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# JSC/FAA INSTRUMENTATION VALIDATION TESTS

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## INTRODUCTION

The FAA has requested NASA/JSC to perform approximately 20 component and full-scale tests in a 737 fuselage located at JSC to provide validation data or indicate changes that need to be made to a fire math model (Dayton Aircraft Cabin Fire Model) developed for the FAA.

The instrumentation required for this test program is more extensive than in previous full-scale tests and in some cases is based on undeveloped techniques; therefore, 3 preliminary tests were conducted to validate the adequacy of planned instrumentation.

This report covers the results of these 3 tests.

## OBJECTIVES

The primary objective of these preliminary tests was to evaluate instrumentation techniques planned for use in a subsequent joint program with the FAA. The specific objectives were as follows:

1. Evaluate tracking of flame propagation on burning materials by the appropriate location of thermocouples on a given test specimen.
2. Measure the burning rate of the flammable materials (of a given test specimen) during the test by continuous weighing of the test specimen.
3. Evaluate the NBS photometric smoke measurement system and compare its results to those of a laser smoke measurement technique.
4. Evaluate the capability of a recently developed bidirectional gas flow device for measuring variable gas flows during flammability tests.
5. Collect gas samples and measure quantities for six gases ($O_2$, $CO_2$, CO, HF, HCN, and HCL).

## DESCRIPTION

Three tests were conducted in a 20 foot section of a 737 fuselage (1400 cu. ft.) utilizing jet A-1 fuel as the ignition source. In test 1 the test specimen consisted of a mockup aircraft seat with state-of-the-art fire resistant aircraft seat cushion foam in the configuration shown in figure 1. The ignition source was one liter of jet A-1 fuel in a pan 12" x 12" located as shown in figure 2. The seat was suspended from a load cell with a cable and bridle system as shown in figure 2. To prevent excessive sidewise movement of the seat due to air currents, right angle tabs were fastened to the floor at each leg position with approximately 1/4" clearance between the tabs and legs. The bottom of each chair leg was approximately 1-1/2" above the aircraft floor to prevent contact with the floor due to support cable thermal expansion. In test 2 the configuration was the same except lower density non-fire retardant foam was used. Test 3 was conducted to further evaluate techniques for measuring weight loss of burning fuel. The fuel for this test consisted of 2-1/2 liters of jet A1 fuel in a pan 18" x 18" located on the seat frame so that the same load cell and bridle used for tests 1 and 2 were used for this test.

## INSTRUMENTATION

Instrumentation was installed as described in the following paragraphs.

Thermocouples - The fire-resistant seat foam for test 1 was instrumented with thermocouples as shown in figure 3. A temperature probe was located above the fuel pan to indicate approximate flame temperatures. Additional thermocouples were located on two thermocouple trees as shown in figure 4. The seat foam in test 2 was not instrumented since the primary object of that test was to verify weight loss measurements.

Load Cells - A 100 pound load cell to measure materials or fuel weight loss during the tests was suspended from a bracket outside the fuselage directly above the seat position. A cable from the load cell traversed through a tube that penetrated the fuselage. A bridle attached at four points of the chair converged to a point directly above the chair center of gravity where it was attached to the cable suspended from the load cell (fig. 2).

Smoke Measuring Equipment - A laser source located 3 feet from its sensor was used along with an NBS photometric smoke measurement system which has a light source one meter from its sensor. These devices were located adjacent to each other approximately 5 feet from the fire and 5 feet above the floor (figure 4).

Bidirectional Gas Flow Probe - A probe to measure low gas velocities based on differential pressure measurements was located as shown on figure 4. The probe was connected with lines to a pressure differential sensor.

Movie Cameras - Two movie cameras were located as shown in figure 4 to photograph the seat during tests 1 and 2. Color film was used at 24 frames per second (realtime) in both cameras.

Still Photography - Still color photographs of the test specimen were taken before and after the initial test.

## GAS COLLECTION AND ANALYSIS

Two systems were used to collect the products of combustion produced in tests 1 and 2. One system utilized microimpinger bubblers to collect hydrolyzable gases (hydrogen cyanide, hydrogen fluoride, and hydrogen chloride). The other system utilized stainless steel collection vessels for collection of non-hydrolyzable gases (carbon monoxide, carbon dioxide, and oxygen). A photograph of the gas collection systems is shown in figure 4. Two ports (one for hydrolyzable gases and the other for non-hydrolyzable gases) were located at each of the two positions shown, 5 feet above the cabin floor. Methodology for each system is as follows:

Hydrolyzable Gas Collection and Analysis - Collection was accomplished with 44 glass microimpinger bubblers filled with 10 ml of 0.1 molar sodium hydroxide solution. The gas collection lines were heated above the dew point to avoid condensation losses, and the air flow rate through each bubbler was 400 ml/minute. Samples were taken every 60 seconds during a 5 minute collection period, plus background samples. Test solutions collected were analyzed with solid state specific ion electrodes.

Non-hydrolyzable Gas Collection and Analysis - Non-hydrolyzable gases were collected in twelve 32-liter stainless steel collection vessels. Because these bottles fill up in 25 to 30 seconds, samples were taken for 30 seconds in the middle of each 60 second bubbler sample interval. The gas samples collected were analyzed using gas chromatography.

## TEST RESULTS

In test 1 after ignition of the jet A-1 fuel ( that is, when the fire completely covered the fuel pan area), approximately 1 minute elapsed prior to significant involvement of the foam in the fire. The jet fuel and foam produced large quantities of smoke that obscured camera visibility approximately 1-1/2 minutes after ignition. The foam melted as it burned, which resulted in the dripping of many flaming particles. The fire burned out after approximately 6 minutes, and although all of the seat bottom was gone, a large portion of the back remained as shown in figure 5. The pre-test weight of the foam was 6.4 lbs and post-test weight of the remaining foam was 2.2 lbs for a total weight of foam burned or melted of 4.2 lbs.

Thermal Data - The temperature responses of four centrally located thermocouples on the seat cushion and back for the first 5 minutes of test 1 are shown in figure 6. Peak temperatures were 1200° F to 1400° F, occurring from 1 minute to 2 minutes when all of the temperatures gradually went down. This was apparently due to the direct flame impingement and the foam receding from the thermocouples as the foam was consummed.

One of the test objectives was to determine the feasibility of tracking fire propagation through thermocouple response; figures 7 through 14 are presented with this objective in mind. Since most of the thermocouples on the foam responded in the first 90 seconds, the time span used on figures 7 through 13 is 100 seconds rather than the full 5 minutes used on the other figures. This expanded time scale permits a better view of the point in time at which the rapid temperature rise indicates flame impingement on the seat. Figure 7 shows the spread of fire reaching four thermocouples on the seat cushion bottom. Thermocouple 3 is closest to the fire and on the side to which the air flow tends to direct the fire and consequently is the first to rise. Its initial reading of 250° F results from calling "time zero" the time at which the fuel pan is covered with fire, which is usually several seconds after ignition because of the slowness of jet A-1 to ignite. Temperatures from thermocouples 2, 4, and 1 follow in expected order based on the fire location and air flow pattern. The other three thermocouples on the seat bottom (fig. 8, thermocouples 5, 6, and 7) do not show a significant spread in time. The opposite pattern occurs on the top of the same seat cushion, as shown in figures 9 and 10, and, as would be expected, the temperature rises occur 30-45 seconds later than on the bottom. All thermocouples on the fire side of the seat cushion back (figs. 11, 12, and 13) show a fairly definite point in time where a significant temperature rise occurs on this surface. Figure 14 shows the relatively lower temperatures occurring on the back side of the seat back, as would be expected from the limited damage on this surface (as shown in fig. 5).

Figure 18 shows four air temperatures 8-feet forward of the fire, and figure 19 shows four air temperatures 5-feet aft of the fire. Maximum temperatures occur at about the same time as those of the seat.

Weight Loss Data - The weighing of the seat frame and foam during test 1 to determine the burning rate of the foam resulted in anomalous data. A weight loss of approximately 3 times the weight of the foam apparently resulted from some constraint or friction between the seat legs and the restraining tabs. Additional tests resulted in weight loss with time rates close to that expected. Test 2 was conducted using a non fire-retardant polyurethane foam which produced a weight loss with respect to time (fig. 15). Test 3 was conducted with a much slower burning fuel (2-1/2 liters of jet A-1 in an 18" X 18" fuel pan located on top of the seat) with the results shown in figure 16. Both tests produced inherent minor inaccuracies concerning actual weight loss due to burning. While the foam was burning, considerable melting and dripping of flaming particles occurred, resulting in some weight loss of material that may not have been due to burning. The burning liquid fuel floats on water and after a period of time the water starts boiling, resulting in weight loss in addition to that of the burning fuel. The weight loss of the water can be determined after the test but not the rate or time of loss.

Smoke Density - A laser system and an NBS smoke density measuring system were used to measure the loss of visibility due to smoke during test 1 (fire retardant polyurethane foam). The comparative results indicate good correlation between the two techniques (fig. 17). The initial levels of smoke density of 17% and 25% are mainly due to the smoke evolved from the hot ignitor prior to ignition of the fuel and during the time the flames cover the fuel pan. The laser system has a time delay smoothing circuit in the electronics which may account for the somewhat smoother data.

Gas Flow Measurements - The bidirectional gas flow system was not calibrated in the 737 fuselage prior to the tests and the results are not considered to be verified. Prior to subsequent tests, the system will be calibrated in the fuselage for various rates of air flow.

Gas Analysis Results - For tests 1 and 2 the concentrations of hydrogen cyanide, carbon monoxide, carbon dioxide, and oxygen are shown as a function of time after ignition in figures 21 through 24. Fluorides were not detected in either test, and no fluoride was expected. No chloride was detected (above 12 ppm) in the non-fire resistant polyurethane foam, but low levels of chloride (12 to 50 ppm) were produced by the fire resistant foam. Generally, combustion product concentrations were greater and oxygen concentrations were lower at the aft ports. This is usually the case because the aft port is only 5 feet from the centerline of the fire, while the forward port is 8 feet away. In addition, the air flow is from fore to aft. The maximum concentrations of nearly all the products of combustion analyzed were obtained 1 to 2 minutes after ignition in both tests. All the minimum concentrations of oxygen were found 2 to 3 minutes after ignition.

## CONCLUDING REMARKS

Three tests were conducted to evaluate instrumentation techniques for a subsequent joint program with the FAA. Most of the test objectives were met or a need for further testing established. As indicated by test 1 results, tracking of flame propagation across burning materials can be determined from temperature response of thermocouples located on the test specimen. Weighing of test specimens and determining the burning rate of materials during burning was achieved. Care must be exercised to insure that the test specimen being weighed does not have any external interference, otherwise inconsistent results occur.

Measurements of smoke density provided by the laser technique and NBS smoke measuring system were in fairly good agreement. A time delay smoothing circuit in the laser system provided more uniform data than the NBS system. Similar circuitry could be applied to the NBS system; however, eliminating significant excursions in the data may not be desirable.

The time that elapses after ignition but prior to full involvement of the ignition fuel results in early response of thermocouples close to the fuel pan and also of the smoke density measurement system. A more rapid coverage of the fuel pan by the fire is desirable, and an attempt to achieve this is being made.

Test 1 conducted with fire resistant polyurethane foam provided greater concentrations of hydrogen cyanide (240 ppm) and carbon monoxide (1775 ppm) than in test 2 using the non-fire resistant polyurethane foam (36 ppm and 324 ppm, respectively). Peak concentrations were similar in both tests for carbon dioxide (2.6 and 2.9%) and oxygen (17.4 and 16.8%). The same volume of each foam was used, but the density of the fire resistant foam was nearly three times that of the non-fire resistant foam. In addition, only two-thirds of the fire resistant foam was consumed, while the non-fire resistant foam was totally destroyed by the fire.

The overall results indicate that the instrumentation planned for the JSC/FAA test program will provide useful data that will support the validation of, or indicate necessary changes to, the fire math model.

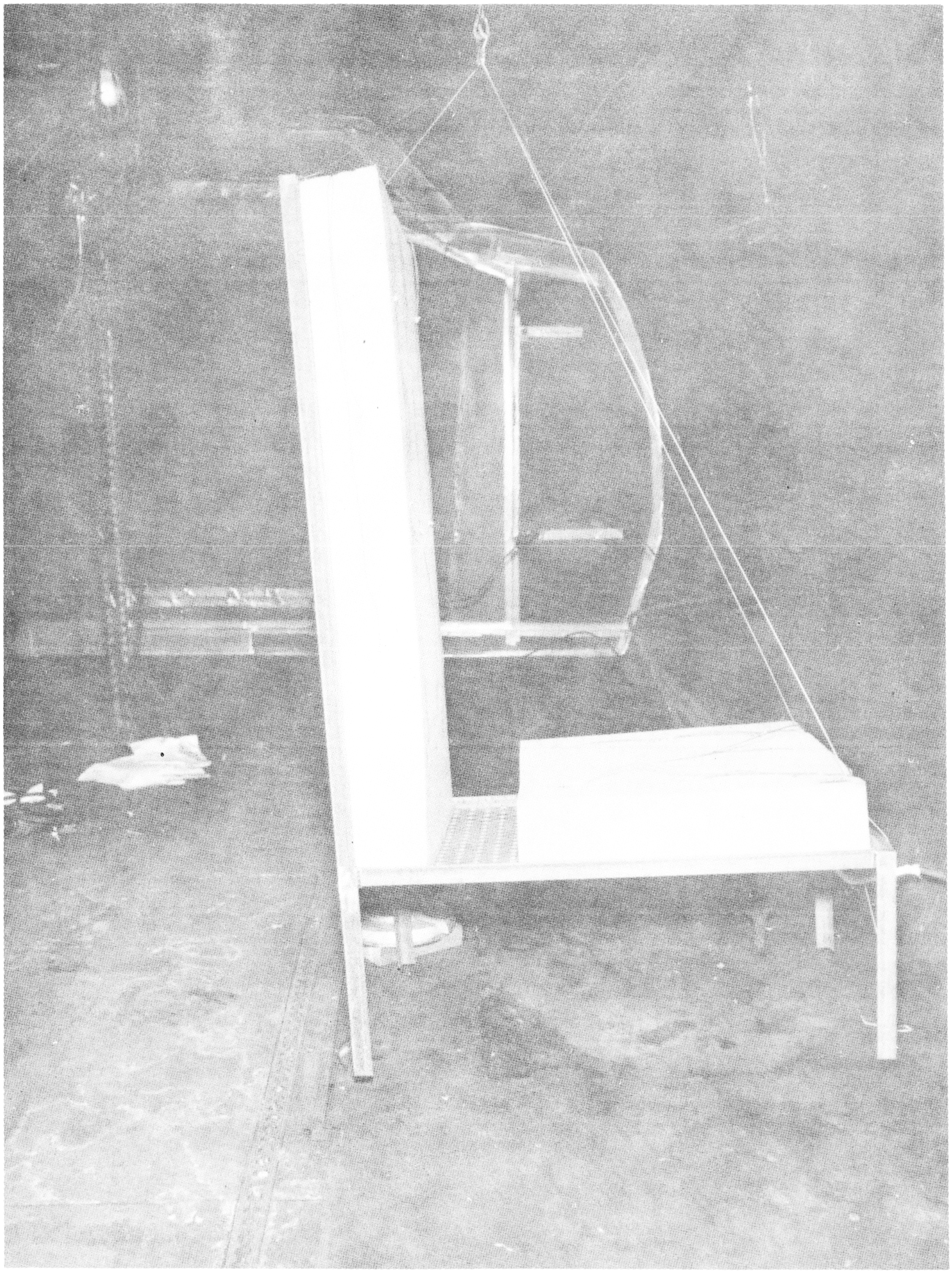

Figure 1.- Mockup seat with fire retardant polyurethane foam(test 1).

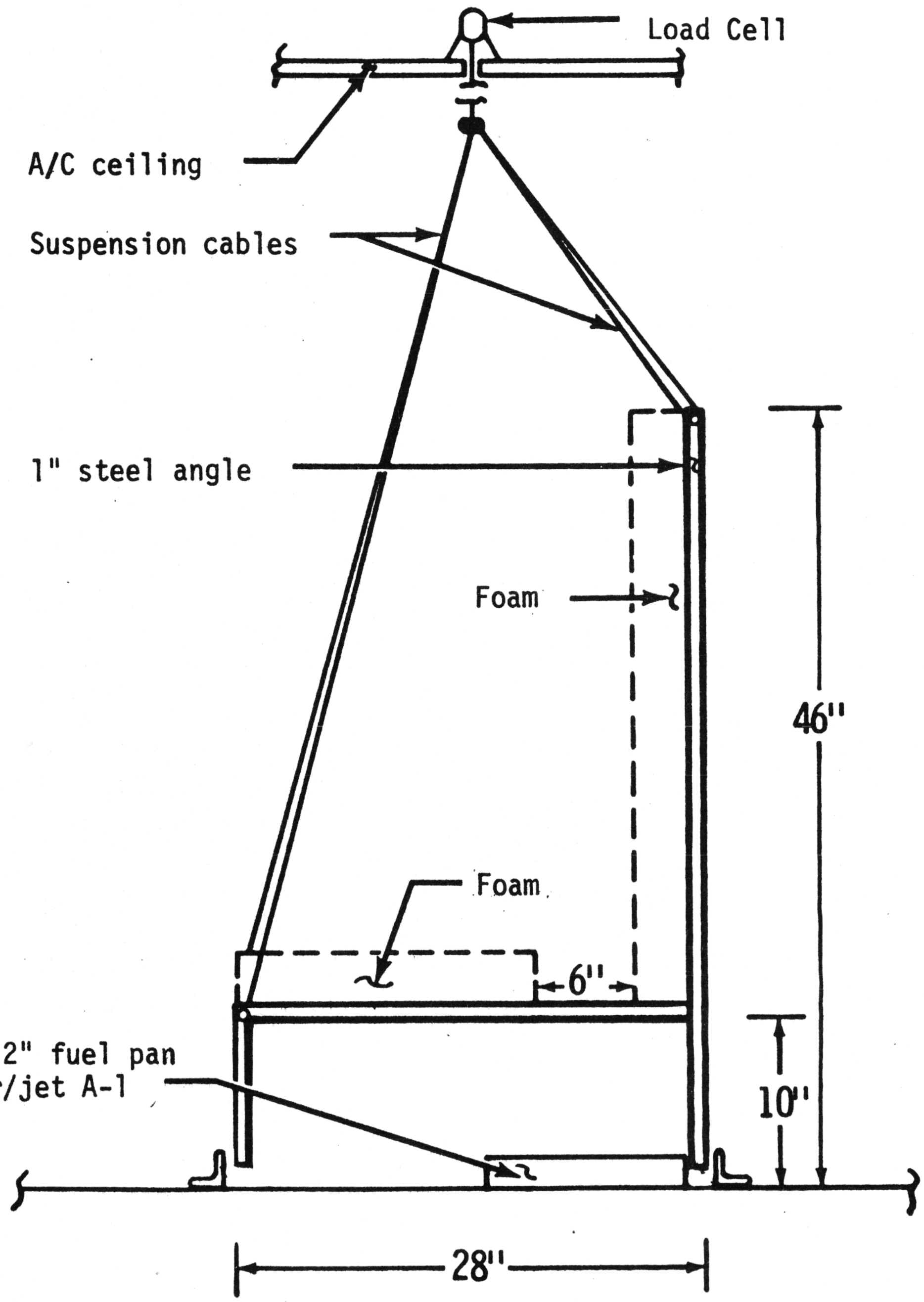


Figure 2.- Test configuration

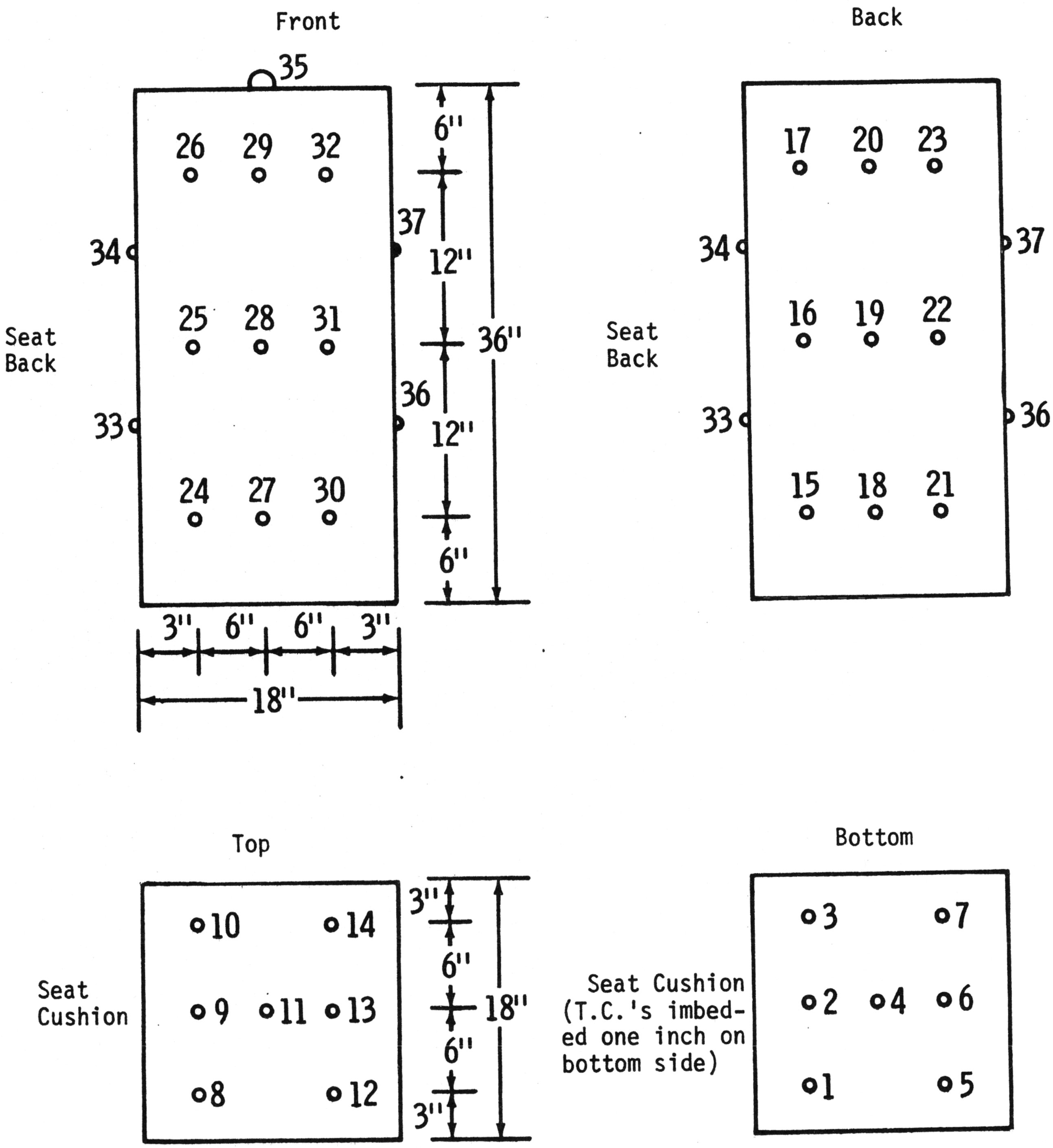


Figure 3.- Seat thermocouple locations (test 1).

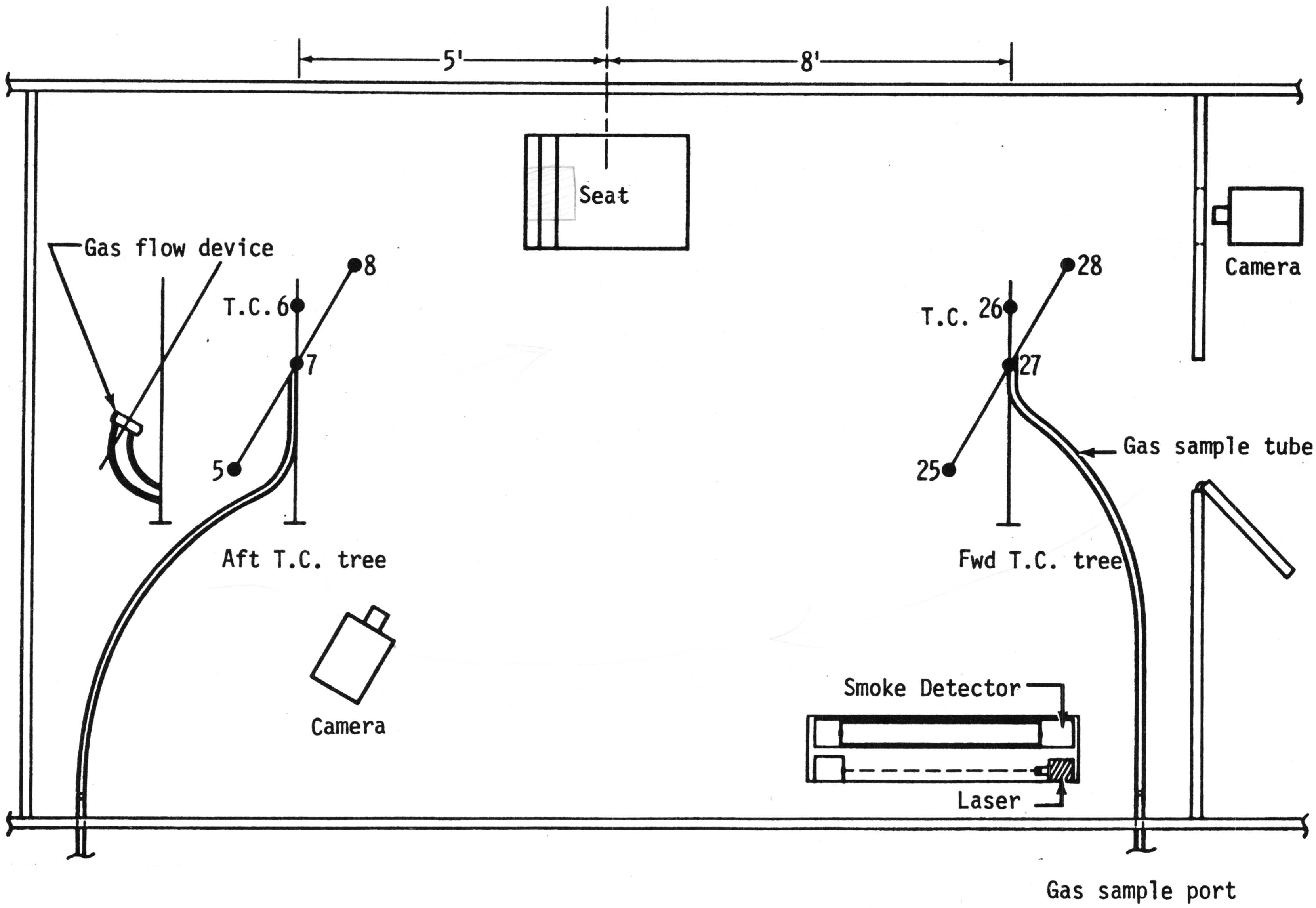


Figure 4.- Instrumentation locations.

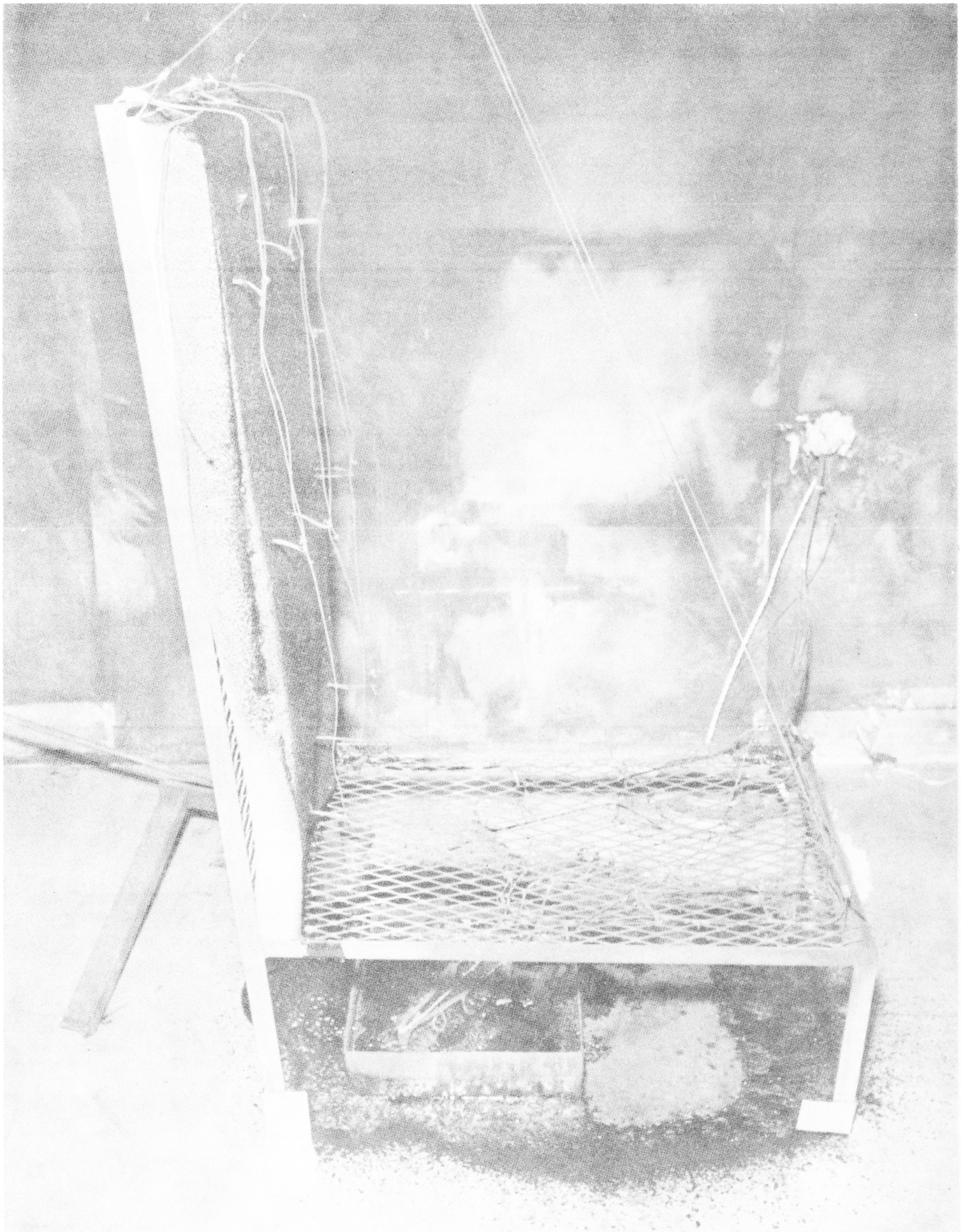

Figure 5.- Post test damage to fire retardant polyurethane foam (test 1).

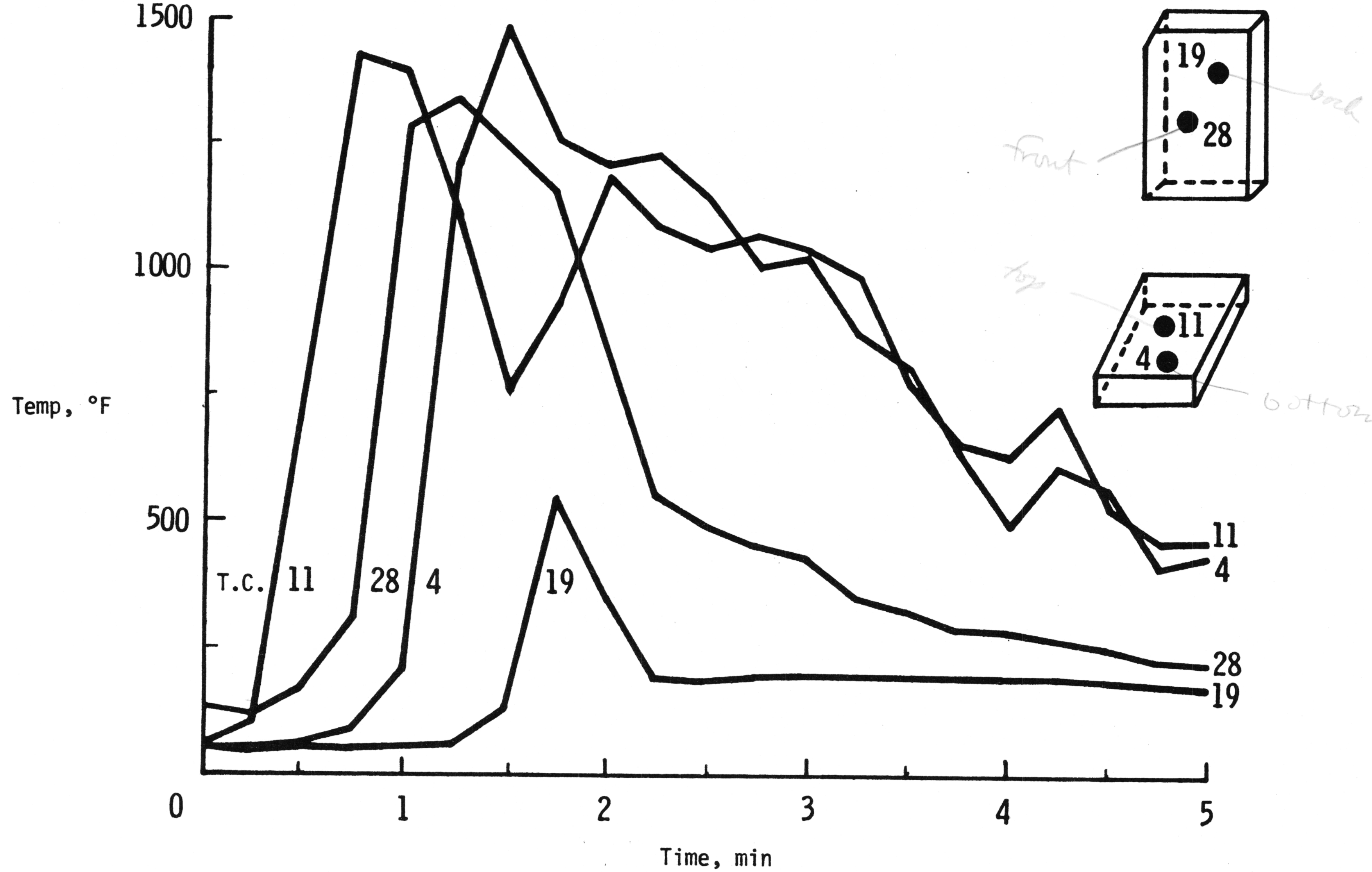


Figure 6.- Temperatures on seat back and cushion (selected T.C.'s in test 1).

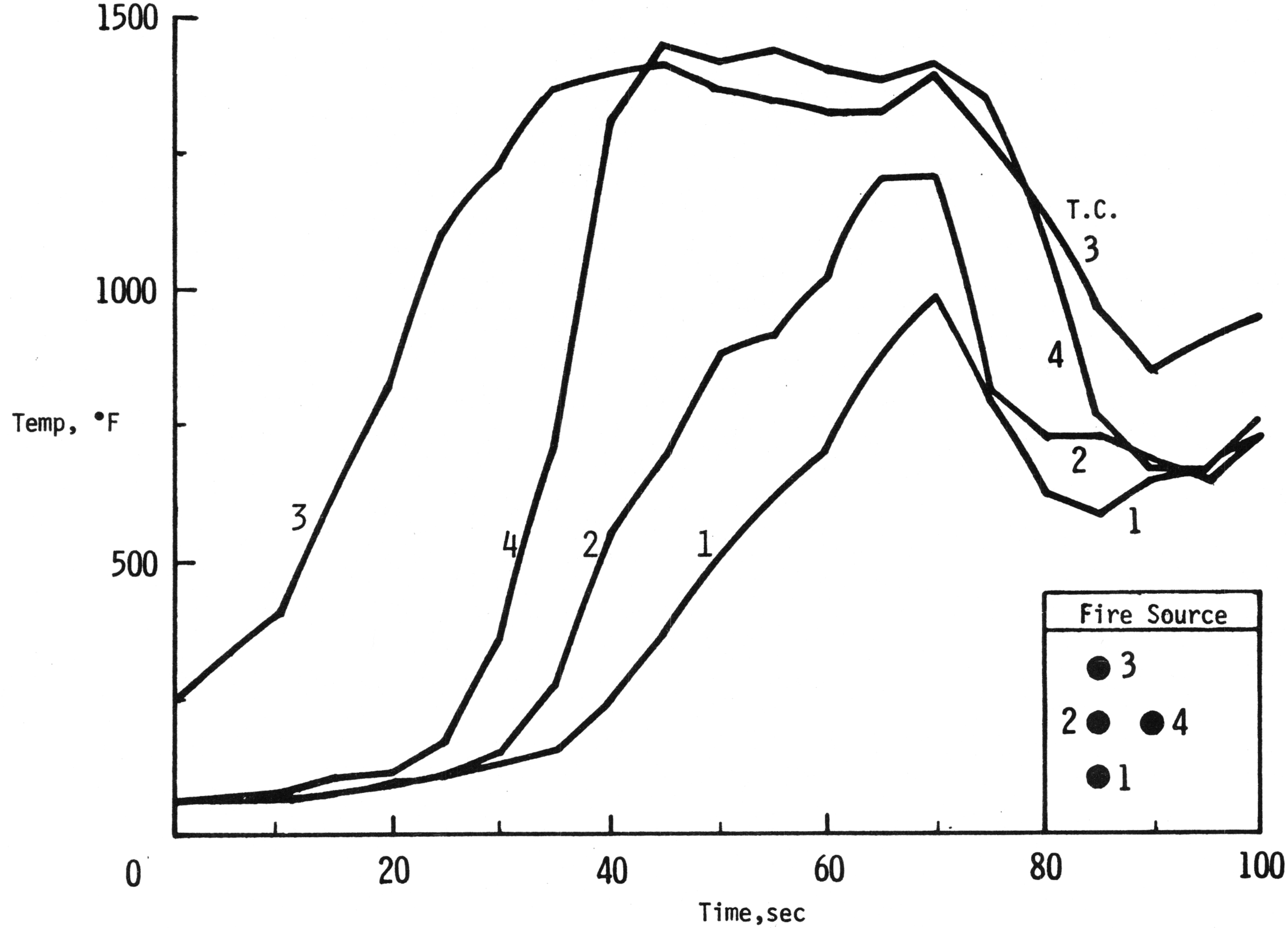


Figure 7.- Temperatures on bottom of seat cushion in test 1 (T.C.'s imbedded 1").

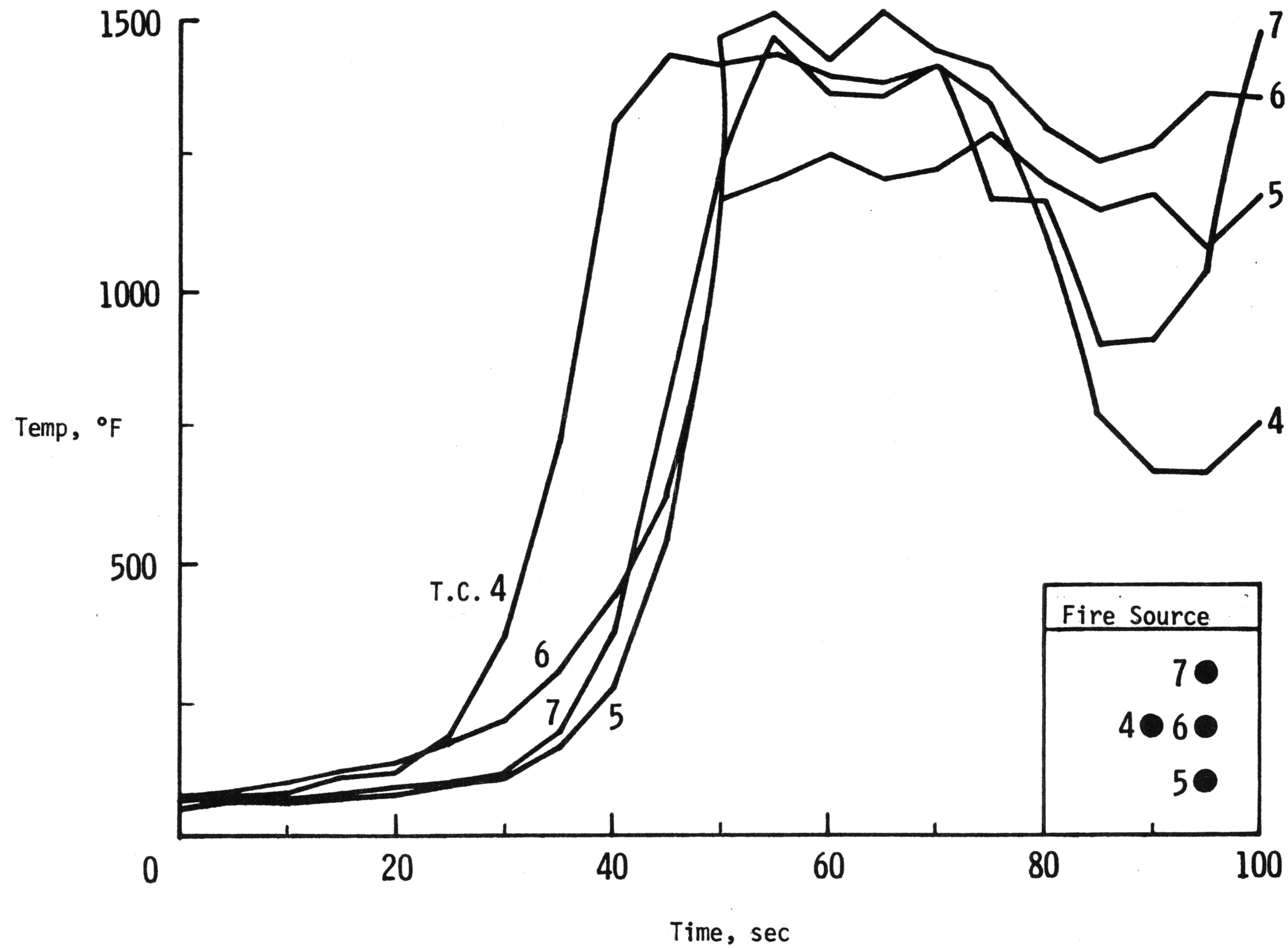


Figure 8.- Temperatures in bottom of seat cushion in test 1 (T.C.'s imbedded 1").

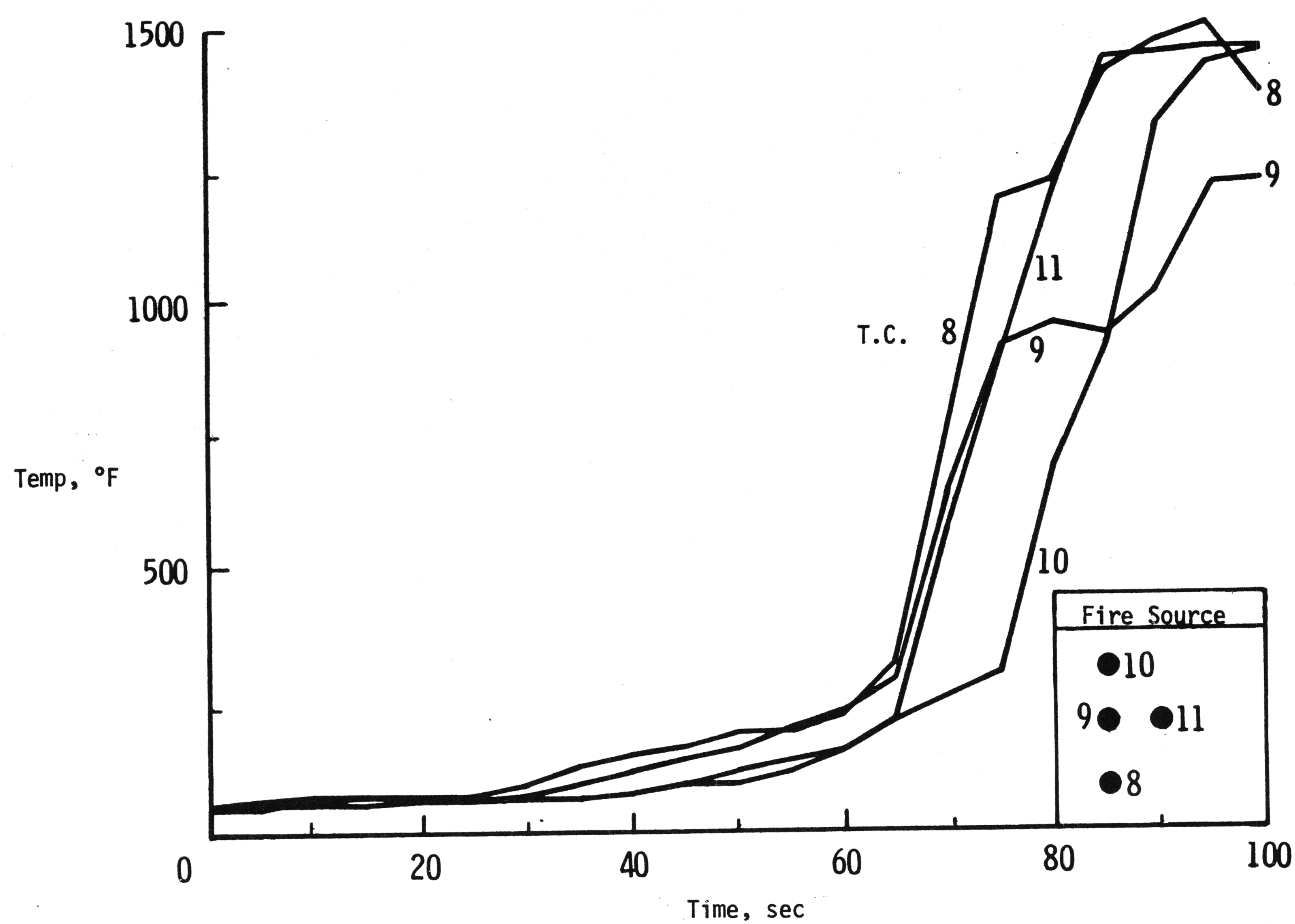


Figure 9.- Temperatures on seat cushion top in test 1 (T.C.'s on surface).

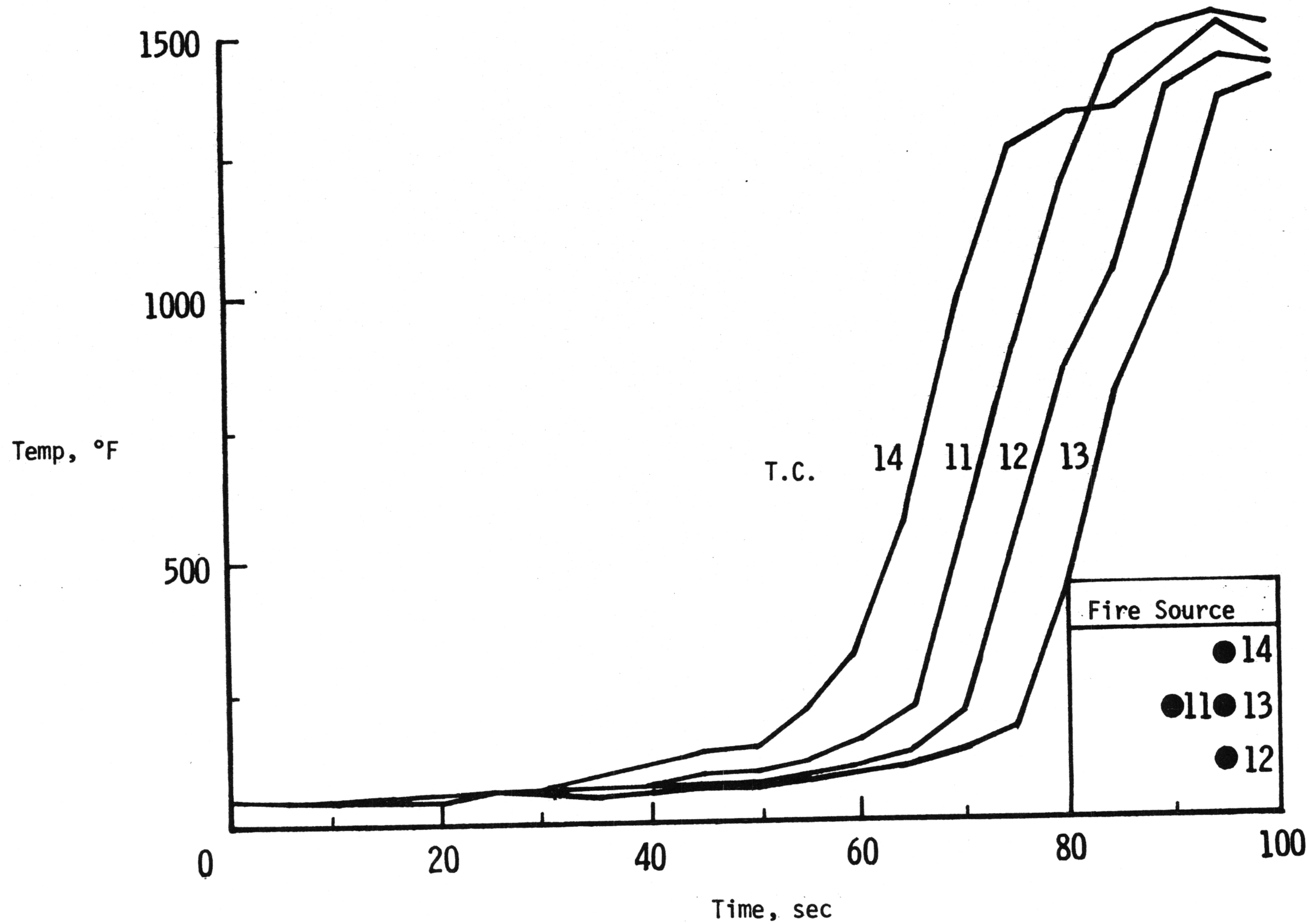


Figure 10.- Temperatures on top of seat cushion in test 1 (T.C.'s on surface).

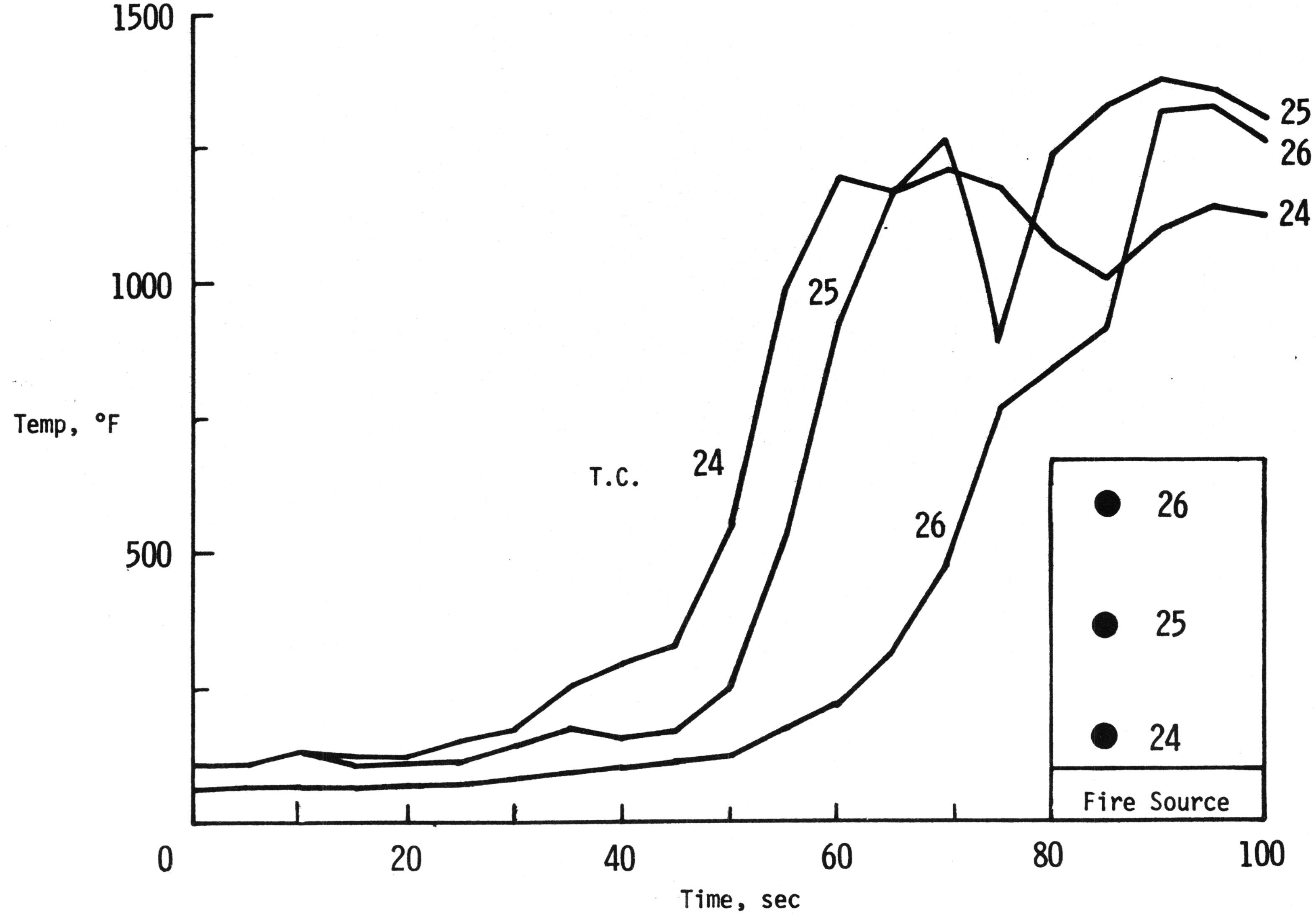


Figure 11.- Temperatures on seat back in test 1 (T.C.'s on surface front side).

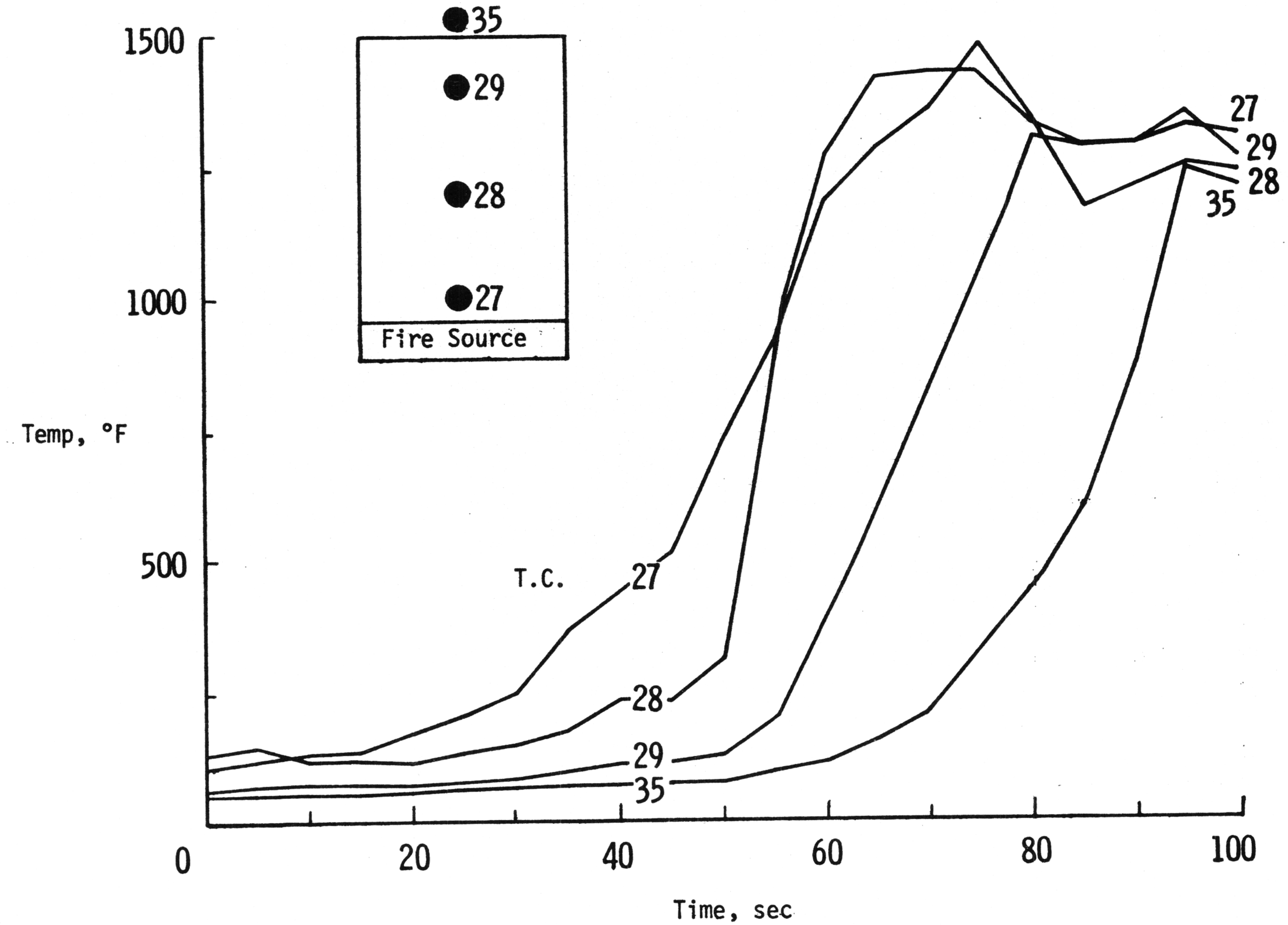


Figure 12.- Temperatures on seat back in test 1 (T.C.'s on surface front side).

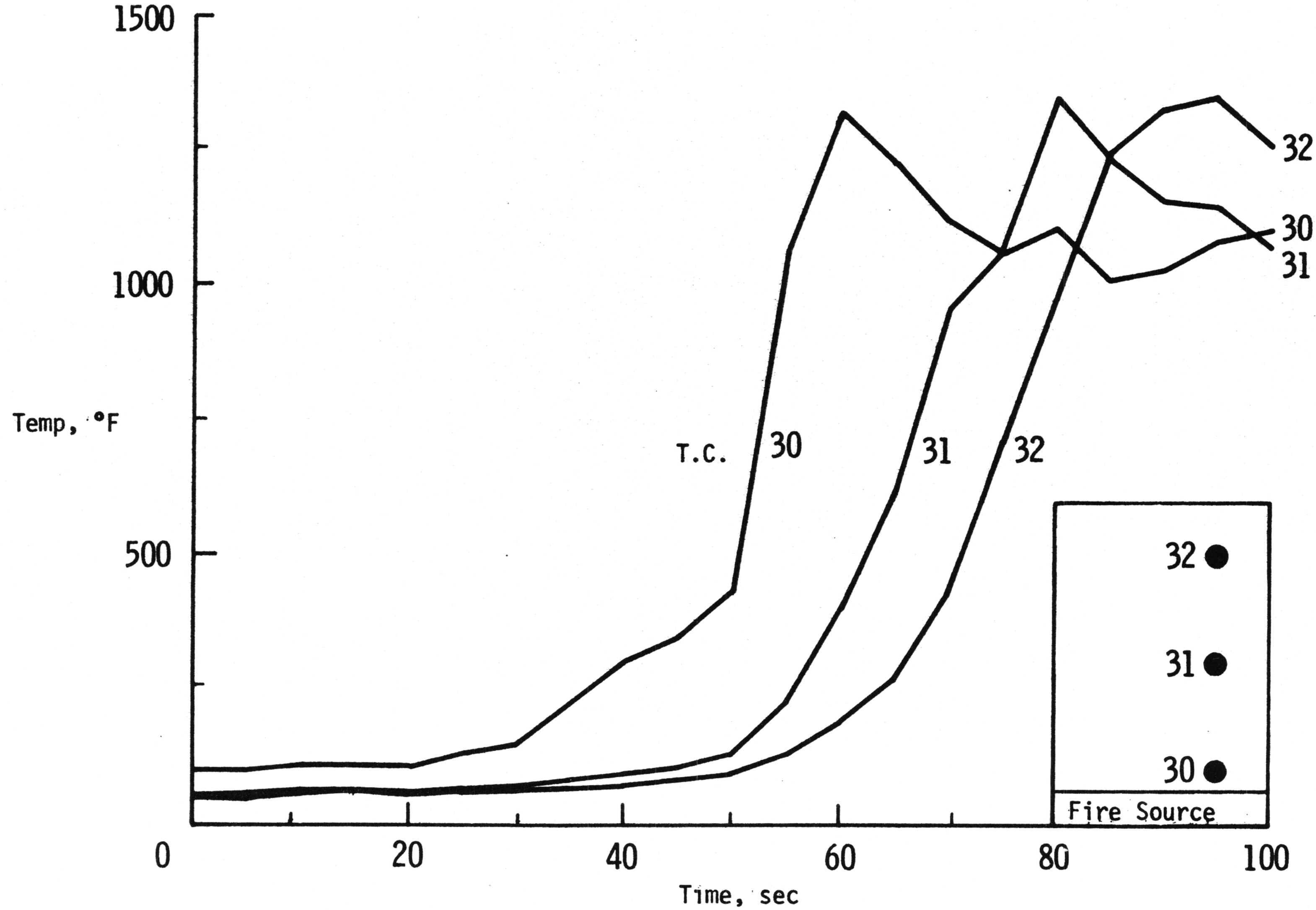


Figure 13.- Temperatures on seat back in test 1 (T.C.'s on surface front side).

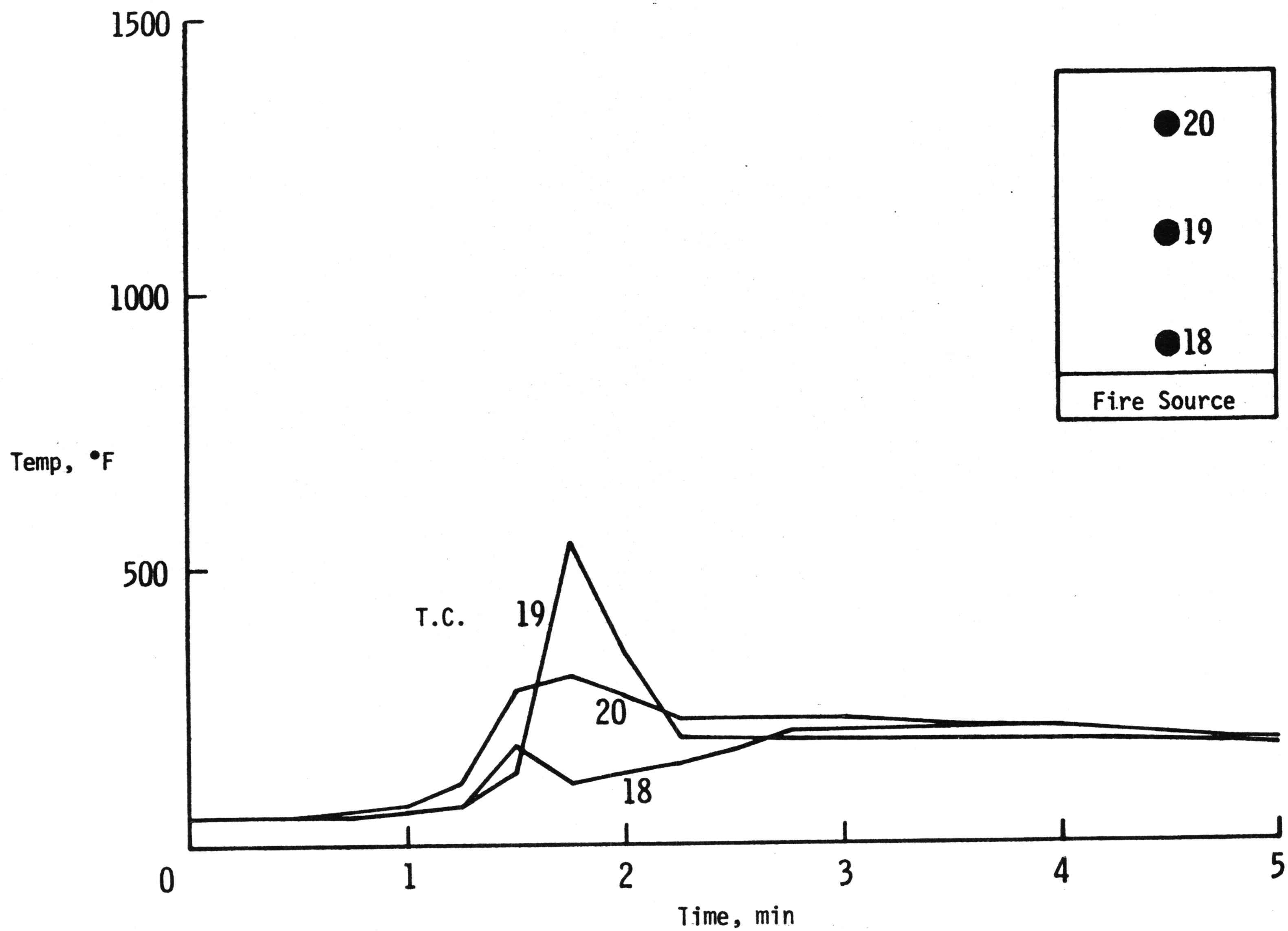


Figure 14.- Temperatures on seat back in test 1 (T.C.'s on surface back side).

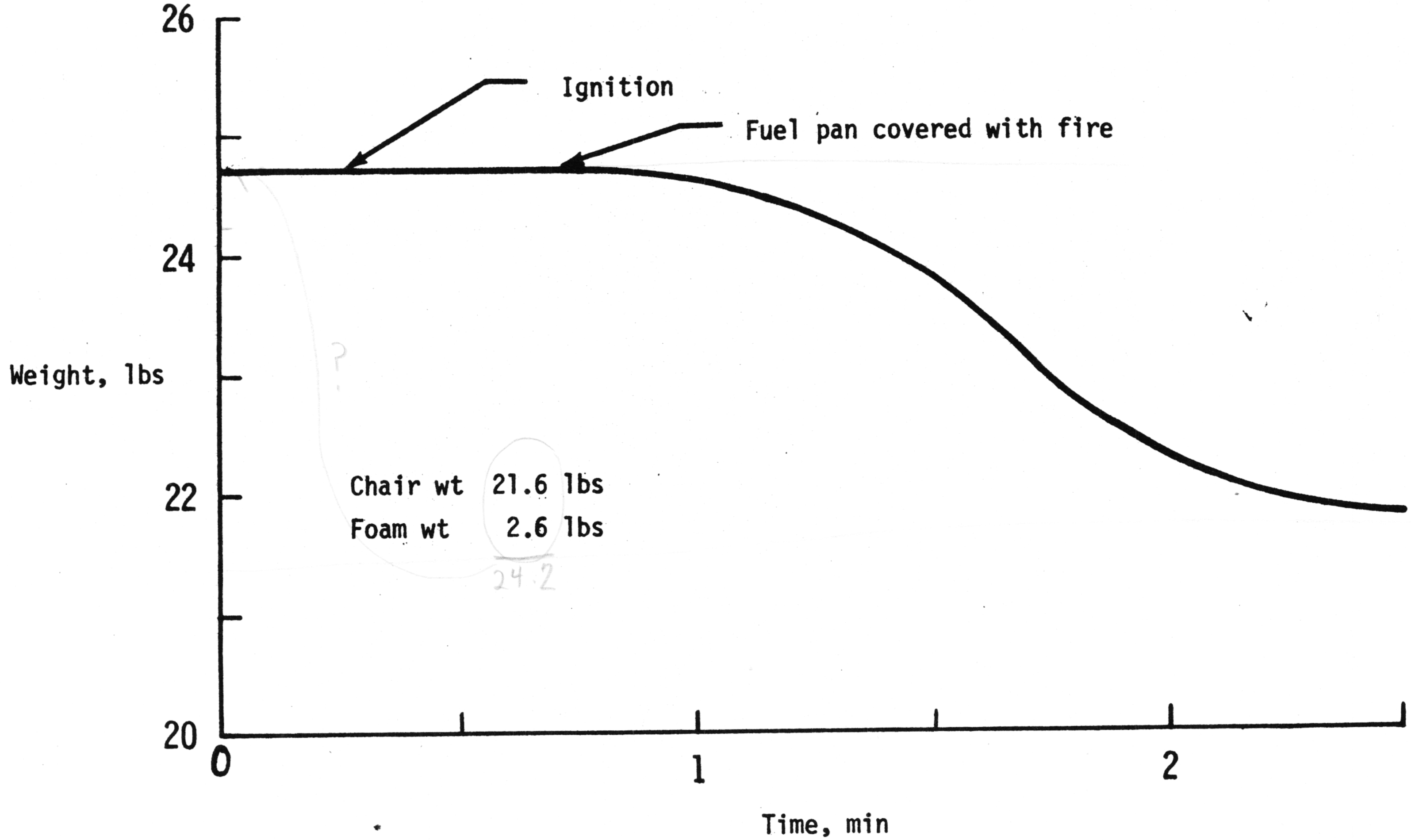


Figure 15.- Polyurethane weight loss versus time in test 2.

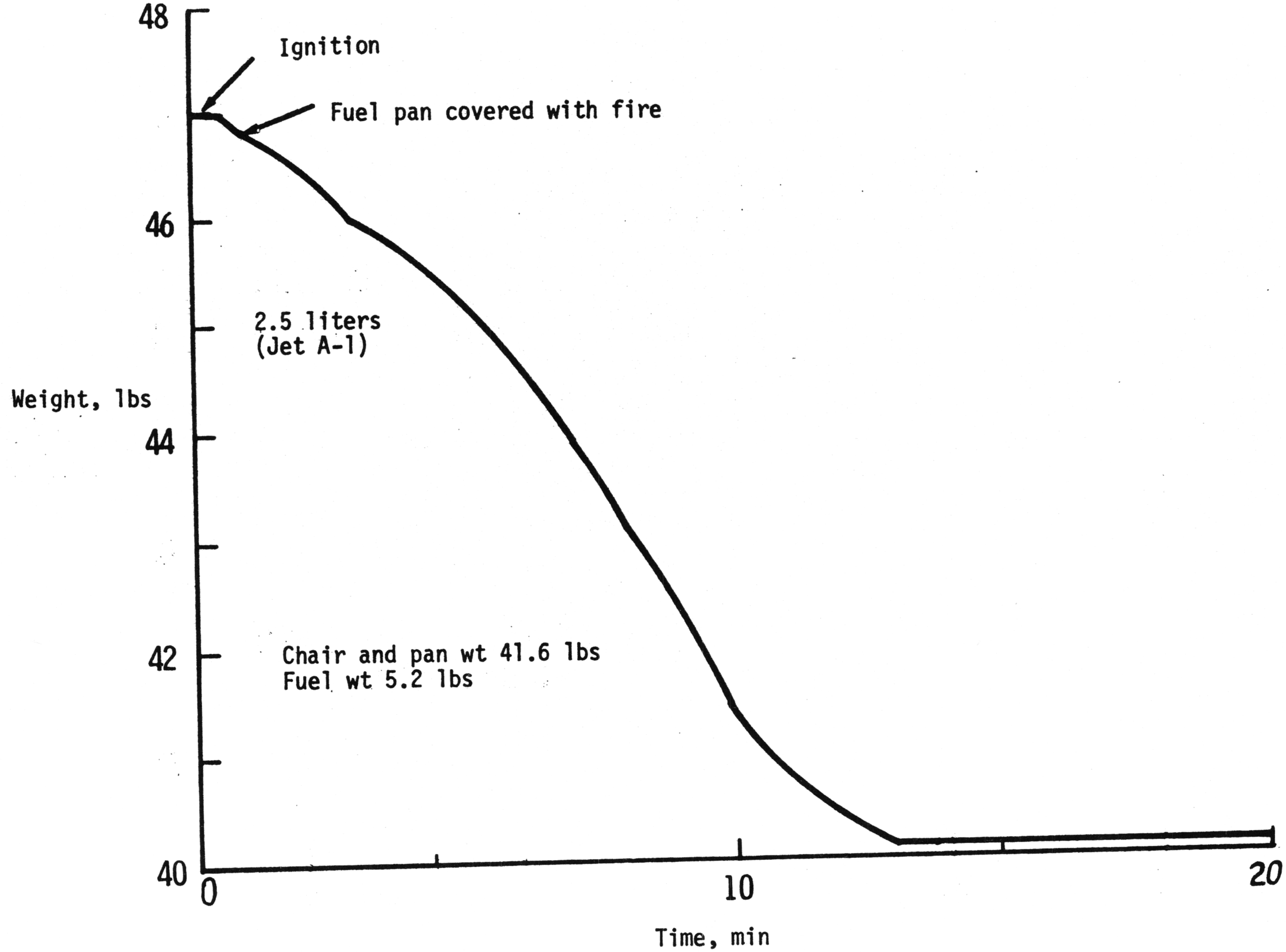


Figure 16.- Jet A-1 fuel weight loss with time in test 3.

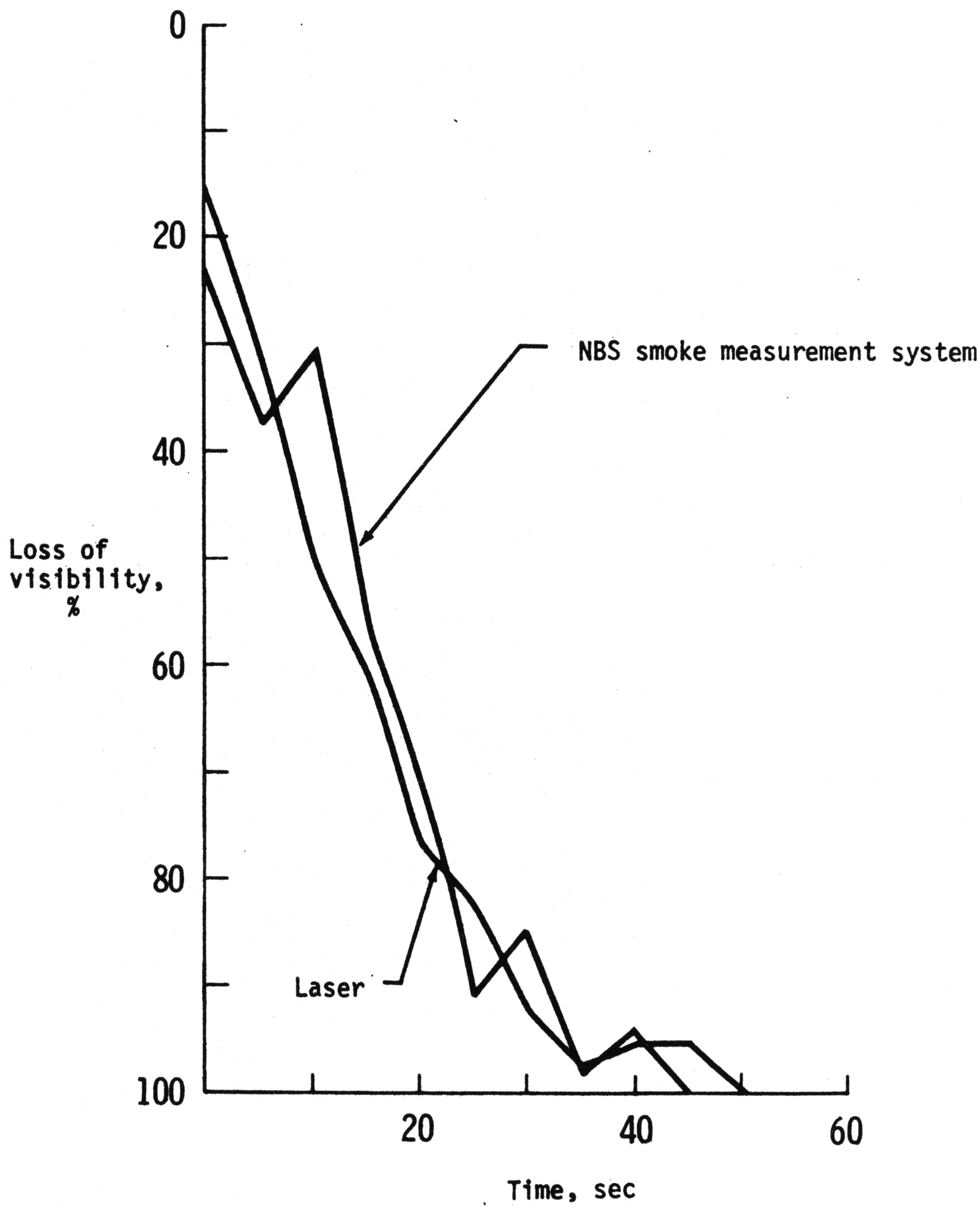


Figure 17.- Loss of visibility versus time in test 1.

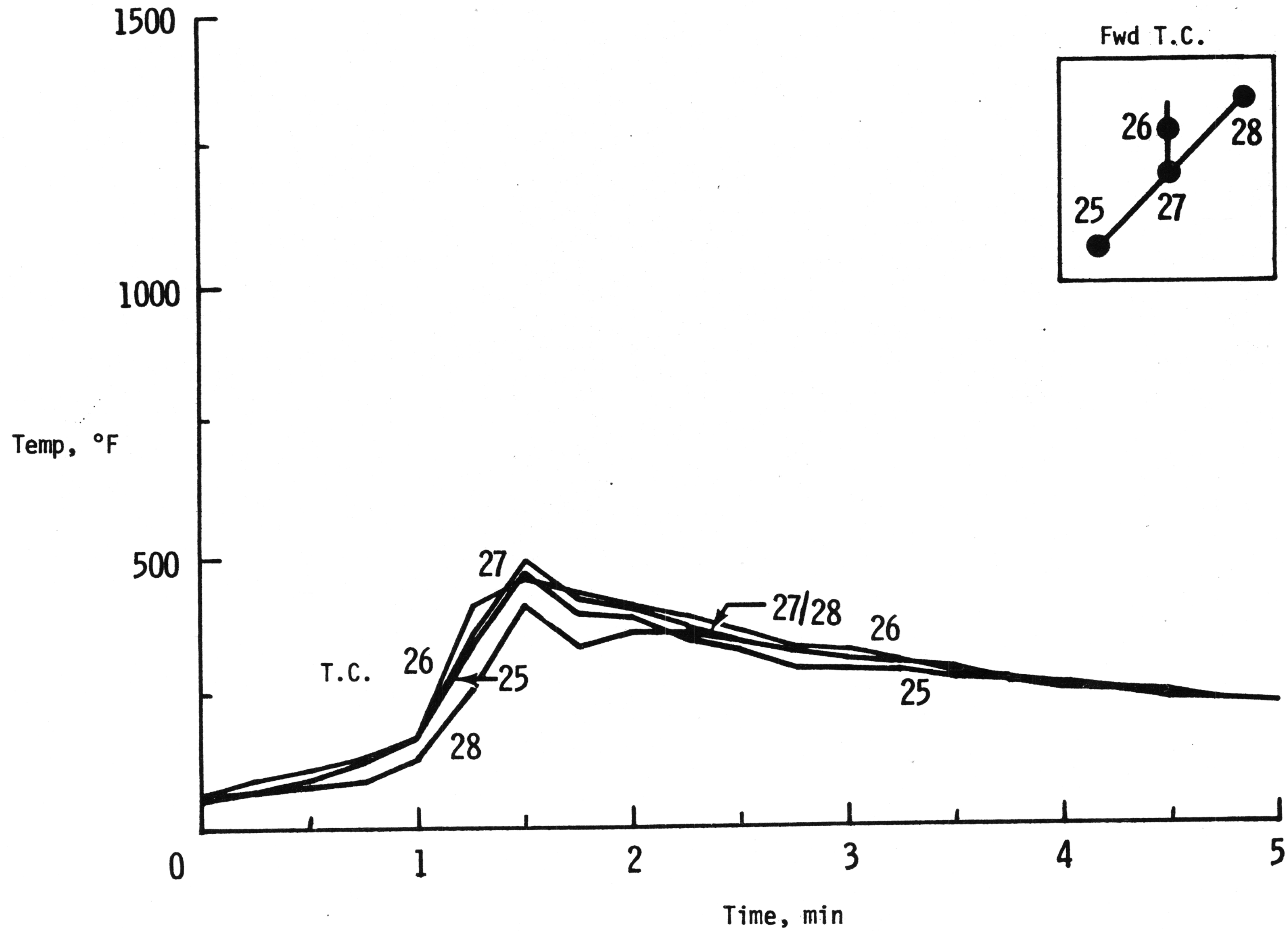


Figure 18.- Temperature of cabin in test 1 (8 ft fwd of fire).

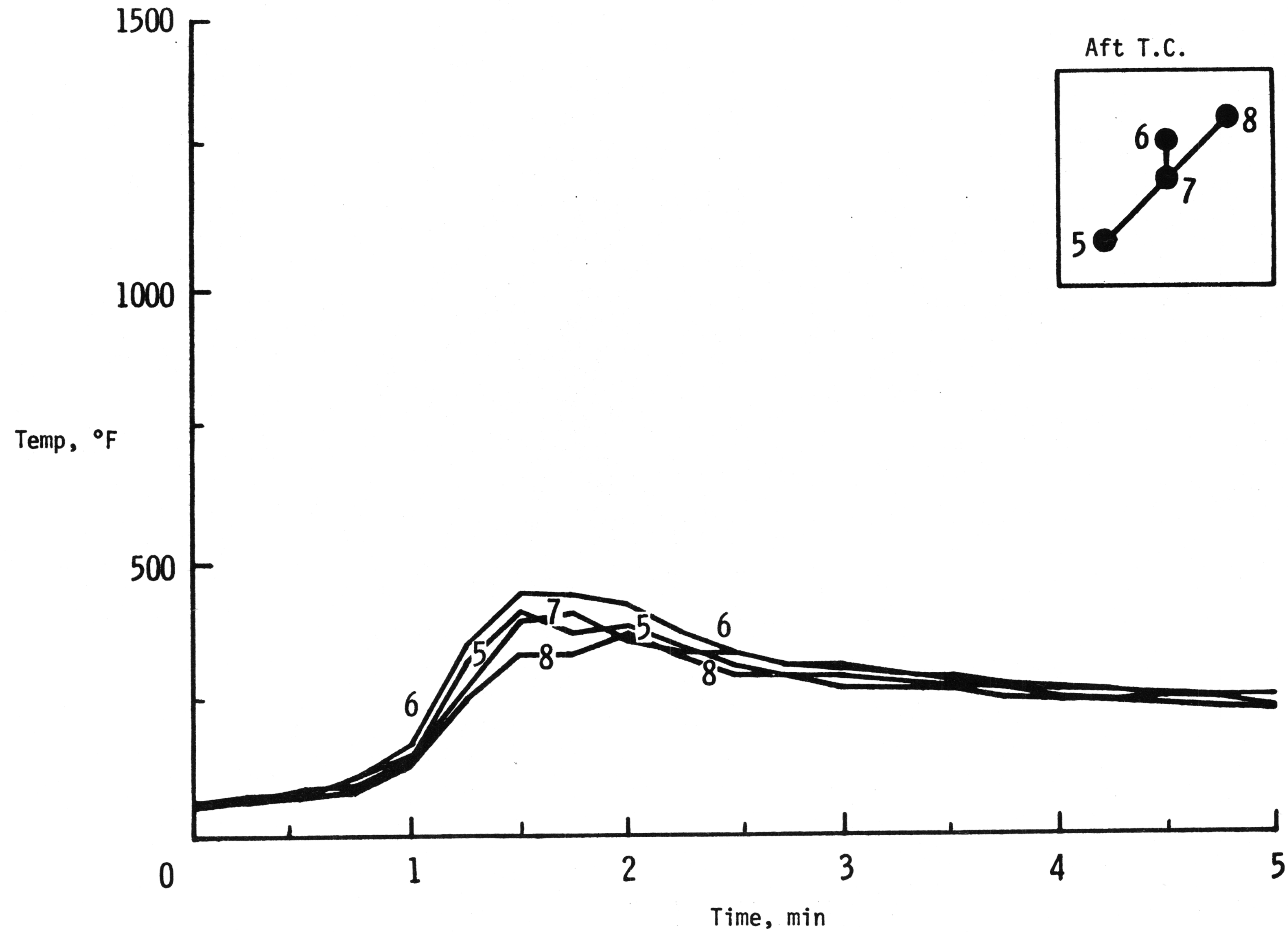


Figure 19.- Temperature of cabin in test 1 (5 ft aft of fire).

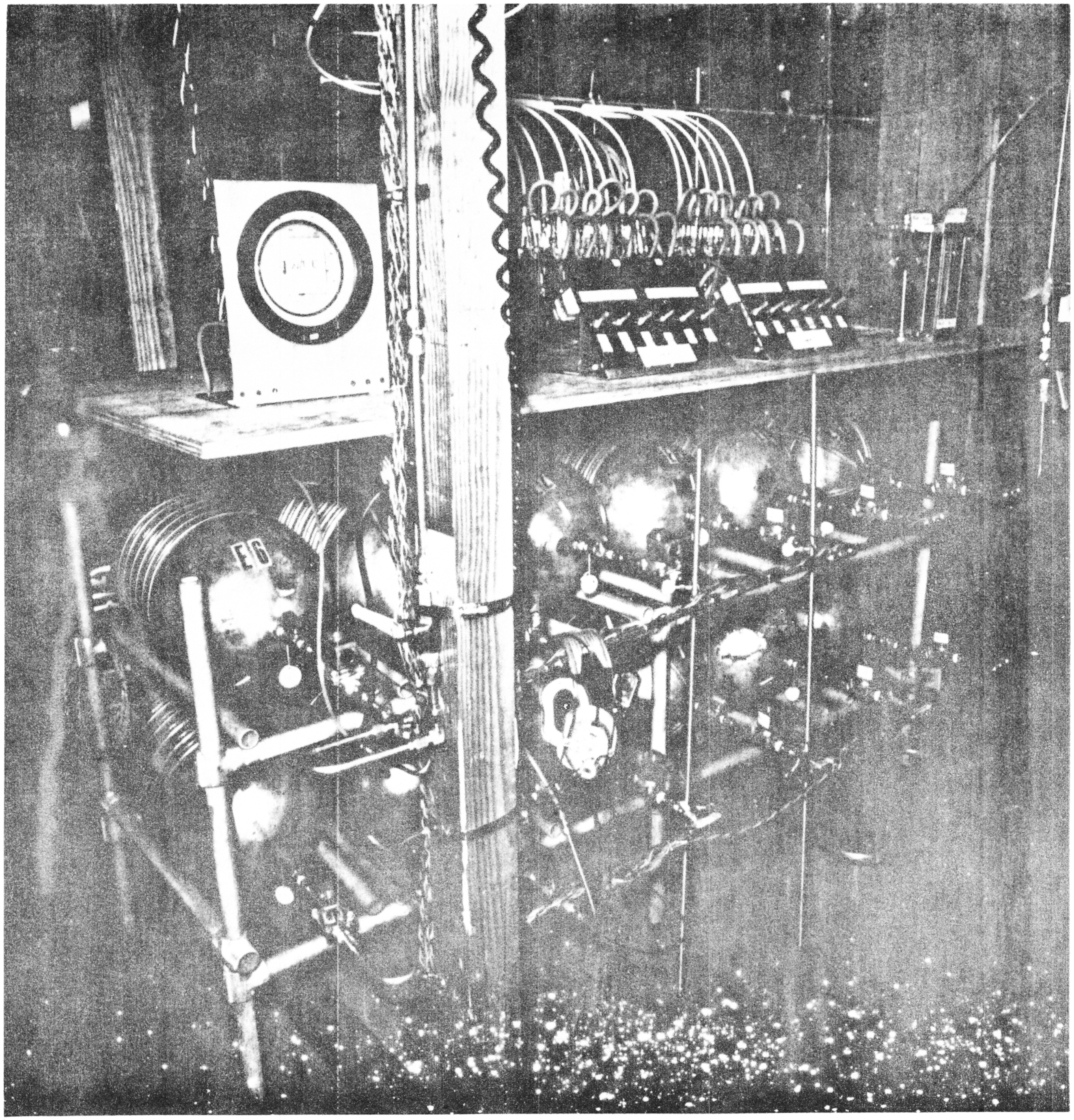


Figure 20.- Gas collection systems for test 1 and 2.

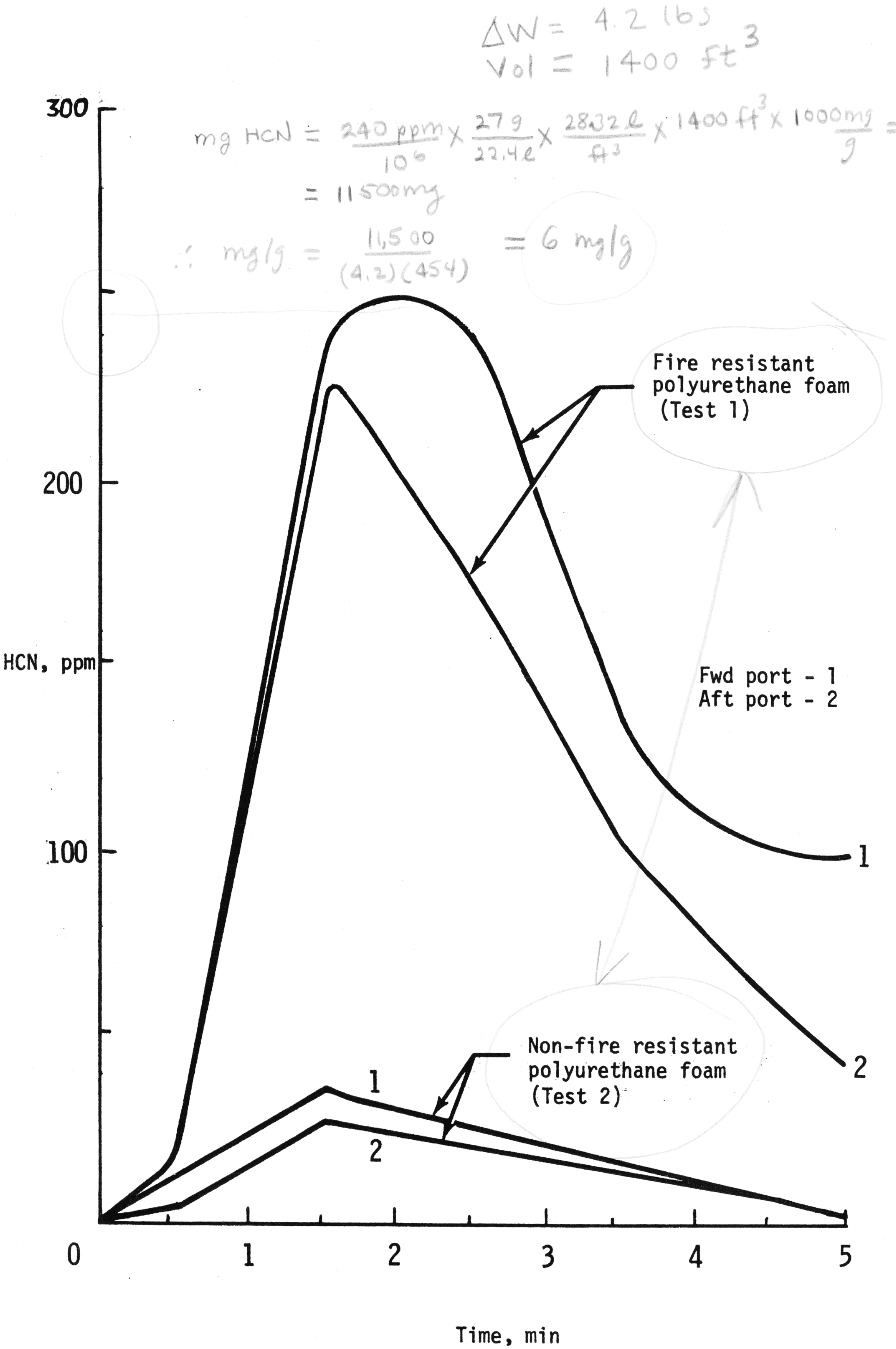


Figure 21.- Hydrogen cyanide concentrations for tests 1 and 2.

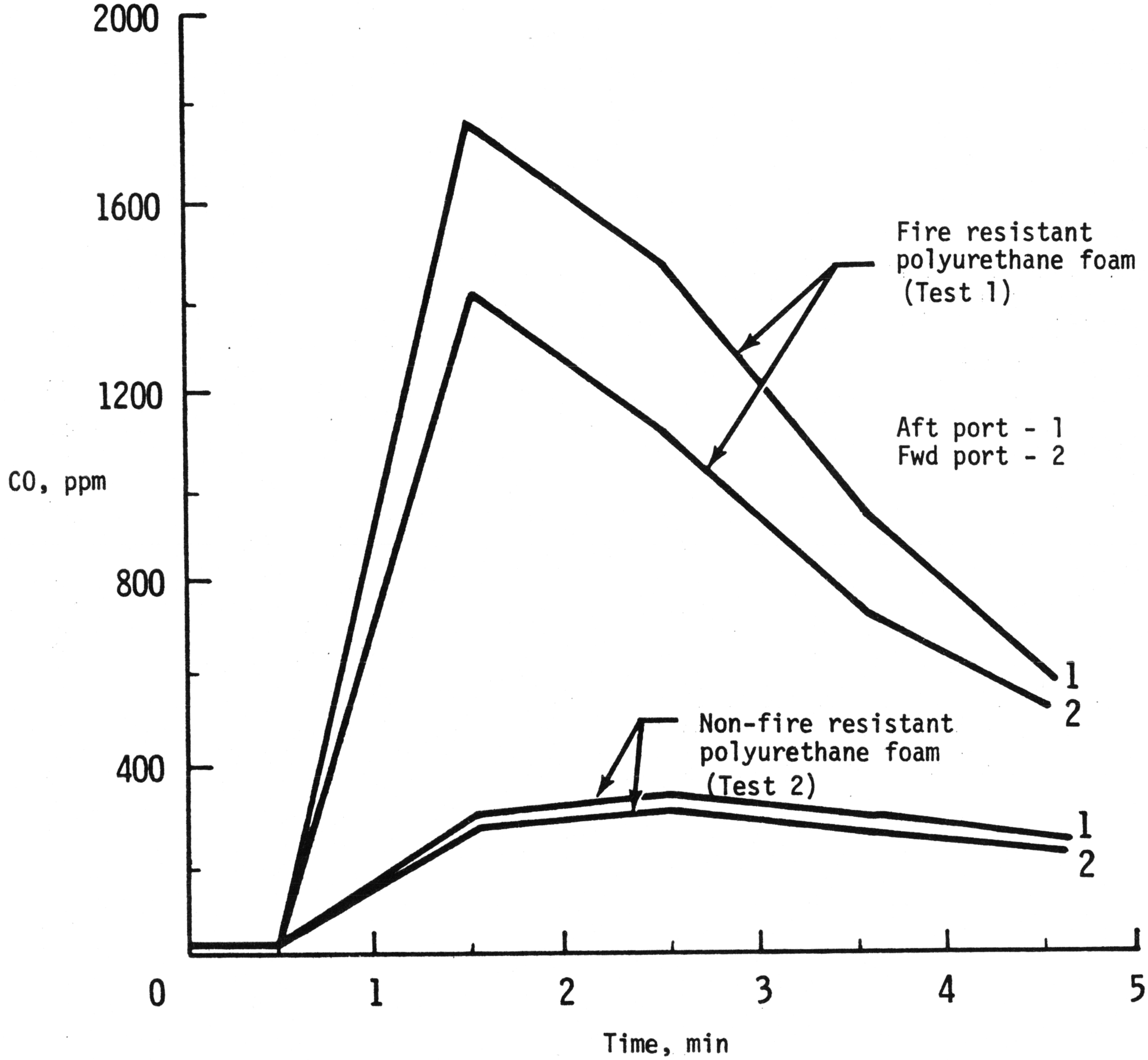


Figure 22.- Carbon monoxide concentrations for tests 1 and 2.

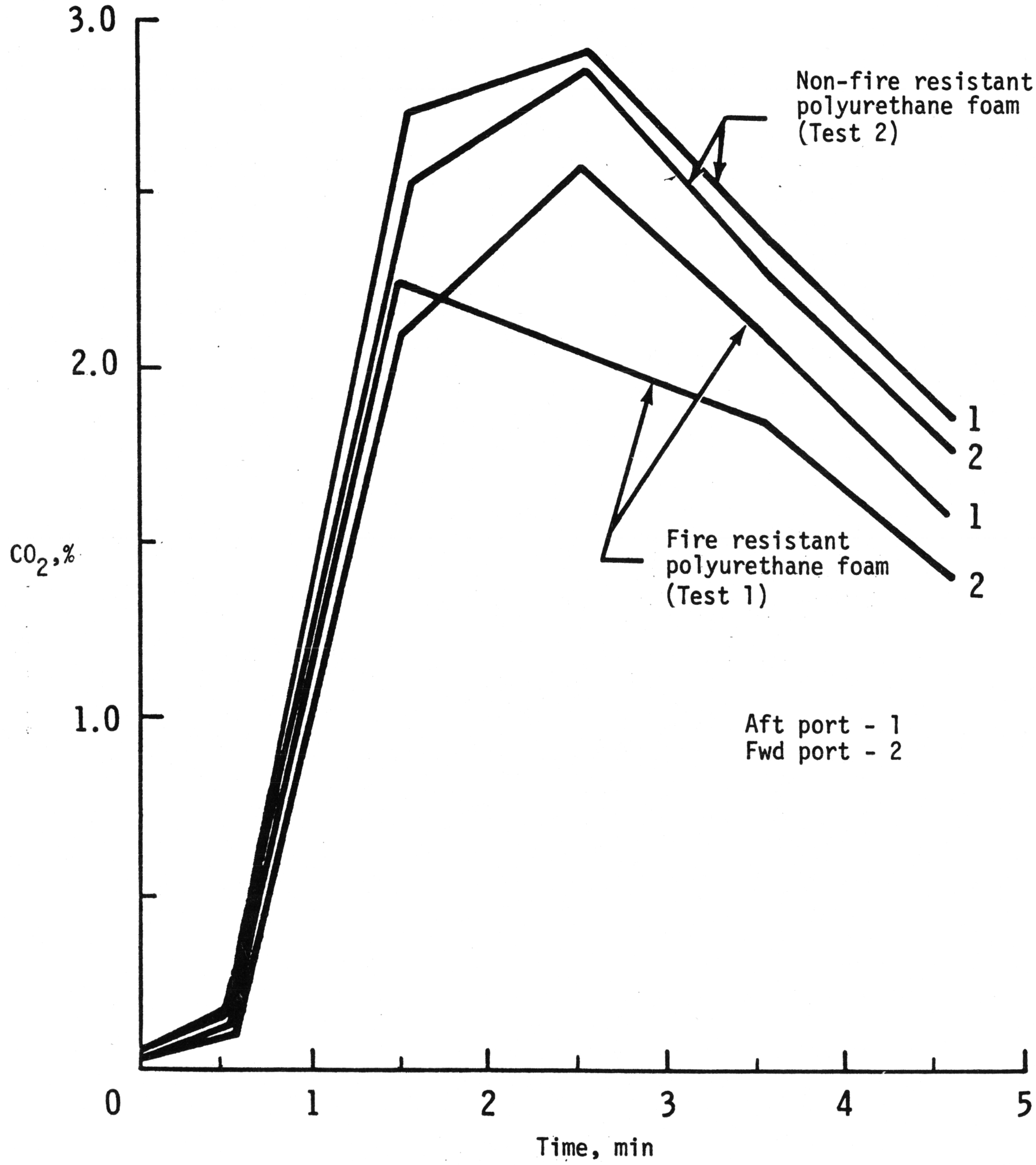


Figure 23.- Carbon dioxide concentrations for tests 1 and 2.

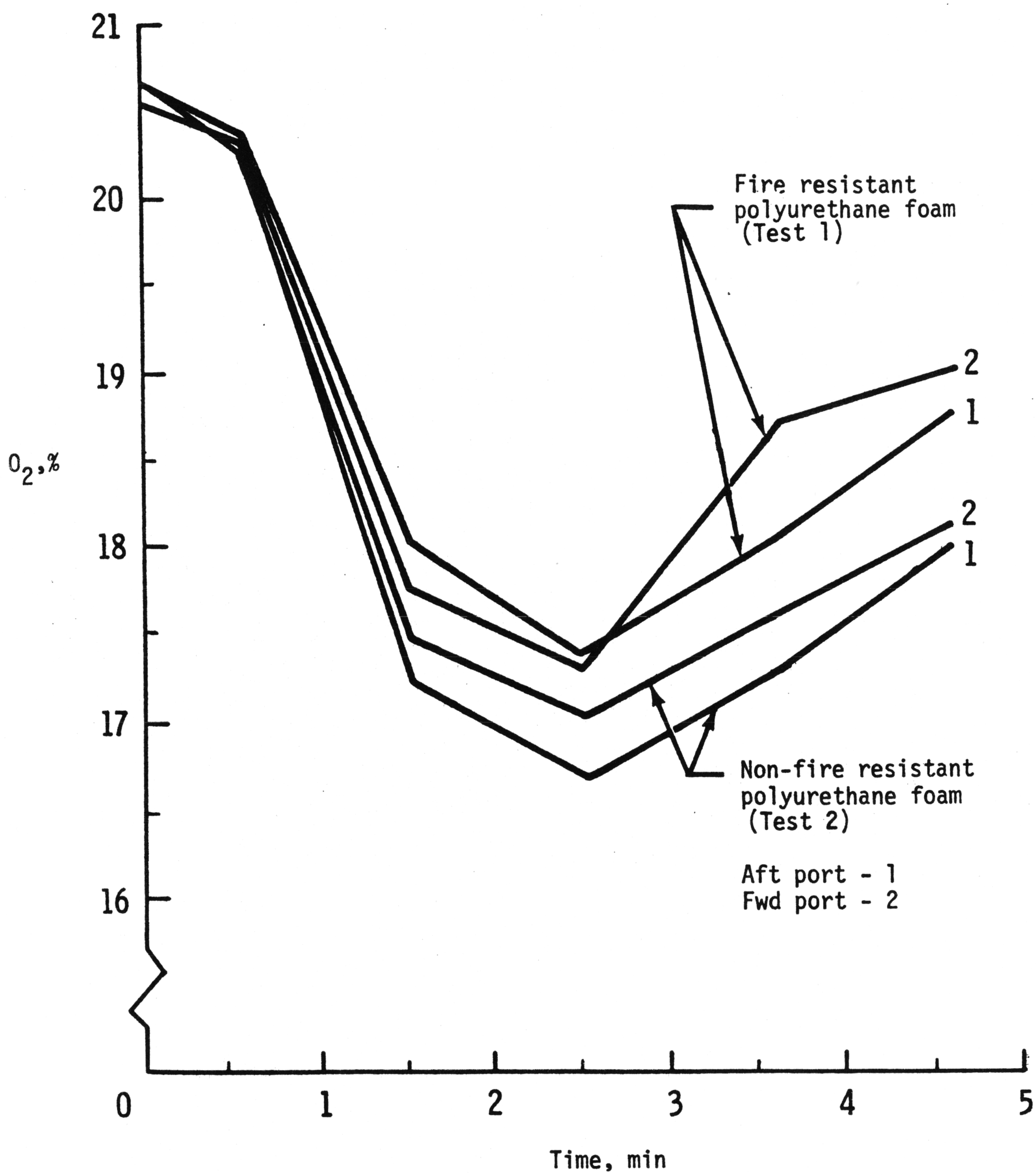


Figure 24.- Oxygen concentrations for tests 1 and 2.

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