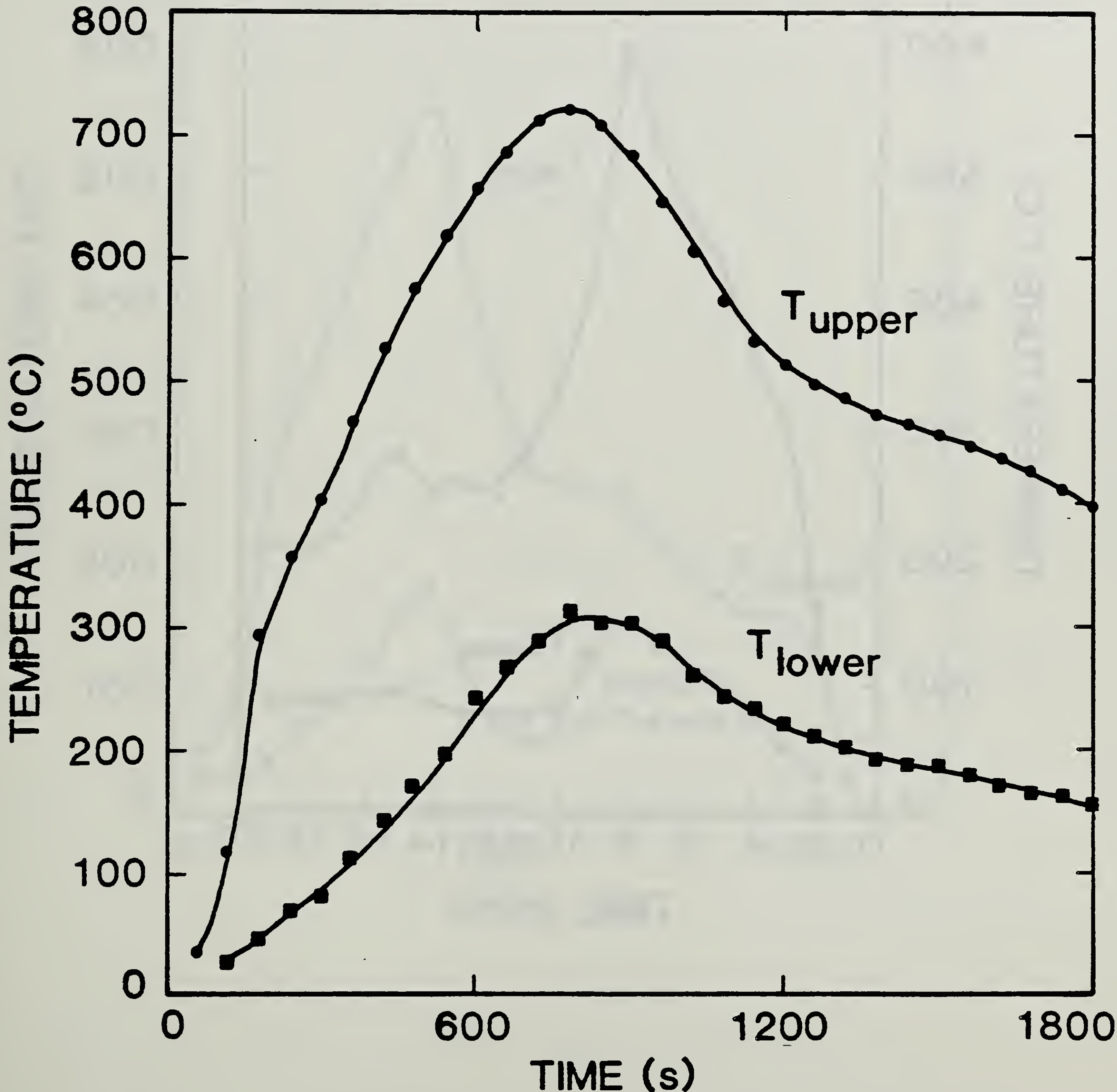


Figure 36. Upper and Lower Layer Average Temperature

Test Number 2

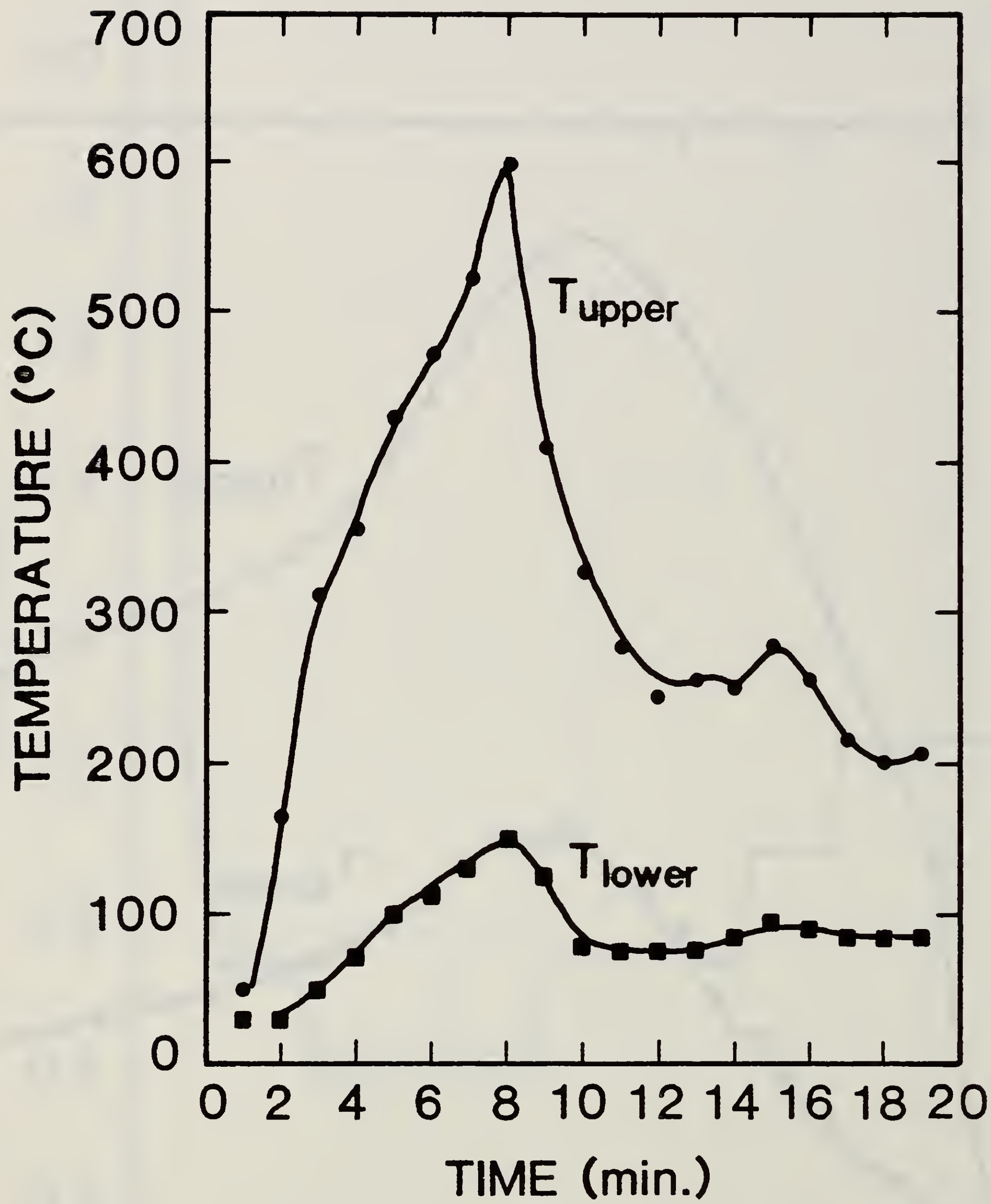


Figure 37. Upper and Lower Layer Average Temperature

Test Number 3

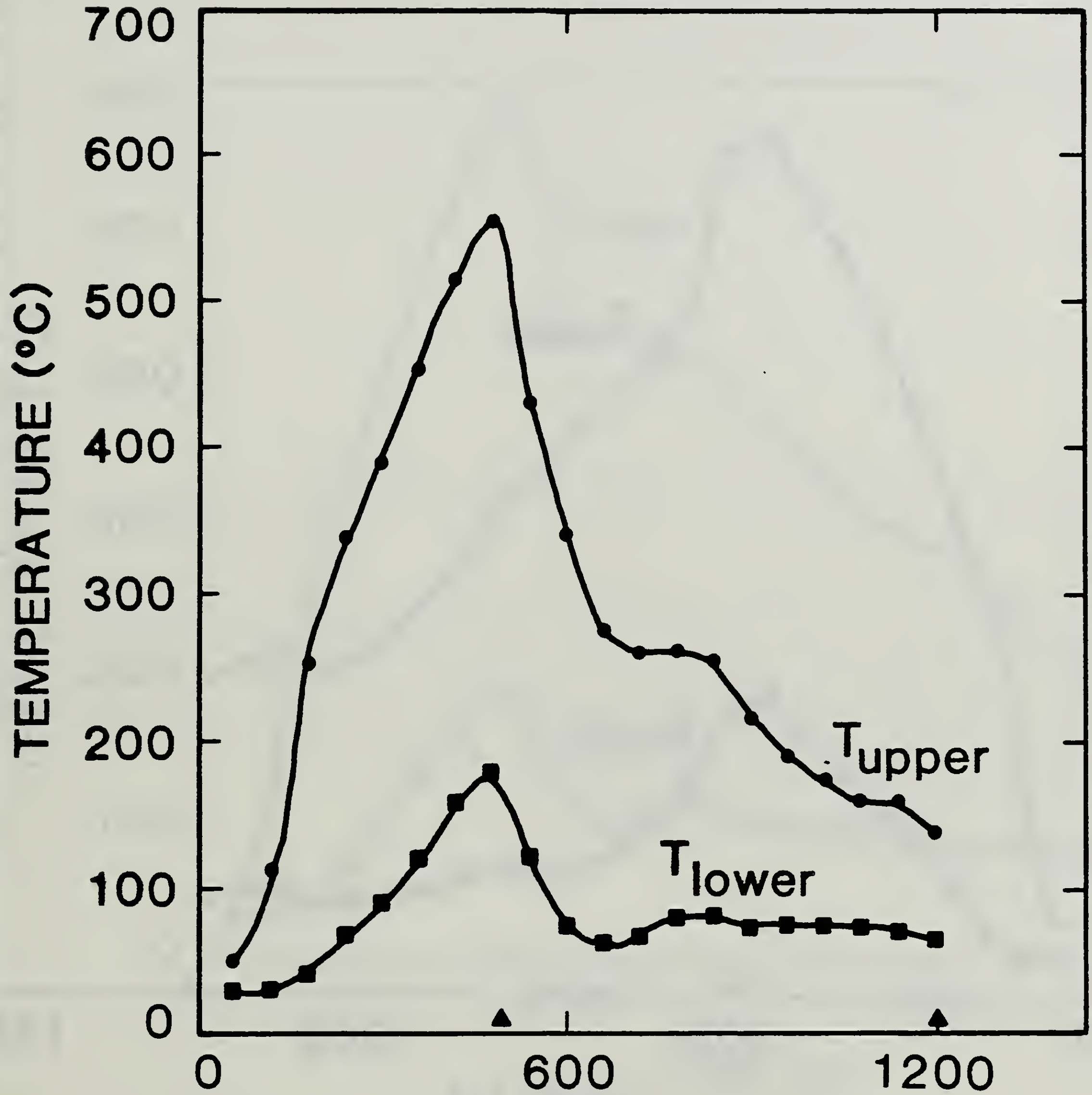


Figure 38. Upper and Lower Layer Average Temperature

Test Number 4

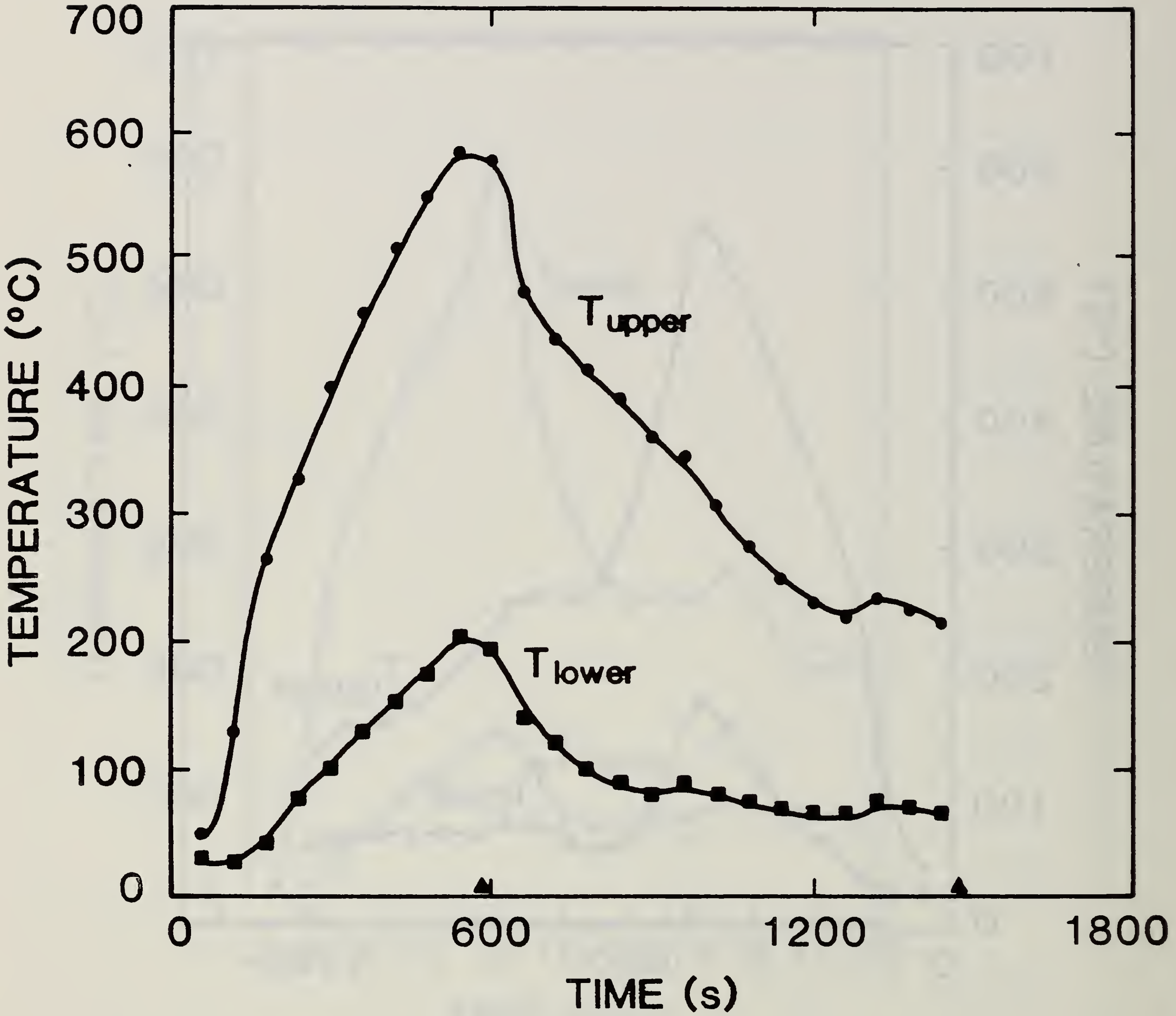
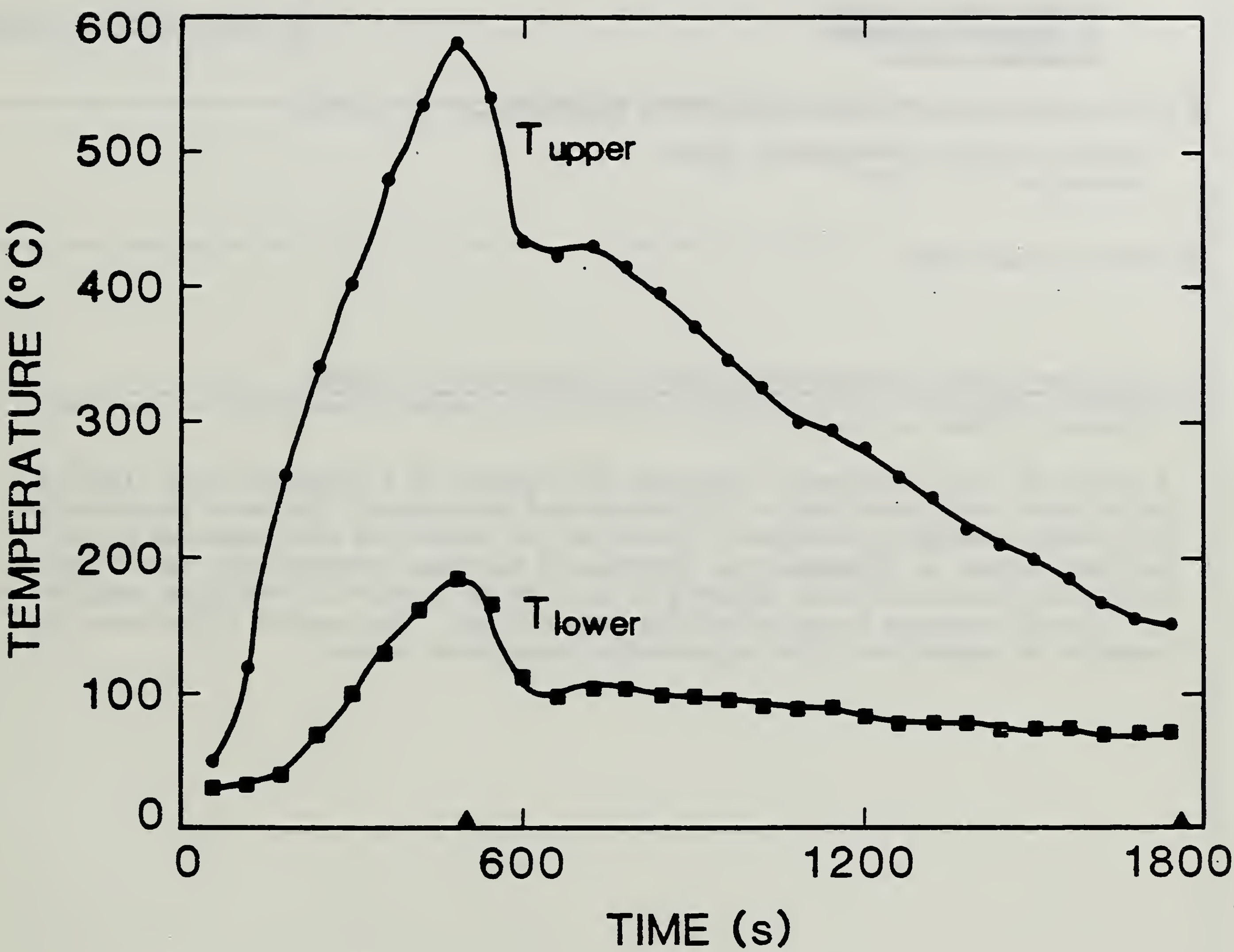


Figure 39. Upper and Lower Layer Average Temperature

Test Number 5



FORM NBS-114A (REV.11-84)

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4. TITLE AND SUBTITLE

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5. AUTHOR(S)

James Milke, David Evans, Warren Hayes, Jr.

6. PERFORMING ORGANIZATION *(If joint or other than NBS, see instructions)*

NATIONAL BUREAU OF STANDARDS
U.S. DEPARTMENT OF COMMERCE
GAITHERSBURG, MD 20899

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

Federal Emergency Management Agency
Washington, DC 20472

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

A series of five experiments examining the effects of a simulated fire fighting water spray introduced into a fully-developed compartment fire were conducted for the Federal Emergency Management Agency by the Center for Fire Research at the National Bureau of Standards per Interagency Agreement (EMW-E-1239) Task Order 4A. Data from these tests were intended to be used as a check of predicted results from the Mission Research Corporation Fire Demand Model. The results illustrate the dynamics of compartment fire suppression using water sprays.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

crib fires; extinguishment; firefighting; room fires; sprinklers; water spray

13. AVAILABILITY

- [X] Unlimited
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