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Flame Roll-Out Study for Gas Fired Water Heaters

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U.S. DEPARTMENT OF COMMERCE
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NATIONAL BUREAU OF STANDARDS, Ernest Ambler, ***Director***

ABSTRACT

Five gas-fired water heaters (four natural gas and one LP gas) were tested in laboratory with simulated home conditions to evaluate their flame roll-out characteristics. Simulated variables were flue blockage, space pressure depression, access door status (in-place and not in-place), and other related factors. Test results were compared with those based on the proposed ANSI test method. The testing concludes that, in addition to flue blockage, pressure depression and door status are major factors in inducing heater flame roll-out; that poor draft hood performance contributes to the likelihood of flame roll-out; that the proposed ANSI test method should add a temperature criterion for determining flame roll-out; that the proposed ANSI blocked flue test appears to be adequate for units equipped with thermal spill switches located at their access doors area. For units not equipped with these particular type of safety devices, the following concerns were identified: 1) Water heaters which pass the proposed ANSI test, with the access doors in place and without the need for additional safety devices, may not pass such a test if the doors were left off, and 2) units which use devices other than thermal switches to detect blocked flues, may pass the proposed ANSI test and still produce dangerous flames and heat outside of their jackets under certain conditions. Recommendations are made that CPSC and the ANSI sub-committee on water heaters consider also requiring the interlocking of access doors with water heater operation, the use of temperature sensing as a means of detecting flame roll-out, and the use of improved draft hood designs and draft hood performance testing to reduce the chances of flame roll-out.

Key Words: Flame roll-out; gas fired water heater; gas water heater; safety; water heater; water heater test

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SI CONVERSION FACTORS

MULTIPLY	BY	TO OBTAIN
Btu	1.055	kJ
Btu/h	0.293	W
°F	°C = (°F - 32)/1.8	
ft	0.3048	m
inch	25.4	mm
inch of water (60°F)	249	Pa

1. INTRODUCTION

According to data gathered by the U.S. Consumer Product Safety Commission (CPSC), during the year 1983 there were an estimated 9400 fires in the United States involving gas fired residential water heaters resulting in an estimated 1060 injuries and 60 deaths [1]. Like any heat producing appliance, fire safety issues are of concern in the correct design, installation, and use of gas fired water heaters. These include clearances from appliances and exhaust vents to surrounding combustibles, protection of combustible flooring beneath the appliance, and appropriate venting of the exhaust.

One significant fire hazard pattern identified by CPSC is the ignition of combustible materials stored near the heaters. Under certain known failure conditions, flames or hot combustion products from a water heater can spill from the combustion chamber and ignite nearby materials [1]. Although good housekeeping may reduce the chance of fires, the CPSC believed that water heaters needed to be examined for possible malfunctions due to adverse operating conditions in order to prevent flames and hot combustion products from exiting at undesirable locations.

To this end, CPSC funded the Calspan Corporation in September of 1984 to test water heaters under atmospheric pressure with the flues constricted to various degrees in order to confirm the occurrence of flame roll-out at the access doors [2]. The study indicated that when the flue area reduction was 60% and higher, the air temperature at the access doors reached over

250°F with the pilot access doors in place. The study also investigated means to prevent possible ignitions of combustible materials stored near water heaters and suggested that thermally operated spill switches would appear to substantially reduce the potential hazard due to spillage under the conditions tested in the study.

Subsequently, the Water Heater Subcommittee of the American National Standards Institute (ANSI) issued a proposed change to the standard for gas water heaters of inputs not greater than 75,000 Btu per hour (ANSI Standard Z21.10.1) [3]. The proposed standard revisions [4] require that water heaters be tested with progressively blocked flue outlets. An initial blockage of 20% of the flue area is increased at 20% increments until the entire flue area is blocked. The proposed revisions requires that water heaters must not issue flames outside the face of their jackets during the tests, and they must operate normally after the tests. A safety shutoff means would have to be provided to shut off gas to the water heater for any unit which could not pass this blocked flue test without such a device.

In the fall of 1986, CPSC contracted with the National Bureau of Standards (NBS) to do further tests on gas water heaters. This study was limited to a examination of flame roll-out and spillage from the access door and the bottom of typical residential water heaters. The contract required that flame roll-out and combustion chamber spillage characteristics of water heaters be tested in the laboratory using five CPSC-supplied heaters. CPSC specifically identified access doors status (in-place or not in-place) and house pressure variations caused by exhaust fans, clothes dryers, and the like as the main factors to be studied. NBS was also required to compare and evaluate the test results against the results of the same water heaters tested under the proposed revisions to the ANSI standard in order to try to identify possible deficiencies in the proposed ANSI standard revisions.

2. CONCLUSIONS AND RECOMMENDATIONS

Extensive laboratory tests were conducted to establish the flame roll-out behavior of the five water heaters. Based on the five water heaters tested, the following conclusions and recommendation are presented:

a. In the laboratory tests, pressure depression is a major factor in water heater flame roll-out. Depressurization can cause flame roll-out and reversal of flow in the flue, and can accelerate flame roll-out under flue blockage conditions. Sustained flame roll-out occurred frequently, with no flue blockage or partial flue blockage, when negative pressure was applied to the test chamber. Test chamber pressures ranging from -0.05" to -0.25" water column (w.c.) produced flame roll-outs frequently. This pressure range is believed to be within the range of pressure variations possible in residential homes.

b. During cyclic tests, no sustained flame roll-out was observed for the natural gas water heaters. With access doors in-place and without pressure depression during the cyclic tests, the LP-gas heater did not have flame roll-out when the flue was partially blocked. However, sustained flame roll-out occurred during pressure-depression cyclic tests for the LP-gas heater, regardless of door status. The proposed ANSI test method does not require cyclic tests, and consequently, would not have detected the flame roll-out observed with the LP-gas heater.

c. Sometimes, flame roll-out was difficult to detect visually during the laboratory tests. The proposed ANSI test method should specifying a temperature level outside the jacket in determining flame roll-out.

d. Closing the inner and outer access doors (throughout this report, the term access doors mean both the inner and outer access doors) properly is an important factor affecting flame roll-out. Without the access doors in-place, the temperature outside the jacket exceeded 250 F in the majority of the tests with flue blockage and pressure depression. Based on this criterion, all five heaters would be fire hazards, even though four heaters would likely pass the proposed ANSI test with the access doors in-place. Because of this, it is recommended that the CPSC and the ANSI subcommittee on water heater standards consider requiring an interlocking device or other means to assure proper access door closure during heater operation and a method to test for proper operation of the interlocking device.

e. The design of water heater components, such as combustion chamber, heat exchanger turbulator, and draft hood, plays an important roll in flame roll-out. The performance of the latter was found to be particularly important during the pressure depression tests. As a result, it is recommended that the CPSC and the ANSI subcommittee on water heaters considering requiring heater manufacturers to strengthen draft hood performance in order to reduce the possibility of flame roll-out caused by negative pressure induced flue reversal. A test procedure to test the effectiveness of draft hoods in preventing flow reversal of the flue gas should also be considered as possible revisions to the proposed ANSI water heater standard and the ANSI draft hood standard (American National

Standard for Draft Hoods, ANSI Z21.12) [5].

f. Consideration should also be given by the CPSC and the ANSI water heater subcommittee to requiring the use of thermal devices (as opposed to other types, such as pressure devices, etc.) for detecting flame roll-out. Coupling this requirement with door interlocking devices, improved draft hoods, and the ANSI flue blocked tests, is likely to provide greater protection against the occurrence of flame roll-out than what is provided by the current revisions to the ANSI standard.

3. TEST HEATERS AND TEST APPARATUS

3.1 Test Heaters

The five test heaters were selected and supplied by CPSC. These heaters were considered by CPSC to be representative of those available on the market, but consists of only a small fraction of the total number of models being sold. In addition, since each model tested was different, no statistical inferences can be made for that model. As a result, the testing conducted by NBS is not to be interpreted as a statistically valid quality control analysis but rather as a study to provide CPSC with general information which would be useful in their efforts to reduce water heater accidents.

The water heater capacities, dimensions, and fuel data are shown in table 1.

Table 1 Test Water Heaters

HEATER NO.	1	2	3	4	5
NAMEPLATE INPUT, Btu/h	30,000	40,000	40,000	35,000	34,000
STORAGE CAPACITY, GAL	30	29	40	40	40
OVERALL HEIGHT, INCH	56	59	59.5	48	47.5
OUTSIDE DIA. INCH	18.5	16	17	20.25	20
GAS TYPE	NATURAL	NATURAL	NATURAL	NATURAL	LPG

The construction of the heat exchanger turbulators of these heaters varied considerably in their arrangements and shapes. The draft hoods of heaters 1, 2, 4, and 5 were of similar configuration -- stamped metal with openings at the top around the periphery and a flat metal blockage at the center. The draft hood of heater 3 was of a different construction. It was shaped with a concave bottom facing downward. The inner access doors of the heaters were similar although some could be closed tighter than others. The outer access doors differed considerably, but all had fairly large openings for gas and thermocouple tube access. The outer access door of heater 1 was flush with the heater outer surfaces and could be closed tightly. Heaters 2, 4, and 5 had doors that extended outside the outer surfaces with their tops and bottoms open. The access door of heater 3 was flush with the jacket except at gas tubes where the top and bottom of the outer door was open. Control thermocouple and pilot light arrangements and locations were somewhat different among the heaters.

3.2 Test Chamber and Facility

A metal cabinet approximately 4-feet wide, 4-feet deep, and 7-feet high was fabricated as the test chamber. It was placed in a test laboratory which was air-conditioned to maintain a nominal temperature of 70 F. The test chamber had gasketed double doors on both sides for access and safety. A plexiglass observation port facing the heater access doors was used to observe flame roll-out. Two adjustable openings were provided on the back wall of the chamber for combustion air intake. The test chamber had a double floor approximately 6 inches from the laboratory floor. The space between the double floors was connected to the inlet side of an exhaust fan. A variable-speed fan control was used to maintain desired negative pressure levels in the chamber. Air openings from the laboratory to the test chamber and from the test chamber to the double floor space had baffles and distributing plates to evenly distribute air flow within the chamber. A three-inch diameter, 5-foot high vent pipe penetrated the test chamber roof, venting the combustion products to the test laboratory. Heater control valves were protected with thermal shields to prevent them from being damaged by high temperature.

3.3 Instrumentation

Figure 1 depicts the temperature, pressure, and combustion gas sensor locations. Depending on the anticipated temperature, Type T (copper-constantan) and Type K (chromel-alumel) thermocouples were used to sense the temperatures at the following locations: upper part of water storage tank, lower part of water storage tank at the same elevation as the heater temperature control sensor, upper part of flue about 6 inches below flue top, lower part of flue at the flue bottom, adjacent to pilot thermocouple, inside vent stack, below draft hood in the path of relief air (referred to as "draft hood" sensor in this report), test chamber, four sensors evenly located on the heater outside jacket approximately 1/2 inch above access door ("door" sensor), on the gas supply tube below the heater control valve ("control" sensor), and one each on both sides of the heater base. These temperature sensors not only provided heater operating data, they also assisted in providing flame roll-out and other event indications. The sensors in the stack and below the draft diverter would indicate when the stack flow was inverted. The sensors in the flue would indicate when the flue flow was reversed. The sensors above access doors, at control, and at heater base were used to detect flame roll-out and combustion air spillage. The sensor beside the pilot thermocouple could indicate condition of the burner flame as well as the extinguishing of burner and pilot. Mainly due to the difference in pilot arrangement among heaters, the temperature of this sensor had considerable variations.

A pressure sensing probe was located in the test chamber at approximately the same height as the burner to detect chamber pressure during pressure depression tests. A differential pressure cell with one probe located in the flue bottom and the other probe located in the test chamber provided the draft readings of the flue just above the combustion chamber. Electrical signals for both chamber pressure and flue draft were fed into electronic manometers for data transmission. It should be noted that the flue draft data presented in this study should only be viewed as relative values for the particular heater tested, since air turbulence caused by combustion and poor air flow conditions (at entrance and exit of pressure instrumentation) inherently prevented ideal draft data collection.

Combustion gas samples were continuously drawn from the top of the flue. An infrared gas analyzer was used to monitor and record the carbon monoxide and carbon dioxide concentration of the combustion products. These gas concentration levels could indicate when flue flow inversion occurred. However, during some flue blockage tests, the carbon monoxide level of the combustion products exceeded the instrumentation range because of low combustion air supply.

All temperature, pressure, and combustion gas data discussed above were fed into a data logger at 30-second intervals and were concurrently transmitted to a micro-computer for recording and analysis.

The carbon monoxide and carbon dioxide levels of the test chamber, barometric pressure, and the voltage output of the heater pilot thermocouple were also monitored during the tests. However, they were not part of the automatic data acquisition system.

4. TESTS AND TEST PROCEDURES

4.1 Definition of Flame Roll-out

Flame roll-out is a term generally used to represent hot air or flames escaping from the lower part of a water heater. In the proposed revisions to the ANSI standard for gas water heaters, flame roll-out is described as "flames issue outside the face of the jacket" of a water heater. In this study, flame roll-out is defined as either visible flames issued outside the face of the jacket or hot combustion products spilled out from the lower part of a heater. Due to the difficulty in observing the presence of flames outside the face of the heater jackets, this study uses an air temperature of 250 F outside the access doors as a criterion for flame roll-out. This 250 F is the spill switch setpoint recommended by the CPSC staff [6] as a result of the Calspan study [2] and was chosen only as an indication of hot gas spillage from the heater. It should not be interpreted as an NBS recommended criterion for alleviating the hazard of ignition of combustibles adjacent to water heaters.

4.2 Chamber Pressure Depression Test

The degree of negative pressure inside a house depends on the sources which create the negative pressure and the tightness of the house. The sources often found include air exhaust appliances such as clothes dryers and exhaust fans, heating appliances such as furnaces and water boilers, and fireplaces. An air circulation fan of a hot air furnace, depending on the furnace location and the air distribution system arrangement of the house, may also create negative pressure in the furnace room or other areas of the house. Even hot water heaters themselves may contribute negative pressure in houses. Outside weather conditions also influence house pressure. Prevailing wind, terrain effect, and outside air temperature may all contribute to pressure differences within a house. The recent emphasis to make houses tighter for energy conservation purposes further exasperates the problem of house pressure depression.

House pressure depression may overcome the stack draft of heating appliances and spill combustion products into the home. When substantial pressure depression exists, the stacks themselves become an air infiltration route. The in-rush of air through the stacks may enter heat exchangers of water heaters and alter the normal operations of the heaters. Large-scale field surveys on house pressure variations which take all these factors into account are difficult to perform and costly and are not available at present. However, previous research projects of limited scope indicated that substantial negative house pressure existed. A survey conducted in Canada [7] revealed that some houses had pressure depressions over 0.07" water column. A study [8] combining exhaust fan, clothes dryer, furnace, and fireplace air requirements and air infiltration data from tests done by others showed theoretically, that indoor pressure depression might reach 0.27" water column for a well-sealed single family detached house. Evidently, a large range of pressure depression may be present in most of the residential housing stock when all relevant factors are combined. Based on these studies [7,8], it was determined that a peak negative pressure of 0.2 to 0.25" water column should be created for the laboratory tests in this investigation. Pressure steps of 0.05" water column were employed to cover the entire pressure range from neutral to the peak negative pressure.

4.3 Access Door Status

Preliminary tests on a water heater previously tested by NBS (referred to as the NBS heater in this report) similar to the five CPSC test heaters, confirmed that the access door status (in-place or not in-place) made substantial difference in flame roll-out behavior of the heater. Although water heater manufacturers post notices to home owners to replace doors after servicing, the Calspan study [2] concluded that "these doors might be expected to be improperly installed or not installed at all in a large number of actual residences" due to the difficulty of properly placing them. Therefore, all tests in this study were conducted both with the access doors (both inner and outer doors) in-place and not in-place on all the heaters.

4.4 Flue Blockage Test

The proposed ANSI test procedure requires that water heaters be tested with flues blocked at 20% increments from 0% to 100% blockage with the ambient pressure maintained at neutral. During this study the flue outlets were blocked at 0%, 20%, 60%, and 100%. The intermediate blockage at 40% and 80% were not used because preliminary tests of this investigation and the Calspan study showed that above 60% blockage the temperature of hot air spillage increased substantially. The flue blockage tests were performed with these four blockages combined with different pressure levels of test chamber ranging from neutral up to negative 0.25" water column as described previously.

4.5 Burner Cyclic Test

As stated previously, when a house is under negative pressure, the in-rush of air through the water heater stack may enter the heat exchanger of the heater in spite of the draft hood. This is especially true when the burner of the heater is not in operation. The temperature in the flue at the heat exchanger baffle may at times be lower than the hot water temperature in the storage tank. When the thermostat of the heater calls for heat, it may take some time for the flue to establish a draft, during which time spillage is likely to occur. Therefore, cyclic tests were performed at various negative chamber pressures up to 0.2" water column to evaluate flame roll-out during burner startup. During each cyclic test, the storage water was heated to the test temperature of approximately 140 F and the heat exchanger temperature was allowed to stabilize. Then hot water was drawn to start the burner. This simulated a burner startup during morning usage (heavy demand after extended standby).

4.6 Thermal Vent Damper Test

During the preliminary test on the NBS heater, the vent stack of the test facility was blocked to simulate a failed thermal vent damper. Blocking of the stack also simulated a thermal vent damper not responding to burner ignition when severe house negative pressure prevented the damper from coming in contact with hot combustion air of the water heater. Test data indicated that the failed damper did not appear to contribute to flame roll-out. The damper actually worked as a baffle to prevent air from entering the test chamber. Therefore, the thermal vent damper test was not incorporated in tests of the five CPSC supplied heaters.

4.7 General Test Conditions

Before a heater was installed for test, the air turbulator of the heat exchanger was removed and observed visually for carbon deposits and general conditions. This examination was also conducted after the heater tests were completed. There was no noticeable increase in carbon deposits caused by the tests. After heater installation, the thermostat setting was adjusted to maintain a cutoff temperature of approximately 140 F. The gas inlet pressure was adjusted as recommended by the heater manufacturer. For natural gas heaters (no. 1 through 4) the gas pressure was 4.5 or 5" water column. Heating values during the tests varied between 1025 and 1070 Btu per cubic foot. Heater no. 5 was tested with propane gas (heating value 2558 Btu per cubic foot) and the inlet pressure was adjusted to 11" water column. The combustion air openings of the test chamber were adjusted so that when the burners of the heaters were on and the chamber doors were closed, no noticeable change in the the concentration of carbon monoxide and carbon dioxide of the flue gas were observed. Then, the burner control was turned on to run a full thermostatic cycle. The purpose of this test was to make certain that all heater settings and operations and the data acquisition system were working properly. One full thermostatic cycle usually took longer than 24 hours.

There were no major modifications to the heaters, except for minor changes for installation of testing instrumentation. The anode rods of some heaters were removed to facilitate the installation of water temperature sensors. Plastic drain valves of some heaters were replaced with metal valves.

4.8 Test Procedures

Each heater was tested according to the following sequences:

4.8.1 Burner Cyclic Test

Cyclic tests were performed in two series -- with access door in-place and removed. In each series, the chamber pressure was initially set at neutral and tests repeated at -0.05" water column steps until the pressure reached -0.2" water column. All heaters were tested without flue blockage and 10 cyclic tests were conducted for each heater. Since the burner of heater 5 continued to burn after flue flow was inverted at -0.2" water column, tests for this heater were repeated with 60% flue blockage. In each cyclic test, the following procedures were followed:

a. Performed tests with access doors in-place, then with doors off.

b. Burner control was turned on to heat the water to the set temperature.

c. After burner was cut off by the thermostat, a 30-minute wait was allowed to stabilize the heat exchanger temperature.

d. Test chamber pressure was adjusted to the desired level.

e. Waited 5 minutes to stabilize heater conditions.

f. Discharged hot water to ignite burner.

g. Let burner run for five minutes, then terminated the test.

h. If sustained flame roll-out occurred, tests would be repeated with 60% flue blockage. This was done for heater 5 only, with the flue blocking being done after step c above.

4.8.2 Chamber Pressure Depression and Flue Blockage Test

Tests were first conducted with access doors in-place, then with doors off. The following procedures were followed during each test:

a. Burner control was turned on to heat the water to the set temperature.
b. Adjusted water valve to maintain the burner on during the test.
c. Blockage installed on top of flue outlet. Blocking flue is part of the proposed ANSI test procedure.
d. Let heater run for 5 minutes to stabilize all conditions.
e. Set chamber pressure as desired for test, starting from neutral.
f. Continued to run heater for 5 minutes.
g. Decreased chamber pressure one step (0.05" water column) and repeated steps e and f above until chamber pressure reached -0.25" water column.
h. If the burner extinguished during any test (not caused by water temperature control), lower chamber pressure tests in the same series (same door status and flue blockage) were not done.
i. If fire rolled out during any stage of the pressure level tests or there was danger of damaging the heater, the test was terminated by either returning chamber pressure to neutral or turning off the gas control valve.

5. TEST RESULTS AND DISCUSSION

5.1 Data Presentation of Test Results

Test data are presented in figures 2 through 52. Each figure shows the results of a series of tests and consists of 6 sub-figures. Sub-figure (1) shows the chamber pressure depression and the flue draft. The chamber depression is presented in positive values for easy comparison. The flue draft is expressed as 10 times the test data. As explained in the instrumentation section, it is not appropriate to compare flue draft among heaters. Major events which happened during the test such as the status of the burner, stack inversion, and flue inversion are also indicated in sub-figure (1). Sub-figure (2) shows the four temperature readings of the sensor located outside and above the access door openings. Sub-figure (3) depicts the temperature outside the access door below the control valve, and at the left and the right sides of the heater base. Sub-figure (4) gives the temperatures at the flue top, flue bottom, and at the pilot light. Although the flue top temperature may be affected sometimes by downward airflow from the stack during chamber pressure depression tests, it does assist in determining the flue flow direction. Since the pilot light and control thermocouple arrangement of different heaters may be quite different, large variations of temperature readings at pilot lights may be found on different heaters. Sub-figure (5) shows temperatures inside the stack and at the air relief opening of the draft hood. Sub-figure (6) provides carbon dioxide readings at the flue top and can be used to confirm flue flow inversion.

Since flame roll-out is a basic concern of this study, tables 2 through 11 shows the maximum temperatures recorded at heater doors, below control valves, and at heater bases. The maximum door temperature is the highest temperature of the four door sensors during the test period.

5.2 Stack flow.

The flow direction of the stack reversed when the chamber pressure was dropped to -0.05" water column. Since the drafts of the vent stack during the tests of the five heaters varied within a very small range, regardless of the door status and the extent of flue blockage, stack flow reversing occurred for all tests below 0.05" water column pressure depression.

5.3 Heater 1 results.

a. Cyclic Test

For both doors in-place and doors not in-place tests (figures 2 and 3), the burner was ignited and then burned normally at neutral and -0.05" water column chamber pressure. While the chamber pressure was at -0.1" water column and lower, the burner self-extinguished in about 5 to 7 seconds after it was ignited and rolled out. Readings of the control thermocouple indicated that the fire extinguishing was not caused by the shutting off of gas valves. Hot air spilled out momentarily from the access door opening when the burner was ignited with access doors off. However, none of the door, control, and heater base temperatures reached 150 F.

b. Chamber Pressure Depression Test

With access doors in-place, flue flow inversions or flame roll-out occurred at -0.15" water column depression with no flue blockage, and at -0.1" water column with 20% and 60% blockage (figures 4, 5, and 6). Sub-figure (1) indicate that the flue draft was decreased by either flue blockage or chamber pressure drops. When flue inversion occurred, the burner extinguished in less than 5 seconds, probably caused by flow stagnation and lack of combustion air in the combustion chamber. With fairly tight access doors, the door temperature did not change greatly. The temperature sensors at the control and at the heater base registered a sudden jump, although they never exceeded 150 F. Table 2 gives the door, control, and heater base temperatures of the tests.

With access doors off (figures 8, 9, and 10), flue flow inversion or flame roll-out occurred at -0.15", -0.2", and -0.05" water column with 0%, 20%, and 60% blockage, respectively. The burner extinguished 5 to 15 seconds after the flue flow inverted. Hot gas spilled out from the door opening when flue blockage or lower chamber pressure was applied. Two door temperature sensors registered over 300 F at times.

When the flue opening was totally blocked (figures 7 and 11), flame roll-out occurred regardless of door status, although small notches at the flue top (notches on the flue to accept air turbulator) kept a very small amount of combustion product flowing upward in the flue. There was no substantial temperature change at the door, control, or heater base when access doors were in place (see table 2).

Table 2 Air temperature at heater door, control, and base for heater 1 with access doors in-place under pressure depression tests

Flue blockage	Test chamber pressure in.w.c.	Maximum at door °F	Maximum at control °F	Maximum at base °F
0%	neutral	86.9	81.0	80.8
	-0.05	95.2	84.0	85.6
	-0.1	97.0	83.7	88.9
	-0.15	108.9	97.9	143.1
20%	neutral	97.0	82.9	87.4
	-0.05	101.5	85.3	91.6
	-0.1	110.5	97.5	125.1
60%	neutral	103.3	83.5	91.4
	-0.05	106.7	84.9	94.1
	-0.1	110.5	94.8	126.0
100%	neutral	270.7	143.6	110.5

Table 3 Air temperature at heater door, control, and base for heater 1 with access doors not in-place under pressure depression tests

Flue blockage	Test chamber pressure in.w.c.	Maximum at door °F	Maximum at control °F	Maximum at base °F
0%	neutral	138.7	86.7	96.4
	-0.05	155.8	91.9	99.3
	-0.1	202.1	110.3	103.3
	-0.15	230.9	119.8	106.3
20%	neutral	144.5	79.9	90.0
	-0.05	184.8	86.9	94.3
	-0.1	236.7	102.0	99.51
	-0.15	342.1	114.1	102.7
	-0.2	315.3	125.2	105.6
60%	neutral	272.8	85.5	97.3
	-0.05	317.8	106.2	99.7
	-0.1	334.6	113.9	101.8
100%	neutral	660.7	89.6	99.3

However, one door temperature sensor reached over 600 F when access doors were off (see table 3). The burner did not extinguish during these two tests until the gas valve was manually turned off.

5.4 Heater 2 Results

a. Cyclic Test

The results for heater 2 were similar to those for heater 1, although the hot air spillage outside the heater was much more severe (figures 12 and 13). The flue inverted at -0.15 and -0.2" water column chamber pressure. When flue inversion occurred at -0.15" water column and with access doors off, the temperature momentarily reached approximately 400 F at the door opening and above 300 F at the control. It took 6 to 14 seconds for the burner to extinguish after ignition.

b. Chamber Pressure Depression Test

With access doors in-place, flue inversion or flame roll-out occurred at -0.25" water column chamber pressure with no flue blockage, at -0.2" water column with 20% blockage, and at -0.1" water column with 60% blockage (figures 14, 15, and 16). The maximum air temperature at door sensors (table 4) was close to 1000 F and at control sensor was close to 800 F. At 100% flue blockage (figure 17), fire rolled out from access doors raising door temperature to over 450 F, although test data indicated that the flue flow was not inverted. Flames were visible during all blockage tests except for 100% blockage.

Table 4 Air temperature at heater door, control, and base for heater 2 with access doors in-place under pressure depression tests

Flue blockage	Test chamber pressure in.w.c.	Maximum at door °F	Maximum at control °F	Maximum at base °F
0%	neutral	158.4	109.9	92.7
	-0.05	169.3	118.4	100.4
	-0.1	170.1	147.4	102.2
	-0.15	177.1	164.8	110.7
	-0.2	264.6	229.5	116.1
	-0.25	912.2	276.1	119.8
20%	neutral	179.1	127.0	108.7
	-0.05	182.8	142.2	110.5
	-0.1	183.0	157.3	110.7
	-0.15	221.0	178.2	116.2
	-0.2	994.6	771.3	125.1
60%	neutral	210.6	137.1	114.1
	-0.05	206.4	163.8	113.7
	-0.1	662.9	381.9	149.0
100%	neutral	466.0	208.0	103.3

Table 5 Air temperature at heater door, control, and base for heater 2 with access doors not in-place under pressure depression tests

Flue blockage	Test chamber pressure in.w.c.	Maximum at door °F	Maximum at control °F	Maximum at base °F
0%	neutral	322.3	176.9	104.5
	-0.05	294.4	181.8	110.1
	-0.1	280.9	147.9	113.0
	-0.15	277.7	114.8	116.4
	-0.2	741.9	930.9	126.0
	-0.25	914.7	779.2	128.1
20%	neutral	344.5	184.1	114.3
	-0.05	327.4	185.5	115.9
	-0.1	280.0	165.2	117.5
	-0.15	349.5	141.6	121.8
	-0.2	932.2	882.3	132.8
60%			(not tested)	
100%			(not tested)	

With access doors not in-place, flow inverted or flame rolled out at -0.2" water column for both no flue blockage and 20% blockage (figures 18 and 19). Flames could be seen outside access doors during both tests. The temperature at the door registered over 900°F (table 5). Tests for this heater were stopped after 20% blockage test. The heater control valve was damaged and rendered useless by high temperature, even though thermal shields were provided during the tests.

Inversions of flue flow at times were not definite. When the flue outlet was partially blocked and the test chamber was under negative pressure, the direction of flue flow appeared to become unstable. This was evidenced by erratic flue temperature and carbon dioxide concentration at the measurement points, as well as temperatures at door and control. However, high air temperature at the door and other points, and visible flames outside the heater assured flame roll-out. Unlike heater 1, the burner fire did not extinguish after flue inversion. The burner was manually turned off at the end of each test in order to protect the heater and control from being damaged.

5.5 Heater 3 Results

a. Cyclic Test

There was no flame roll-out during cyclic tests with the doors in-place (figure 20). With doors not in-place (figure 21), the temperature momentarily reached over 320°F at -0.05" water column and over 270°F at -0.1" water column. The burner kept on burning after ignition until it was turned off manually at all test pressure levels. At the time of ignition hot air spilled out from the access doors momentarily.

b. Chamber Pressure Depression Test

There was no flue inversion or flame roll-out during pressure depression tests, except at 100% flue blockage with access doors off, when flames were visibly seen outside of the heater jacket (figures 22 through 29). With access doors in-place, the highest door temperature recorded in all blockages was just under 250°F (table 6). With doors off, it reached 492°F at 100% flue blockages (table 7). It was interesting to note that

Table 6 Air temperature at heater door, control, and base for heater 3 with access doors in-place under pressure depression tests

Flue blockage	Test chamber pressure in.w.c.	Maximum at door °F	Maximum at control °F	Maximum at base °F
0%	neutral	187.2	107.7	96.9
	-0.05	178.2	104.4	96.6
	-0.1	178.9	100.9	94.1
	-0.15	156.7	95.5	93.0
	-0.2	139.5	94.5	92.3
	-0.25	137.1	93.7	91.6
20%	neutral	200.3	112.5	97.2
	-0.05	200.7	108.3	97.9
	-0.1	200.7	105.1	95.2
	-0.15	196.0	105.1	93.4
	-0.2	152.1	96.8	93.0
	-0.25	143.1	95.7	92.8
60%	neutral	249.9	120.6	97.2
	-0.05	244.9	119.8	95.2
	-0.1	248.5	112.5	95.2
	-0.15	240.1	111.2	95.4
	-0.2	235.9	108.5	95.0
	-0.25	235.9	105.4	95.0
100%	neutral	213.3	131.7	84.2

Table 7 Air temperature at heater door, control, and base for heater 3 with access doors not in-place under pressure depression tests

Flue blockage	Test chamber pressure in.w.c.	Maximum at door °F	Maximum at control °F	Maximum at base °F
0%	neutral	307.8	128.7	95.9
	-0.05	317.7	129.6	95.9
	-0.1	292.3	125.6	93.4
	-0.15	270.1	122.2	93.0
	-0.2	241.0	110.8	92.1
	-0.25	183.0	103.5	91.9
20%	neutral	332.4	134.1	95.4
	-0.05	363.4	134.2	95.5
	-0.1	330.8	131.5	94.1
	-0.15	306.7	126.5	93.6
	-0.2	257.0	113.0	92.8
	-0.25	208.4	107.2	93.6
60%	neutral	472.8	210.2	98.6
	-0.05	471.6	207.3	96.3
	-0.1	463.3	214.0	95.5
	-0.15	424.6	216.9	94.6
	-0.2	417.4	178.0	94.8
	-0.25	395.1	160.3	94.1
100%	neutral	491.9	533.1	93.2

this heater showed lower temperatures at the door and control when higher depression was applied.

At 100% flue blockage, the burner extinguished in less than 5 seconds after the blockage was placed during the doors in-place test (figure 25). When the doors were off (figure 29), flames rolled out as soon as the blockage was applied. The burner was turned off manually.

5.6 Heater 4 Results

a. Cyclic Test

This heater behaved much like heater 3 during cyclic tests (figures 30 and 31). When doors were off, 310°F hot air spilled momentarily over the door opening at the time of burner ignition.

b. Chamber Pressure Depression Test

No flue inversion or flame roll-out occurred at 0% and 20% blockage in both doors status (figures 32, 33, 36, and 37). Flue inversion took place at 60% blockage and flames were visible outside the access door. With the

Table 8 Air temperature at heater door, control, and base for heater 4 with access doors in-place under pressure depression tests

Flue blockage	Test chamber pressure in.w.c.	Maximum at door °F	Maximum at control °F	Maximum at base °F
0%	neutral	166.3	109.9	89.1
	-0.05	170.6	108.0	88.7
	-0.1	159.6	110.8	88.2
	-0.15	160.9	112.5	87.3
	-0.2	157.5	116.2	87.6
	-0.25	151.7	115.3	88.5
20%	neutral	175.3	114.6	88.9
	-0.05	167.7	113.0	88.7
	-0.1	168.1	115.9	87.8
	-0.15	168.6	117.5	87.6
	-0.2	163.6	117.0	88.2
	-0.25	161.2	118.4	88.9
60%	neutral	180.1	117.5	81.1
	-0.05	189.9	120.2	85.5
	-0.1	190.9	132.4	86.7
	-0.15	206.2	150.6	87.4
	-0.2	567.9	558.7	87.4
	-0.25	974.7	955.8	88.0
100%	neutral	259.7	168.1	84.6

doors in place, inversion occurred at -0.2" water column (figure 34). Without doors it occurred at -0.25" water column (figure 38). At 100% flue blockage, fire rolled out when blockage was applied (figures 35 and 39). In all flame roll-out and flue inversion cases, the burner was manually turned off. Tables 8 and 9 show the maximum temperature recorded during doors in-place and not in-place tests. The temperature at door and control reached above 950°F (60% blockage and -0.25" water column) with doors in-place while it was about 400°F (100% blockage and neutral pressure) with doors not in-place.

Table 9 Air temperature at heater door, control, and base for heater 4 with access doors not in-place under pressure depression tests

Flue blockage	Test chamber pressure in.w.c.	Maximum at door °F	Maximum at control °F	Maximum at base °F
0%	neutral	374.5	163.2	92.3
	-0.05	395.6	166.3	92.7
	-0.1	383.2	158.4	91.8
	-0.15	355.8	114.8	92.8
	-0.2	357.3	110.5	92.7
	-0.25	343.9	109.6	92.8
20%	neutral	364.1	177.1	93.0
	-0.05	372.9	176.0	93.6
	-0.1	373.5	174.6	93.9
	-0.15	393.4	129.6	95.0
	-0.2	424.8	126.5	94.6
	-0.25	407.7	134.6	94.1
60%	neutral	342.5	231.8	86.0
	-0.05	316.2	247.5	90.1
	-0.1	407.7	236.3	91.6
	-0.15	395.8	219.9	92.8
	-0.2	376.9	168.1	93.9
	-0.25	355.1	142.9	92.7
100%	neutral	399.7	265.3	86.5

5.7 Heater 5 Results

a. Cyclic Test

Heater 5 was a LP-gas heater. It behaved differently during cyclic tests from the other heaters in that flames rolled out continuously at certain pressure depressions without flue blockage (figures 40 and 42). Therefore, 60% flue blockage tests were added to the cyclic tests (figures 41 and 43). Without flue blockage, door temperature exceeded 250°F at -0.2" water column chamber pressure with doors in-place and at all pressure levels with doors not in-place. With 60% blockage, flame rolled out and continued to roll out at lesser pressure depression. Roll-out occurred at -0.15" and -0.2" water column when access doors were in-place and at 0", -0.15", and -0.2" water column when doors were off.

b. Chamber Pressure Depression Test

With access doors in place, flame roll-out did not appear without flue blockage (figure 44). Roll-out occurred at all blockages even when pressure depression was not applied (figures 45, 46, and 47). However, in all occasions the burner extinguished within 30 seconds after flames rolled out. With access doors off and 20% blockage (figure 49), flames rolled out intermittently at -0.15" and -0.2" water column chamber pressure until the pressure was raised back to -0.05" water column when the burner was extinguished by suffocation. At 60% and 100% blockage (figures 50 and 51), with the doors off, the burner fire extinguished within 42 seconds of flame roll-out. The thermocouple output of the heater control was monitored during the tests. No burner self-extinguishing was caused by the heater control action. Tables 10 (doors in-place) and 11 (doors not in-place) list the maximum temperature registered at the door, control, and base of the heater for pressure depression tests.

Table 10 Air temperature at heater door, control, and base for heater 5 with access doors in-place under pressure depression tests

Flue blockage	Test chamber pressure in.w.c.	Maximum at door °F	Maximum at control °F	Maximum at base °F
0%	neutral	146.8	107.4	93.2
	-0.05	144.1	103.8	90.9
	-0.1	136.2	102.4	92.1
	-0.15	138.4	102.7	93.2
	-0.2	151.5	104.9	93.2
	-0.25	193.5	138.6	93.6
20%	neutral	159.4	102.6	92.1
	-0.05	146.5	103.6	90.3
	-0.1	153.5	111.9	92.5
	-0.15	218.7	150.8	95.5
	-0.2	238.5	207.5	134.2
60%	neutral	199.2	113.4	85.6
	-0.05	356.0	203.9	85.6
	-0.1	455.0	320.0	109.9
100%	neutral	330.4	253.4	84.6

Table 11 Air temperature at heater door, control, and base for heater 5 with access doors not in-place under pressure depression tests

Flue blockage	Test chamber pressure in.w.c.	Maximum at door °F	Maximum at control °F	Maximum at base °F
0%	neutral	349.7	197.6	96.1
	-0.05	320.9	195.3	95.9
	-0.1	340.3	185.7	96.3
	-0.15	368.2	180.3	95.2
	-0.2	404.2	139.3	95.0
	-0.25	424.0	129.2	93.7
20%	neutral	315.0	172.6	84.2
	-0.05	388.2	318.6	145.8
	-0.1	393.8	251.4	150.3
	-0.15	350.2	215.2	152.2
	-0.2	337.8	161.8	151.2
60%	neutral	443.5	209.3	89.4
	-0.05	514.9	303.3	93.9
	-0.1	498.7	351.1	100.8
100%	neutral	657.0	539.2	91.0

5.8 Summary of Test Results

5.8.1 Flue Inversion and Flame Roll-out

Tables 12 and 13 summarize the flue inversion and flame roll-out occasions for the five water heaters. These tables show the levels of flue blockage and chamber pressure depression when flame roll-out occurred. They also indicate if the burner was self-extinguishing after flame roll-out occurred, because a fire burning continuously after roll-out is considered more dangerous than one which is self-extinguishing by suffocation. Also shown is whether visible flames were observed during tests. However, observation of flames may not be a reliable indication of flame roll-out, since flame roll-out is sometimes intermittent and also may not be visible.

Table 12 Flame roll-out occurrences for cyclic tests

Heater no.	Doors in Place: Flue inversion or flame roll-out (% block. - in.w.c. pressure)	Burner self-extinct (burner on-time, seconds)	Visible flames	Doors Off: Flue inversion or flame roll-out (% block. - in.w.c. pressure)	Burner self-extinct (burner on-time, seconds)	Visible flames
1	0% - 0.1"	Y (5)	N	0% - 0.1"	Y (7)	N
	0% - 0.15"	Y (5)	N	0% - 0.15"	Y (5)	N
	0% - 0.2"	Y (5)	N	0% - 0.2"	Y (6)	N
2	0% - 0.15"	Y (12)	N	0% - 0.15"	Y (14)	Y
	0% - 0.2"	Y (6)	N	0% - 0.2"	Y (8)	Y
3	(no r-o)	N	N	0% - 0.05"	N	N *
				0% - 0.1"	N	N *
4	(no r-o)	N	N	0% - 0"	N	N *
				0% - 0.05"	N	N *
				0% - 0.15"	N	N *
				0% - 0.2"	N	N *
5	0% - 0.15"	Y (6)	N	0% - 0.1"	Y (41)	Y
	0% - 0.2"	N	N	0% - 0.15"	N	Y
				0% - 0.2"	N	Y
				60% - 0"	N	Y
	60% - 0.05"	Y (<5)	Y	60% - 0.05"	Y (32)	Y
	60% - 0.1"	Y (46)	Y	60% - 0.1"	Y (71)	Y
	60% - 0.15"	N	N	60% - 0.15"	N	N
	60% - 0.2"	N	N	60% - 0.2"	N	N

Y = yes
N = no
* = Temperature exceeded 250°F momentarily at access doors at the moment of burner ignition.

Table 13 clearly indicates that the combination of flue blockage and pressure depression accelerated flue inversion and flame roll-out. When more flue blockage was applied, less pressure depression was needed to induce flame roll-out. In several cases, only -0.1" water column pressure was enough to have flame roll-out when heater flues were blocked 20 or 60%. Therefore, pressure depression is an important factor in flame roll-out. With a few exceptions, door status (in-place or not in-place) also

Table 13 Flame roll-out occurrences for pressure depression tests

Heater no.	Doors in Place: Flue inversion or flame roll-out (% block. - in.w.c. pressure)	Doors in Place: Burner self-extinct (burner on-time, seconds)	Doors in Place: Visible flames	Doors Off: Flue inversion or flame roll-out (% block. - in.w.c. pressure)	Doors Off: Burner self-extinct (burner on-time, seconds)	Doors Off: Visible flames
1	0% - 0.15"	Y (<5)	N	0% - 0.15"	Y (15)	Y
	20% - 0.1"	Y (<5)	N	20% - 0.1"	Y (15)	Y
	60% - 0.1"	Y (<5)	N	60% - 0.1"	Y (5)	Y
	100% - 0"	Y (90)	N	100% - 0"		Y
2	0% - 0.25"	N	Y	0% - 0.2"	N	Y
	20% - 0.2"	N	Y	20% - 0.2"	N	Y
	60% - 0.1"	N	Y			
	100% - 0"	N	N			
3	0% (no r-o)	N	N	0% - 0"	N	N
	20% (no r-o)	N	N	20% - 0"	N	N
	60% (no r-o)	N	N	60% - 0"	N	N
	100% (no r-o)	Y (<5)	N	100% - 0"	N	Y
4	0% (no r-o)	N	N	0% - 0"	N	N
	20% (no r-o)	N	N	20% - 0"	N	N
	60% - 0.2"	N	Y	60% - 0.25"	N	Y
	100% - 0"	N	N	100% - 0"	N	Y
5	0% (no r-o)	N	N	0% - 0"	N	N
	20% - 0"	Y (20)	N	20% - 0.15"	N	Y
	60% - 0"	Y (30)	Y	60% - 0.1"	Y (42)	Y
	100% - 0"	Y (<5)	Y	100% - 0"	Y (<5)	Y

Y = yes
N = no

influenced flame roll-out greatly. It took less pressure depression to induce flame roll-out or flames rolled out for longer periods of time before extinguishing with access doors not in-place than with doors in-place.

Comparing cyclic tests with pure pressure depression tests for the same heater and flue blockage, a majority of cases showed that flame roll-out occurred at less pressure depression under cyclic conditions than under pure depression conditions. However, with the exception of heater 5, burners all extinguished within a short time after ignition during cyclic tests.

5.8.2 Flame Roll-out and Hot Air Spillage

Tables 2 through 11 show that hot air spillage from the heater base does not appear to be a significant problem. It is also clear that, except for a very few instances, the temperature of hot air spillage and flame roll-out were much more severe with access doors not in-place than with them in-place. Table 14 tabulates the results of all pressure depression tests with and without the access doors in place. A measured temperature outside the access doors of 250°F or higher is indicated by a "Y" in the appropriate column. With doors in-place, heater 1 exceeded 250°F at 100% flue blockage, heater 3 did not exceed this criterion under any of the test conditions. With doors off, heater 1 failed this criterion when flue blockage was at 20% and over. The other heaters failed in all flue blockage tests including no blockage cases. Heaters 1 and 3 had less flame roll-out than the other heaters and heater 2 had flame roll-out more severe than the others.

Table 14 Results of pressure depression tests using a criterion of 250°F outside the access doors for hot gas spillage

Heater	Flue blockage (%)	Chamber Pressure (in.w.c.)	Doors in-place	Doors off
1	0	neutral	N	N
		-0.05	N	N
		-0.1	N	N
		-0.15	N	N
	20	neutral	N	N
		-0.05	N	N
		-0.1	N	N
		-0.15	N	Y
		-0.2	N	Y
	60	neutral	N	Y
		-0.05	N	Y
		-0.1	N	Y
	100	neutral	Y	Y
2	0	neutral	N	Y
		-0.05	N	Y
		-0.1	N	Y
		-0.15	N	Y
		-0.2	Y	Y
		-0.25	Y	Y
	20	neutral	N	Y
		-0.05	N	Y
		-0.1	N	Y
		-0.15	N	Y
		-0.2	Y	Y
	60	neutral	N	(not tested)
		-0.05	N	(not tested)
		-0.1	Y	(not tested)
	100	neutral	Y	(not tested)
3	0	neutral	N	Y
		-0.05	N	Y
		-0.1	N	Y
		-0.15	N	Y
		-0.2	N	Y
		-0.25	N	N
	20	neutral	N	Y
		-0.05	N	Y
		-0.1	N	Y
		-0.15	N	Y
		-0.2	N	Y
		-0.25	N	N

Symbols: Y = over 250°F
N = not over 250°F

Table 14 Results of pressure depression tests using a criterion of 250°F outside the access doors for hot gas spillage (continued)

Heater	Flue blockage (%)	Chamber Pressure (in.w.c.)	Doors in-place	Doors off
	60	neutral	N	Y
		-0.05	N	Y
		-0.1	N	Y
		-0.15	N	Y
		-0.2	N	Y
		-0.25	N	Y
	100	neutral	N	Y
4	0	neutral	N	Y
		-0.05	N	Y
		-0.1	N	Y
		-0.15	N	Y
		-0.2	N	Y
		-0.25	N	Y
	20	neutral	N	Y
		-0.05	N	Y
		-0.1	N	Y
		-0.15	N	Y
		-0.2	N	Y
		-0.25	N	Y
	60	neutral	N	Y
		-0.05	N	Y
		-0.1	N	Y
		-0.15	N	Y
		-0.2	Y	Y
		-0.25	Y	Y
	100	neutral	Y	Y
5	0	neutral	N	Y
		-0.05	N	Y
		-0.1	N	Y
		-0.15	N	Y
		-0.2	N	Y
		-0.25	N	Y
	20	neutral	N	Y
		-0.05	N	Y
		-0.1	N	Y
		-0.15	N	Y
		-0.2	N	Y
	60	neutral	N	Y
		-0.05	Y	Y
		-0.1	Y	Y
	100	neutral	Y	Y

Symbols: Y = over 250°F
N = not over 250°F

Flame roll-out results at neutral chamber pressure are of particular interest, since these test conditions satisfied the test requirements of the proposed revisions to the ANSI standard. With doors in-place, the door or control temperature of heaters 1, 2, 4, and 5 exceeded 250°F only when 100 % flue-blockage were applied. However, when the access doors were removed, 16 of the 18 neutral pressure cases in table 14 exceeded this temperature limit. More discussion of these results and the proposed ANSI test method is given in the next section.

Although the investigation of how water heater construction effect flame roll-out is beyond the scope of this study, no-blockage tests were performed under chamber pressure depression on heater 3 with the draft hood from heater 2. Quite contrasting results were observed. As described previously, heater 3 had the least tendency for flame roll-out and its draft hood appeared to be substantially better constructed than the draft hoods of the other four heaters. With access doors off and with its own draft hood, the flame was not observed outside the access door until 100% flue blockage was applied (see table 13 and discussion in paragraph 5.4). However, with heater 2's draft hood in place on heater 3, flame roll-out was clearly observed during pressure depression tests even without any blockage. This experiment demonstrated that draft hood design affected stack downdraft and water heater performance substantially. Both the ANSI standards on water heaters [3] and draft hoods [5] require that "draft hood shall not extinguish the main burner flames nor cause them to flash back, lift, float, burn outside the water heater", when a total downdraft pressure ranging from zero to 0.05" water column is imposed at the outlet of the draft hood. It was quite clear from the tests that one draft hood resisted downdrafts of more than 0.05" water column much better than other draft hoods.

5.8.3 Comparison with Proposed ANSI Test Method

The proposed ANSI test procedure requires that the heater be tested under neutral pressure and its flue be blocked at 20% increments until it is entirely blocked off. At no time during this test shall flames issue outside the face of the jacket. If a unit can not meet this requirement, a safety device must be provided to cut off gas to the burner during the blockage test. The proposed standard revisions do not specify the kind of devices to be used. Presumably, the water heater manufacturers may use temperature, pressure, or other means to sense flue blockage and activate the gas cut off action.

None of the heaters tested in this study were equipped with safety devices to conform to the proposed standard revisions, and thus no conclusion can be made as to whether the inclusion of such safety devices would allow for the compliance of these heaters with the proposed revisions to the ANSI standard. However, for the heaters tested, comparisons of the proposed ANSI test method (flue blockage without pressure depression) with the tests performed in this study, combination of flue blockage, pressure depression, and door status, may be made*.

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* Under the chamber pressure depression test of this study, the proposed ANSI test method was actually performed when various flue blockages were applied with neutral chamber pressure.

Although the proposed ANSI test procedures do not specifically state whether the access doors are in-place or not in-place during tests, judging from other required tests in the gas water heater standard (ANSI Z21.10.1), it was presumed that all tests are intended to be conducted with doors in-place. Based on this assumption and a criterion of 250°F hot air spillage temperature being a indication of flame roll-out, table 15 was constructed to compare the results of the proposed ANSI test method (flue blockage only) and other tests conducted in this study. All heaters, except heater 5, satisfied the ANSI proposed requirements for no visible flame roll-out and would not need for additional safety devices. However, if 250°F air temperature outside the access doors is also added as a criterion of flame roll-out, then only heater 3 did not have flame roll-out. Heater 3 also satisfied the above temperature criterion for no flame roll-out during the combined flue blockage/pressure depression tests with access doors in-place. However, it failed the pressure depression tests with the doors off. Thus, in order to protect home owners who leave the water heater access doors open, the CPSC and the ANSI water heater standards subcommittee should consider requiring that either water heaters be provided with a means to assure that the access doors are closed properly during operation (e.g. interlocking devices) and/or the units be tested both with doors in-place and doors removed. The former requirement should be considered by CPSC and the ANSI subcommittee in combination with a possible additional requirement that water heaters be also equipped with piezoelectric ignition systems in order to alleviate the necessity of opening the access doors by the home owners to light the burners.

Table 15 Comparison of proposed ANSI test and pressure depression test results

Heater no.	Flue blockage only		Combination flue blockage and pressure depression ANSI method & 250°F	
	ANSI method	ANSI method and 250°F	Doors in-place	Doors not in-place
1	no roll-out	roll-out	roll-out	roll-out
2	no roll-out	roll-out	roll-out	roll-out
3	no roll-out	no roll-out	no roll-out	roll-out
4	no roll-out	roll-out	roll-out	roll-out
5	roll-out	roll-out	roll-out	roll-out

In addition, it has also been demonstrated that flame roll-out can occur either under negative pressure or at partial flue blockage with negative pressure. Not knowing the kind of safety devices heater manufacturers will provide to satisfy the proposed ANSI revisions, these devices may well satisfy the blocked flue tests under neutral pressure, yet fail to work properly under depressurization conditions or situations combining partial flue blockage and depressurization.

REFERENCES

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2. Adams, D.E., and Morphy, C.C., "Testing of Gas Fired Water Heaters and Water Heater Combination Control Valves", Calspan Corporation, (September, 1985).

3. American National Standard Institute, Inc., "American National Standard for Gas Water Heaters, Volume I, Automatic Storage Water Heaters With Inputs of 75,000 Btu Per Hour or Less", Secretariat American Gas Association, ANSI Z21.10.1, (1984).

4. American National Standard Institute, Inc., "Draft text for review and comment on Proposed Revisions to American National Standard for Gas Water Heaters, Volume I, Storage Water Heaters with Input Ratings of 75,000 Btu Per Hour or Less", (January, 1987)

5. American National Standard Institute, Inc., "American National Standard for Draft Hoods", Secretariat American Gas Association, ANSI Z21.12, (1981).

6. Switzer, D., "Final Report on ES Water Heater Contract", U.S. Consumer Product Safety Commission, (September, 1985).

7. Moffatt, S., "Backdrafting Woes", Progressive Builder, (December, 1986).

8. TRW Energy Systems Group, "Combustion Guidelines for Single and Multifamily Dwellings", American Gas Association, (1980).

TEMPERATURE:
- T1 - vent stack
- T2 - draft hood
- T3 - flue top
- T4 - flue bottom
- T5 - storage top
- T6 - storage bottom
- T7 - control
- T8 - door (4)
- T9 - heater bottom (2)
- T10 - pilot
- T11 - chamber

PRESSURE:
- P1 - chamber
- P2 - flue draft
- P3 - barometric

GAS CONCENTRATION: (CO & CO2)
- G1 - flue top
- G2 - chamber

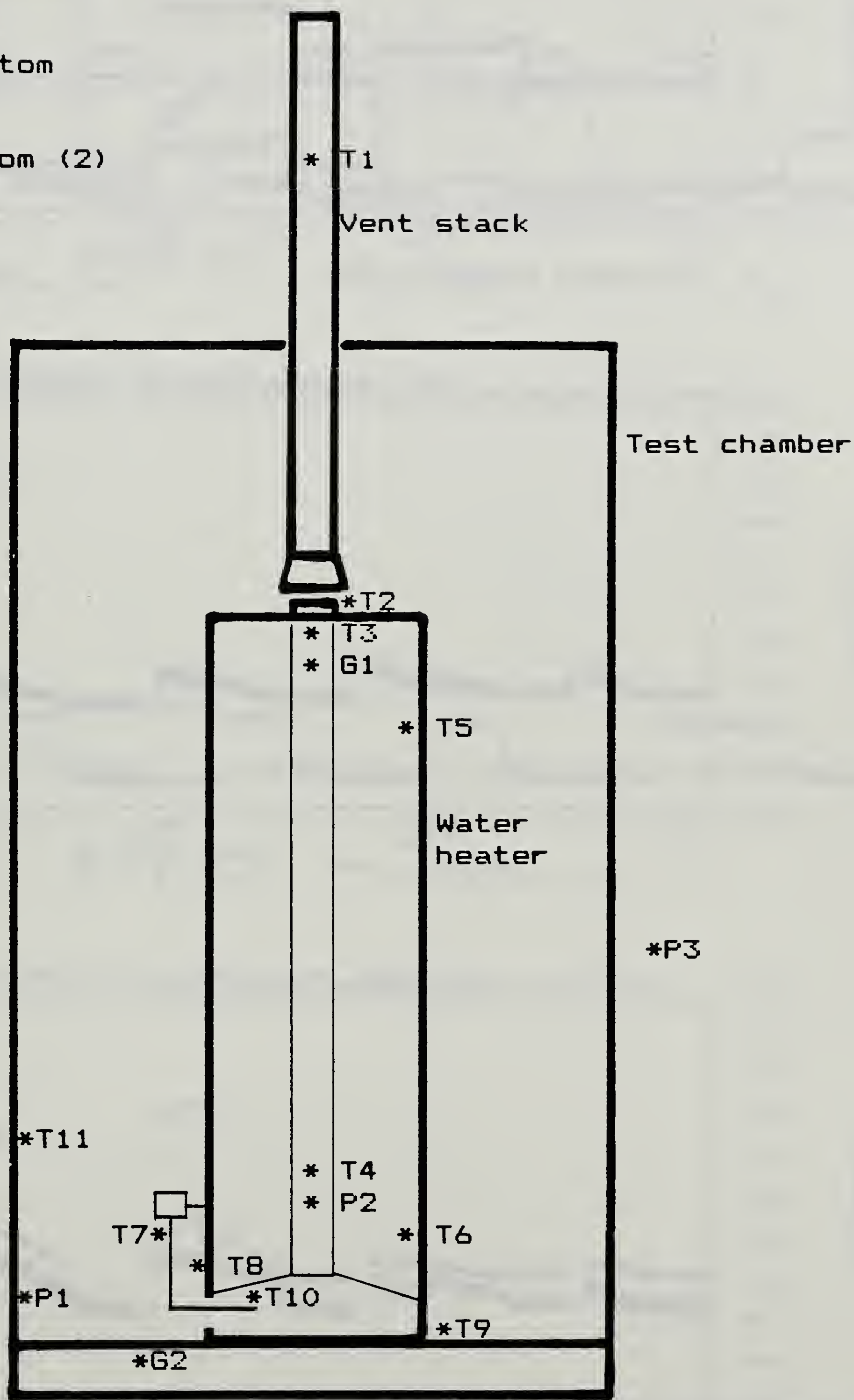


Figure 1 Schematic diagram showing sensor locations for temperature, pressure, and gas concentration

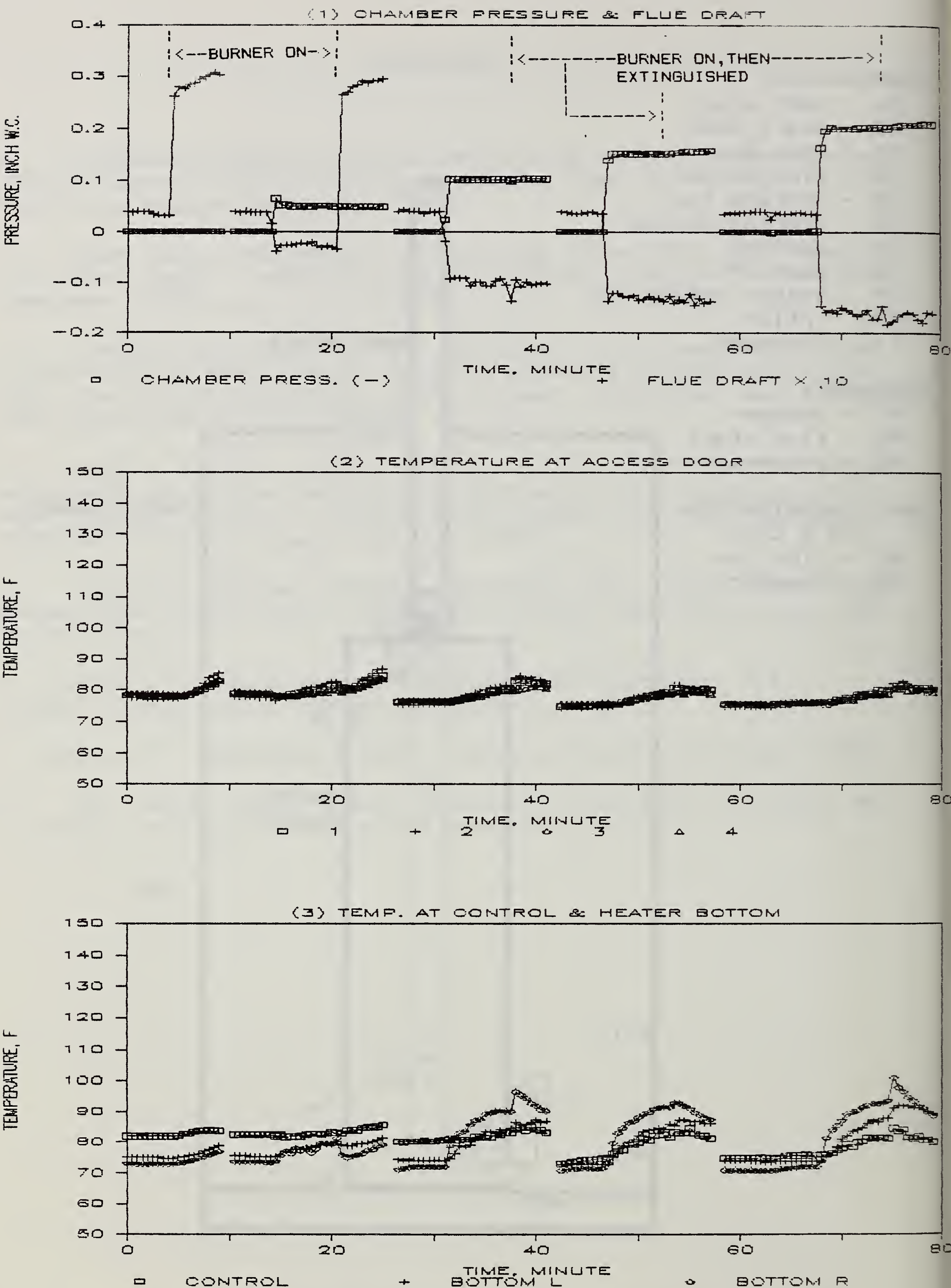


Figure 2 Cyclic test, access doors in-place -- Heater no. 1

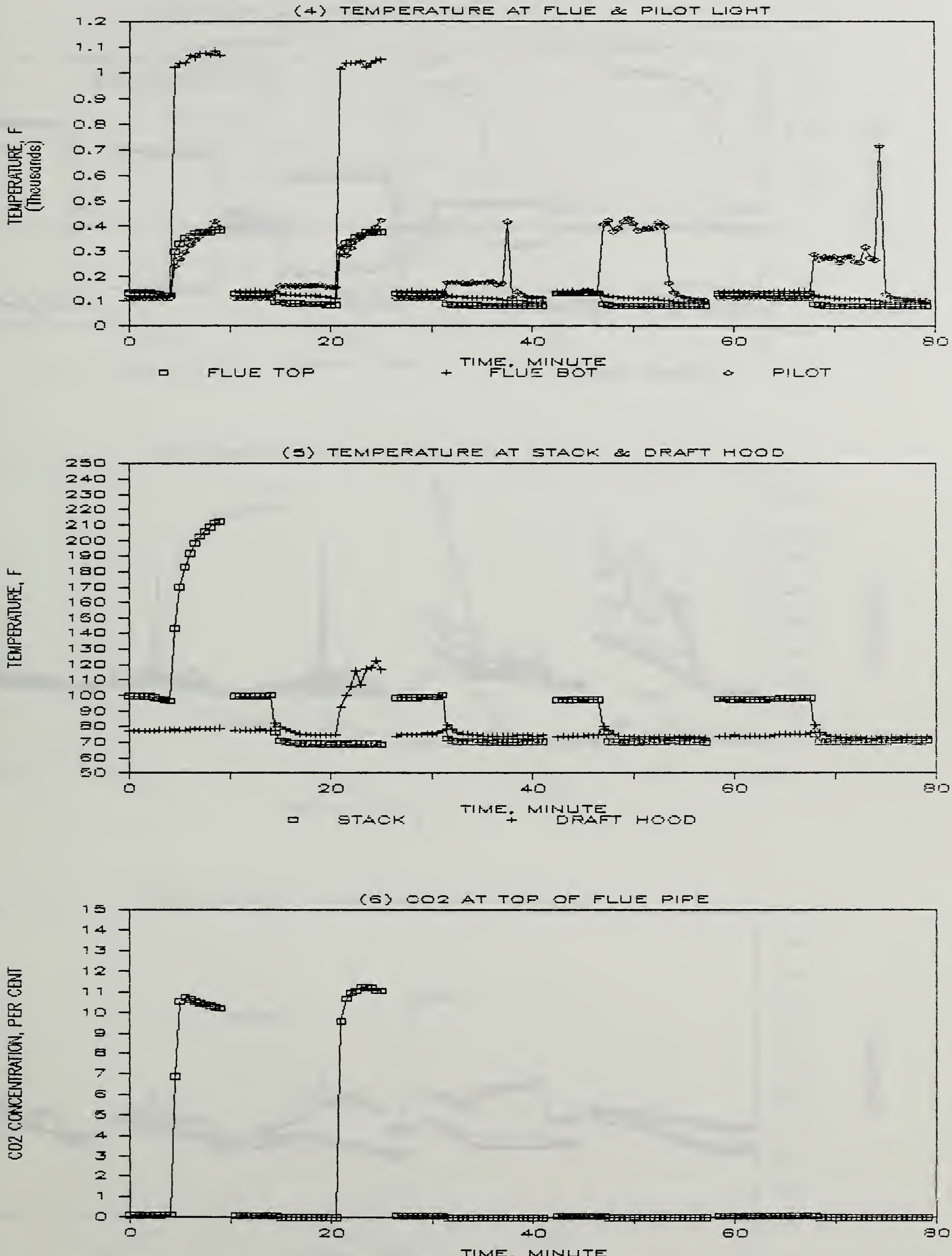


Figure 2 Cyclic test, access doors in place -- Heater no. 1

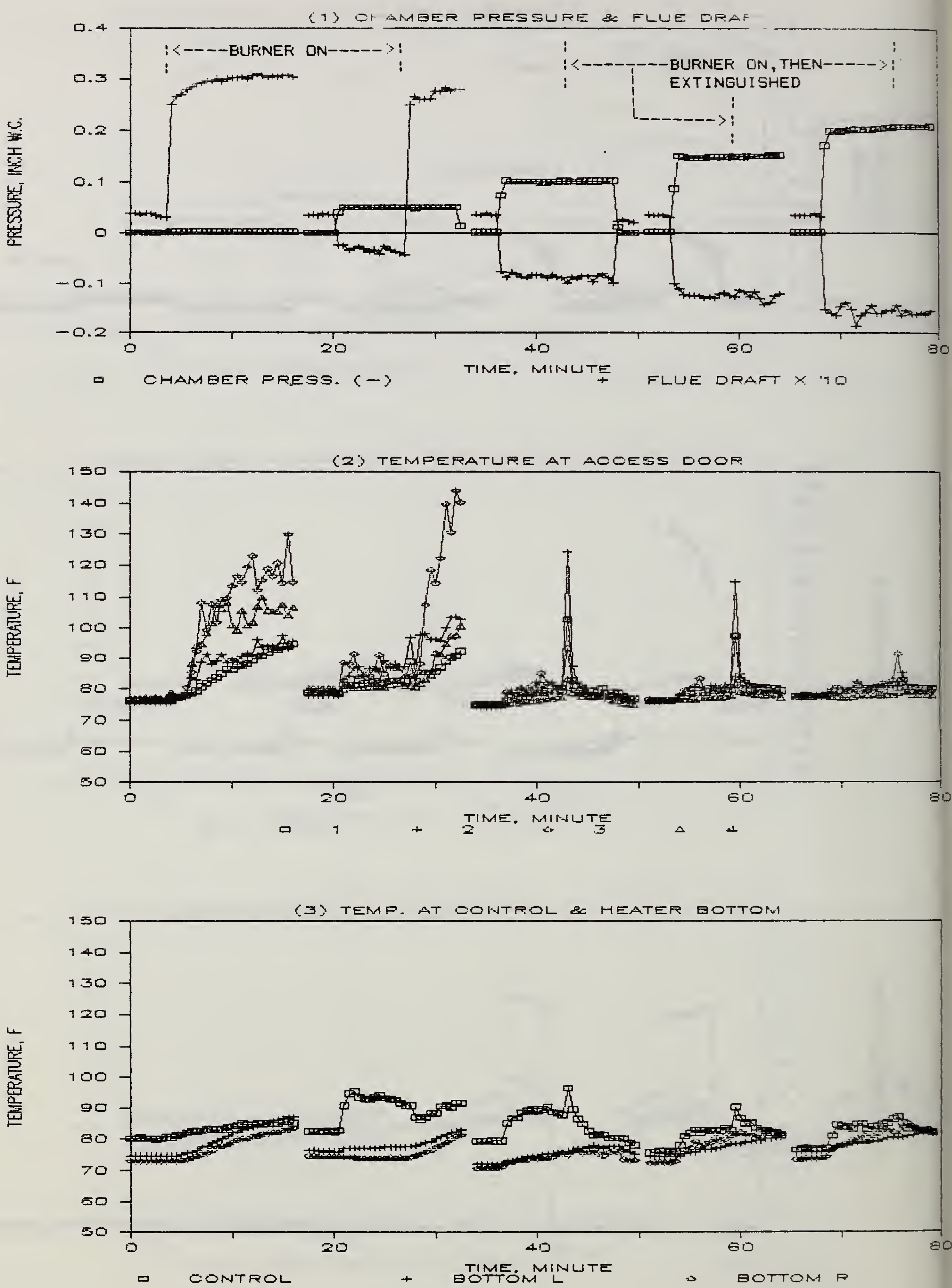


Figure 3 Cyclic test, access doors off -- Heater no. 1

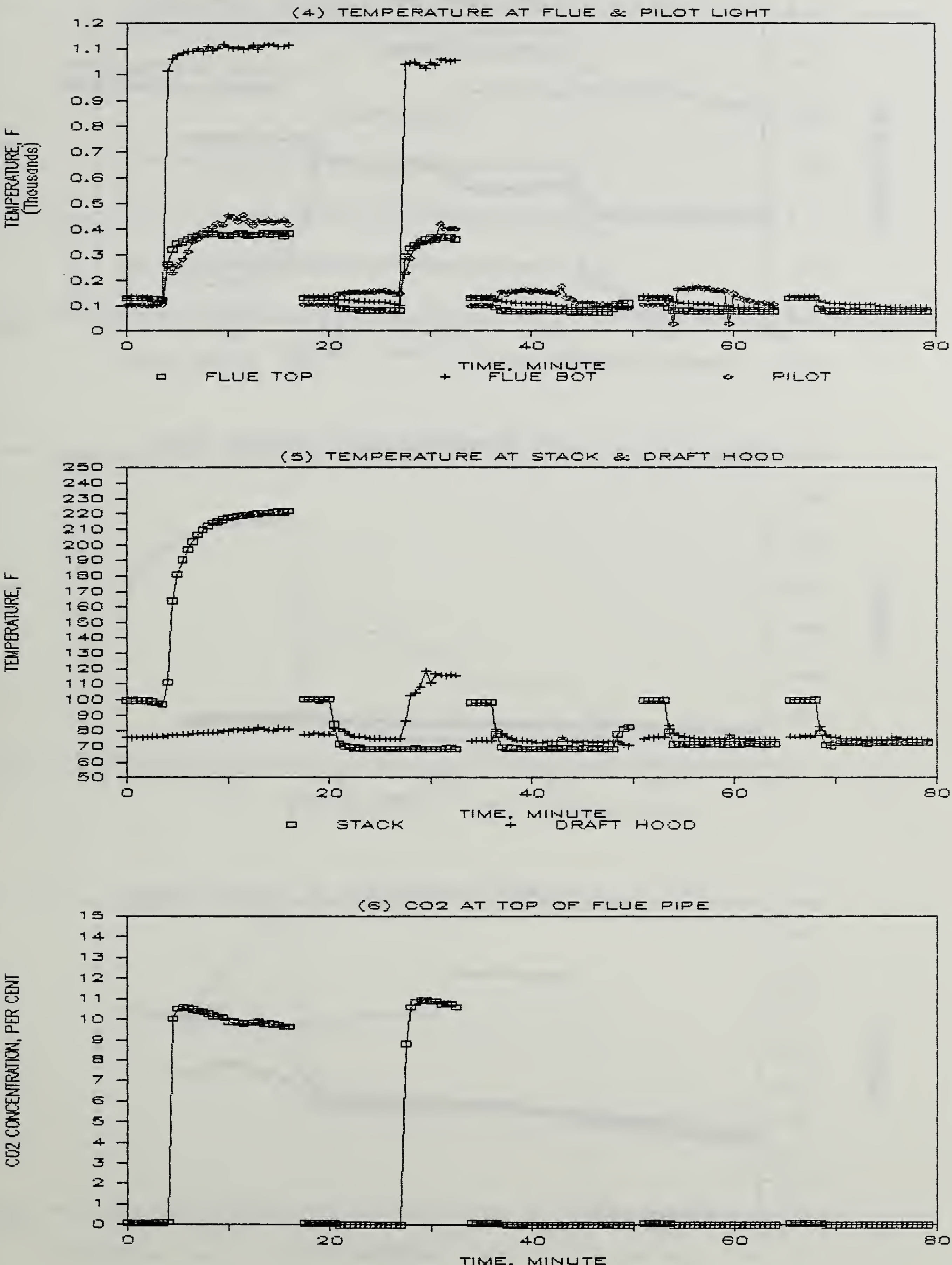


Figure 3 Cyclic test, access doors off -- Heater no. 1

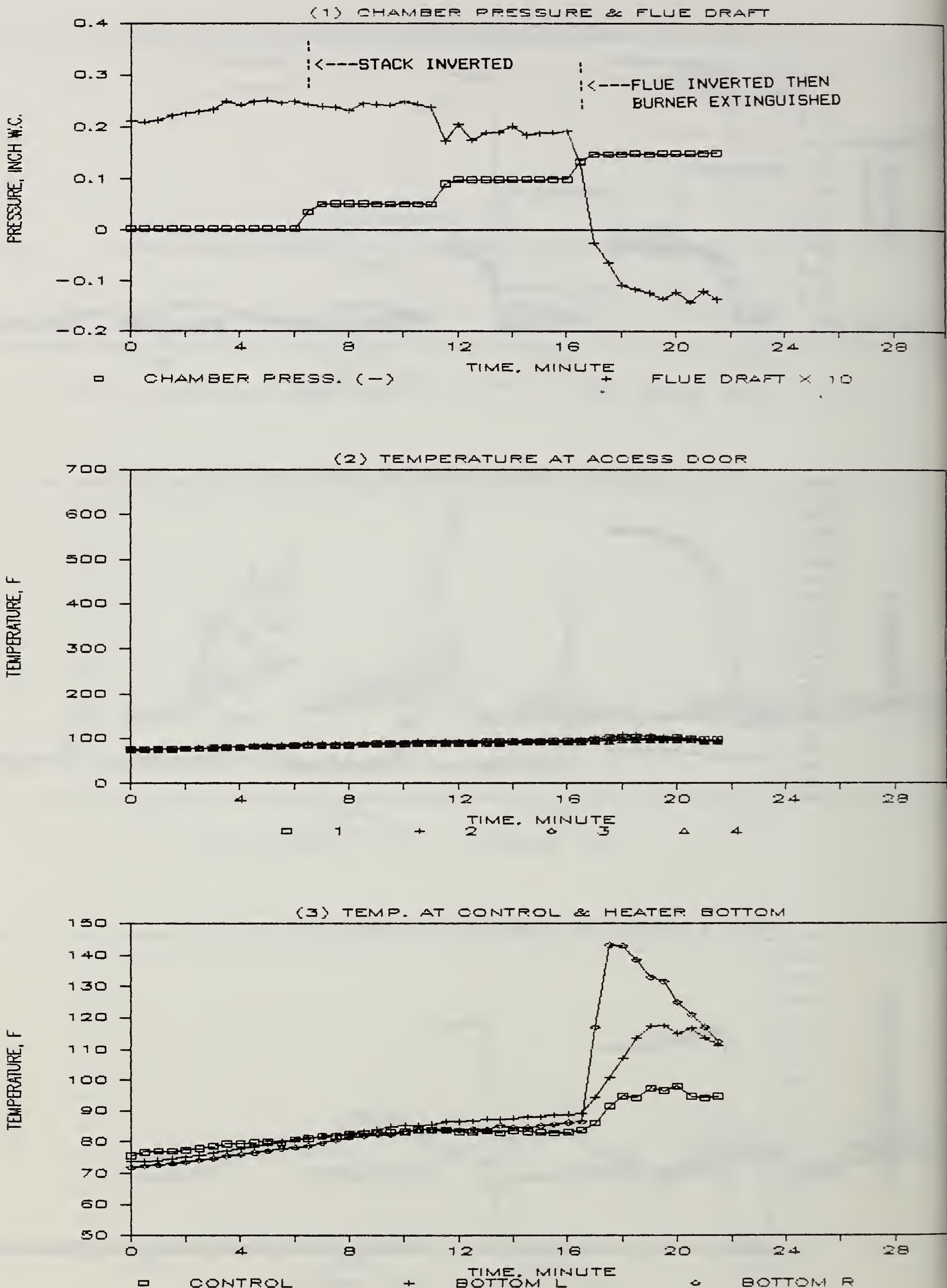
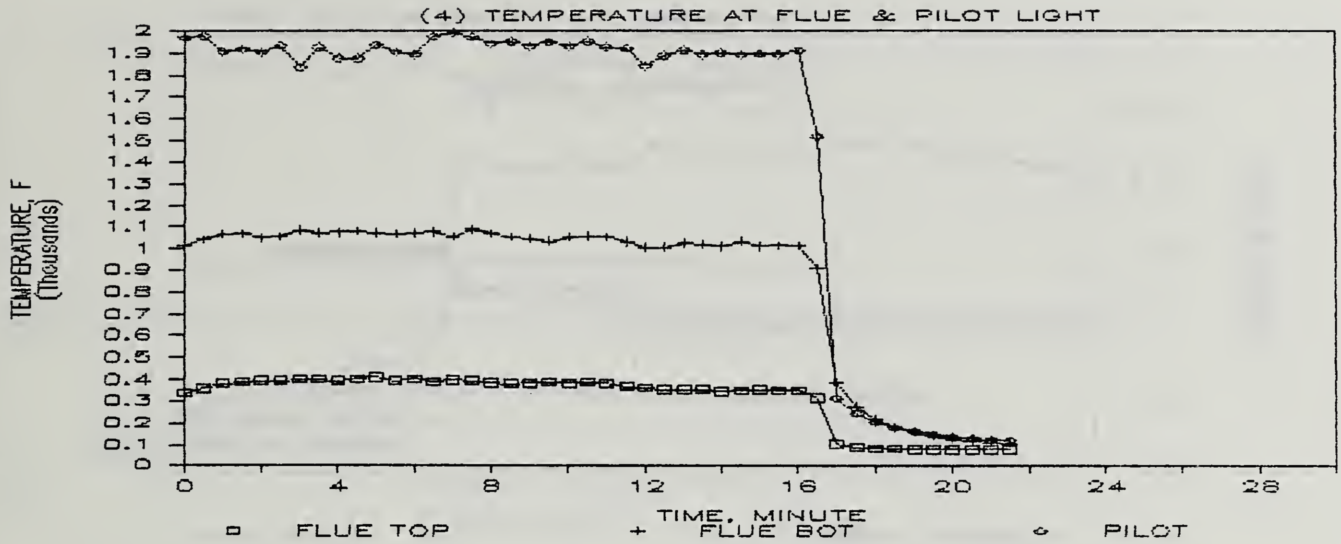
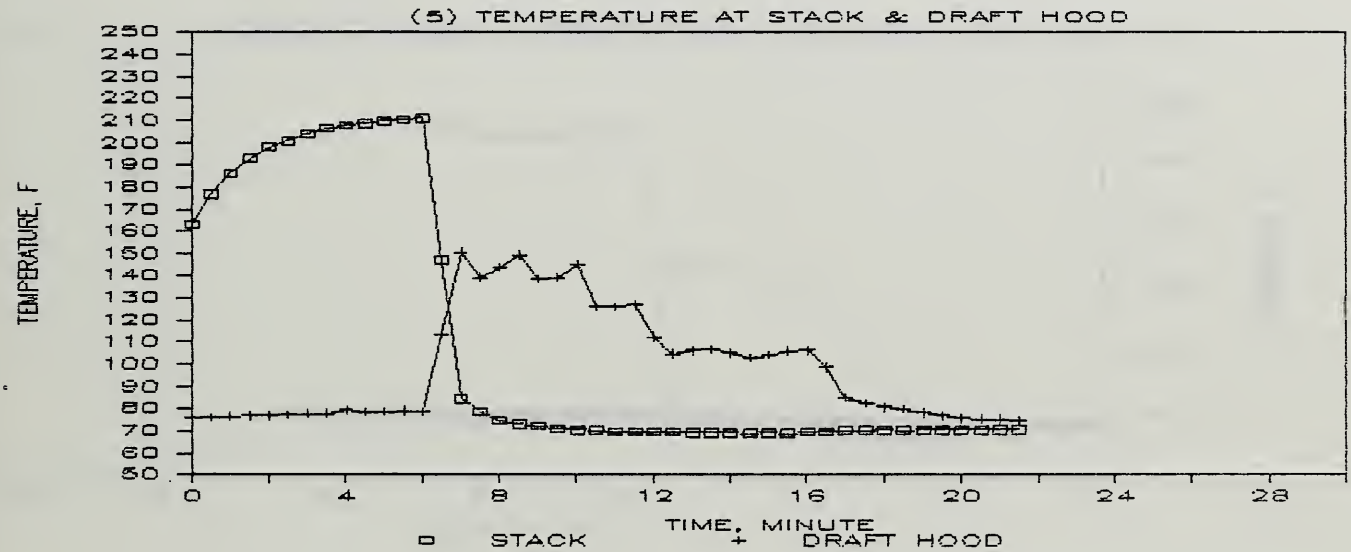


Figure 4 Pressure test, access doors in-place, no flue blockage -- Heater no. 1





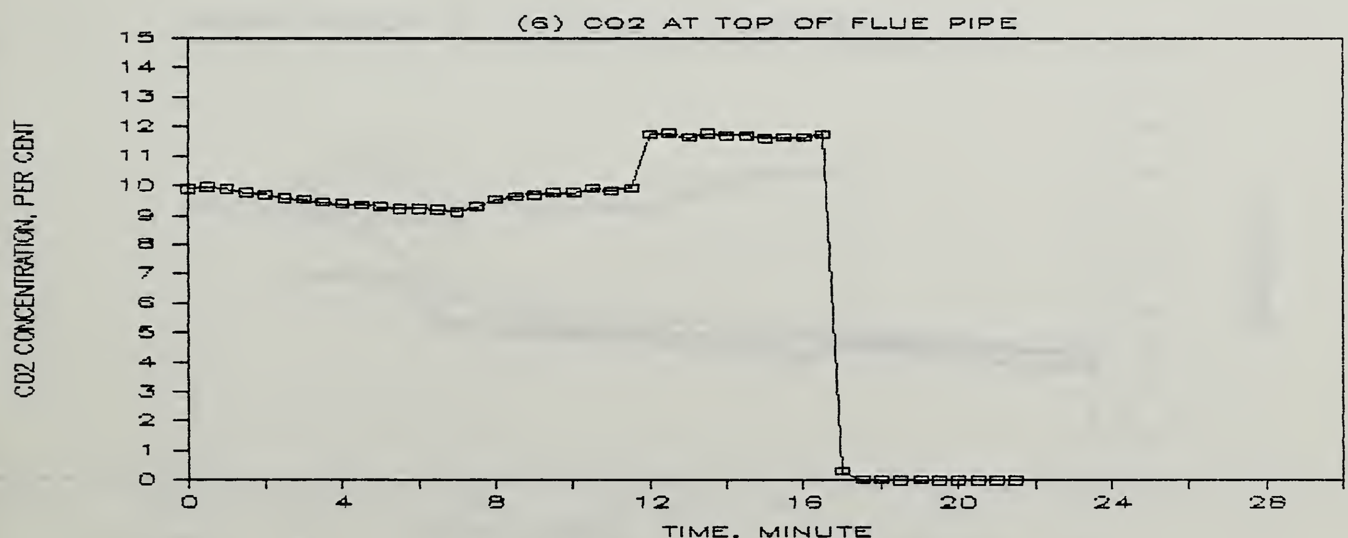


Figure 4 Pressure test, access doors in place, no flue blockage
-- Heater no. 1

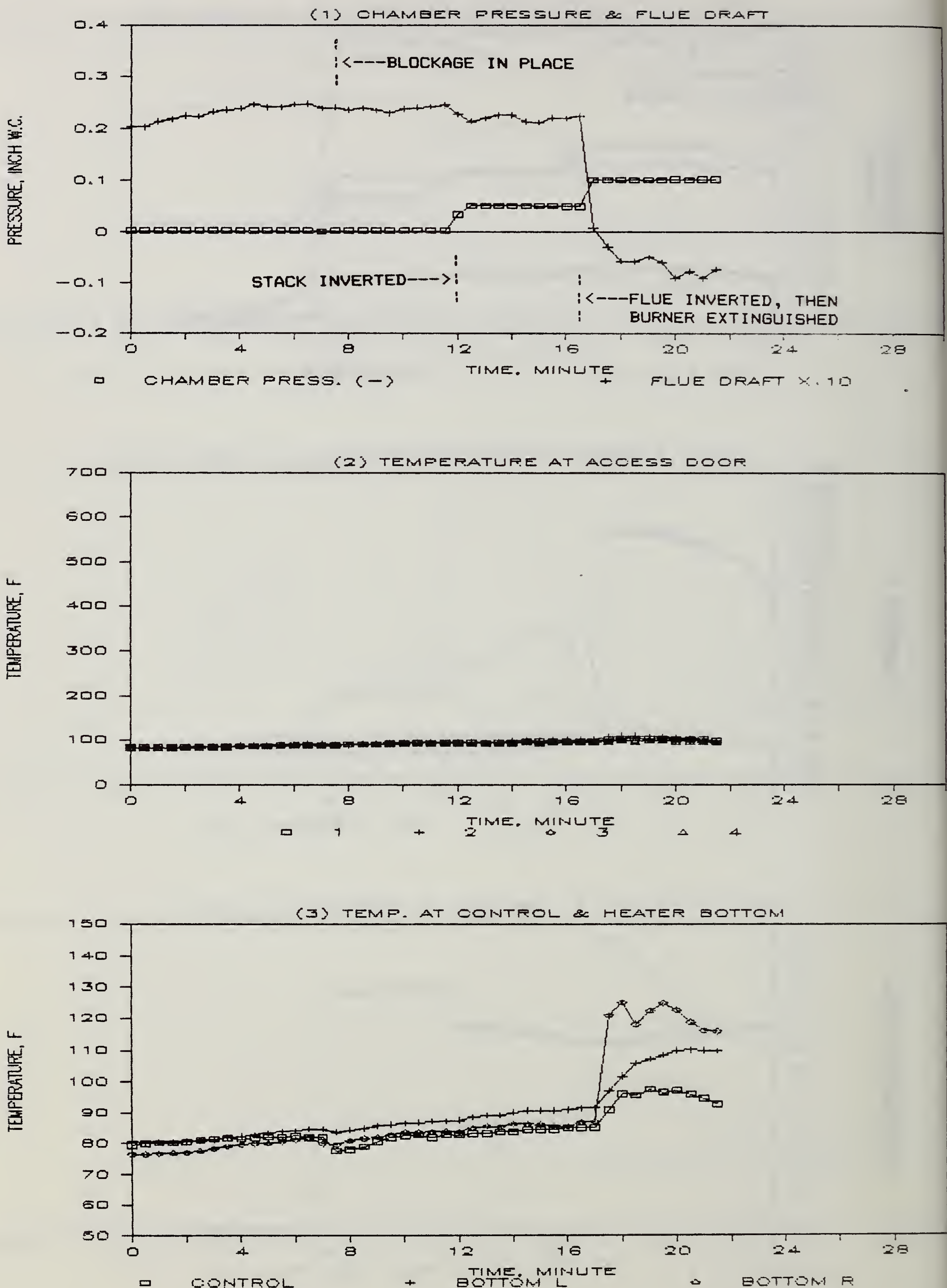


Figure 5 Pressure test, access doors in-place, 20% flue blockage -- Heater no. 1

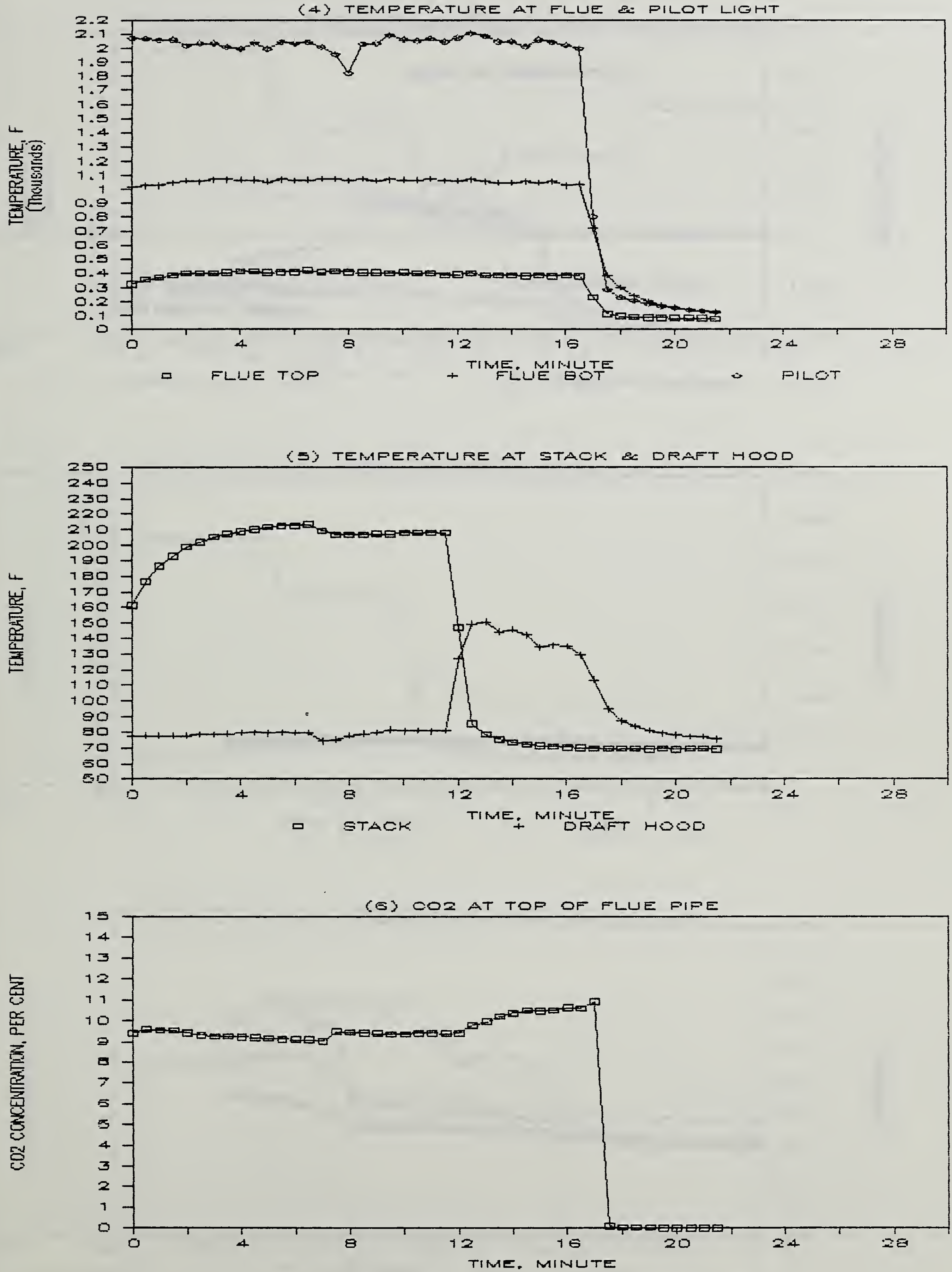


Figure 5 Pressure test, access doors in place, 20% flue blockage
-- Heater no. 1

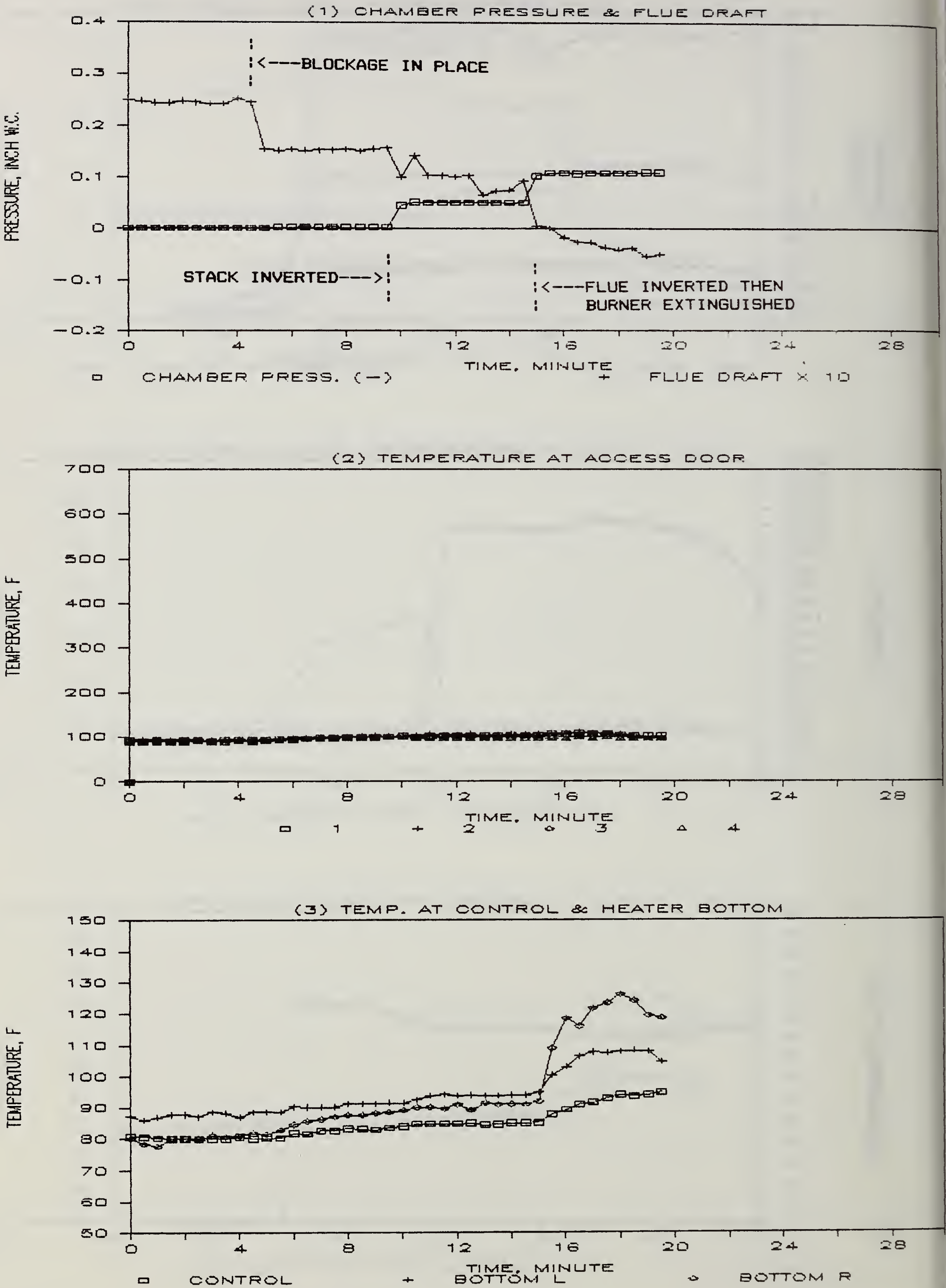


Figure 6 Pressure test, access doors in-place, 60% flue blockage -- Heater no. 1

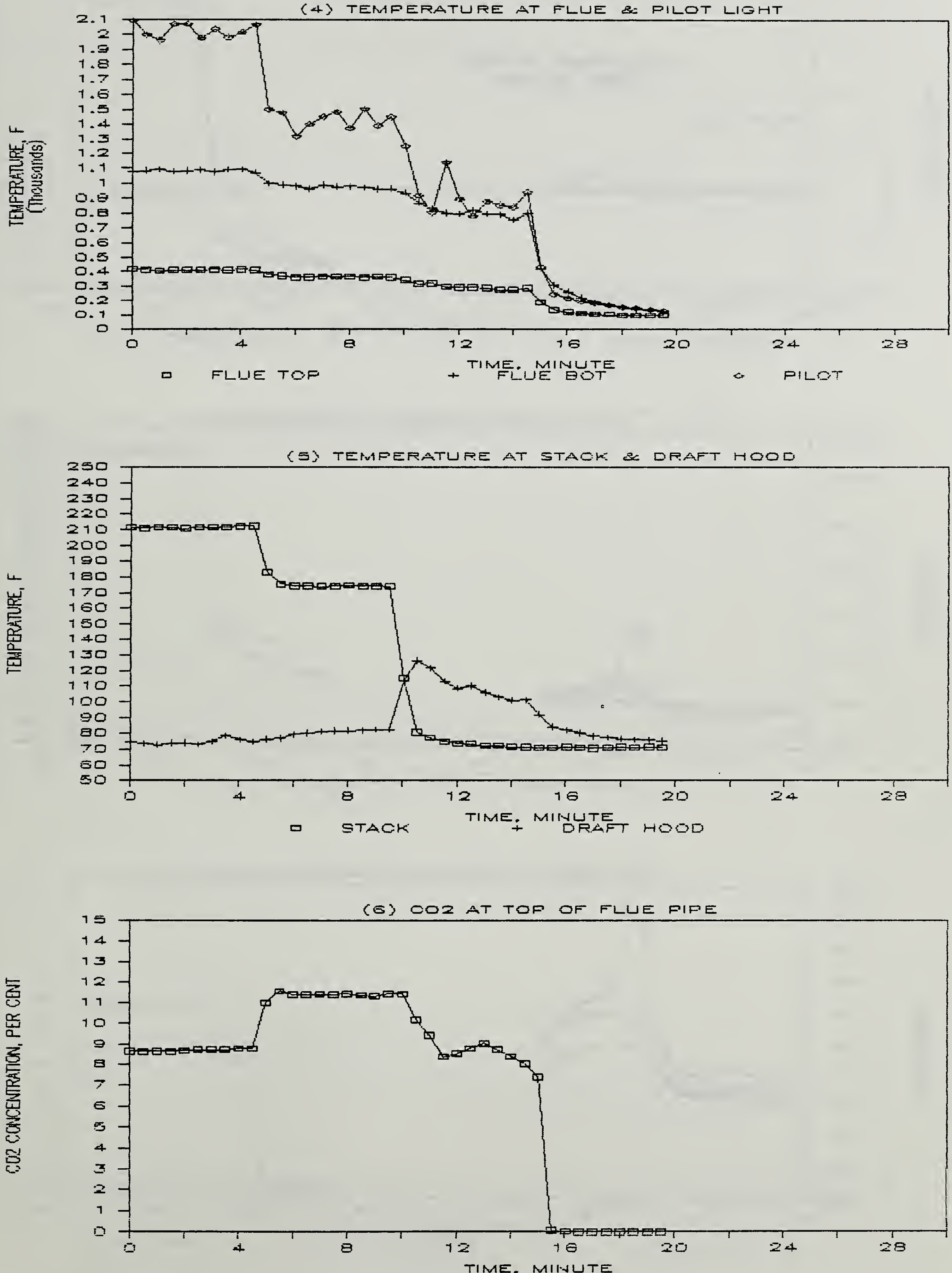


Figure 6 Pressure test, access doors in place, 60% flue blockage -- Heater no. 1

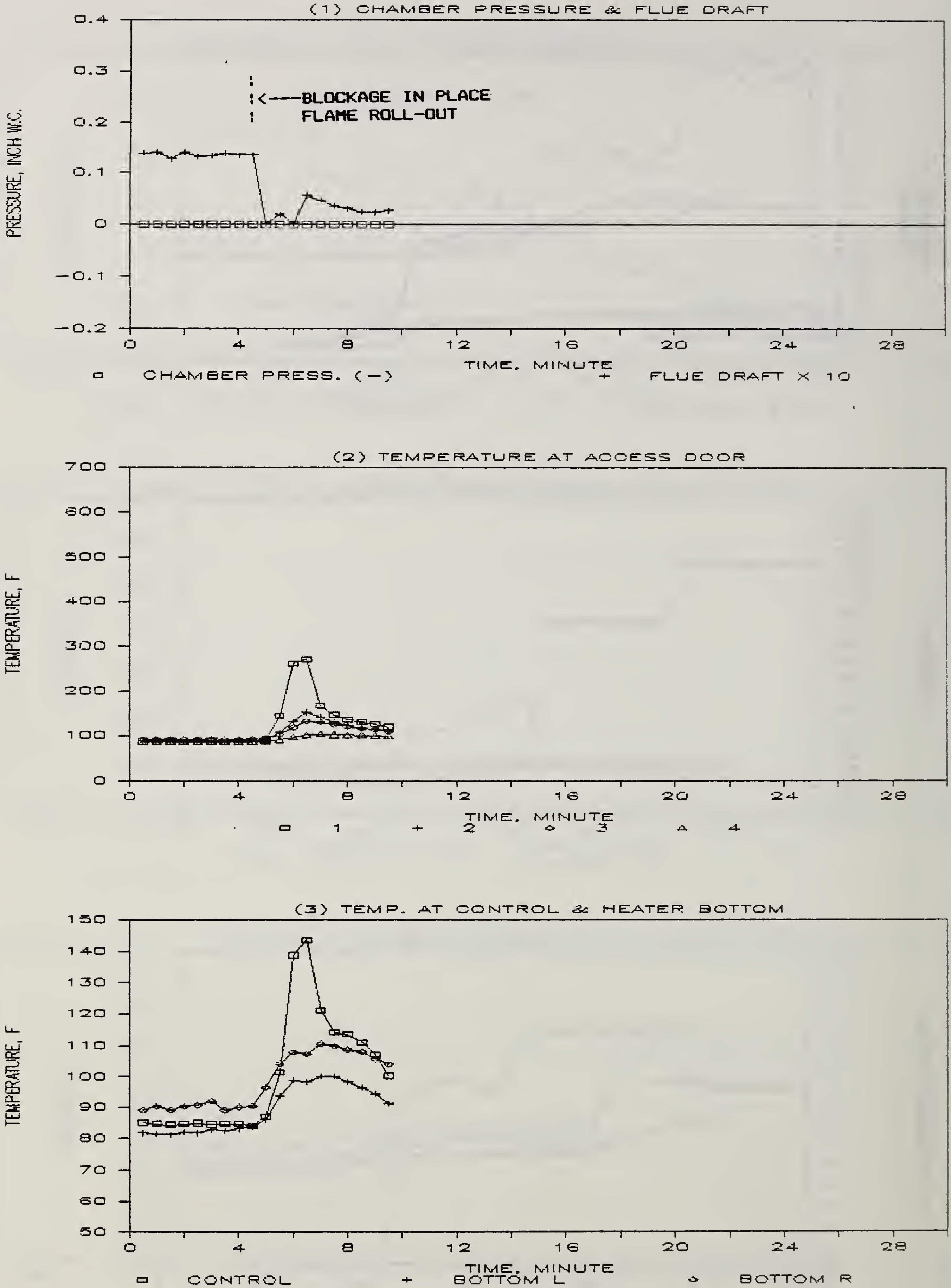


Figure 7 Pressure test, access doors in-place, 100% flue blockage
-- Heater no. 1

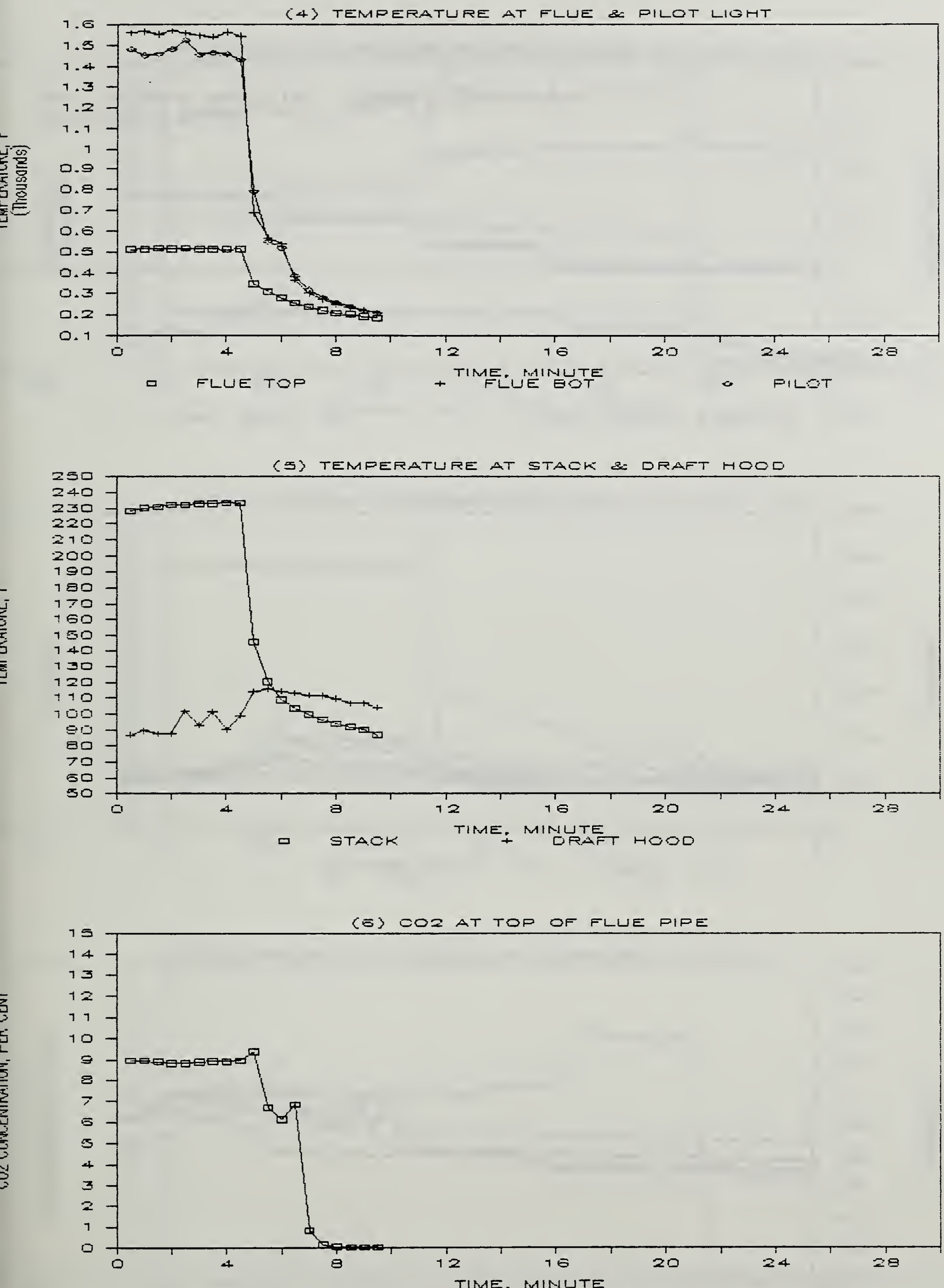


Figure 7 Pressure test, access doors in place, 100% flue blockage -- Heater no. 1

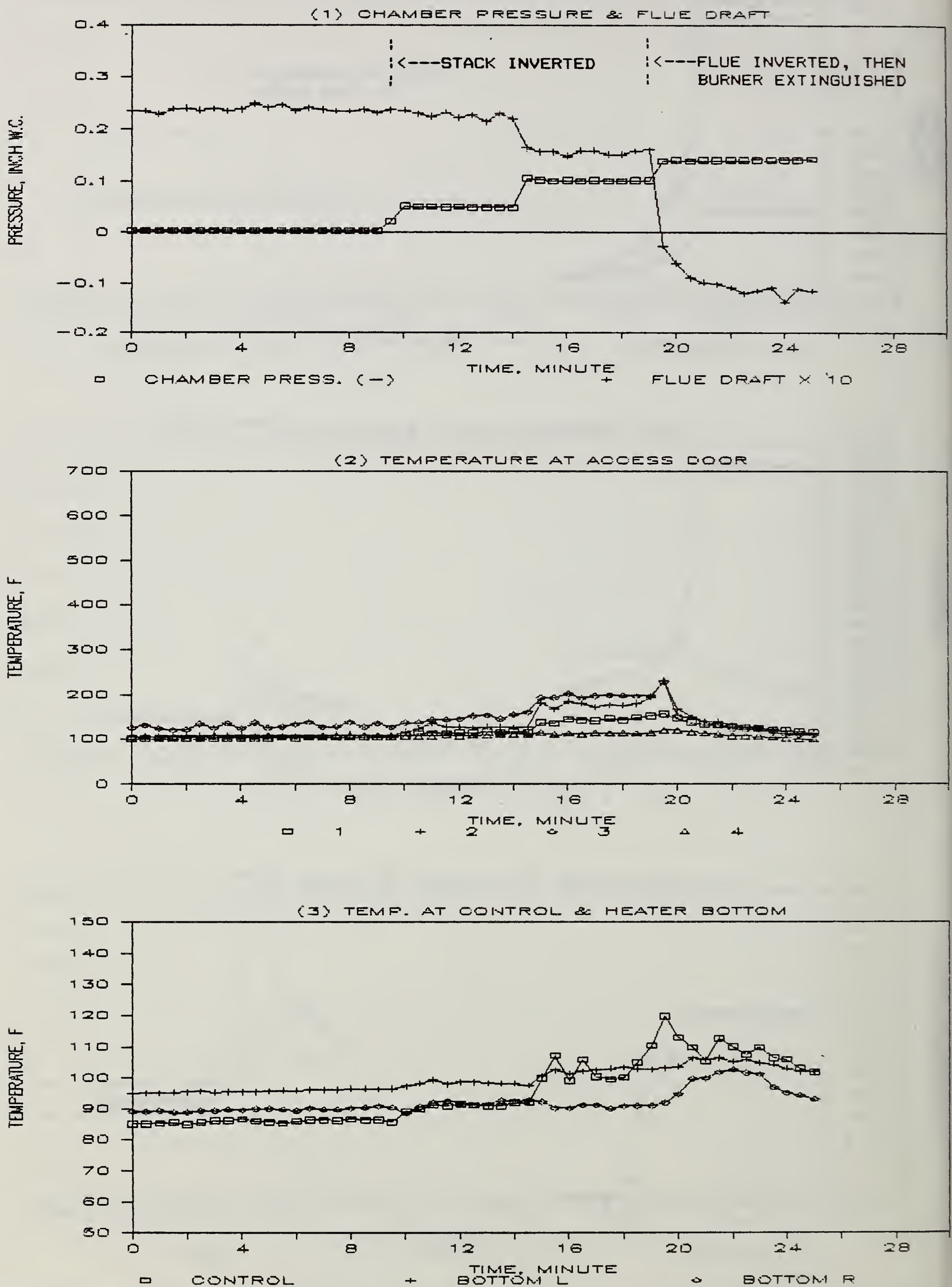
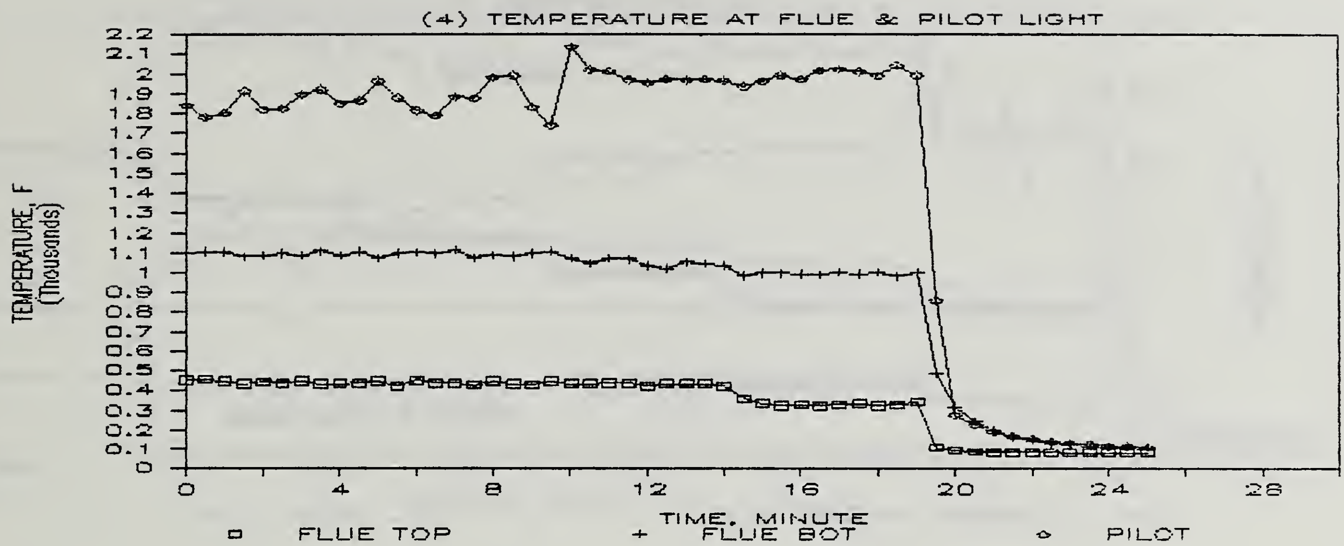
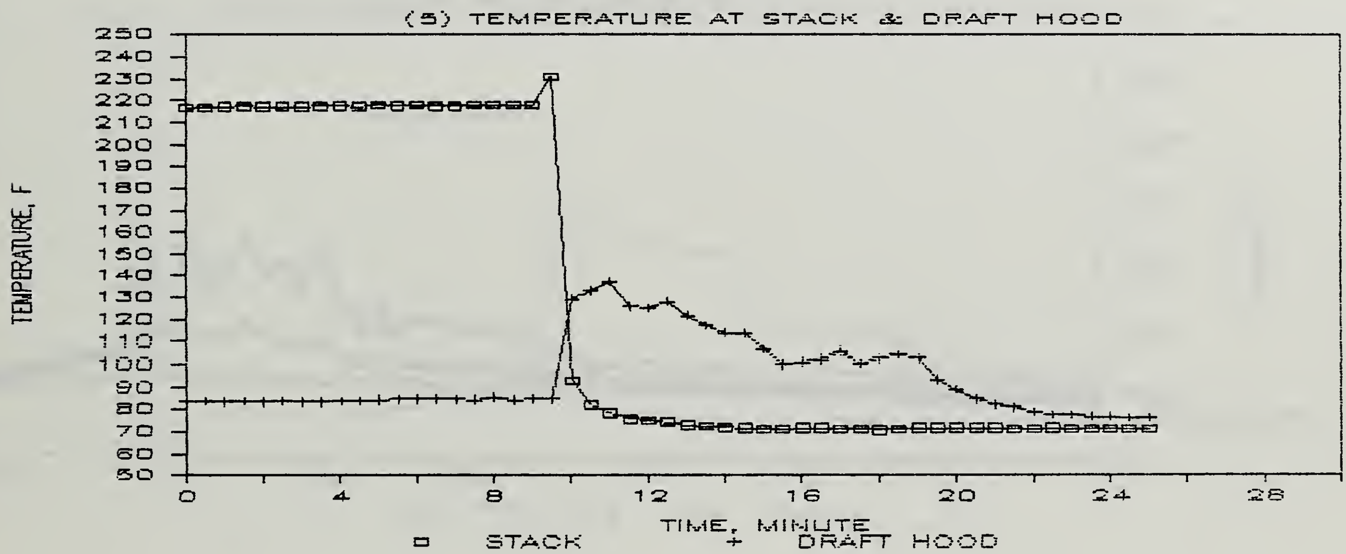


Figure 8 Pressure test, access doors off, no flue blockage
-- Heater no. 1





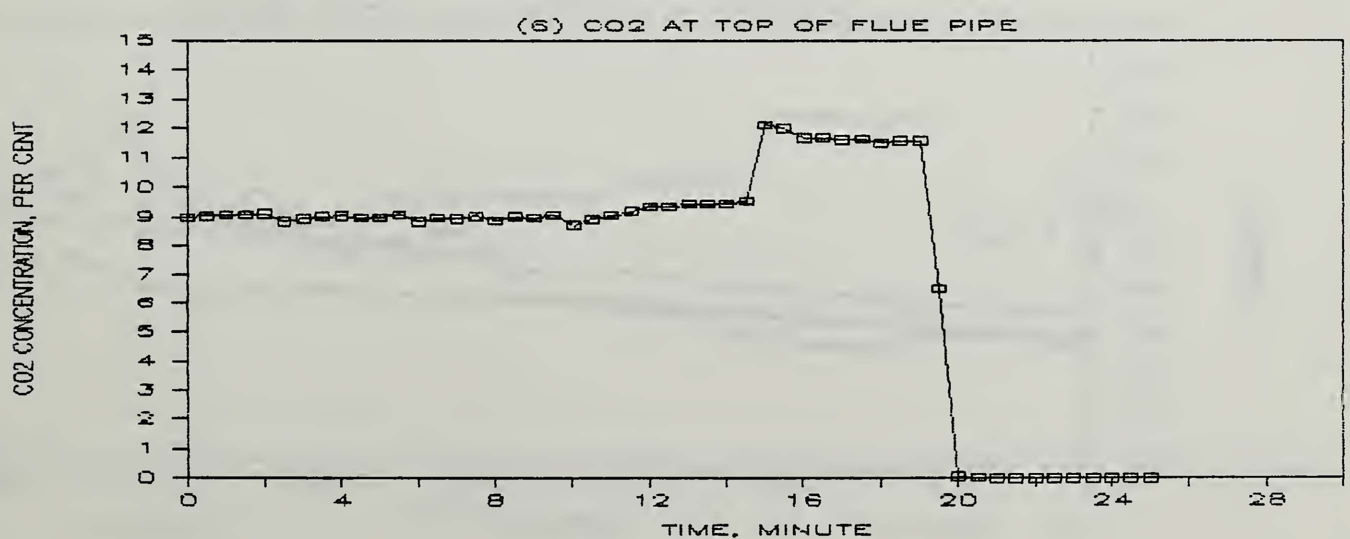


Figure 8 Pressure test, access doors off, no flue blockage -- Heater no. 1

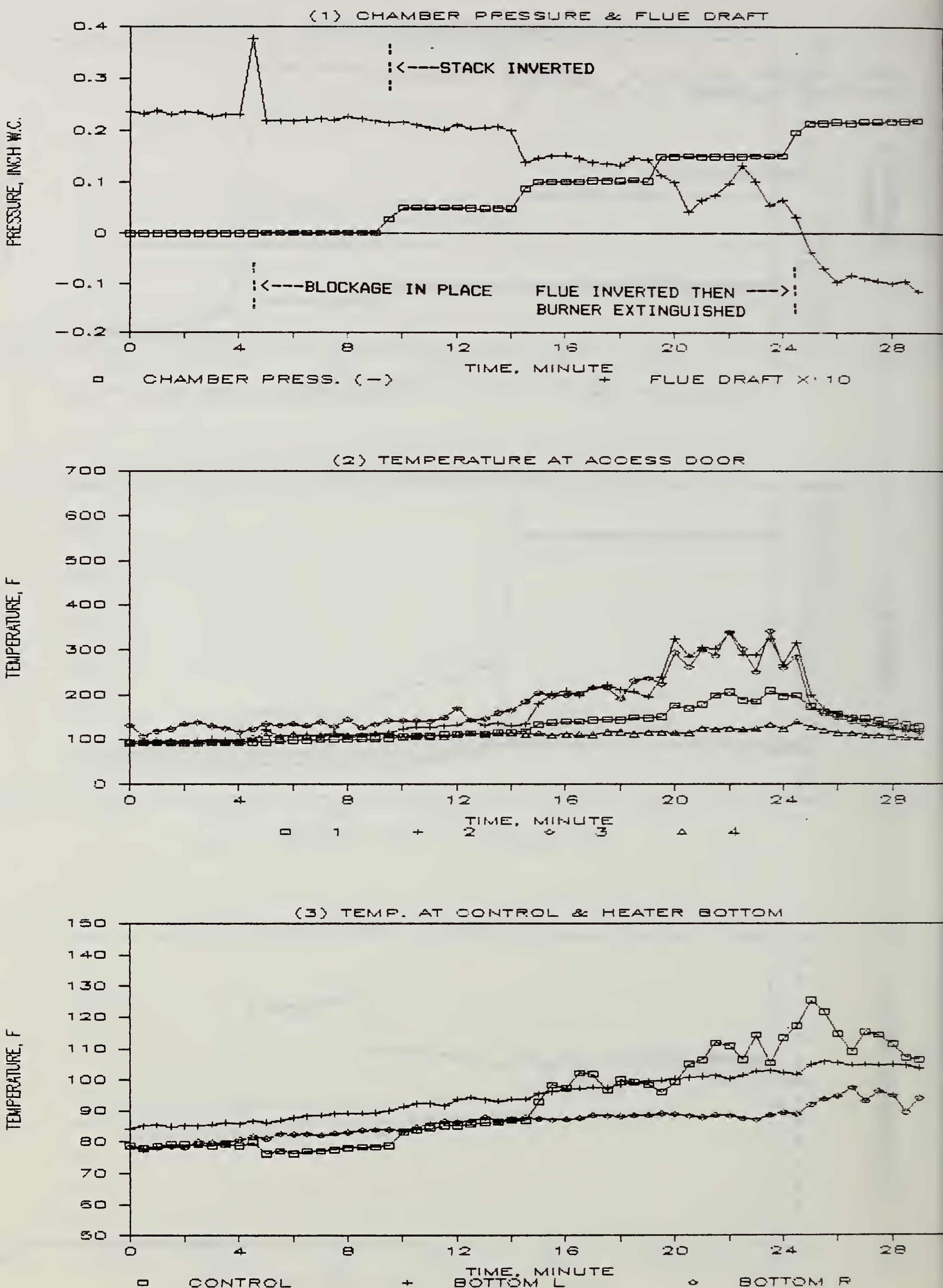
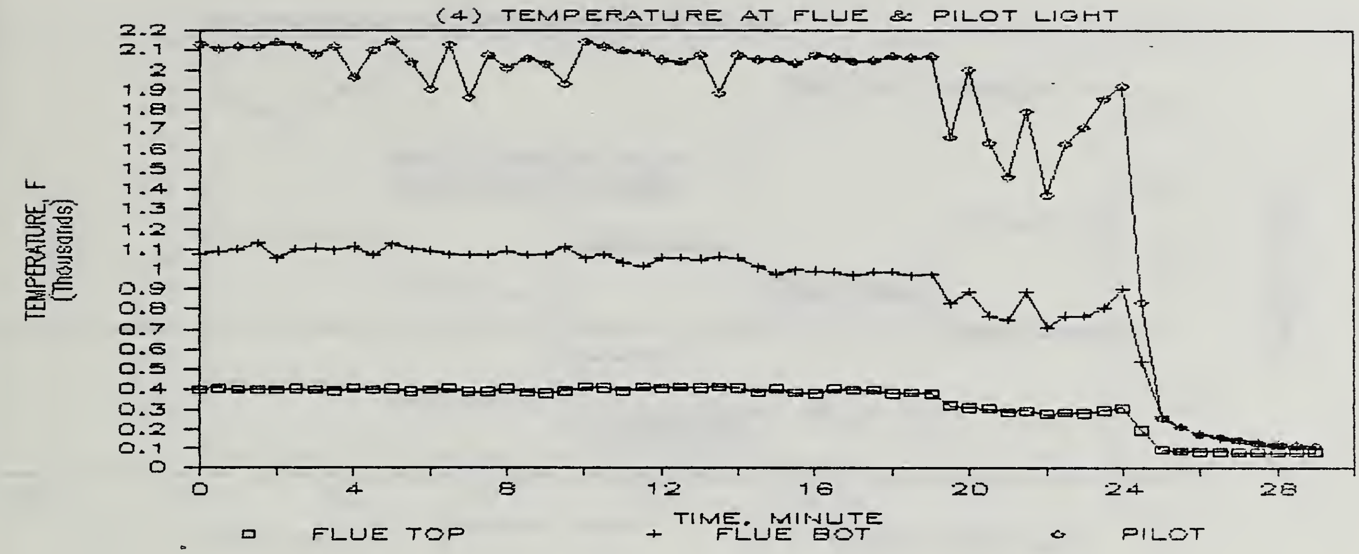
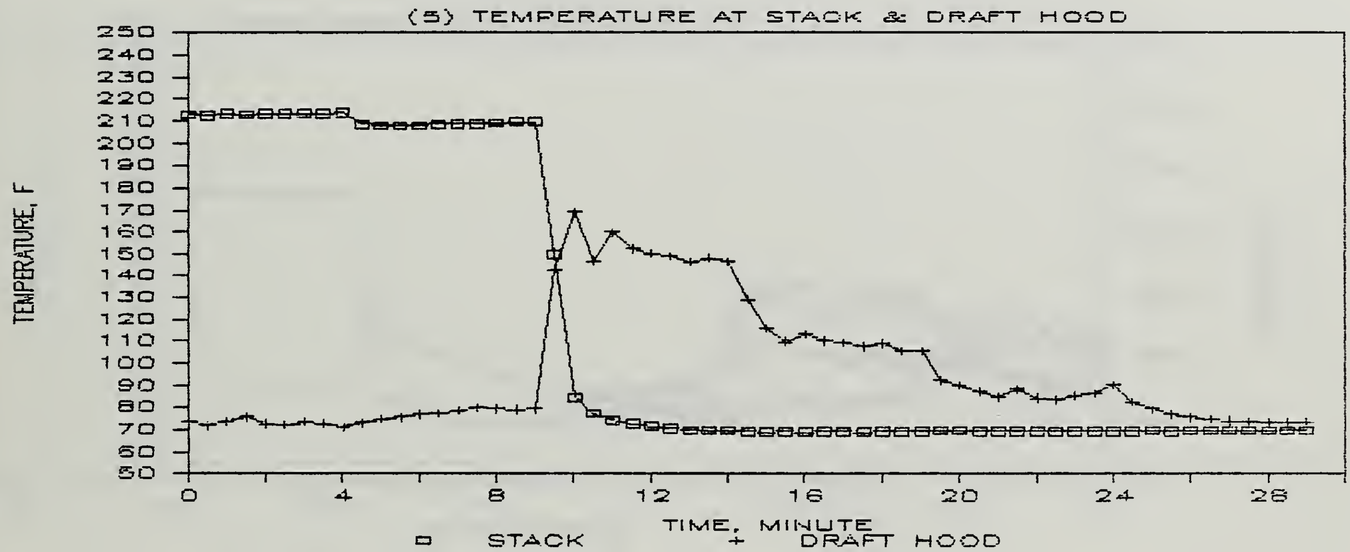


Figure 9 Pressure test, access doors off, 20% flue blockage -- Heater no. 1





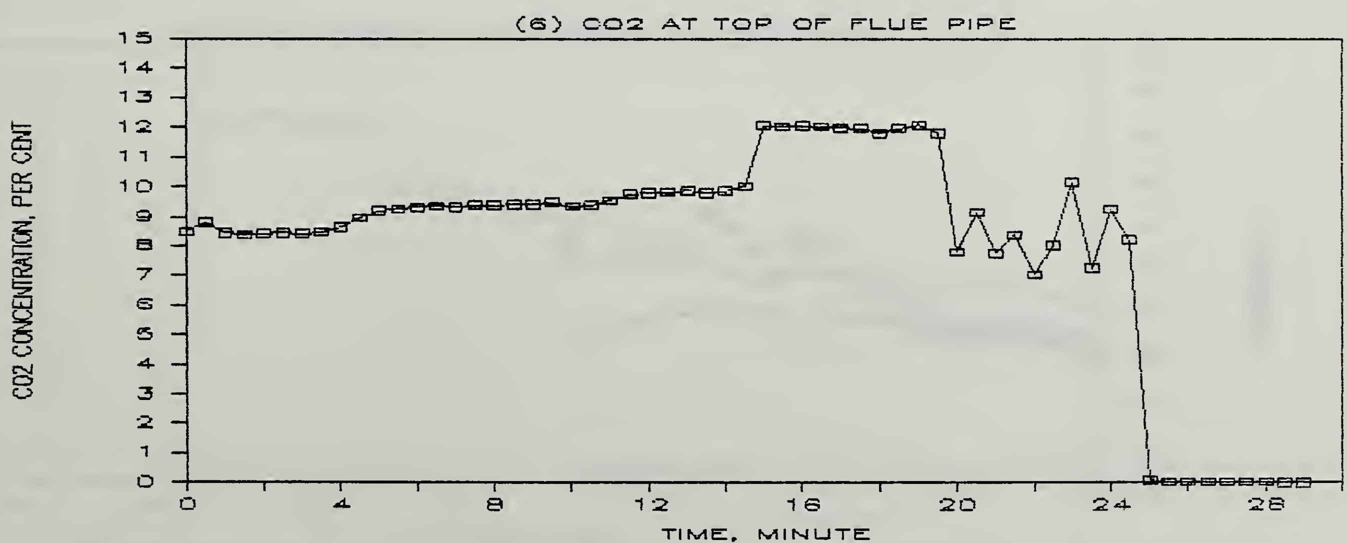


Figure 9 Pressure test, access doors off, 20% flue blockage -- Heater no. 1

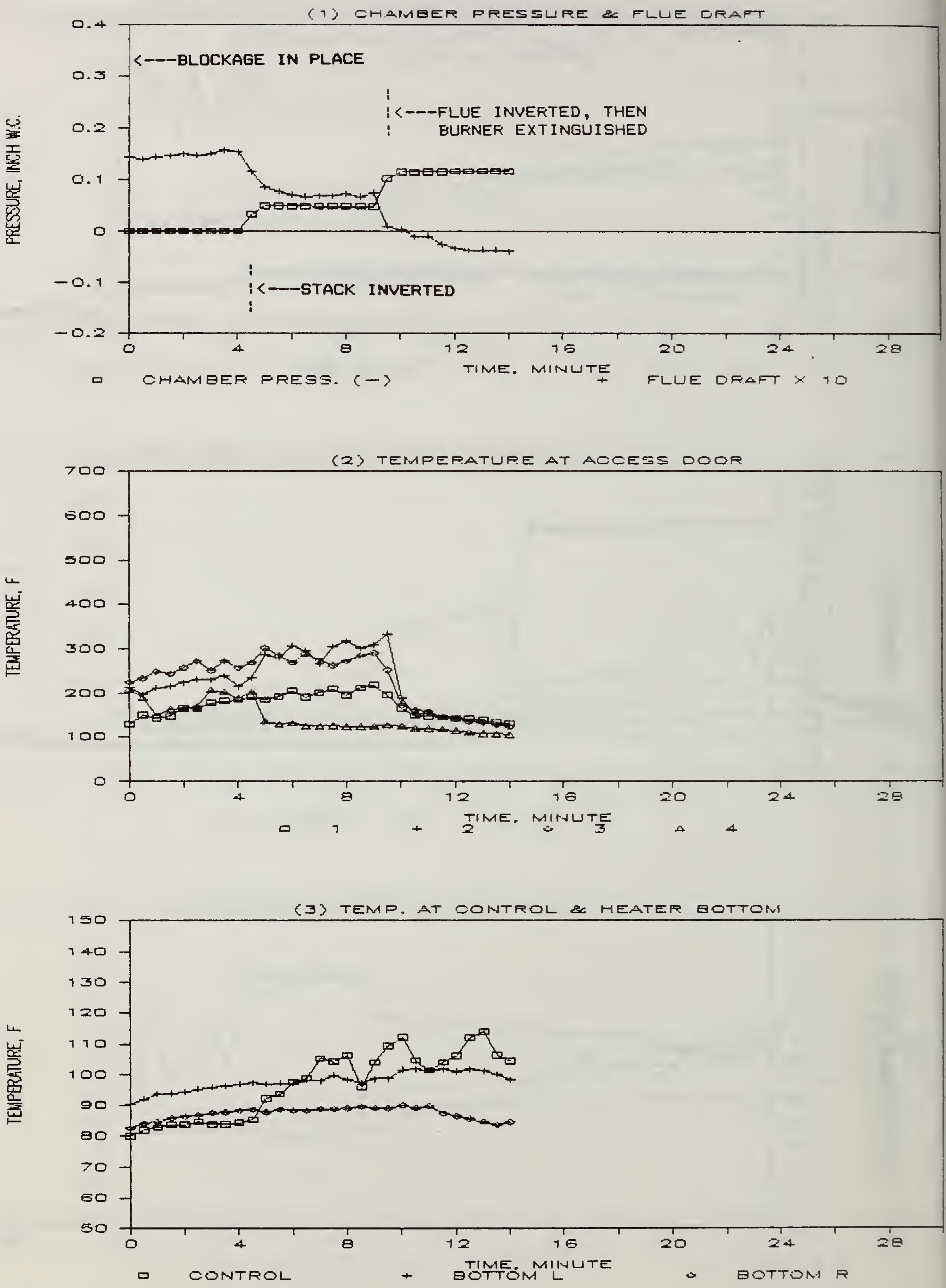


Figure 10 Pressure test, access doors off, 60% flue blockage -- Heater no. 1

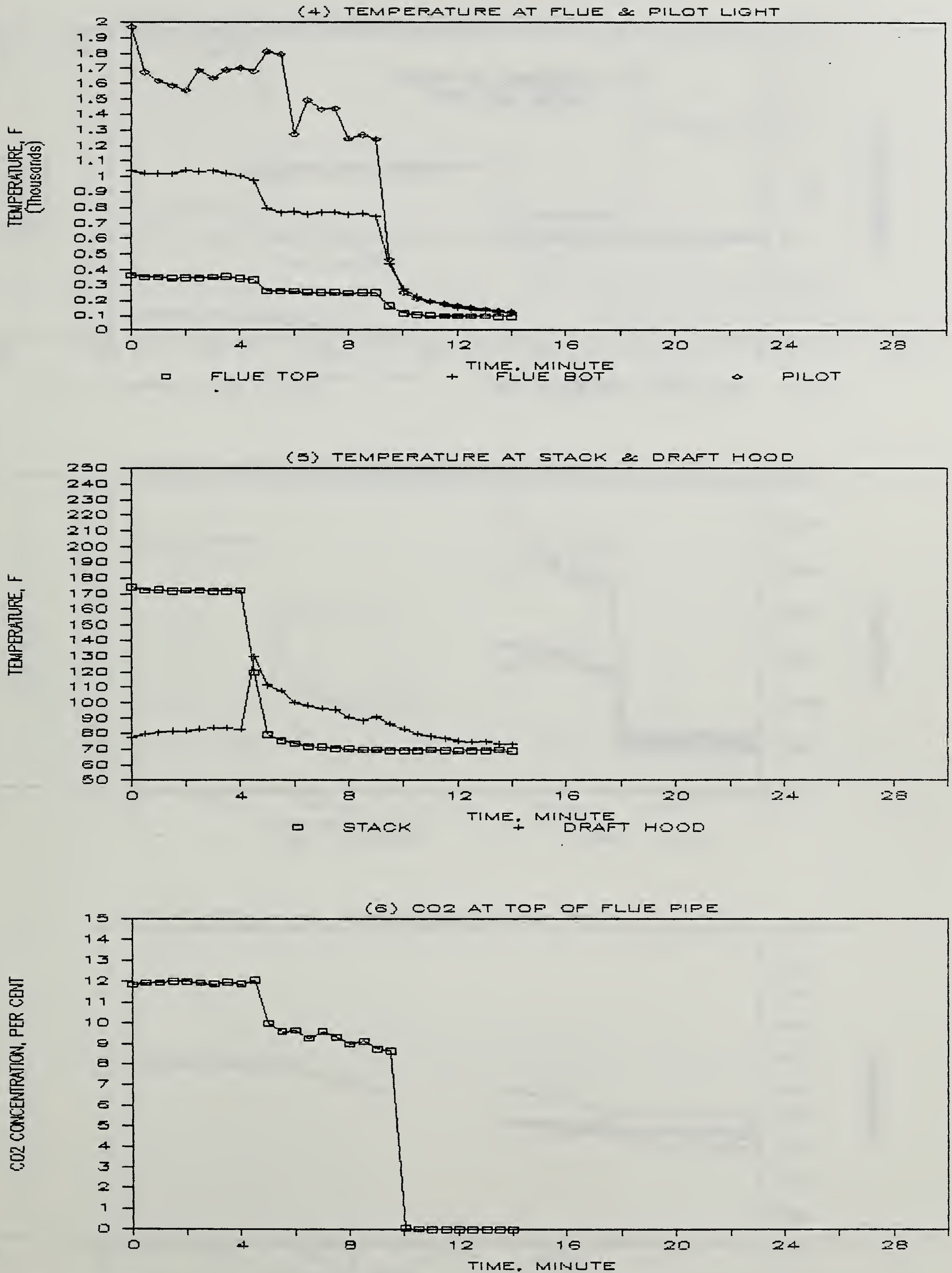


Figure 10 Pressure test, access doors off, 60% flue blockage -- Heater no. 1

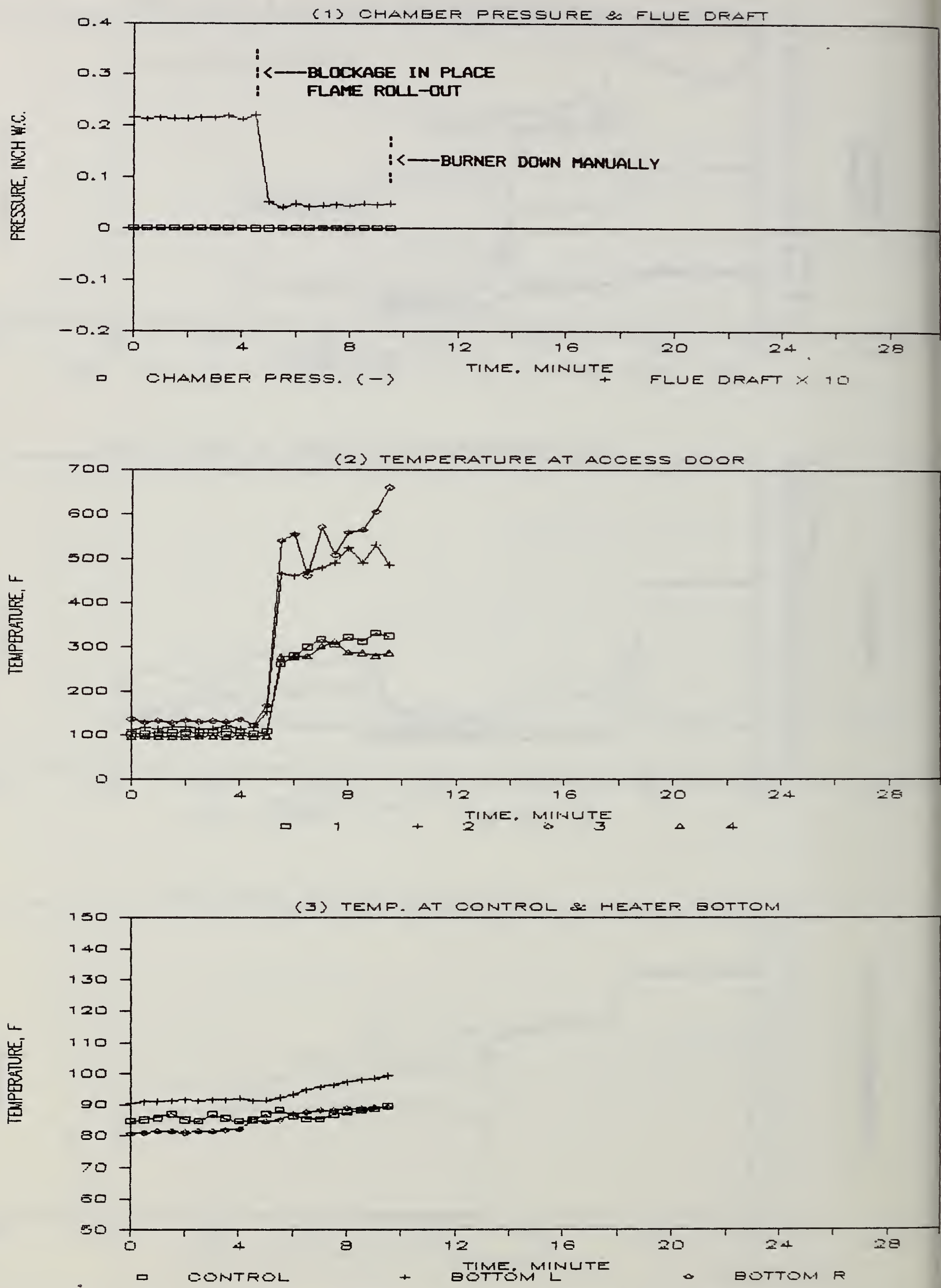
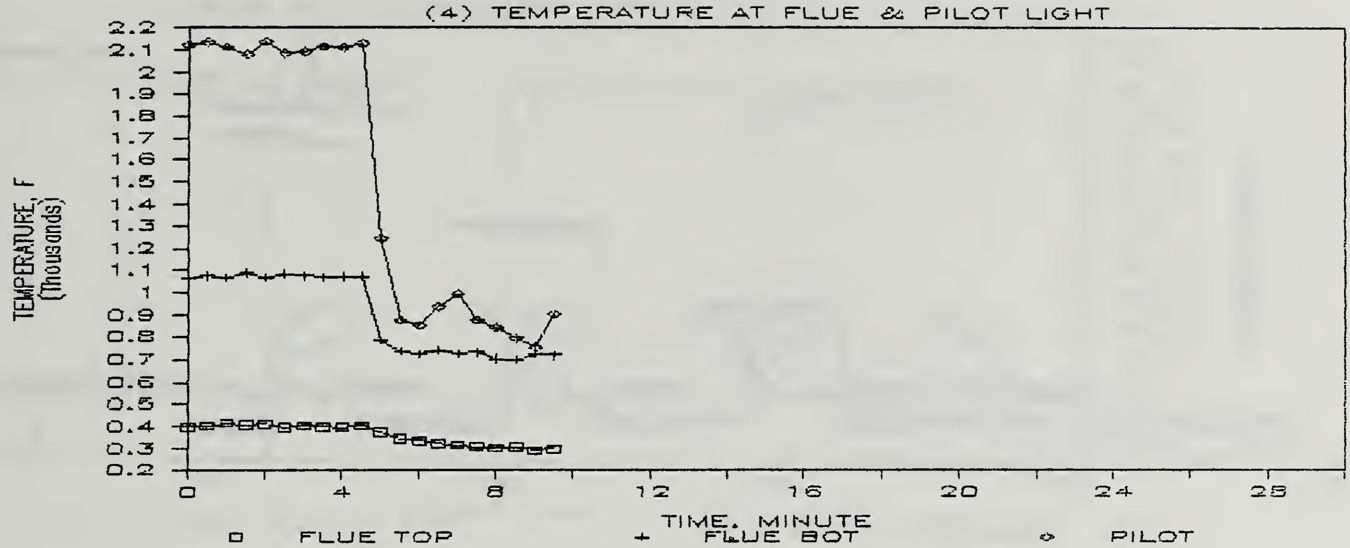
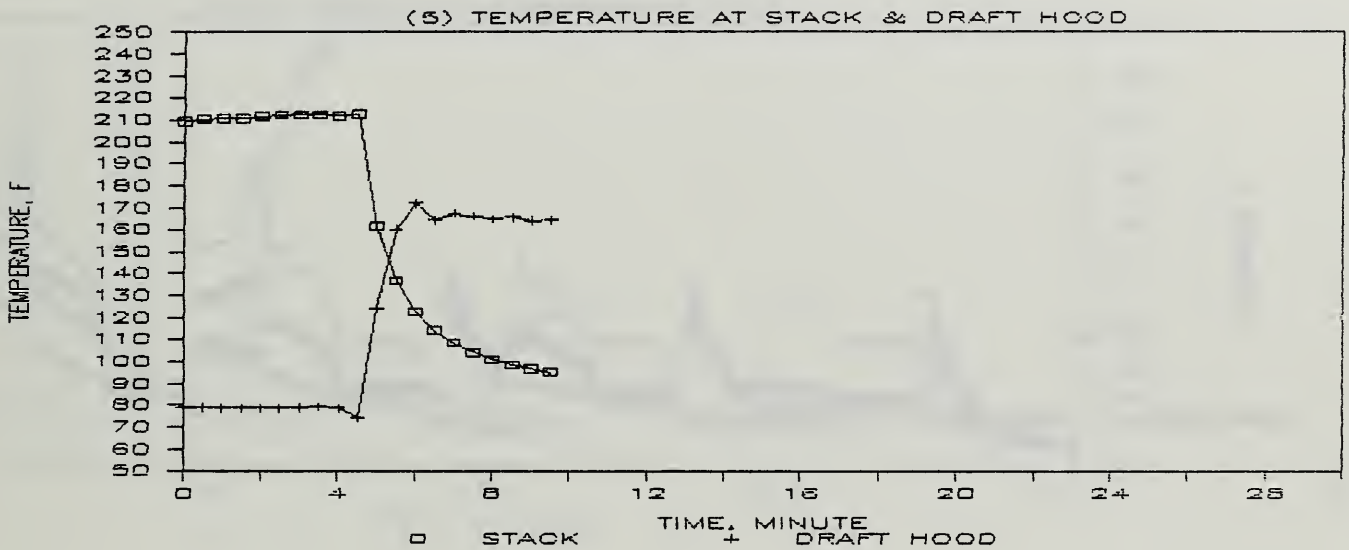


Figure 11 Pressure test, access doors off, 100% flue blockage -- Heater no. 1





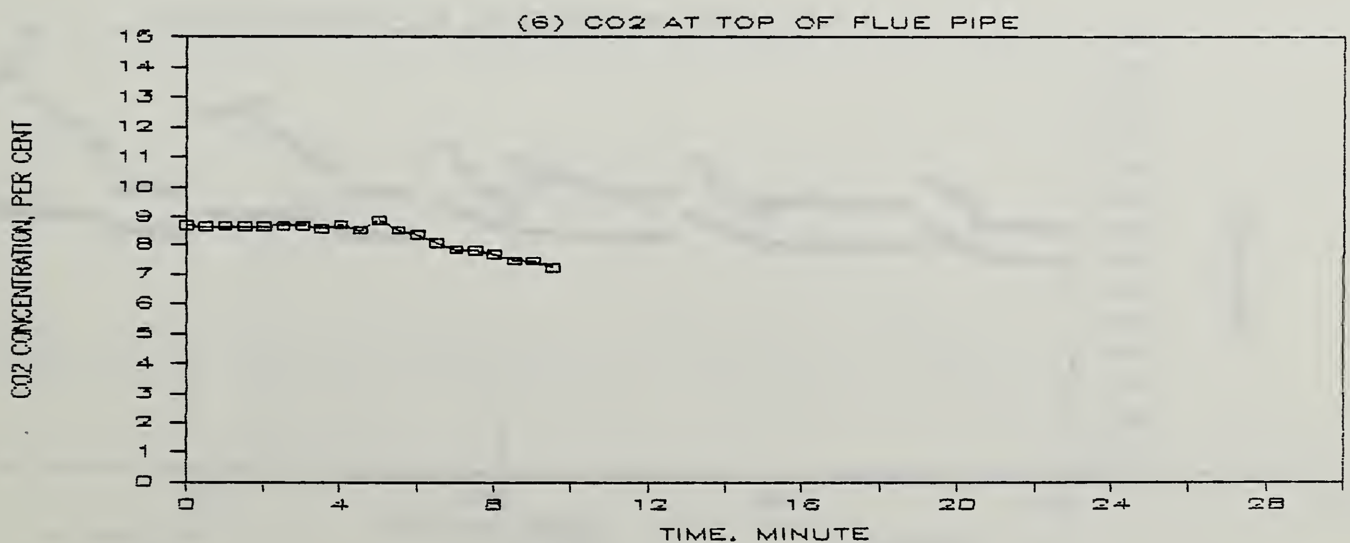


Figure 11 Pressure test, access doors off, 100% flue blockage
— Heater no. 1

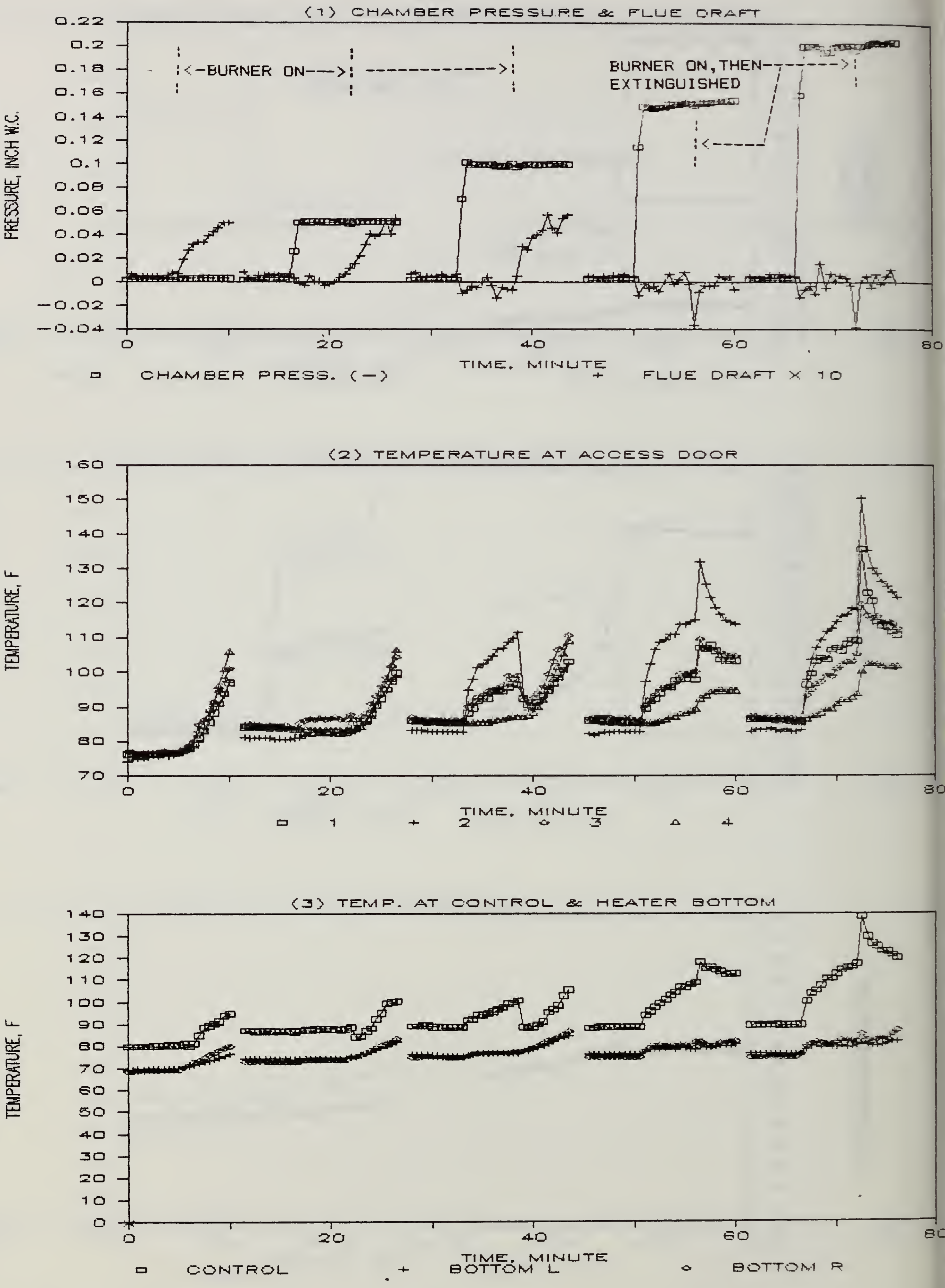


Figure 12 Cyclic test, access doors in-place -- Heater no. 2

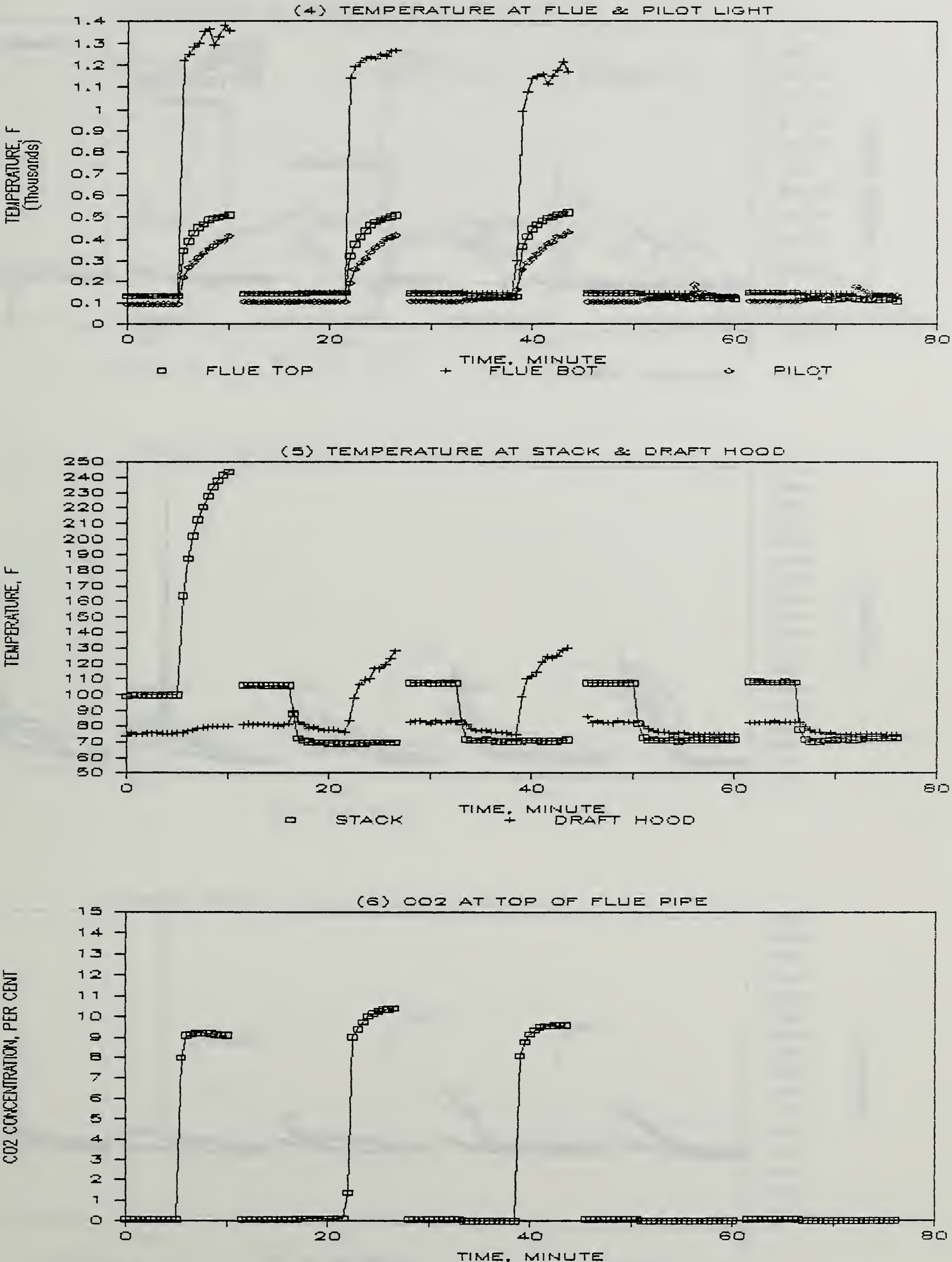


Figure 12. Cyclic test, access doors in place -- Heater no. 2

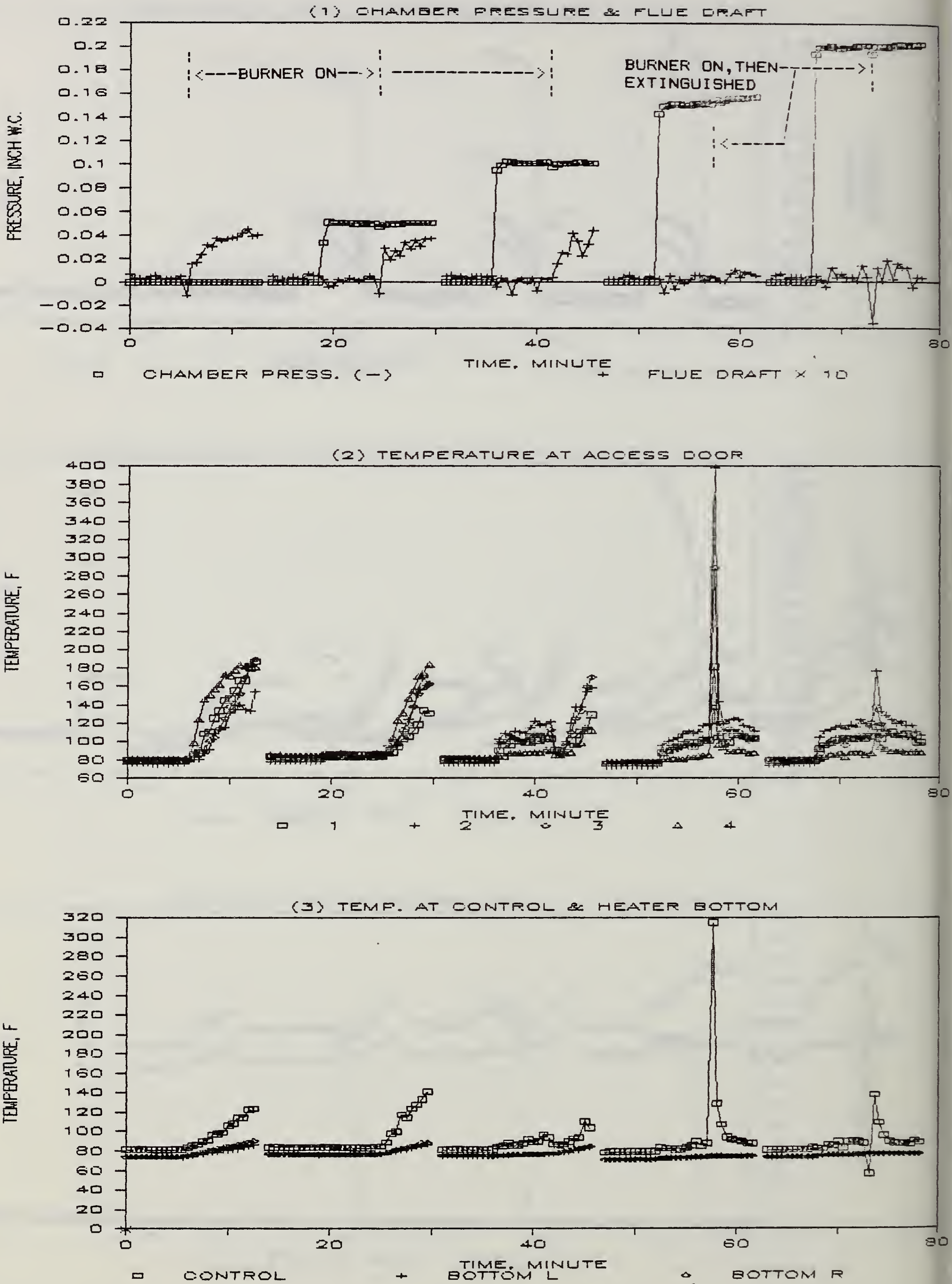
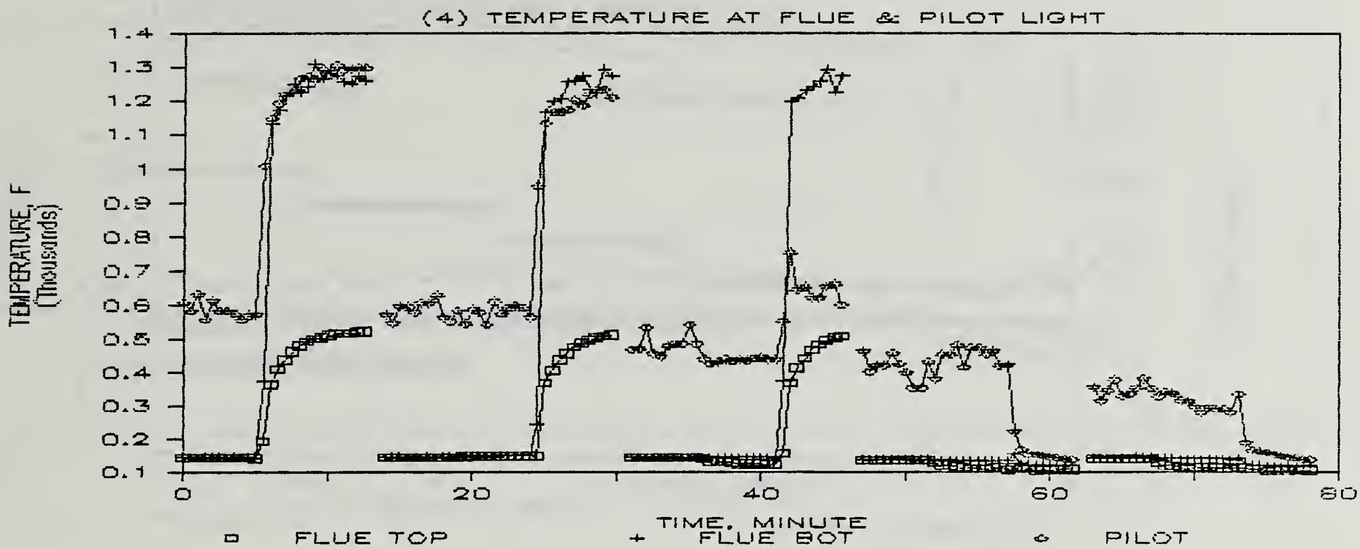
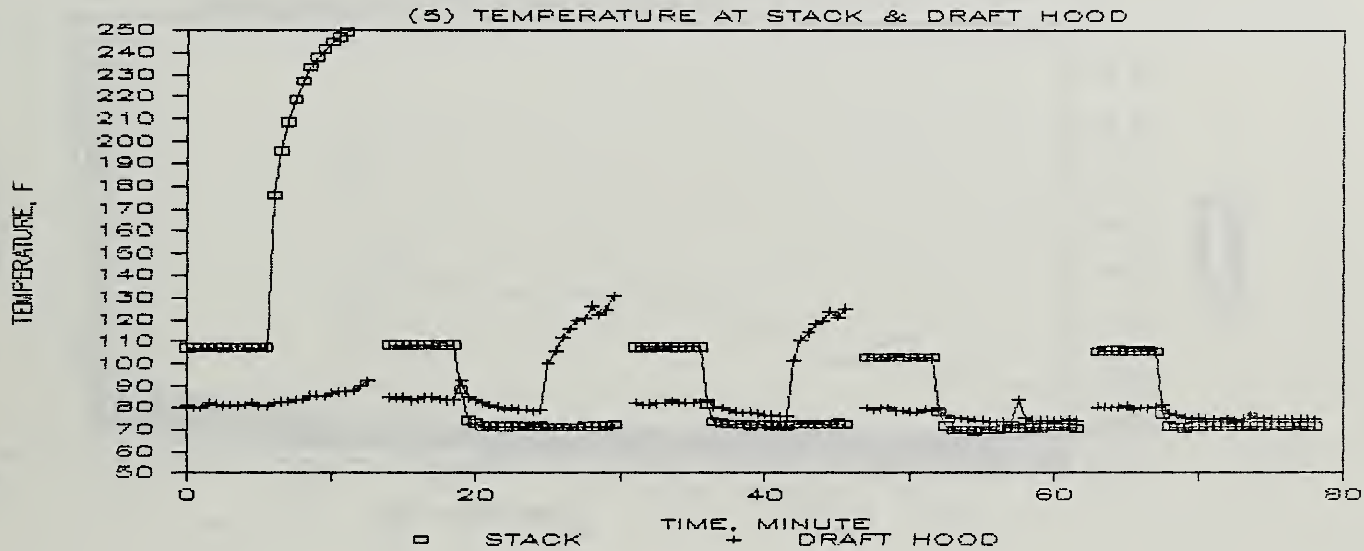


Figure 13 Cyclic test, access doors off -- Heater no. 2





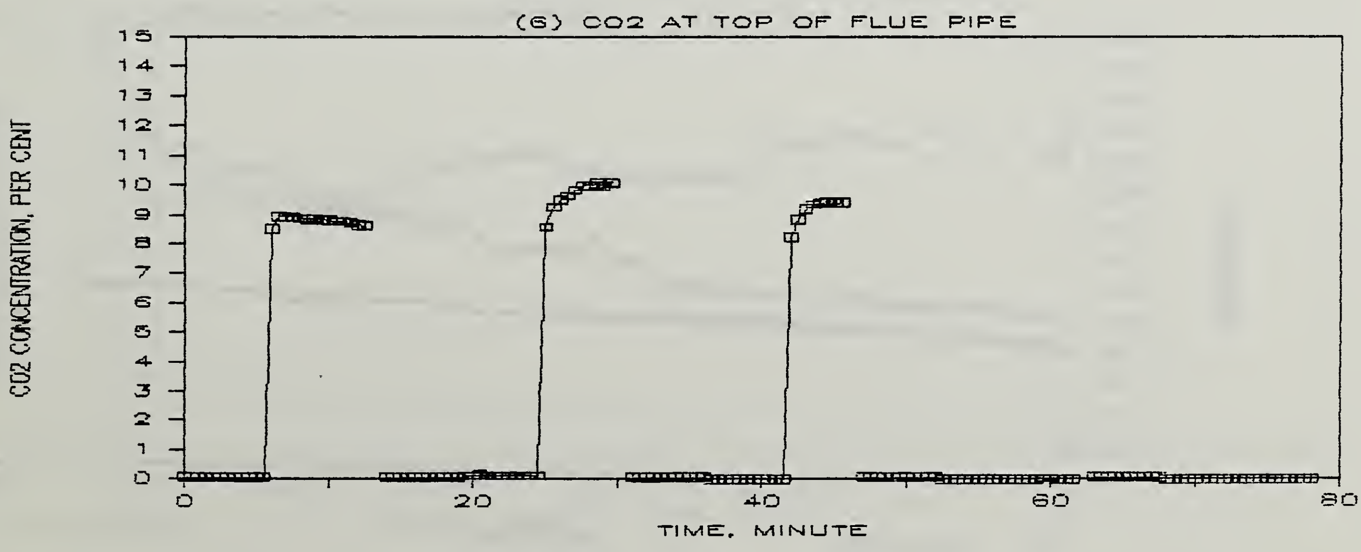


Figure 13 Cyclic test, access doors off -- Heater no. 2

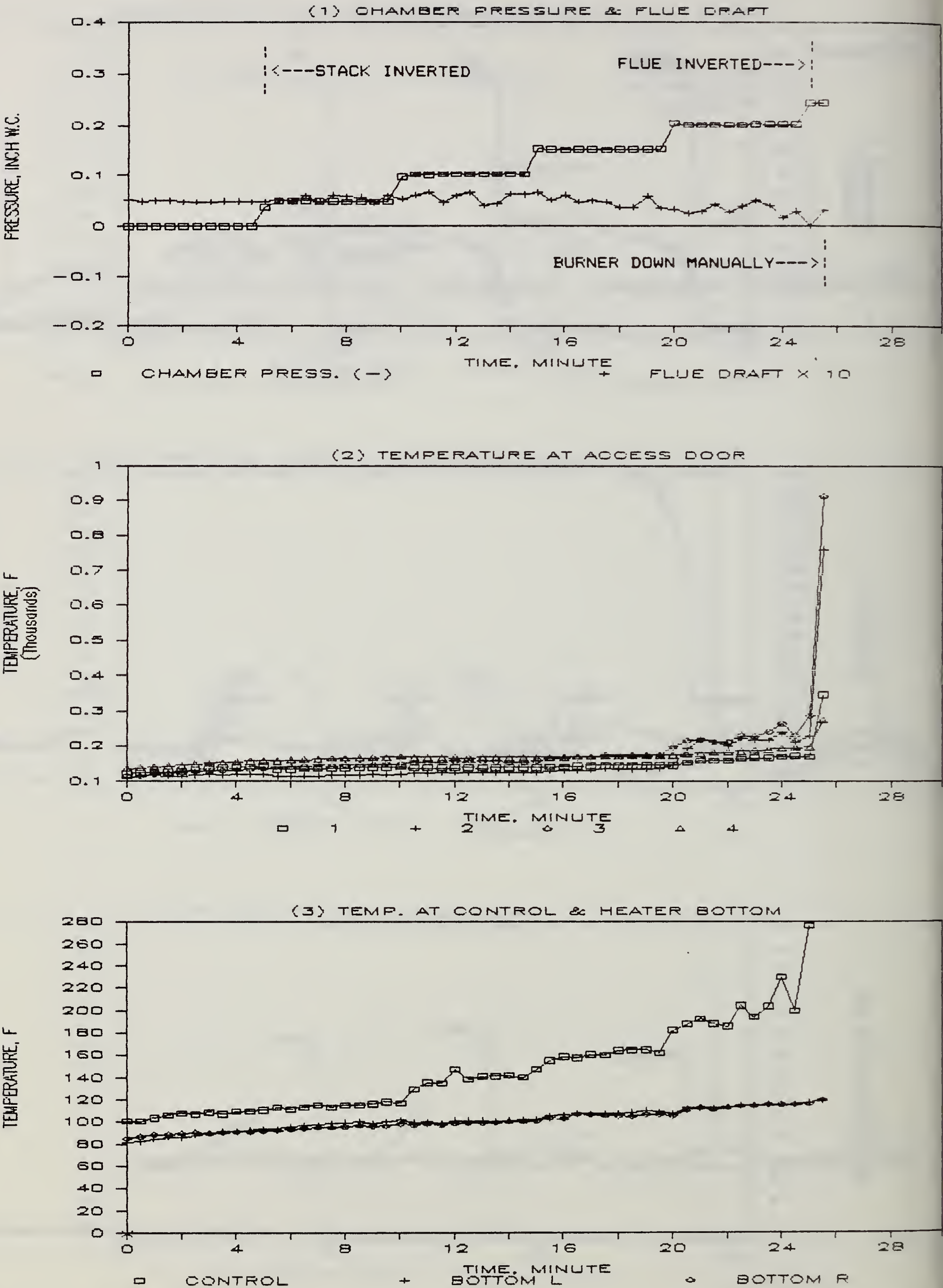


Figure 14 Pressure test, access doors in-place, no flue blockage
-- Heater no. 2

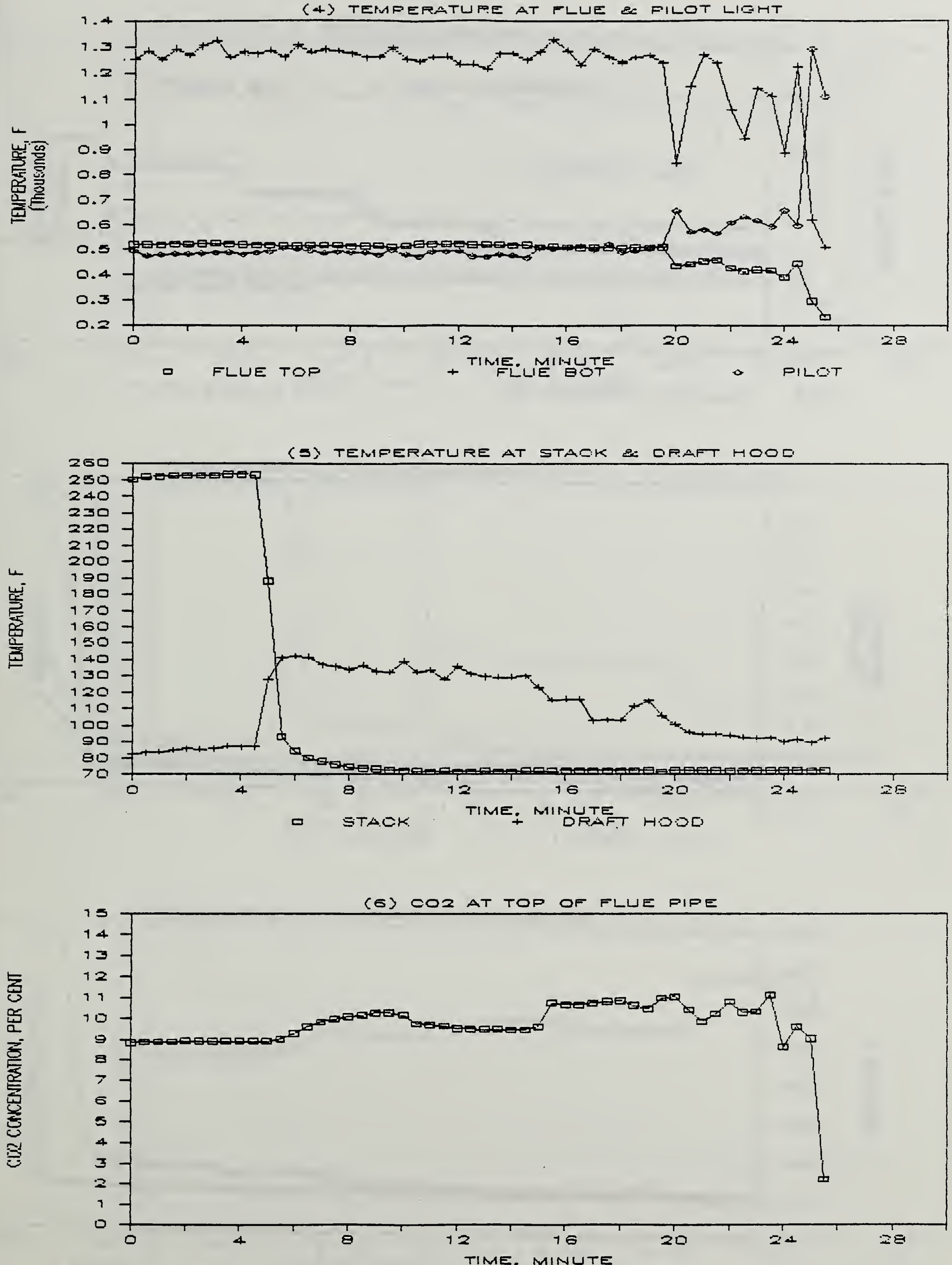


Figure 14 Pressure test, access doors in place, no flue blockage -- Heater no. 2

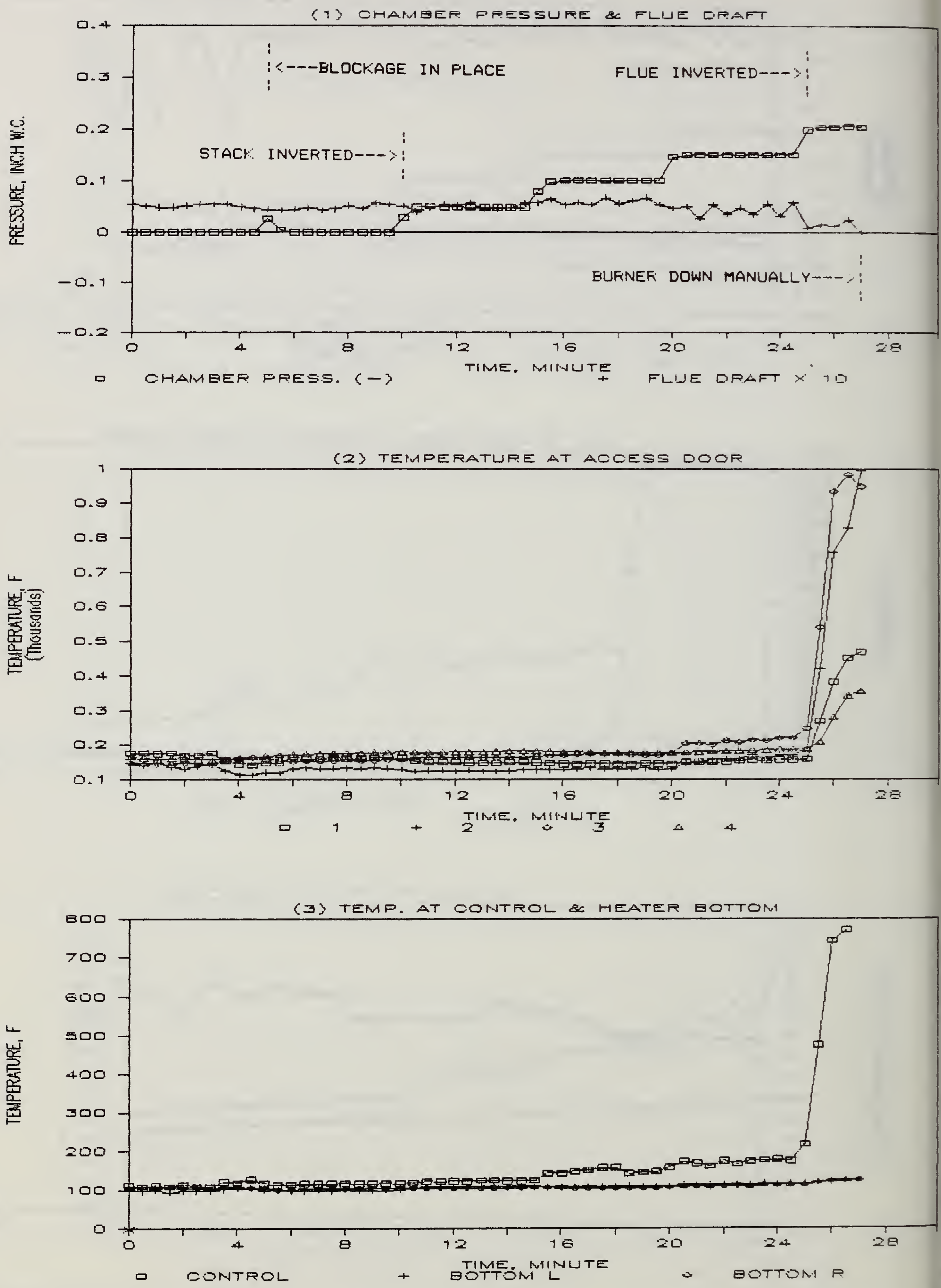


Figure 15 Pressure test, access doors in-place, 20% flue blockage -- Heater no. 2

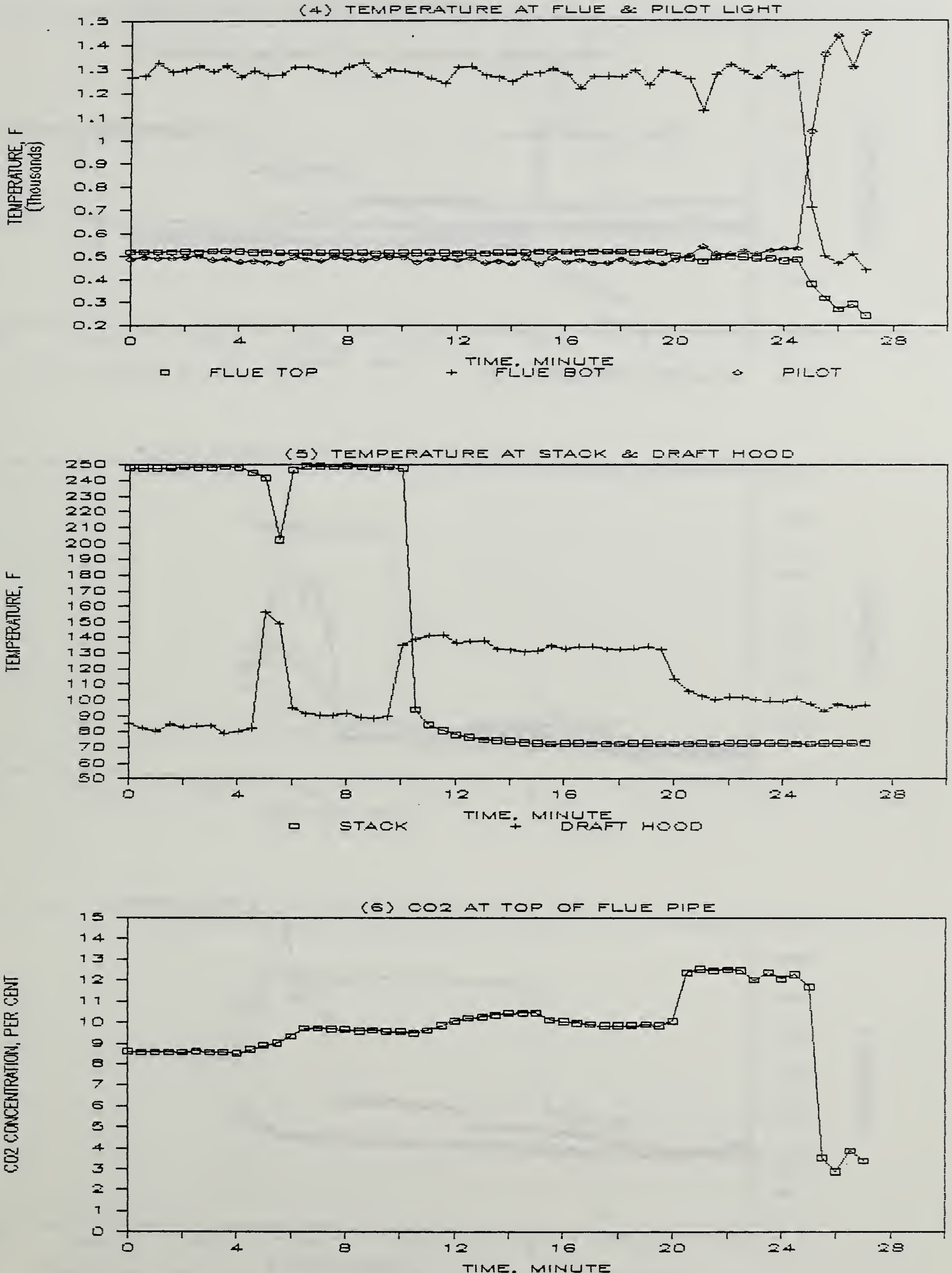


Figure 15 Pressure test, access doors in place, 20% flue blockage -- Heater no. 2

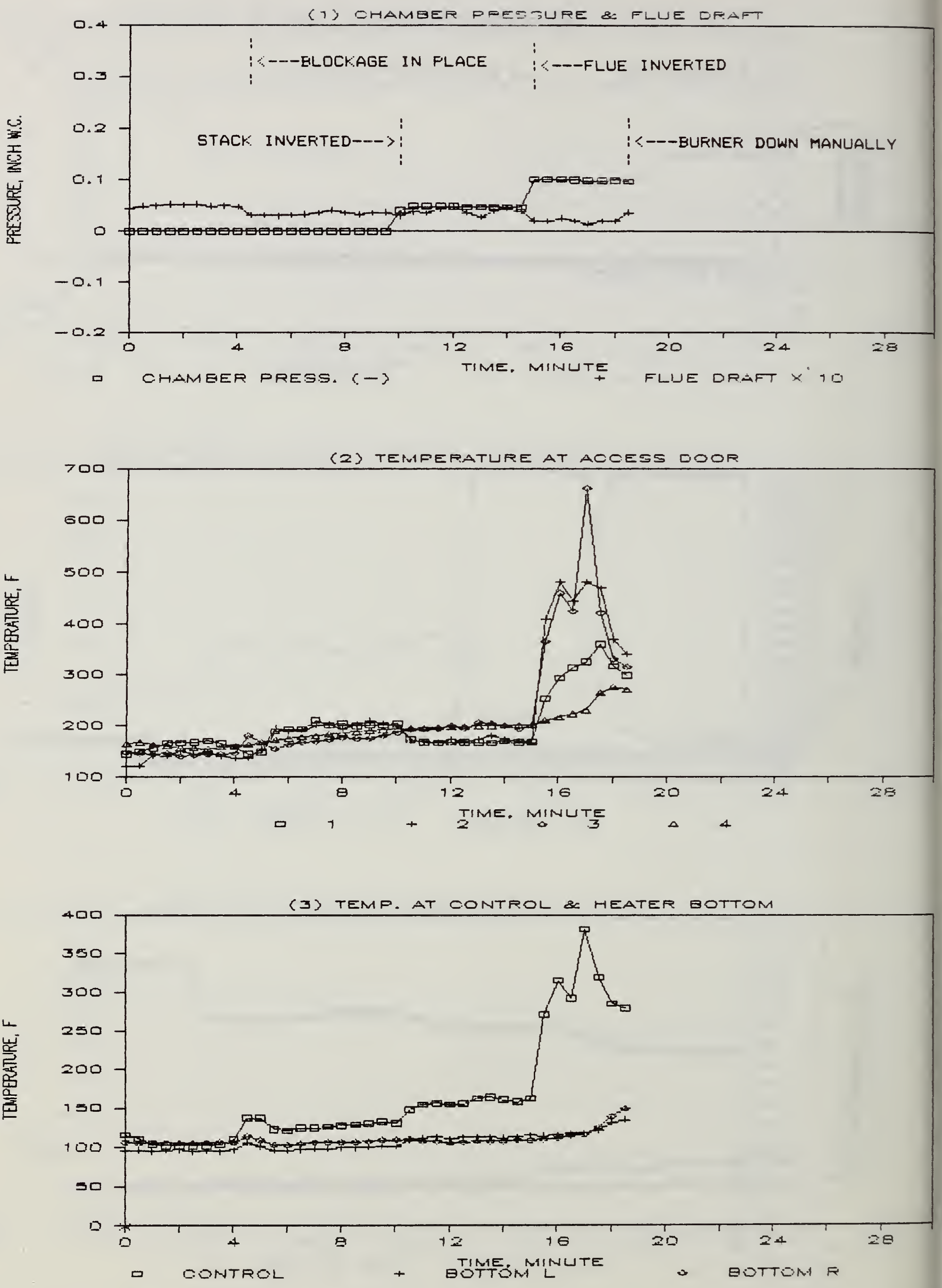
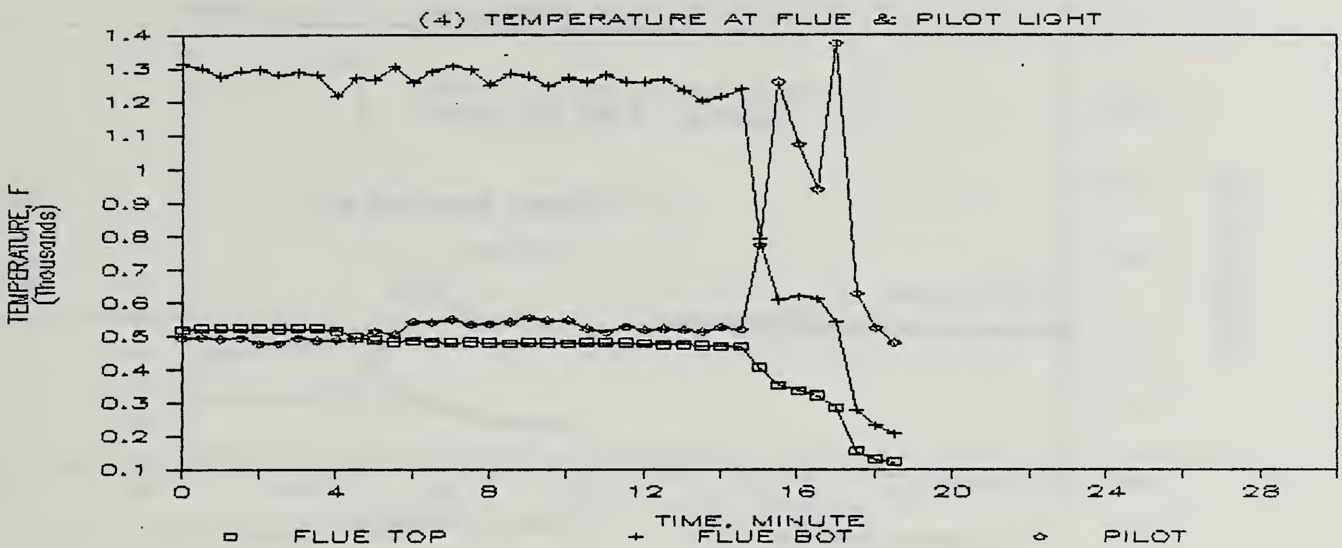
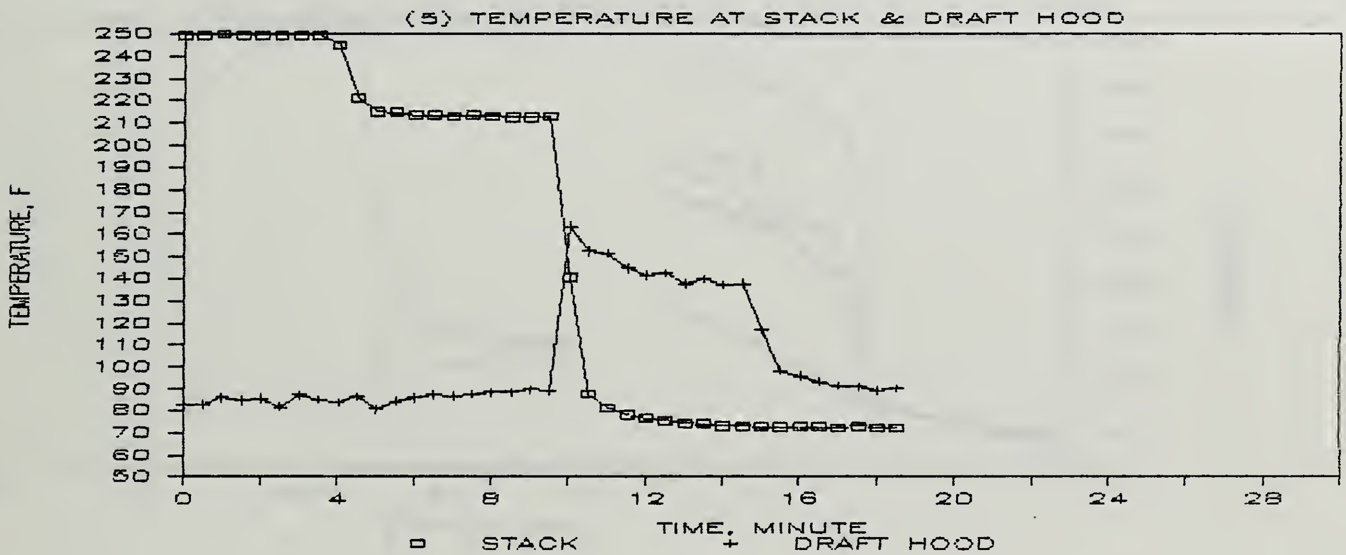


Figure 16 Pressure test, access doors in-place, 60% flue blockage -- Heater no. 2





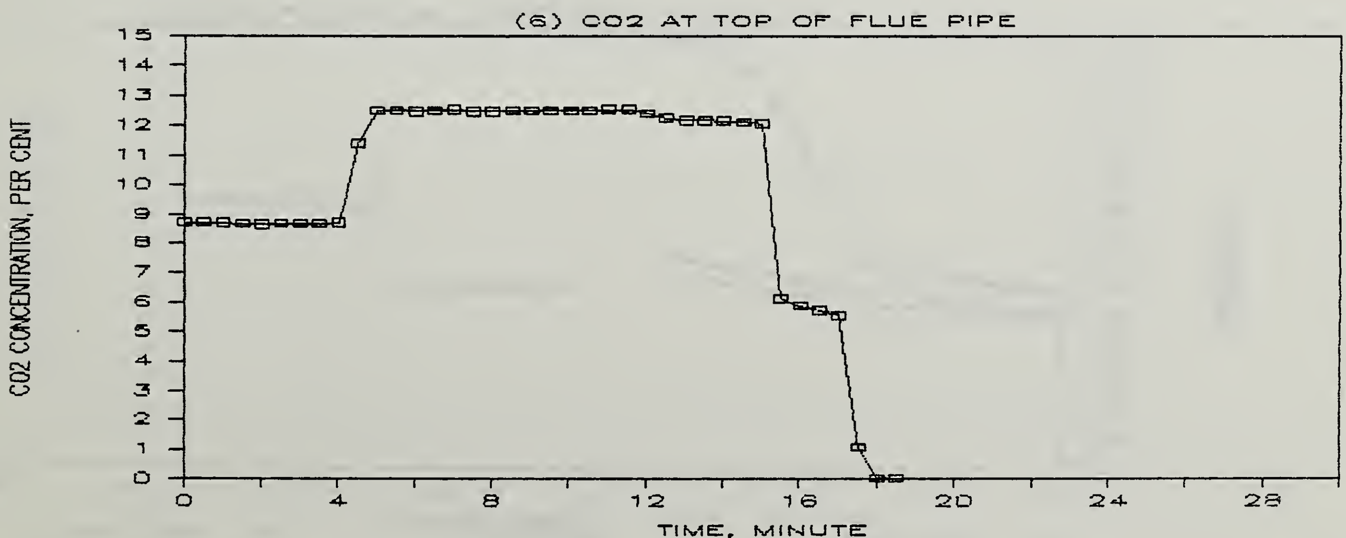


Figure 16 Pressure test, access doors in place, 60% flue blockage -- Heater no. 2

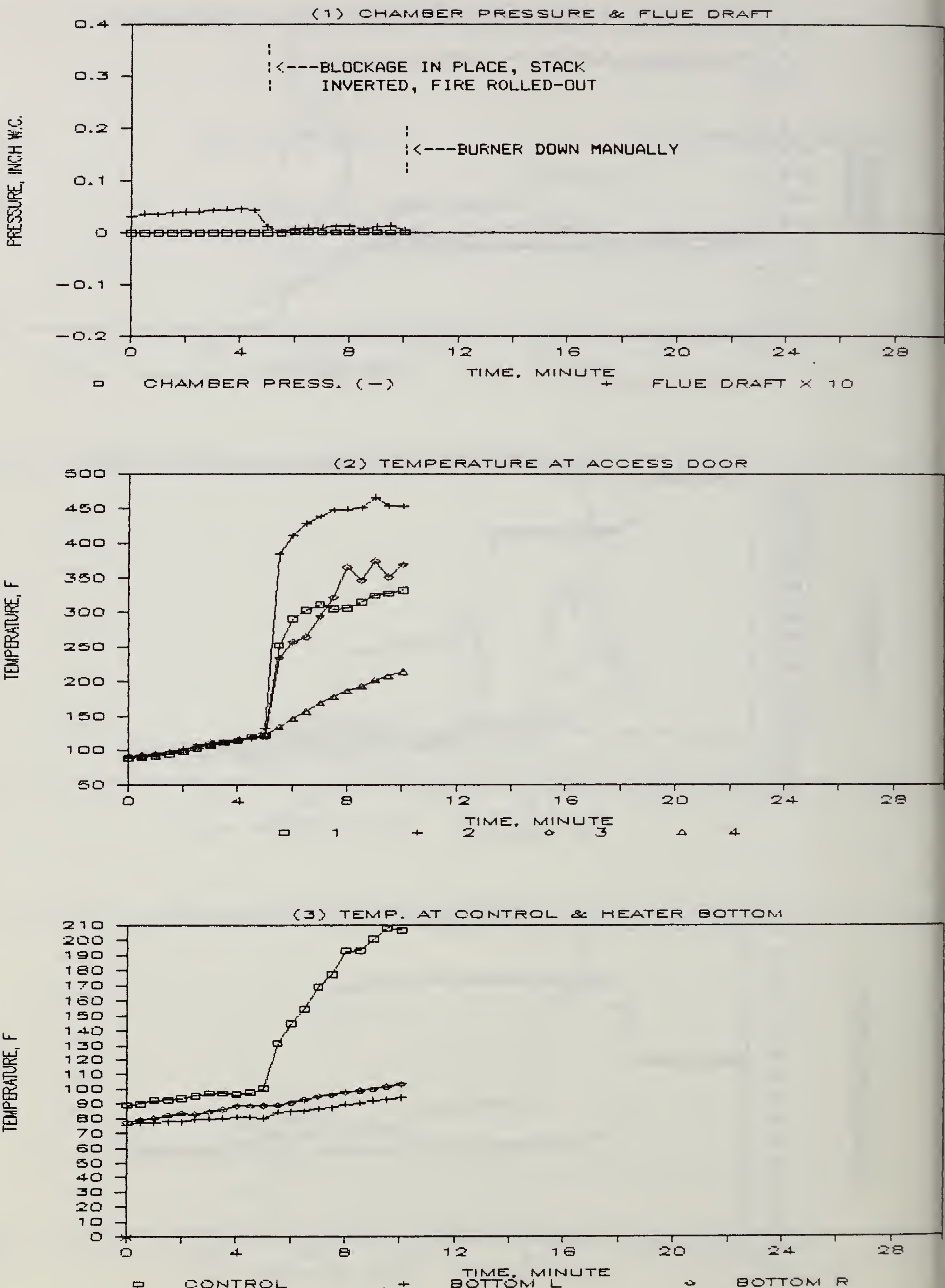
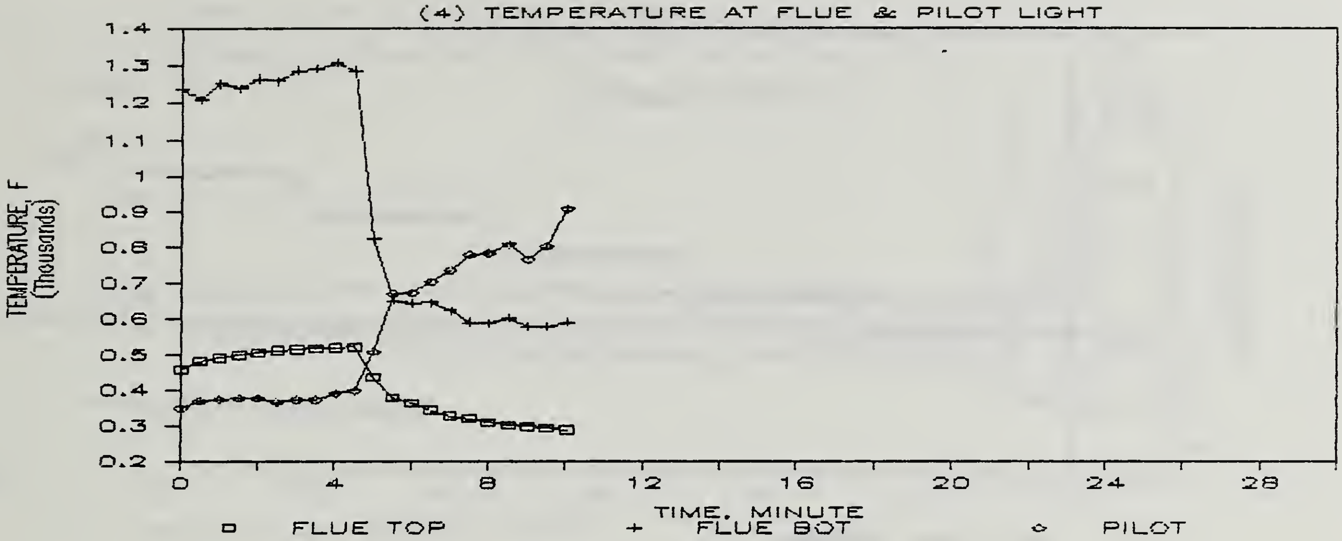
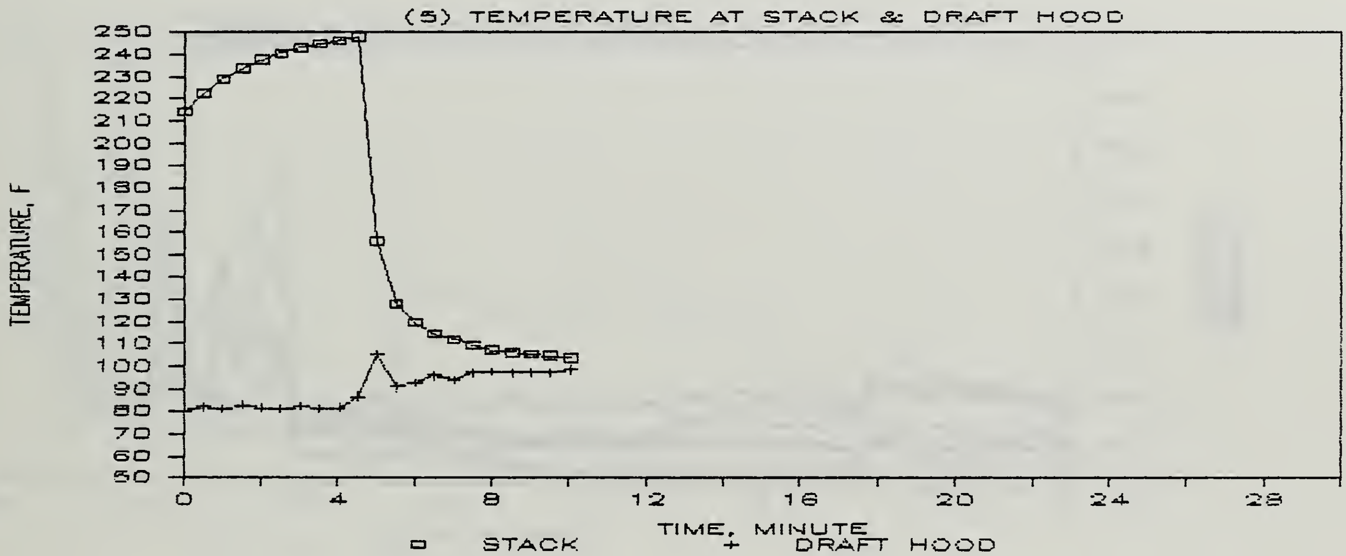


Figure 17 Pressure test, access doors in-place, 100% flue blockage -- Heater no. 2





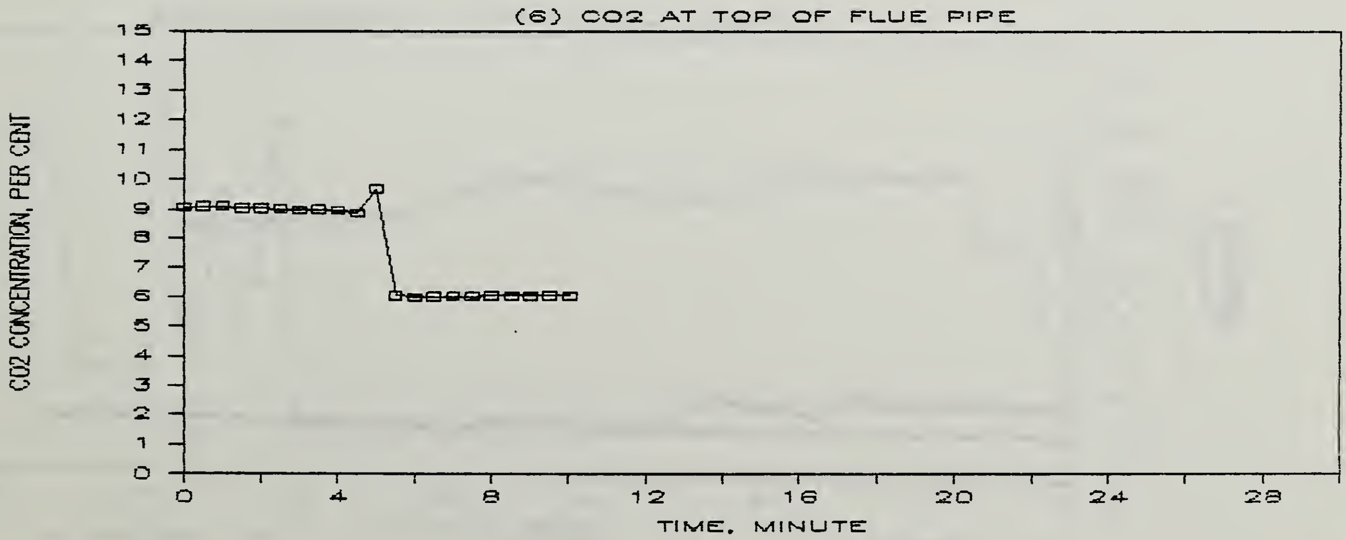


Figure 17 Pressure test, access doors in place, 100% flue blockage -- Heater no. 2

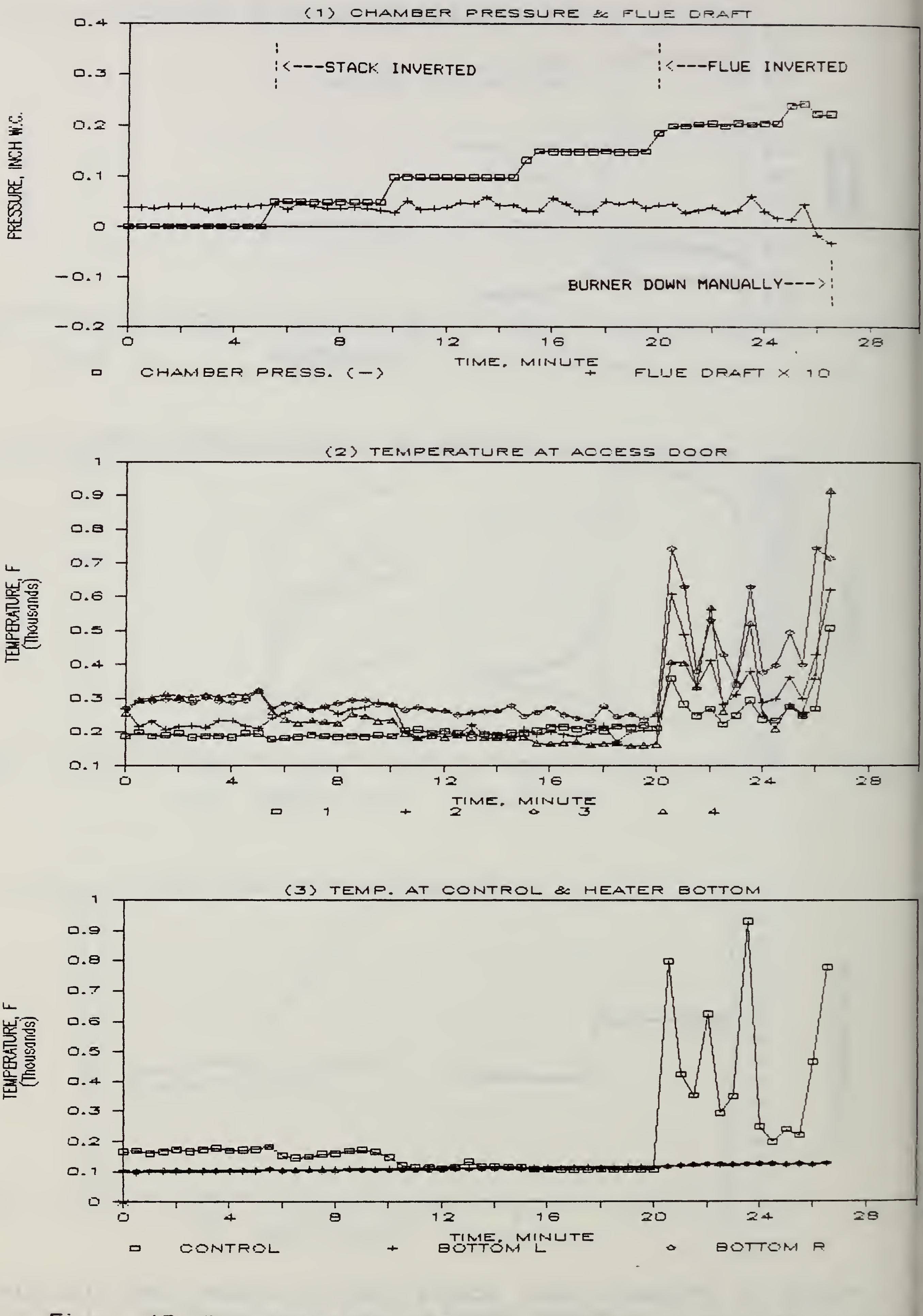


Figure 18 Pressure test, access doors off, no flue blockage -- Heater no. 2

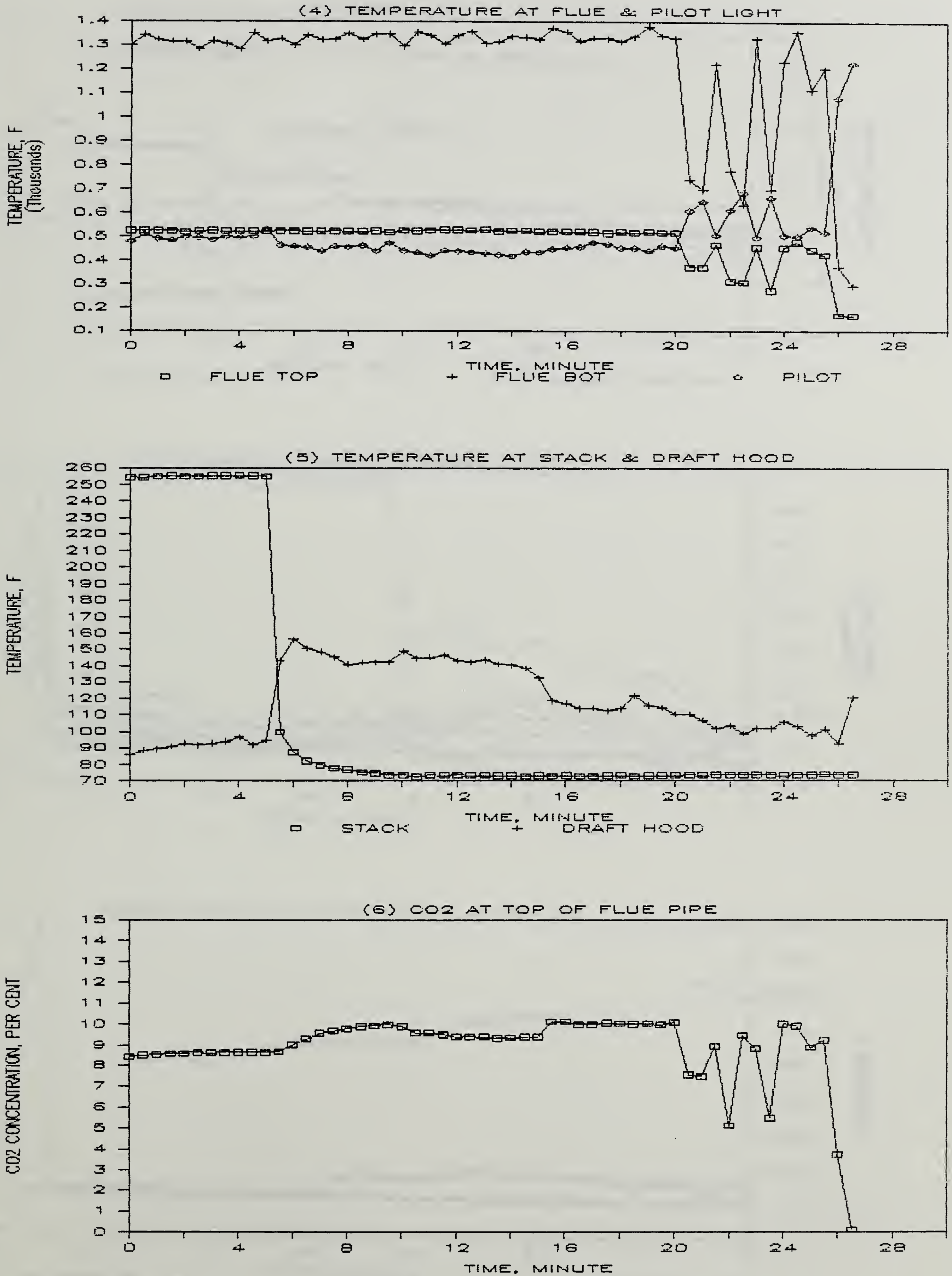


Figure 18 Pressure test, access doors off, no flue blockage -- Heater no. 2

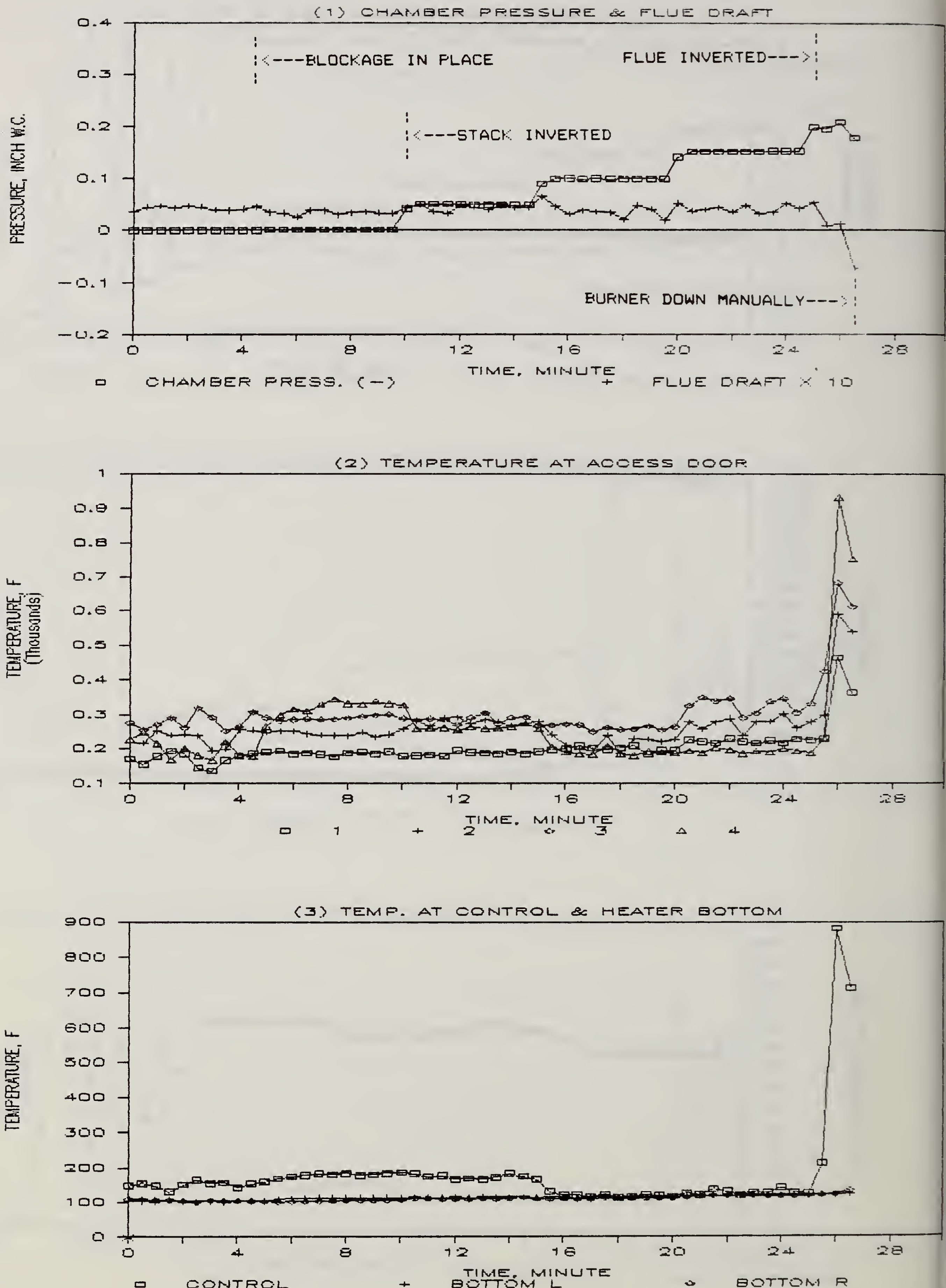


Figure 19 Pressure test, access doors off, 20% flue blockage -- Heater no. 2

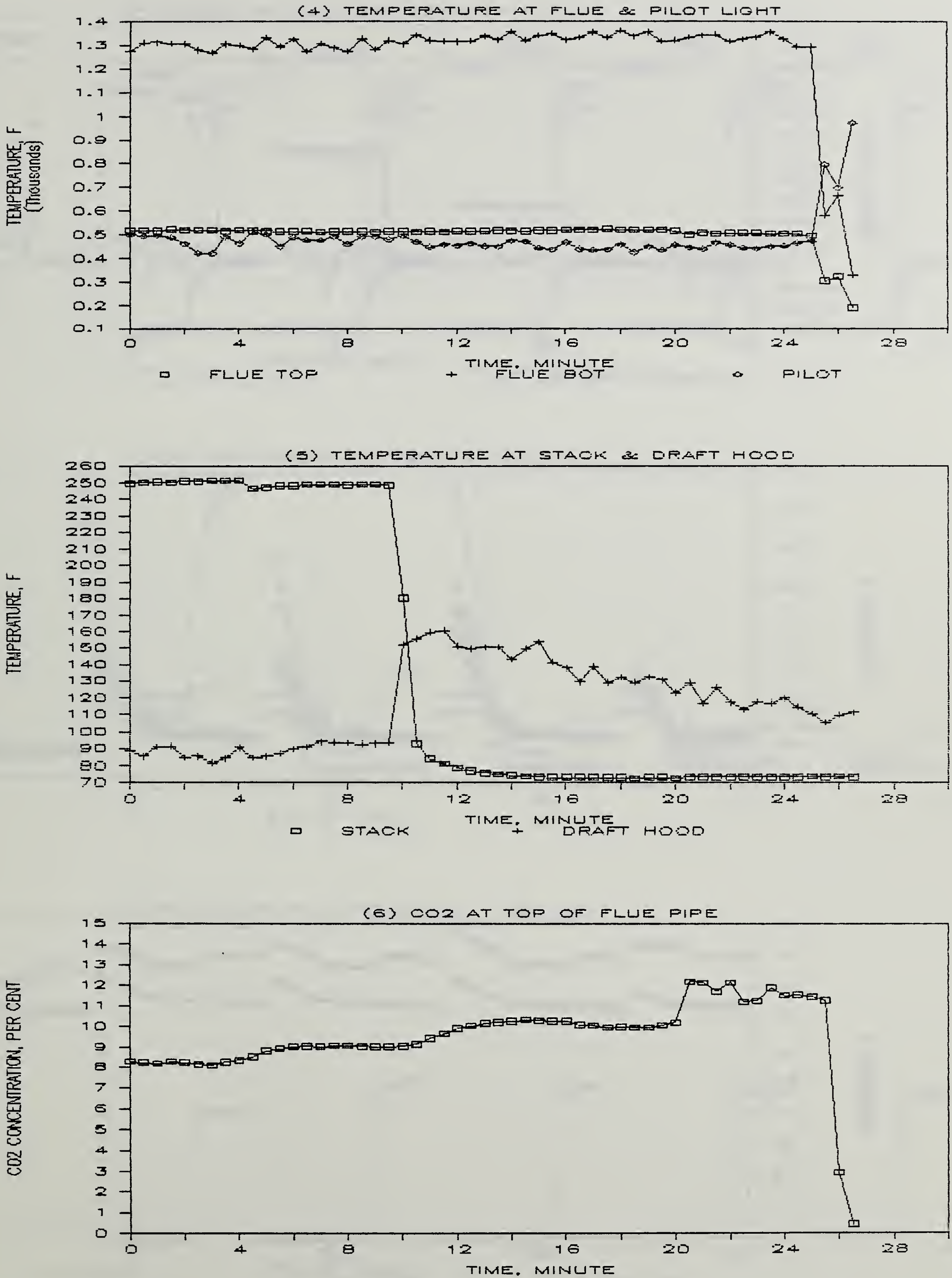


Figure 19 Pressure test, access doors off, 20% flue blockage
-- Heater no. 2

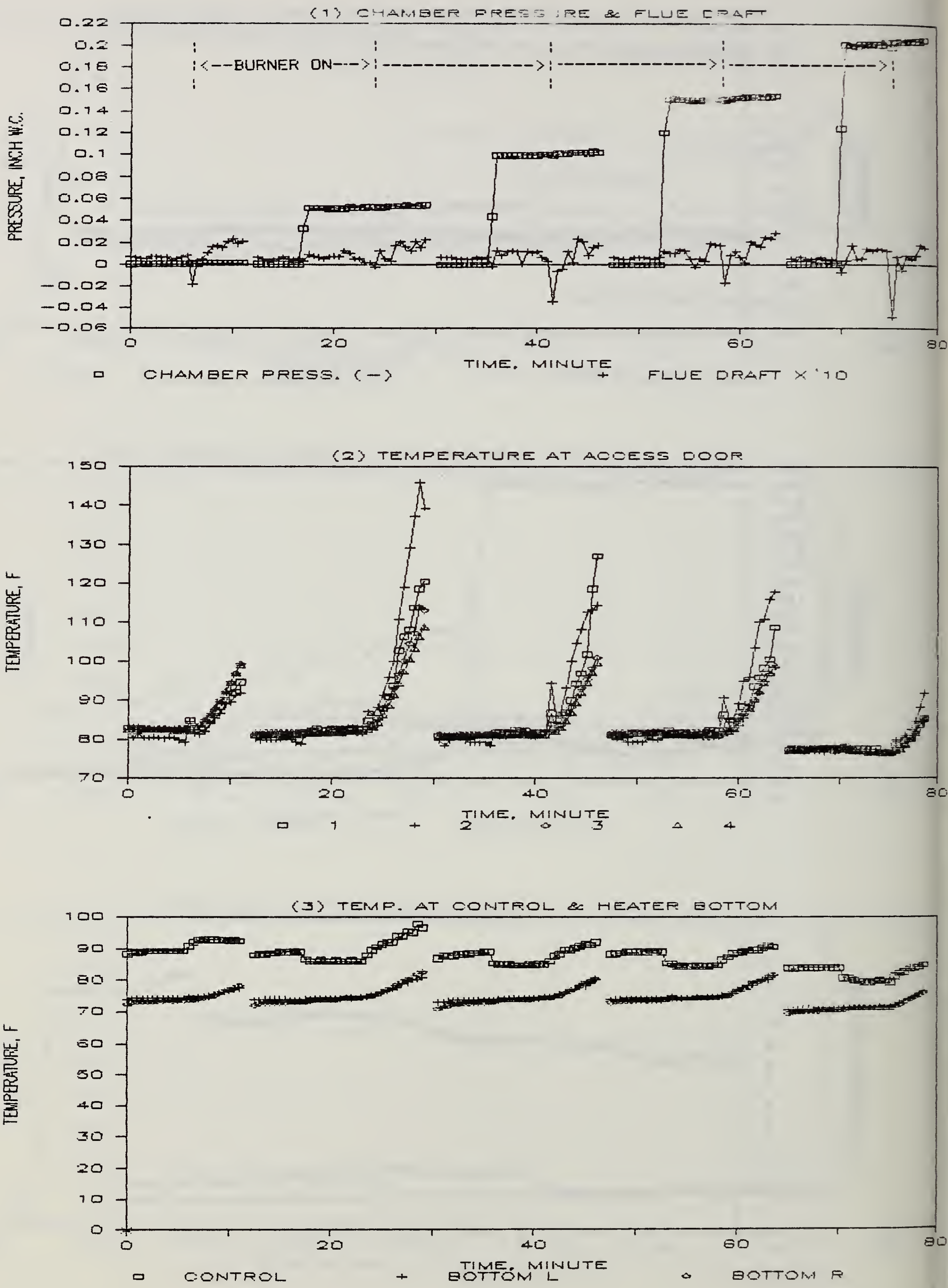


Figure 20 Cyclic test, access doors in-place -- Heater no. 3

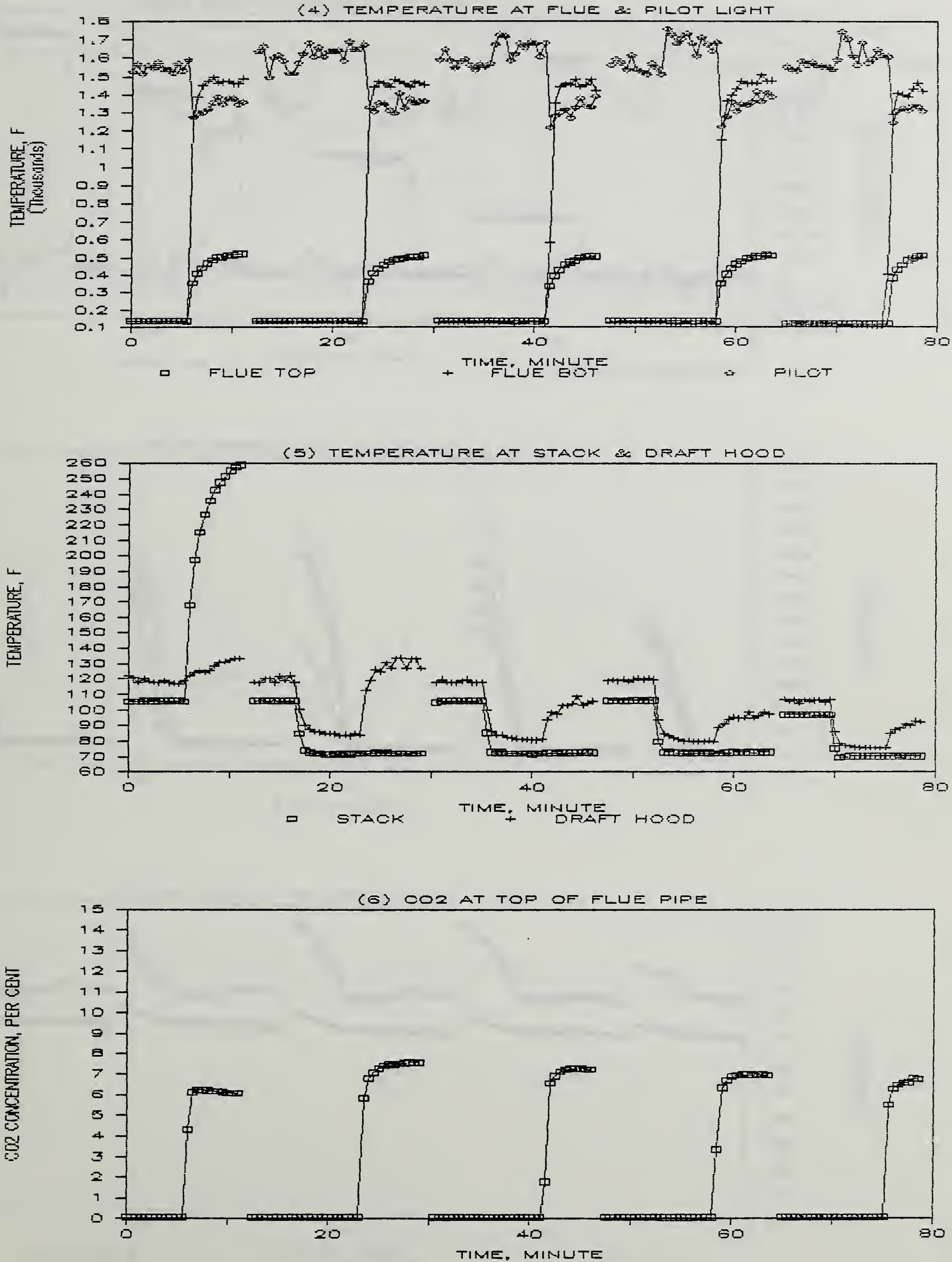


Figure 20 Cyclic test, access doors in place -- Heater no. 3

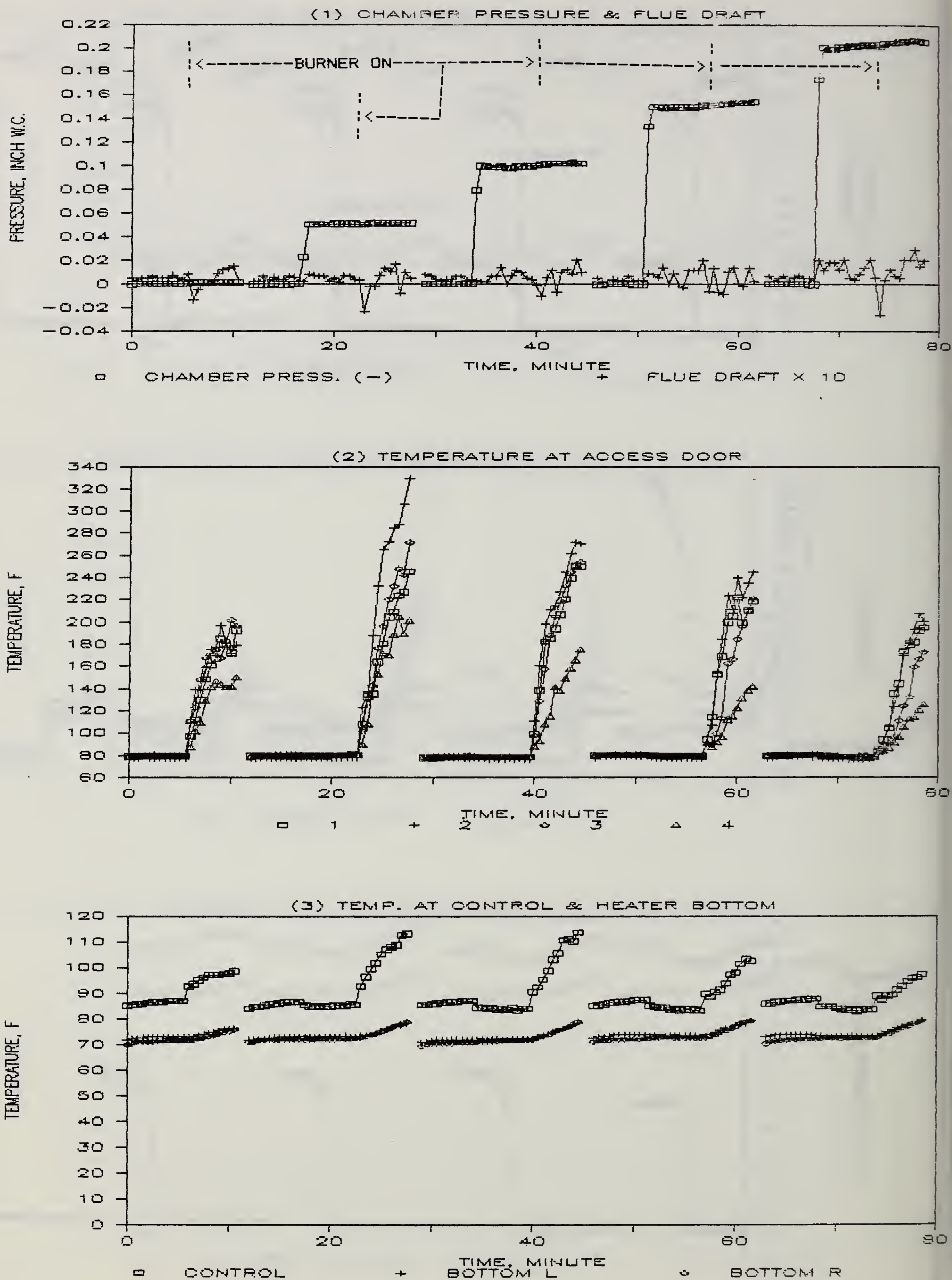


Figure 21 Cyclic test, access doors off -- Heater no. 3

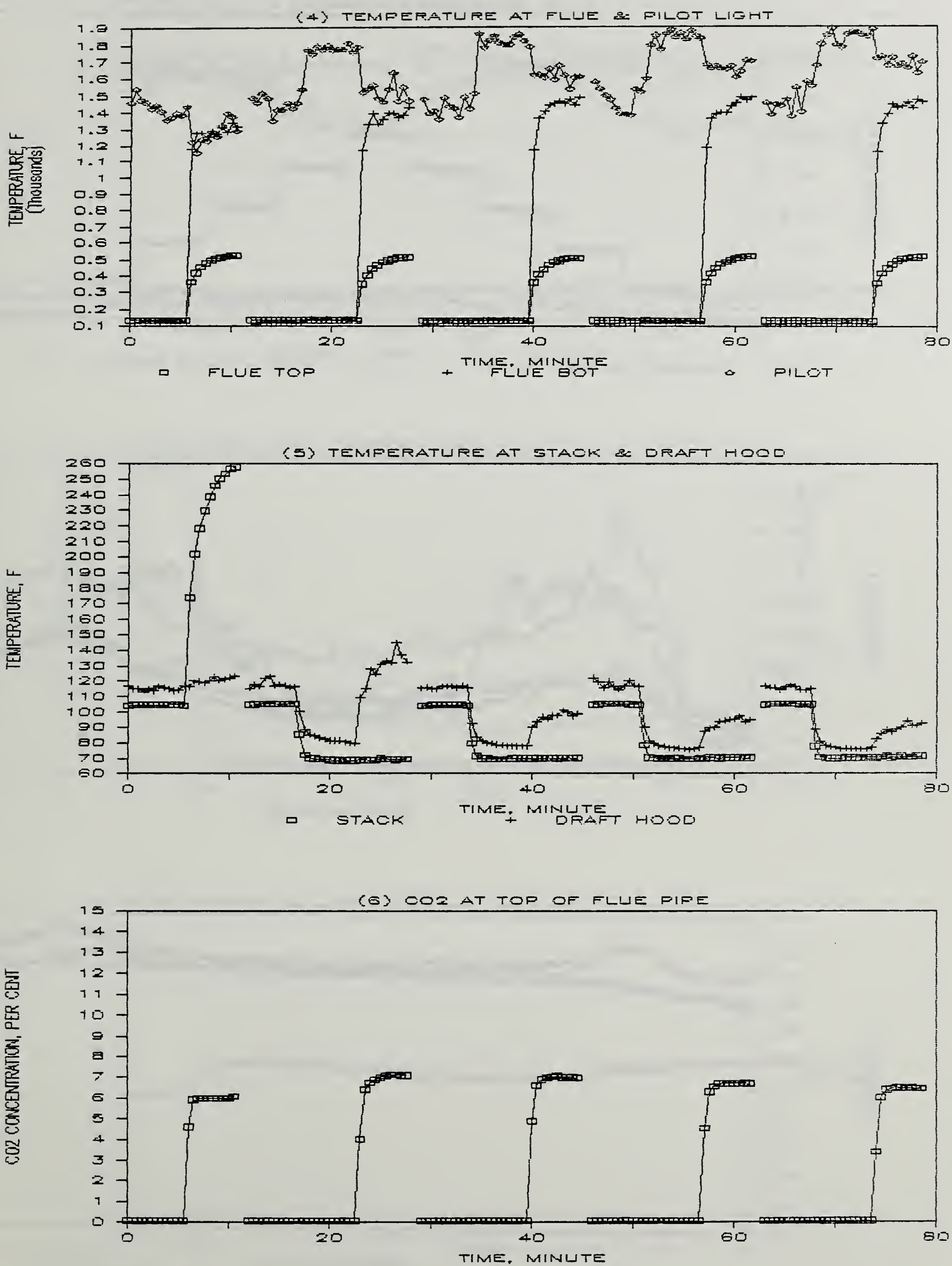


Figure 21 Cyclic test, access doors off -- Heater no. 3

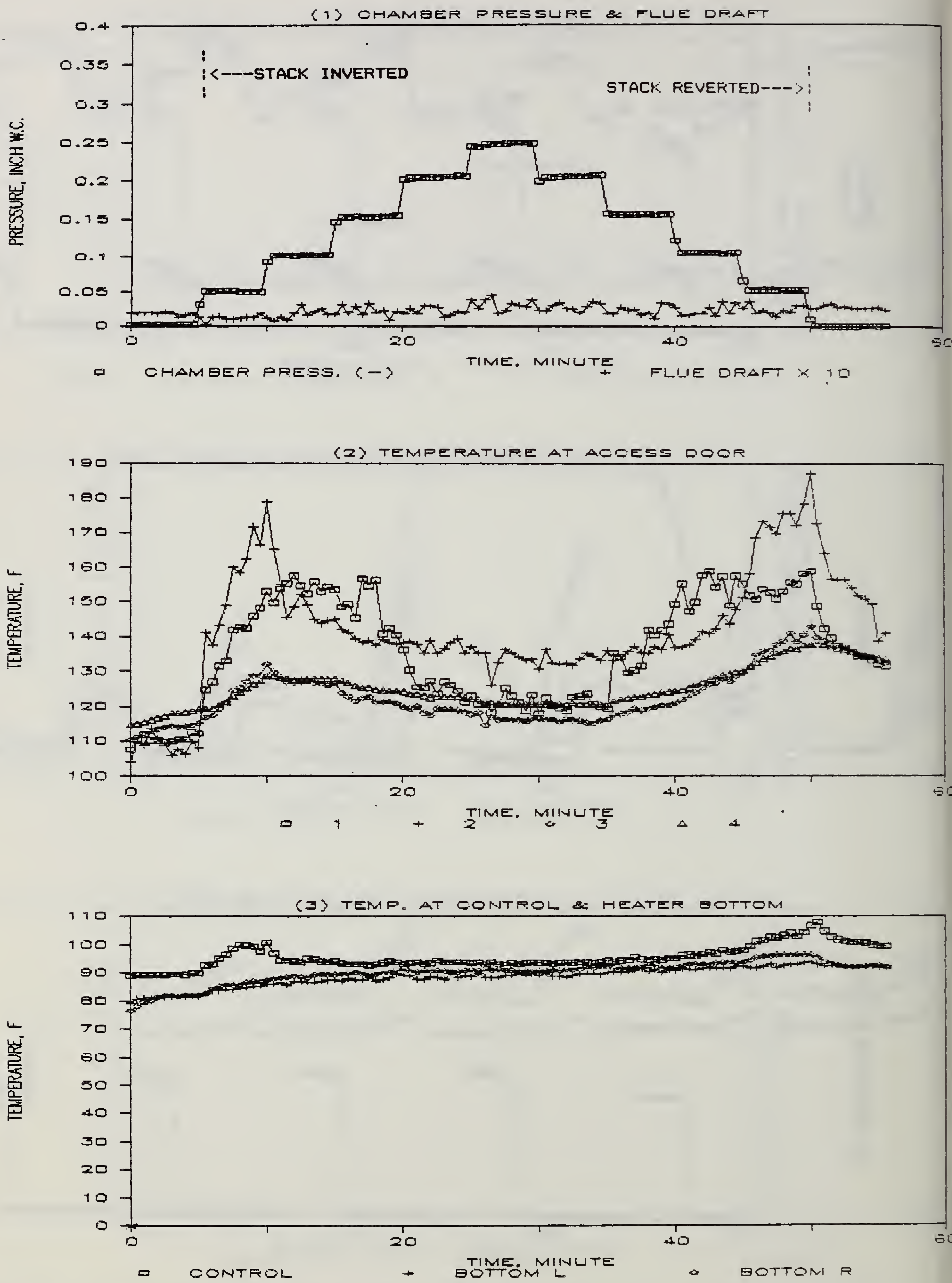
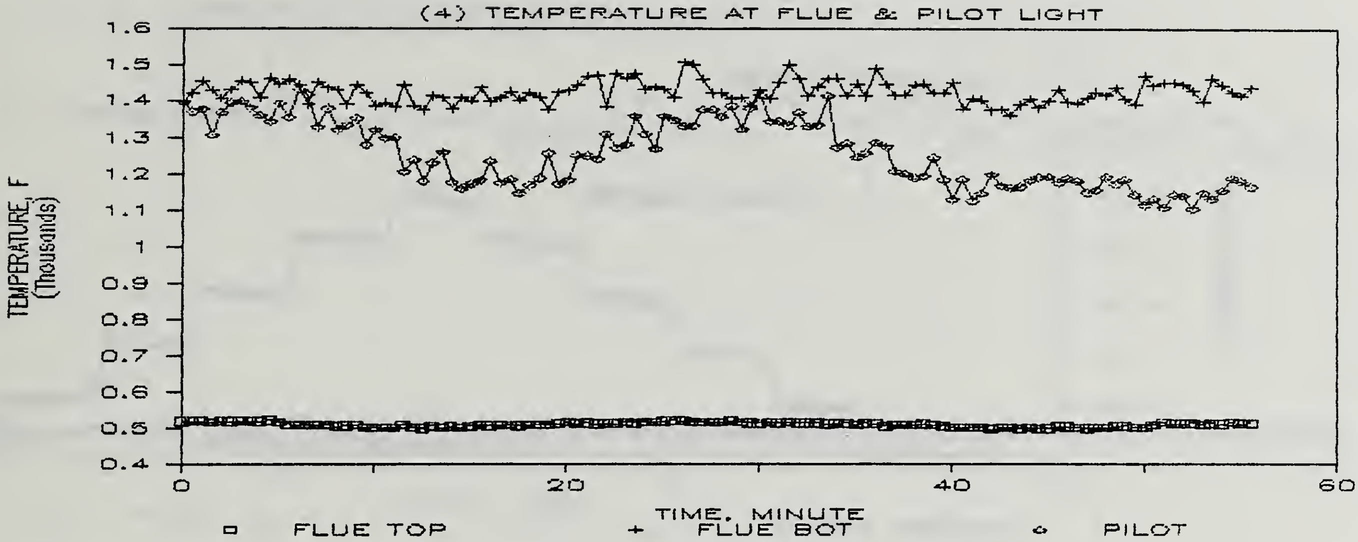
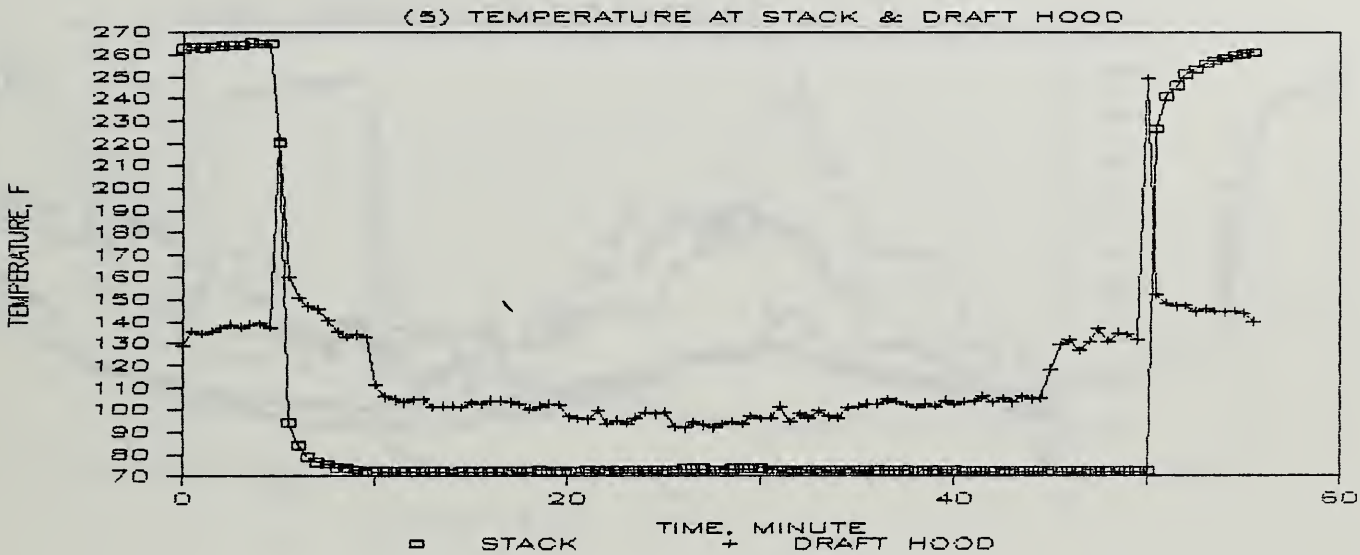


Figure 22 Pressure test, access doors in-place, no flue blockage -- Heater no. 3





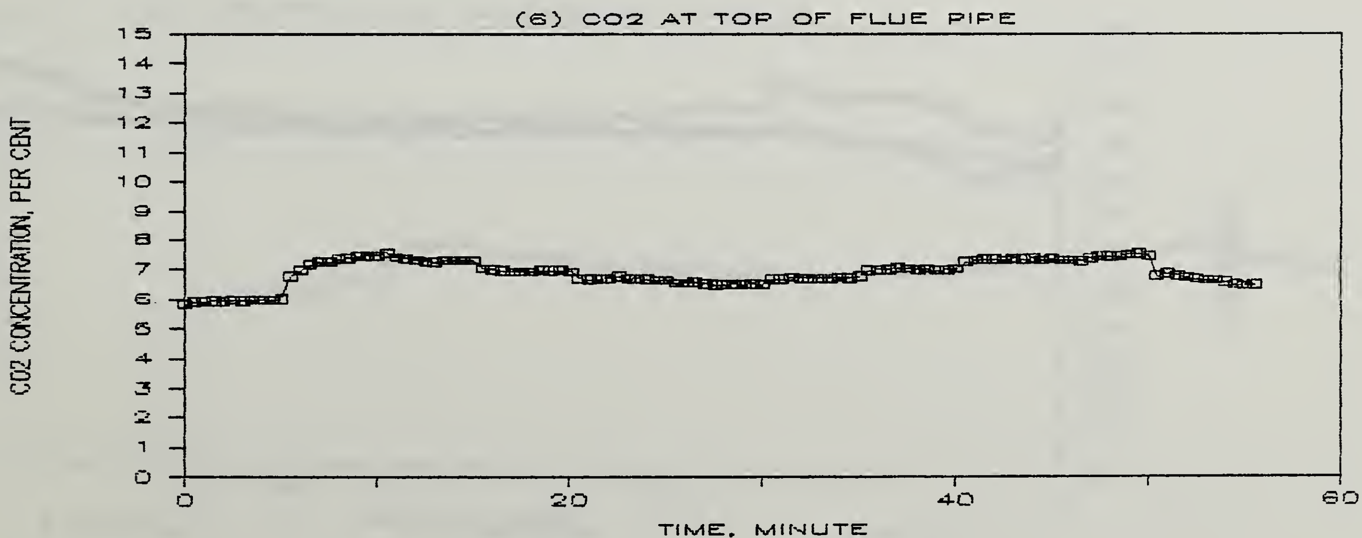


Figure 22 Pressure test, access doors in place, no flue blockage -- Heater no. 3

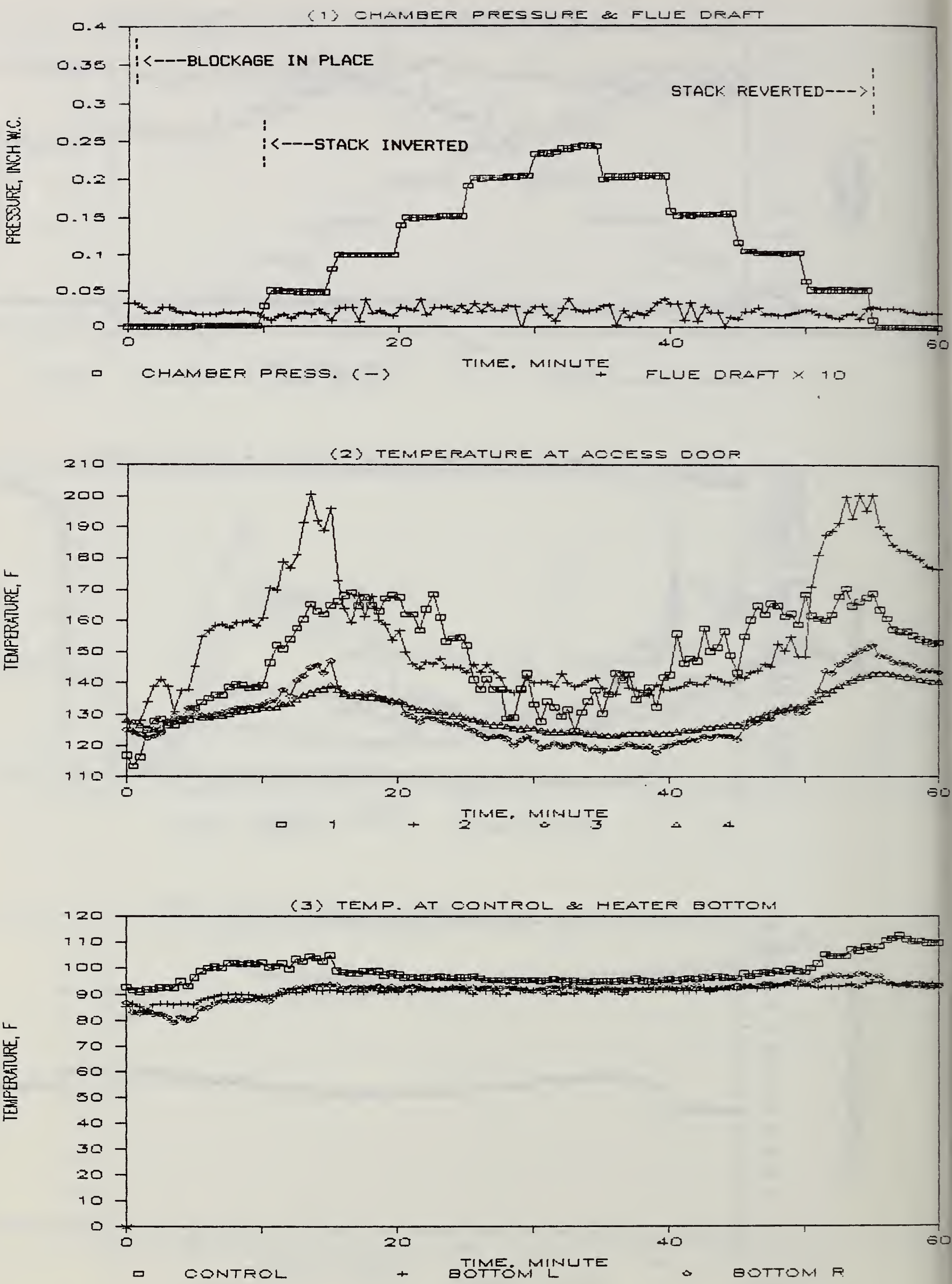


Figure 23 Pressure test, access doors in-place, 20% flue blockage -- Heater no. 3

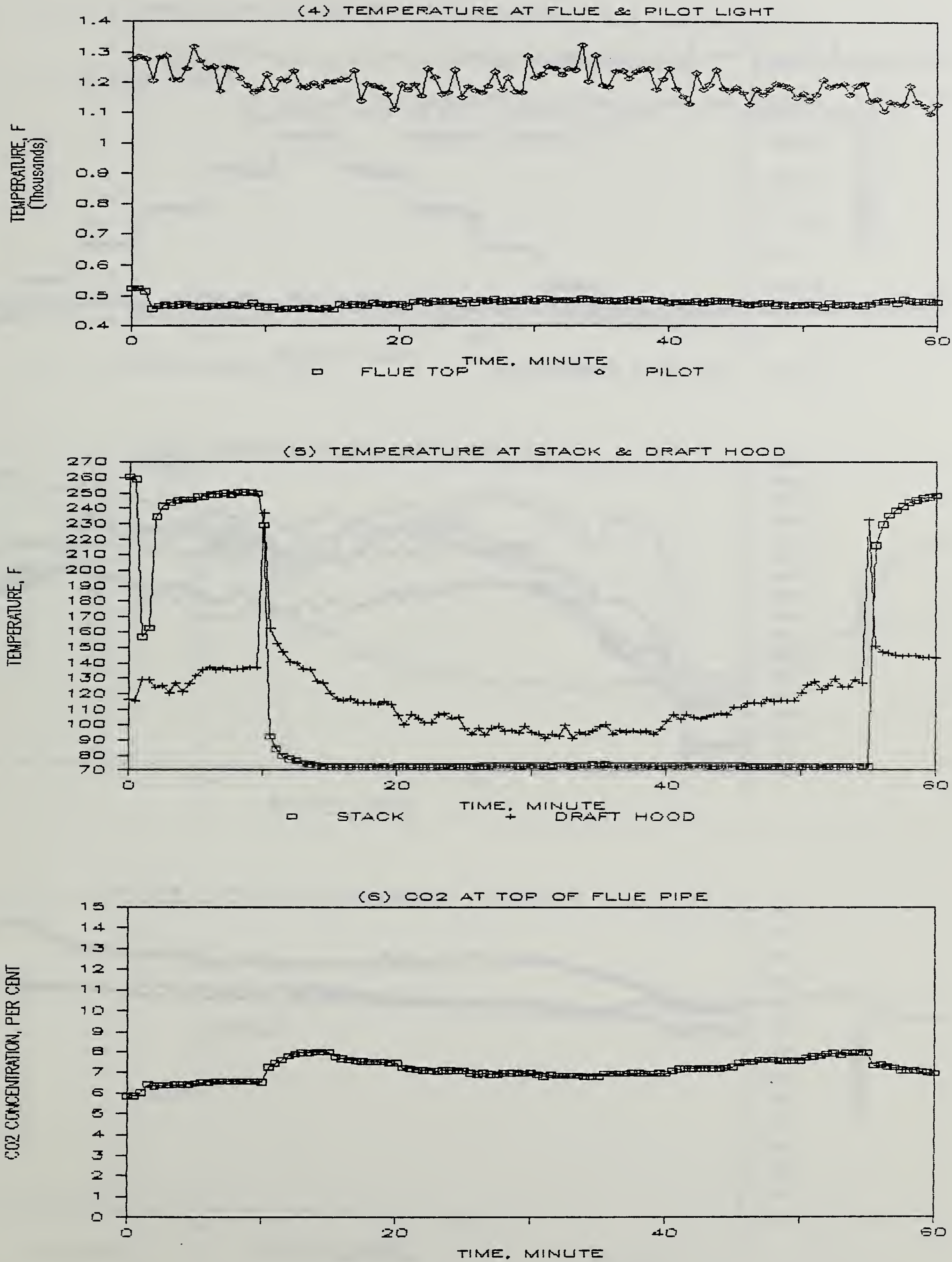


Figure 23 Pressure test, access doors in place, 20% flue blockage -- Heater no. 3

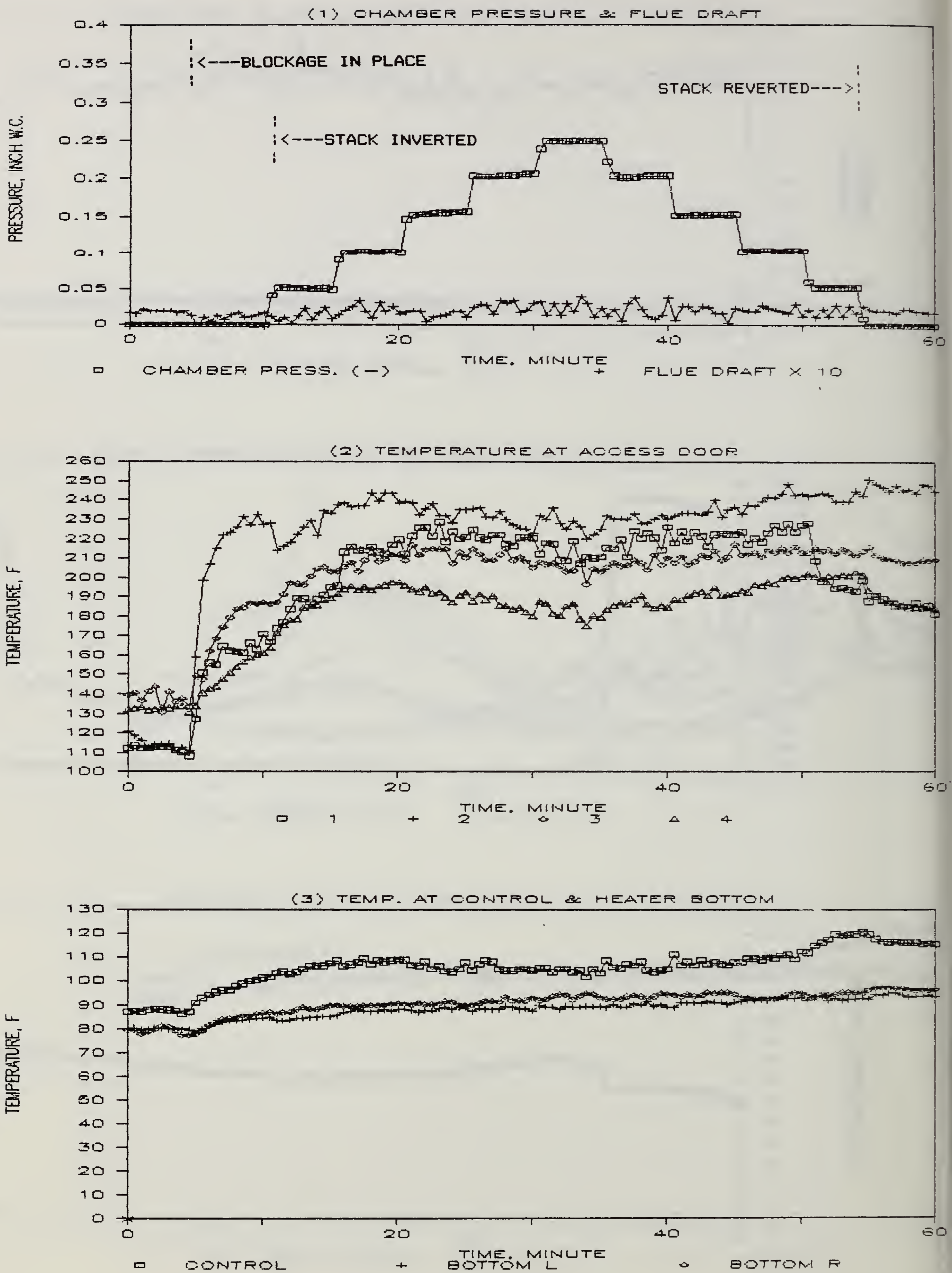


Figure 24 Pressure test, access doors in-place, 60% flue blockage -- Heater no. 3

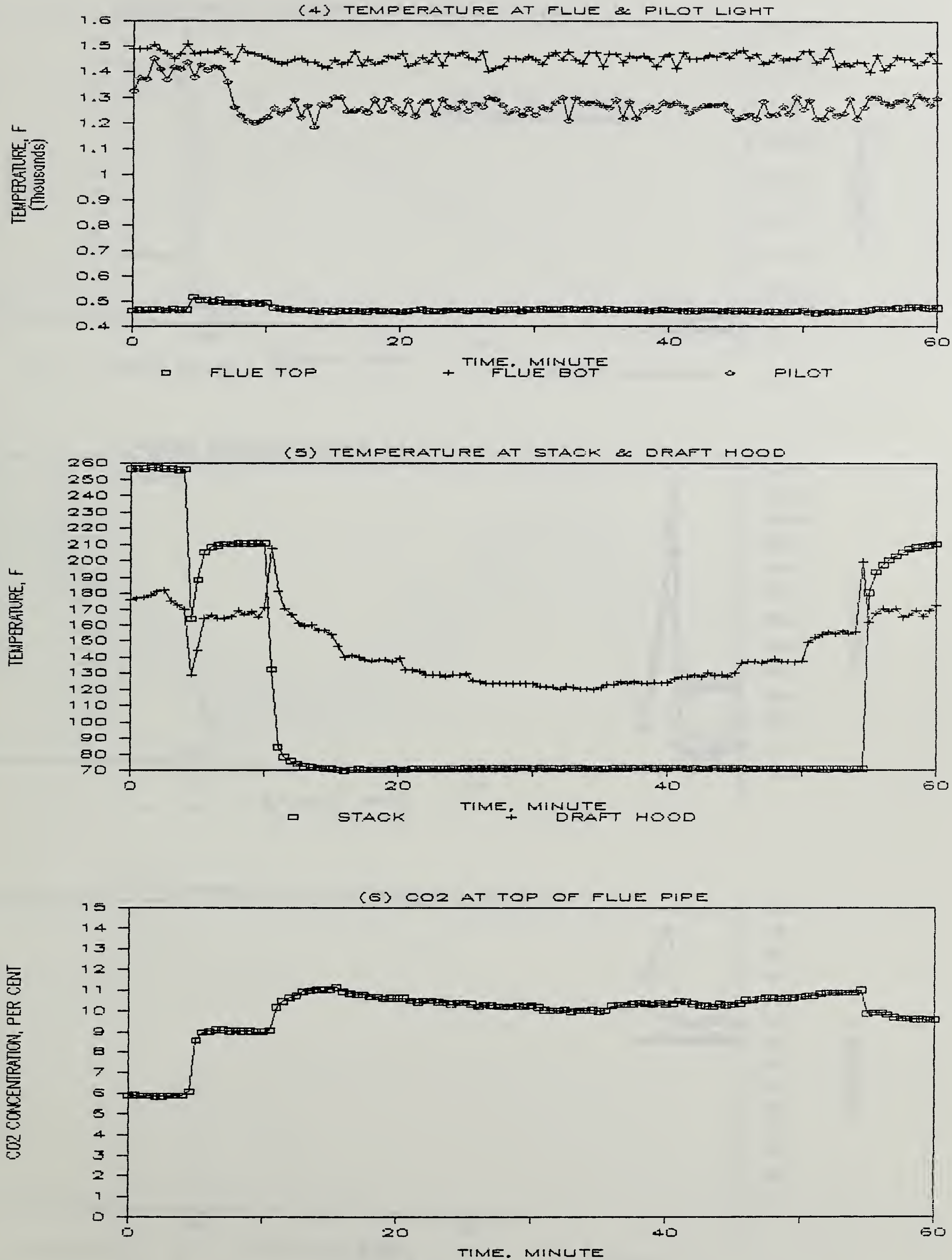


Figure 24 Pressure test, access doors in place, 60% flue blockage -- Heater no. 3

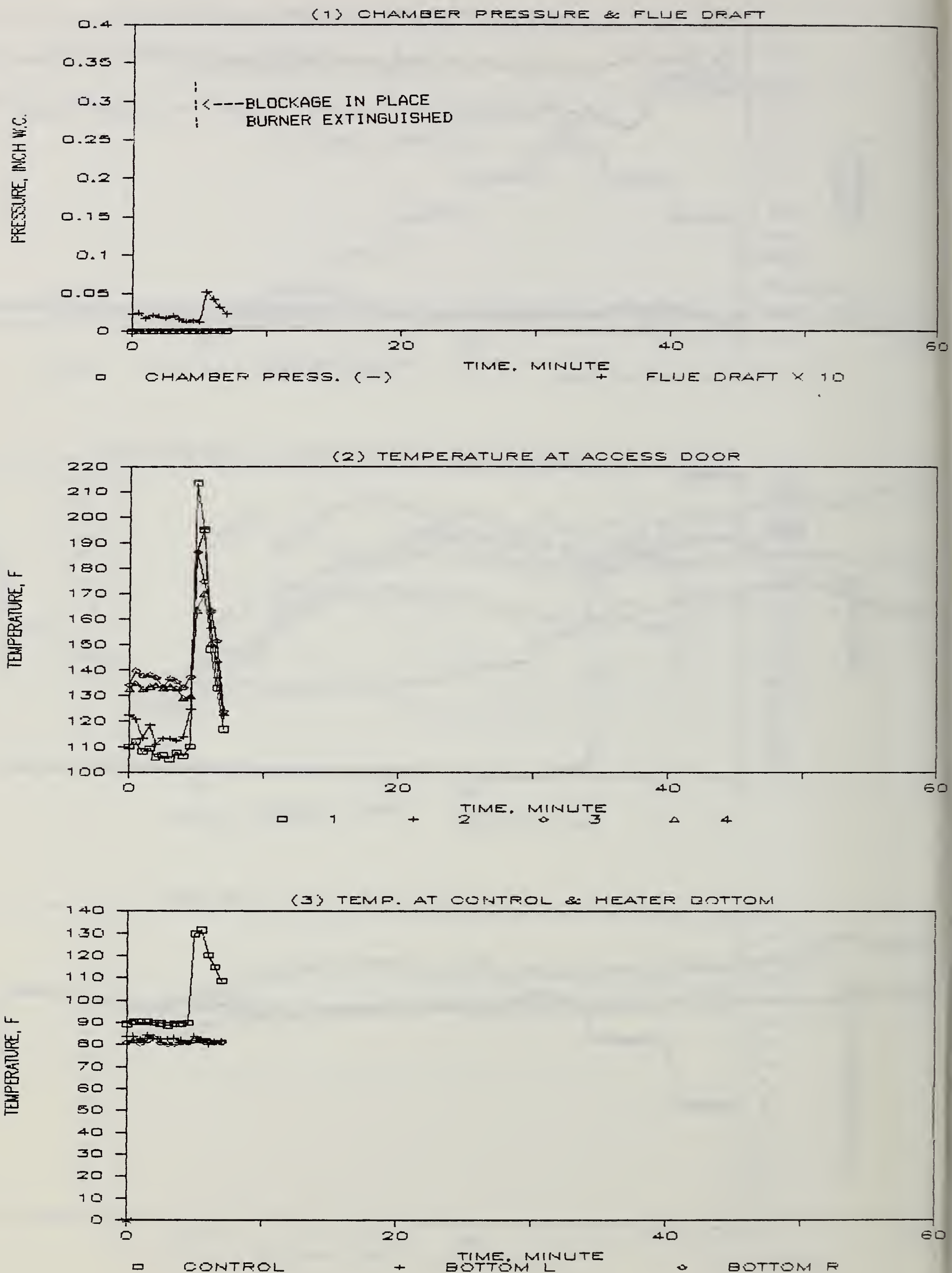
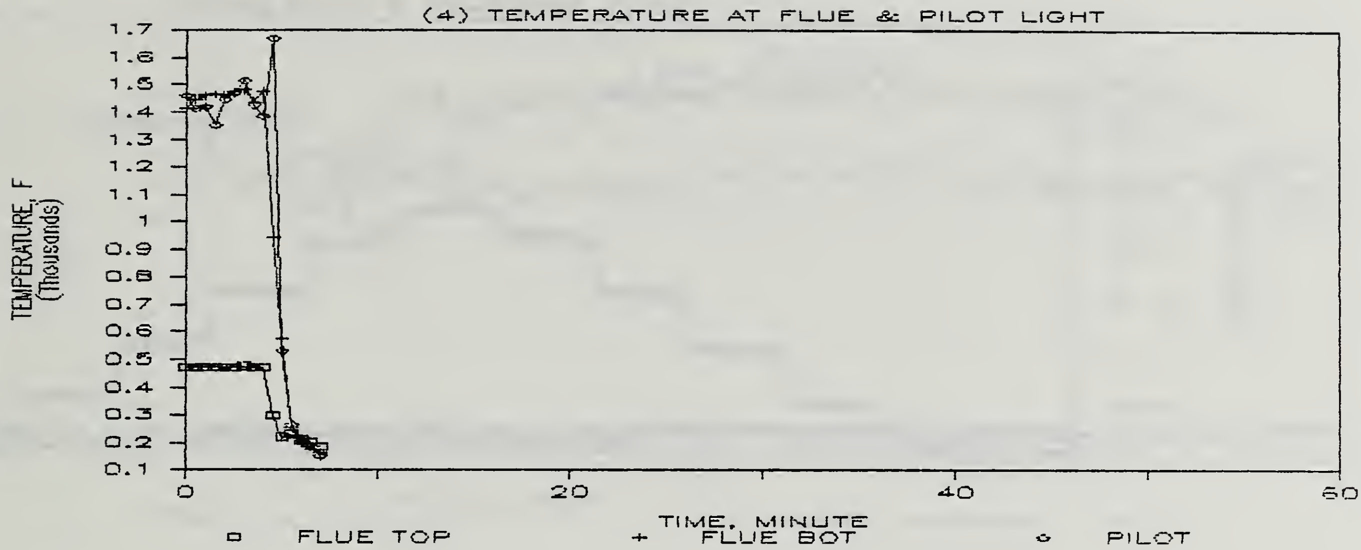
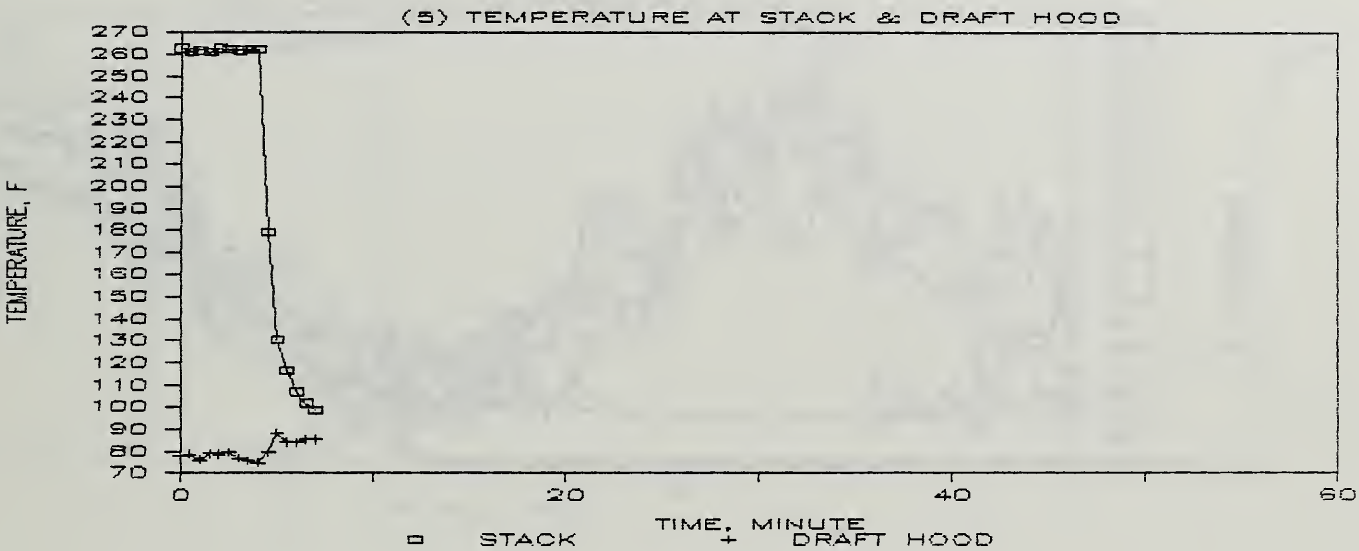


Figure 25 Pressure test, access doors in-place, 100% flue blockage -- Heater no. 3





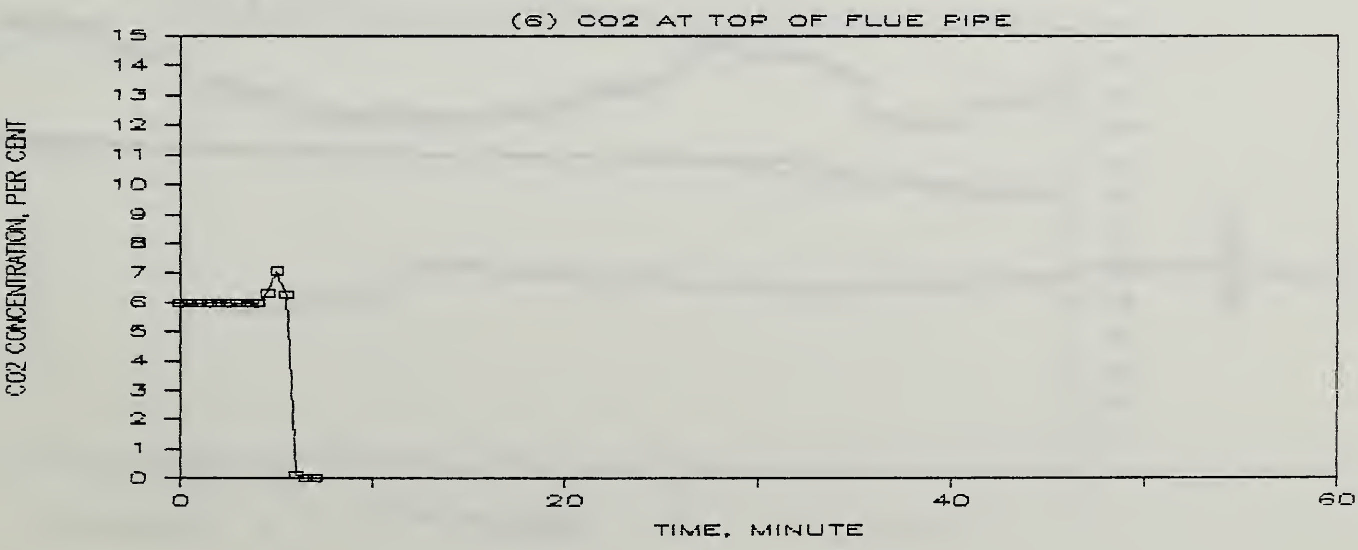


Figure 25 Pressure test, access doors in place, 100% flue blockage — Heater no. 3

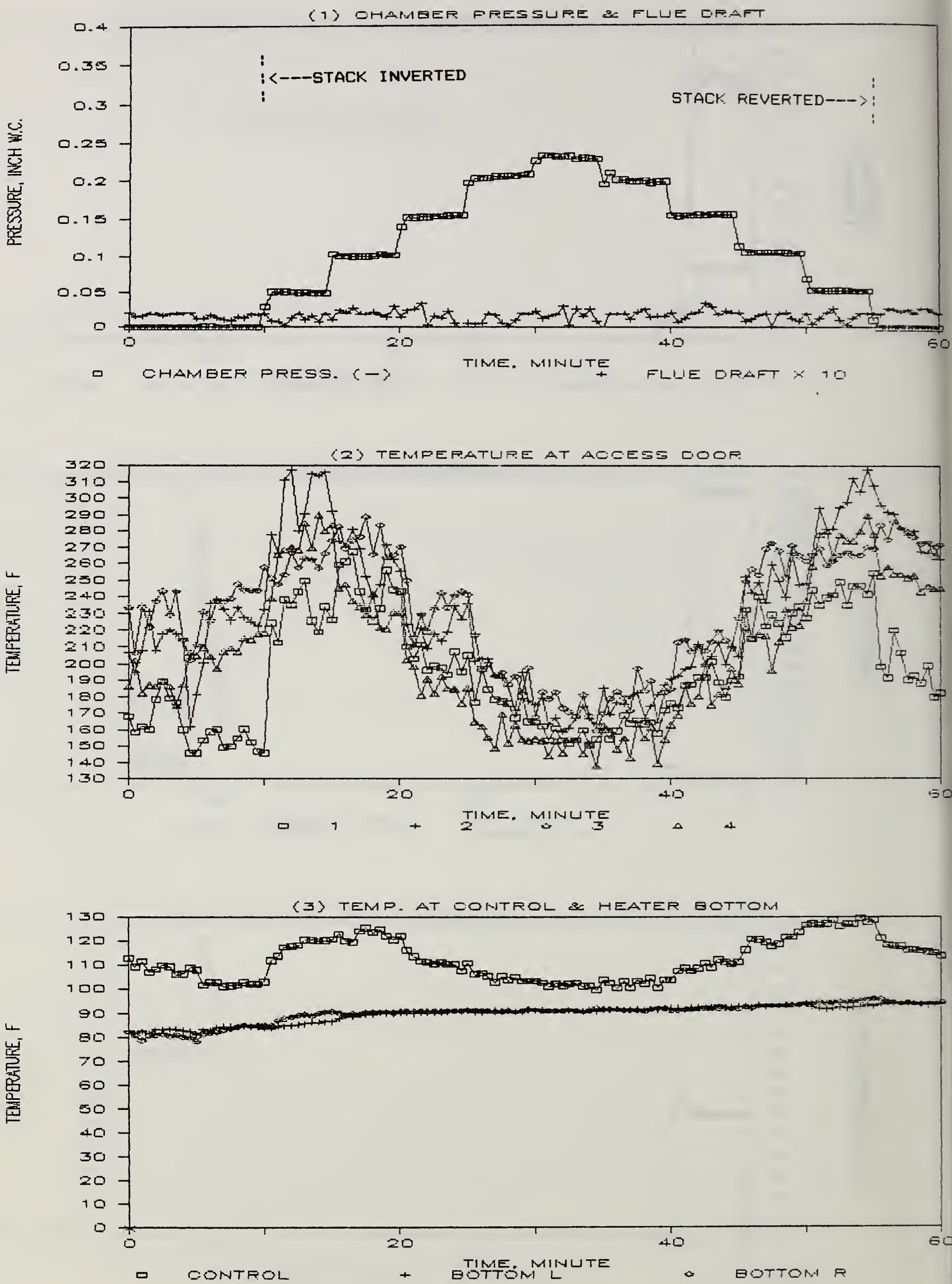


Figure 26 Pressure test, access doors off, no flue blockage -- Heater no. 3

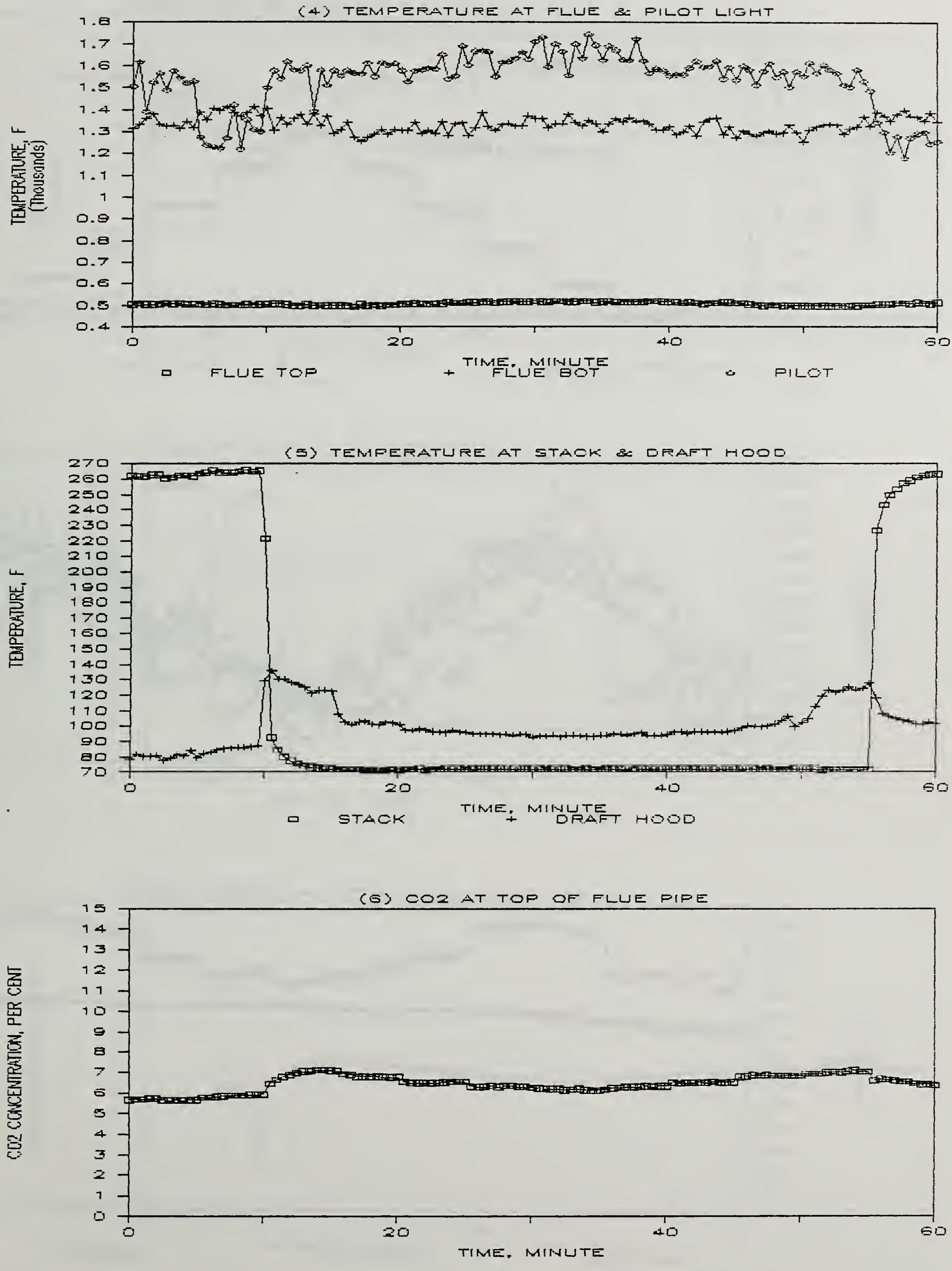


Figure 26 Pressure test, access doors off, no flue blockage -- Heater no. 3

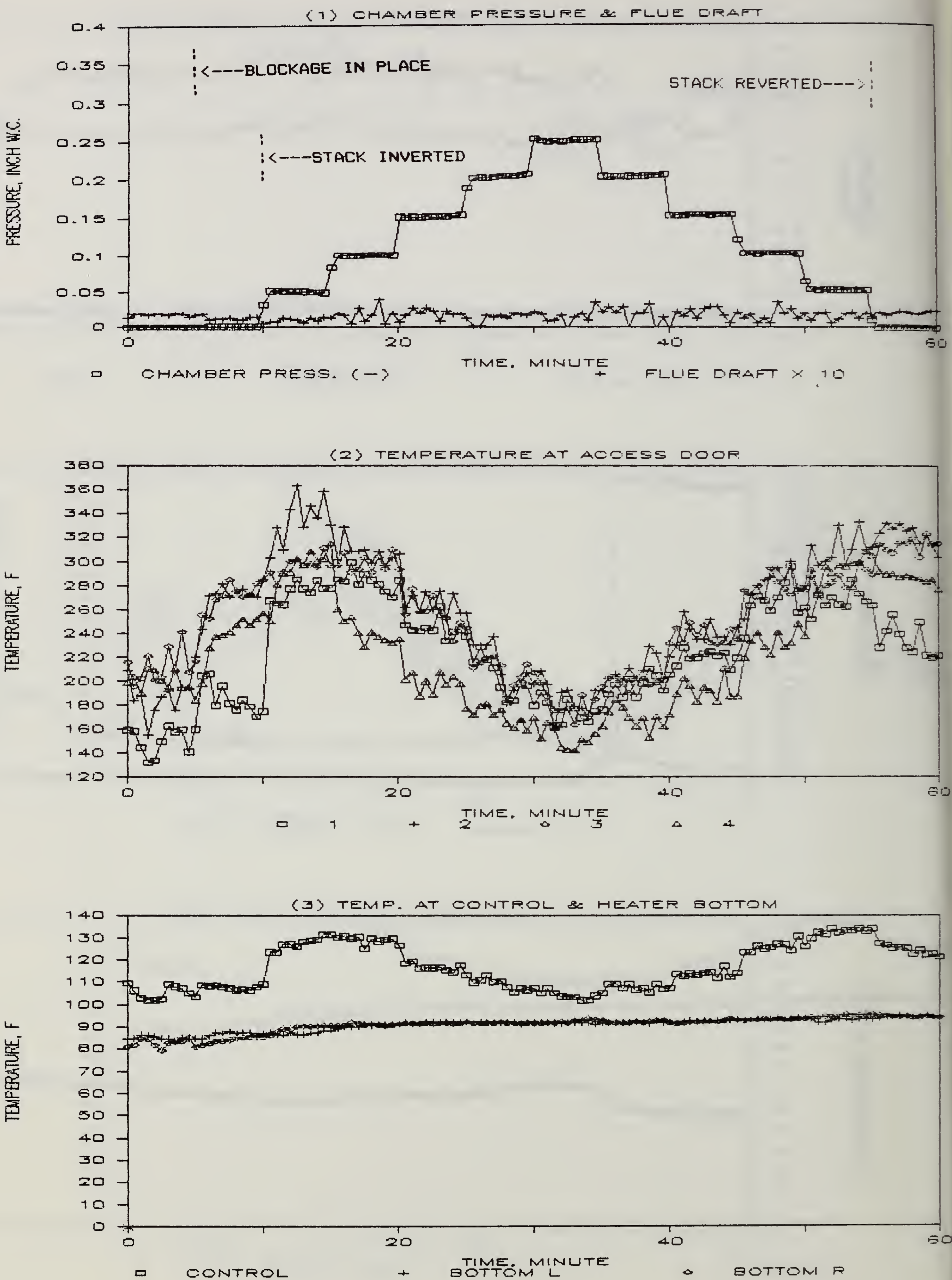


Figure 27 Pressure test, access doors off, 20% flue blockage -- Heater no. 3

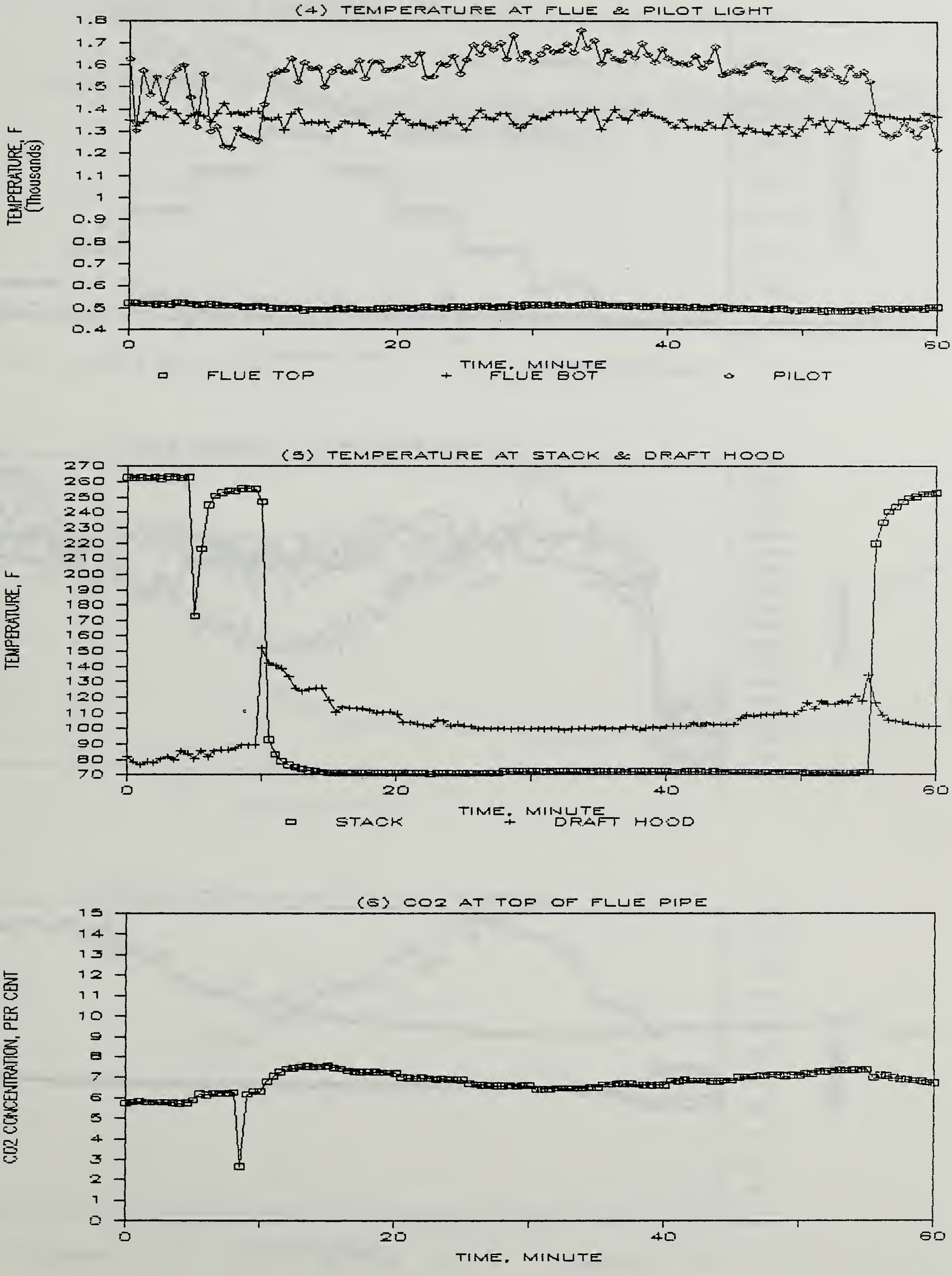


Figure 27 Pressure test, access doors off, 20% flue blockage
-- Heater no. 3

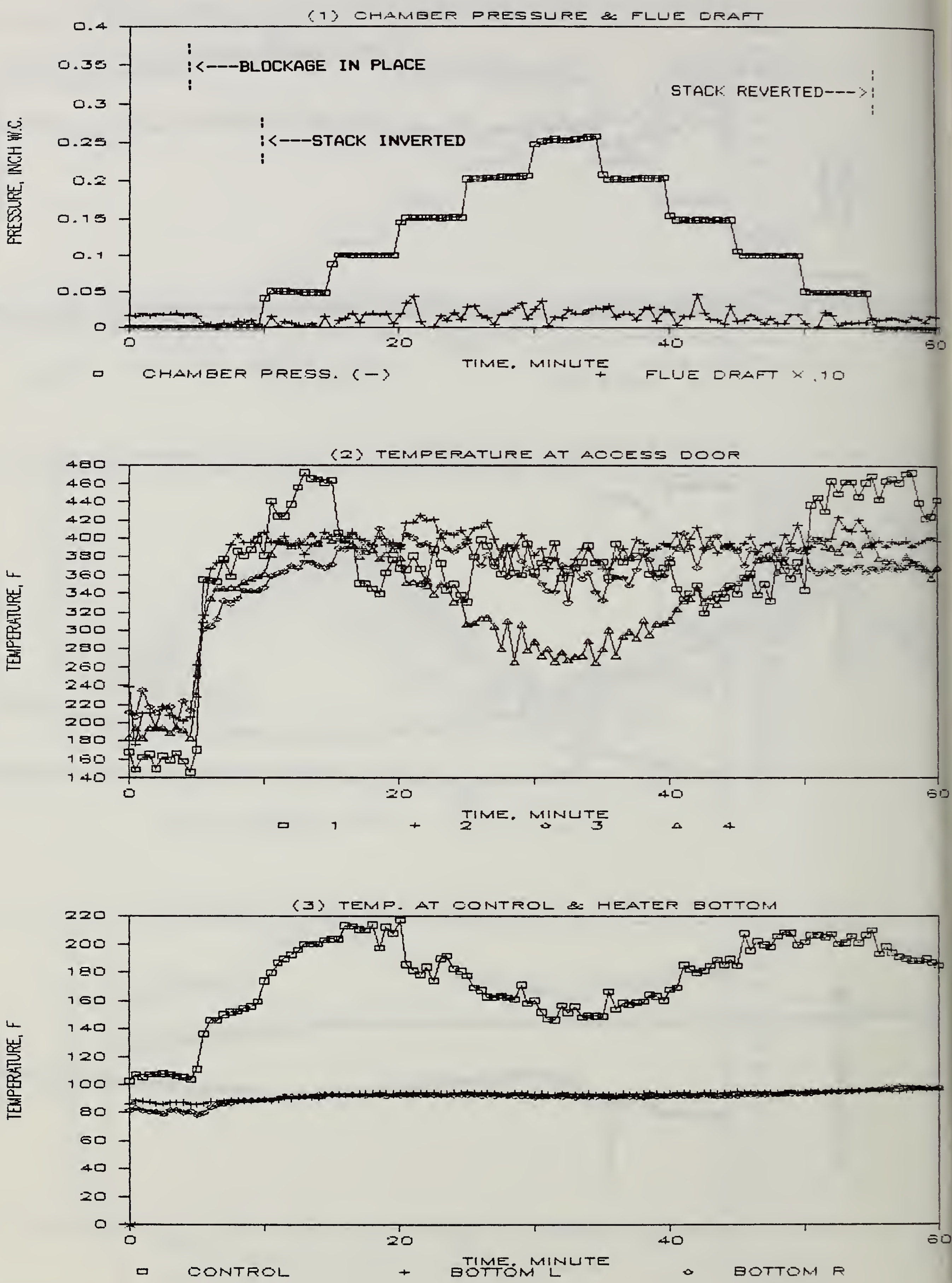


Figure 28 Pressure test, access doors off, 60% flue blockage -- Heater no. 3

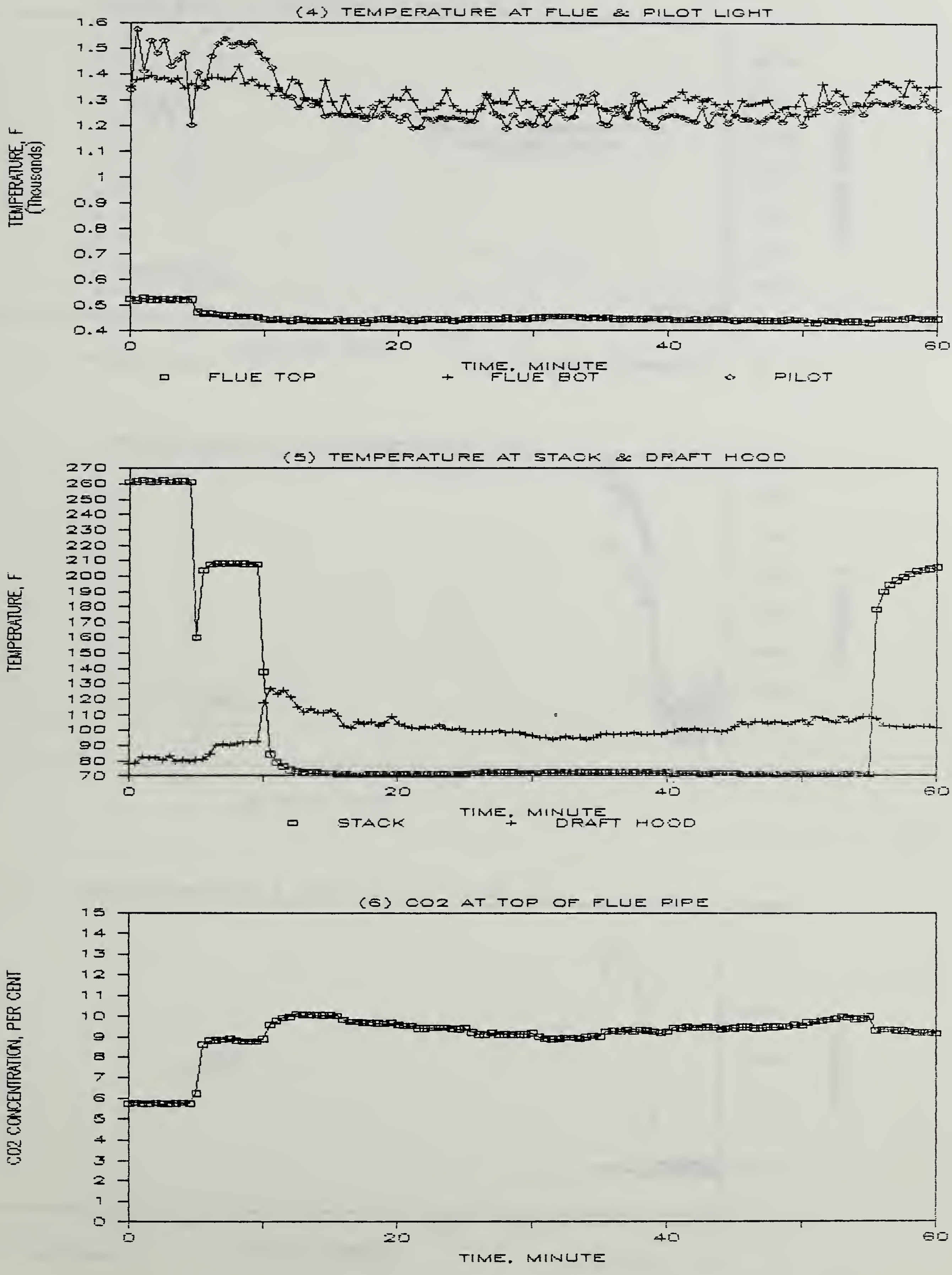


Figure 28 Pressure test, access doors off, 60% flue blockage
-- Heater no. 3

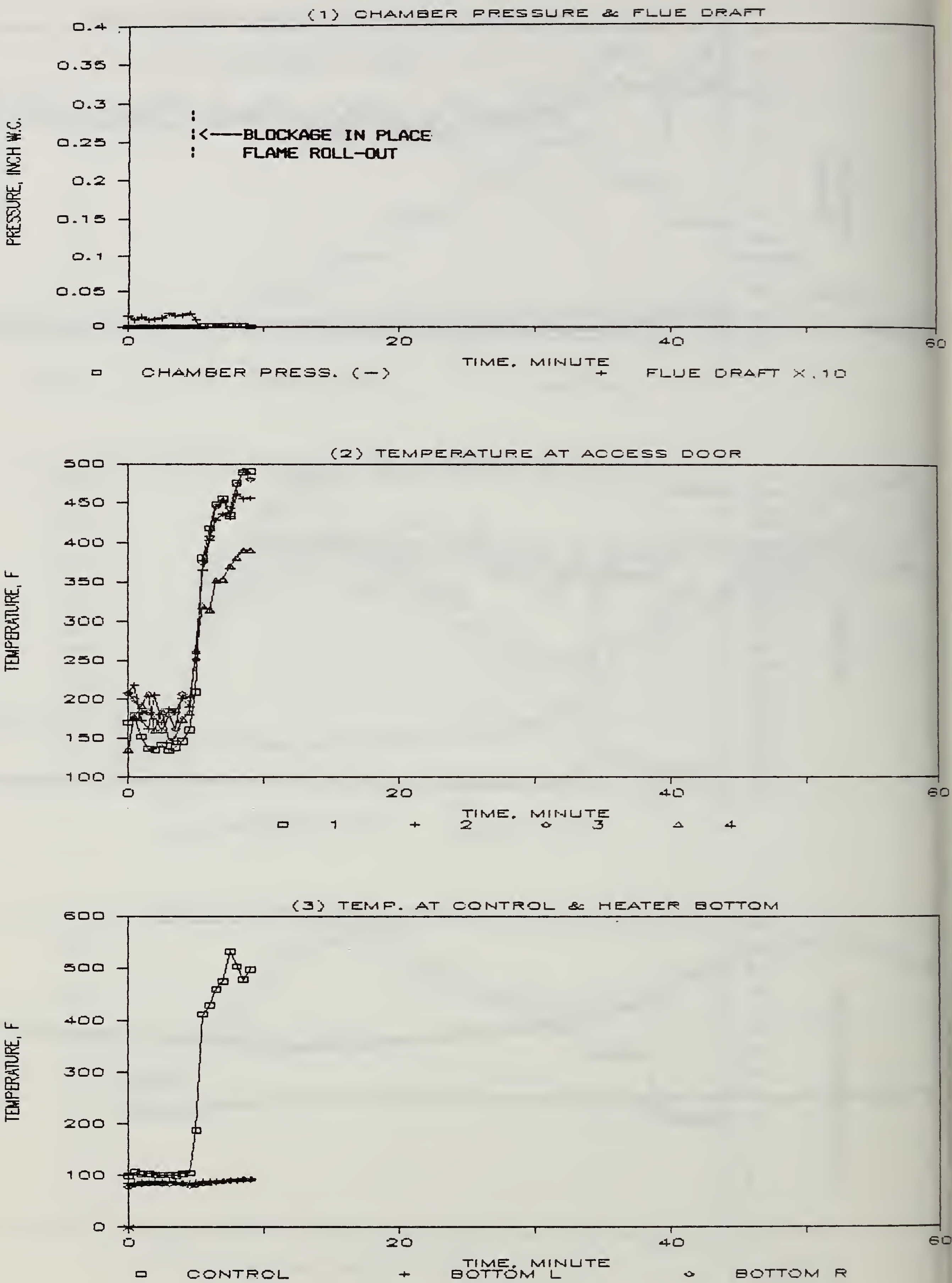
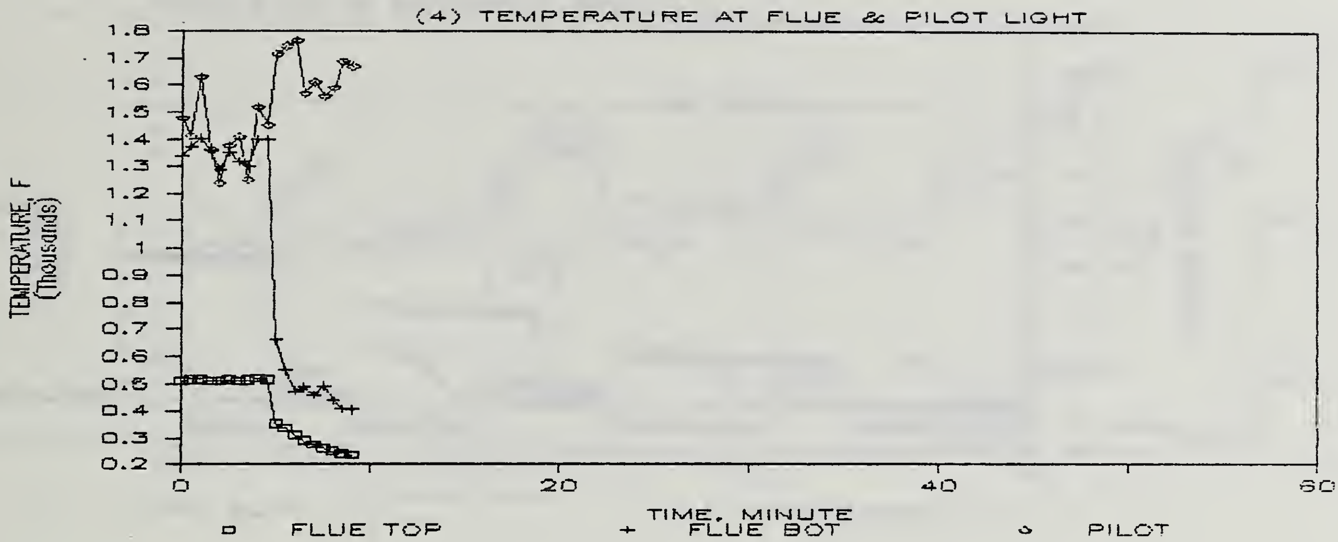
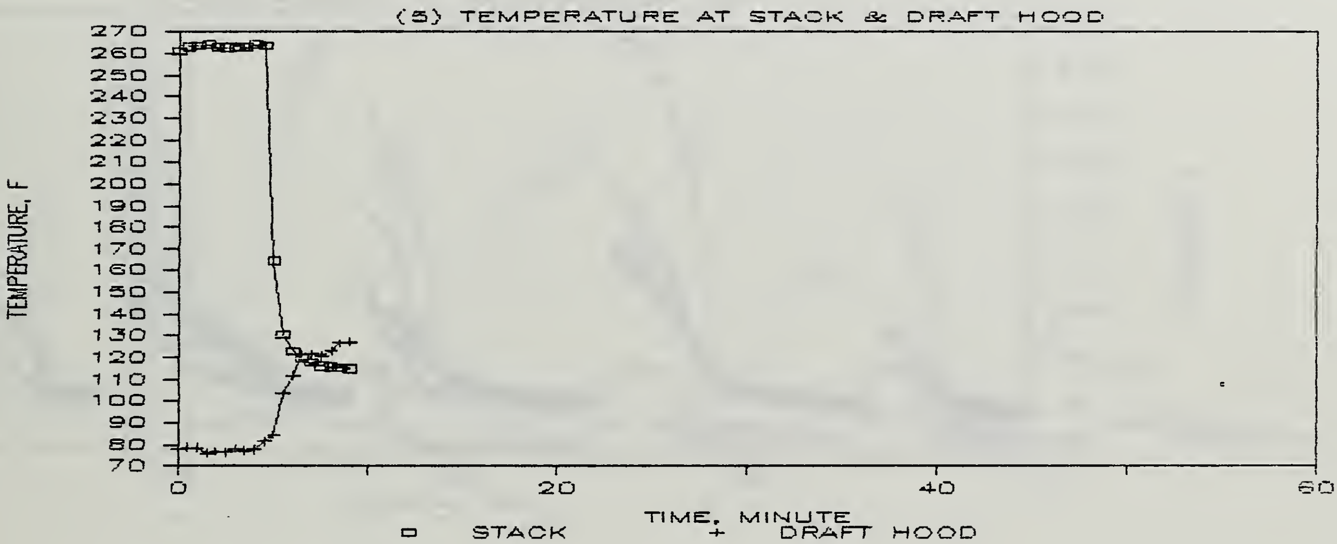


Figure 29 Pressure test, access doors off, 100% flue blockage -- Heater no. 3





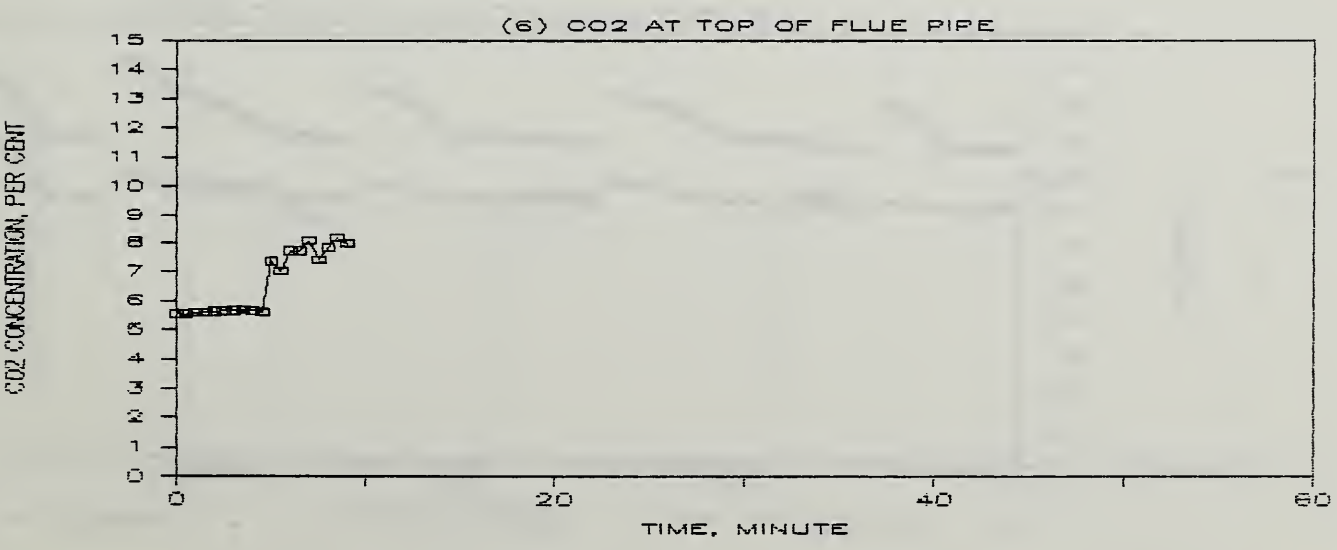


Figure 29 Pressure test, access doors off, 100% flue blockage -- Heater no. 3

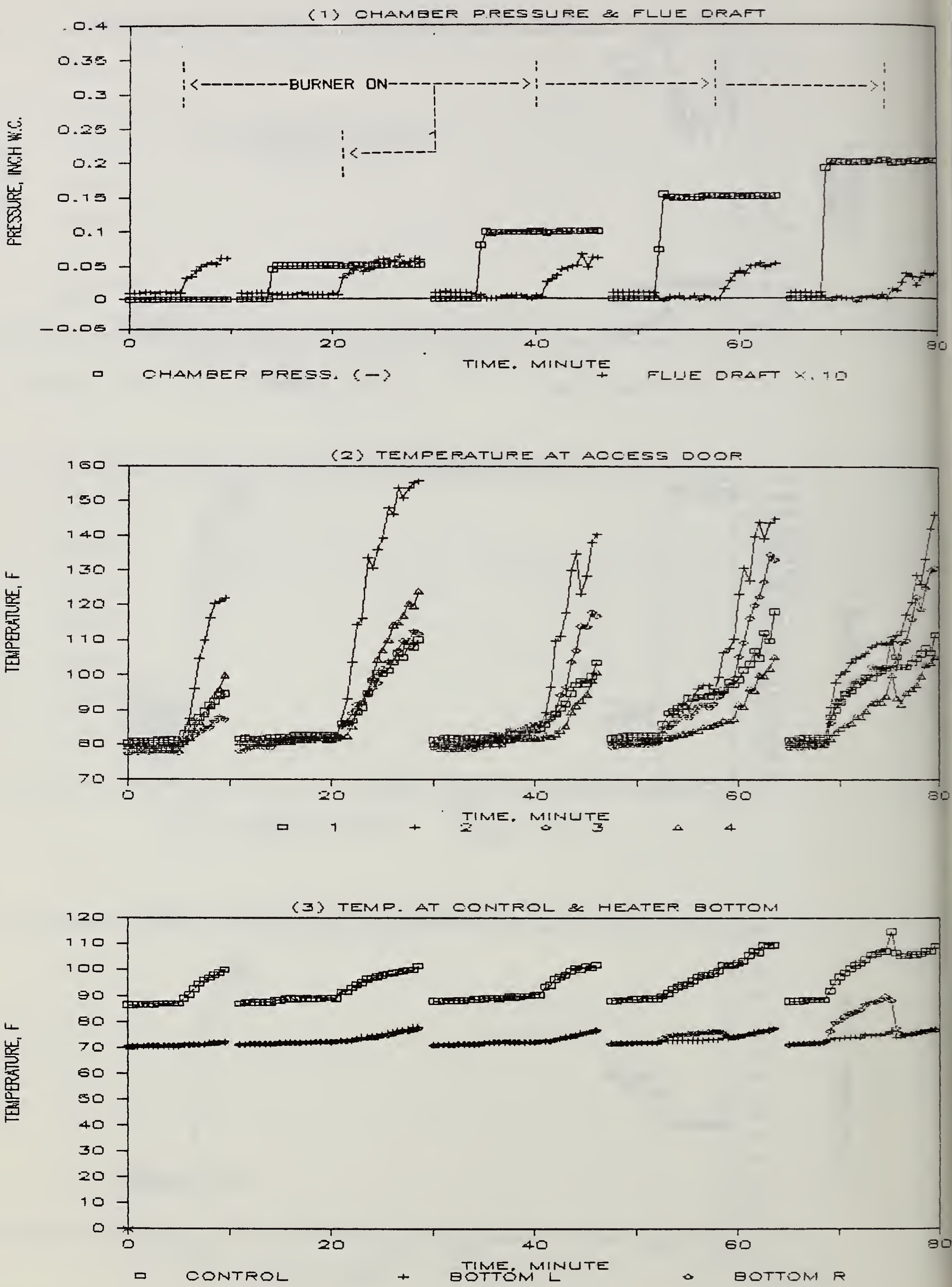


Figure 30 Cyclic test, access doors in-place -- Heater no. 4

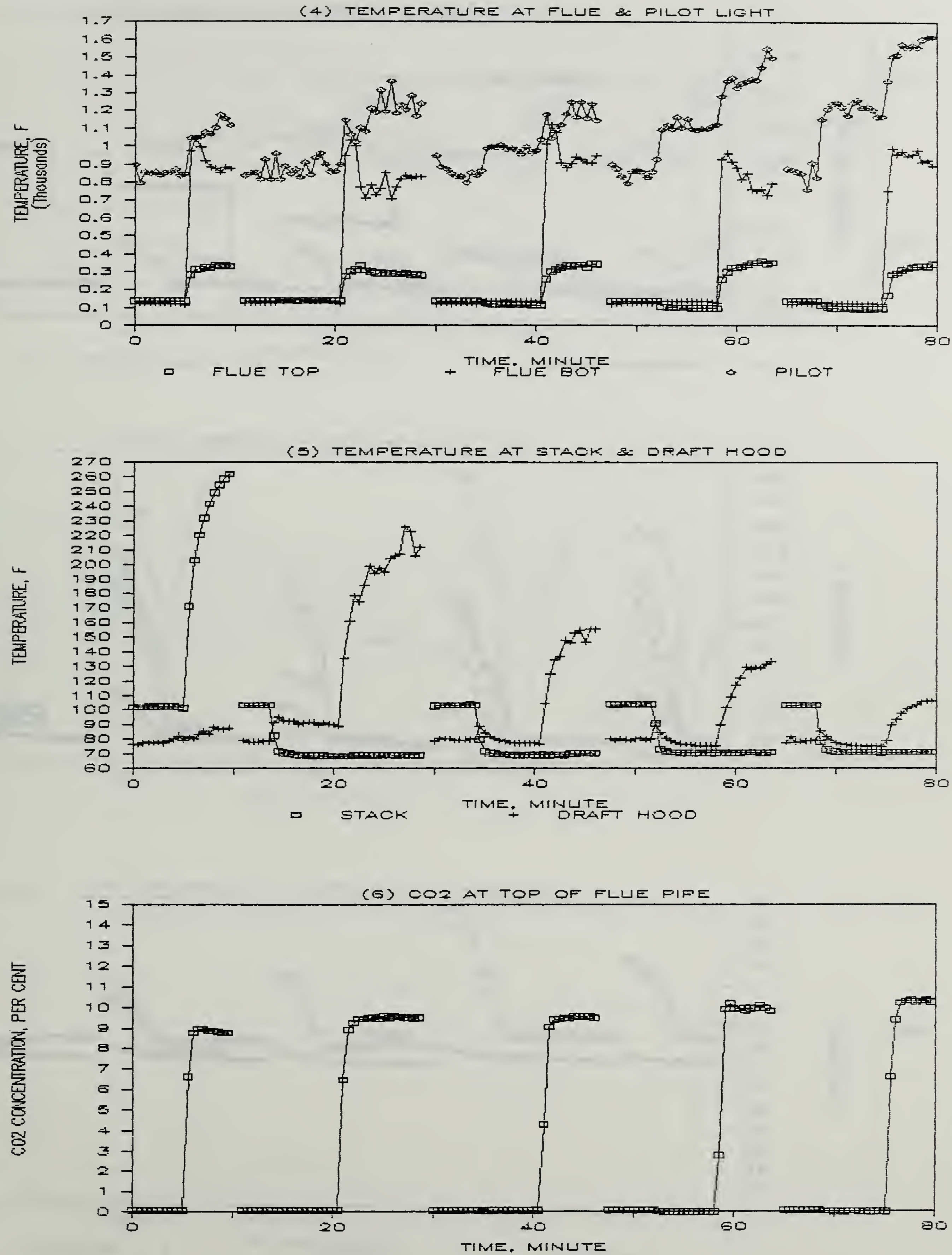


Figure 30 Cyclic test, access doors in place -- Heater no. 4

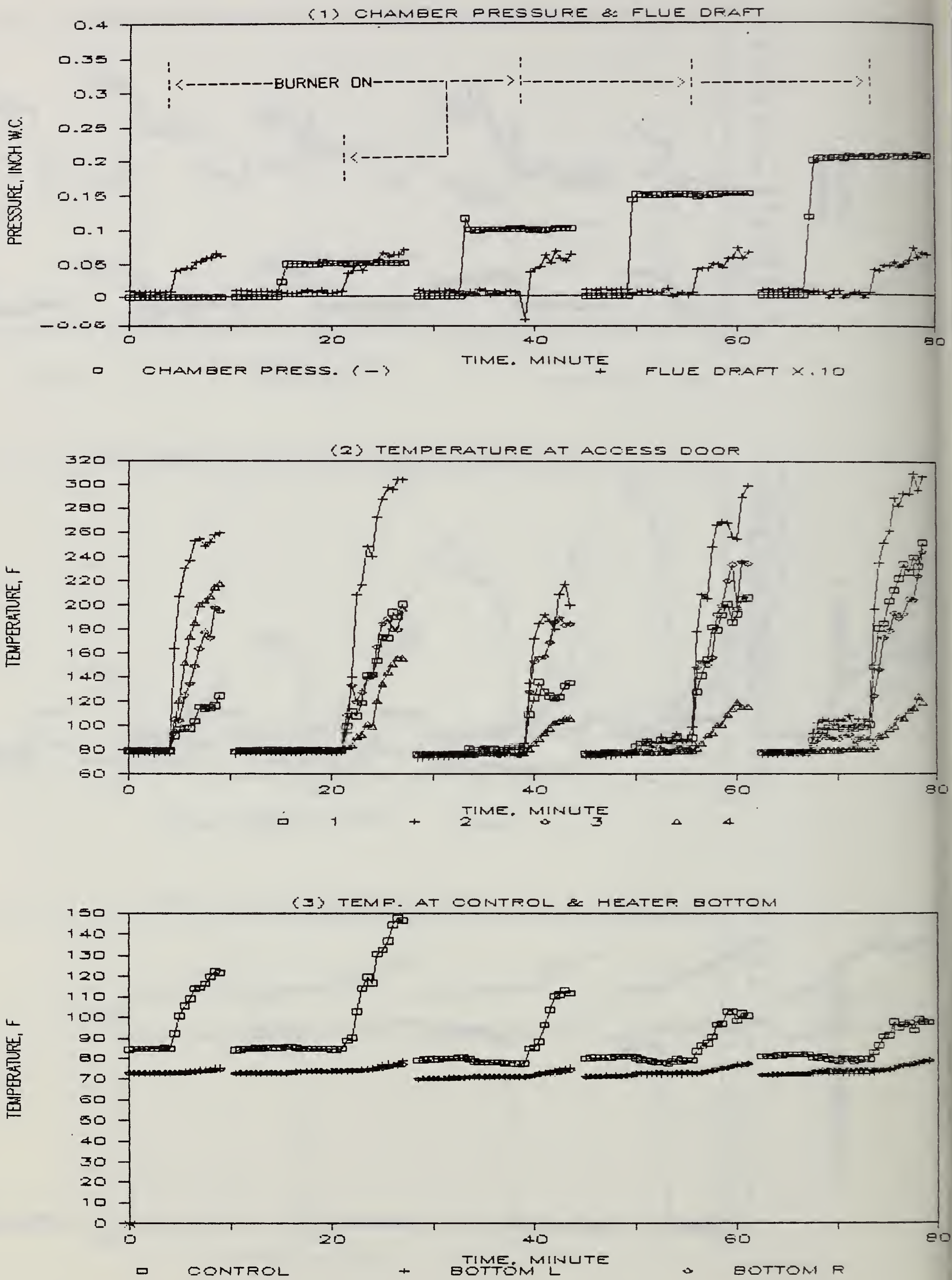


Figure 31 Cyclic test, access doors off -- Heater no. 4

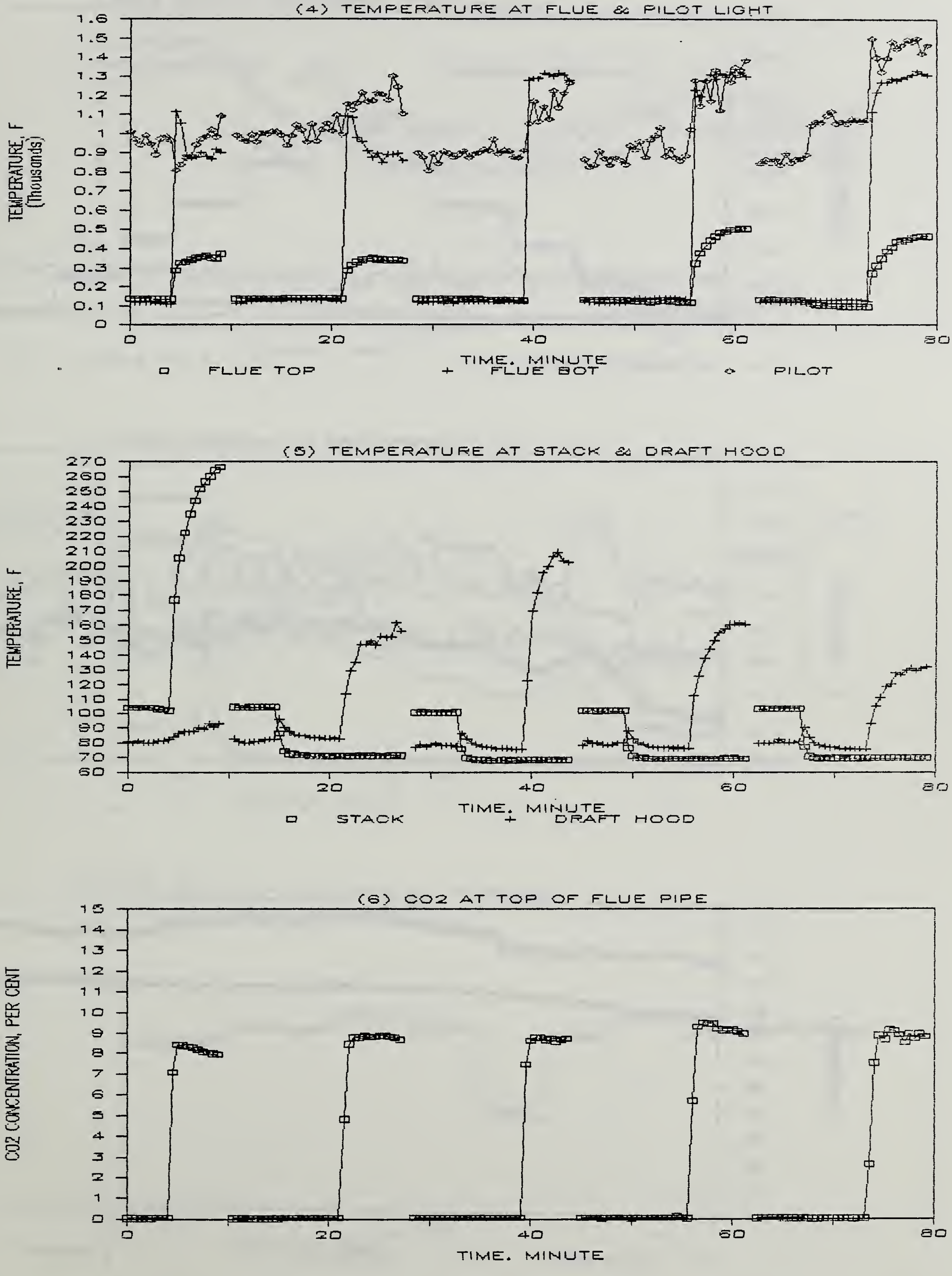


Figure 31 Cyclic test, access doors off -- Heater no. 4

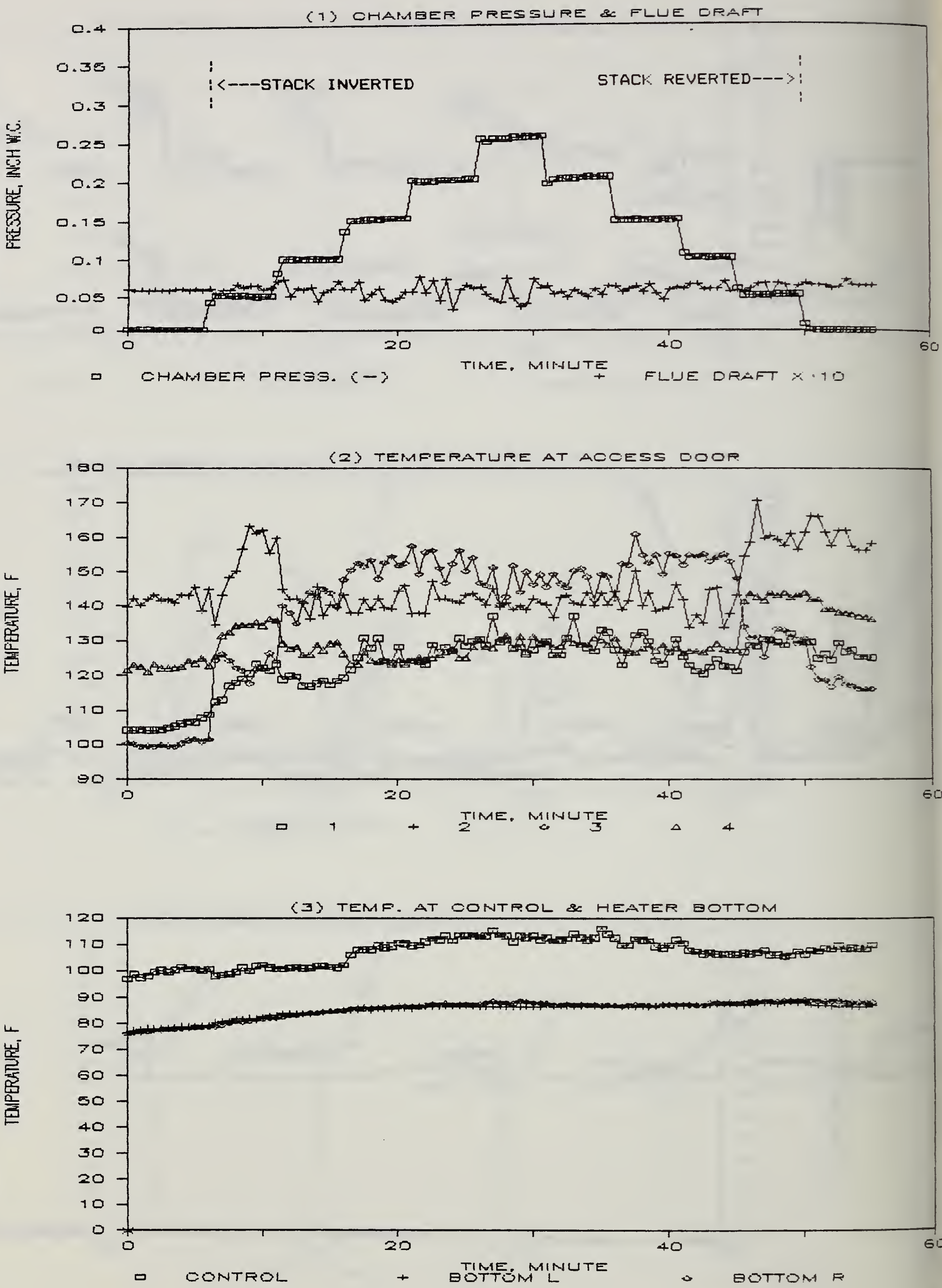


Figure 32 Pressure test, access doors in-place, no flue blockage -- Heater no. 4

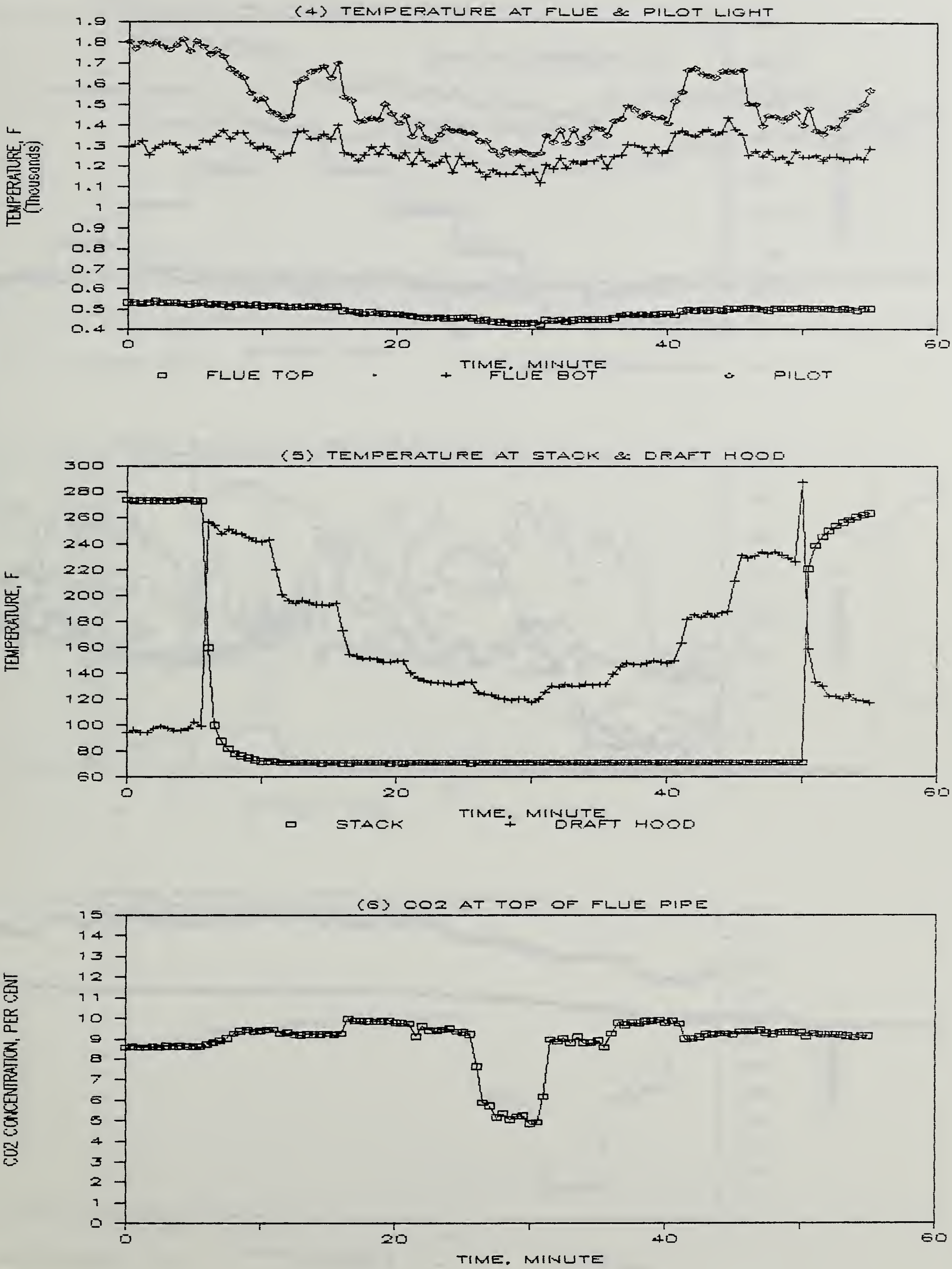


Figure 32 Pressure test, access doors in place, no flue blockage -- Heater no. 4

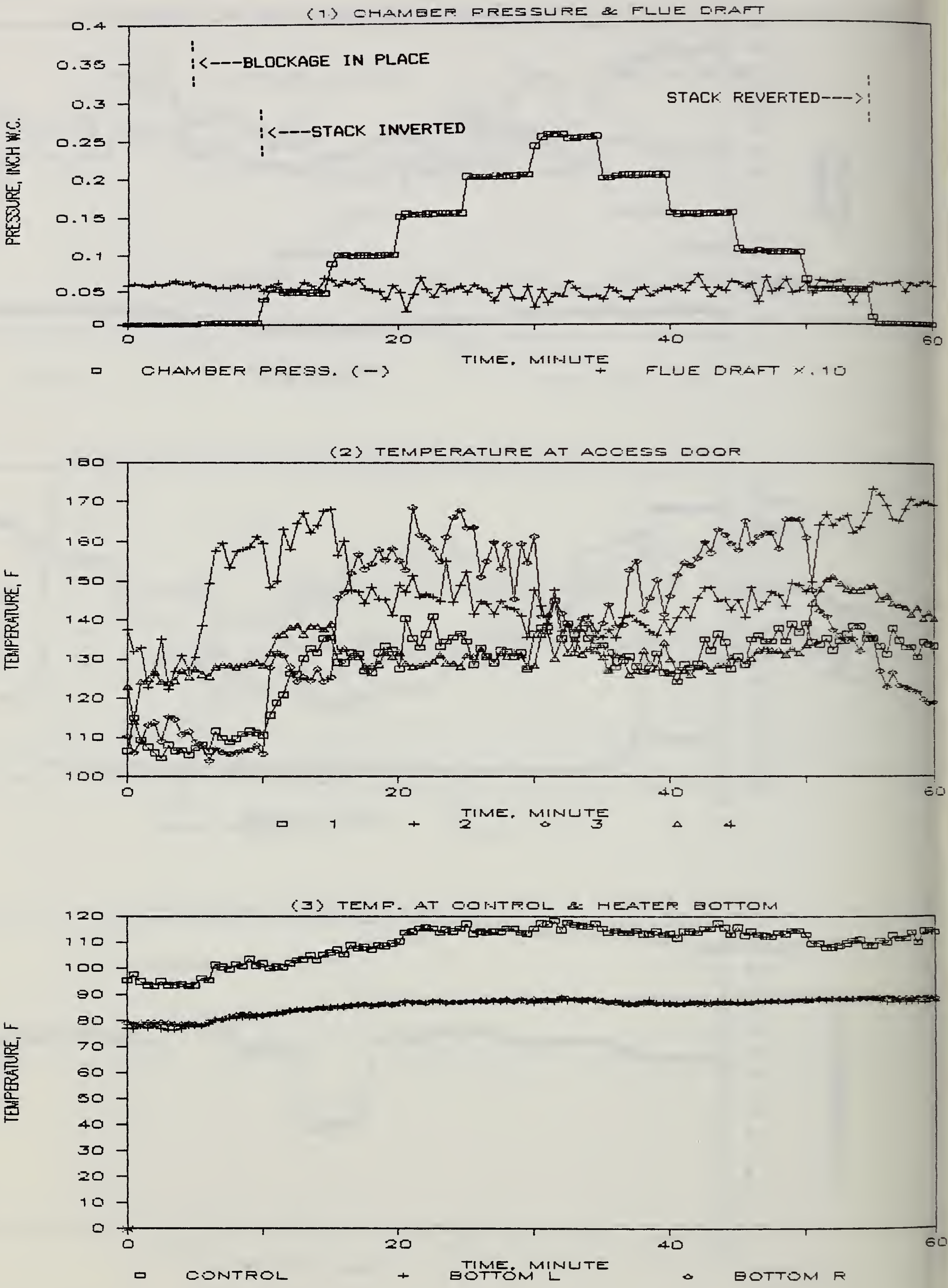


Figure 33 Pressure test, access doors in-place, 20% flue blockage -- Heater no. 4

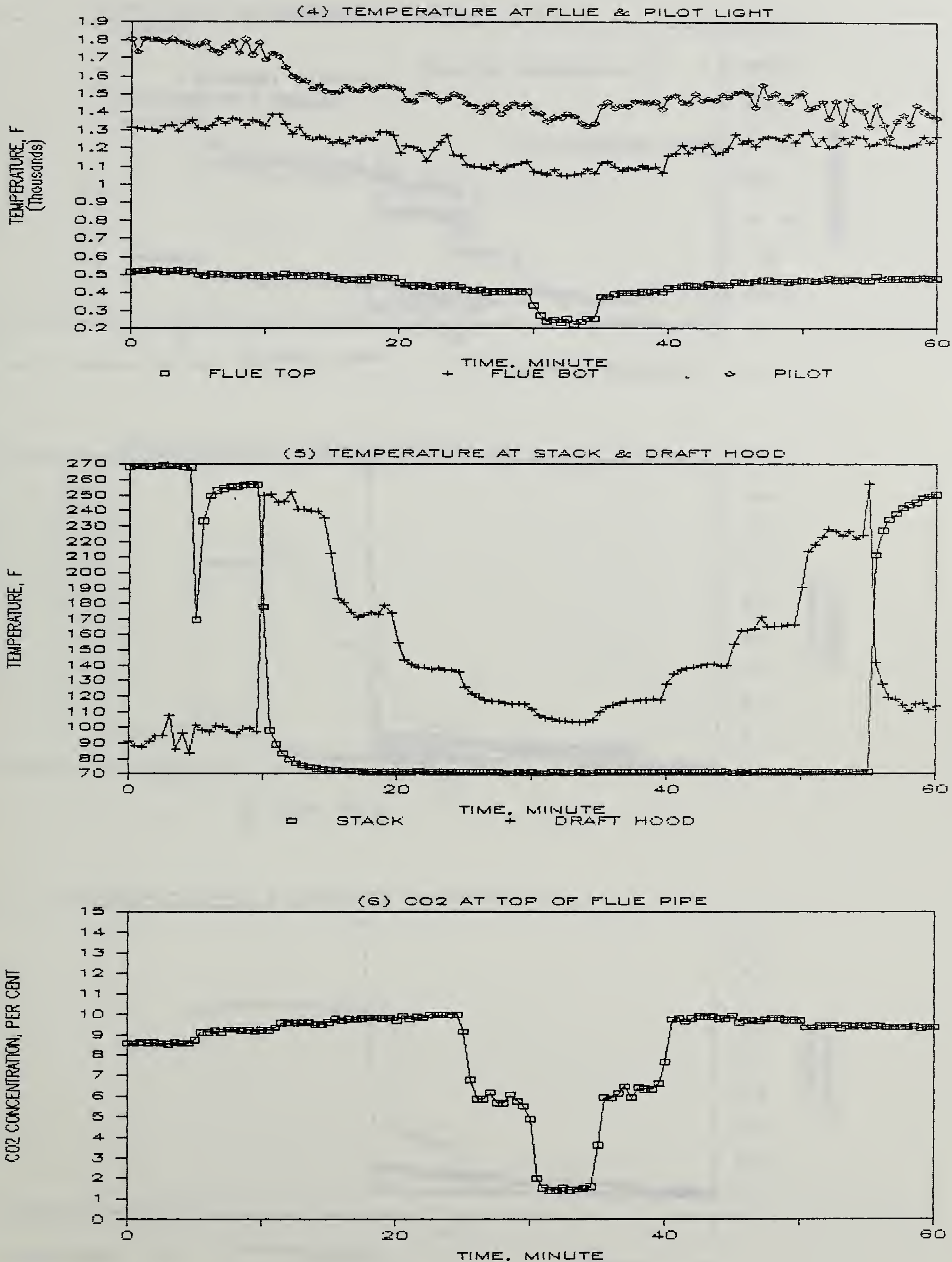


Figure 33 Pressure test, access doors in place, 20% flue blockage
-- Heater no. 4

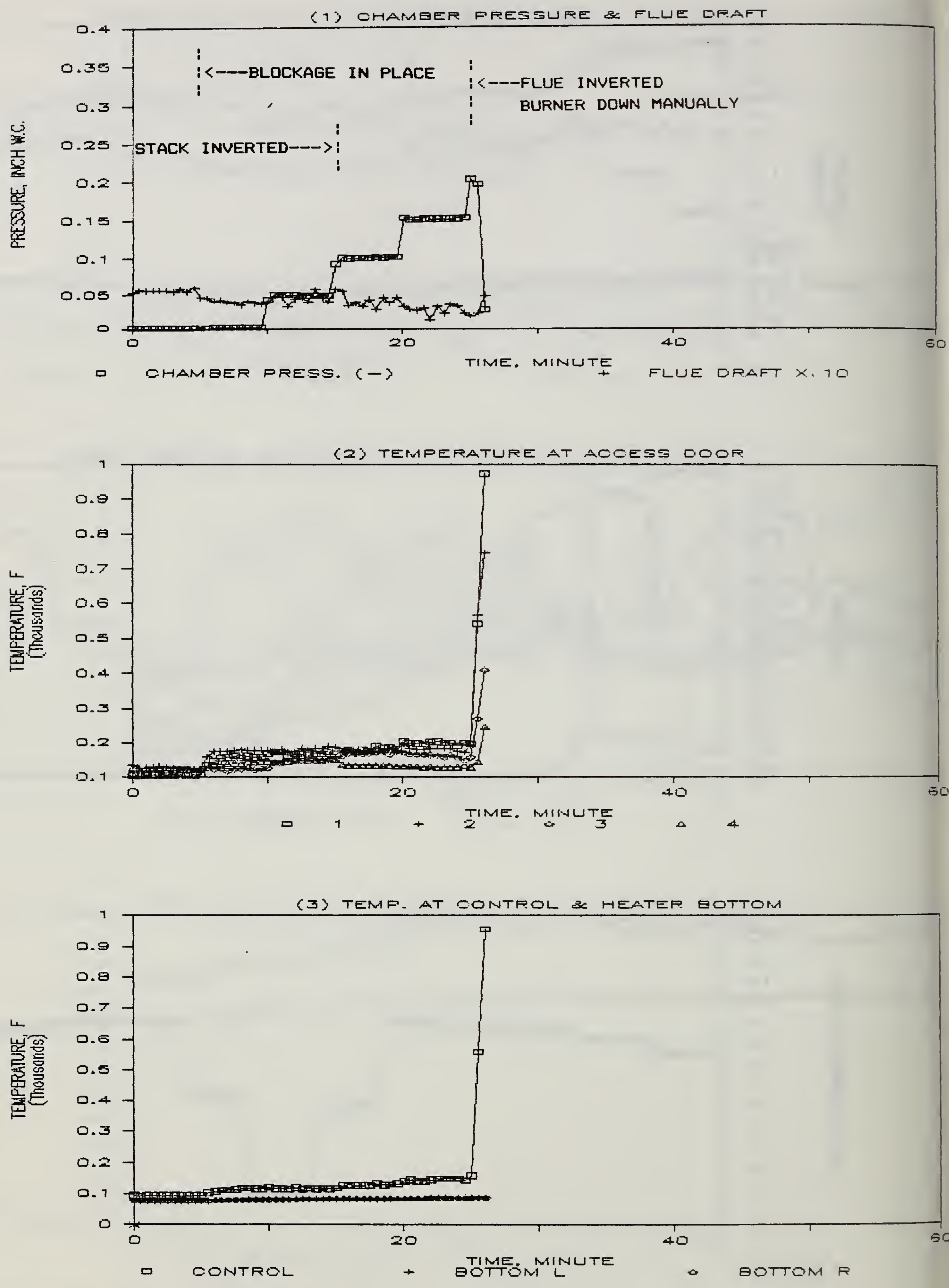
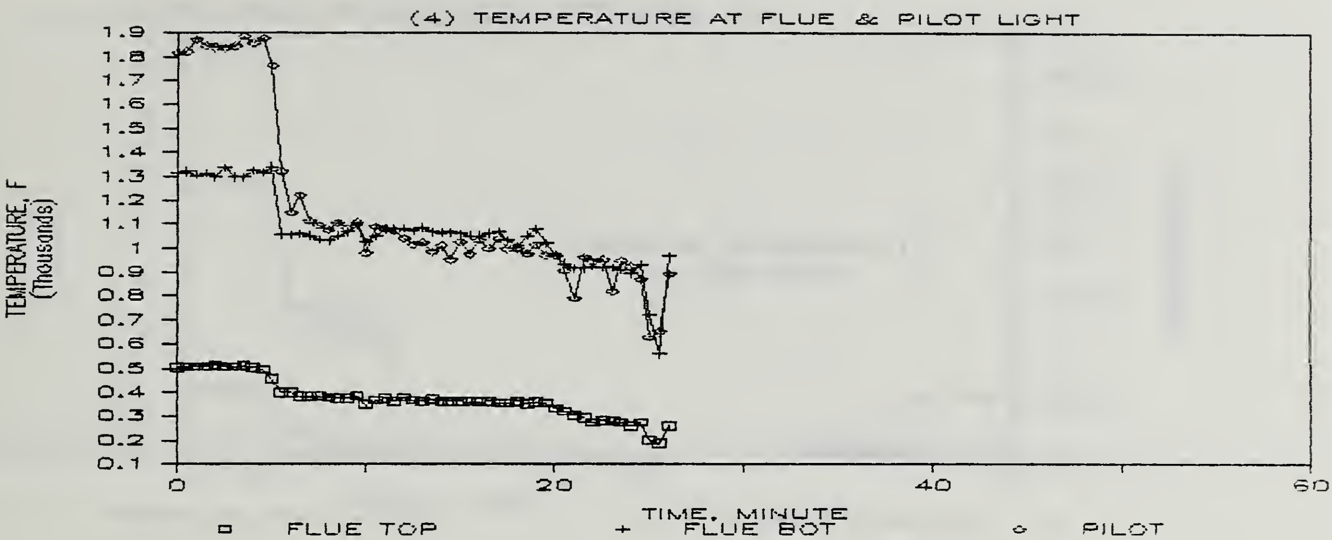
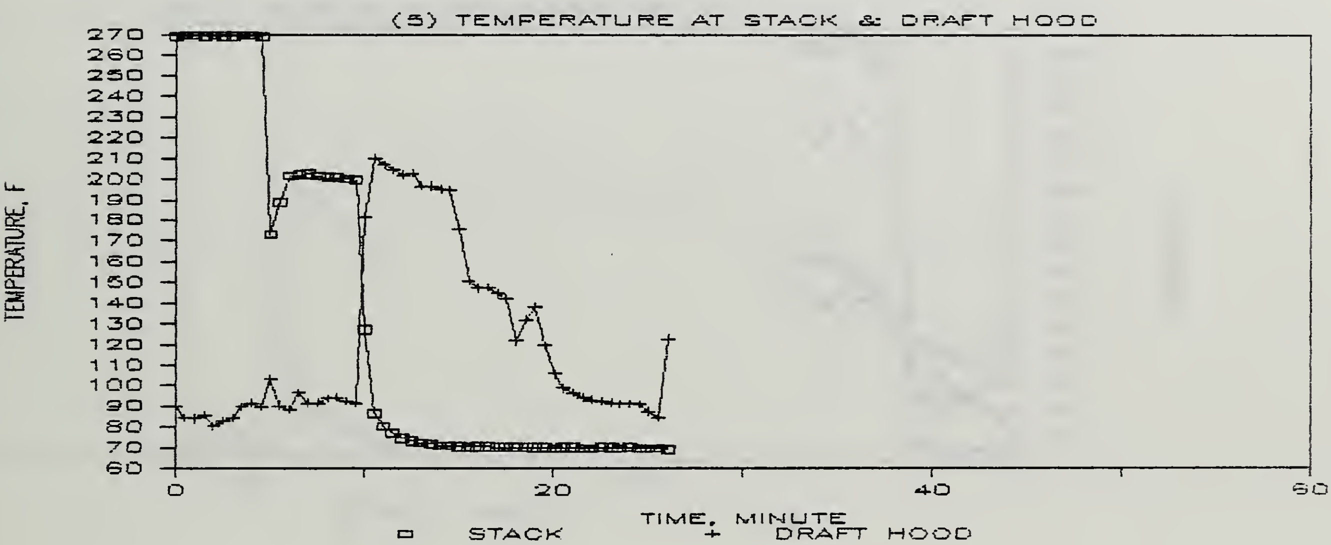


Figure 34 Pressure test, access doors in-place, 60% flue blockage -- Heater no. 4





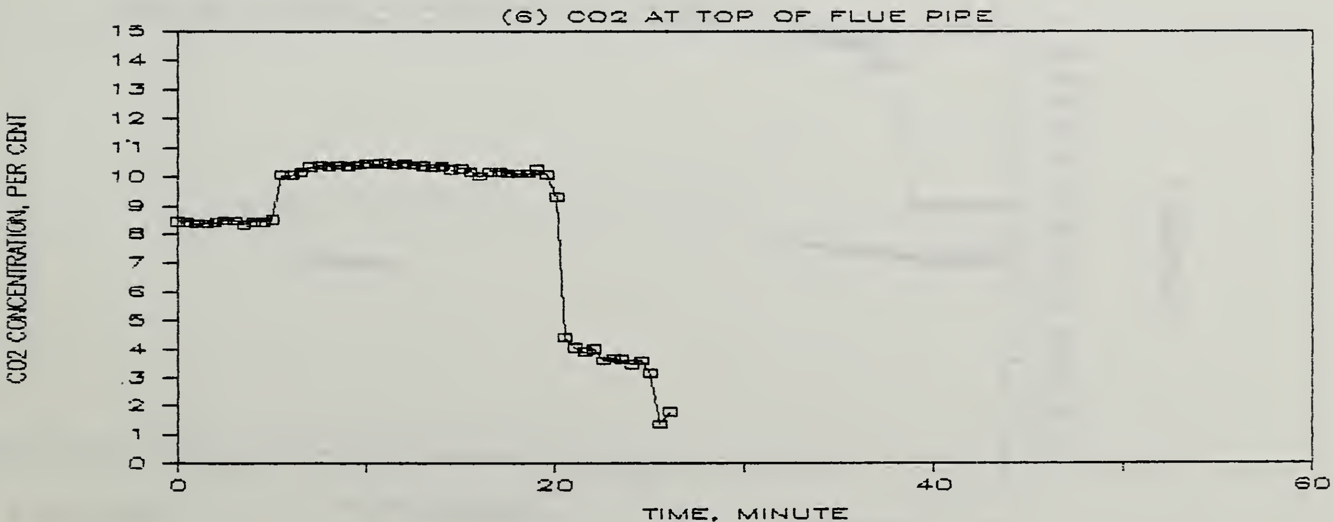


Figure 34 Pressure test, access doors in place, 60% flue blockage — Heater no. 4

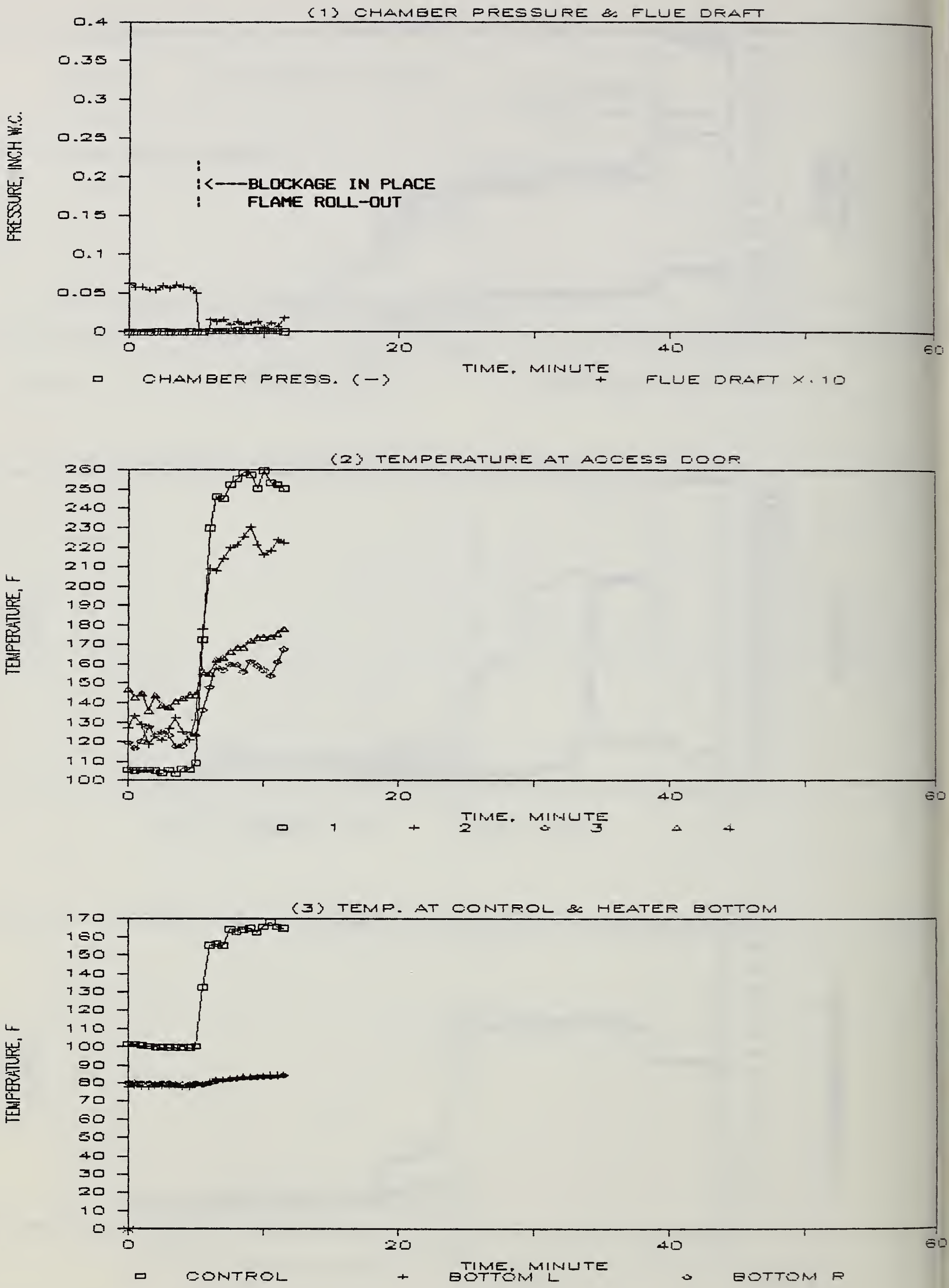


Figure 35 Pressure test, access doors in-place, 100% flue blockage -- Heater no. 4

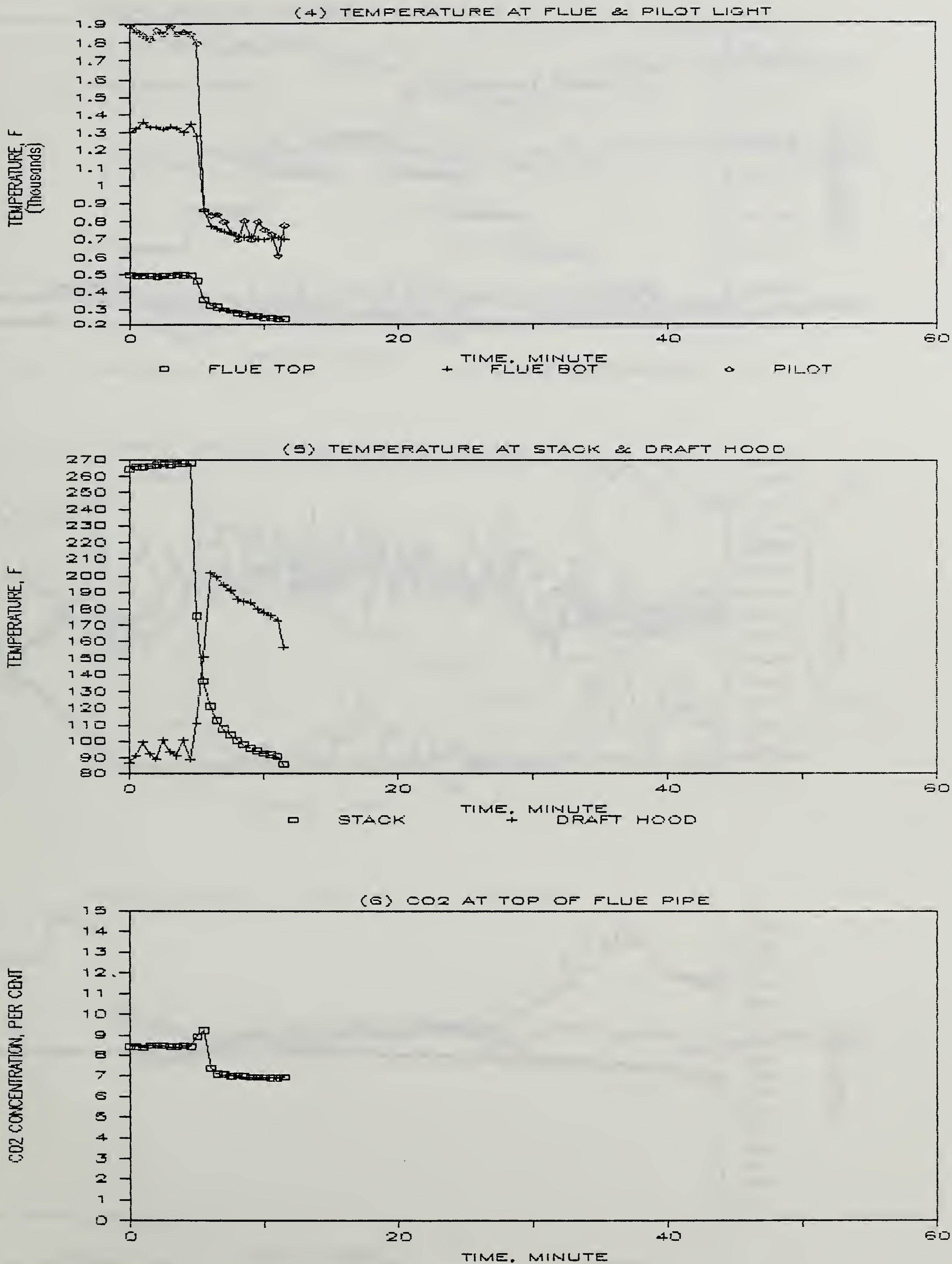


Figure 35 Pressure test, access doors in place, 100% flue blockage -- Heater no. 4

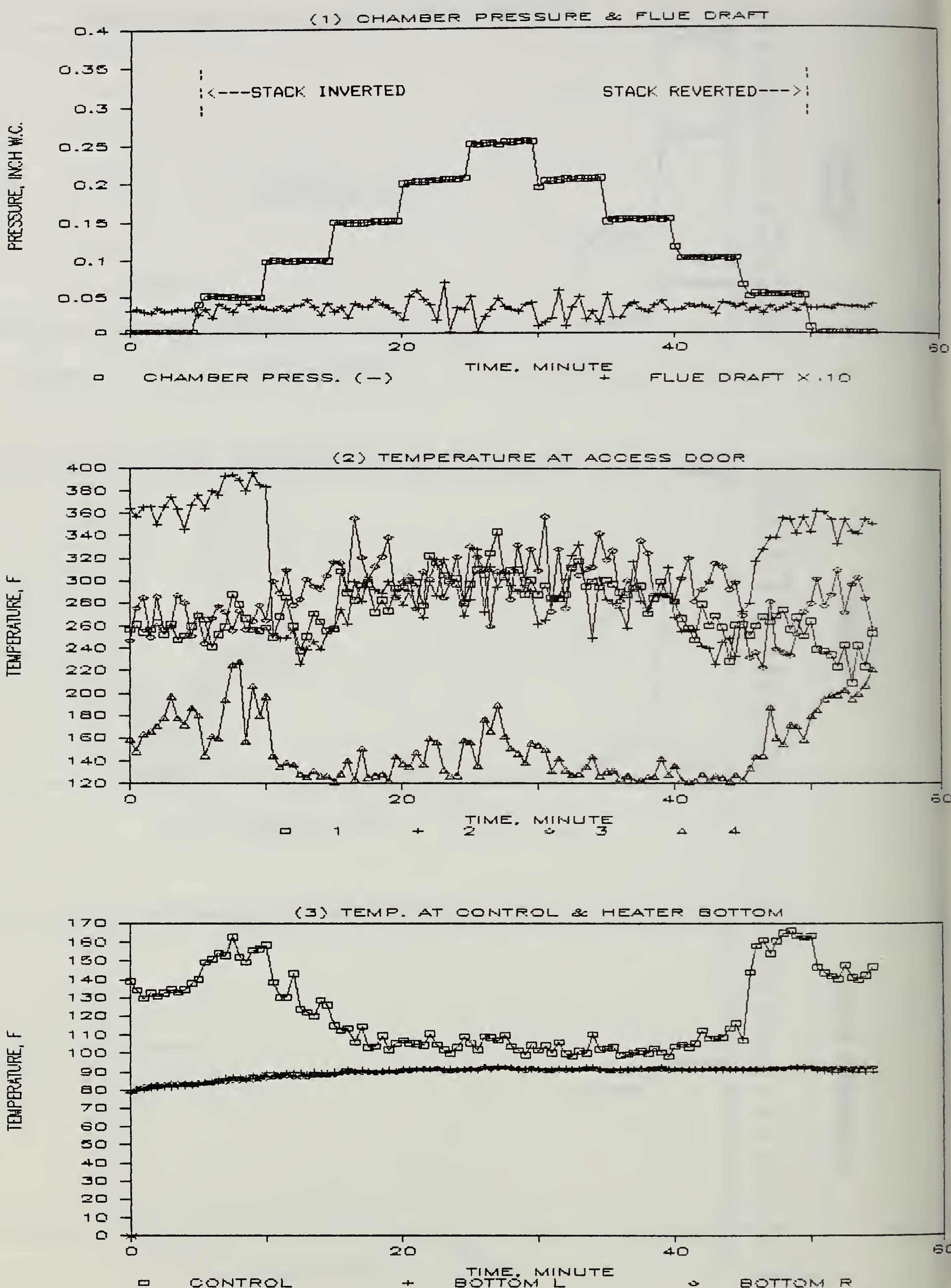


Figure 36 Pressure test, access doors off, no flue blockage
-- Heater no. 4

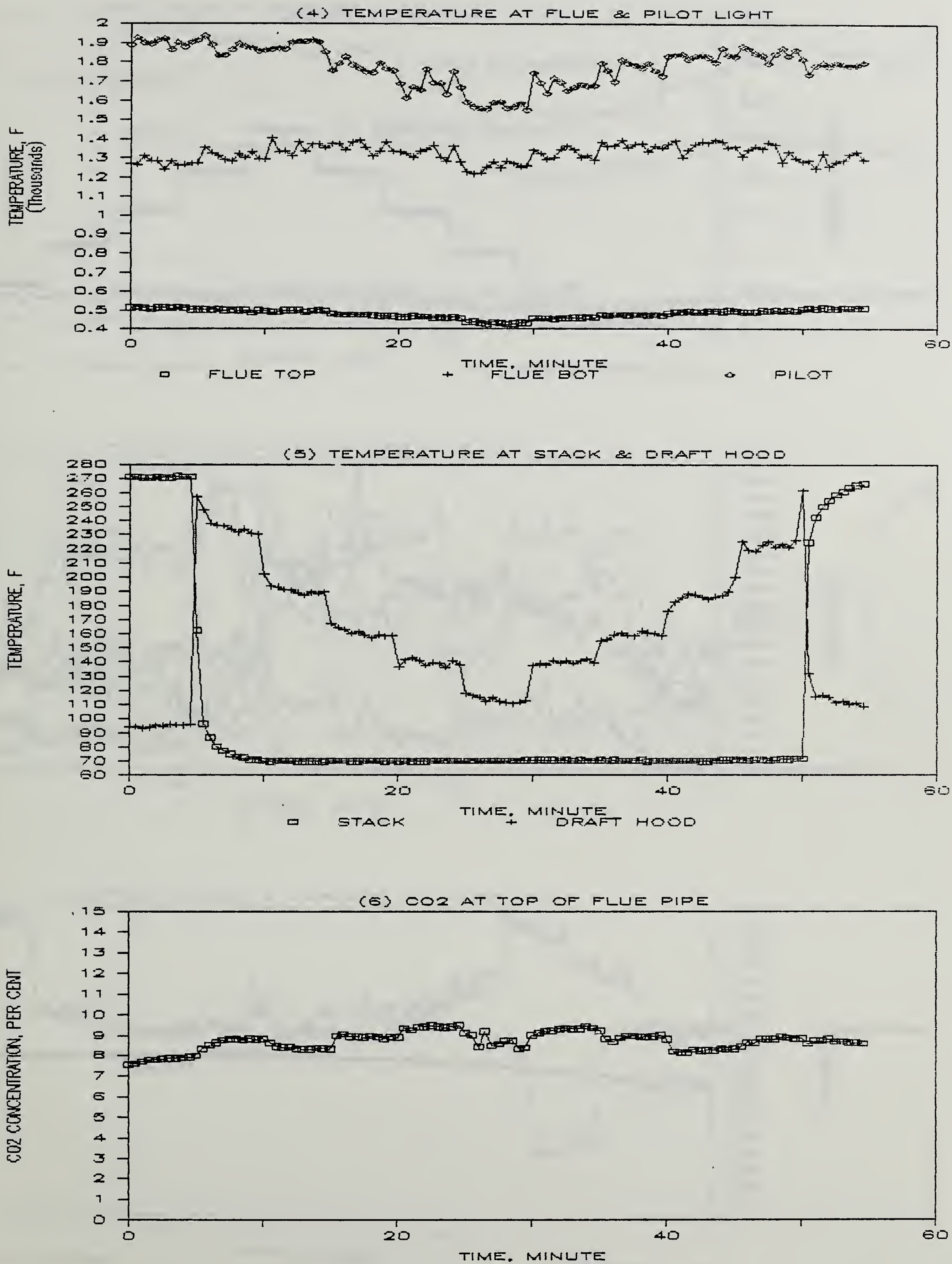


Figure 36 Pressure test, access doors off, no flue blockage -- Heater no. 4

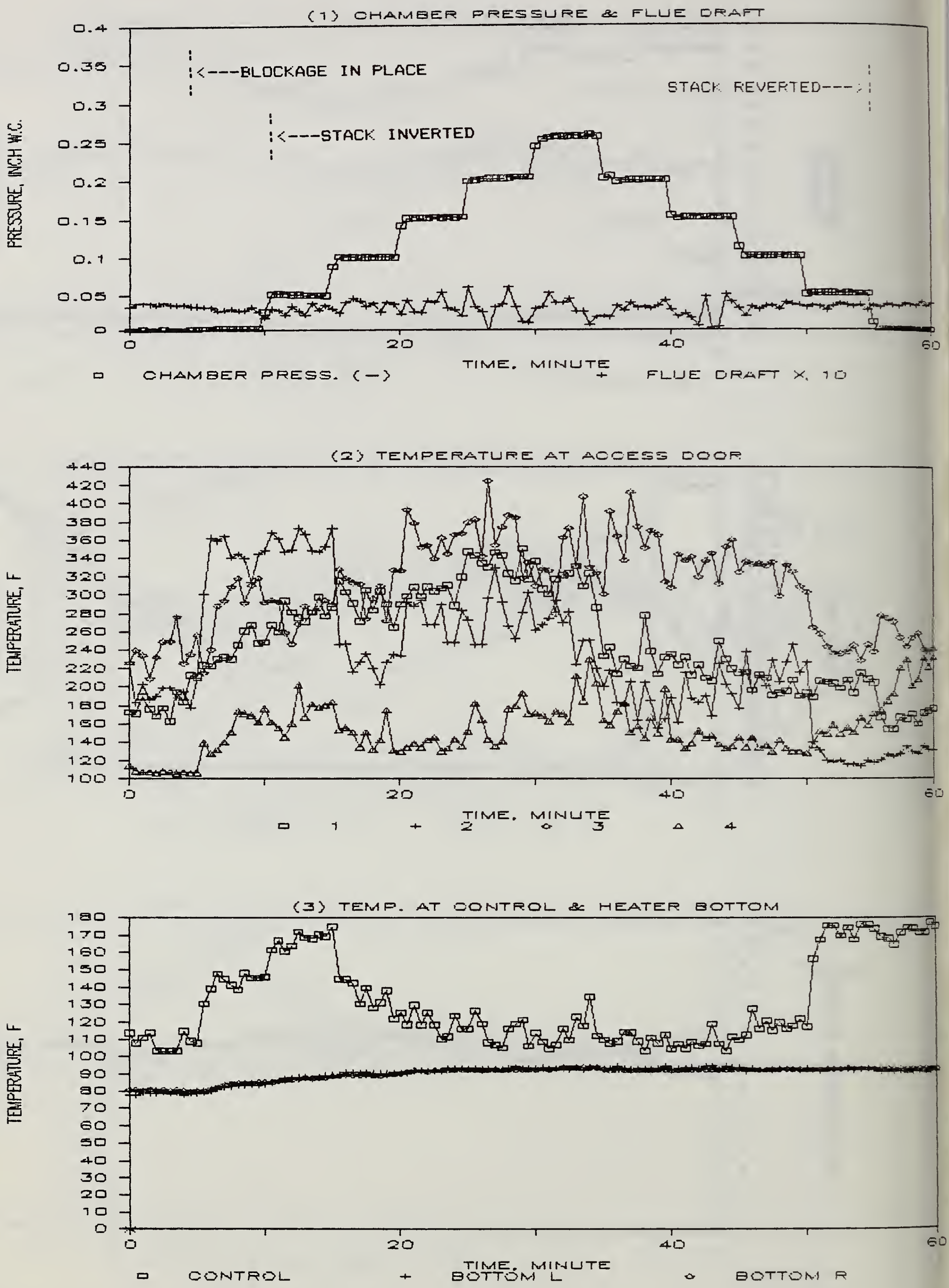


Figure 37 Pressure test, access doors off, 20% flue blockage -- Heater no. 4

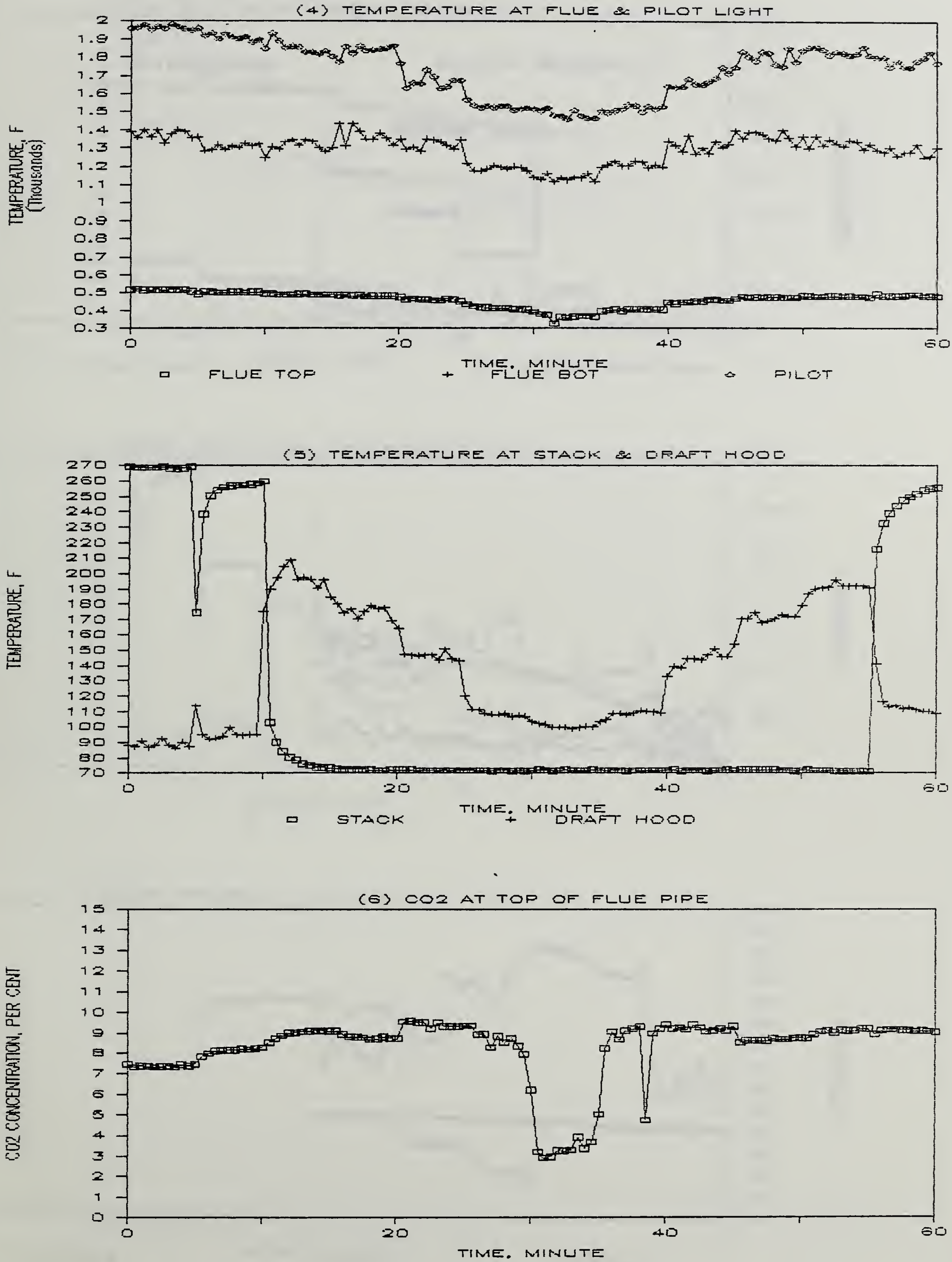


Figure 37 Pressure test, access doors off, 20% flue blockage -- Heater no. 4

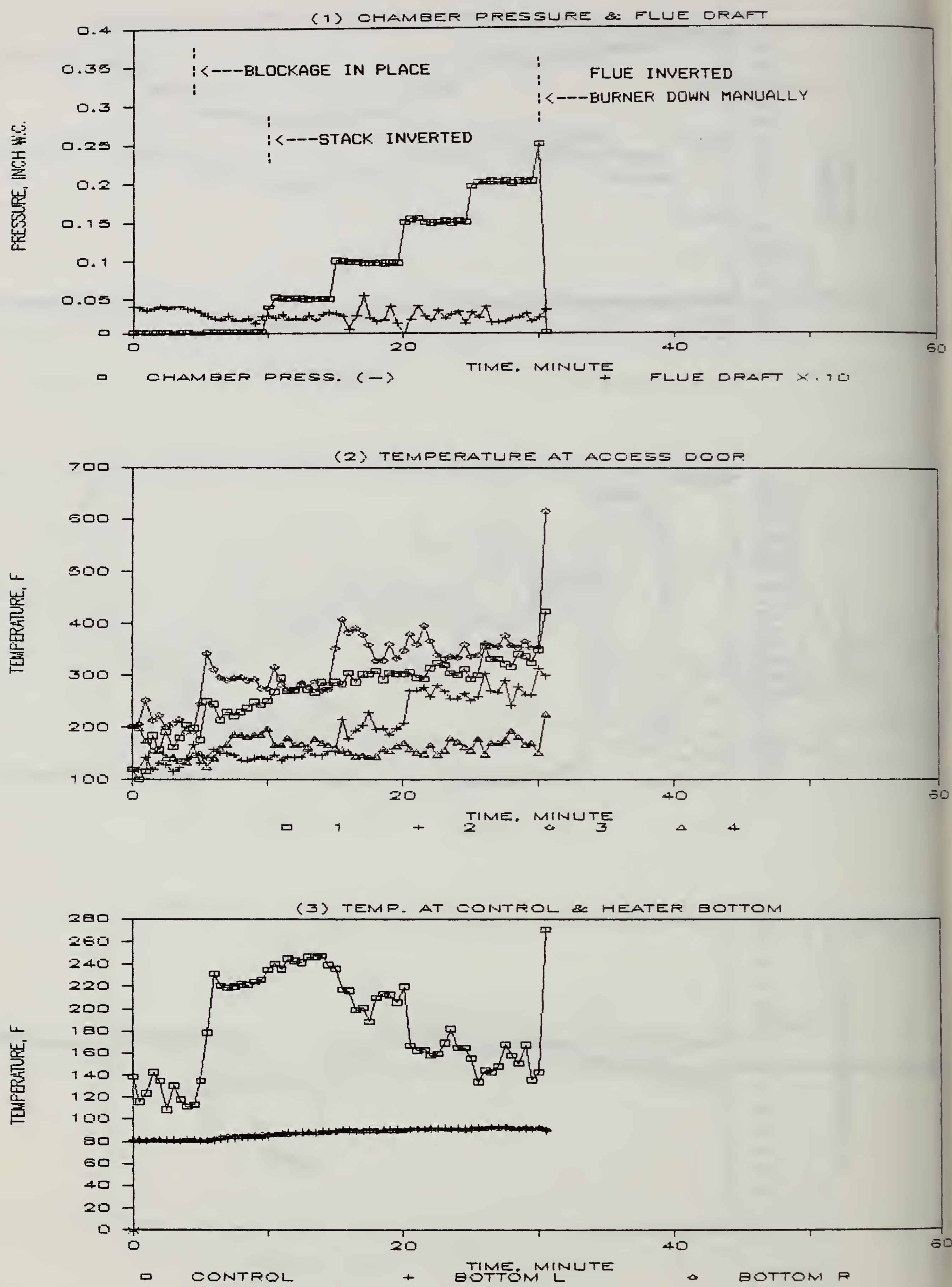


Figure 38 Pressure test, access doors off, 60% flue blockage -- Heater no. 4

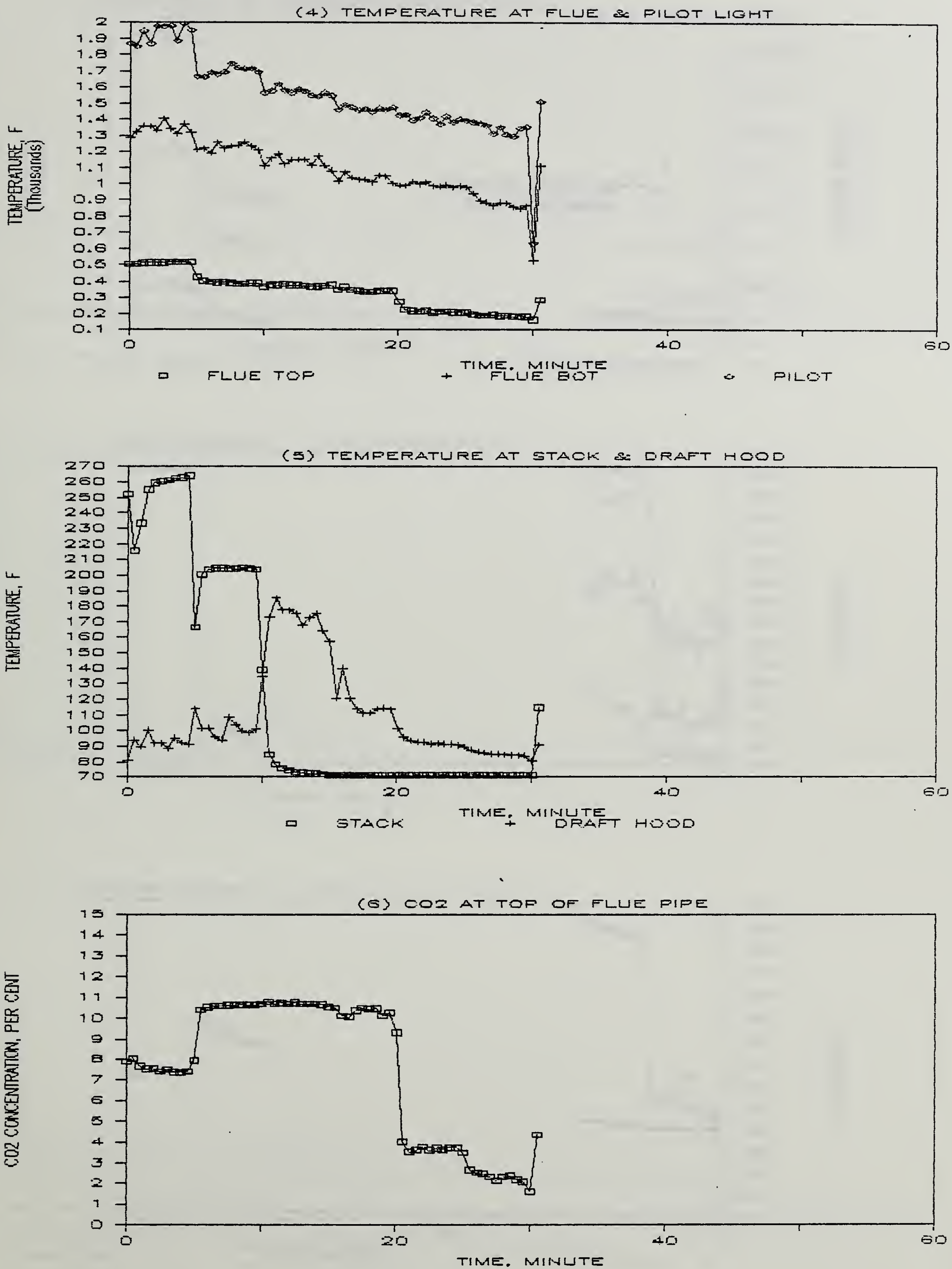


Figure 38 Pressure test, access doors off, 60% flue blockage -- Heater no. 4

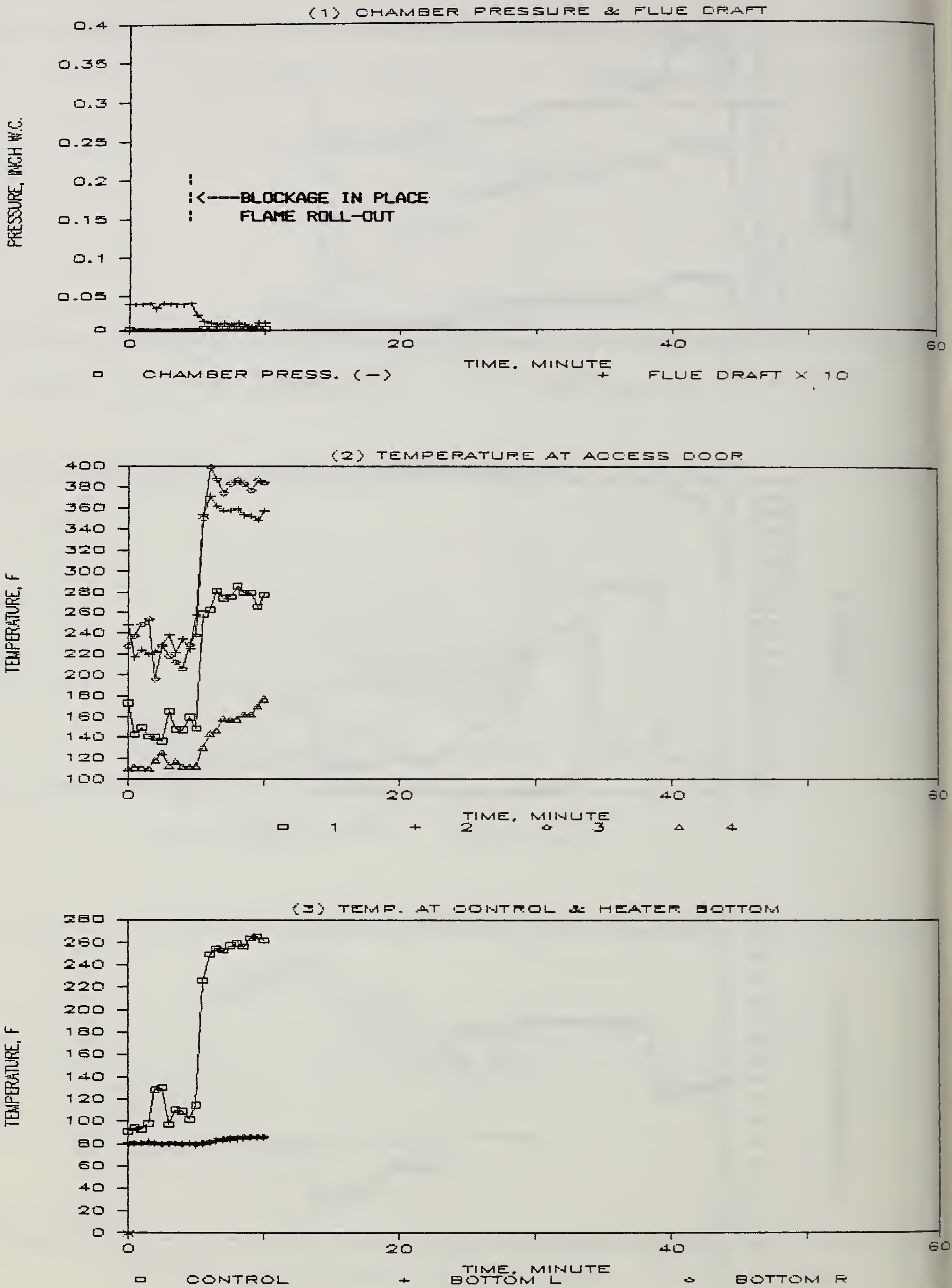


Figure 39 Pressure test, access doors off, 100% flue blockage
-- Heater no. 4

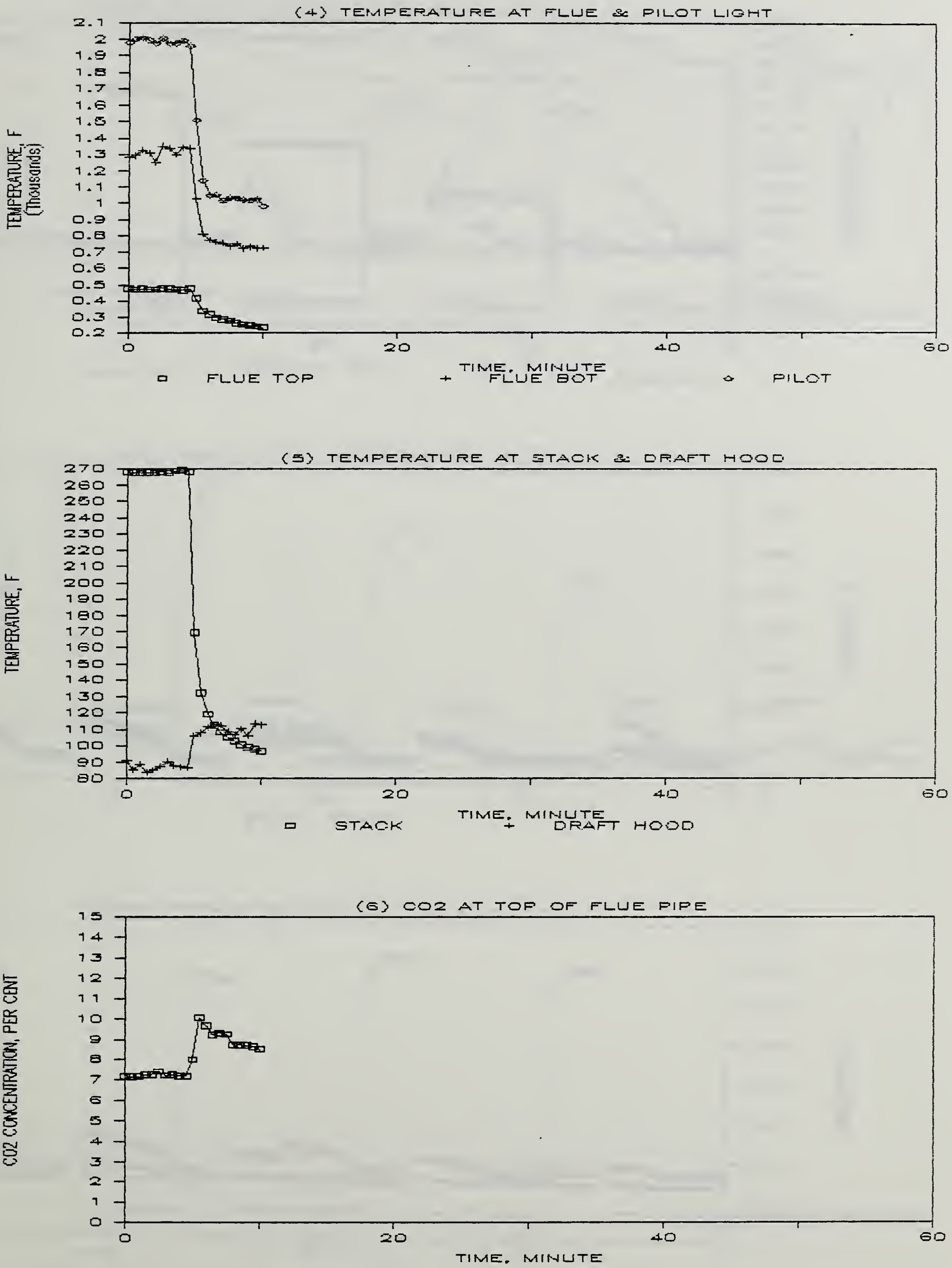


Figure 39 Pressure test, access doors off, 100% flue blockage -- Heater no. 4

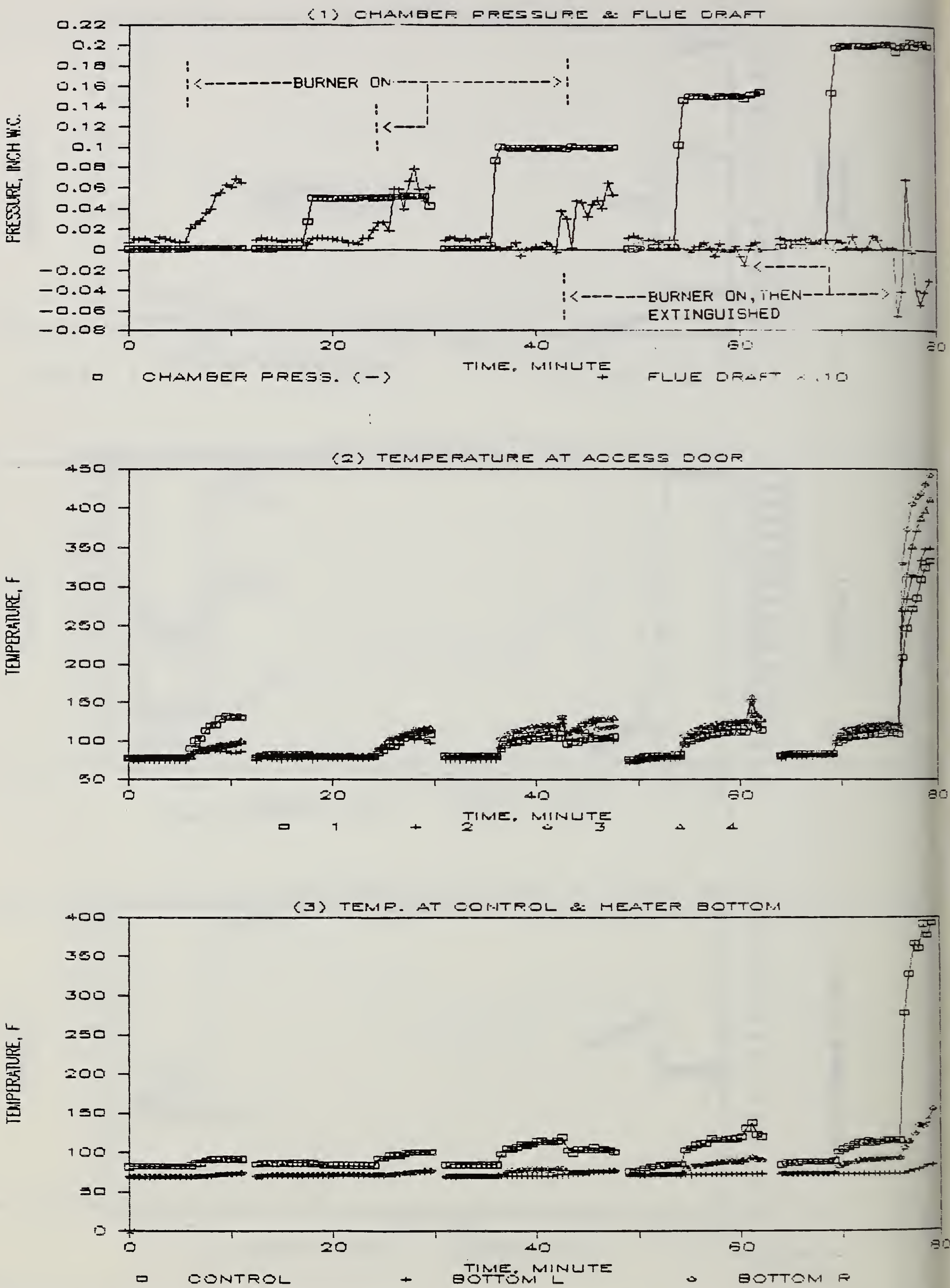


Figure 40 Cyclic test, access doors in-place, no flue blockage
-- Heater no. 5

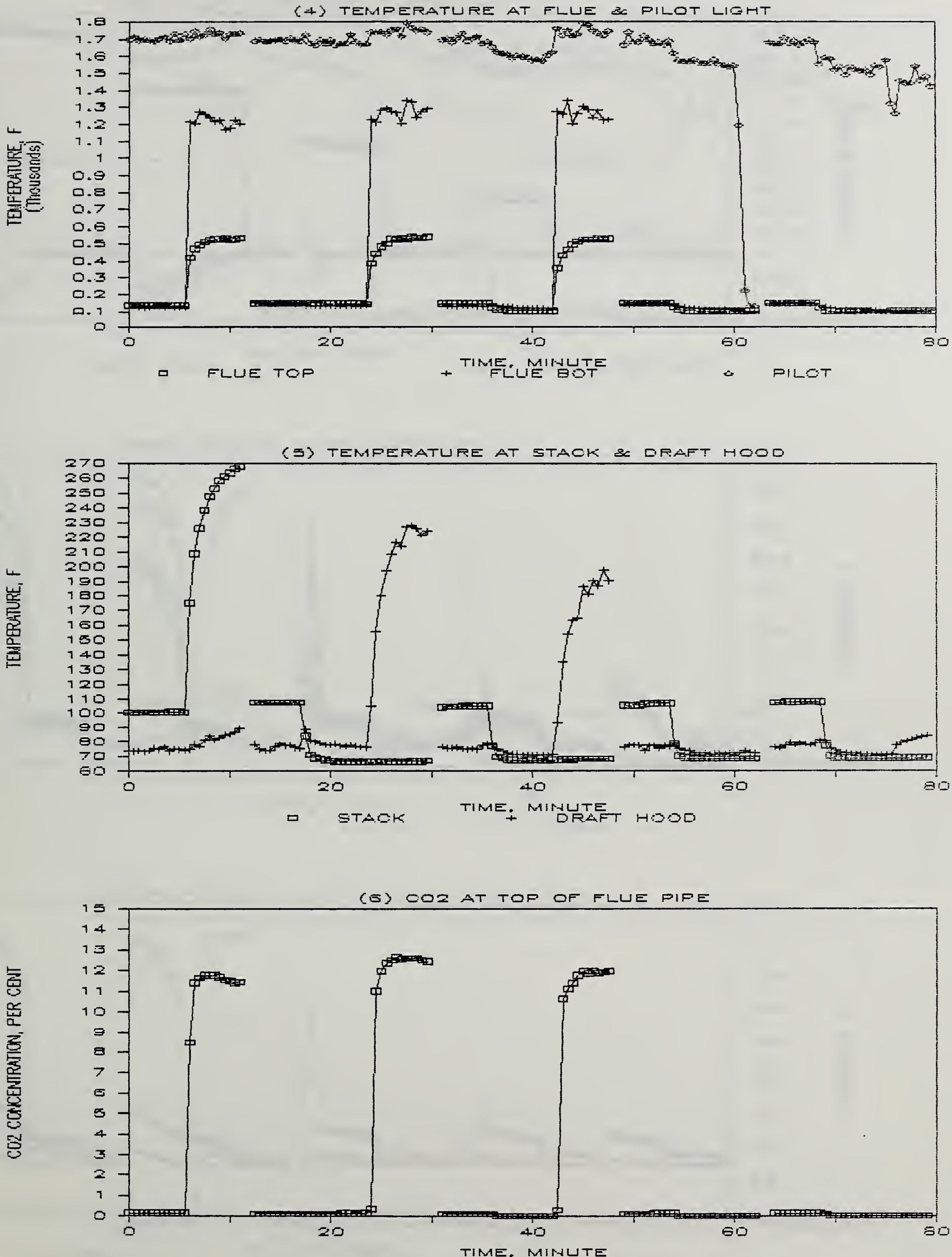


Figure 40 Cyclic test, access doors in place, no flue blockage -- Heater no. 5

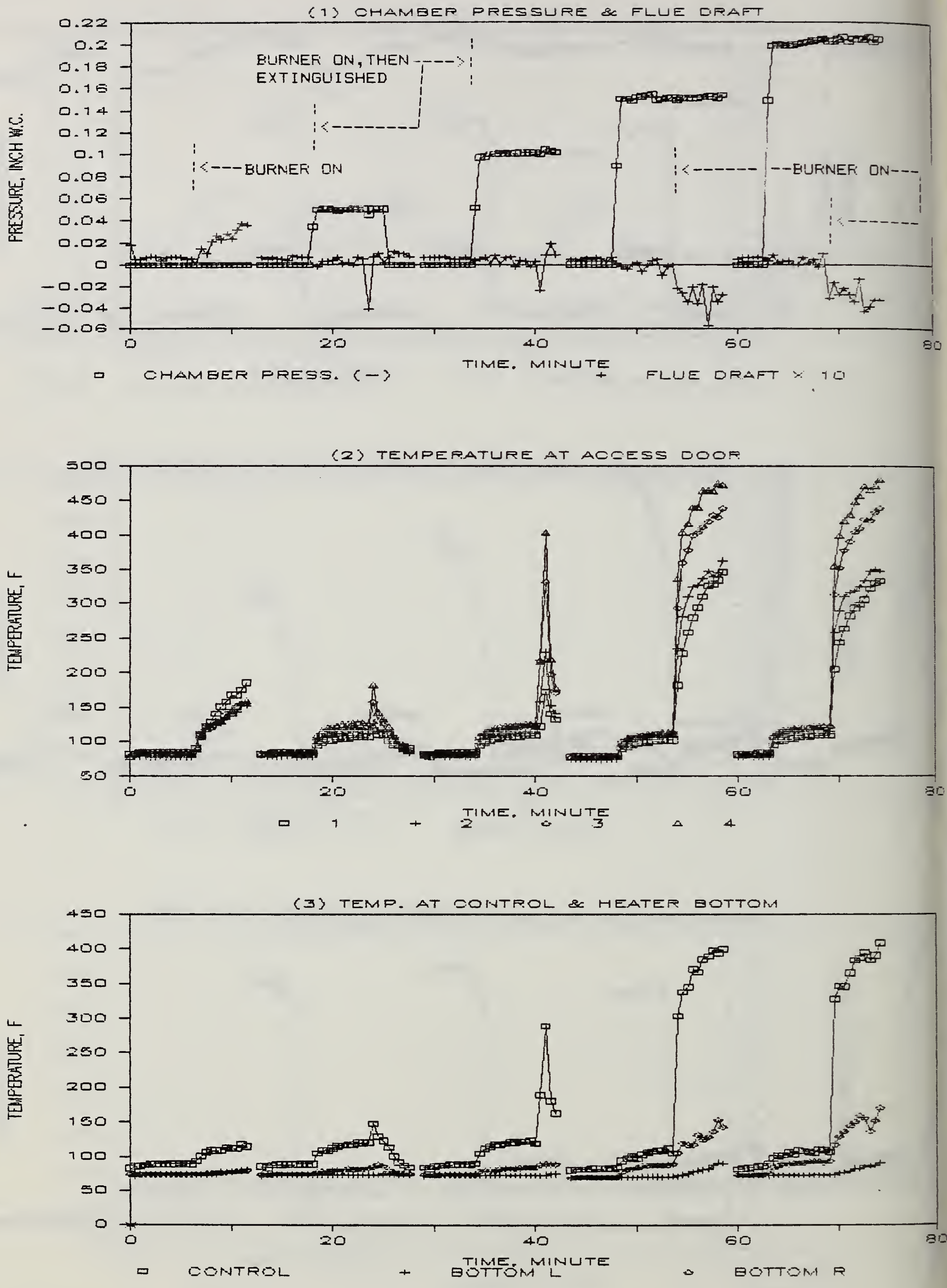


Figure 41 Cyclic test, access doors in-place, 60% flue blockage -- Heater no. 5

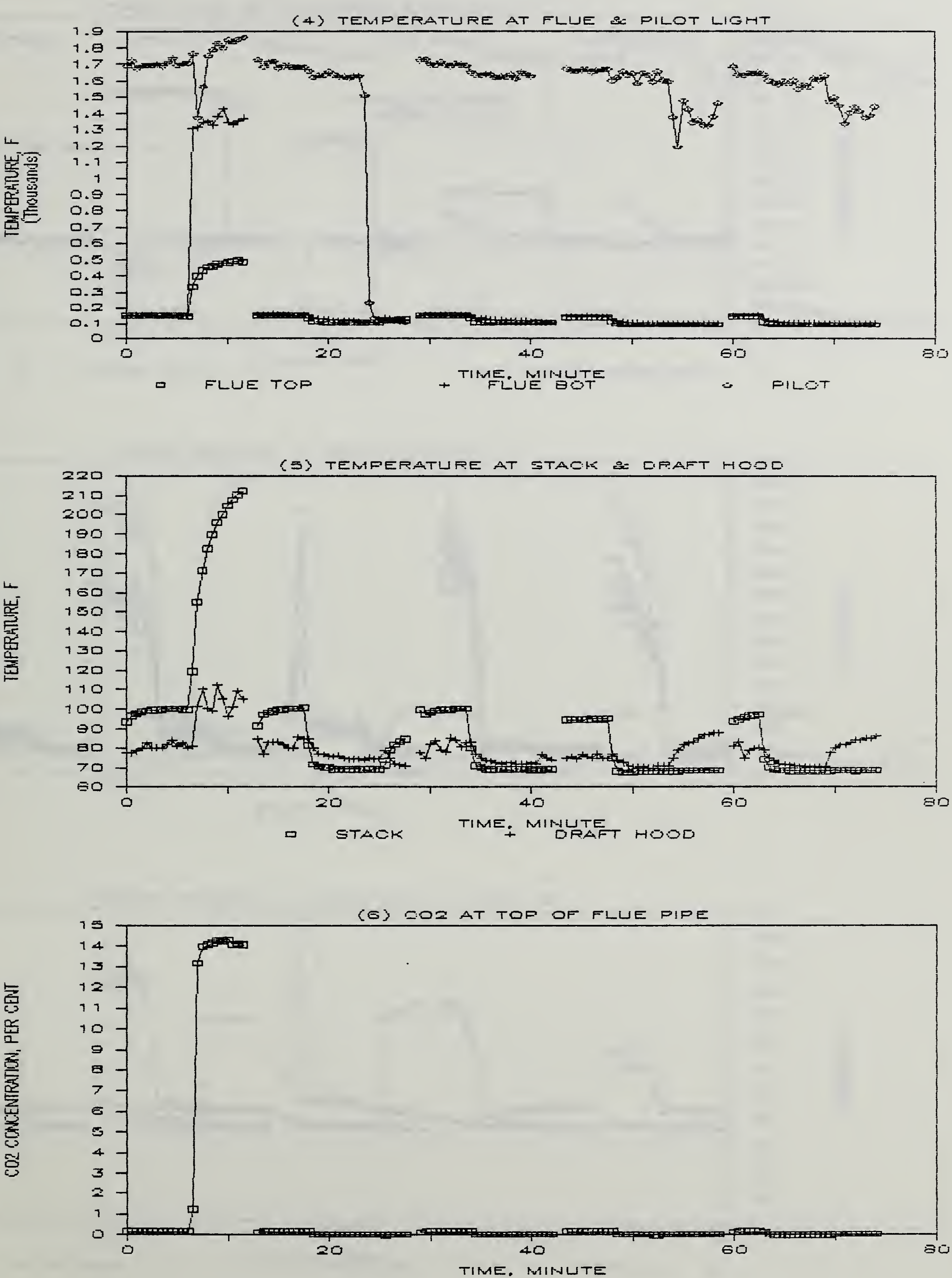


Figure 41 Cyclic test, access doors in place, 60% flue blockage
-- Heater no. 5

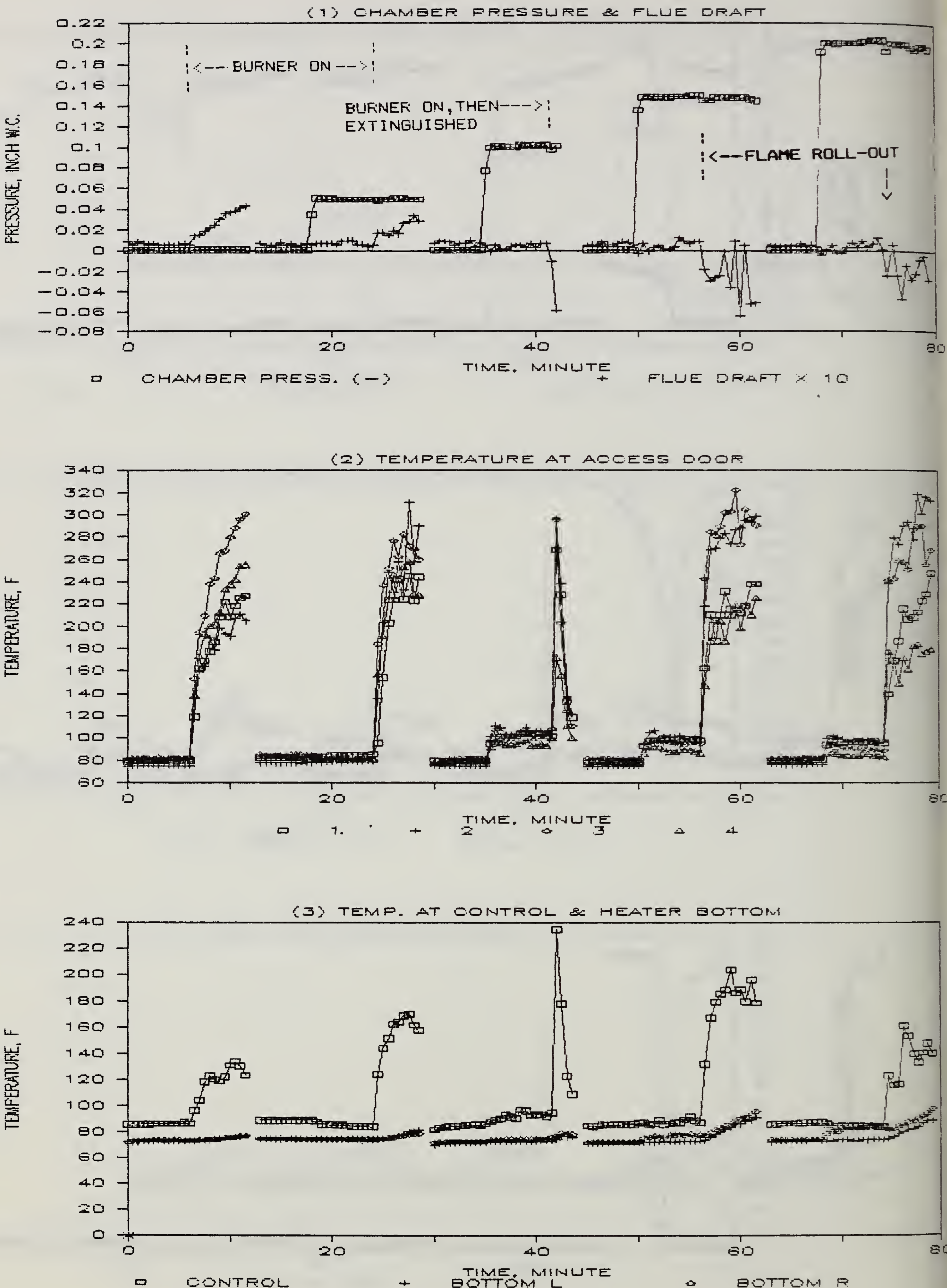


Figure 42 Cyclic test, access doors off, no flue blockage -- Heater no. 5

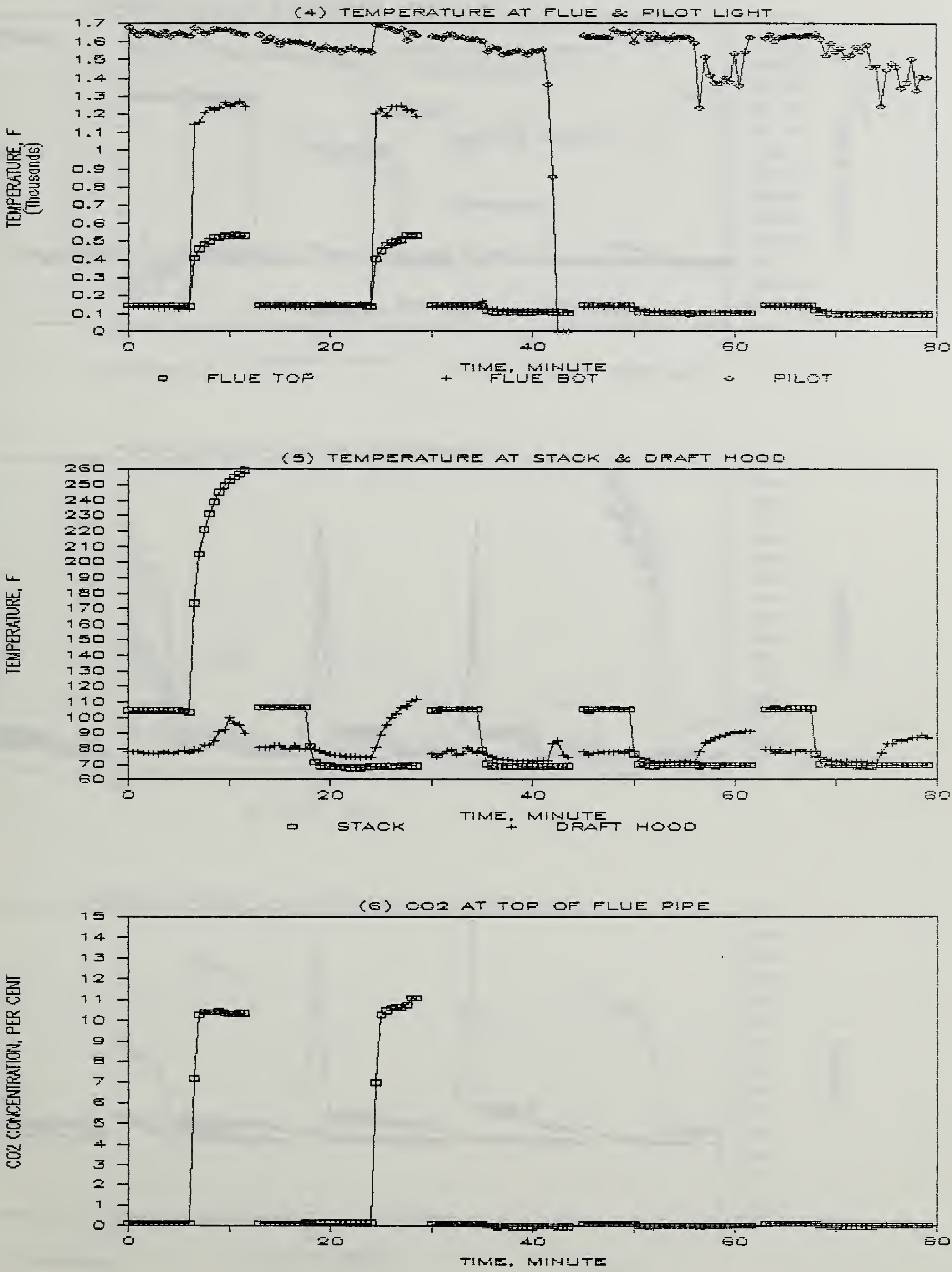


Figure 42 Cyclic test, access doors off, no flue blockage
-- Heater no. 5

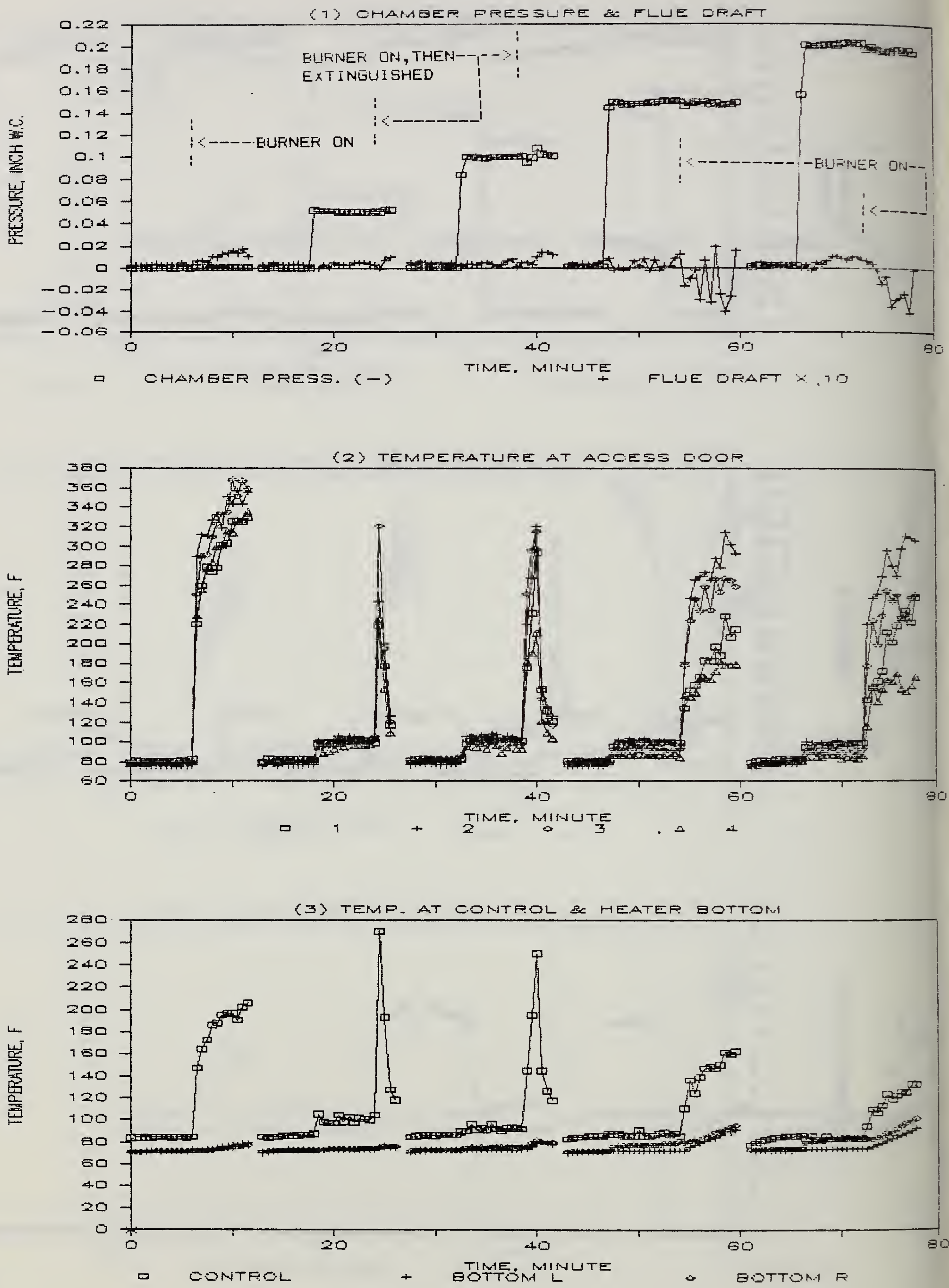


Figure 43 Cyclic test, access doors off, 60% flue blockage -- Heater no. 5

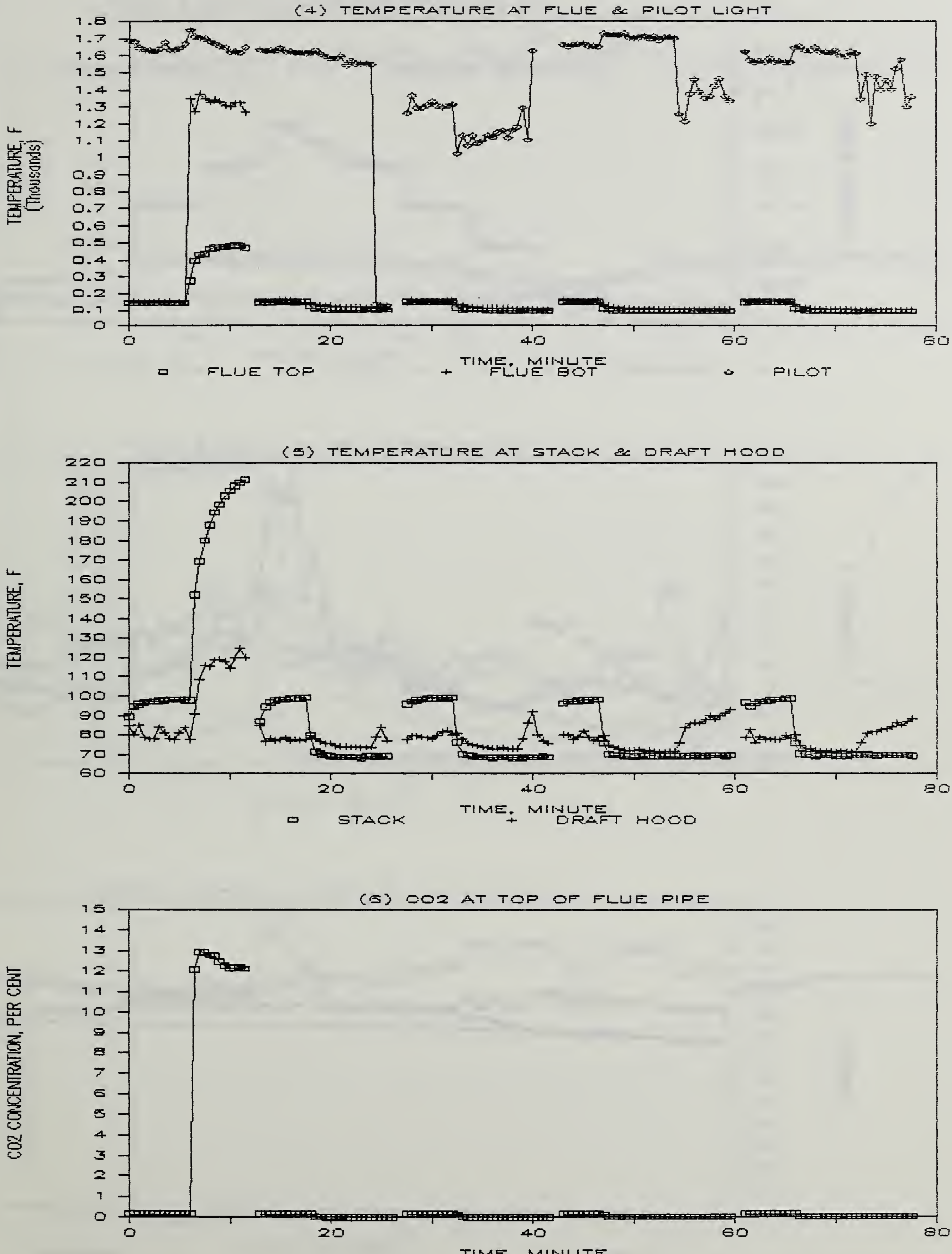


Figure 43 Cyclic test, access doors off, 60% flue blockage -- Heater no. 5

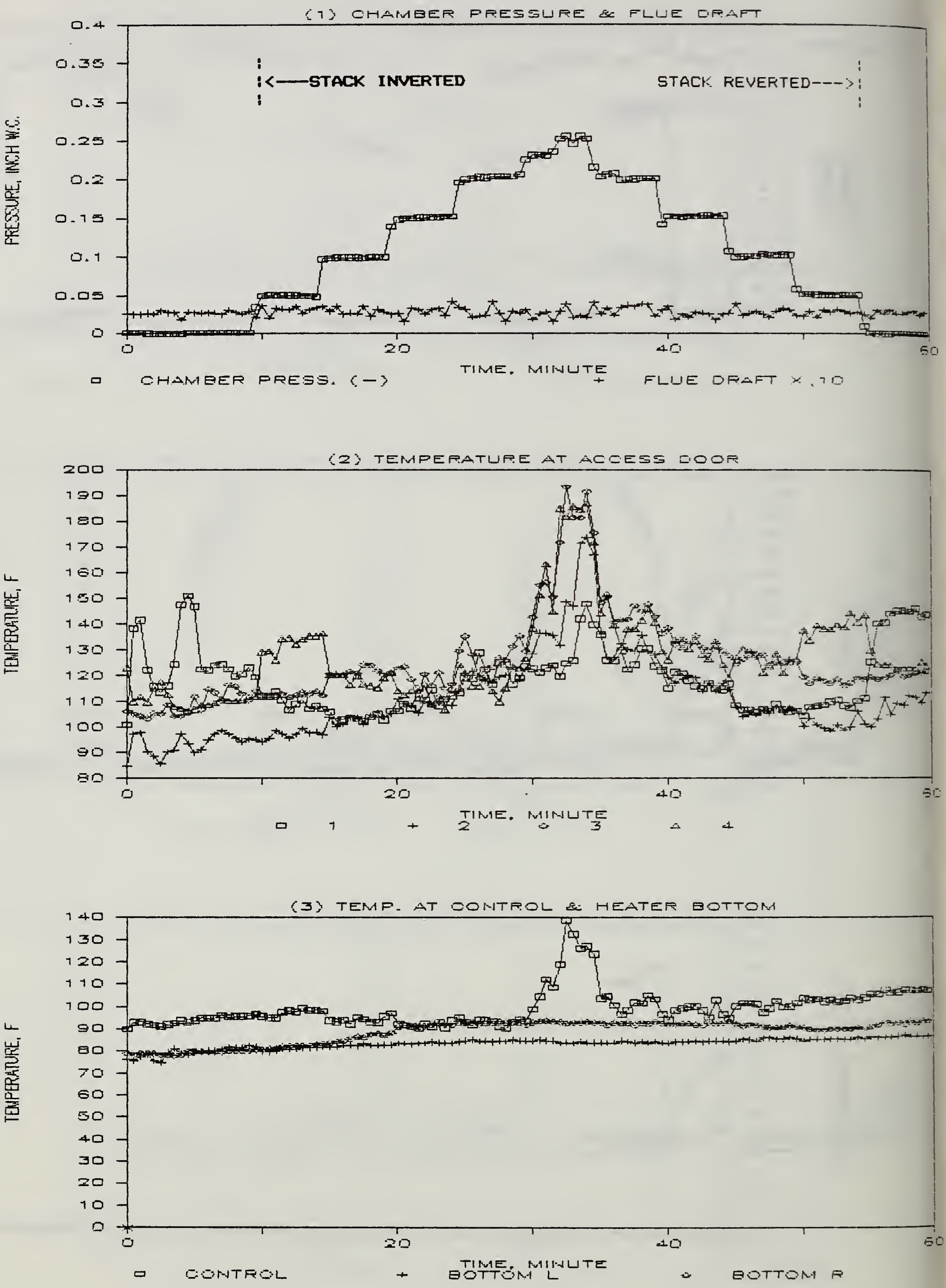


Figure 44 Pressure test, access doors in-place, no flue blockage -- Heater no. 5

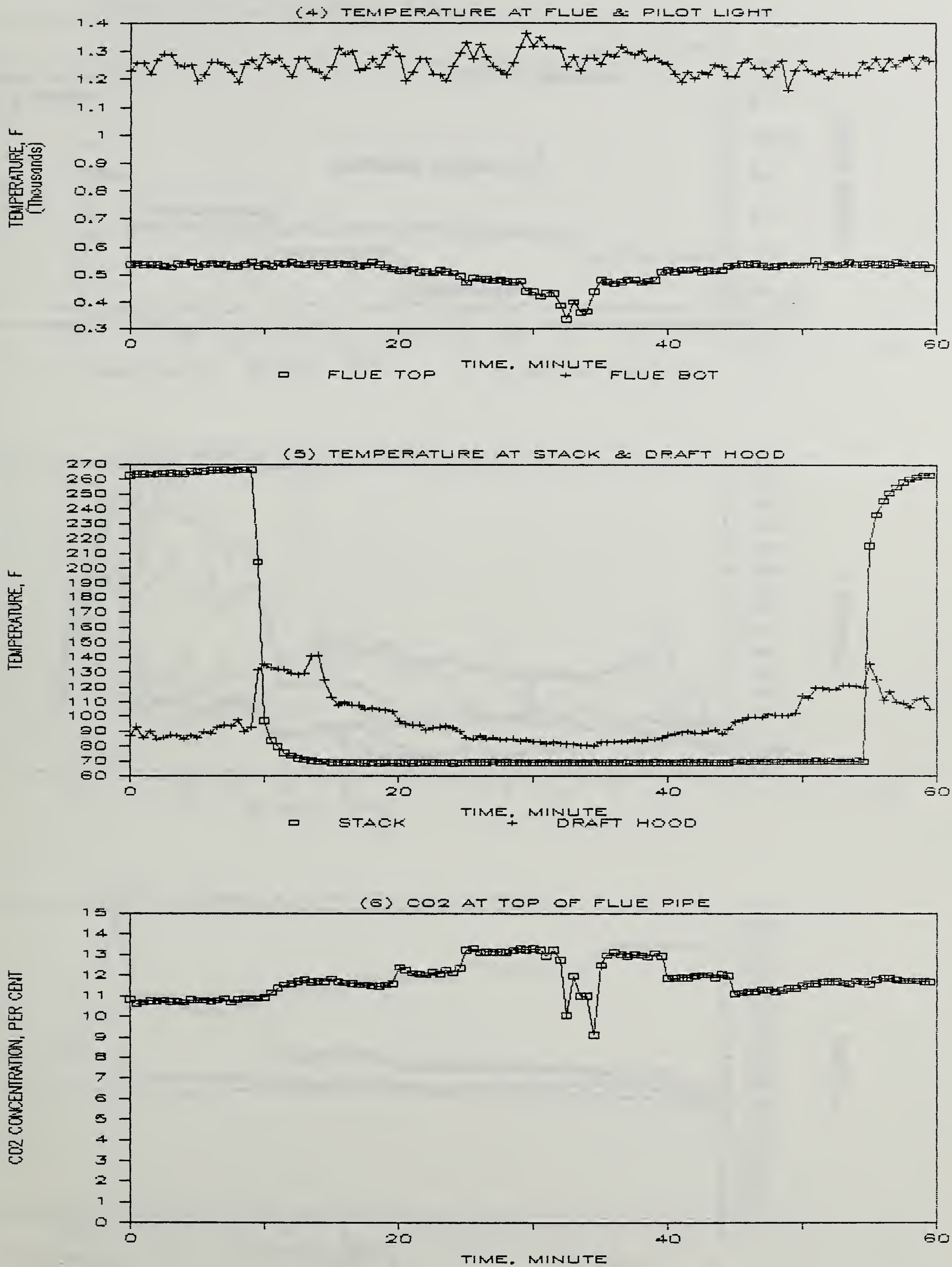


Figure 44 Pressure test, access doors in place, no flue blockage
-- Heater no. 5

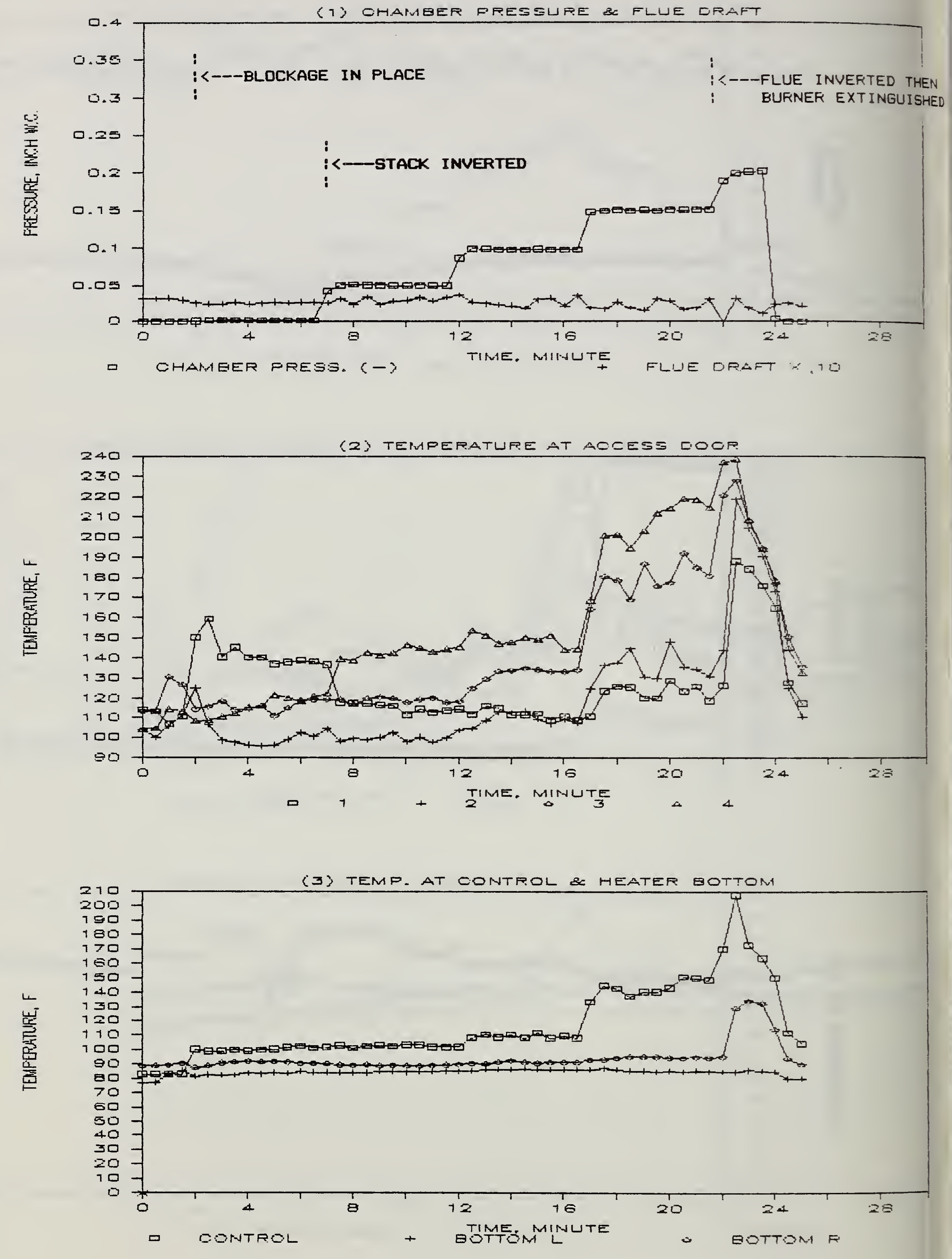


Figure 45 Pressure test, access doors in-place, 20% flue blockage -- Heater no. 5

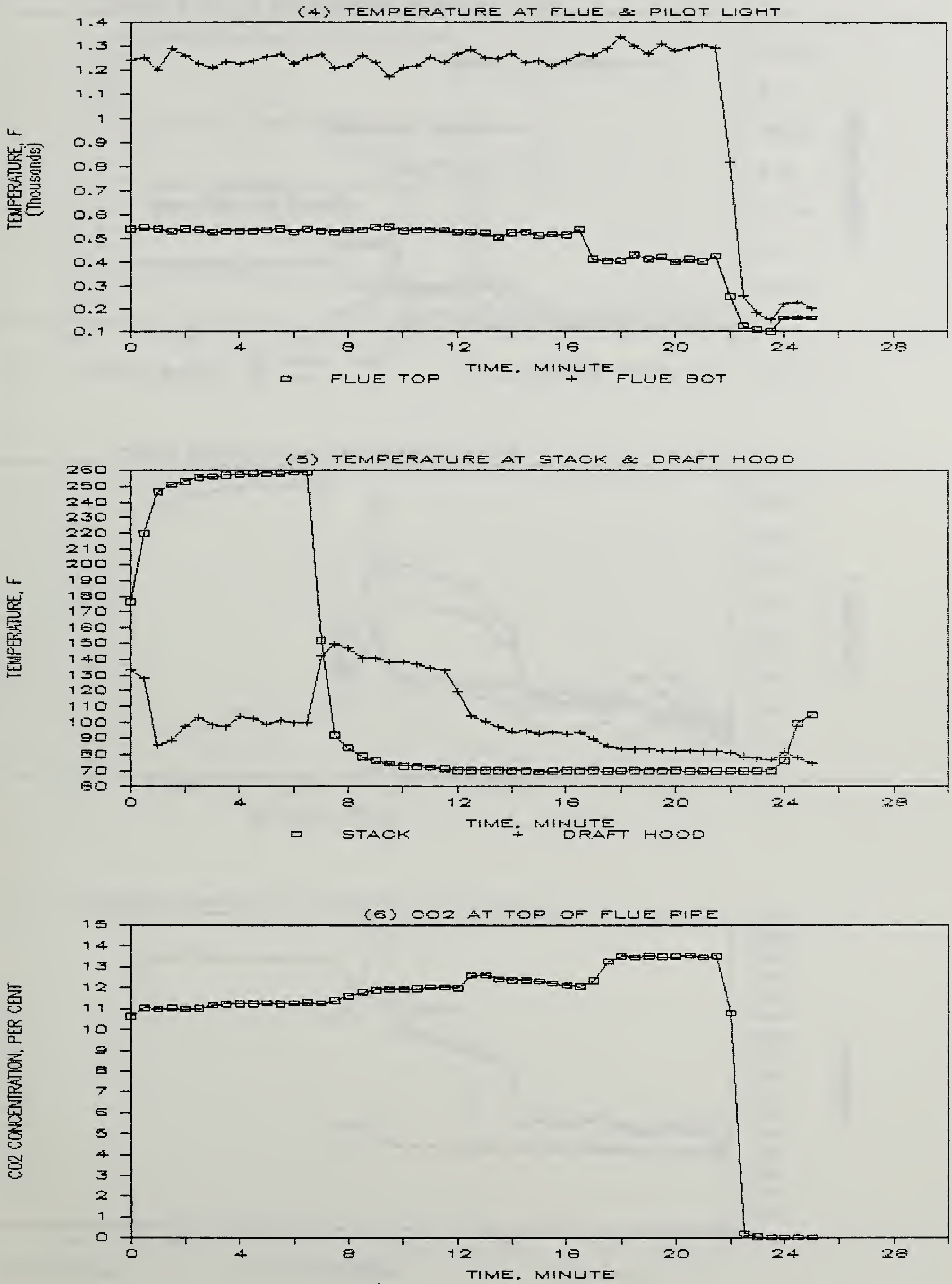


Figure 45 Pressure test, access doors in place, 20% flue blockage -- Heater no. 5

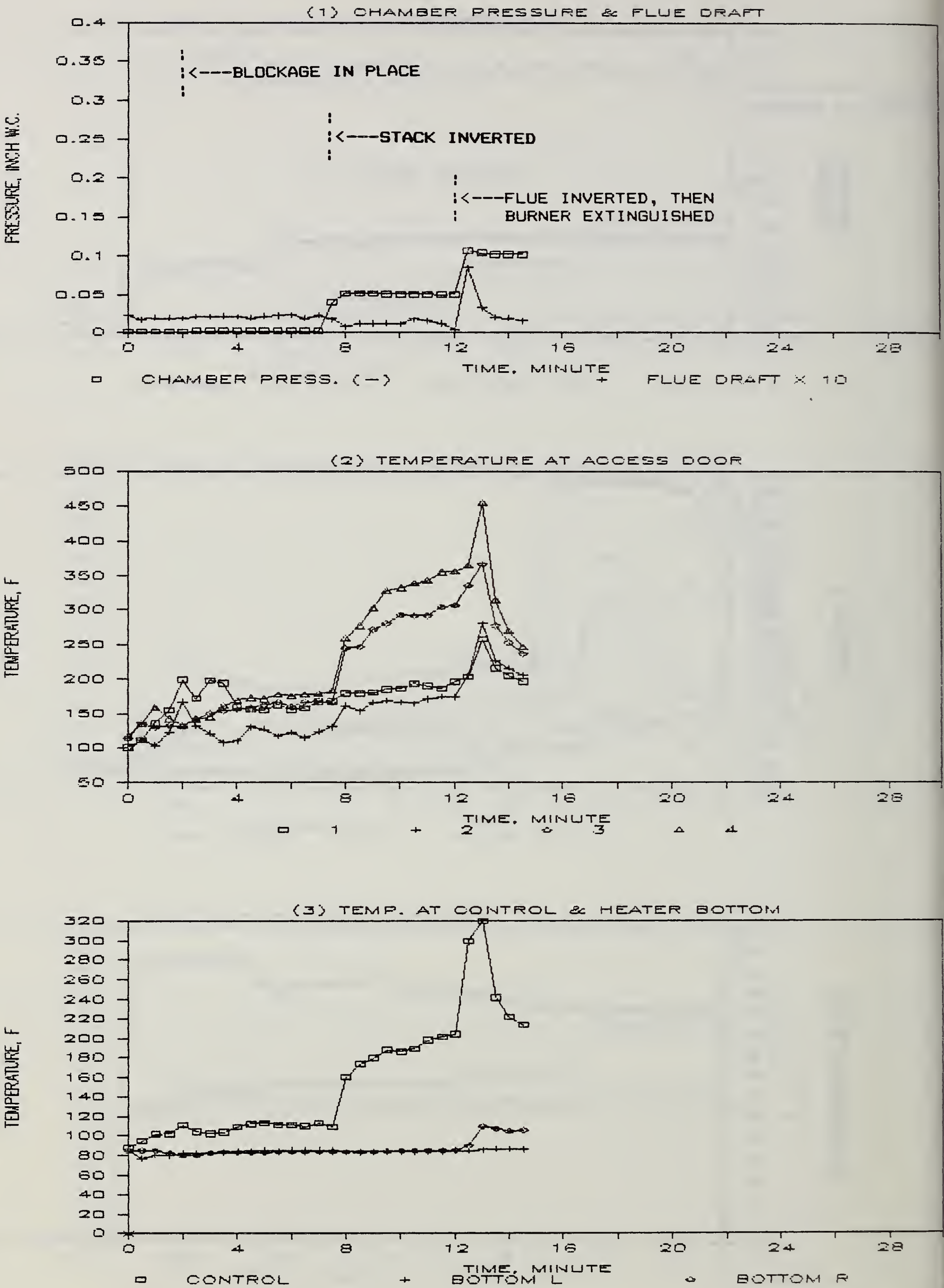
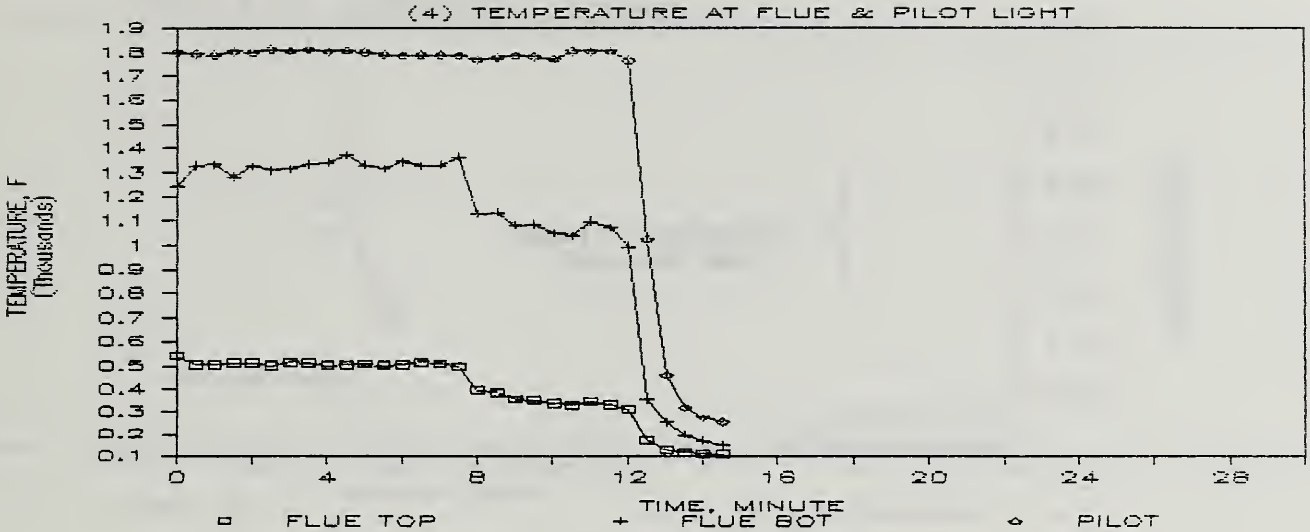
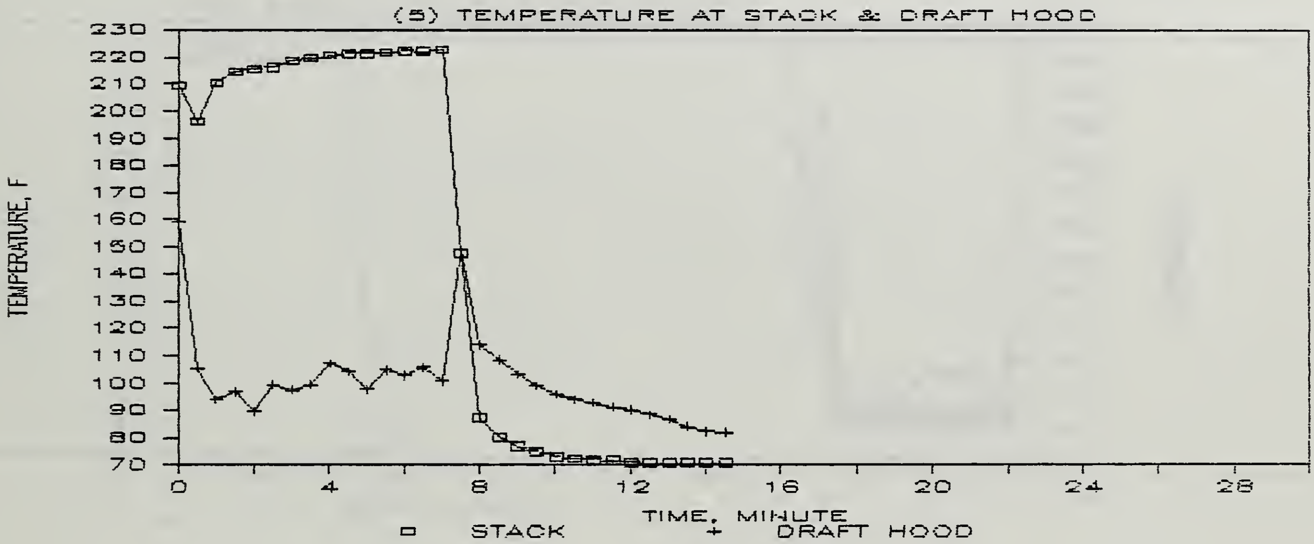


Figure 46 Pressure test, access doors in-place, 60% flue blockage -- Heater no. 5





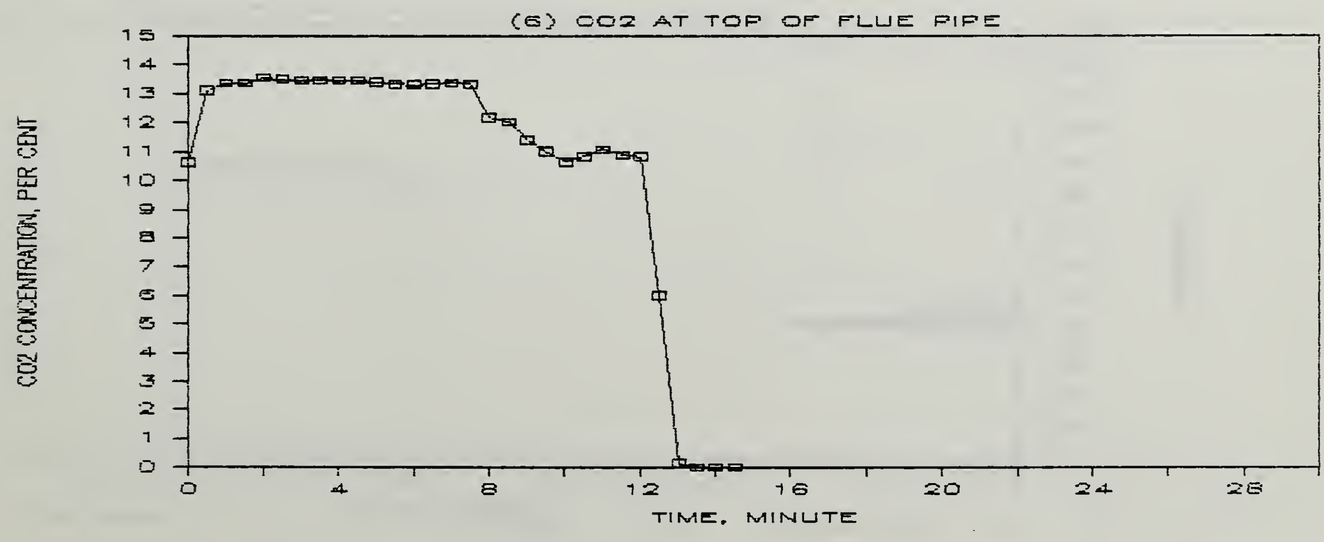


Figure 46 Pressure test, access doors in place, 60% flue blockage -- Heater no. 5

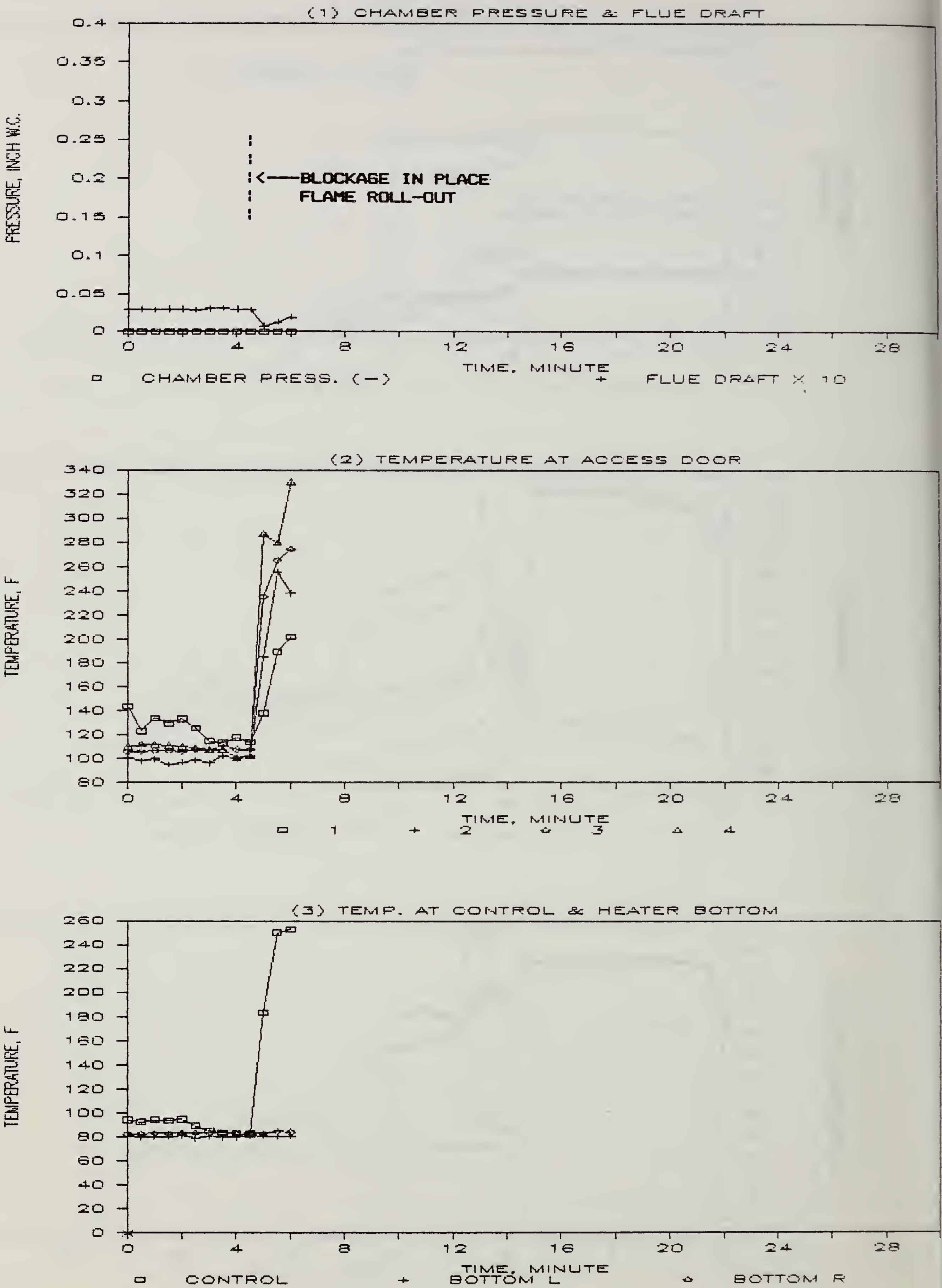
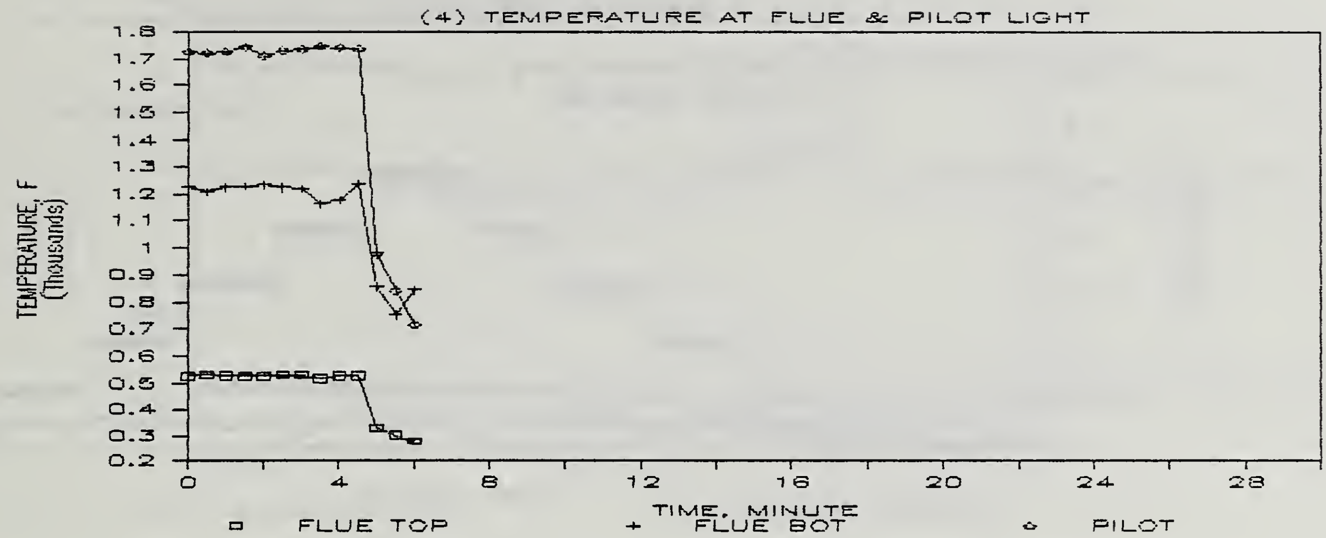
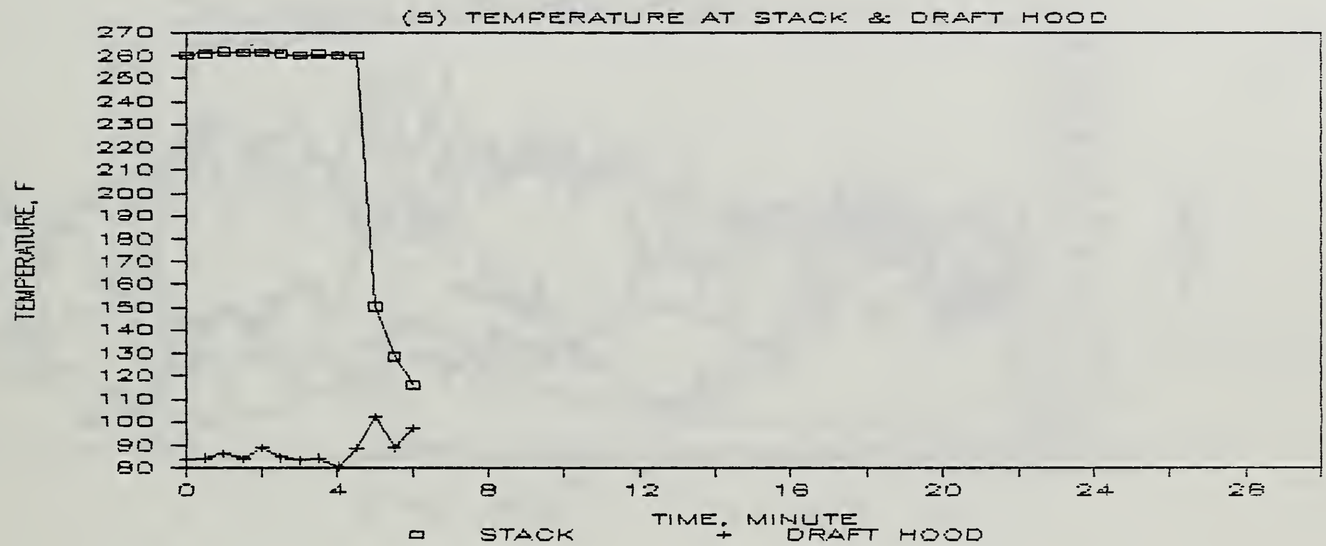


Figure 47 Pressure test, access doors in-place, 100% flue blockage -- Heater no. 5





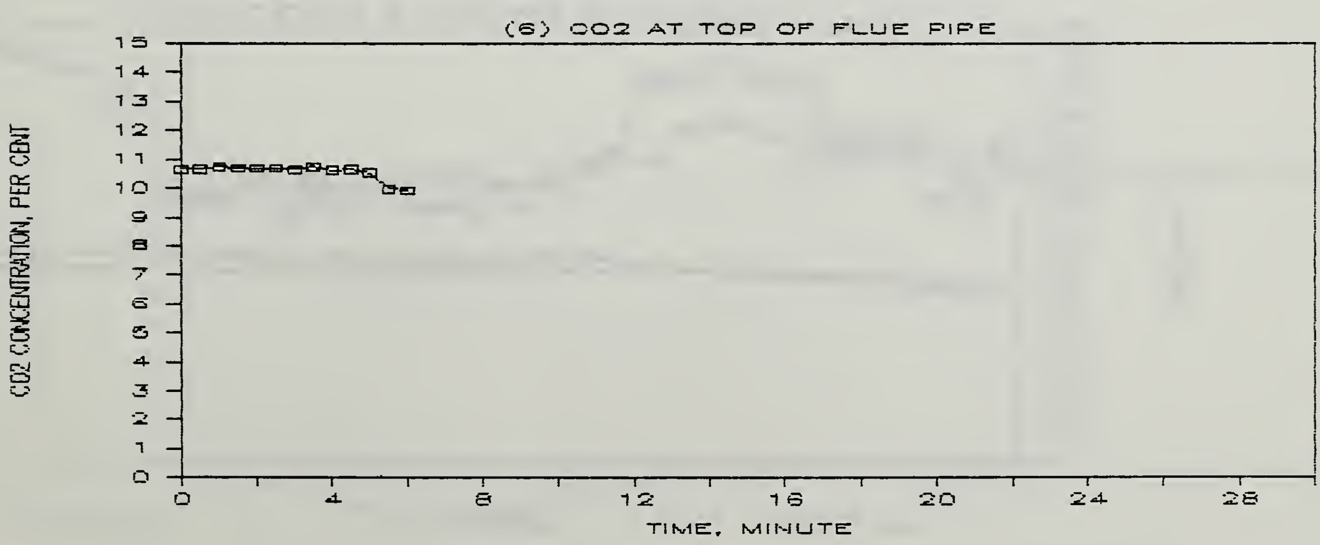


Figure 47 Pressure test, access doors in place, 100% flue blockage -- Heater no. 5

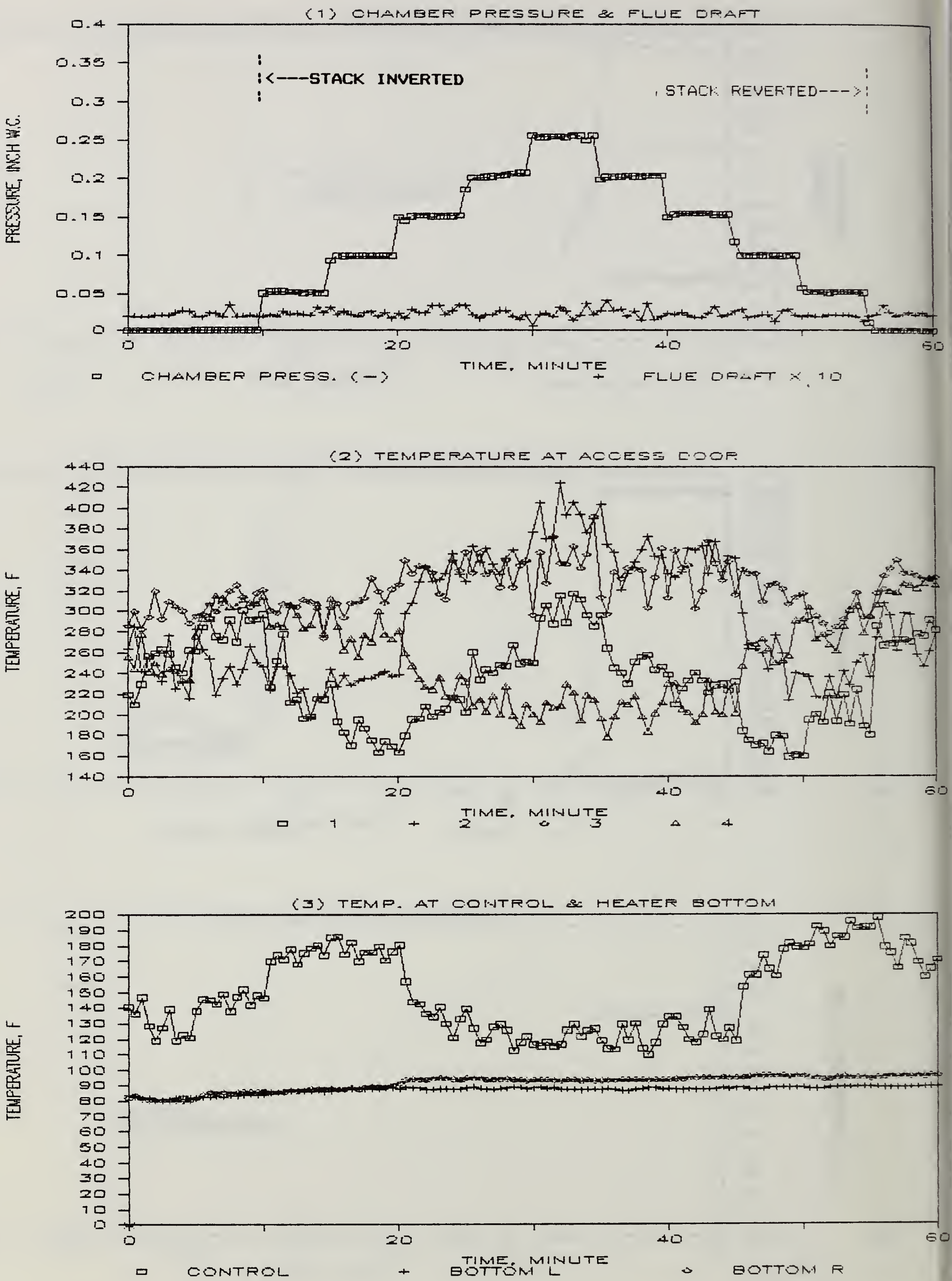


Figure 48 Pressure test, access doors off, no flue blockage
-- Heater no. 5

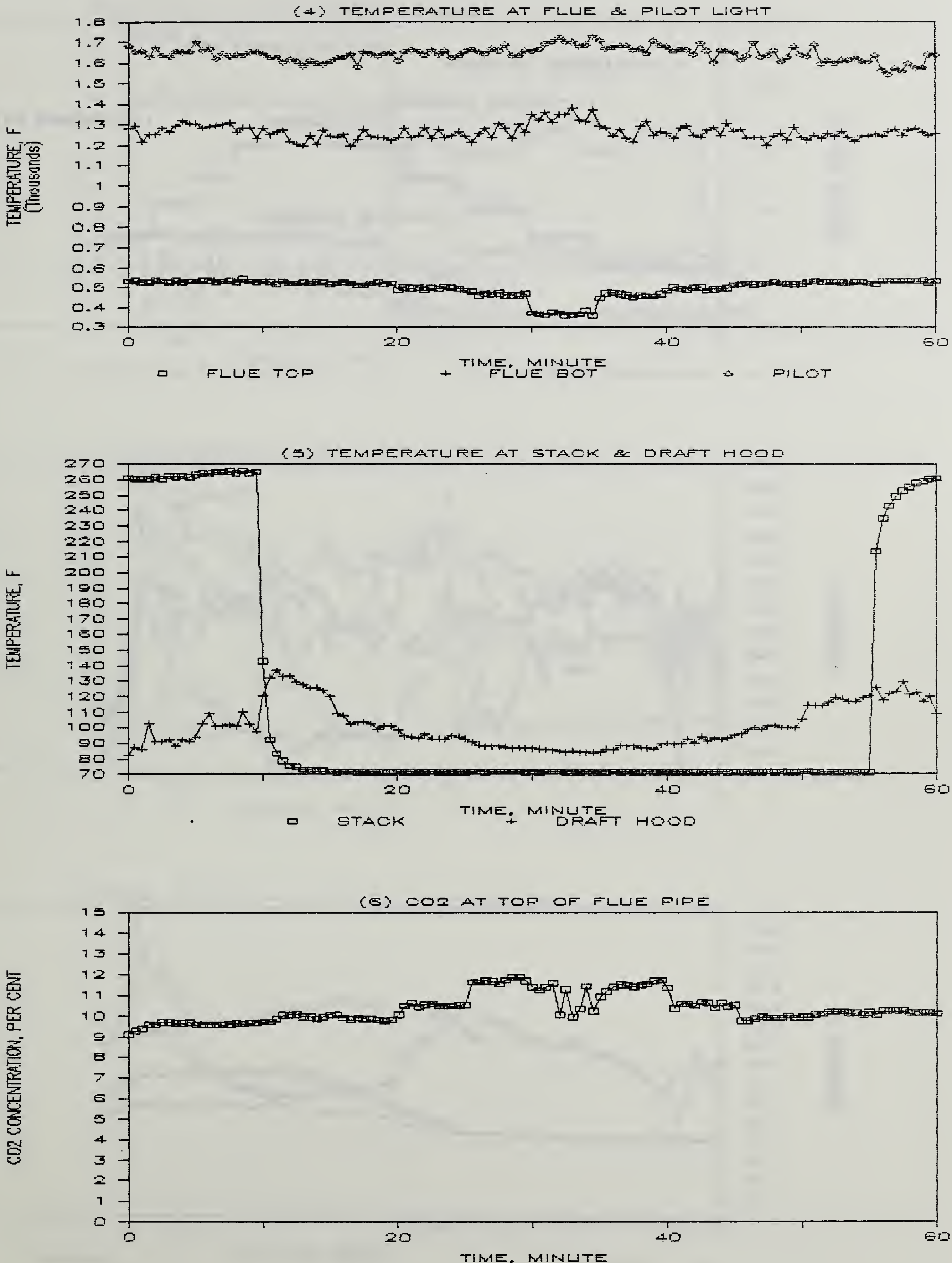


Figure 48 Pressure test, access doors off, no flue blockage -- Heater no. 5

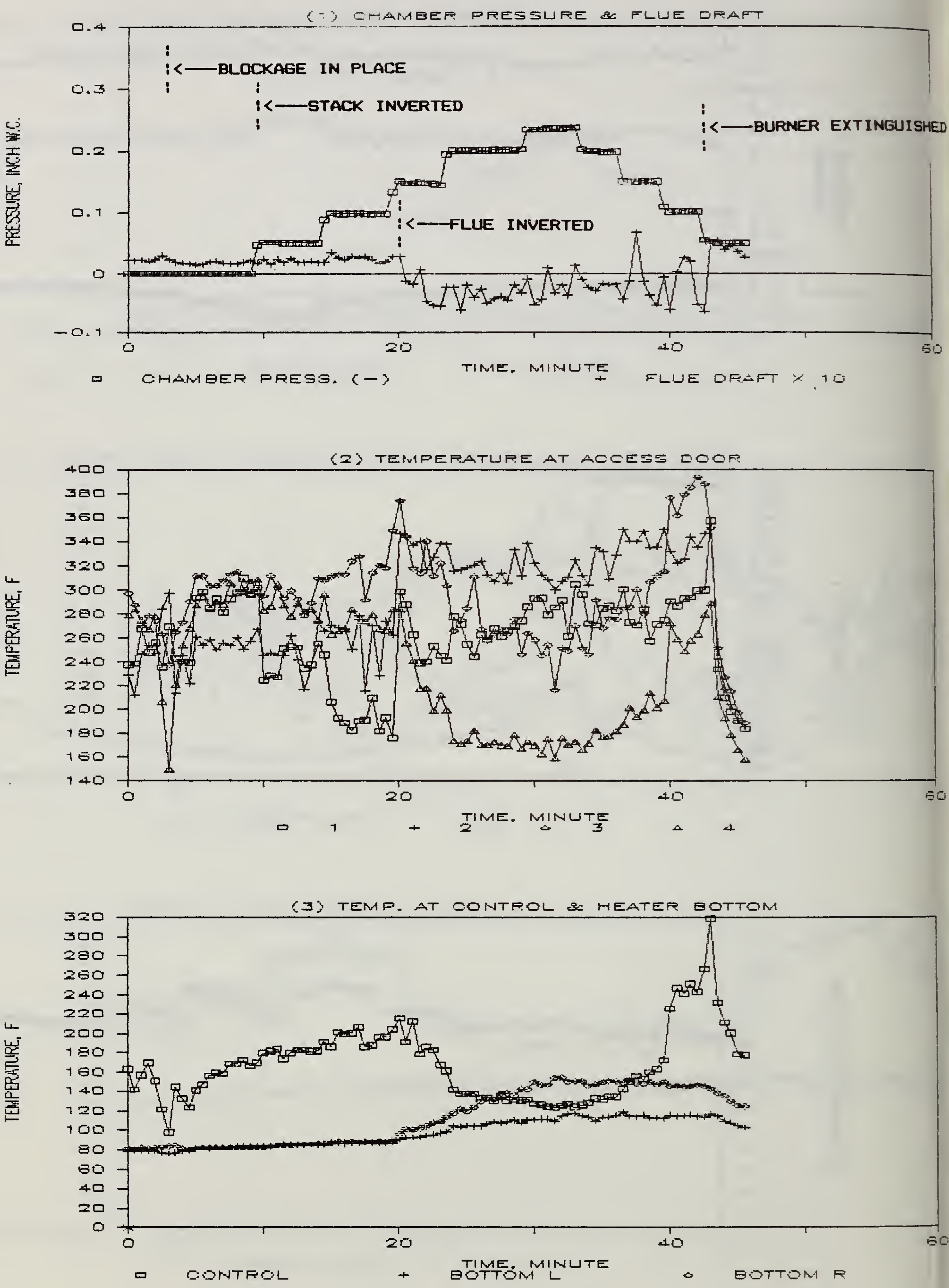
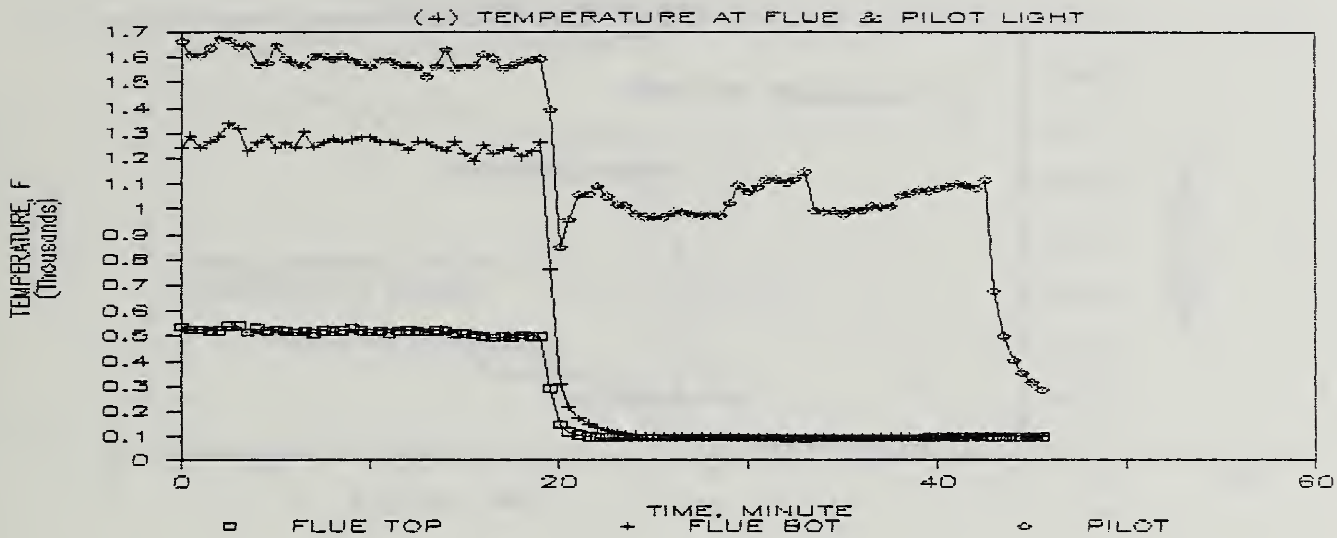
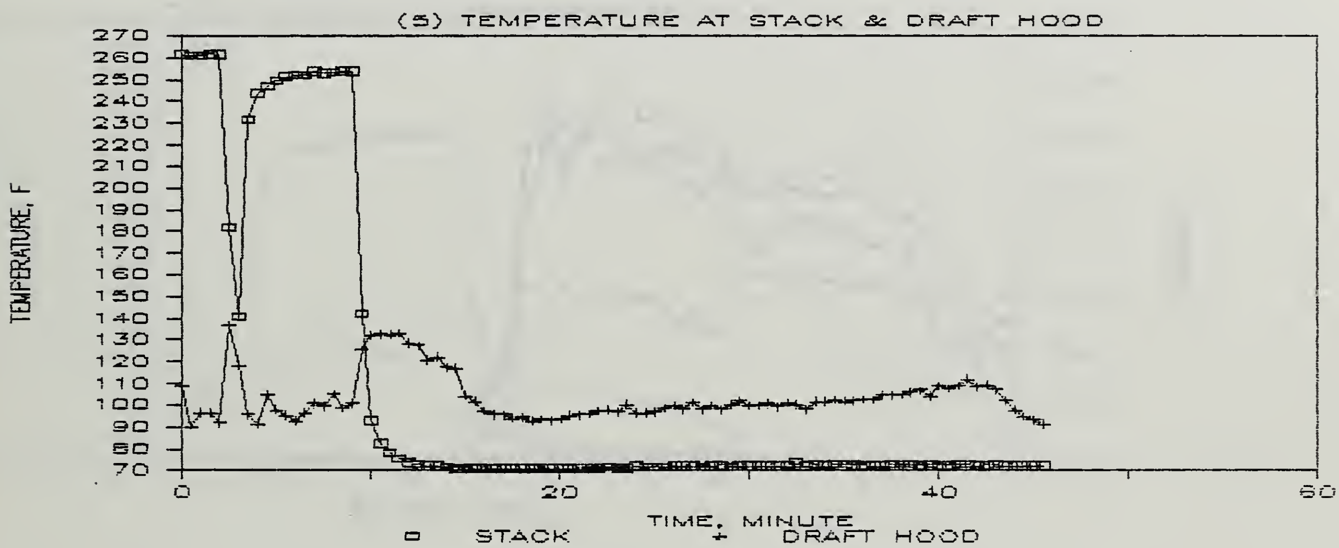


Figure 49 Pressure test, access doors off, 20% flue blockage -- Heater no. 5





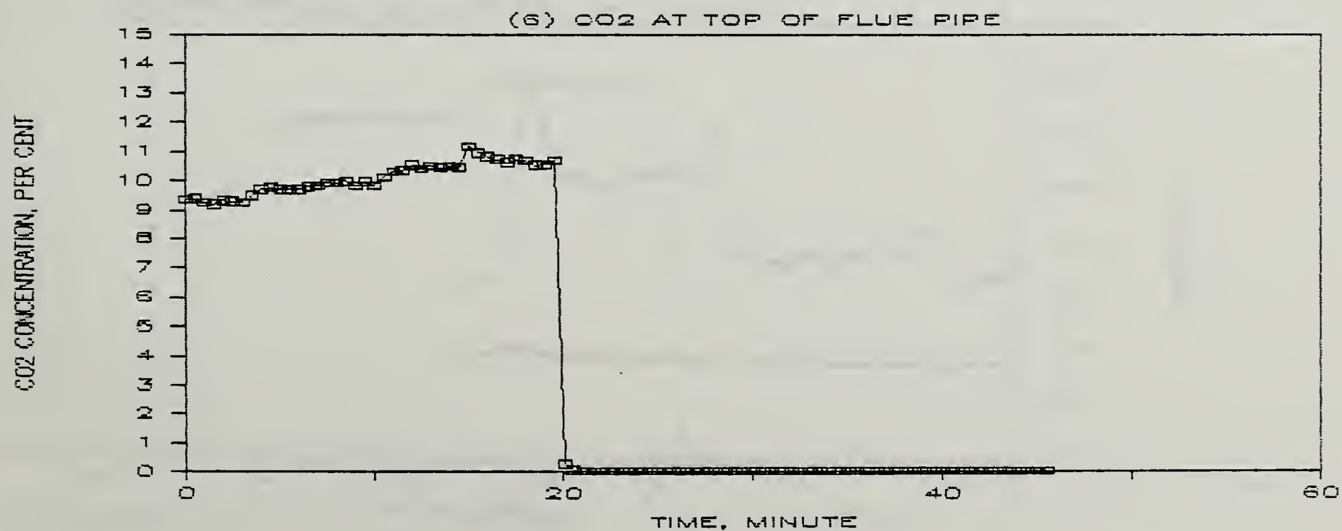


Figure 49 Pressure test, access doors off, 20% flue blockage -- Heater no. 5

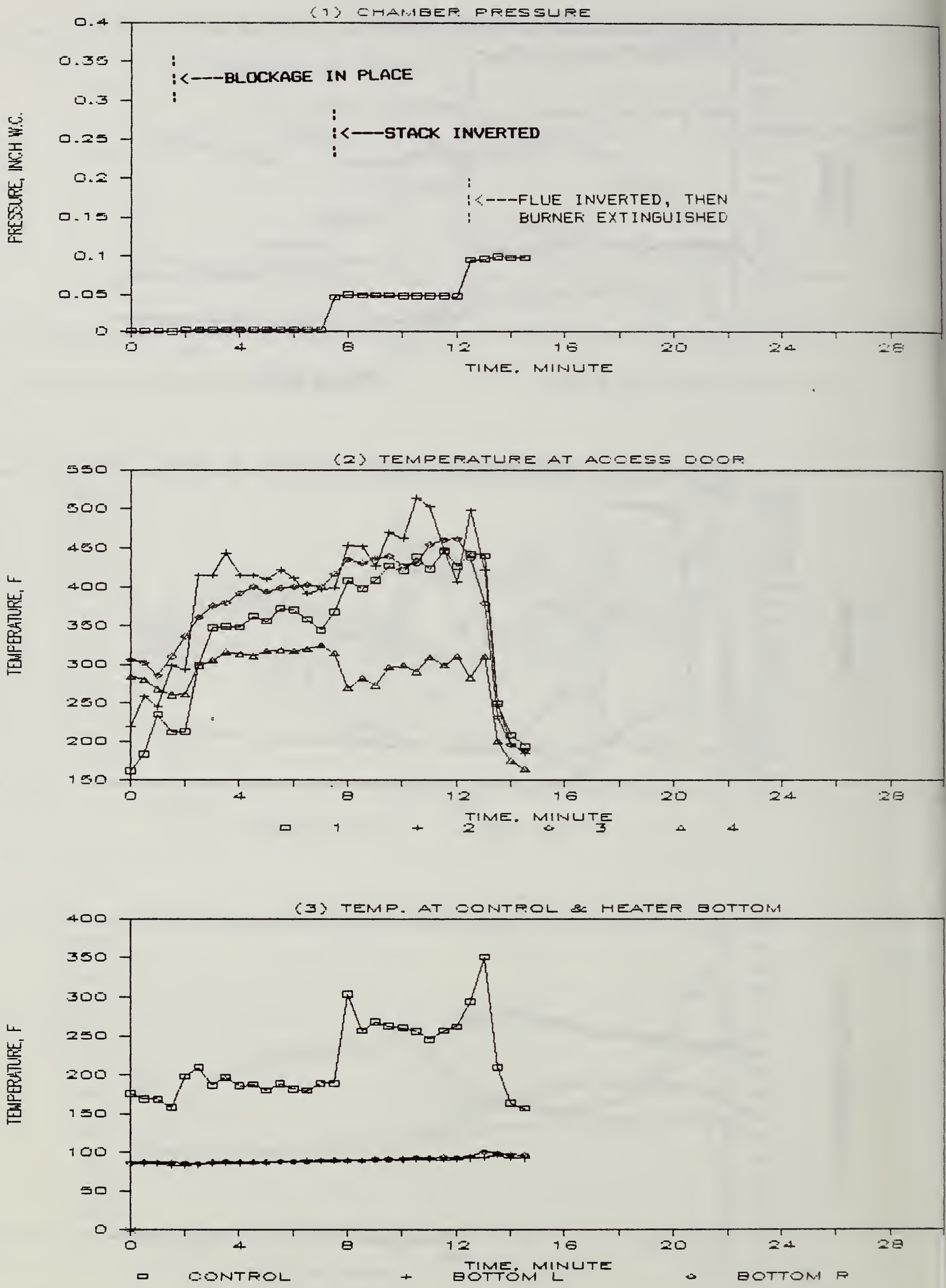


Figure 50 Pressure test, access doors off, 60% flue blockage -- Heater no. 5

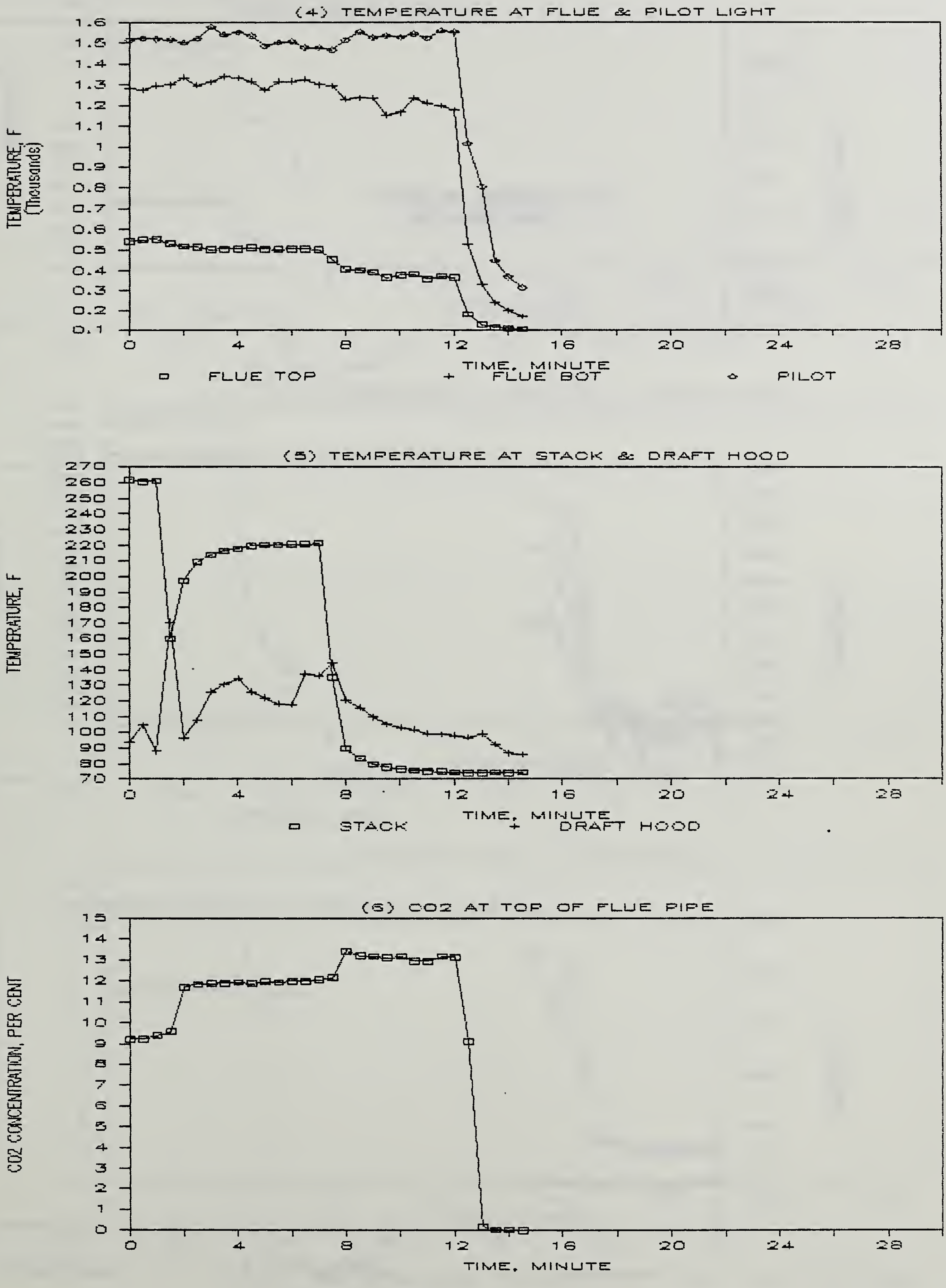


Figure 50 Pressure test, access doors off, 60% flue blockage -- Heater no. 5

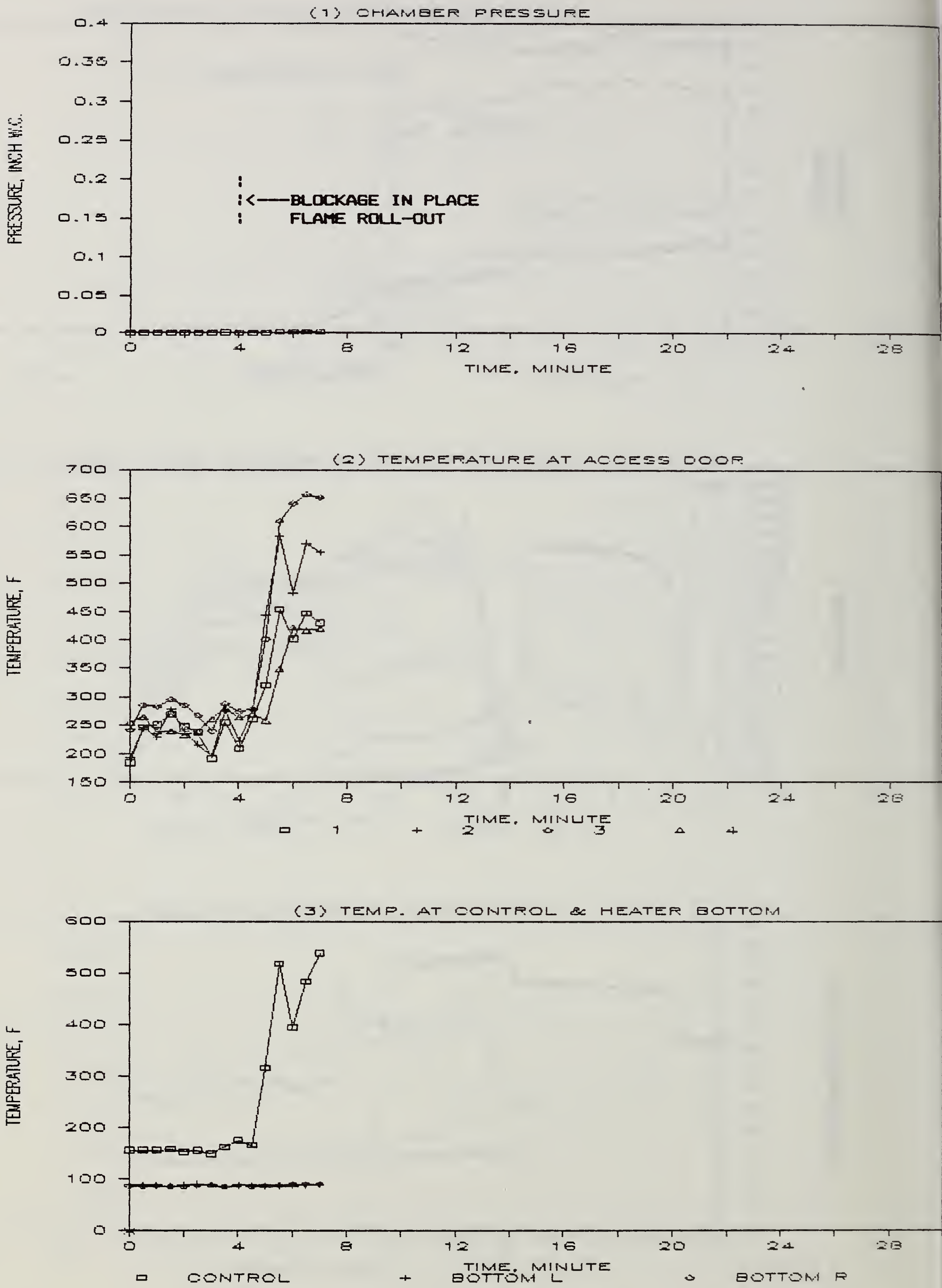


Figure 51 Pressure test, access doors off, 100% flue blockage -- Heater no. 5

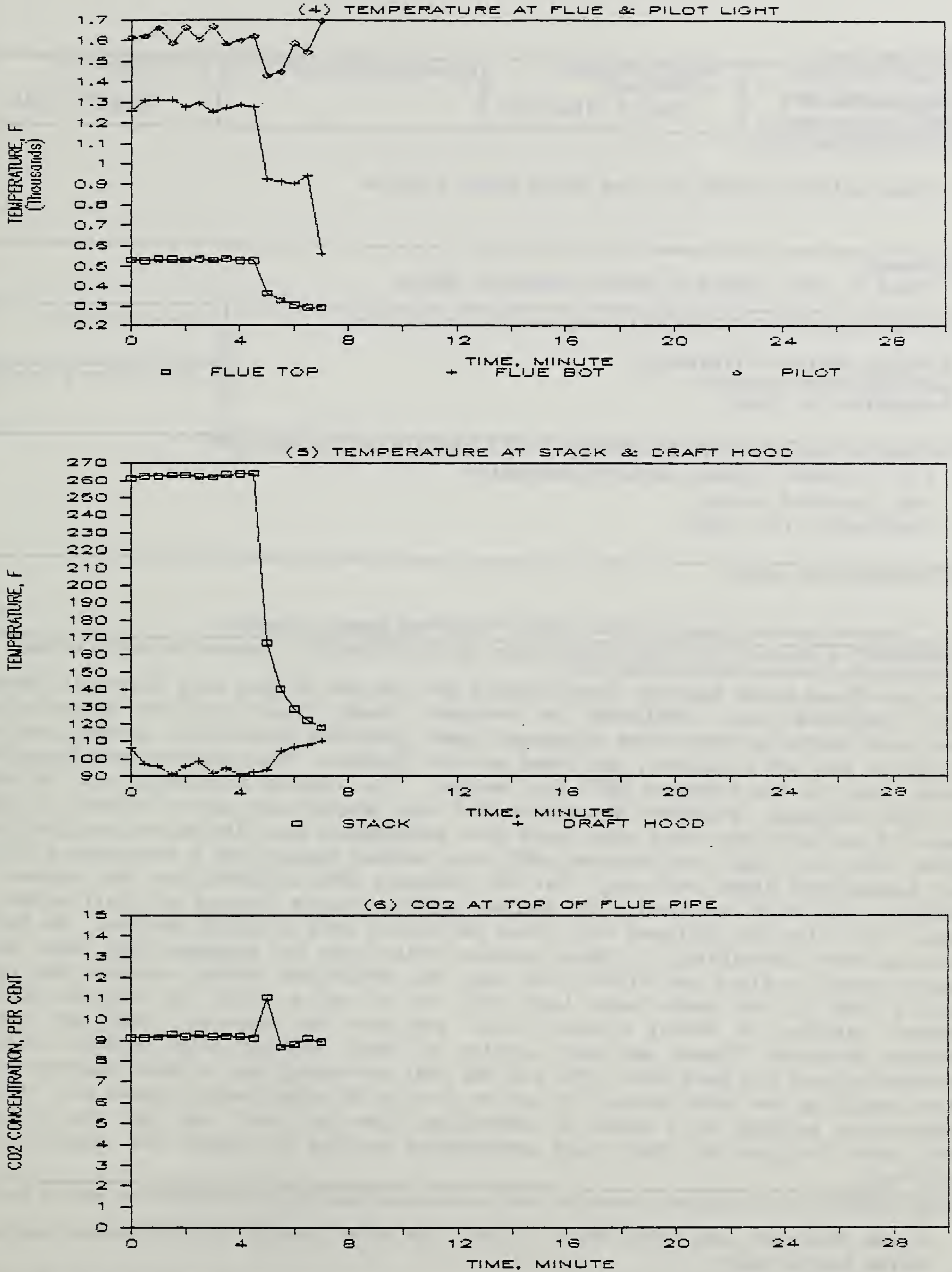


Figure 51 Pressure test, access doors off, 100% flue blockage -- Heater no. 5

NBS-114A (REV. 2-80)

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4. TITLE AND SUBTITLE

Flame Roll-Out Study for Gas Fired Water Heaters

5. AUTHOR(S)

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

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Washington, DC 20207

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)

Five gas-fired water heaters (four natural gas and one LP gas) were tested in laboratory with simulated home conditions to evaluate their flame roll-out characteristics. Simulated variables were flue blockage, space pressure depression, access door status (in-place and not in-place), and other related factors. Test results were compared with those based on the proposed ANSI test method. The testing concludes that, in addition to flue blockage, pressure depression and door status are major factors in inducing heater flame roll-out; that poor draft hood performance contributes to the likelihood of flame roll-out; that the proposed ANSI test method should add a temperature criterion for determining flame roll-out; that the proposed ANSI blocked flue test appears to be adequate for units equipped with thermal spill switches located at their access doors area. For units not equipped with these particular type of safety devices, the following concerns were identified: 1) Water heaters which pass the proposed ANSI test, with the access doors in place and without the need for additional safety devices, may not pass such a test if the doors were left off, and 2) units which use devices other than thermal switches to detect blocked flues, may pass the proposed ANSI test and still produce dangerous flames and heat outside of their jackets under certain conditions. Recommendations are made that CPSC and the ANSI sub-committee on water heaters consider also requiring the interlocking of access doors with water heater operation, the use of temperature sensing as a means of detecting flame roll-out, and the use of improved draft hood designs and draft hood performance testing to reduce the chances of flame roll-out.

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

flame roll-out; gas fired water heater; gas water heater; safety; water heater; water heater test.

13. AVAILABILITY

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Evaluation of a Copy Prevention Method for Digital Audio Tape Systems

National Engineering Laboratory

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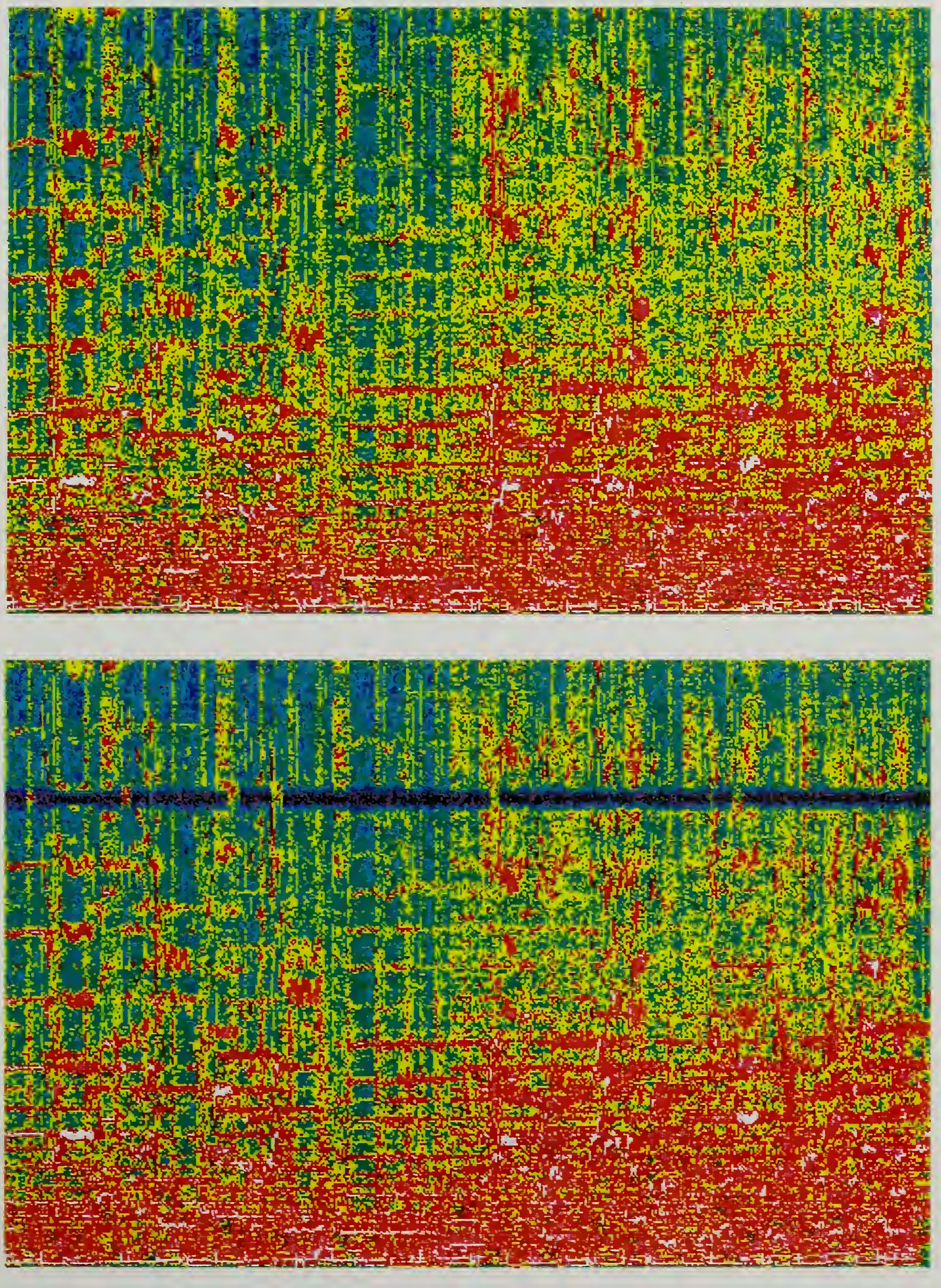

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The front cover illustrates the effect of the copy-protection encoder on a segment of Barbra Streisand singing "Somewhere." The upper color spectrograph corresponds to the original recording; the dark streak through the otherwise identical lower spectrograph shows where spectral components have been removed by the encoder. In these spectrographs, the vertical axis corresponds to frequency, increasing from 0 Hz at the bottom to 5000 Hz at the top. The horizontal axis indicates time. Relative signal level is indicated by color, as shown in the color bar below, where white corresponds to the highest signal levels and black to the lowest levels.