NBSIR 83-2771

Intensity and Duration of Chimney Fires in Several Chimneys

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Fire Research
Washington, DC 20234

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Prepared for:
U.S. Consumer Product Safety Commission
Bethesda, MD 20016

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NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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Abstract

A series of tests was conducted in five instrumented chimneys to study the intensity and duration of chimney fires due to the ignition and burning of combustible deposits accumulated on the chimney lining over a prolonged period of time. These tests were conducted (1) to establish typical conditions including temperatures in the chimneys and on combustible surfaces nearby, (2) to determine the duration of the burnout as evidenced by elevated temperatures within the chimneys, and (3) to compare these measured values with those obtained during overfire conditions - prolonged firing of the appliances at high rates.

The results of these tests point out some areas where the codes and standards covering residential wood heating appliances should be modernized to better protect against failure due to chimney fires.

Key words: Chimney fires; chimneys; creosote; fire safety; fire tests; flues; heating equipment; stoves; wood.

1. INTRODUCTION

The U.S. Department of Energy (DOE) and the U.S. Consumer Product Safety Commission (CPSC), as part of a program to investigate safety risks involved with the use of solid-fuel burning appliances, have sponsored experimental studies at the Center for Fire Research (CFR) at the National Bureau of Standards (NBS) to identify some of the hazards associated with solid-fuel heating, to provide information to improve safety practices for the use of the appliances, and to provide data forming the basis for improved codes and standards.

During the first year of the program, an accident survey, literature review, and codes and standards analysis were performed to establish accident

patterns, to determine the types of risks involved with the use of wood-burning appliances, and to ascertain the adequacy of existing codes and standards in addressing these risks [1-3][1]. Overwhelmingly, conditions related to installation, operation, and maintenance were responsible for the fire incidents studied. Only a small percentage of the fires was attributed to product design or product defects. Thus, the safe installation and use of wood-burning appliances is a critical requirement for preventing fire accidents involving the equipment. Most of the criteria for the installation and use of wood-burning appliances are based upon data developed over 40 years ago and do not provide information on materials of construction, or appliances available in the current market.

The present research program at CFR includes research on:

- clearances to combustibles from appliances and chimney connectors;
- methods of protection to allow reduced clearances to walls and ceilings;
- temperatures developed in and around fireplaces with and without fireplace inserts installed;
- intensity and duration of chimney fires in factory-built and masonry chimneys; and
- temperatures on combustible material surrounding chimney connectors passing through walls and/or connecting to chimneys.

This report, one of a series of reports providing information from the DOE/CPSC sponsored experimental program on wood-burning safety at NBS, presents the results of fire tests conducted on a number of chimneys, of both factory-built and masonry design. The tests were conducted to establish maximum temperatures and duration of these elevated temperature levels during

[1]Numbers in brackets refer to literature references listed in section 10 at the end of this report.

creosote burnouts in chimneys serving wood-burning appliances. The intended uses of these data are to define appropriate levels for testing of chimneys to simulate chimney fires and to provide information for improved construction requirements for masonry chimneys.

2. REVIEW OF PREVIOUS WORK

2.1 Fire Incidents Involving Wood-Burning Appliances

Recent statistics on fires and injuries related to wood-burning appliances are alarming:

Year	Fires	Percent Change	Deaths	Dollar Loss
1978	66,800		250	$134 million
1979	70,700	+14%	210	$175 million
1980	112,000	+58%	350	not available
1981	130,100	+16%	290	$265 million

Source: National Fire Protection Association, U.S. Fire Administration, U.S. Consumer Product Safety Commission/EPHA

There were more fires in solid-fuel burning equipment, and a larger percentage increase over previous years, than were reported for any other kind of heating equipment - including gas, electric, and oil-burning appliances [4,5]. A recent analysis indicated wood-burning appliances were the third leading cause of multiple deaths from fires in residential properties from 1971 to 1980 [6]. Clearly, accidental fires from wood-burning appliances are an increasingly important problem.

In a study of the hazards associated with the use of wood or coal-burning stoves by the U.S. Consumer Product Safety Commission, chimneys, flues, or chimney connectors were identified as a leading cause of fires [7]. In 1981, out of an estimated 130,100 fires involving heating equipment, 52,000, or about 40 percent, were attributed to chimneys, flues or chimney connectors. About 85 percent (44,700) of these fires were from chimneys and flues and about 15 percent (7,900) from chimney connectors [4]. An earlier study by NBS

presented an analysis of fire incident data related to wood-burning appliances [1-2,8]. Product malfunctions, construction defects, design deficiencies, or worn out equipment were attributed to be the cause in only 13 percent of the solid fuel related fires recorded in the U.S. Fire Administration data base. Overwhelmingly, conditions related to the installation, operation, or maintenance of the appliances were reported as responsible for the fires. Shelton [3,9] supports this conclusion with studies in the state of Massachusetts and from an insurance company in Wisconsin. A breakdown of solid fuel appliance related fire incidents by probable cause and by equipment type indicates that except for improper maintenance, the appliances themselves were involved in most of the fires rather than chimneys or chimney connectors -- over 70 percent in these cases [8]. However, under the category of improper maintenance, appliances were involved in only 26 percent of the recorded fires. Improper maintenance is the significant problem associated with chimneys and chimney connectors.

2.2 Chimney and Connector Construction

Recommendations for minimum construction specifications for masonry chimneys and chimney connectors are available in the various model building codes [10-17]. A fire-clay flue liner, 16 mm (5/8 in) thick, is surrounded by a masonry wall of solid masonry units not less than 102 mm (4 in) in thickness, or of reinforced portland or refractory cement concrete at least 102 mm (4 in) thick or of rubble stone masonry not less than 305 mm (12 in) thick. The flue liner is separated from the chimney wall by an air space.

For factory-built chimneys, performance based specifications are available in standards used for testing and listing of chimneys [18]. The standards specify maximum operating temperatures for the chimneys during normal and overfire conditions, maximum allowable temperatures on chimney and surrounding combustible surfaces, and structural requirements for the chimneys. In addition complete installation and operation instructions are required.

2.3 Chimney and Chimney Connector Clearances

Clearances to combustible materials for chimneys and chimney connectors are also specified in the various model codes [10-17]. For simplicity and ease of enforcement, a single, hopefully conservative clearance is given for each type of chimney and chimney connector. For residential solid fuel chimneys, typically 51 mm (2 in) of clearance is required. Chimney connectors for solid fuel burning residential appliances require a clearance of at least 0.46 m (18 in) to combustible materials. However, by protecting combustible material, these clearances may be reduced.

The experimental basis for these code requirements is not, however, quite so clear. Several experimental studies have been carried out to determine minimum acceptable clearances to combustible materials. Voigt [19], in a 1933 publication, recommends a minimum clearance of 0.30 m (12 in) for chimney connectors 0.23 m (9 in) in diameter. A more extensive study, performed by Underwriters Laboratories in 1943 [20], presents minimum safe clearances for both unprotected surfaces and surfaces protected by various methods. Distances at which a maximum temperature rise of 50°C (90°F) above room temperature is reached are presented as a function of the temperature of the exposed face of a heat producing appliance. The relative protection afforded by various materials used as heat barriers between the appliance and combustible surface is also examined. Lawson, Fox, and Webster [21] and Lawson and Simms [22] have studied the heating of wall panels and wood by radiation. With experimentation and theoretical predictions, they present safe clearances between flue pipes and wall surfaces as a function of the pipe diameter and the pipe surface temperature. To maintain a maximum wall temperature of 100°C (212°F), a 0.15 m (6 in) pipe should not exceed 350°C (660°F) in surface temperature at a clearance of 0.46 m (18 in) [21].

These experimental studies established limits for two important parameters: appliance surface temperature and clearance to combustibles for unprotected and protected surfaces. Maximum appliance surface temperature for the appliances studied ranged from 300 to 350°C (600 to 660°F). Minimum safe wall clearance for unprotected surfaces range from 0.3 m to 0.91 m (12 in to 36 in). Most of the current code provisions are only adequate for maximum appliance surface temperatures up to 300 to 350°C.

2.4 Temperatures Developed in Heating Appliances

Tests made with prefabricated porcelain-enameled metal chimneys for solid or liquid fuel furnaces [23,24] established a limiting temperature rise of 190°C (375°F) on the outer surface of the chimney for a flue gas temperature of 540°C (1000°F). With this limitation, wood framing spaced 51 mm (2 in) or more away from the chimney was considered safe. Satisfactory insulation of the chimneys to reduce the outer surface temperatures to acceptable levels was obtained with asbestos paper plies totaling about 45 mm (1 3/4 in) in thickness. In the same study, some asbestos-cement pipe coverings also were found to be capable of reducing heat transmission to the extent required for safety of nearby combustibles.

To establish performance requirements for lightweight prefabricated chimneys, tests were conducted with lined and unlined masonry chimneys having 102 mm (4 in) thick walls [25]. Temperatures in excess of 50°C (90°F) above ambient on wood framing spaced 51 mm (2 in) away from the chimney were noted with a steady-state flue gas temperature of 480°C (900°F) for the unlined chimney and 590°C (1100°F) for the lined chimney. However, these hazardous conditions were not reached in the lined chimney tests until after 13 hours. In order to study operating conditions with typical fuels, a number of firing tests [26] were conducted with heating appliances known to give high flue gas temperatures, using wood and soft coal as fuels. With a coal-fired, jacketed type heater, gas temperatures ranging from 650°C to 705°C (1200°F to 1300°F) were measured for an hour or more in the flue at the ceiling level above the heater. Thus, temperatures in excess of safe limits can be produced for extended periods of time.

Lawson, et al. [21] present the results of tests to measure surface temperatures of the flue pipes to validate theoretical predictions. Measured for a variety of flue systems using solid fuels--mostly coal and coke--they report temperatures of about 148°C (300°F) under "normal conditions" and temperatures as high as 815°C (1500°F) under overload conditions.

Fox and Whittaker [26] report temperatures on metal flues of several heating appliances over a range likely to be encountered in normal use.

Maximum flue pipe surface temperatures ranged from 700 to 815°C (1300 to 1500°F) at the appliance flue outlet, 360 to 510°C (680 to 950°F) at a distance of 1 m (3 ft) from the appliance flue outlet and 280 to 330°C (550 to 620°F) at a distance of 2 m (6 ft) from the appliance flue outlet.

Shoub [23] concludes that combustible materials will be ignited if maintained in continued contact with a chimney of 121 mm (4 3/4 in) wall thickness and with flue gas temperatures of 400°C (750°F).

Current test procedures for prefabricated chimneys require testing of chimney assemblies with hot flue gases [27]. Flue gas temperatures of 540°C (1000°F) are maintained until steady-state conditions are reached, followed by 760°C (1400°F) for 1 hour and 925°C (1700°F) for 10 minutes. These conditions are intended to simulate worst-case conditions.

In tests for the U.S. Department of Energy, maximum surface temperatures ranging from 212 to 456°C (414 to 853°F) were recorded on single wall chimney connectors. The average maximum surface temperature for seventeen tests of five different appliances was 375°C (707°F). Flue gas temperatures ranging from 600 to 800°C (1100 to 1475°F) were noted at the appliance flue outlet. Further downstream at 2 m (6 ft) from the appliance flue outlet, flue gas temperatures dropped to 400 to 550°C (750 to 1020°F) [8].

2.5 Limiting Safe Temperatures on Combustible Surfaces

Listings of chimneys for heat producing appliances by nationally recognized testing laboratories and methods for setting clearances between chimneys and combustible surfaces are based on temperature rises on combustible surfaces of:

Firing Condition	Flue Gas Temperature (°C/°F)	Maximum Temperature Rise: Exposed Surface (°C/°F)	Maximum Temperature Rise: Unexposed Surface (°C/°F)
Continuous firing at	538/1000	65/117	50/90
1 hour overload at	760/1400	78/140	78/140
10 min overload at	927/1700	97/175	97/175
3-10 min overloads at	1149/2100	97/175	97/175

Source: UL 103 and UL 1482 (references [18] and [28]).

These requirements are based on the fact that, while the ignition temperature of wood products is generally quoted to be on the order of 200°C (400°F) [8], wood that is exposed to constant heating over a period of time may undergo a chemical change resulting in a much lower ignition temperature and increased potential for self-ignition [28].

Mitchell [30] presents data on wood fiberboard exposed to temperatures as low as 109°C (228°F) that resulted in ignition after an exposure of several months. MacLean [31,32] reports charring of wood samples at temperatures as low as 93°C (200°F) after longer exposures. He concludes that wood should not be exposed to temperatures appreciably higher than 66°C (150°F) for long periods. McGuire [33], suggests that the maximum safe temperature on the surface of a combustible material adjacent to a constant heat source should be no more than 100°C (212°F).

Clearly, the ignition of wood at moderately elevated temperatures is a complex phenomenon. The time of exposure is indeed an important parameter [34]. While exact limits recommended in the literature vary due to exposure time and details of the tests conducted, the numerous documented fires involving the ignition of wood members near low pressure steam pipes [35] suggest an upper temperature limit for wood exposed to long-term low-level heating should not be appreciably higher than 100°C (212°F).

2.6 Creosoting and Chimney Fires

Published literature related to creosoting and chimney fires is scarce. A brief review of efforts to characterize chimney creosoting is included below.

The term "creosote" is used in several different ways in relation to wood heating. It may refer to whatever accumulates in a chimney or chimney connector attached to a wood-burning appliance, such as tar, liquids, and soot; or to the tar and liquids only; or to the liquids only; or to one particular compound in the liquid [9]. For the purposes of this study, a definition by Shelton [9] is appropriate: "everything in the chimney that might burn or need cleaning, but excluding such things as birds' nests."

Flink [36] presents the results of a number of chimney fire tests conducted to establish test criteria for factory-built chimneys. He reports two regimes of burning during a chimney fire. In all cases of artificially produced chimney fires, a primary fire with flue gas temperatures of 971°C (1780°F) is followed by up to four secondary fires resulting in a rise in the gas temperature during the successive secondary fires to as high as 1166°C (2130°F). Outer chimney surface temperatures of approximately 260°C (500°F) were noted.

Stone [37] notes peak flue gas temperatures from 717°C (1322°F) to 806°C (1483°F) during two chimney fire tests. He concludes that igniting chimney fires under controlled conditions may prevent creosote buildup from becoming too dangerous, while not creating unsafe temperatures on surrounding combustibles.

Studies at Auburn University present interesting insights into the build-up of creosote deposits prior to a chimney fire [38-40]. Eighteen different tests were performed on one chimney using three different types of wood (hickory, oak, and yellow pine), each with three different wood geometries. Tests were also performed using different moisture levels. The wood type, moisture content, and geometry did affect the creosote formation by the stove used in the tests. Dry wood produced slightly more creosote than wet wood.

Hardwoods, such as hickory and oak, produced more creosote than yellow pine. However, in all tests, significant amounts of creosote were generated.

3. TEST DESIGN AND INSTRUMENTATION

The work reported herein consists of a series of tests conducted with five different chimneys for residential solid-fuel appliances. The tests were designed to provide data on the intensity and duration of chimney fires in chimneys serving wood-burning appliances. Five different chimneys were studied: four factory-built chimneys and one masonry chimney. Areas of interest included:

- temperatures developed on chimney surfaces and on surrounding combustibles,
- temperatures developed in the flue gas,
- duration of elevated temperatures in the chimney and on surrounding combustible surfaces, and
- structural integrity of the chimney--does any failure occur in the chimney as a result of the chimney fire that leads to unsafe conditions?

3.1 Chimney Systems

Five different chimney systems were selected by their design as being representative of those available in the marketplace. Obviously, with many manufacturers of factory-built chimneys and an almost infinite variety of masonry chimneys, it would be impossible to test every variation. However, the chimneys used represent a selection of those on the market. A description of each chimney is included below. Figures 1 to 3 show the experimental setup used during the tests of the factory-built chimneys and the masonry chimney. Figures 4 and 5 provide details of construction of the chimneys.

3.1.1 Chimney Designs

Chimney 1 is a 0.15 m (6 in) inside diameter air-insulated factory-built chimney constructed of three concentric metal pipes, each separated by an air space. The inside pipe is of stainless steel and the center and outer pipe (0.20 m/8 in and 0.25 m/10 in in diameter) are of aluminized and galvanized steel, respectively. The three pipes are held in place by four spacers at the ends of each chimney section. The entire chimney is capped at the ends to minimize the air circulation both along the length of the chimney and between the two air spaces formed by the walls of the chimney. Total chimney height is 3 m (10 ft) plus 1.8 m (6 ft) of single-wall steel chimney connector between the appliance outlet and the chimney inlet. The chimney is a listed unit.

Chimney 2 is a 0.15 m (6 in) inside diameter solid-packed factory-built chimney. Outside diameter of the chimney was 0.20 m (8 in). High temperature insulation separates the inner chimney wall of stainless steel and the outer chimney wall of aluminum coated steel. Total chimney height is 3 m (10 ft) plus 1.8 m (6 ft) of single-wall steel chimney connector between the appliance outlet and the chimney inlet. The chimney system is a listed unit.

Chimney 3 is a masonry chimney constructed to minimum building code requirements. A nominal 0.3 m x 0.3 m (12 in x 12 in) fireclay flue liner is encased by a single course of nominal 0.1 m (4 in) wide common brick. The flue liner was separated from the brick by a minimum 25 mm (1 in) air space. Total height of the masonry chimney was 3.5 m (12 ft) plus 0.9 m (3 ft) of single wall chimney connector between the appliance outlet and the chimney inlet.

Chimney 4 is a 0.15 m (6 in) inside diameter solid-packed factory-built chimney similar to chimney 2. Both chimney walls are of stainless steel and the chimney sections join differently than those of chimney 2. Height and connection are the same as chimney 2. The chimney is a listed unit. Chimney 4 was selected because it was identified in accident data as being involved in a large number of fires.

Chimney 5 is a 0.2 m (8 in) inside diameter solid-packed factory-built chimney of a design identical to chimney 4 (except for the chimney diameter). Total chimney height was 5.6 m (18.4 ft) plus 1.2 m (4 ft) of single-wall steel chimney connector between the appliance outlet and the chimney inlet. The chimney is a listed unit.

3.1.2 Installation

The four factory-built chimney systems were installed with clearances to combustible materials as recommended by the manufacturer. Typically, the minimum clearance to combustibles was specified as 50 mm (2 in). For chimney 2, however, a clearance of 25 mm (1 in) was allowed where the chimney passed through walls and ceilings with the use of a chimney support/radiation shield. The masonry chimney was installed with a clearance of 25 mm (1 in) to combustible materials, consistent with minimum recommendations in model building codes.

An enclosure of 13 mm (1/2 in) thick exterior grade plywood was constructed around chimneys 1 through 4 surrounding these chimneys on all sides. The enclosure began at the base of the chimney, encased the chimney for 2.4 m (8 ft) vertically, and was closed at both ends with typical floor and ceiling construction. Details of the enclosure are presented in figure 5. Chimney 5 was installed without an enclosure and exposed to outside conditions throughout the test series.

3.2 Appliance Design

Two different wood-burning appliances were used during the creosote buildup tests. The appliances were chosen as two different designs (radiant and convective types) and sizes. Construction details are described below.

Appliance 1 is a small radiant room heater constructed of 6.4 mm (1/4 in) and 8 mm (5/16 in) plate steel for the top, sides, and bottom of the appliance. The inside of the firechamber is lined with fire brick refractory. The door is cast iron with a single draft inlet and draft control knob to adjust the intensity of the fire. A 0.15 m (6 in) diameter flue collar projects out

the back of the unit and sheet steel bottom heat shield is attached to block radiation from the appliance to the floor surface. The appliance was 46 cm long by 37 cm high by 65 cm wide (18 x 14 1/2 x 25 1/2 in) with a hearth area of 1250 cm^2 (194 in^2).

Appliance 2 is a circulating or convective type room heater, a radiant room heater with an exterior cabinet allowing air circulation around the appliance. The firebox is constructed of cast iron and the cabinet of sheet steel. A thermostatically controlled damper regulates the air supply for combustion. Wood inside the unlined firebox rests on a grate with an ash pan and ash door below for removal of ashes. The flue collar attachment for a 0.15 m (6 in) diameter flue is on the back of the appliance. The appliance was larger than appliance 1, measuring 53 cm x 89 cm x 54 cm (21 in x 35 in x 21 in) with a hearth area of 2280 cm^2 (353 in^2).

3.3 Temperature Control

For the creosote buildup tests, the temperature of the flue gas entering the chimney was maintained within preset limits in order to 1) prevent the gas temperature from rising enough to ignite the deposits in the chimney, 2) to keep flue gas temperatures low to promote creosote production, and 3) to allow unattended operation of the appliances. Thus, when the flue gas temperature fell below a predetermined lower limit, the draft inlet on the appliance was opened fully and when the temperature rose above a second predetermined limit, the draft inlet on the appliance was closed completely. A dual set point temperature controller was used with relay outputs and associated electronics to power a linear stepping motor to open or close the draft inlet of the appliance. Limit switches were installed on the appliance draft inlet to sense when the inlet was fully open or fully closed and protect the motor from burnout. The control temperature was measured approximately 0.25 m (10 in) from the base of the chimney. Figure 6 illustrates the temperature control circuitry.

3.4 Instrumentation

The appliances, chimney connector, and chimney were instrumented to measure conditions throughout the tests. All instrument data were automatically recorded at regular intervals on a digital data acquisition system.

Twenty-four-gauge chromel-alumel thermocouples were used to measure temperatures on appliance surfaces, chimney surfaces and on the face of combustible surfaces adjacent to the chimneys. Flue gas temperatures were monitored with shielded 24-gauge thermocouples mounted in the center of the flue. Thermocouples were placed in the flue gas, on the inside wall of the chimney, on the outside wall of the chimney, and at four locations on the enclosure approximately every 0.3 m (1 ft) for the entire height of the chimney. Thermocouple locations for the factory-built chimneys are indicated in tables 1 and 2 as well as in figures 7 and 8. Locations of thermocouples in the masonry chimney are shown in table 3 and figure 9.

4. FIRING CONDITIONS

A total of 19 experiments were conducted on the five different chimneys previously described. Typically, three types of experiments were conducted with each chimney--a creosote buildup test, a creosote burnout test, and an overfire test. The creosote buildup test consisted of a lengthy firing (from one week to several months) at low burning rates (controlling the flue gas temperature) to generate and deposit creosote on the lining of the chimney. Details of one day's buildup in each of the five chimneys is provided in this report. A creosote burnout test followed the period of creosote buildup. After the deposits were ignited, the chimney fire was allowed to burn until it burned out. No attempt was made to extinguish the fires. Several burnout tests were conducted on each chimney. For ease of discussion, the tests were assigned a test number, one through twelve. Test results are presented with these test numbers. Data acquisition continued until maximum temperatures were reached. The overfire tests, prolonged firing at high burning rates, were conducted for comparison of maximum temperatures during a chimney fire with those during extreme firing of a clean chimney. The test lasted as long as necessary to reach maximum temperatures.

In table 4, details of the twelve burnout tests are presented. Also detailed in table 4 are the length of the buildup prior to each burnout test and the amount of wood burned.

4.1 Test Procedure, Buildup Tests

Using the temperature controllers described earlier allowed continuous operation of the appliances for 24 hours per day, five days per week. Each appliance was charged with wood in the morning, refueled as necessary during the day and fully loaded in the evening for overnight burning. Typically, the flue gas temperature was maintained between 80°C (176°F) and 100°C (212°F) for the duration of the buildup tests. From table 4, an average of 1.6 kg/hr (3.6 lb/hr) of wood was burned in the buildup experiments. The amount of wood consumed was, of course, dependent upon the appliance size. Since the experiments were conducted in a conditioned laboratory space, the effect of variations in outside air temperature was minimal. Periodically, the chimney connector pipes were removed to examine the progress of the buildup. Table 4 provides the thickness of buildup at the base of the chimney prior to each burnout test.

4.2 Test Procedure, Burnout Tests

Following the lengthy buildup period, the deposits in the chimney were ignited and allowed to burn until it was evident that maximum temperatures had been reached. To ignite the creosote deposits, a large hot fire was built in the appliance firebox to raise the flue gas temperature (and the temperature of the deposits) high enough to lead to ignition of the creosote. Typically temperatures in excess of 650°C to 725°C (1170°F to 1300°F) were obtained at the appliance outlet before ignition of the deposits was evident. Once it was apparent that the creosote had ignited, all wood was removed from the firebox to observe the effects of the chimney fire alone. The fire was allowed to burn until it died out naturally. Data were recorded until temperatures on surrounding combustibles reached maximum levels and began to decrease. For chimneys 1 to 4, ambient conditions surrounding the chimneys was controlled to about 20 to 24°C (68 to 75°F) for the tests.

For chimney 5, outside air temperature at the beginning of the test was -6°C (21°F). As with the other burnout tests, the deposits were ignited with a large hot fire on the firebox. Once it was apparent that the deposits had ignited, all wood was removed from the firebox to observe the effects of the chimney fire alone. For the first 100 minutes of the test, the fire was mainly confined to the chimney connector, with little burning in the chimney. Upon investigation (by removal of the bottom plate of the Tee) the reason for this became obvious — deposits from the upper levels of the chimney had fallen to nearly totally block the chimney at the Tee. After dislodging the blockage at the Tee, an intense fire in the chimney ensued.

4.3 Test Procedure, Overfire Tests

Underwriters Laboratories standard 1482 for solid fuel burning room heaters provides guidelines for testing wood-burning appliances [28]. In the "brand-fire test," specially constructed, oven-dry douglas fir brands are added at 7 1/2 minute intervals after ignition until it is apparent that maximum temperatures have been reached. The brands are constructed as two crossed layers of nominal 25 mm (1 in) douglas fir spaced 25 mm (1 in) apart on center. Each brand is sized (width x length) to be approximately 1/3 the area of the hearth of the appliance.

5. TEST RESULTS

5.1 Buildup Tests

Measurements of flue gas temperature, chimney surface temperatures, and enclosure temperature at the base of the chimney during a day of typical buildup are shown in figures 10 to 14 for the five chimneys studied. Average temperatures over the entire duration of the tests are presented in tables 5 to 9 and figures 15 to 19 as profiles of temperature through the entire height of the flue.

5.2 Burnout Tests

Measurements of flue gas temperature, chimney surface temperatures, and enclosure temperature at the base of the chimney during the twelve burnout tests are presented in figures 20 to 31 for the five chimneys studied. Maximum temperatures over the entire duration of the tests are presented in tables 10 to 21 and figures 32 to 43. The duration of these elevated temperatures is presented in figures 44 to 48 as the amount of time during the test the temperature of the flue gas or chimney wall temperature was above given levels. The duration of time the enclosure temperature exceeded a level of 50°C (90°F) above ambient temperature is shown in figure 49. Table 22 summarizes the temperature levels attained in the tests.

5.3 Overfire Tests

Measurements of flue gas temperature, chimney surface temperatures, and enclosure temperature at the base of the chimney during the five overfire tests are shown in figures 50 to 54. Maximum temperatures over the entire duration of the tests are presented in figures 55 to 59 and in tables 23 to 27.

6. BUILDUP TESTS

Temperature profiles during the buildup tests on the five chimneys (figures 15 to 19) were understandably similar due to the controlled flue gas temperature. The average temperatures at the base of the chimneys were:

Chimney	Gas	Inner Lining	Outer Surface	Enclosure
	(°C/°F)	(°C/°F)	(°C/°F)	(°C/°F)
1	88/190	59/138	29/84	25/77
2	89/192	69/156	39/102	27/81
3	76/169	52/126	40/104	34/93
4	88/190	76/169	45/113	30/86
5	85/184	69/156	13/55	n.r.

n.r. = not recorded

The flue gas temperatures were somewhat lower in the masonry chimney due to the high mass and larger size of the masonry chimney. A reduced draft in the larger masonry chimney kept firing rates low and made control of the flue gas temperature difficult and response sluggish. The high mass of the chimney led to slow response to changes in the air inlet. However, once operating temperatures were reached in the masonry chimney, steady temperatures were easily maintained with little variation in the flue gas temperature.

Enclosure temperatures rose little above ambient temperatures during the buildup tests. Maximum temperature rises above ambient on the enclosures were +3°C (5°F), +5°C (9°F), +12°C (22°F), and +10°C (18°F) for chimneys 1 through 4, respectively. Since chimney 5 was installed outdoors, with no enclosure, no readings were recorded for this chimney.

Surprisingly, significant levels of creosote deposits were generated on the linings of all chimneys in very short periods of time in a laboratory space whose air temperature averaged approximately 25°C (77°F) in the vicinity of the chimneys. The buildup of deposits prior to tests 1 and 5 resulted from a total of only seven days continuous burning. After this short period, deposits up to 3 mm to 6 mm (1/8 in to 1/4 in) were evident in the chimneys. During the longer tests, connector pipe elbows became clogged with deposits after about six weeks. The heaviest buildup was noted for the test of chimney 5. Since this chimney was allowed to build deposits over a longer period of time and was exposed to ambient temperatures much lower than the other chimneys, this result was expected.

Since the chimneys were not disassembled and weighed during the tests, no quantitative data are available on the relative amounts of creosote produced. Significant levels of creosote deposits were generated in the five different chimney designs, with both hard/seasoned and soft/green woods. This is consistent with other studies. No discernable difference was noted in the level of buildup between the two appliances used in the buildup tests. Both appliances produced thicknesses of deposit sufficient for severe chimney fires.

7. BURNOUT TESTS

7.1 Gas Temperatures

The highest flue gas temperatures were usually noted in the section of the chimney connector closest to the appliance during the burnout tests. Peak temperatures for all chimneys ranged from a low of 908°C (1666°F) to a high of more than 1370°C (2500°F).

Peak Flue Gas Temperatures

Chimney	Peak Temperature (°C/°F)							
1	(1)	1008/1846	(2)	988/1810	(3)	1109/2028	(4)	996/1825
2	(5)	958/1756	(6)	965/1769	(7)	1050/1922	(8)	1030/1886
3	(9)	1095/2003						
4	(10)	908/1666	(11)	1022/1872				
5	(12)	>1370/>2500						

Note: Numbers in parentheses are test numbers of the burnout tests

The average peak flue gas temperatures in the four chimneys tested in a conditioned laboratory were 1025°C (1877°F), 1044°C (1911°F), 1095°C (2003°F), and 965°C (1769°F) for chimney 1, 2, 3, and 4, respectively. The difference between the lowest average flue gas temperature (chimney 4) and the highest average flue gas temperature (chimney 3) was only 12 percent. Chimney 5, the solid-packed chimney tested outdoors in a colder environment was markedly different, however. Peak flue gas temperature during this test exceeded 1370°C (2500°F), 275°C (495°F) higher than the highest temperature recorded during the tests in a conditioned laboratory and 358°C (645°F) higher than the average peak temperature noted during the eleven indoor tests.

At the base of the chimney, beyond the chimney connector, temperatures were generally lower. Temperature measurement was made approximately 0.25 m (10 in) from the base of the chimney at a point 2.1 m (82 in) from the appliance outlet for the factory-built chimneys tested in a conditioned laboratory space (chimneys 1 to 4). Since the masonry chimney was connected to the appliance by a shorter (0.9 m/3 ft) section of chimney connector, temperature

measurement was made at a point 1.2 m (4 ft) from the appliance outlet. Consequently, a higher flue gas temperature at the base of the chimney was recorded during the burnout test of the masonry chimney at 1095°C (2003°F) than for the other indoor chimneys. At a point 2.1 m (6.8 ft) from the appliance outlet, flue gas temperature in the masonry chimney was 918°C (1684°F), within the range of temperatures noted for chimneys 1, 2, and 4. For the other tests, the average maximum flue gas temperature at the base of the chimney was 883°C (1621°F) with a coefficient of variation of ± 9 percent. As before, temperatures recorded during the burnout test of chimney 5 were considerably higher than those noted for the other chimneys. Individual maximums taken from figures 20 through 31 or tables 10 to 21 were:

Flue Gas Temperatures at the Base of the Chimneys

Chimney	Peak Temperature (°C/°F)			
1	(1) 870/1598	(2) 711/1311	(3) 933/1711	(4) 931/1707
2	(5) 902/1655	(6) 954/1749	(7) 810/1490	(8) 889/1632
3	(9) 1095/2003			
4	(10) 851/1563	(11) 974/1785		
5	(12) 1370/2498			

Note: Numbers in parentheses are test numbers of the burnout tests

Maximum flue gas temperatures within the chimney were not always recorded at the base of the chimney. Location of peak temperature inside the chimney varied from the base of the chimney in the majority of tests (4 to 10 and 12) to the top of the chimney during test 2. Maximum temperatures were always close to the temperature measured at the base of the chimney:

Maximum Flue Gas Temperatures Inside Chimney

Chimney	Peak Temperature (°C/°F)			
1	(1) 948/1738	(2) 754/1389	(3) 934/1713	(4) 931/1707
2	(5) 902/1655	(6) 954/1749	(7) 810/1490	(8) 889/1632
3	(9) 1095/2003			
4	(10) 851/1563	(11) 984/1803		
5	(12) 1370/2498			

Note: Numbers in parentheses are test numbers of the burnout tests

The average maximum flue gas temperature inside the chimney for the factory-built chimneys tested indoors (chimneys 1, 2, and 4) was 896°C (1644°F) with a coefficient of variation of ± 8 percent. If chimney 5 is included in the average, this temperature rises to 939°C (1745°F) ± 17 percent

Temperature variation from the base of the chimney to the top of the chimney (figures 32-43) was usually 200°C (360°F) or less. The largest variation in flue gas temperature over the length of the chimney was recorded for the masonry chimney (610 to 1095°C/1130 to 2003°F), the smallest in the solid-packed factory-built chimneys--838 to 889°C (1540 to 1632°F) during test 8 and 902 to 984°C (1656 to 1803°F) during test 11--a range of only 51°C (92°F) and 82°C (148°F), respectively:

Variation in Peak Flue Gas Temperatures Inside the Chimney

Chimney	Temperature Range (°C)			
1	(1) 767-948	(2) 642-754	(3) 724-934	(4) 726-931
2	(5) 756-902	(6) 775-954	(7) 665-810	(8) 838-889
3	(9) 610-1095			
4	(10) 633-851	(11) 902-984		
5	(12) 921-1370			

Chimney	Temperature Range (°F)			
1	(1) 1413-1738	(2) 1188-1389	(3) 1335-1713	(4) 1339-1708
2	(5) 1393-1656	(6) 1427-1749	(7) 1229-1490	(8) 1540-1632
3	(9) 1130-2003			
4	(10) 1171-1564	(11) 1656-1803		
5	(12) 1690-2498			

Note: Numbers in parentheses are test numbers of the burnout tests

The high thermal mass of the masonry chimney, combined with slower moving flue gas due to the larger size of the masonry chimney flue allowed the gas to cool to lower temperatures. The large range noted for chimney 5 was due to the colder ambient temperature leading to faster heat loss from the flue gas

to the chimney surfaces. The lower mass but effective insulation of the solid-packed factory-built chimneys led to less heat loss along the length of these chimneys than noted for the masonry chimney.

The duration of the chimney fires as evidenced by elevated chimney temperatures varied considerably from test to test, even with similar periods of creosote buildup. The length of the chimney fires, defined here as flue gas temperatures greater than 200°C (392°F), varied from 760 s to 5940 s--more than 1 1/2 hours:

Duration of Flue Gas Temperatures Above 200°C (392°F) During Chimney Fires

Chimney	Time (s)			
1	(1) 2280	(2) 5415	(3) 760	(4) 980
2	(5) 3210	(6) 2625	(7) 840	(8) 1310
3	(9) 1040			
4	(10) 940	(11) 3390		
5	(12) 5940			

Note: Numbers in parentheses are test numbers of the burnout tests

The duration of higher temperatures and of peak temperatures was considerably less, however. Flue gas temperatures were above 700°C (1292°F) for only 100 s to 2250 s during the burnout tests:

Duration of Flue Gas Temperatures Above 700°C (1292°F) During Chimney Fires

Chimney	Time (s)			
1	(1) 860	(2) 100	(3) 500	(4) 310
2	(5) 690	(6) 865	(7) 250	(8) 380
3	(9) 440			
4	(10) 260	(11) 1290		
5	(12) 2250			

Note: Numbers in parentheses are test numbers of the burnout tests

Flue gas temperatures at levels above 1000°C (1832°F) were rarer still. Temperatures of 1000°C (1832°F) were reached in only seven of the twelve burnout tests. The duration of time above 1000°C (1832°F) ranged from only 10 s in test 1 to 500 s in test 12:

Duration of Flue Gas Temperatures Above 1000°C (1832°F) During Chimney Fires

Chimney	Time (s)			
1	(1) 10	(2) 0	(3) 370	(4) 0
2	(5) 0	(6) 0	(7) 90	(8) 50
3	(9) 190			
4	(10) 0	(11) 50		
5	(12) 500			

Notes: Numbers in parentheses are test numbers of the burnout tests

7.2 Chimney Surface Temperatures

Temperatures on the outside surface of the inside chimney wall (the flue liner) were, naturally, lower than the flue gas temperatures--averaging 186°C (336°F) lower. As with the flue gas temperatures, the peak inner chimney surface temperature was not necessarily recorded at the base of the chimney. Peak temperatures for all chimneys ranged from a low of 265°C (509°F) in the masonry chimney to 1111°C (2031°F) in one of the solid-packed factory-built chimneys:

Peak Chimney Surface Temperatures

Chimney	Peak Temperature (°C/°F)			
1	(1) 778/1432	(2) 653/1207	(3) 814/1497	(4) 906/1662
2	(5) 758/1396	(6) 867/1592	(7) -	(8) 874/1605
3	(9) 265/509			
4	(10) 715/1319	(11) 917/1682		
5	(12) 1111/2031			

Note: Numbers in parentheses are test numbers of the burnout tests

Few differences were noted comparing the peak inner chimney surface temperatures of the three factory-built chimneys tested in a conditioned laboratory space (chimneys 1, 2, and 4). The average of peak temperatures for all tests of the three individual factory-built chimneys were 788°C (1450°F), 805°C (1481°F), and 812°C (1494°F)--a range of only 24°C (43°F). Understandably, the temperature on the masonry chimney was lower. Since all inner chimney wall temperatures were measured on the outer surface of the wall, the 16 mm (5/8 in) of fire clay flue lining provided more insulation to heat conduction than the thinner stainless steel linings of the factory-built chimneys. Following the flue gas temperatures, inner chimney wall temperatures for chimney 5 were considerably higher than those recorded for the other chimneys.

Variation in the inner chimney wall temperatures from the base of the chimney to the top was larger in magnitude than the variation in flue gas temperatures, averaging 234°C (422°F). Lowest temperatures were usually, although not always, noted at the top of the chimney. Since the upper sections of chimney in all tests was not enclosed, greater heat loss was possible high in the chimney:

Variation in Inner Chimney Wall Temperatures

Chimney	Temperature Range (°C)			
1	(1) 590-778	(2) 488-653	(3) 514-814	(4) 640-906
2	(5) 448-758	(6) 531-867	(7) 465-721	(8) 650-874
3	(9) 108-265			
4	(10) 413-715	(11) 836-909		
5	(12) 714-1111			

Chimney	Temperature Range (°F)			
1	(1) 1094-1432	(2) 910-1207	(3) 957-1497	(4) 1184-1663
2	(5) 838-1396	(6) 988-1593	(7) 869-1330	(8) 1202-1605
3	(9) 226-509			
4	(10) 775-1319	(11) 1537-1668		
5	(12) 1317-1111			

Note: Numbers in parentheses are test numbers of the burnout tests

Peak temperatures on the exterior surface of the chimneys ranged from 46°C (115°F) on the outside surface of the masonry chimney to 433°C (811°F) on the outside surface of the air-insulated factory-built chimney. Averages of peak temperatures for all tests of the individual chimneys were 376°C (709°F), 205°C (401°F), 46°C (115°F), 212°C (414°F), and 289°C (552°F) for chimney 1, chimney 2, chimney 3, chimney 4, and chimney 5, respectively:

Peak Outer Chimney Surface Temperature

Chimney	Peak Temperature (°C/°F)							
1	(1)	420/788	(2)	325/617	(3)	327/620	(4)	433/811
2	(5)	222/431	(6)	233/451	(7)	200/392	(8)	168/334
3	(9)	46/114						
4	(10)	137/278	(11)	288/550				
5	(12)	289/552						

Note: Numbers in parentheses are test numbers of the burnout tests

Thus, while flue gas temperatures were very similar in the four chimney designs, the different designs varied in their ability to retain the heat of the flue gas within the chimney. The masonry chimney, by virtue of its high mass, barely reacted at all to the relatively short duration of the chimney fire (940 s). In contrast, the light weight of the air-insulated chimney allowed temperatures to rise considerably.

The length of time the outside chimney surface remained at elevated temperature levels varied considerably from test to test. In several tests, 200°C (392°F) was never reached while in other tests, temperatures on the outside of the chimney were in excess of 200°C (392°F) for more than 1300 s:

Duration of Elevated Temperatures on Outside Chimney Wall

Chimney	Time (s)			
1	(1) 1390	(2) 1475	(3) 640	(4) 800
2	(5) 790	(6) 905	(7) 5	(8) 0
3	(9) 0			
4	(10) 0	(11) 1860		
5	(12) 1416			

Notes: Numbers in parentheses are test numbers of the burnout tests

7.3 Enclosure Temperatures

Temperature levels on the surfaces of the combustible enclosure facing the chimneys also varied considerably from test to test. Maximum temperatures measured ranged from 39°C (102°F) to 234°C (453°F). Following the ranking of the chimneys by outside surface temperature, the lowest temperatures were noted for the masonry chimney and the highest temperatures for the air-insulated chimney. Average maximum temperatures for all enclosure thermocouples in each test were 133°C (271°F), 91°C (196°F), 37°C (99°F) and 91°C (196°F) for chimney 1, chimney 2, chimney 3, and chimney 4, respectively. Since no enclosure was used for chimney 5, no data are noted:

Peak Enclosure Surface Temperature

Chimney	Peak Temperature (°C/°F)			
1	(1) 154/309	(2) 182/359	(3) 177/350	(4) 234/453
2	(5) 97/206	(6) 112/233	(7) 112/233	(8) 95/203
3	(9) 39/102			
4	(10) 62/143	(11) 149/300		
5	(12) -			

Note: Numbers in parentheses are test numbers of the burnout tests. No enclosure wall used for chimney 5.

In all tests but one, peak temperatures on the enclosure surface were recorded at the topmost thermocouple location. During the test of the masonry chimney, the highest temperature was noted at the base of the enclosure. However,

during this test, all the enclosure temperatures were within 3°C (5°F) of the peak temperature of 39°C (102°F) with a rise in temperature of only 10 to 13°C (18 to 23°F) above room ambient air temperature.

Temperatures on combustible enclosure surfaces were elevated for considerable periods of time during most tests. Enclosure temperatures exceeded the criterion used for testing and listing of chimneys of 50°C (90°) above room temperature for times as long as 56 minutes. In some tests, temperatures on enclosure surfaces were elevated for periods of time equal to or greater than the duration of the creosote fire in the chimney:

Duration of Elevated Temperatures on Enclosure Surfaces
(50°C/90°F Rise Above Room Temperature)

Chimney	Time (s)			
1	(1) 1350	(2) 2150	(3) 610	(4) 1660
2	(5) 750	(6) 945	(7) 145	(8) 1170
3	(9) 0			
4	(10) 0	(11) 3330		
5	(12) -			

Note: Numbers in parentheses are test numbers of the burnout tests. No enclosure was used for chimney 5.

7.4 Damage to Chimney Systems

There was little visible damage to the chimneys after most of the chimney fires. After four chimney creosote burnouts of chimney 1, degradation of the galvanized outer pipe was evidenced by a dulling of the coating on the upper sections of the chimney. While this would not affect chimney performance immediately, the loss of galvanization would lead to corrosion over longer periods of time. Flue linings were undamaged. After tests of chimneys 2 and 4 (two solid-packed factory-built chimneys) no damage was apparent on the interior or exterior of the chimneys. Flue linings were relatively clean, with no distortions visible.

Damage to chimney 3 (a masonry chimney) and to chimney 5 (a solid-packed factory-built chimney) were more significant, however. Inspection of the masonry chimney after the creosote burnout test revealed cracks along the molding seams of the tile liners 6 to 12 mm (1/4 to 1/2 in) in width along the entire length of the chimney. Numerous smaller cracks were evident throughout the liner sections upon subsequent disassembly of the chimney. After the test of chimney 5, damage was evident in all sections of the chimney. In the Tee section, where temperatures were the highest, holes were found over the entire surface of the inner wall. The holes ranged in size from small, barely noticeable penetrations to one approximately 50 by 80 mm (2 by 3 in). Although most severe at the base of the chimney, buckling of the inner wall was apparent in all sections. Buckling in both the radial and longitudinal directions was found, resulting in separation at the ends of each section and exposing the insulation between the walls. Figures 60 to 63 illustrate the damage to chimneys 3 and 5.

8. OVERFIRE TESTS

Overfire tests--continuous firing at maximum rates for extended periods of time--were conducted to compare with temperature levels attained during the chimney fire burnout tests. Each chimney and appliance combination was fired continuously until maximum temperatures were attained on all surfaces. All chimneys, except chimney 5, were tested prior to conducting creosote burnout tests. Chimney 5 was tested in a damaged condition to assess temperatures on exterior surfaces after damage had occurred.

8.1 Maximum Temperatures

Maximum temperatures recorded during the overfire tests were always noted at the base of the chimney or in the lower sections of the chimney. Temperatures at the base of the chimney ranged from 772 to 916°C (1422 to 1681°F) in the flue gas, 358 to 849°C (676 to 1560°F) on the inner wall of the chimney, 143 to 305°C (289 to 581°F) on the outer wall of the chimney and 57 to 145°C (135 to 293°F) on the enclosure. Peak temperatures at any position within the chimney were similar to those recorded at the base of the chimney:

Maximum Temperatures During Overfire Tests

At Base of Chimney

Chimney	Flue Gas	Inner Wall	Outer Wall	Enclosure
		(°C/°F)		
1	830/1526	654/1209	182/360	57/135
2	939/1722	673/1243	199/390	66/151
3	772/1422	358/676	143/289	100/212
4	916/1681	849/1560	305/581	145/293
5	692/1277	n.r.	160/320	-

Overall

Chimney	Flue Gas	Inner Wall	Outer Wall	Enclosure
		(°C/°F)		
1	836/1537	668/1234	270/518	118/244
2	939/1722	831/1528	206/403	108/226
3	772/1422	358/676	156/313	116/241
4	916/1681	849/1560	334/633	171/340
5	718/1324	635/1175	160/320	-

n.r. = not recorded. No enclosure was used for chimney 5.

The average of the peak flue gas temperatures during the overfire tests of the factory-built chimneys was 830°C (1526°F) with a coefficient of variation of ± 12 percent--somewhat lower than the average of the peak flue gas temperatures during the burnout tests. During most tests of the factory-built chimneys, inside chimney surface temperatures were, in contrast, considerably lower during the overfire tests than during the burnout tests. In the overfire test of the masonry chimney, both flue gas temperatures and chimney surface temperatures were higher than those recorded during the burnout tests.

During a creosote burnout, combustion takes place on or near the chimney walls. Thus, measurement of the flue gas at the midpoint of the chimney may not indicate maximum temperatures in the chimney. Temperatures are likely to be considerably higher nearer to the walls of the chimney. Thus, a measurement of simply a single flue gas temperature may not be sufficient to fully understand the effects of a chimney fire. In the masonry chimney, the high thermal mass of the chimney and the relatively short duration of the chimney fire allowed the chimney to absorb the heat from the chimney fire.

8.2 Duration of Elevated Temperatures

Perhaps more enlightening than peak temperatures is the duration of elevated temperatures during the overfire tests. Flue gas temperatures were above 200°C (392°F) for 87 to 98 percent of the overfire tests of the factory-built chimneys but only 34 percent of the duration of the masonry chimney overfire test. Gas temperatures were above 700°C (1292°F) for 12 to 39 percent of the tests of the factory-built chimneys but only 0.4 percent of the masonry chimney test. Enclosure surface temperatures, however, do not reveal the same split. Temperatures on the surfaces surrounding the chimneys were more than 50°C (90°F) above room temperature for 11 to 89 percent of the time during the overfire tests of the factory-built chimneys and 50 percent of the time during the masonry chimney overfire test.

Duration of Elevated Temperatures During Overfire Tests

Chimney	Flue Gas > 200°C	Flue Gas > 700°C	Outer Surface > 200°C	Enclosure > 50°C rise
	(%)	(%)	(%)	(%)
1	95	12	n.r.	25
2	95	15	n.r.	11
3	34	0.4	n.r.	50
4	87	39	75	89
5	98	31	n.r.	-

n.r. = not reached. No enclosure was used for chimney 5.

9. CONCLUSIONS

A total of 22 tests were conducted on five chimneys of differing designs. The tests were run to investigate the effects of creosote fires on the chimneys and on surrounding combustibles. Three series of tests were conducted:

- Five "buildup tests" where measurements of chimney temperatures and surrounding surface temperatures were recorded for a full day during the long periods of low-level burning to deposit creosote on the chimney surfaces,

- Twelve "burnout tests" where the deposits were ignited and allowed to burn freely until maximum temperatures were reached in the chimney and on surrounding surfaces, and

- Five "overfire tests" where the appliances were fired at high rates for extended periods of time until steady-state conditions were obtained.

Significant levels of buildup were noted in all chimneys using both seasoned hardwoods and green softwoods. While buildup rates and quantities of deposits were not measured quantitatively, little difference was noted in the amount of buildup thickness during the various tests. Flue gas temperature, chimney surface temperature, and duration of the buildup period appear to be more important to creosote buildup than the type of chimney used or wood burned.

Flue gas temperatures in excess of 1370°C (2498°F) were obtained for short periods of time during the chimney fire "burnout tests." Maximum chimney surface temperatures over 1100°C (2000°F) were recorded. The fire clay flue lining of the masonry chimney was severely cracked during the chimney fire "burnout test." However, because of the chimney's high mass, temperatures on the outside brick surface never approached an unacceptable level of 50°C (90°F) above ambient temperature as defined in the various testing standards [17,27]. Severe damage was noted after one chimney fire in one of the factory-built chimney tests. Holes were found in the inner wall of the chimney near the base and buckling of the metal lining was noted in all sections.

Temperatures on surrounding combustible surfaces reached as high as 234°C (453°F) during the "burnout tests," far in excess of acceptable limits and nearing the ignition temperature commonly reported for wood. The highest enclosure temperatures were noted during tests of the air-insulated chimney, the lowest during tests of the masonry chimney. Enclosure temperatures exceeded the criterion used for testing and listing of chimneys of 50°C (90°F) above room temperature for times as long as 56 minutes. In some tests, temperatures on surrounding combustibles were elevated above acceptable limits for periods of time equal to or greater than the duration of the creosote fire in the chimney.

"Overfire tests"--continuous firing at maximum rates for extended periods of time--were nearly as severe as the "burnout tests." Flue gas temperatures of 772 to 939°C (1422 to 1722°C) were recorded. Enclosure surface temperatures as high as 171°C (340°F) were obtained. In addition, flue gas temperatures during the "overfire tests" were above 200°C (392°F) for 87 to 98 percent of the duration of the tests and above 538°C (1000°F) for 3 to 58 percent of the duration of the tests.

Some specific conclusions can be made based upon the results of these tests:

- Current test procedures for factory-built chimneys include provisions for testing to simulate chimney fires by a 10 minute test at a flue gas temperature of 927°C (1700°F) or three 10 minute tests at 1149°C (2100°F). Based upon the tests reported herein, the duration of a chimney fire simulation should be longer--a period of 20 minutes or longer would be more appropriate. Little damage to chimney systems were noted at temperatures of 927 to 1149°C (1700 to 2100°F). Significantly higher temperatures were recorded during a test of one chimney in cold climatic conditions, with notable damage to the chimney. However, the results presented in this report are based upon a limited number of tests. Other chimney systems, and certainly colder climatic conditions could lead to more severe results. More tests would be necessary to provide information on reproducibility and temperature levels for other appliances and chimneys.

- Since burning occurs on and near the chimney walls, measurement of flue gas temperature near the walls or of chimney wall surface temperature is more appropriate than measurement of flue gas temperature at a single point on the center of the flue.

- Highest flue gas temperatures were usually noted at or near the appliance flue outlet. If damage were to occur due to the heat generated by a chimney fire, it would most likely occur near the appliance flue outlet. Thus, placing of factory-built chimney sections directly at the appliance flue outlet may be hazardous. Since flue gas tempera-

tures are the highest at this location and since the factory-built chimney sections are insulated to hold the heat in, excessive temperatures may result. A length of single wall chimney connector (with proper clearances to nearby combustibles) would reduce the problem.

- Particularly noticeable on the surrounding combustible surfaces were the high temperatures resulting from the long duration of the overfire tests. Temperature rises in excess of recommended limits were recorded for long periods of time for all four chimneys. In some cases, temperature rises of more than 150°C (270°F) were noted.

10. REFERENCES

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Table 1
Instrumentation for Chimneys 1, 2, and 4

Measurement	Locations
Ambient Air Temperature	
Flue Gas in Connector	0.5, 1.4 m level, measured from appliance outlet.
Flue Gas in Chimney	2.1, 2.3, 2.9, 3.1, 3.6, 3.9, 4.4, 4.6 m level, measured from appliance outlet.
Inner Chimney Wall	2.1, 2.3, 2.9, 3.1, 3.6, 3.9, 4.4, 4.6 m level, measured from appliance outlet.
Outer Chimney Wall	2.1, 2.3, 2.9, 3.1, 3.6, 3.9, 4.4, 4.6 m level, measured from appliance outlet.
Enclosure Surface	2.1, 2.3, 2.9, 3.1, 3.6, 3.9 m level, measured from appliance outlet.

Table 2
Instrumentation for Chimney 5

Measurement	Locations
Ambient Air Temperature	
Flue Gas in Connector	0.5, 1.2 m level, measured from appliance outlet.
Flue Gas in Chimney	1.5, 2.0, 2.2, 2.7, 3.0, 3.5, 3.8, 4.3, 4.5, 5.0, 5.3, 5.8, 6.1, 6.6, 6.8 m level, measured from appliance outlet.
Inner Chimney Wall	2.0, 2.2, 2.7, 3.0, 3.5, 3.8, 4.3, 4.5, 5.0, 5.3, 5.8, 6.1, 6.6, 6.8 m level, measured from appliance outlet.
Outer Chimney Wall	2.0, 2.2, 2.7, 3.0, 3.5, 3.8, 4.3, 4.5, 5.0, 5.3, 5.8, 6.1, 6.6, 6.8 m level, measured from appliance outlet.

Table 3
Instrumentation for Chimney 3

Measurement	Locations
Ambient Air Temperature	
Flue Gas in Chimney	0.6, 1.2, 1.8, 2.4, 3.1, 3.5 m level, measured from appliance outlet.
Inner Chimeny Wall	0.3, 0.6, 0.9, 1.2, 1.5, 1.8, 2.1, 2.4, 2.7, 3.1, 3.4, 3.5 m level, measured from appliance outlet.
Outer Chimney Wall	0.3, 0.6, 0.9, 1.2, 1.5, 1.8, 2.1, 2.4, 2.7, 3.1, 3.4, 3.5 m level, measured from appliance outlet.
Enclosure Surface	0.3, 0.6, 0.9, 1.2, 1.5, 1.8, 2.1, 2.4, 2.7 m level, measured from appliance outlet.
Stove Surface	Door, Center Left Side, Center Right Side, Top Center, Back Center, Front Center.

Table 4
Summary of Creosote Burnout Tests in Several Chimneys

Test	Appliance	Chimney	Buildup Prior to Burnout[a] Ambient Temperature[e] (°C)	Total Wood Burned (kg/lb)	Average Burning Rate (kg/hr) (lb/hr)	Total Length of Buildup (hr)	Thickness of Deposit[c] (mm)	Wood Type
1	1	1 (Air-Insulated)	24	115/254	1.5/3.3	76[b]	3-13	Green Pine
2	1		19	1206/2659	2.1/4.6	568	13-19	Green Pine
3[d]	1		20	--	--	--	--	--
4	1		23	1015/2238	2.4/5.3	429	13-19	Green Pine
5	1	2 (Solid-Packed)	25	115/254	1.5/3.3	76[b]	3-13	Green Pine
6	1		23	1255/2767	2.1/4.6	594	13-19	Green Pine
7[d]	1		21	--	--	--	--	--
8	1		20	1015/2238	2.4/5.3	429	13-19	Green Pine
9	1	3 (Masonry)	22	746/1646	0.9/2.0	823	6-13	Seasoned Oak
10	1	4 (Solid-Packed)	22	565/1246	0.9/2.0	630	6-13	Seasoned Oak
11	2		23	639/1409	0.9/2.0	674	6-13	Seasoned Oak
12	2	5 (Solid-Packed)	-6	2733/6012	1.5/3.3	1752	13-64	Seasoned Oak

Notes: a - Flue gas temperature monitored and controlled at 80-100°C throughout the buildup tests.

b - Total length of low temperature burning. Tests were run eight hours per day.

c - Thickness of deposit is an estimation based upon an examination of the chimney sections prior to each burnout test. Thickness varied over the length of the chimney -- thickest deposit at the bottom of the chimney.

d - Tests 3 and 7 were run as a follow on to test 2 and 6, respectively, since deposit did not burn completely during these tests. Approximtely 25 percent of the deposit remained after tests 2 and 6.

e - Ambient air temperature at the beginning of the burnout test.

Table 5: Temperature Profiles From Chimney Buildup Test of Chimney 1

Table of Averages
(Air-Insulated)

Ambient Air Temperature (°C/°F): 24/76

Thermocouple Location	Level	Flue Gas Temperature (°C/°F)	Inner Wall Surface Temperature (°C/°F)	Outer Wall Surface Temperature (°C/°F)	Enclosure Surface Temperature Rise (°C/°F)	Appliance Surface Temperature (°C/°F)
Appliance Surface						82/179
Appliance Surface						112/235
Appliance Surface						119/247
Appliance Surface						128/264
Appliance Surface						119/246
Chimney Connector	(0.46 m)	125/257				
Chimney Connector	(1.37 m)	99/210				
Chimney Level 1	(2.08 m)	87/189	58/137	29/84	0/0	
Chimney Level 2	(2.34 m)	89/192	70/159	29/85	0/0	
Chimney Level 3	(2.85 m)	85/185	59/138	31/88	1/2	
Chimney Level 4	(3.10 m)	83/181	66/150	31/89	2/3	
Chimney Level 5	(3.61 m)	79/175	64/148	32/91	3/5	
Chimney Level 6	(3.86 m)	79/174	66/151	34/94	3/7	
Chimney Level 7	(4.37 m)	74/166	62/144	36/97		
Chimney Level 8	(4.62 m)	72/162	62/144	34/93		

Table 6: Temperature Profiles From Chimney Buildup Test of Chimney 2

Table of Averages
(Solid-Packed 1)

Ambient Air Temperature (°C/°F): 24/76

Thermocouple Location	Level	Flue Gas Temperature (°C/°F)	Inner Wall Surface Temperature (°C/°F)	Outer Wall Surface Temperature (°C/°F)	Enclosure Surface Temperature Rise (°C/°F)	Appliance Surface Temperature (°C/°F)
Appliance Surface						80/176
Appliance Surface						114/237
Appliance Surface						126/259
Appliance Surface						107/225
Appliance Surface						32/90
Chimney Connector	(0.46 m)	145/293				
Chimney Connector	(1.37 m)	85/186				
Chimney Level 1	(2.08 m)	88/192	69/156	39/102	1/2	
Chimney Level 2	(2.34 m)	84/184	74/165	40/105	1/3	
Chimney Level 3	(2.85 m)	82/181	47/117	39/103	3/5	
Chimney Level 4	(3.10 m)	81/179	69/156	37/100	4/7	
Chimney Level 5	(3.61 m)	79/174	67/154	36/96	4/8	
Chimney Level 6	(3.86 m)	78/172	*	37/99	5/10	
Chimney Level 7	(4.37 m)	72/162	65/149	39/103		
Chimney Level 8	(4.62 m)	72/162	61/142	31/88		

* Readings of zero were found in calculating this value

Table 7: Temperature Profiles From Chimney Buildup Test of Chimney 3

Table of Averages
(Masonry)

Ambient Air Temperature (°C/°F): 24/76

Thermocouple Location	Level	Flue Gas Temperature (°C/°F)	Inner Wall Surface Temperature (°C/°F)	Outer Wall Surface Temperature (°C/°F)	Enclosure Surface Temperature Rise (°C/°F)	Appliance Surface Temperature (°C/°F)
Appliance Surface						113/235
Appliance Surface						100/213
Appliance Surface						134/273
Appliance Surface						112/234
Appliance Surface						114/238
Appliance Surface						94/202
Chimney Level 1	(0.30 m)		52/125	39/103	8/15	
Chimney Level 2	(0.61 m)	76/169	58/138	43/110	11/20	
Chimney Level 3	(0.91 m)		59/139	44/111	12/22	
Chimney Level 4	(1.22 m)	71/161	58/137	44/111	12/22	
Chimney Level 5	(1.52 m)		54/130	43/110	11/21	
Chimney Level 6	(1.83 m)	63/145	52/126	41/107	10/19	
Chimney Level 7	(2.13 m)		48/120	39/103	9/17	
Chimney Level 8	(2.44 m)	55/131	46/115	38/101	9/17	
Chimney Level 9	(2.74 m)		43/110	36/96	8/14	
Chimney Level 10	(3.05 m)	45/114	40/105	32/89		
Chimney Level 11	(3.35 m)		37/99	31/87		
Chimney Level 12	(3.51 m)	39/102	34/93	30/87		

Table 8: Temperature Profiles From Chimney Buildup Test of Chimney 4

Table of Averages
(Solid-Packed 2)

Ambient Air Temperature (°C/°F): 24/76

Thermocouple Location	Level	Flue Gas Temperature (°C/°F)	Inner Wall Surface Temperature (°C/°F)	Outer Wall Surface Temperature (°C/°F)	Enclosure Surface Temperature Rise (°C/°F)	Appliance Surface Temperature (°C/°F)
Appliance Surface						104/219
Appliance Surface						125/257
Appliance Surface						114/238
Appliance Surface						101/215
Appliance Surface						99/211
Chimney Connector	(0.46 m)	71/160				
Chimney Connector	(1.37 m)	90/194				
Chimney Level 1	(2.08 m)	87/189	76/168	44/112	4/8	
Chimney Level 2	(2.34 m)	77/171	72/163	43/109	5/9	
Chimney Level 3	(2.85 m)	76/168	68/154	42/109	5/9	
Chimney Level 4	(3.10 m)	72/162	66/151	43/110	5/10	
Chimney Level 5	(3.61 m)	68/154	62/143	42/108	5/10	
Chimney Level 6	(3.86 m)	66/151	61/141	42/109	6/12	
Chimney Level 7	(4.37 m)	64/147	58/137	44/112		
Chimney Level 8	(4.62 m)	61/143	54/129	30/87		

Table 9: Temperature Profiles From Chimney Buildup Test of Chimney 5

Table of Averages
(Solid-Packed 3)

Ambient Air Temperature (°C/°F): -2/28

Thermocouple Location	Level	Flue Gas Temperature (°C/°F)	Inner Wall Surface Temperature (°C/°F)	Outer Wall Surface Temperature (°C/°F)	Enclosure Surface Temperature Rise (°C/°F)	Appliance Surface Temperature (°C/°F)
Chimney Connector	(0.46 m)	117/243				
Chimney Connector	(1.22 m)	165/330				
Chimney Level 1	(1.47 m)	61/143				
Chimney Level 2	(1.98 m)	84/184	68/155	12/55		
Chimney Level 3	(2.24 m)	79/174	62/144	14/57		
Chimney Level 4	(2.74 m)	70/159	53/127	7/45		
Chimney Level 5	(3.00 m)	65/150	51/125	7/45		
Chimney Level 6	(3.51 m)	61/142	43/110	8/46		
Chimney Level 7	(3.76 m)	57/135	40/105	4/40		
Chimney Level 8	(4.27 m)	53/128	39/103	4/39		
Chimney Level 9	(4.52 m)	52/127	40/104	5/42		
Chimney Level 10	(5.03 m)	49/120	35/96	4/39		
Chimney Level 11	(5.28 m)	48/119	34/93	4/40		
Chimney Level 12	(5.79 m)	45/114	35/96	*		
Chimney Level 13	(6.06 m)	45/113	35/95	*		
Chimney Level 14	(6.55 m)	43/109	34/94	2/37		
Chimney Level 15	(6.81 m)	41/107	33/93	6/44		

* Readings of zero were found in calculating this value

Table 10: Temperature Profiles From Chimney Burnout Test of Chimney 1, Test 1

Table of Maximums
(Air-Insulated)

Ambient Air Temperature (°C/°F): 29/84

Thermocouple Location	Level	Flue Gas Temperature (°C/°F)	Inner Wall Surface Temperature (°C/°F)	Outer Wall Surface Temperature (°C/°F)	Enclosure Surface Temperature Rise (°C/°F)	Appliance Surface Temperature (°C/°F)
Appliance Surface						371/699
Appliance Surface						147/296
Appliance Surface						177/350
Appliance Surface						215/419
Appliance Surface						170/338
Chimney Connector	(0.46 m)	1008/1846				
Chimney Connector	(1.37 m)	914/1677				
Chimney Level 1	(2.08 m)	870/1598	692/1277	290/554	43/77	
Chimney Level 2	(2.34 m)	948/1738	774/1425	314/597	65/117	
Chimney Level 3	(2.85 m)	925/1697	773/1423	349/660	82/147	
Chimney Level 4	(3.10 m)	893/1639	778/1432	373/703	97/174	
Chimney Level 5	(3.61 m)	852/1565	668/1234	416/780	5/9	
Chimney Level 6	(3.86 m)	823/1513	708/1306	420/788	126/226	
Chimney Level 7	(4.37 m)	773/1423	640/1184	394/741		
Chimney Level 8	(4.62 m)	767/1412	590/1094	309/588		

Table 11: Temperature Profiles From Chimney Burnout Test of Chimney 1, Test 2

Table of Maximums
(Air-Insulated)

Ambient Air Temperature (°C/°F): 31/87

Thermocouple Location	Level	Flue Gas Temperature (°C/°F)	Inner Wall Surface Temperature (°C/°F)	Outer Wall Surface Temperature (°C/°F)	Enclosure Surface Temperature Rise (°C/°F)	Appliance Surface Temperature (°C/°F)
Appliance Surface						113/235
Appliance Surface						370/698
Appliance Surface						273/523
Appliance Surface						259/498
Appliance Surface						334/633
Chimney Connector	(0.46 m)	988/1810				
Chimney Connector	(1.37 m)	811/1491				
Chimney Level 1	(2.08 m)	711/1311	626/1158	265/509	55/99	
Chimney Level 2	(2.34 m)	704/1299	653/1207	277/530	85/153	
Chimney Level 3	(2.85 m)	676/1248	584/1083	237/458	96/172	
Chimney Level 4	(3.10 m)	669/1236	581/1077	229/444	115/207	
Chimney Level 5	(3.61 m)	667/1232	547/1016	282/539	147/264	
Chimney Level 6	(3.86 m)	642/1187	563/1045	303/577	152/273	
Chimney Level 7	(4.37 m)	675/1247	576/1068	325/617		
Chimney Level 8	(4.62 m)	754/1389	488/910	305/581		

Table 12: Temperature Profiles From Chimney Burnout Test of Chimney 1, Test 3

Table of Maximums
(Air-Insulated)

Ambient Air Temperature (°C/°F): 32/89

Thermocouple Location	Level	Flue Gas Temperature (°C/°F)	Inner Wall Surface Temperature (°C/°F)	Outer Wall Surface Temperature (°C/°F)	Enclosure Surface Temperature Rise (°C/°F)	Appliance Surface Temperature (°C/°F)
Appliance Surface						50/122
Appliance Surface						304/579
Appliance Surface						143/289
Appliance Surface						112/233
Appliance Surface						303/577
Chimney Connector	(0.46 m)	1109/2028				
Chimney Connector	(1.37 m)	958/1756				
Chimney Level 1	(2.08 m)	933/1711	802/1475	298/568	61/109	
Chimney Level 2	(2.34 m)	934/1713	814/1497	302/575	84/151	
Chimney Level 3	(2.85 m)	893/1639	762/1403	275/527	97/174	
Chimney Level 4	(3.10 m)	856/1572	755/1391	258/496	114/205	
Chimney Level 5	(3.61 m)	825/1517	635/1175	295/563	141/253	
Chimney Level 6	(3.86 m)	797/1466	662/1223	327/620	146/262	
Chimney Level 7	(4.37 m)	750/1382	583/1081	318/604		
Chimney Level 8	(4.62 m)	724/1335	514/957	281/537		

Table 13: Temperature Profiles From Chimney Burnout Test of Chimney 1, Test 4

Table of Maximums
(Air-Insulated)

Ambient Air Temperature (°C/°F): 30/86

Thermocouple Location	Level	Flue Gas Temperature (°C/°F)	Inner Wall Surface Temperature (°C/°F)	Outer Wall Surface Temperature (°C/°F)	Enclosure Surface Temperature Rise (°C/°F)	Appliance Surface Temperature (°C/°F)
Appliance Surface						25/77
Appliance Surface						114/237
Appliance Surface						67/152
Appliance Surface						65/149
Appliance Surface						227/440
Chimney Connector	(0.46 m)	996/1824				
Chimney Connector	(1.37 m)	825/1517				
Chimney Level 1	(2.08 m)	931/1707	791/1455	200/392	36/64	
Chimney Level 2	(2.34 m)	868/1594	717/1322	214/417	56/100	
Chimney Level 3	(2.85 m)	805/1481	733/1351	261/501	88/158	
Chimney Level 4	(3.10 m)	873/1603	738/1360	264/507	122/219	
Chimney Level 5	(3.61 m)	903/1657	814/1497	342/647	164/295	
Chimney Level 6	(3.86 m)	896/1644	906/1662	433/811	206/370	
Chimney Level 7	(4.37 m)	866/1590	705/1301	384/723		
Chimney Level 8	(4.62 m)	726/1338	640/1184	362/683		

Table 14: Temperature Profiles From Chimney Burnout Test of Chimney 2, Test 5

Table of Maximums
(Solid-Packed 1)

Ambient Air Temperature (°C/°F): 35/95

Thermocouple Location	Level	Flue Gas Temperature (°C/°F)	Inner Wall Surface Temperature (°C/°F)	Outer Wall Surface Temperature (°C/°F)	Enclosure Surface Temperature Rise (°C/°F)	Appliance Surface Temperature (°C/°F)
Appliance Surface						254/489
Appliance Surface						150/302
Appliance Surface						254/489
Appliance Surface						278/532
Appliance Surface						405/761
Chimney Connector	(0.46 m)	958/1756				
Chimney Connector	(1.37 m)	911/1671				
Chimney Level 1	(2.08 m)	902/1655	758/1396	198/388	35/63	
Chimney Level 2	(2.34 m)	873/1603	745/1373	219/426	47/84	
Chimney Level 3	(2.85 m)	830/1526	448/838	214/417	58/104	
Chimney Level 4	(3.10 m)	812/1493	663/1225	211/411	59/106	
Chimney Level 5	(3.61 m)	792/1457	647/1196	210/410	57/102	
Chimney Level 6	(3.86 m)	786/1446	632/1169	212/413	64/115	
Chimney Level 7	(4.37 m)	771/1419	524/975	222/431		
Chimney Level 8	(4.62 m)	756/1392	625/1157	160/320		

Table 15: Temperature Profiles From Chimney Burnout Test of Chimney 2, Test 6

Table of Maximums
(Solid-Packed 1)

Ambient Air Temperature (°C/°F): 30/86

Thermocouple Location	Level	Flue Gas Temperature (°C/°F)	Inner Wall Surface Temperature (°C/°F)	Outer Wall Surface Temperature (°C/°F)	Enclosure Surface Temperature Rise (°C/°F)	Appliance Surface Temperature (°C/°F)
Appliance Surface						71/159
Appliance Surface						361/681
Appliance Surface						167/332
Appliance Surface						174/345
Appliance Surface						354/669
Chimney Connector	(0.46 m)	965/1769				
Chimney Connector	(1.37 m)	935/1715				
Chimney Level 1	(2.08 m)	954/1749	*	173/343	47/84	
Chimney Level 2	(2.34 m)	933/1711	*	227/440	62/111	
Chimney Level 3	(2.85 m)	856/1572	539/1002	205/401	77/138	
Chimney Level 4	(3.10 m)	818/1504	761/1401	191/375	81/145	
Chimney Level 5	(3.61 m)	775/1427	722/1331	182/359	80/144	
Chimney Level 6	(3.86 m)	784/1443	*	179/354	82/147	
Chimney Level 7	(4.37 m)	821/1509	727/1340	233/451		
Chimney Level 8	(4.62 m)	892/1637	867/1592	164/327		

* Readings of zero were found in calculating this value

Table 16: Temperature Profiles From Chimney Burnout Test of Chimney 2, Test 7

Table of Maximums
(Solid-Packed 1)

Ambient Air Temperature (°C/°F): 35/95

Thermocouple Location	Level	Flue Gas Temperature (°C/°F)	Inner Wall Surface Temperature (°C/°F)	Outer Wall Surface Temperature (°C/°F)	Enclosure Surface Temperature Rise (°C/°F)	Appliance Surface Temperature (°C/°F)
Appliance Surface						137/278
Appliance Surface						374/705
Appliance Surface						326/618
Appliance Surface						337/638
Appliance Surface						536/996
Chimney Connector	(0.46 m)	*				
Chimney Connector	(1.37 m)	910/1670				
Chimney Level 1	(2.08 m)	810/1490	*	191/375	40/72	
Chimney Level 2	(2.34 m)	787/1448	*	200/392	54/97	
Chimney Level 3	(2.85 m)	754/1389	*	191/375	72/129	
Chimney Level 4	(3.10 m)	740/1364	606/1122	179/354	78/140	
Chimney Level 5	(3.61 m)	721/1329	*	169/336	76/136	
Chimney Level 6	(3.86 m)	708/1306	*	168/334	79/142	
Chimney Level 7	(4.37 m)	687/1268	465/869	188/370		
Chimney Level 8	(4.62 m)	665/1229	514/957	121/249		

* Readings of zero were found in calculating this value

Table 17: Temperature Profiles From Chimney Burnout Test of Chimney 2, Test 8

Table of Maximums
(Solid-Packed 1)

Ambient Air Temperature (°C/°F): 27/80

Thermocouple Location	Level	Flue Gas Temperature (°C/°F)	Inner Wall Surface Temperature (°C/°F)	Outer Wall Surface Temperature (°C/°F)	Enclosure Surface Temperature Rise (°C/°F)	Appliance Surface Temperature (°C/°F)
Appliance Surface						23/73
Appliance Surface						96/204
Appliance Surface						70/158
Appliance Surface						70/158
Appliance Surface						25/77
Chimney Connector	(0.46 m)	1030/1886				
Chimney Connector	(1.37 m)	919/1686				
Chimney Level 1	(2.08 m)	889/1632	827/1520	130/266	21/37	
Chimney Level 2	(2.34 m)	881/1617	859/1578	151/303	35/63	
Chimney Level 3	(2.85 m)	840/1544	*	162/323	55/99	
Chimney Level 4	(3.10 m)	866/1590	874/1605	168/334	64/115	
Chimney Level 5	(3.61 m)	854/1569	800/1472	153/307	68/122	
Chimney Level 6	(3.86 m)	871/1599	*	157/314	70/126	
Chimney Level 7	(4.37 m)	838/1540	721/1329	168/334		
Chimney Level 8	(4.62 m)	869/1596	*	121/249		

* Readings of zero were found in calculating this value

Table 18: Temperature Profiles From Chimney Burnout Test of Chimney 3, Test 9

Table of Maximums
(Masonry)

Ambient Air Temperature (°C/°F): 26/78

Thermocouple Location	Level	Flue Gas Temperature (°C/°F)	Inner Wall Surface Temperature (°C/°F)	Outer Wall Surface Temperature (°C/°F)	Enclosure Surface Temperature Rise (°C/°F)	Appliance Surface Temperature (°C/°F)
Appliance Surface						864/1587
Appliance Surface						24/75
Appliance Surface						77/170
Appliance Surface						55/131
Appliance Surface						59/138
Appliance Surface						166/330
Chimney Level 1	(0.30 m)		265/509	44/111	15/27	
Chimney Level 2	(0.61 m)	1095/2003	237/458	46/114	12/21	
Chimney Level 3	(0.91 m)		217/422	45/113	13/23	
Chimney Level 4	(1.22 m)	918/1684	156/312	45/113	13/23	
Chimney Level 5	(1.52 m)		176/348	45/113	14/25	
Chimney Level 6	(1.83 m)	803/1477	168/334	45/113	14/25	
Chimney Level 7	(2.13 m)		152/305	42/107	13/23	
Chimney Level 8	(2.44 m)	763/1405	145/293	42/107	13/23	
Chimney Level 9	(2.74 m)		125/257	40/104	12/21	
Chimney Level 10	(3.05 m)	657/1214	115/239	36/96		
Chimney Level 11	(3.35 m)		112/233	37/98		
Chimney Level 12	(3.51 m)	610/1130	108/226	43/109		

Table 19: Temperature Profiles From Chimney Burnout Test of Chimney 4, Test 10

Table of Maximums
(Solid-Packed 2)

Ambient Air Temperature (°C/°F): 29/84

Thermocouple Location	Level	Flue Gas Temperature (°C/°F)	Inner Wall Surface Temperature (°C/°F)	Outer Wall Surface Temperature (°C/°F)	Enclosure Surface Temperature Rise (°C/°F)	Appliance Surface Temperature (°C/°F)
Appliance Surface						24/75
Appliance Surface						67/152
Appliance Surface						64/147
Appliance Surface						52/125
Appliance Surface						230/446
Chimney Connector	(0.46 m)	488/910				
Chimney Connector	(1.37 m)	908/1666				
Chimney Level 1	(2.08 m)	851/1563	706/1302	116/240	23/41	
Chimney Level 2	(2.34 m)	790/1454	629/1164	114/237	22/39	
Chimney Level 3	(2.85 m)	741/1365	541/1005	120/248	24/43	
Chimney Level 4	(3.10 m)	757/1394	629/1164	123/253	27/48	
Chimney Level 5	(3.61 m)	735/1355	629/1164	128/262	29/52	
Chimney Level 6	(3.86 m)	740/1364	715/1319	127/260	37/66	
Chimney Level 7	(4.37 m)	673/1243	603/1117	137/278		
Chimney Level 8	(4.62 m)	633/1171	413/775	71/159		

Table 20: Temperature Profiles From Chimney Burnout Test of Chimney 4, Test 11

Table of Maximums
(Solid-Packed 2)

Ambient Air Temperature (°C/°F): 34/94

Thermocouple Location	Level	Flue Gas Temperature (°C/°F)	Inner Wall Surface Temperature (°C/°F)	Outer Wall Surface Temperature (°C/°F)	Enclosure Surface Temperature Rise (°C/°F)	Appliance Surface Temperature (°C/°F)
Appliance Surface						259/498
Appliance Surface						499/930
Appliance Surface						188/370
Appliance Surface						323/613
Appliance Surface						613/1135
Chimney Connector	(0.46 m)	1022/1871				
Chimney Connector	(1.37 m)	971/1779				
Chimney Level 1	(2.08 m)	974/1785	901/1653	280/536	79/142	
Chimney Level 2	(2.34 m)	984/1803	917/1682	273/523	82/148	
Chimney Level 3	(2.85 m)	959/1758	*	292/557	99/178	
Chimney Level 4	(3.10 m)	971/1779	854/1569	288/550	102/184	
Chimney Level 5	(3.61 m)	902/1655	*	276/528	112/202	
Chimney Level 6	(3.86 m)	960/1760	866/1590	280/536	119/214	
Chimney Level 7	(4.37 m)	925/1697	*	285/545		
Chimney Level 8	(4.62 m)	899/1650	850/1562	200/392		

* Readings of zero were found in calculating this value

Table 21: Temperature Profiles From Chimney Burnout Test of Chimney 5, Test 12

Table of Maximums
(Solid-Packed 3)

Ambient Air Temperature (°C/°F): 2/35

Thermocouple Location	Level	Flue Gas Temperature (°C/°F)	Inner Wall Surface Temperature (°C/°F)	Outer Wall Surface Temperature (°C/°F)	Enclosure Surface Temperature Rise (°C/°F)	Appliance Surface Temperature (°C/°F)
Chimney Connector	(0.46 m)	970/1778				
Chimney Connector	(1.22 m)	1071/1959				
Chimney Level 1	(1.47 m)	1370/2498				
Chimney Level 2	(1.98 m)	1166/2130	1111/2031	289/552		
Chimney Level 3	(2.24 m)	1138/2080	1047/1916	101/213		
Chimney Level 4	(2.74 m)	1083/1981	999/1830	250/482		
Chimney Level 5	(3.00 m)	1040/1904	969/1776	174/345		
Chimney Level 6	(3.51 m)	1018/1864	932/1709	102/215		
Chimney Level 7	(3.76 m)	999/1830	*	165/329		
Chimney Level 8	(4.27 m)	962/1763	864/1587	140/284		
Chimney Level 9	(4.52 m)	997/1826	840/1544	134/273		
Chimney Level 10	(5.03 m)	944/1731	791/1455	100/212		
Chimney Level 11	(5.28 m)	921/1689	780/1436	114/237		
Chimney Level 12	(5.79 m)	929/1704	745/1373	102/215		
Chimney Level 13	(6.06 m)	944/1731	748/1378	114/237		
Chimney Level 14	(6.55 m)	957/1754	714/1317	107/224		
Chimney Level 15	(6.81 m)	955/1751	724/1335	105/221		

* Readings of zero were found in calculating this value

Table 22
Maximum Temperatures Measured During Several Chimney Fires in Five Different Chimneys

Test	Flue Gas Overall (°C)	Flue Gas in Chimney (°C)	Inner Chimney Wall (°C)	Outer Chimney Wall (°C)	Enclosure (°C)
Air Insulated Chimney					
1	1008	948	778	420	154
2	988	754	653	325	182
3	1109	934	814	327	177
4	996	931	906	433	234
Solid-Packed Chimney #1					
5	958	902	758	222	97
6	965	954	867	233	112
7	1050	810	n.r.	200	112
8	1030	889	874	168	95
Masonry Chimney					
9	1095	1095	265	46	39
Solid-Packed Chimney #2					
10	908	851	715	137	62
11	1022	984	917	288	149
Solid-Packed Chimney #3					
12	>1370	>1370	1111	289	--

Notes: "Overall" Flue Gas Temperature refers to peak of temperatures measured in the entire chimney system, including the chimney connector. "In chimney" measurements are the maximum of only those within the chimney, not includi the chimney connector.

n.r. = not recorded. No enclosure was used for chimney 5.

Table 23: Temperature Profiles From Chimney Overfire Test of Chimney 1

Table of Maximums
(Air-Insulated)

Ambient Air Temperature (°C/°F): 51/123

Thermocouple Location	Level	Flue Gas Temperature (°C/°F)	Inner Wall Surface Temperature (°C/°F)	Outer Wall Surface Temperature (°C/°F)	Enclosure Surface Temperature Rise (°C/°F)	Appliance Surface Temperature (°C/°F)
Appliance Surface						156/312
Appliance Surface						344/651
Appliance Surface						309/588
Appliance Surface						374/705
Appliance Surface						477/890
Chimney Connector	(0.46 m)	988/1810				
Chimney Connector	(1.37 m)	915/1679				
Chimney Level 1	(2.08 m)	830/1526	654/1209	182/359	7/12	
Chimney Level 2	(2.34 m)	836/1536	668/1234	185/365	8/14	
Chimney Level 3	(2.85 m)	804/1479	628/1162	200/392	25/45	
Chimney Level 4	(3.10 m)	779/1434	634/1173	180/356	38/68	
Chimney Level 5	(3.61 m)	752/1385	599/1110	218/424	59/106	
Chimney Level 6	(3.86 m)	732/1349	571/1059	254/489	69/124	
Chimney Level 7	(4.37 m)	698/1288	515/959	270/518		
Chimney Level 8	(4.62 m)	673/1243	493/919	236/456		

Table 24: Temperature Profiles From Chimney Overfire Test of Chimney 2

Table of Maximums
(Solid-Packed 1)

Ambient Air Temperature (°C/°F): 51/123

Thermocouple Location	Level	Flue Gas Temperature (°C/°F)	Inner Wall Surface Temperature (°C/°F)	Outer Wall Surface Temperature (°C/°F)	Enclosure Surface Temperature Rise (°C/°F)	Appliance Surface Temperature (°C/°F)
Appliance Surface						91/195
Appliance Surface						362/683
Appliance Surface						339/642
Appliance Surface						252/485
Appliance Surface						538/1000
Chimney Connector	(0.46 m)	1037/1898				
Chimney Connector	(1.37 m)	899/1650				
Chimney Level 1	(2.08 m)	927/1700	673/1243	199/390	20/36	
Chimney Level 2	(2.34 m)	939/1722	831/1527	206/402	25/45	
Chimney Level 3	(2.85 m)	907/1664	*	201/393	37/66	
Chimney Level 4	(3.10 m)	879/1614	785/1445	181/357	46/82	
Chimney Level 5	(3.61 m)	849/1560	750/1382	166/330	55/99	
Chimney Level 6	(3.86 m)	844/1551	738/1360	181/357	62/111	
Chimney Level 7	(4.37 m)	817/1502	680/1256	204/399		
Chimney Level 8	(4.62 m)	789/1452	646/1194	143/289		

* Readings of zero were found in calculating this value

Table 25: Temperature Profiles From Chimney Overfire Test of Chimney 3

Table of Maximums
(Masonry)

Ambient Air Temperature (°C/°F): 30/86

Thermocouple Location	Level	Flue Gas Temperature (°C/°F)	Inner Wall Surface Temperature (°C/°F)	Outer Wall Surface Temperature (°C/°F)	Enclosure Surface Temperature Rise (°C/°F)	Appliance Surface Temperature (°C/°F)
Appliance Surface						996/1824
Appliance Surface						330/626
Appliance Surface						469/876
Appliance Surface						401/753
Appliance Surface						413/775
Appliance Surface						538/1000
Chimney Level 1	(0.30 m)		358/676	143/289	74/133	
Chimney Level 2	(0.61 m)	772/1421	339/642	156/312	84/151	
Chimney Level 3	(0.91 m)		299/570	146/294	90/162	
Chimney Level 4	(1.22 m)	705/1301	301/573	149/300	85/153	
Chimney Level 5	(1.52 m)		271/519	144/291	85/153	
Chimney Level 6	(1.83 m)	558/1036	262/503	134/273	81/145	
Chimney Level 7	(2.13 m)		248/478	128/262	77/138	
Chimney Level 8	(2.44 m)	517/962	233/451	128/262	77/138	
Chimney Level 9	(2.74 m)		222/431	117/242	71/127	
Chimney Level 10	(3.05 m)	462/863	214/417	83/181		
Chimney Level 11	(3.35 m)		203/397	79/174		
Chimney Level 12	(3.51 m)	428/802	189/372	89/192		

Table 26: Temperature Profiles From Chimney Overfire Test of Chimney 4

Table of Maximums
(Solid-Packed 2)

Ambient Air Temperature (°C/°F): 34/93

Thermocouple Location	Level	Flue Gas Temperature (°C/°F)	Inner Wall Surface Temperature (°C/°F)	Outer Wall Surface Temperature (°C/°F)	Enclosure Surface Temperature Rise (°C/°F)	Appliance Surface Temperature (°C/°F)
Appliance Surface						209/408
Appliance Surface						441/825
Appliance Surface						409/768
Appliance Surface						348/658
Appliance Surface						502/935
Chimney Connector	(0.46 m)	1043/1909				
Chimney Connector	(1.37 m)	924/1695				
Chimney Level 1	(2.08 m)	916/1680	*	305/581	115/207	
Chimney Level 2	(2.34 m)	909/1668	849/1560	306/582	114/205	
Chimney Level 3	(2.85 m)	886/1626	*	323/613	114/205	
Chimney Level 4	(3.10 m)	873/1603	822/1511	326/618	122/219	
Chimney Level 5	(3.61 m)	847/1556	780/1436	336/636	126/226	
Chimney Level 6	(3.86 m)	832/1529	774/1425	325/617	141/253	
Chimney Level 7	(4.37 m)	816/1500	*	334/633		
Chimney Level 8	(4.62 m)	788/1450	*	163/325		

* Readings of zero were found in calculating this value

Table 27: Temperature Profiles From Chimney Overfire Test of Chimney 5

Table of Maximums
(Solid-Packed 3)

Ambient Air Temperature (°C/°F): 19/66

Thermocouple Location	Level	Flue Gas Temperature (°C/°F)	Inner Wall Surface Temperature (°C/°F)	Outer Wall Surface Temperature (°C/°F)	Enclosure Surface Temperature Rise (°C/°F)	Appliance Surface Temperature (°C/°F)
Chimney Connector	(0.46 m)	786/1446				
Chimney Connector	(1.22 m)	899/1650				
Chimney Level 1	(1.47 m)	692/1277				
Chimney Level 2	(1.98 m)	718/1324	*	160/320		
Chimney Level 3	(2.24 m)	714/1317	635/1175	131/267		
Chimney Level 4	(2.74 m)	699/1290	615/1139	127/260		
Chimney Level 5	(3.00 m)	685/1265	612/1133	123/253		
Chimney Level 6	(3.51 m)	670/1238	590/1094	106/222		
Chimney Level 7	(3.76 m)	659/1218	*	104/219		
Chimney Level 8	(4.27 m)	644/1191	566/1050	92/197		
Chimney Level 9	(4.52 m)	638/1180	*	105/221		
Chimney Level 10	(5.03 m)	626/1158	540/1004	93/199		
Chimney Level 11	(5.28 m)	625/1157	530/986	96/204		
Chimney Level 12	(5.79 m)	611/1131	522/971	93/199		
Chimney Level 13	(6.06 m)	609/1128	519/966	81/177		
Chimney Level 14	(6.55 m)	600/1112	506/942	78/172		
Chimney Level 15	(6.81 m)	591/1095	114/237	81/177		

* Readings of zero were found in calculating this value

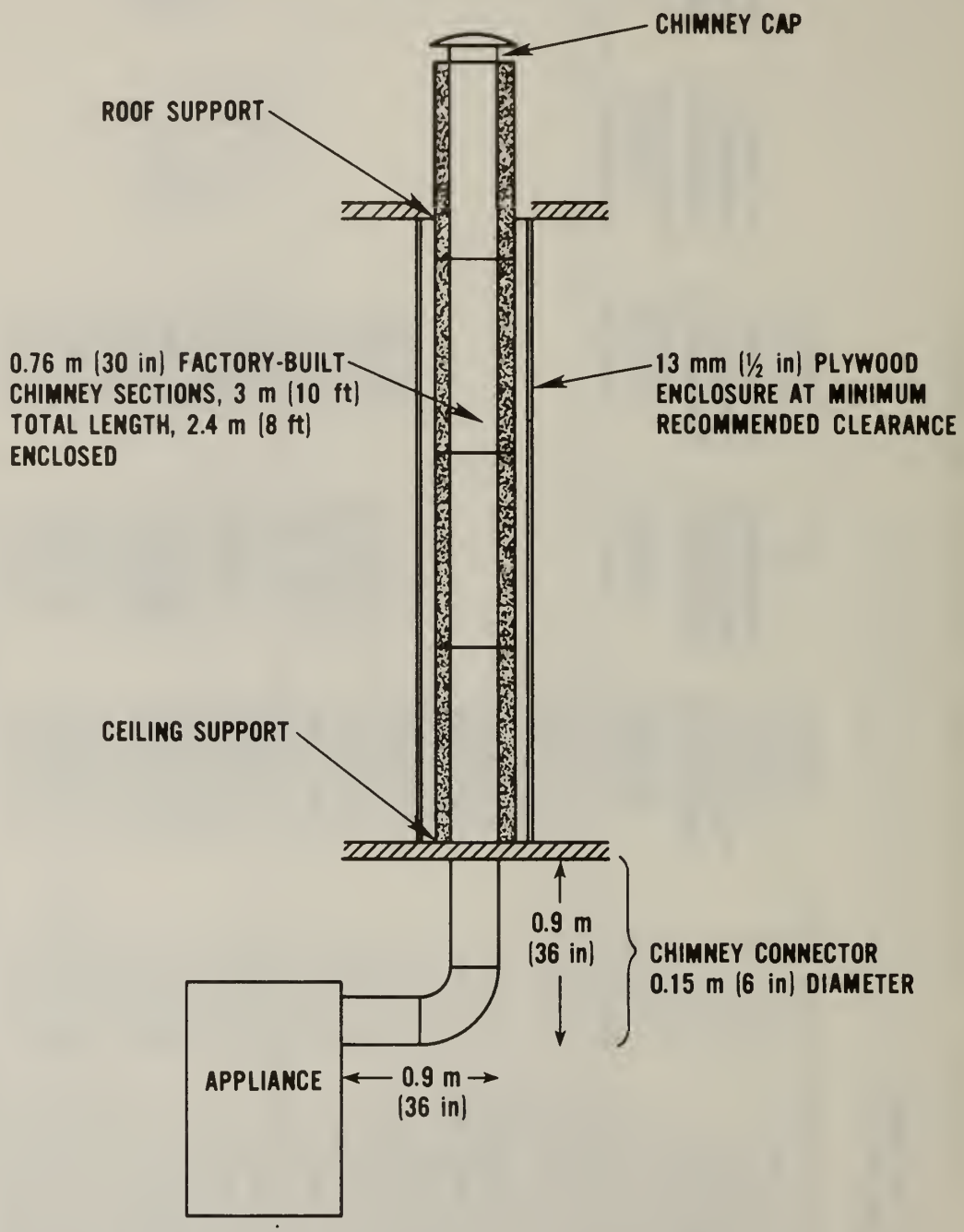


Figure 1. Installation of Factory-Built Chimneys 1, 2, and 4 for Chimney Fire Tests.

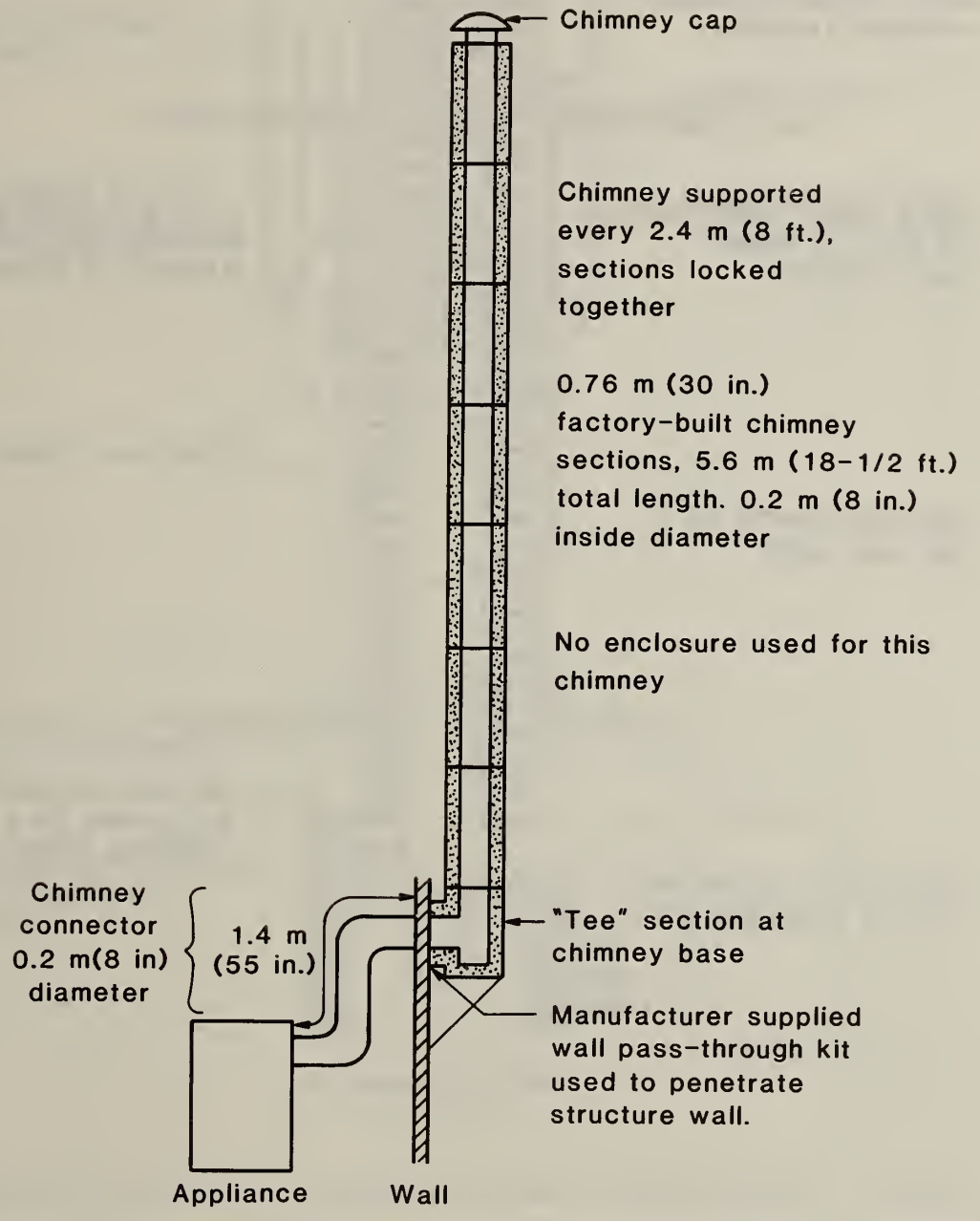


Figure 2. Installation of Factory-Built Chimney 5 for Chimney Fire Tests.

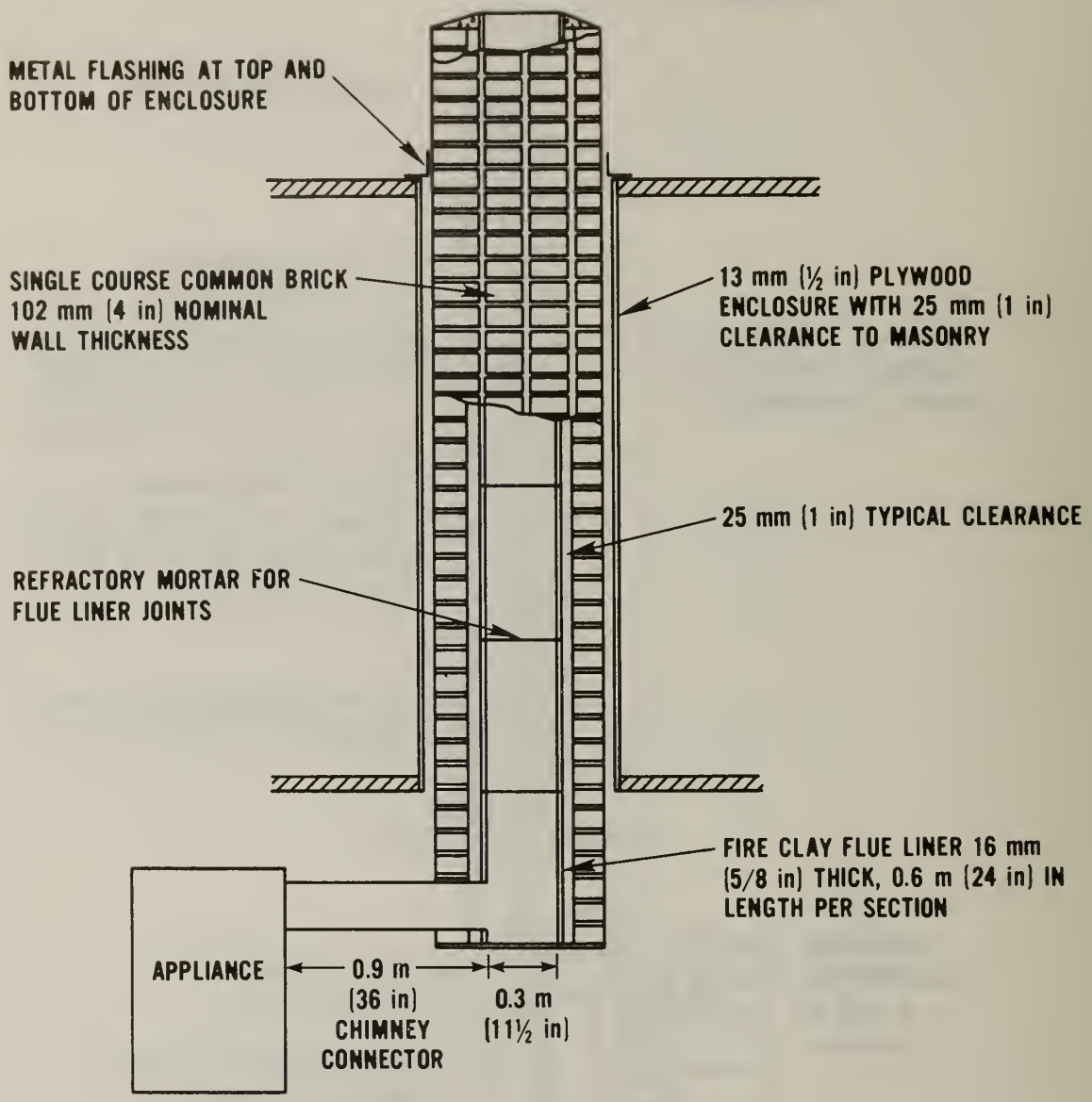
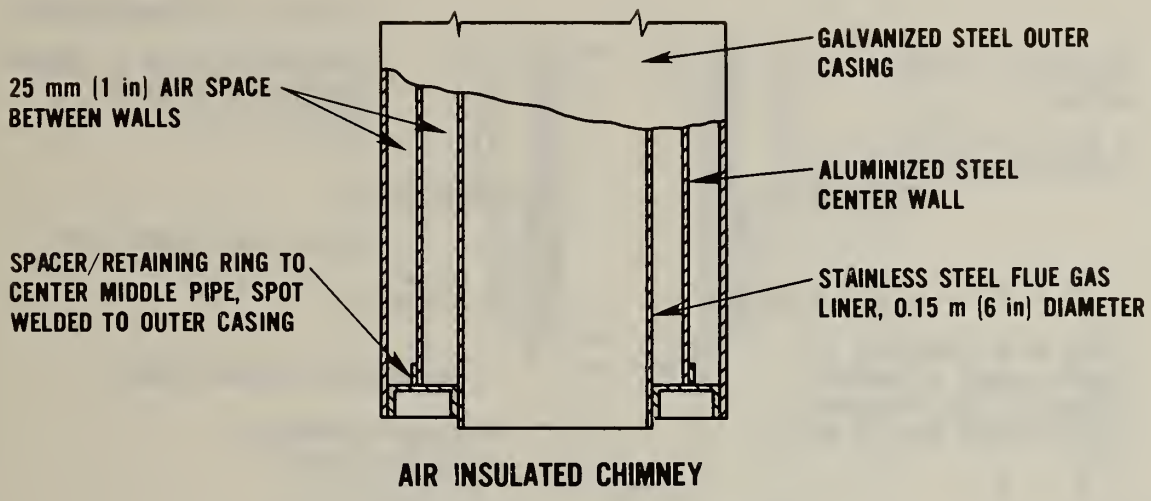


Figure 3. Installation of Masonry Chimney 3 for Chimney Fire Tests.



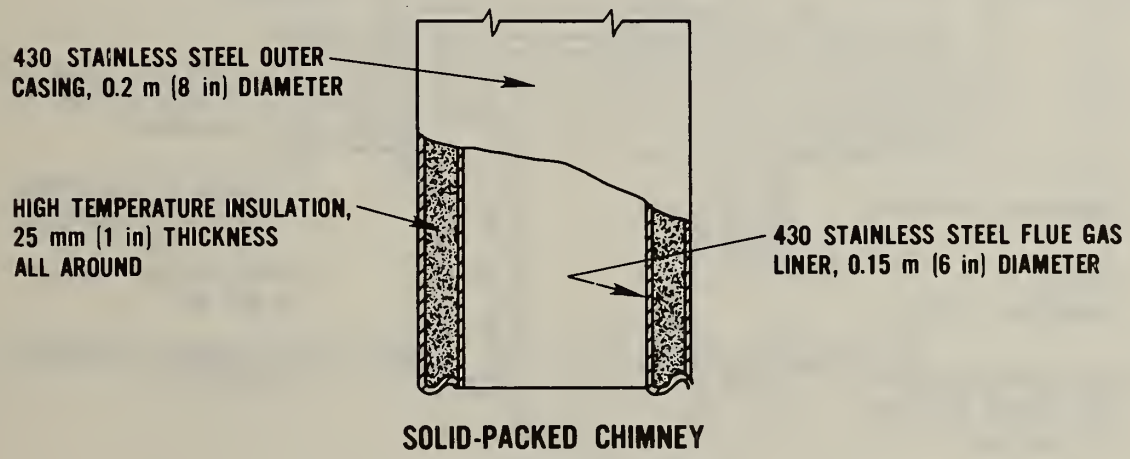
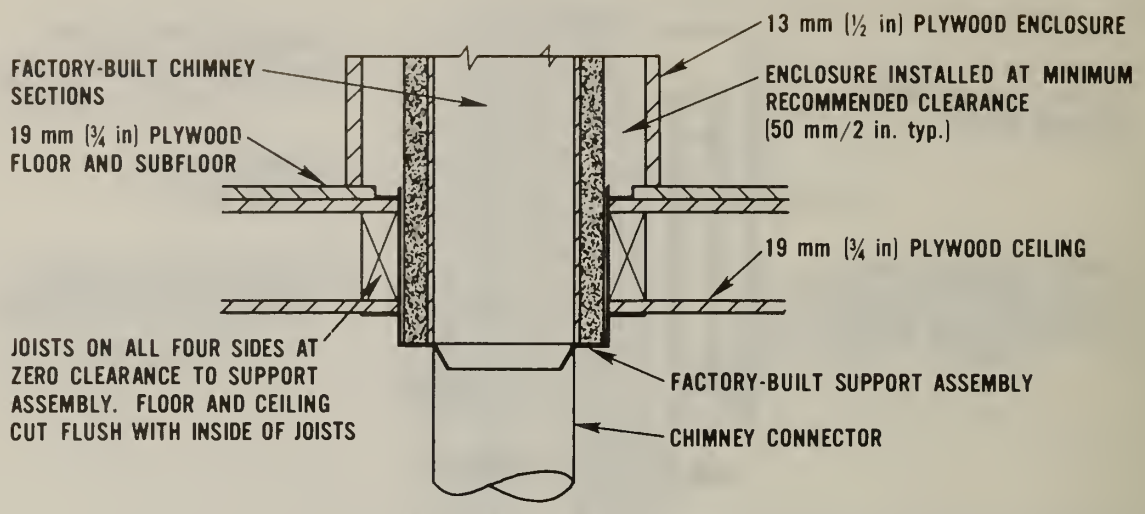
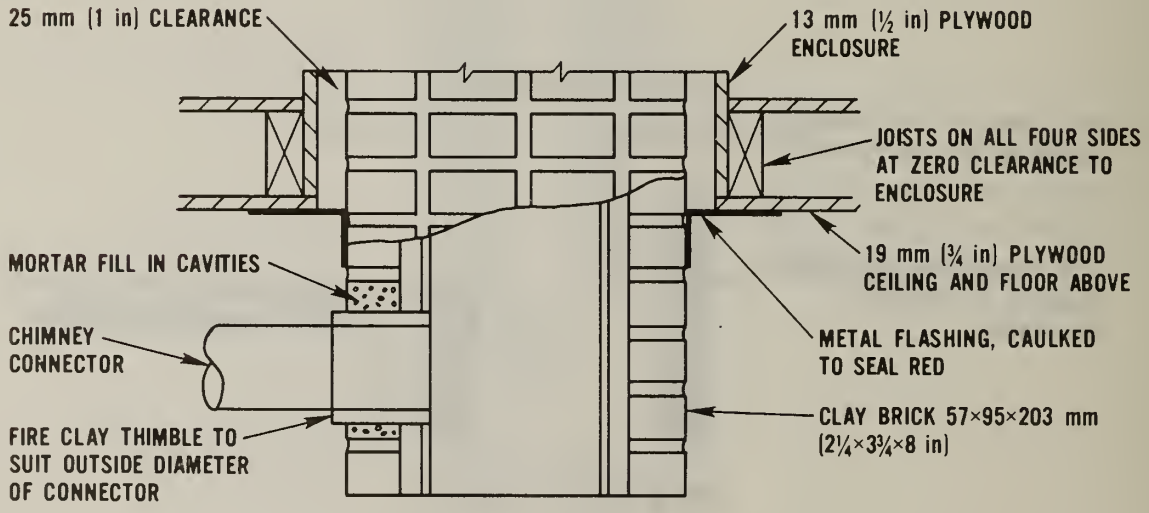


Figure 4. Details of the Construction of the Factory-Built Chimneys Tested.



FACTORY-BUILT CHIMNEYS



MASONRY CHIMNEYS

Figure 5. Details of the Construction of Combustible Enclosures Used to Surround Chimneys 1 through 4.

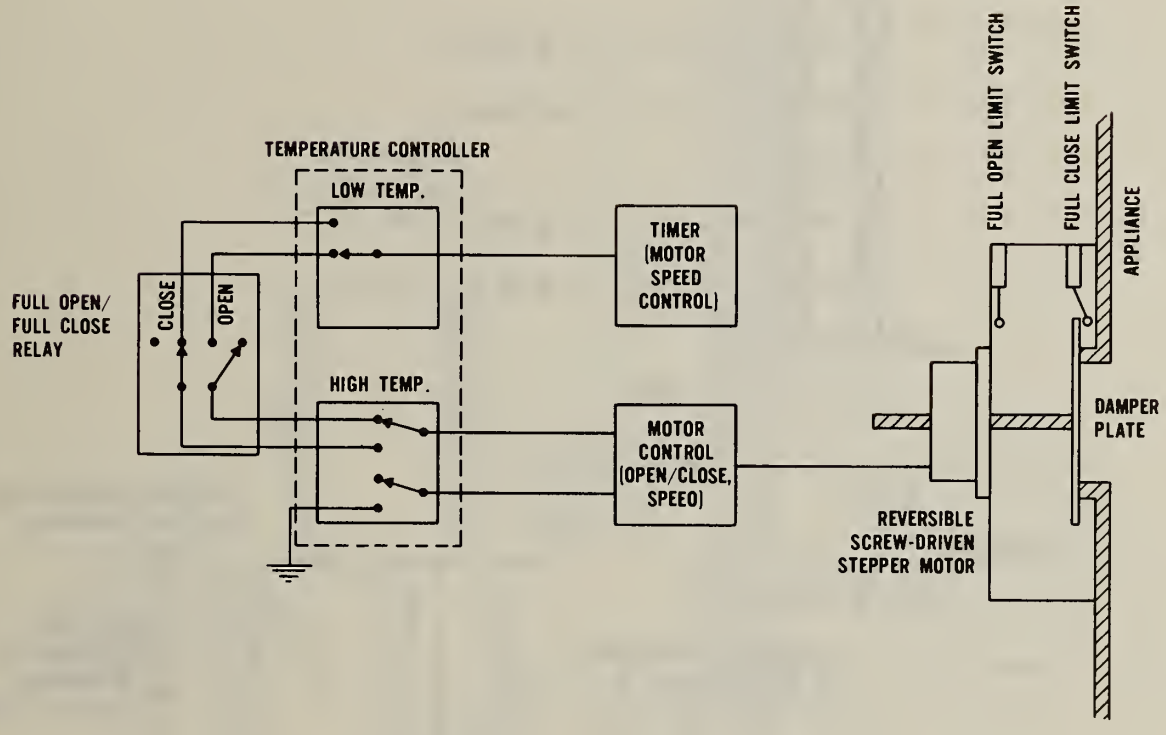


Figure 6. Temperature Control and Appliance Air Inlet Control Systems Design.

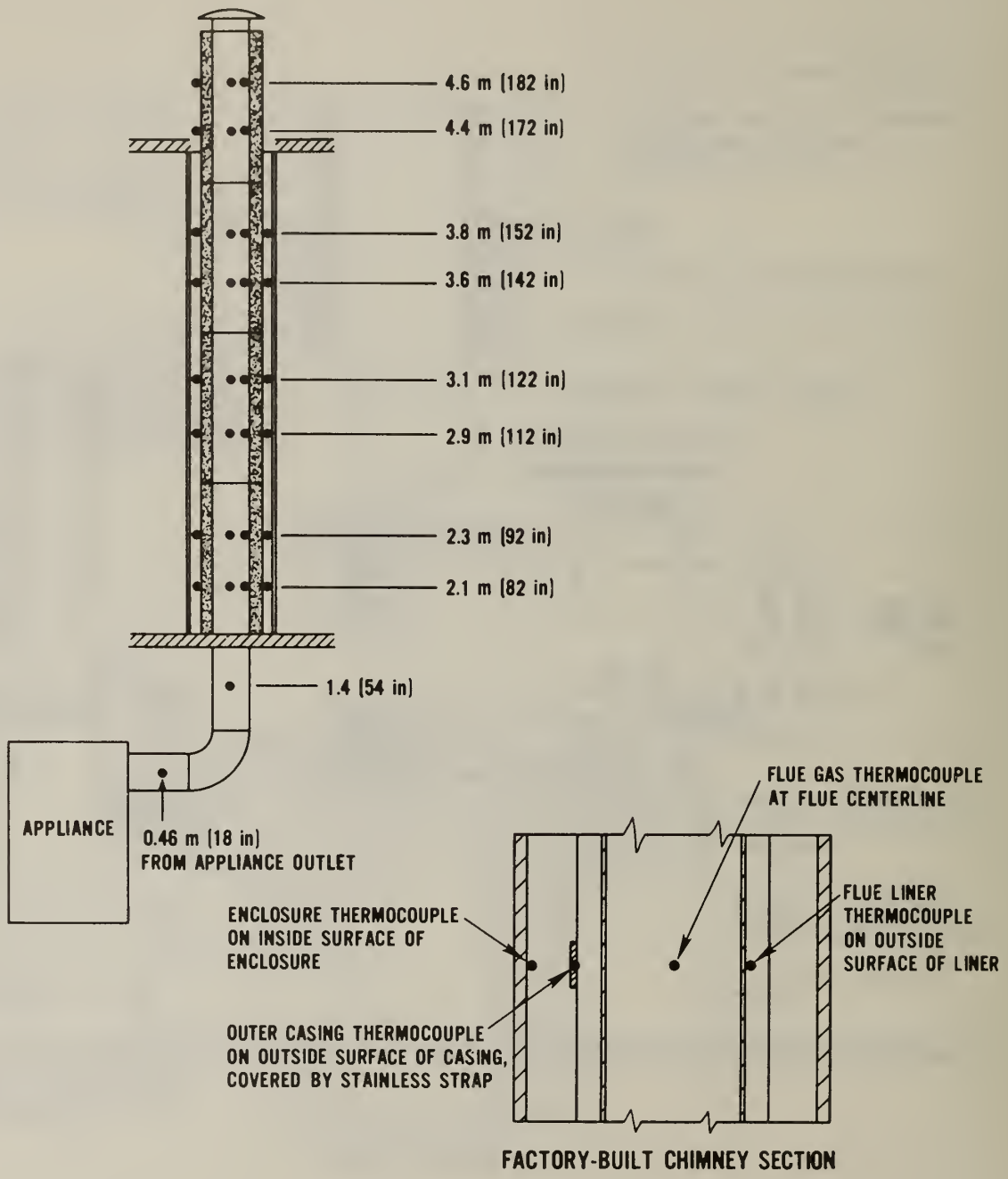


Figure 7. Instrumentation Locations for Tests of Factory-Built Chimneys 1, 2, and 4.

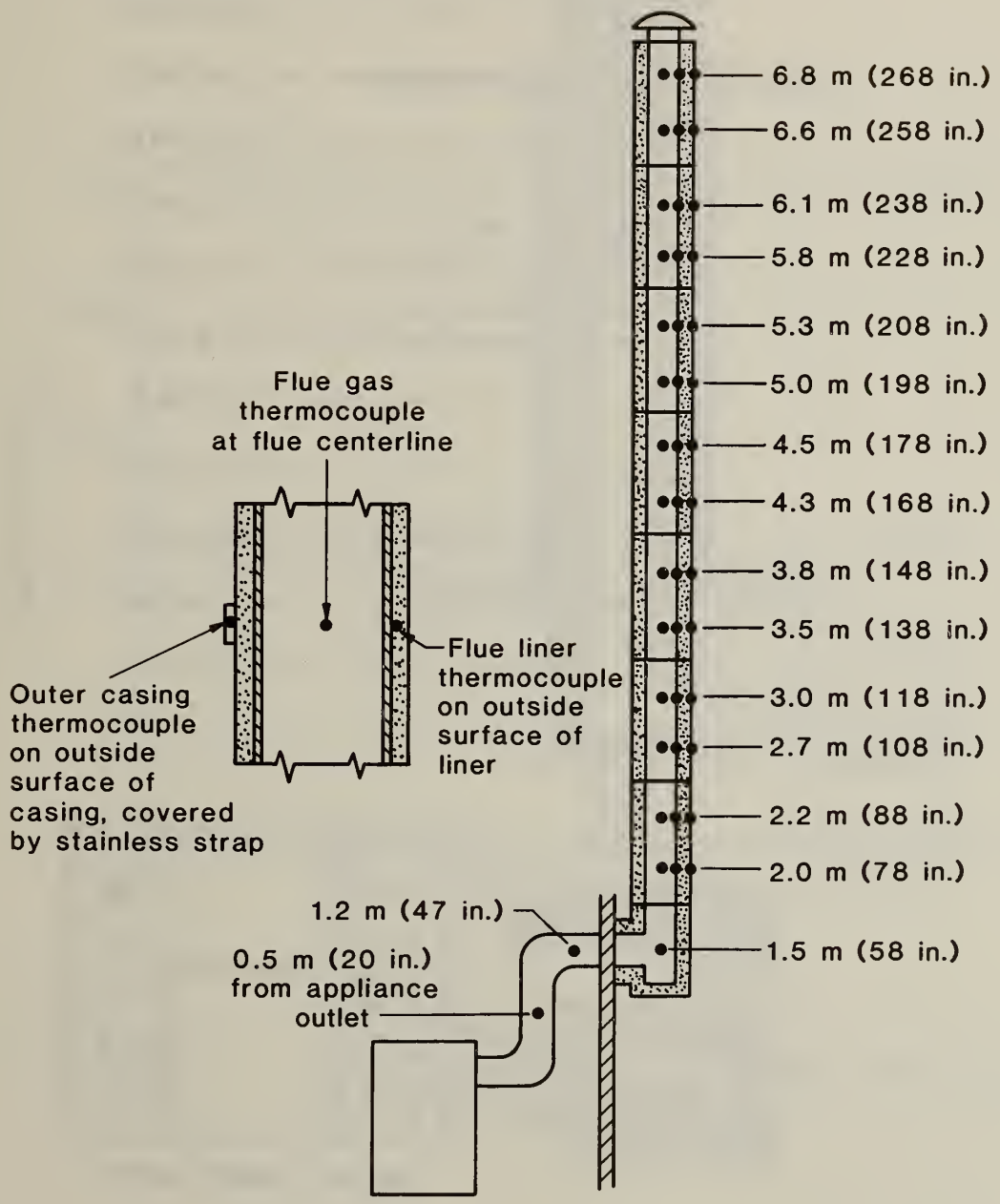


Figure 8. Instrumentation Locations for Tests of Factory Built Chimney 5.

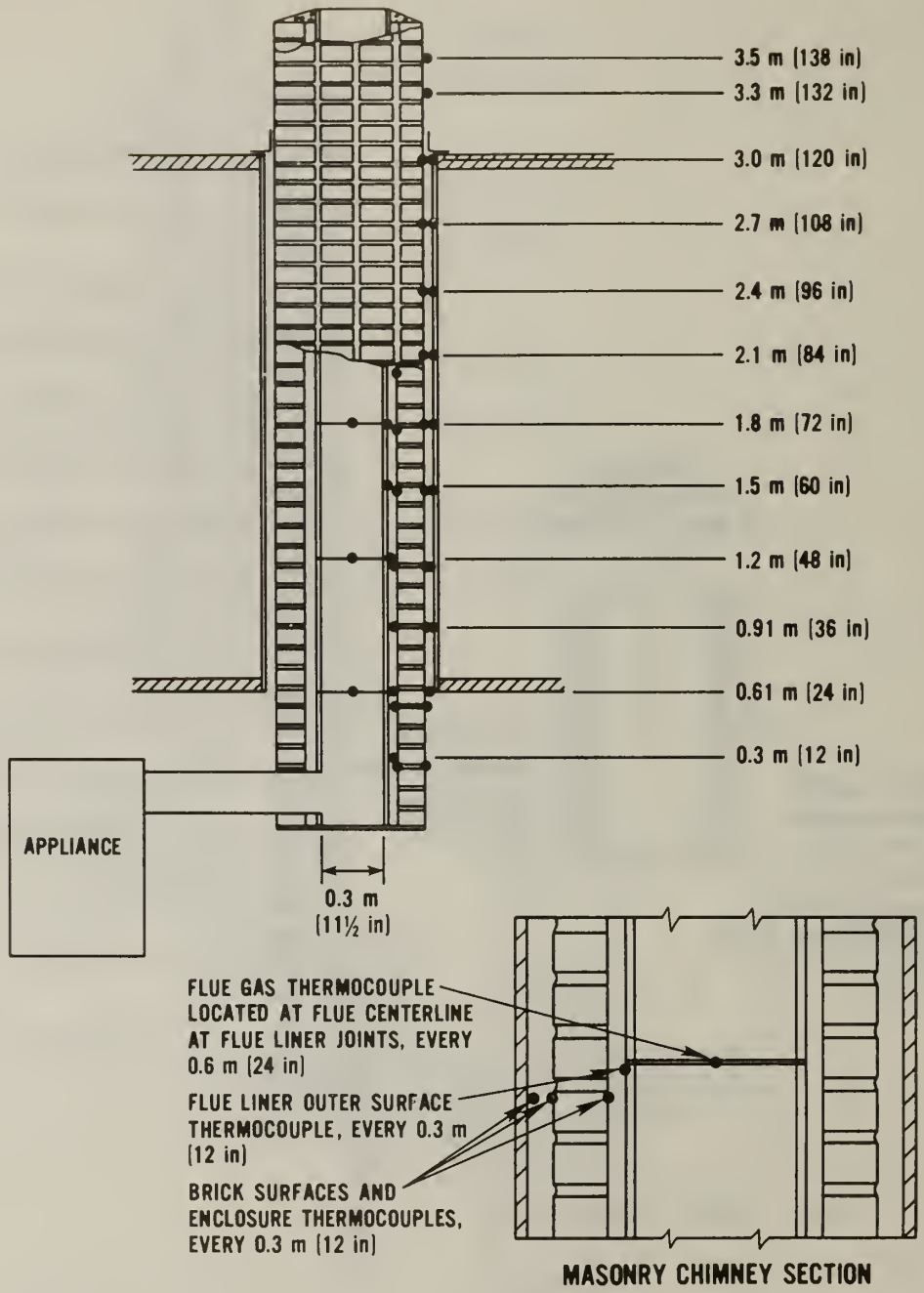


Figure 9. Instrumentation Locations for Tests of Masonry Chimney 3.

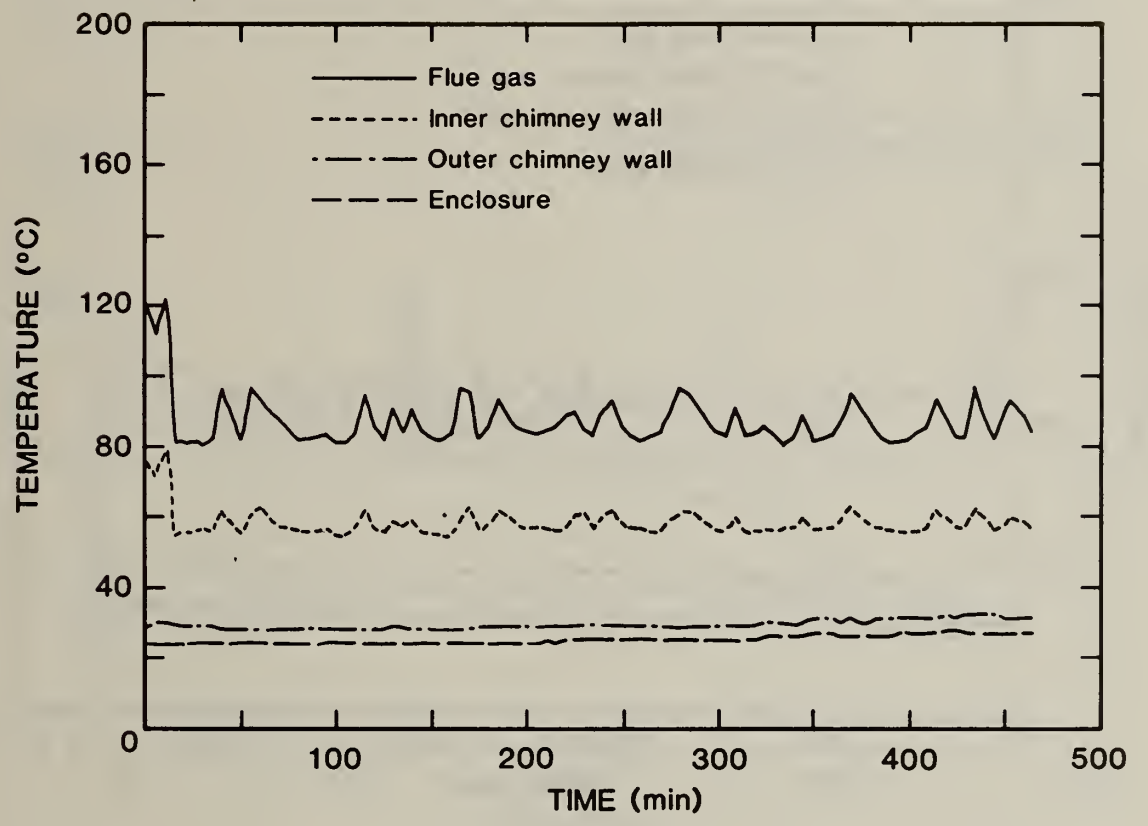


Figure 10. Temperatures at Chimney Base During Creosoting Buildup Test of Chimney 1.

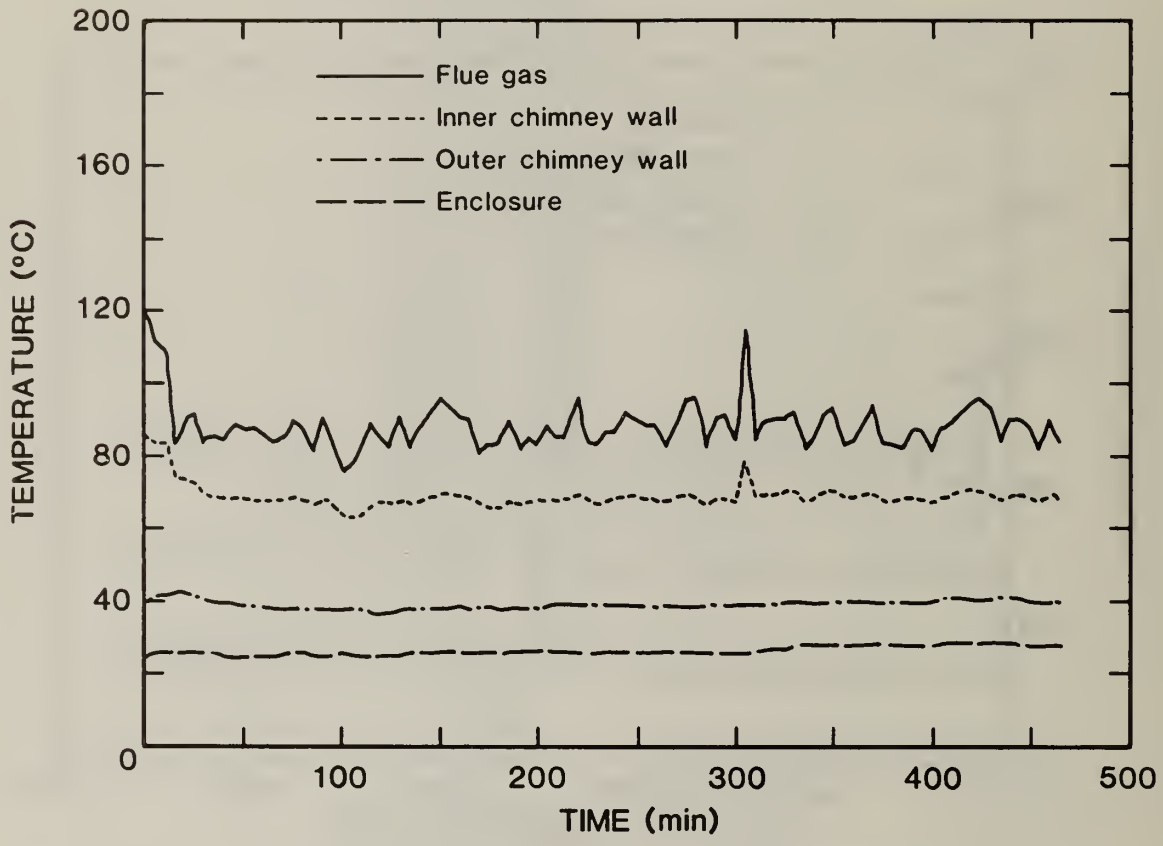


Figure 11. Temperatures at Chimney Base During Creosoting Buildup Test of Chimney 2.

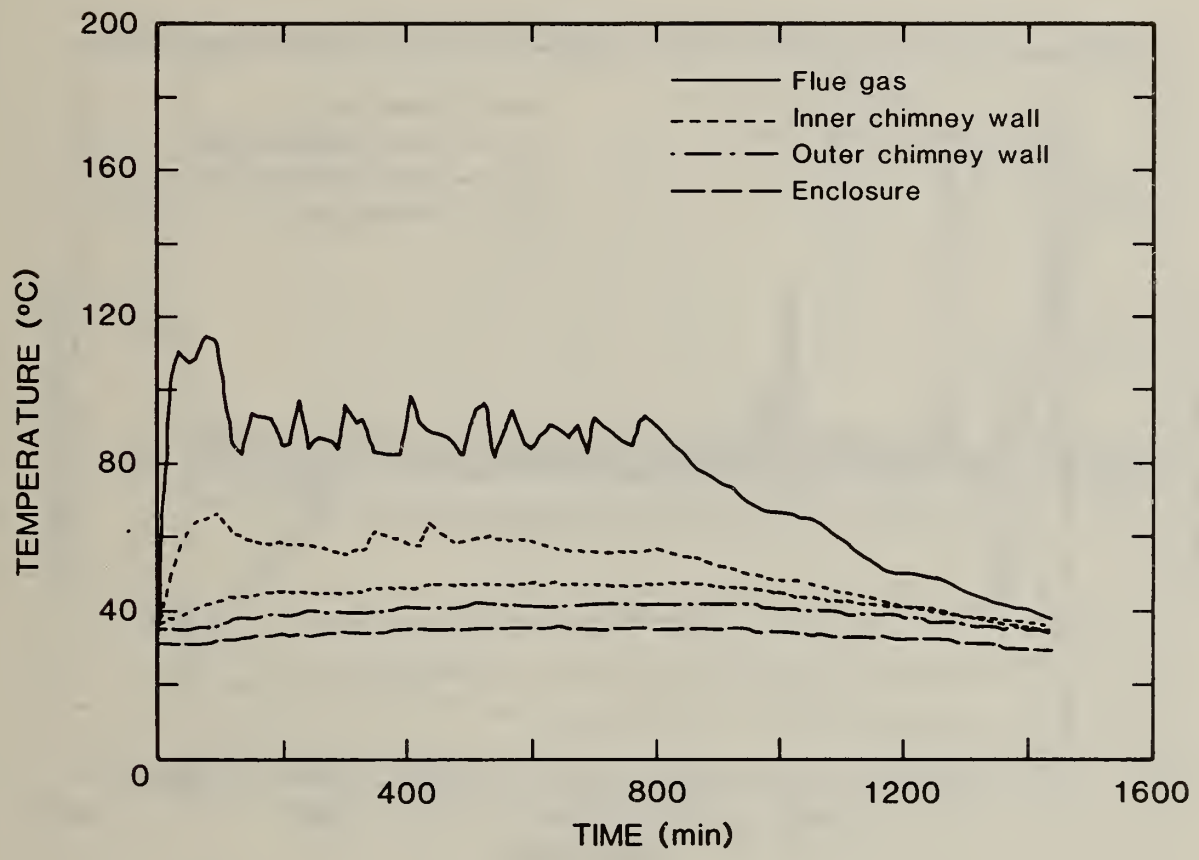


Figure 12. Temperatures at Chimney Base During Creosoting Buildup Test of Chimney 3.

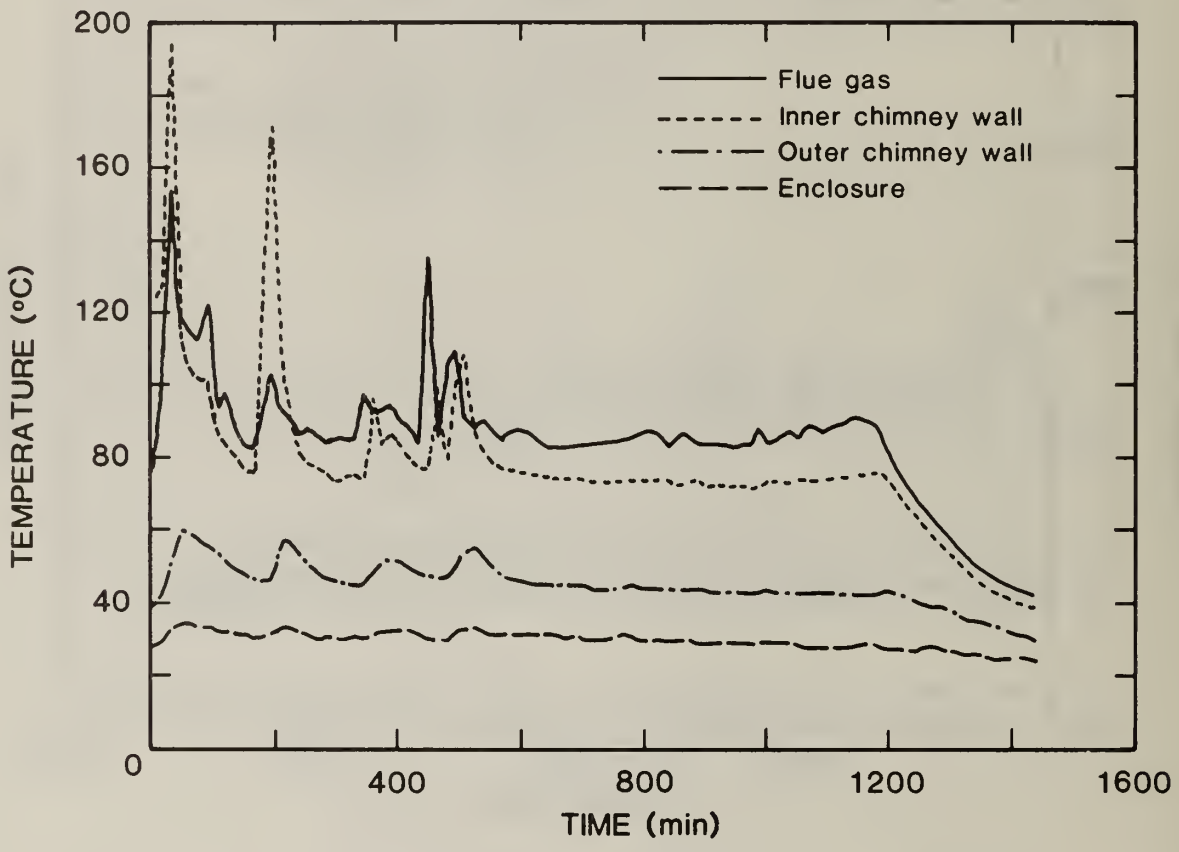


Figure 13. Temperatures at Chimney Base During Creosoting Buildup Test of Chimney 4.

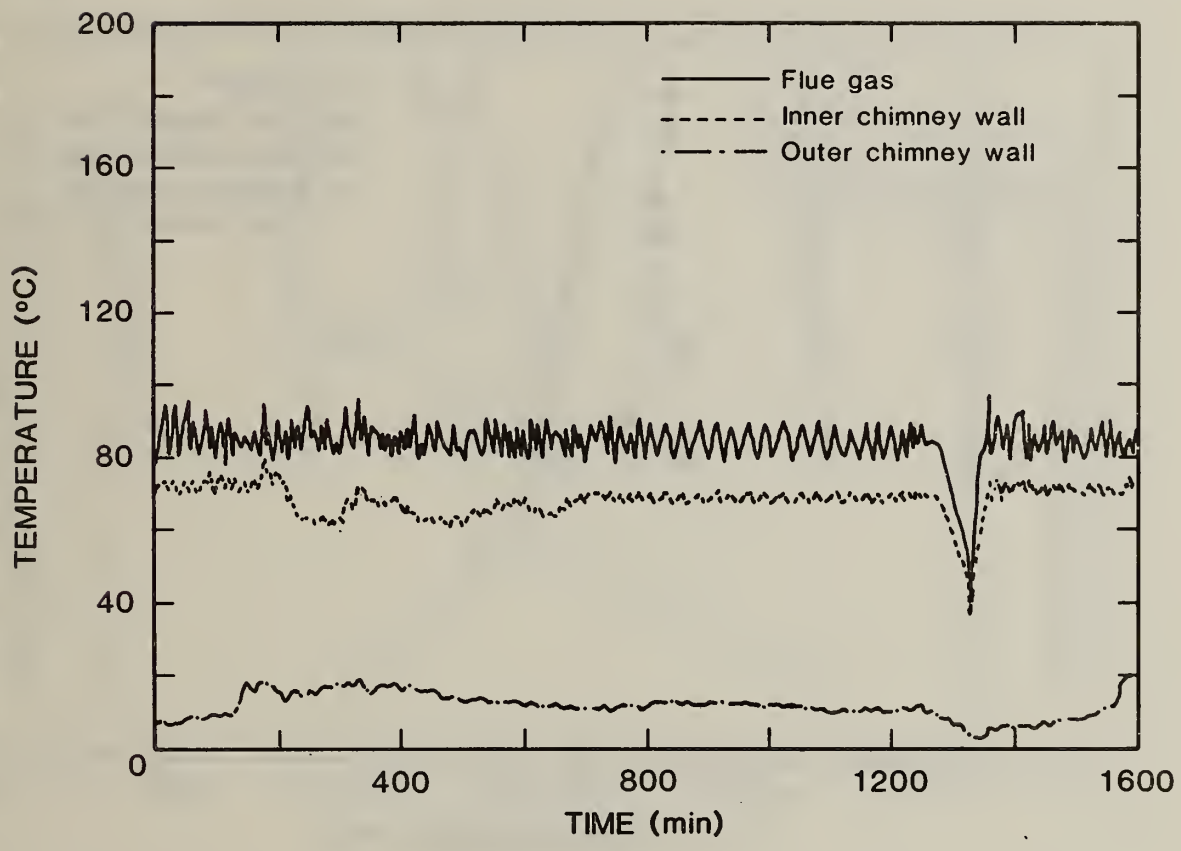


Figure 14. Temperatures at Chimney Base During Creosoting Buildup Test of Chimney 5.

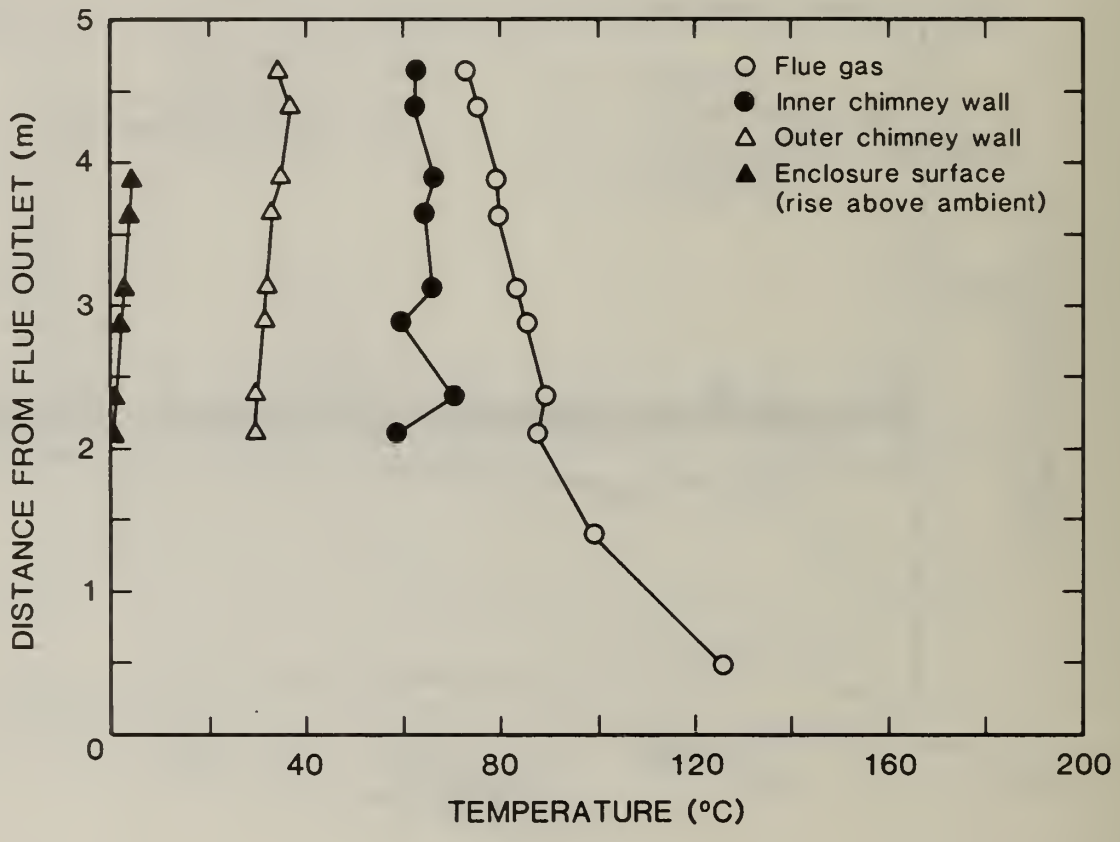


Figure 15. Temperature Profiles During Creosoting Buildup Test of Chimney 1.

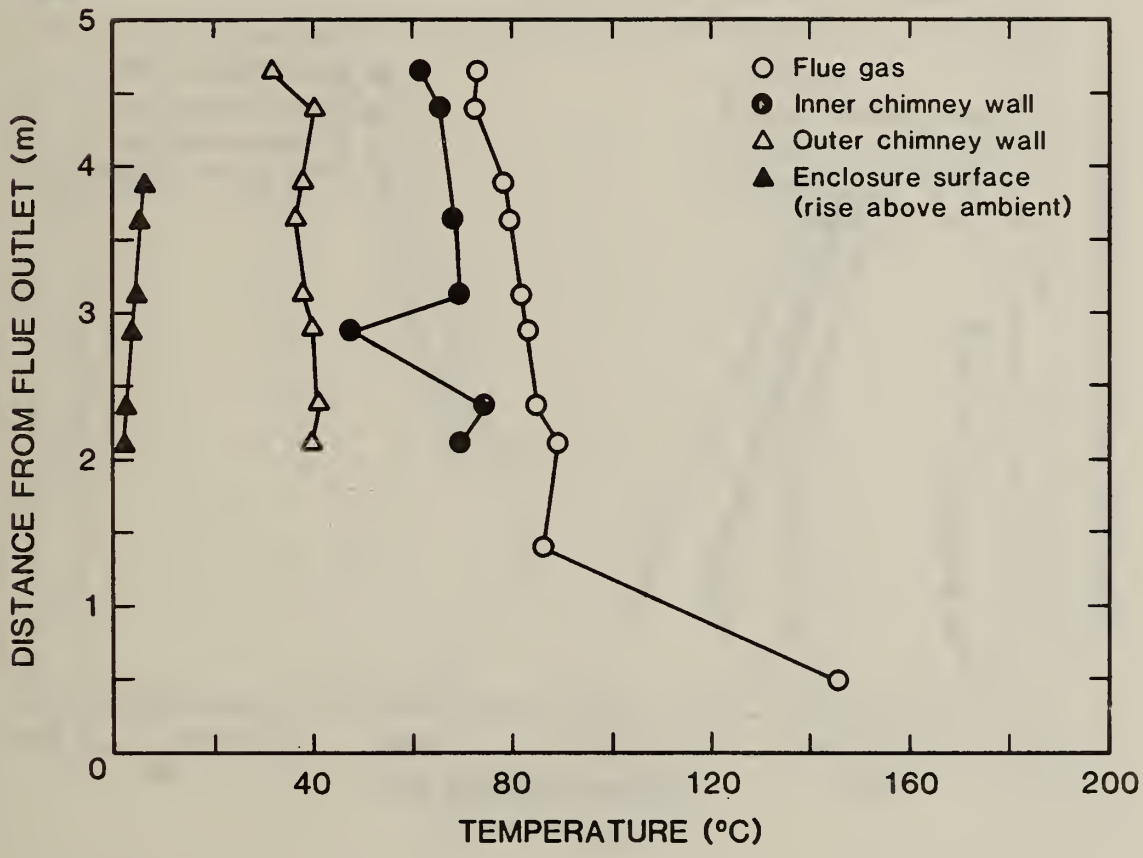


Figure 16. Temperature Profiles During Creosoting Buildup Test of Chimney 2.

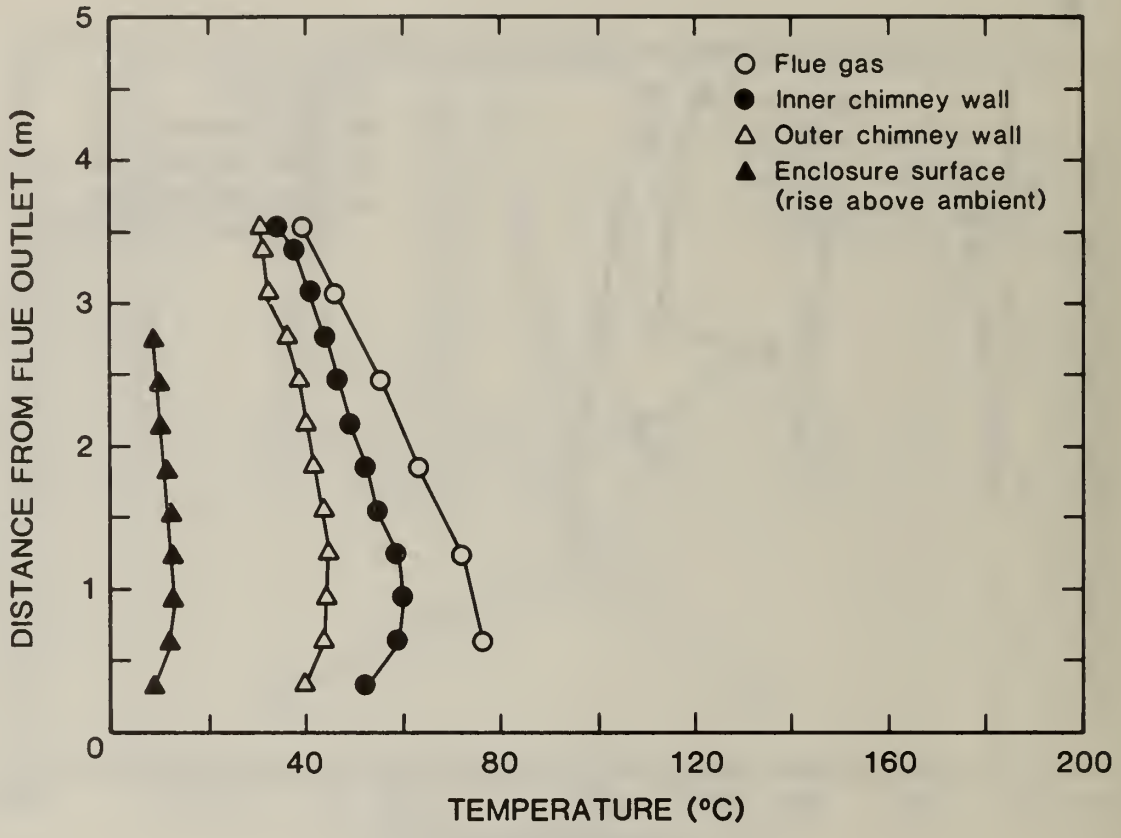


Figure 17. Temperature Profiles During Creosoting Buildup Test of Chimney 3.

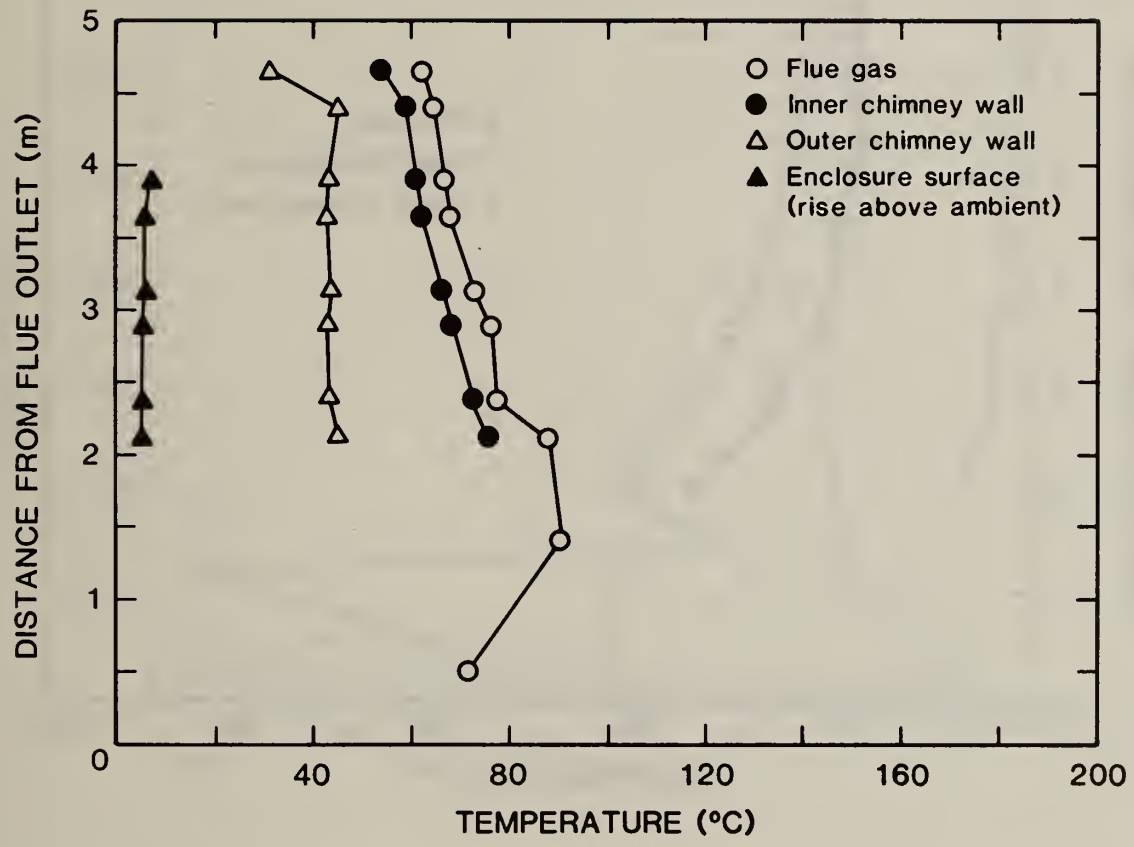


Figure 18. Temperature Profiles During Creosoting Buildup Test of Chimney 4.

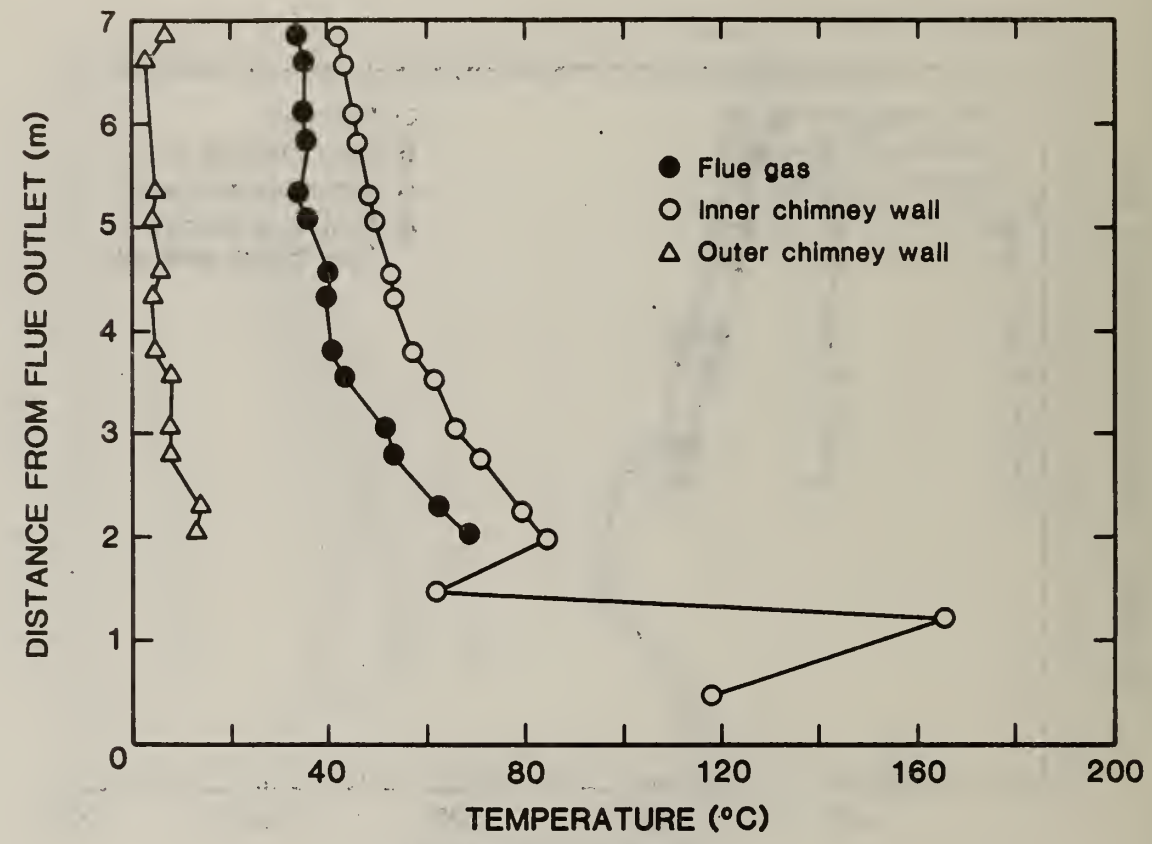


Figure 19. Temperature Profiles During Creosoting Buildup Test of Chimney 5.

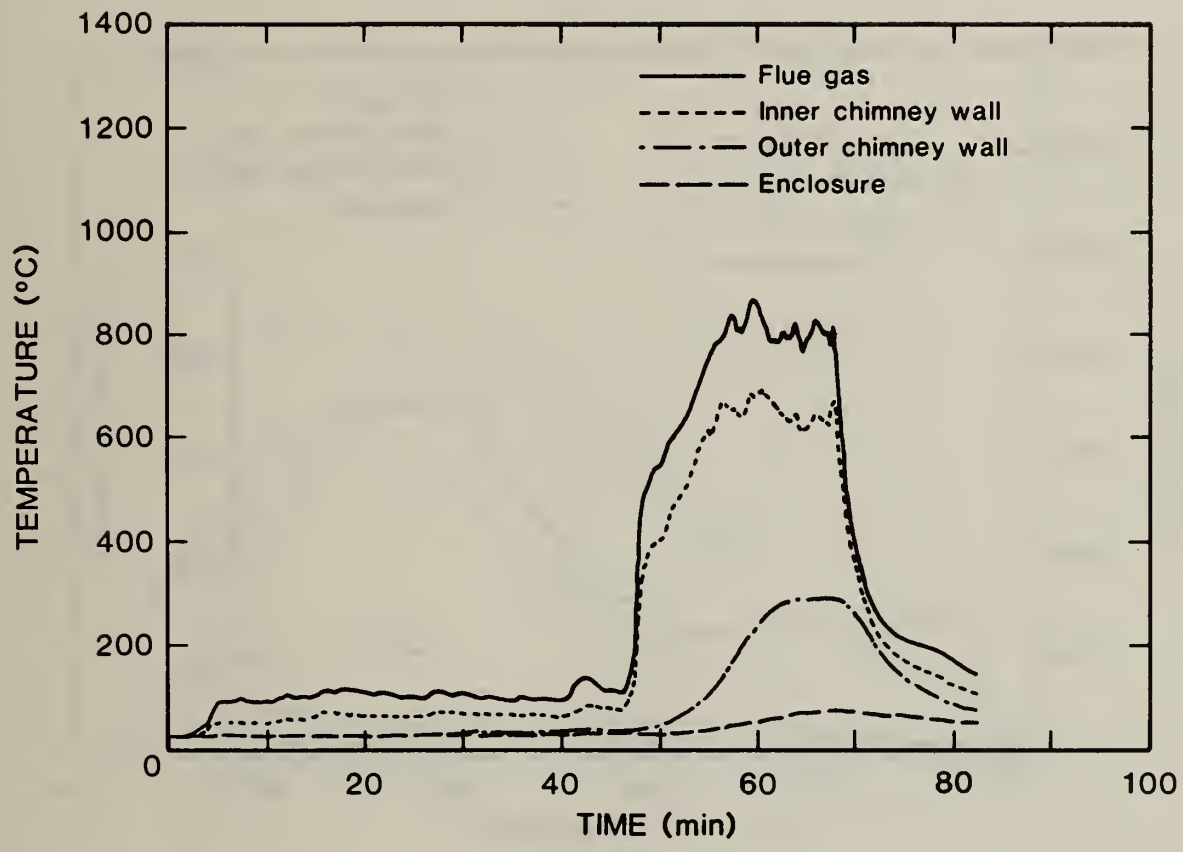


Figure 20. Temperatures at Chimney Base During Burnout of Chimney 1, Test 1.

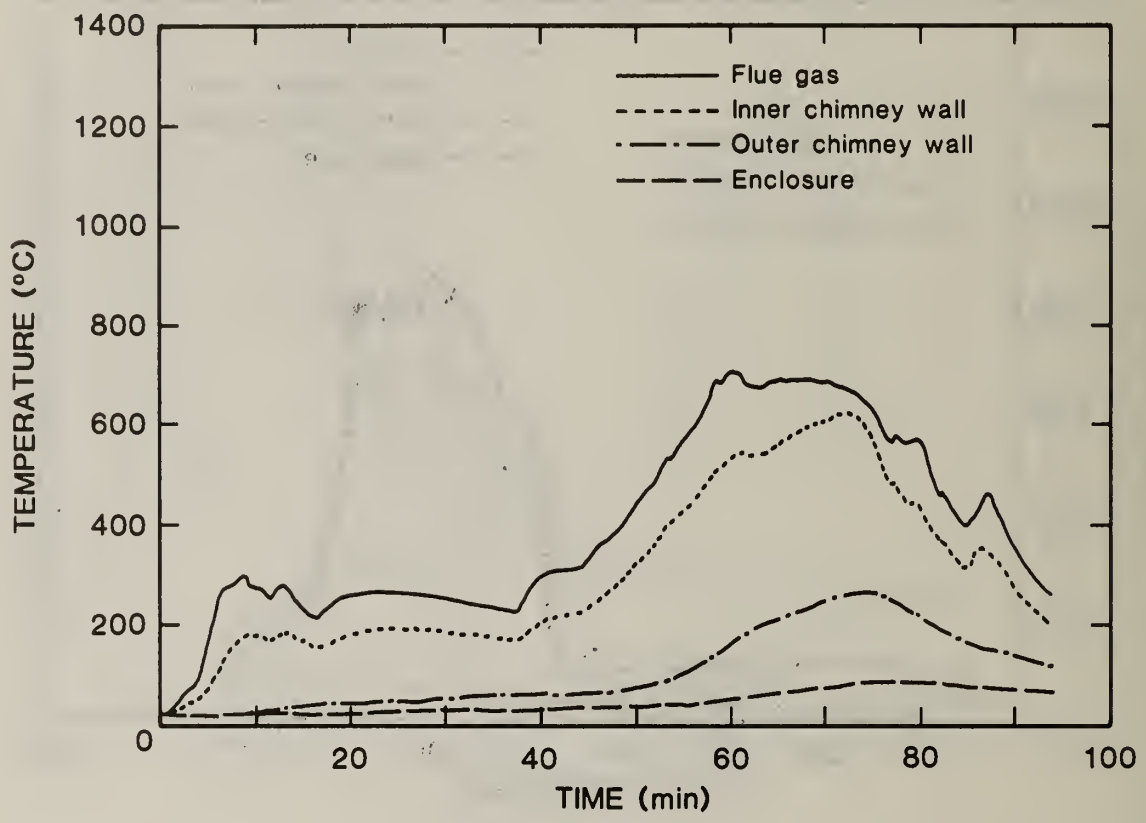


Figure 21. Temperatures at Chimney Base During Burnout of Chimney 1, Test 2.

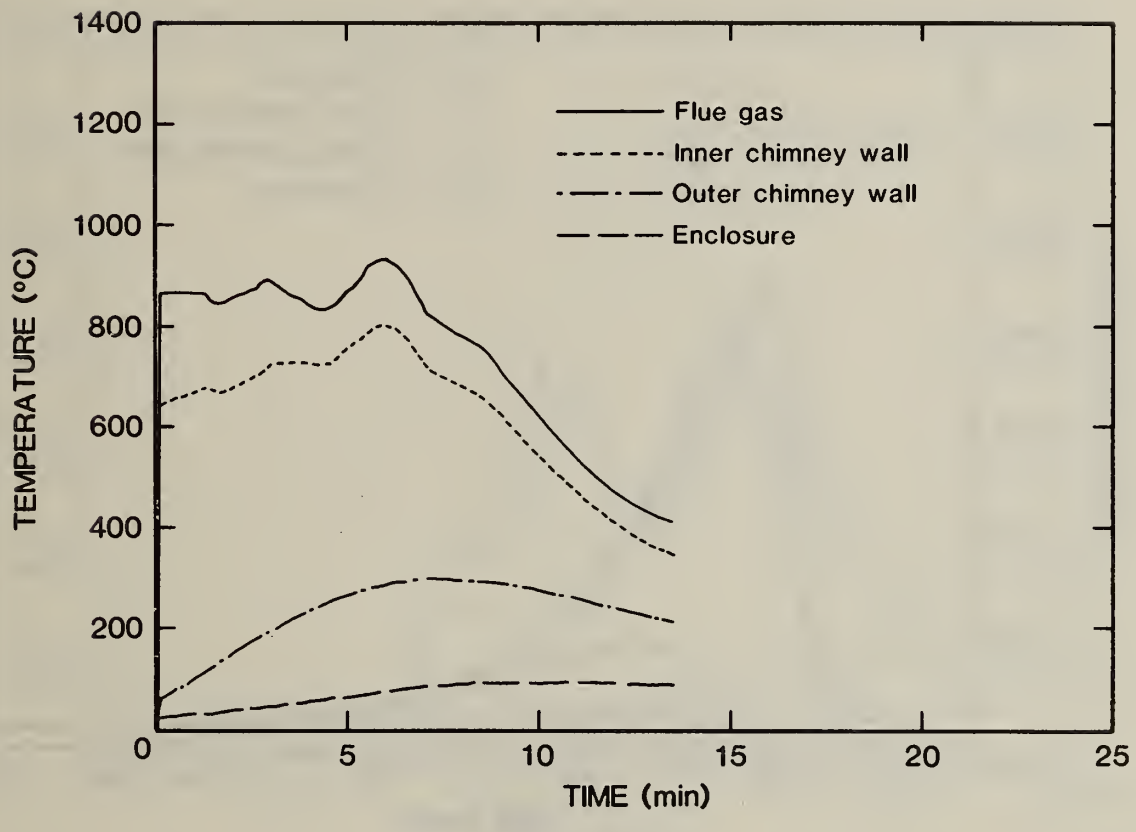


Figure 22. Temperatures at Chimney Base During Burnout of Chimney 1, Test 3.

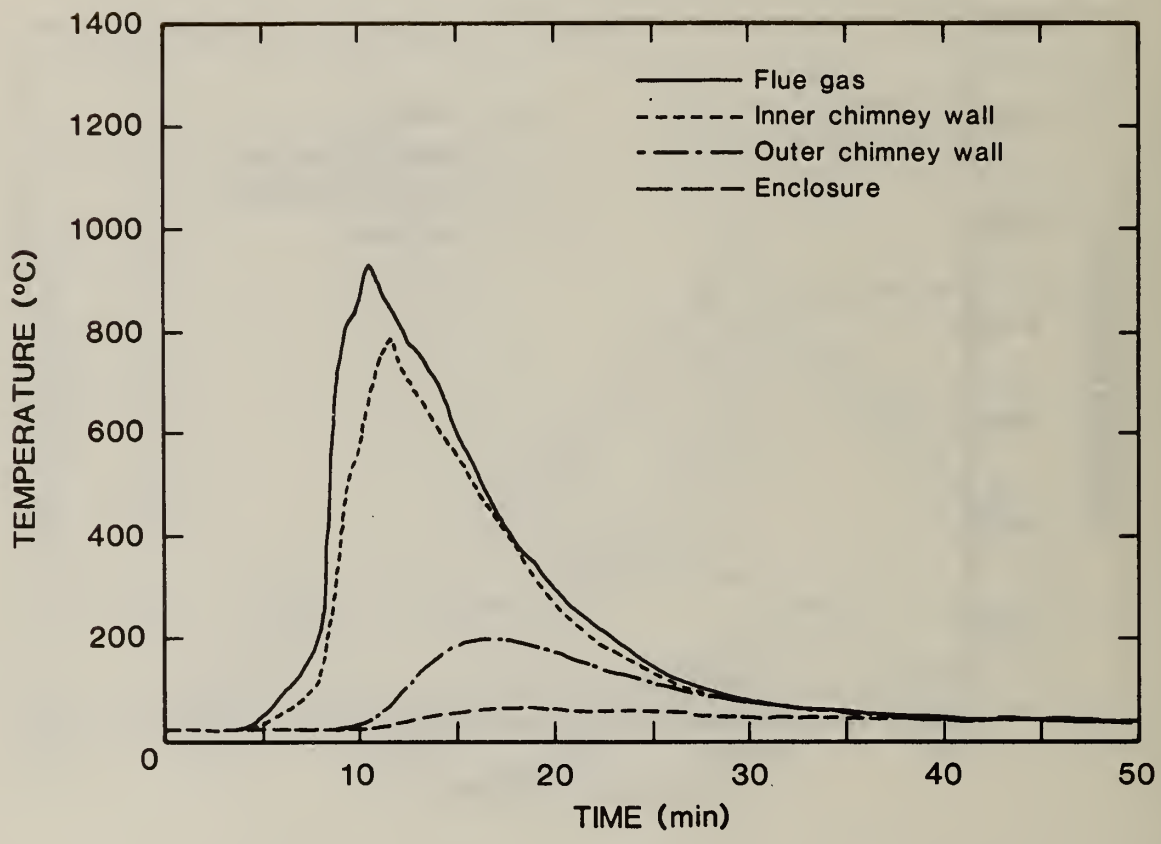


Figure 23. Temperatures at Chimney Base During Burnout of Chimney 1, Test

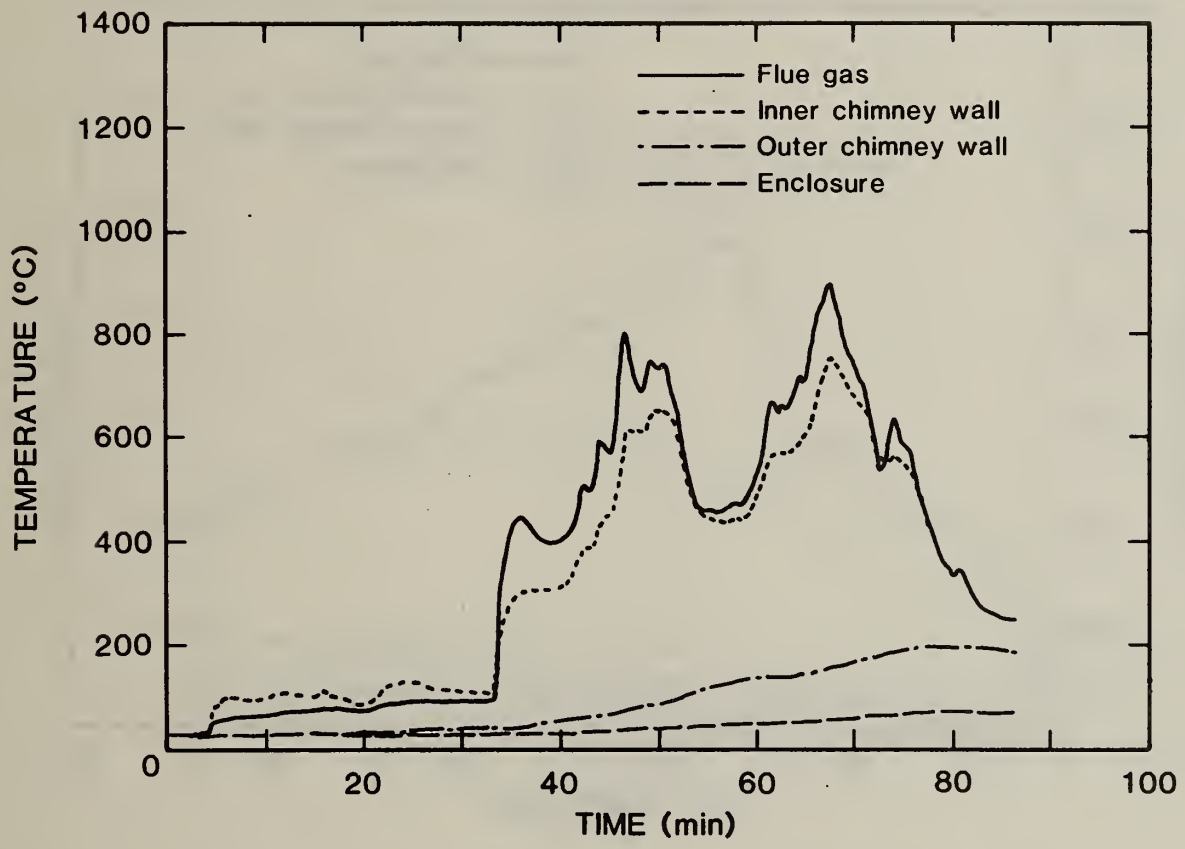


Figure 24. Temperatures at Chimney Base During Burnout of Chimney 2, Test 5.

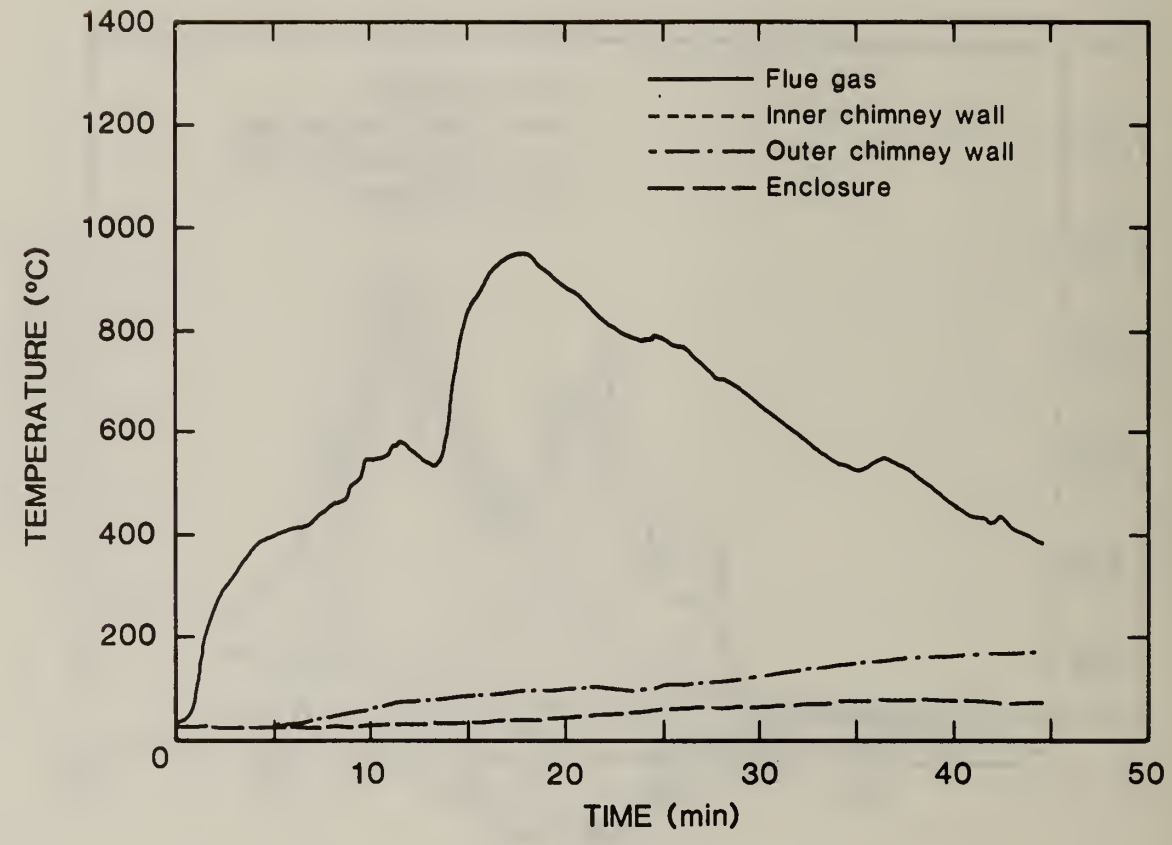


Figure 25. Temperatures at Chimney Base During Burnout of Chimney 2, Test 6.

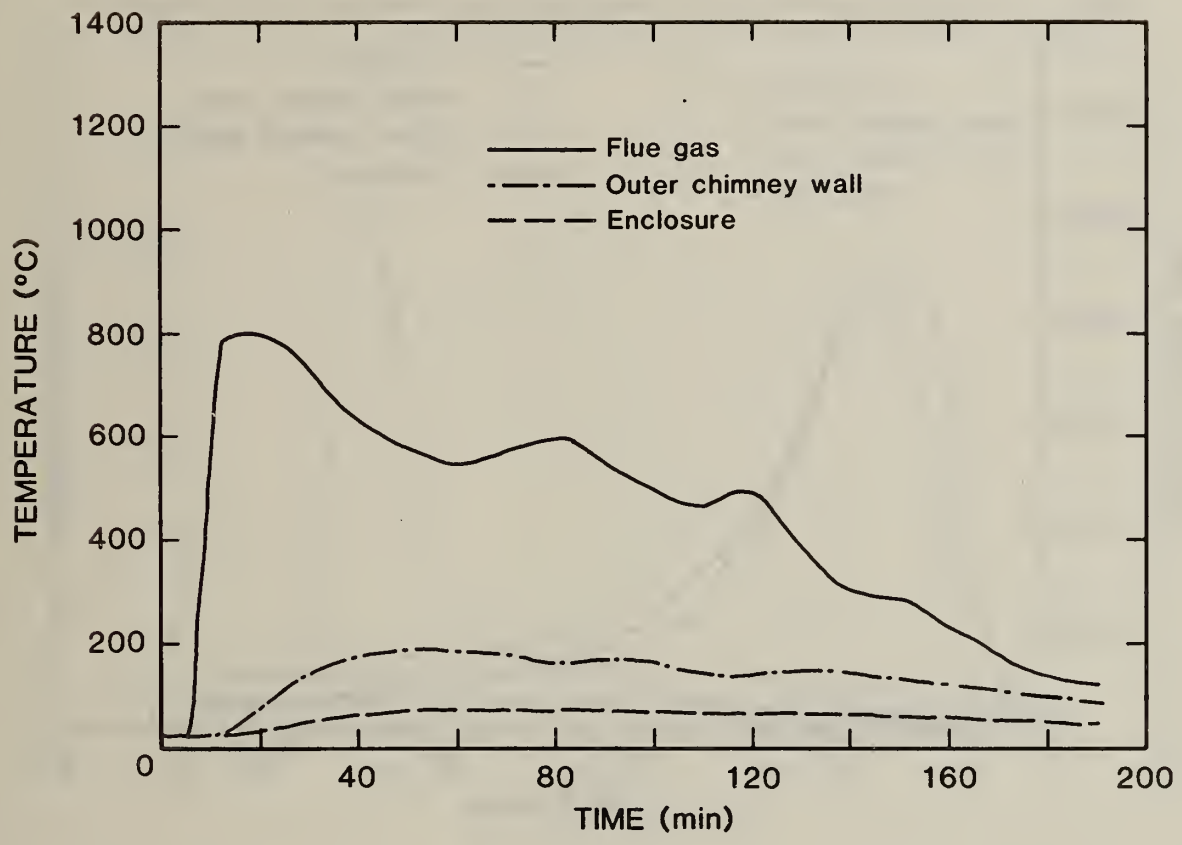


Figure 26. Temperatures at Chimney Base During Burnout of Chimney 2, Test 7.

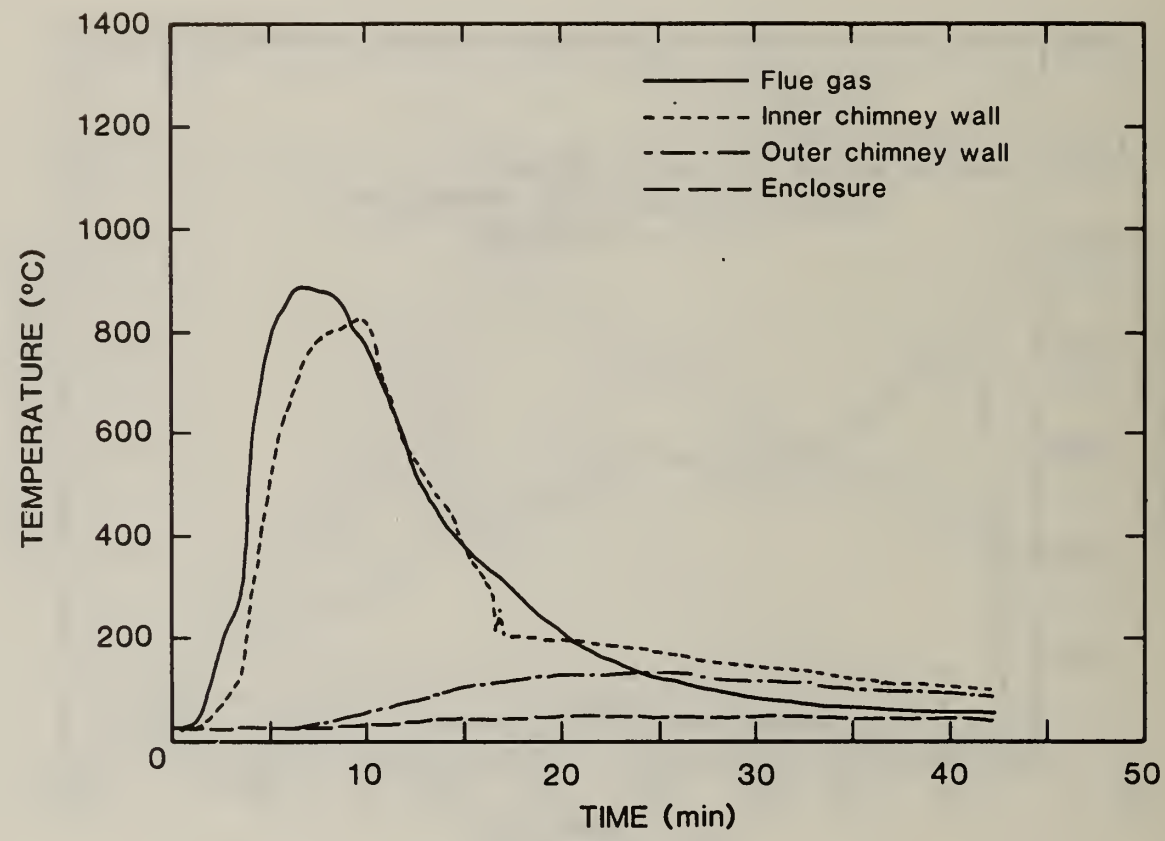


Figure 27. Temperatures at Chimney Base During Burnout of Chimney 2, Test 8.

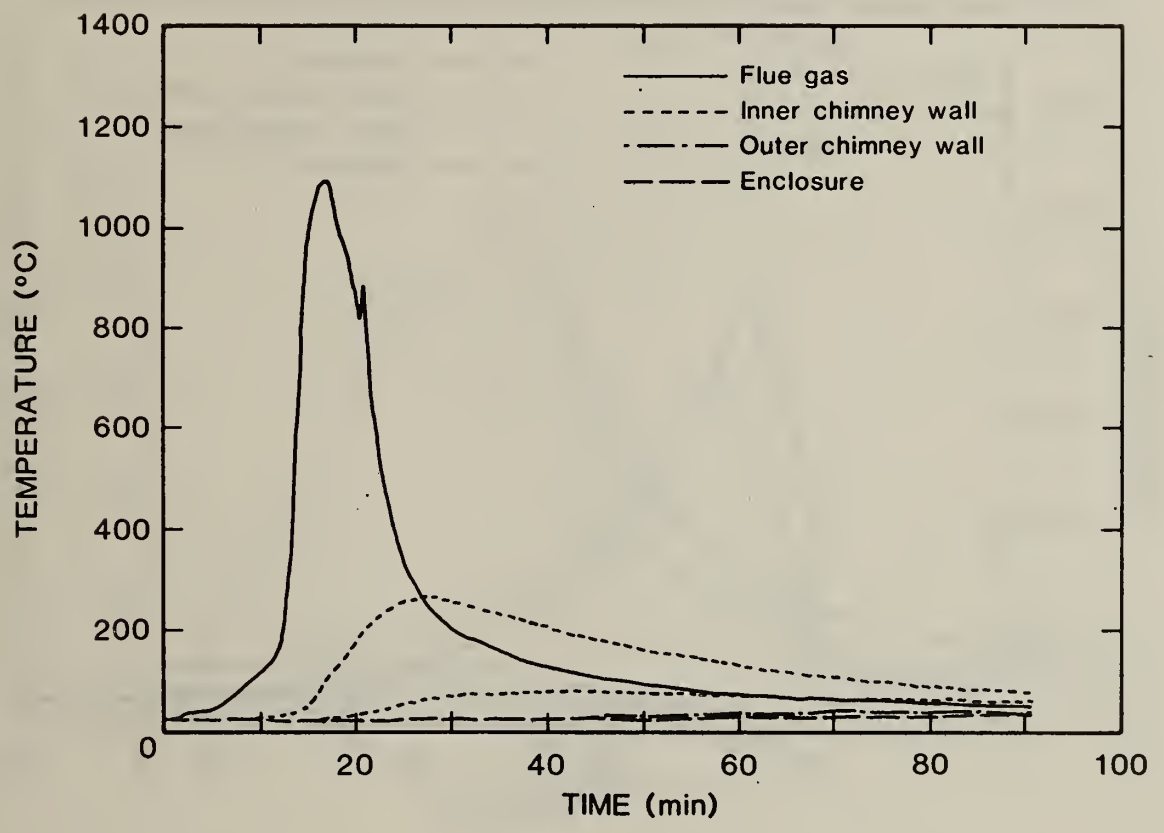


Figure 28. Temperatures at Chimney Base During Burnout of Chimney 3, Test 9.

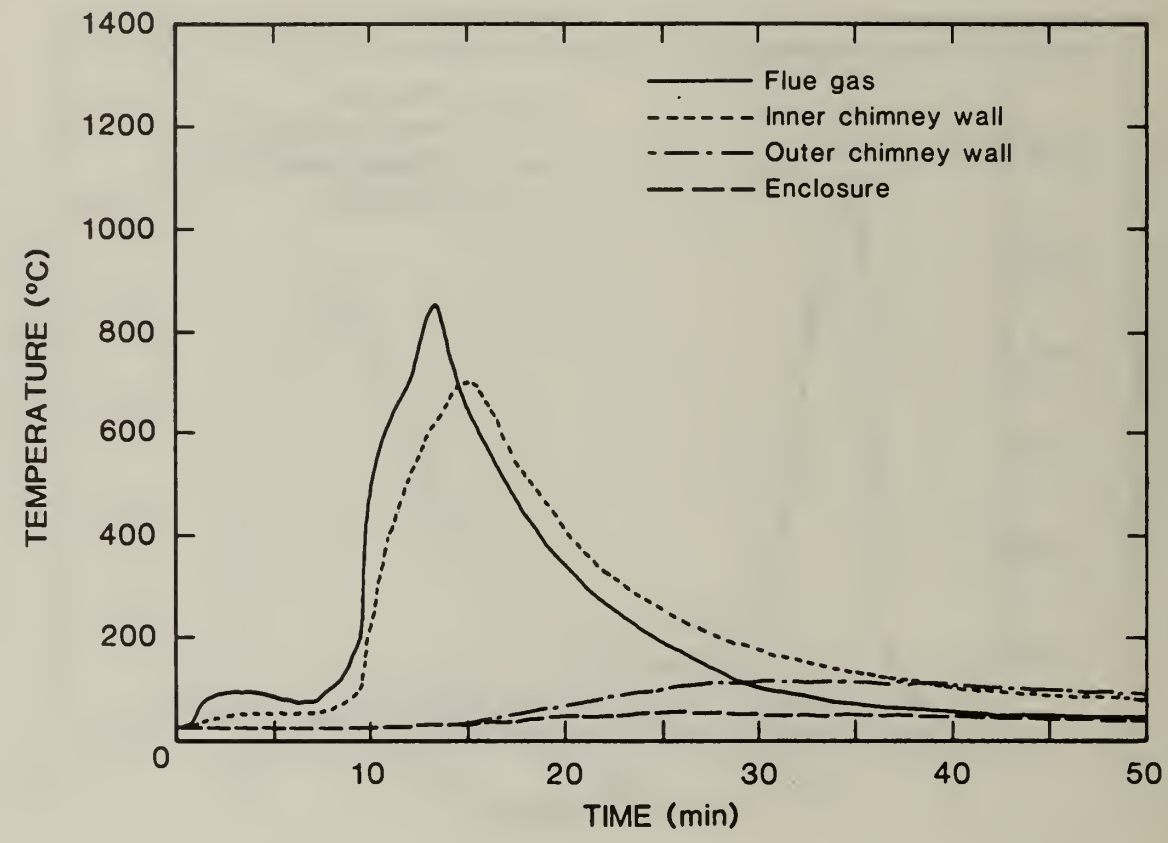


Figure 29. Temperatures at Chimney Base During Burnout of Chimney 4, Test 10.

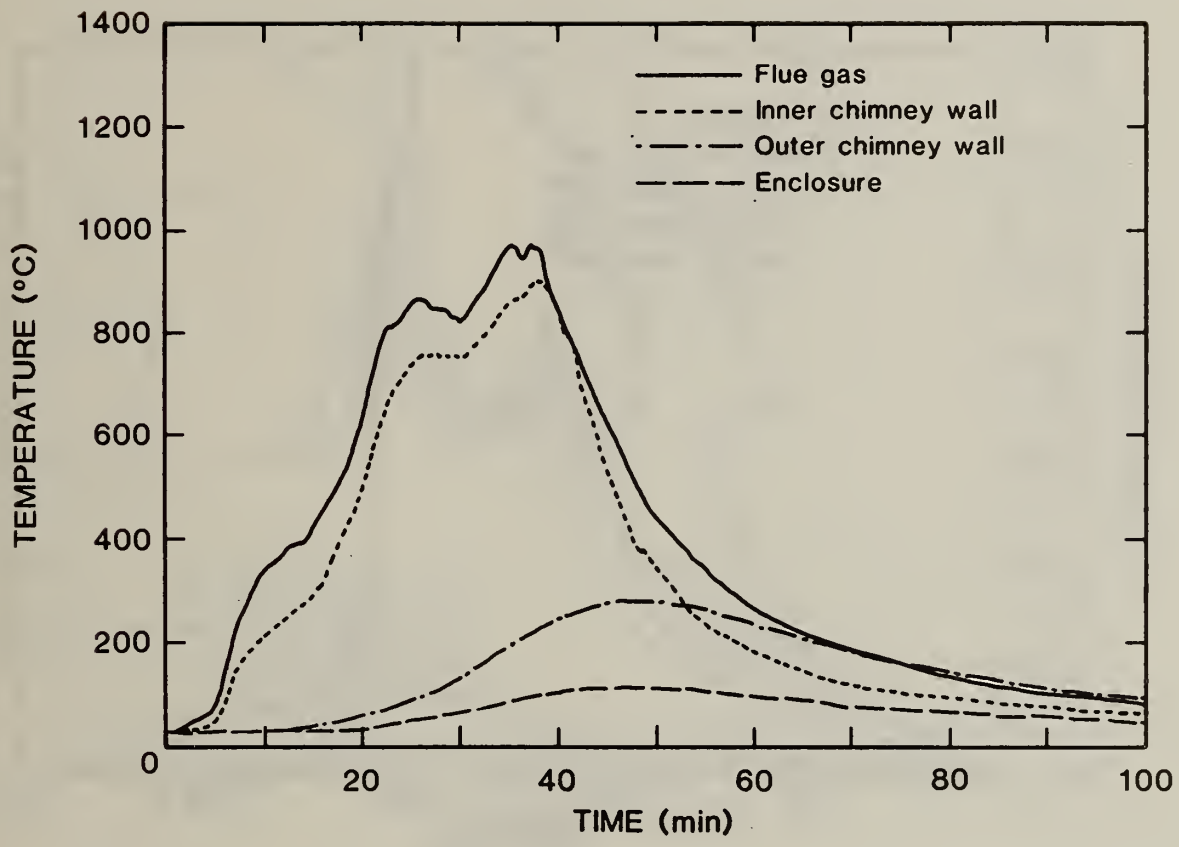


Figure 30. Temperatures at Chimney Base During Burnout of Chimney 4, Test 11.

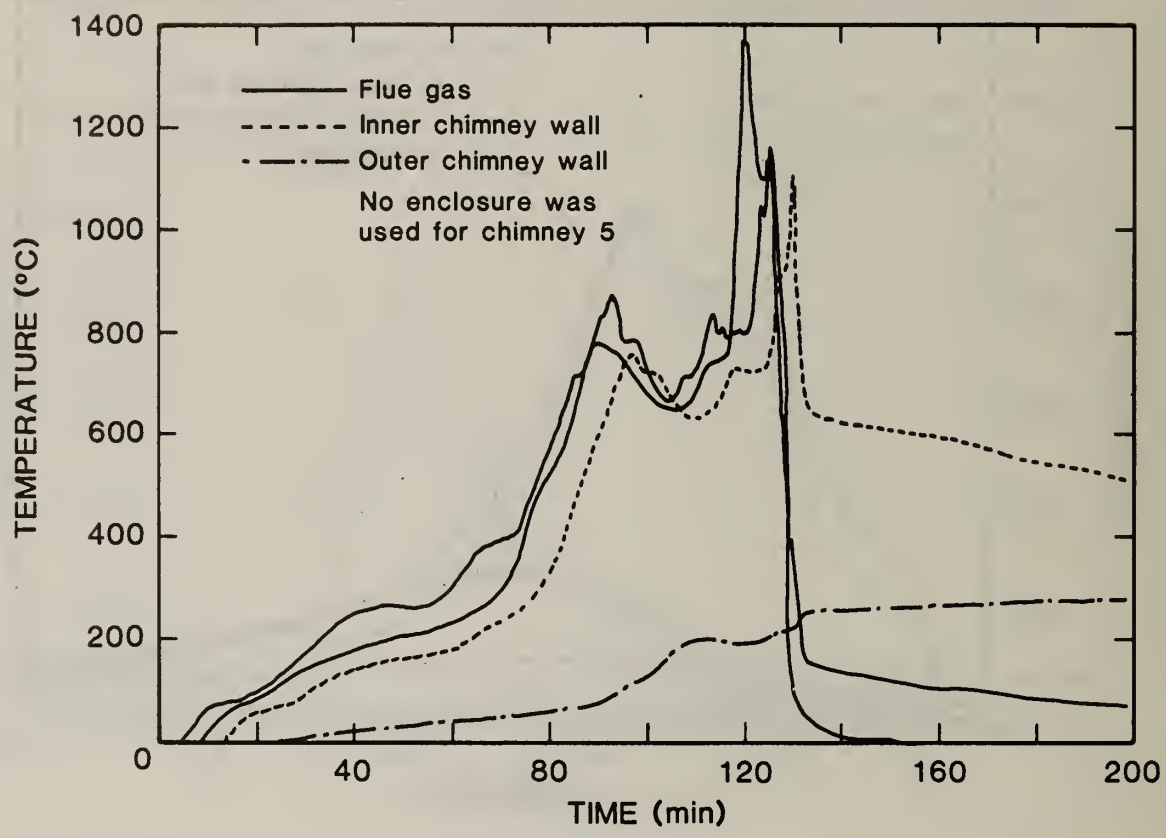


Figure 31. Temperatures at Chimney Base During Burnout of Chimney 5, Test 12.

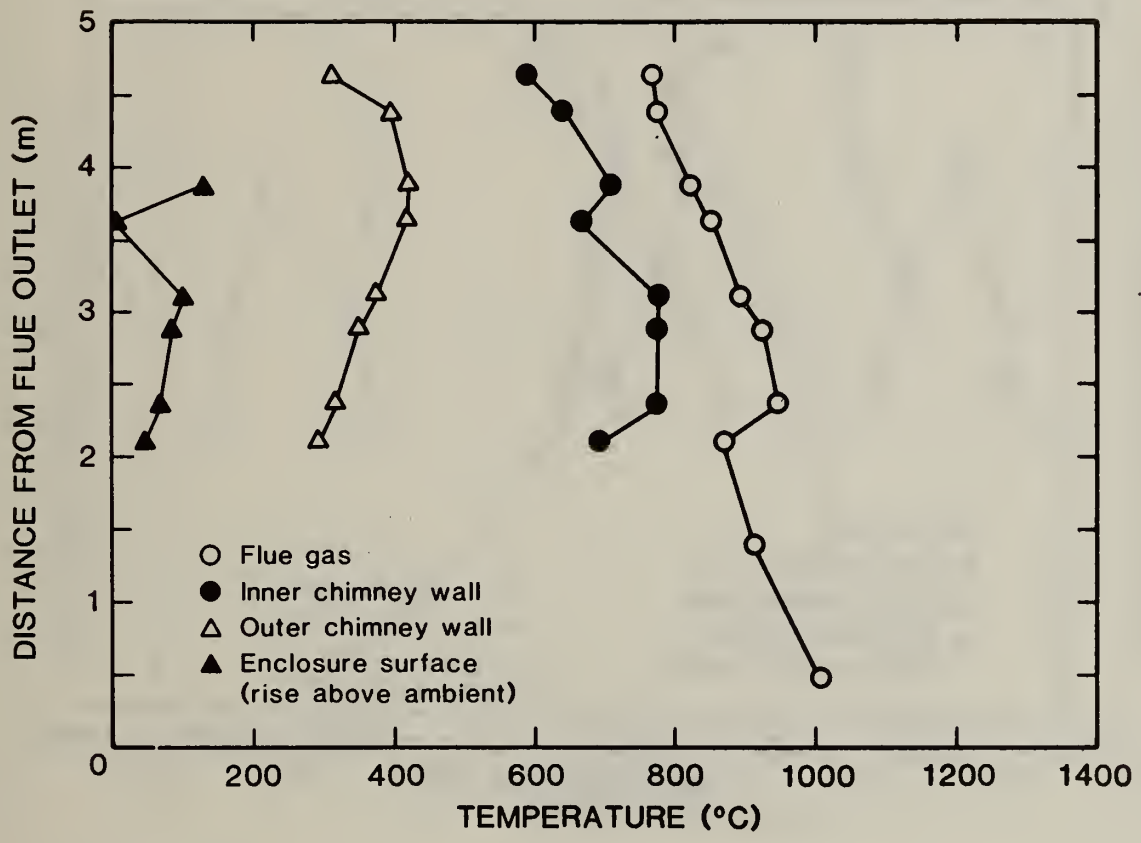


Figure 32. Temperature Profiles During Burnout Test of Chimney 1, Test 1.

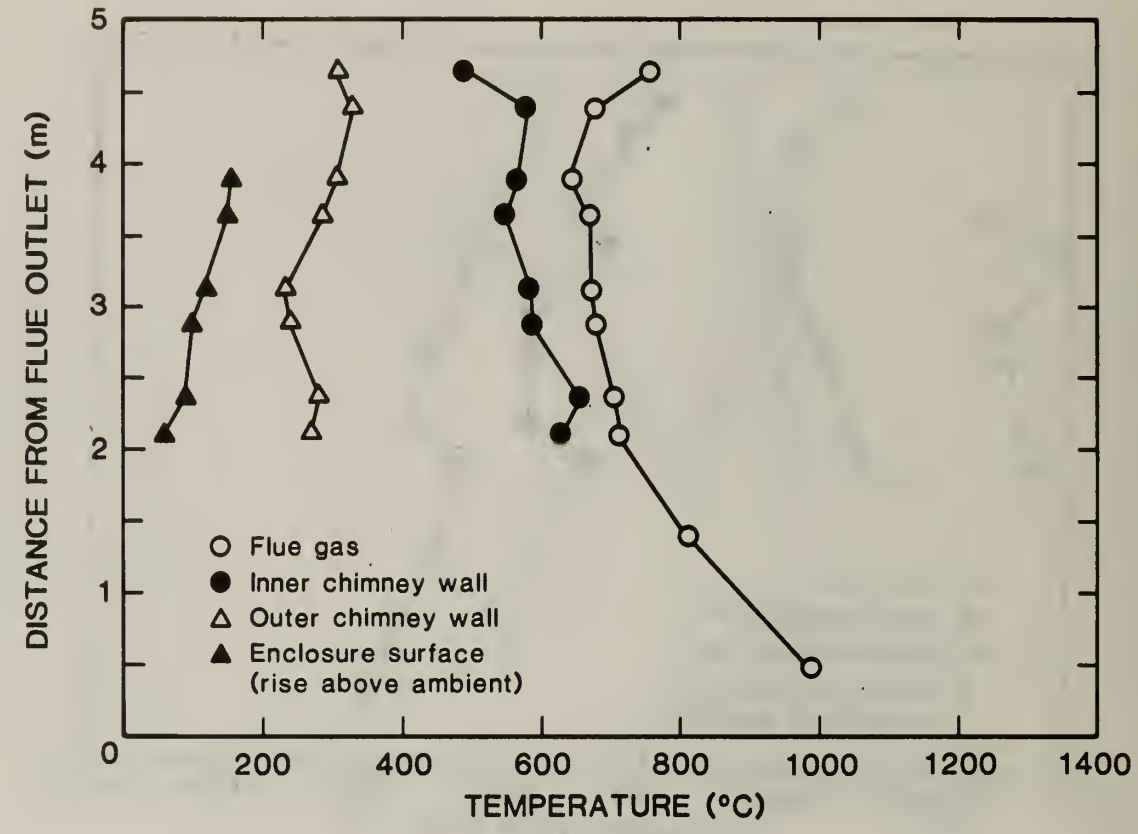


Figure 33. Temperature Profiles During Burnout Test of Chimney 1, Test 2.

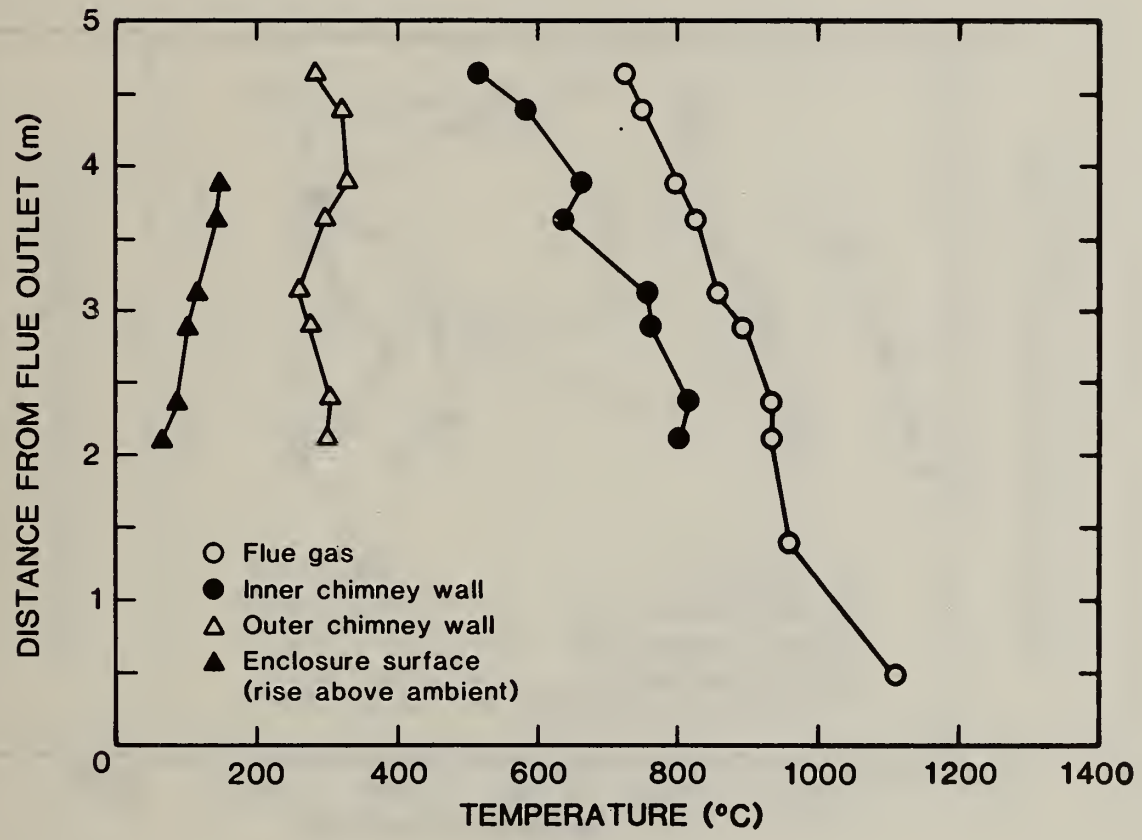


Figure 34. Temperature Profiles During Burnout Test of Chimney 1, Test 3.

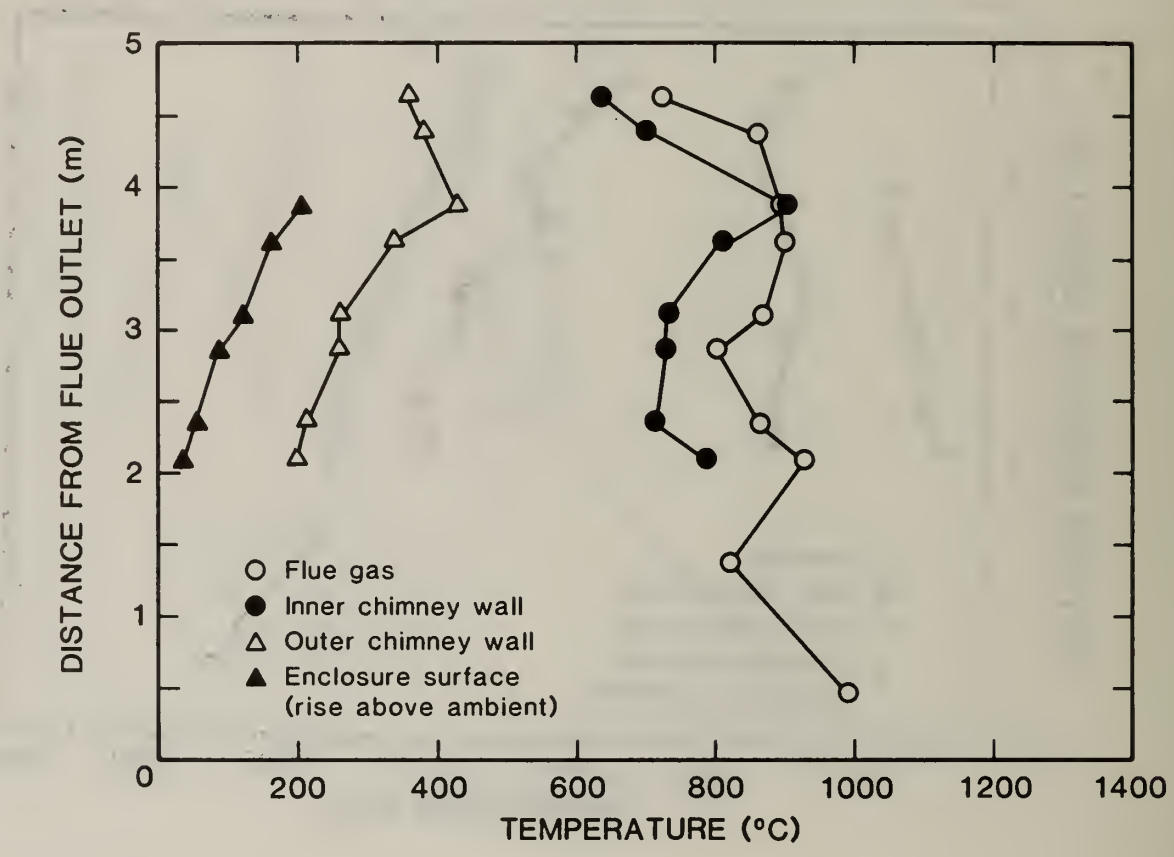


Figure 35. Temperature Profiles During Burnout Test of Chimney 1, Test 4.

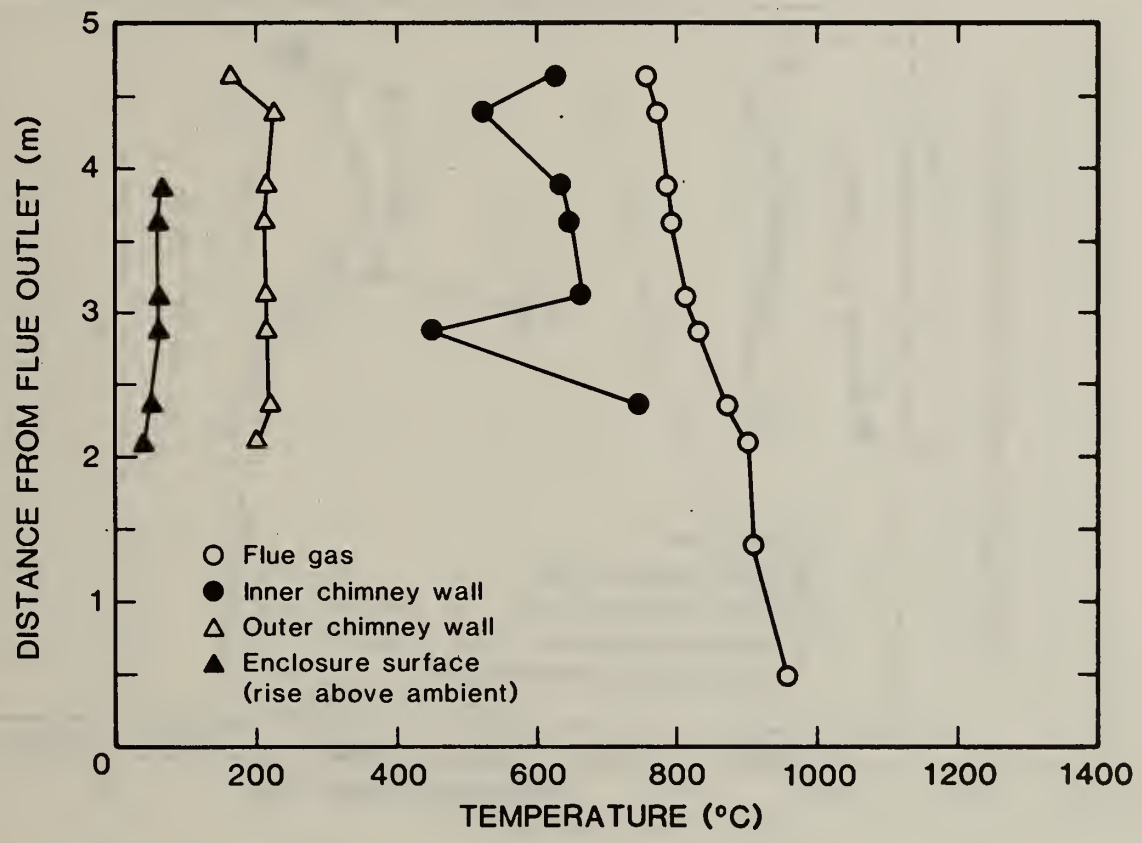


Figure 36. Temperature Profiles During Burnout Test of Chimney 2, Test 5.

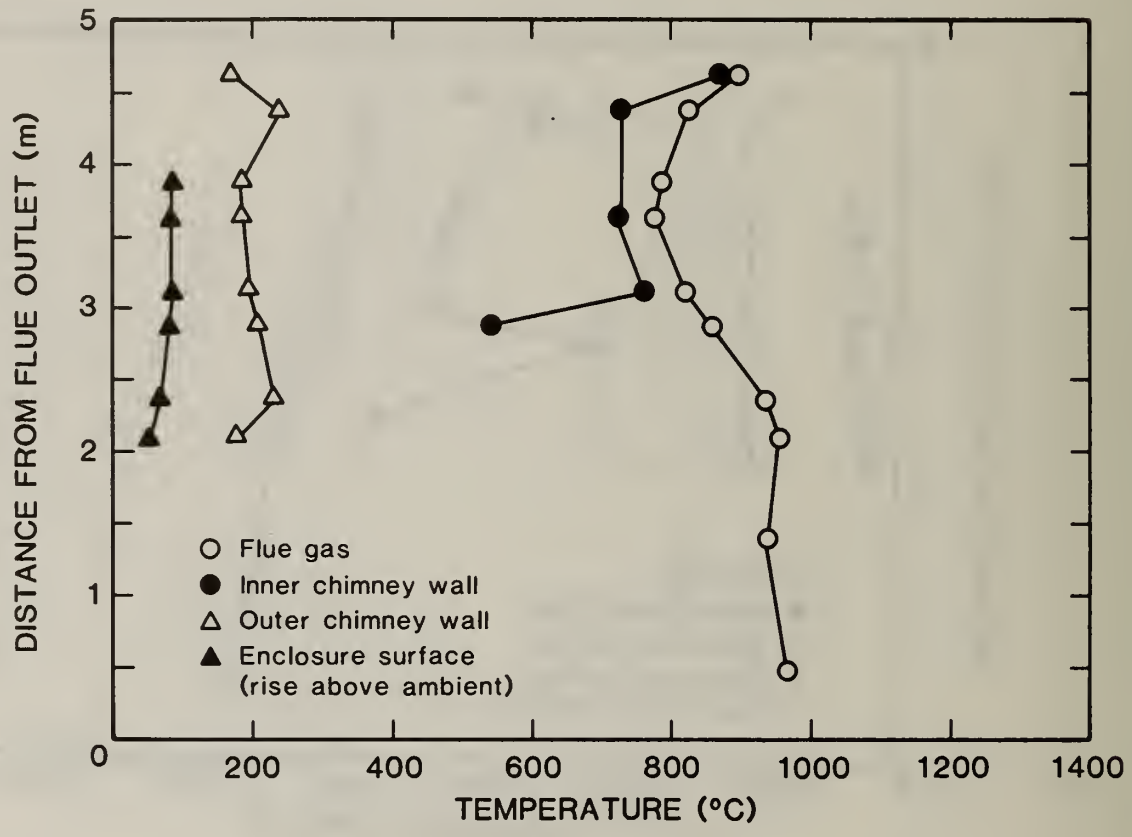


Figure 37. Temperature Profiles During Burnout Test of Chimney 2, Test 6.

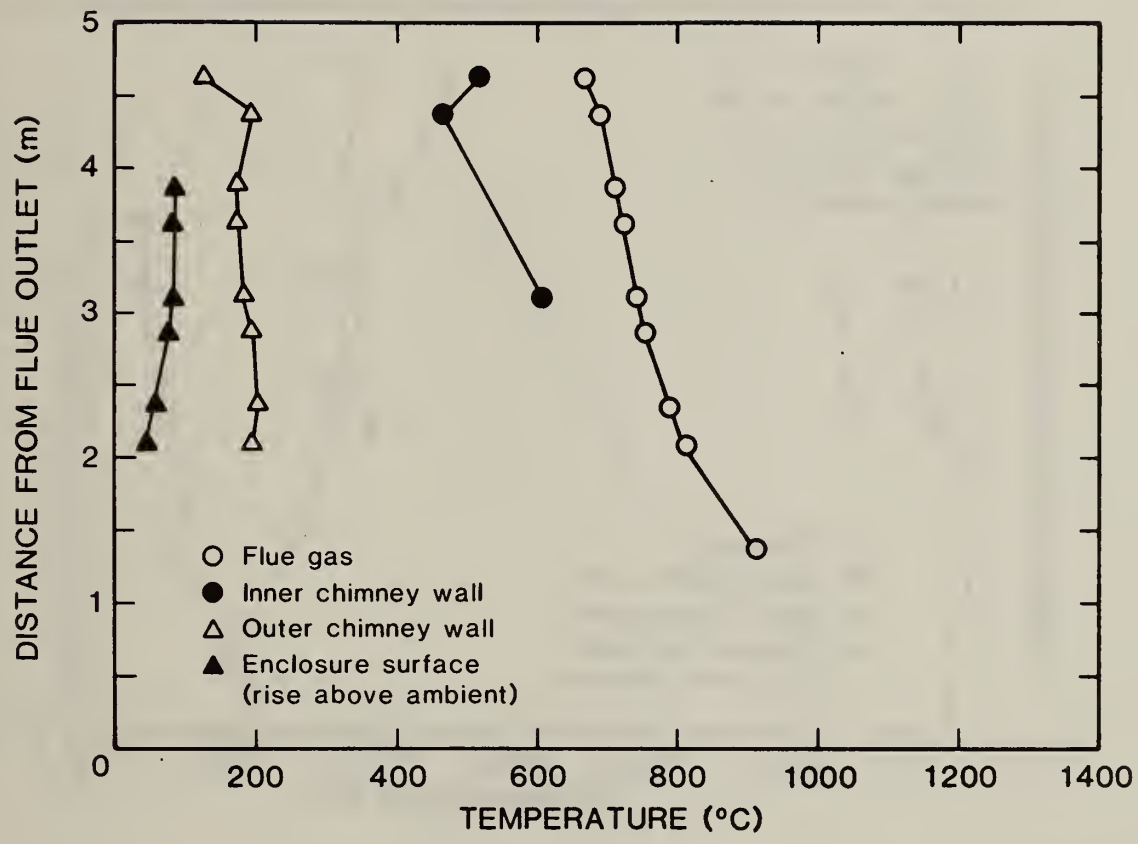


Figure 38. Temperature Profiles During Burnout Test of Chimney 2, Test 7.

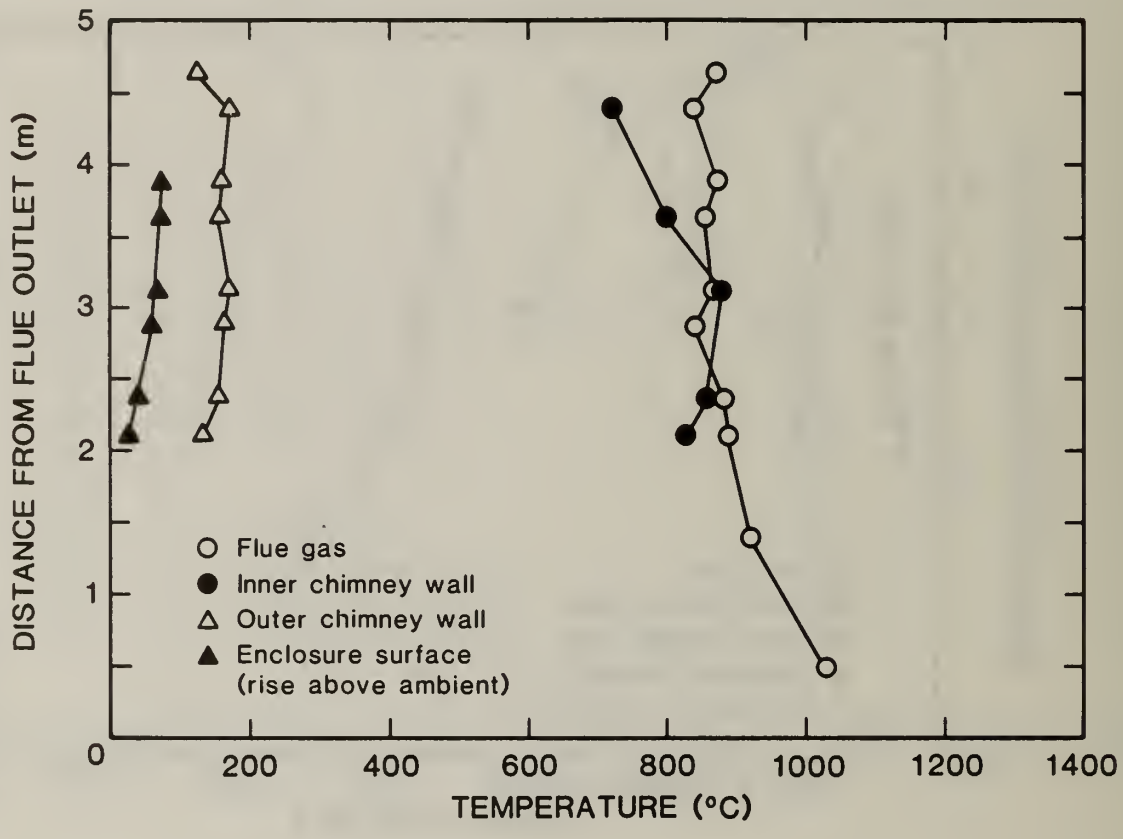


Figure 39. Temperature Profiles During Burnout Test of Chimney 2, Test 8.

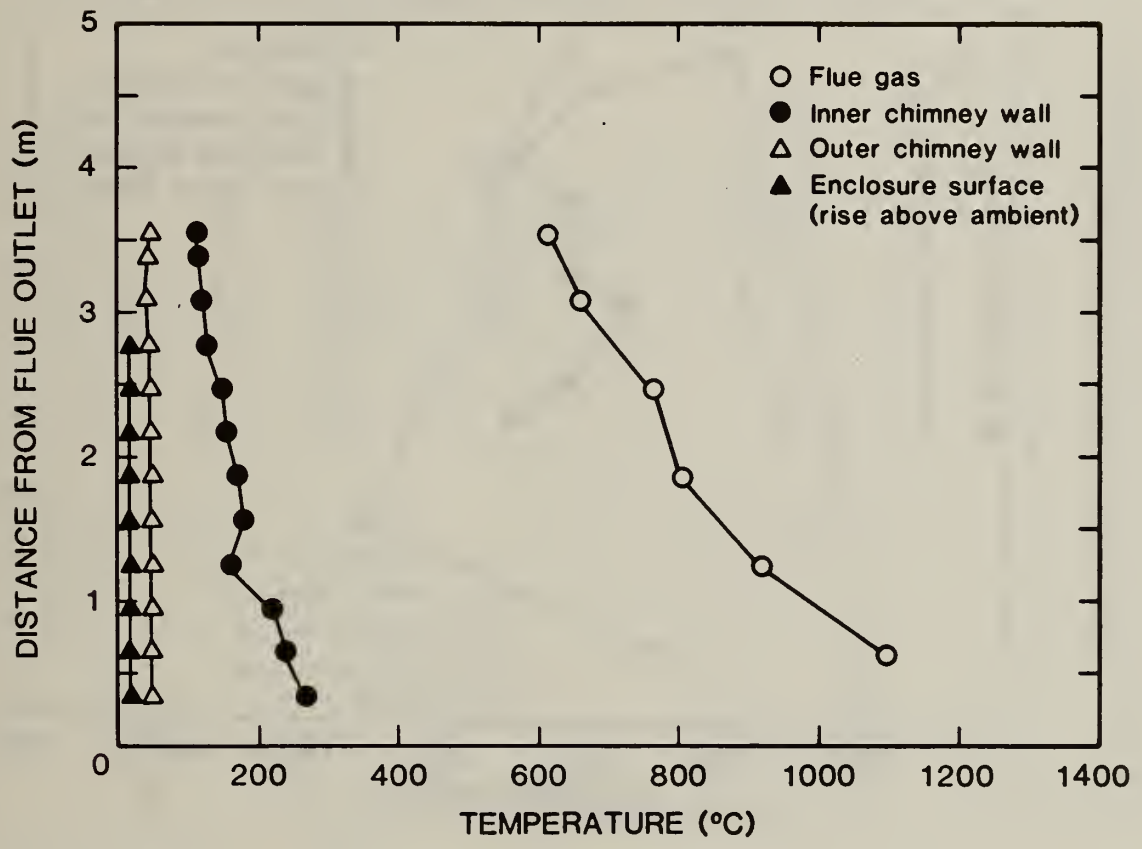


Figure 40. Temperature Profiles During Burnout Test of Chimney 3, Test 9.

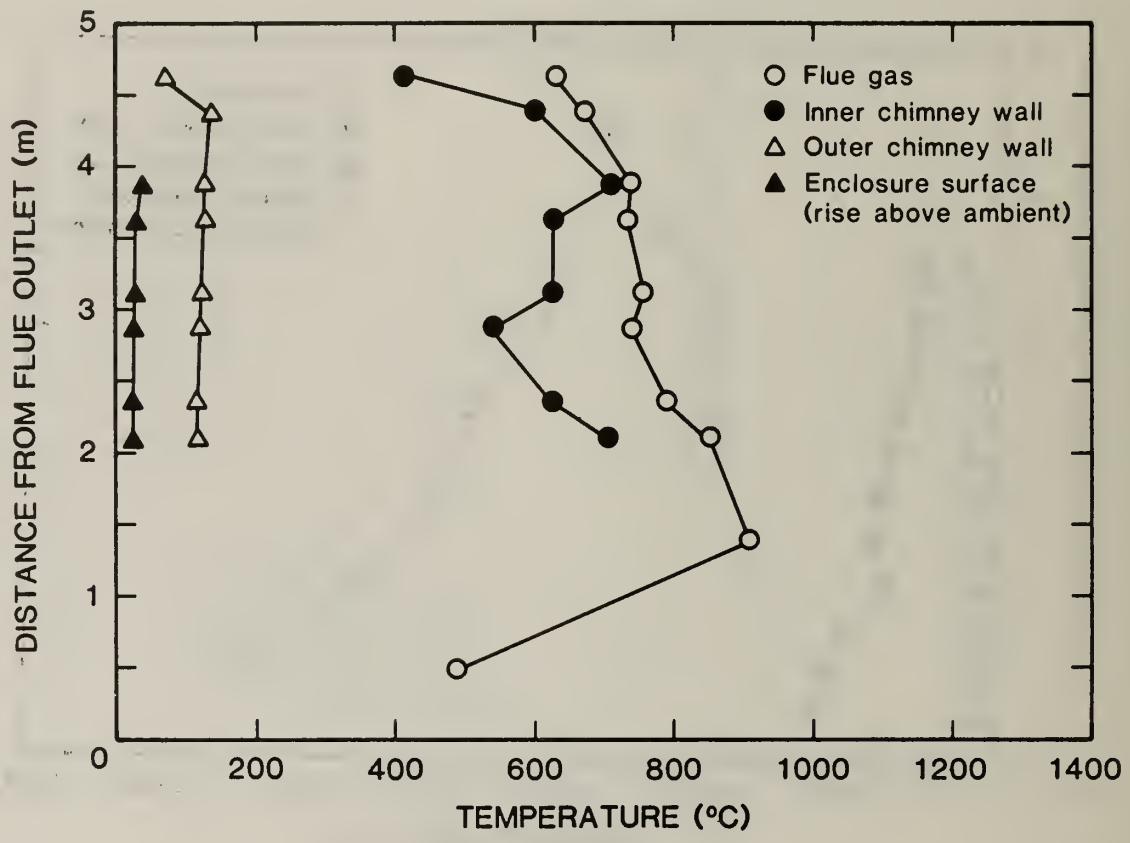


Figure 41. Temperature Profiles During Burnout Test of Chimney 4, Test 10.

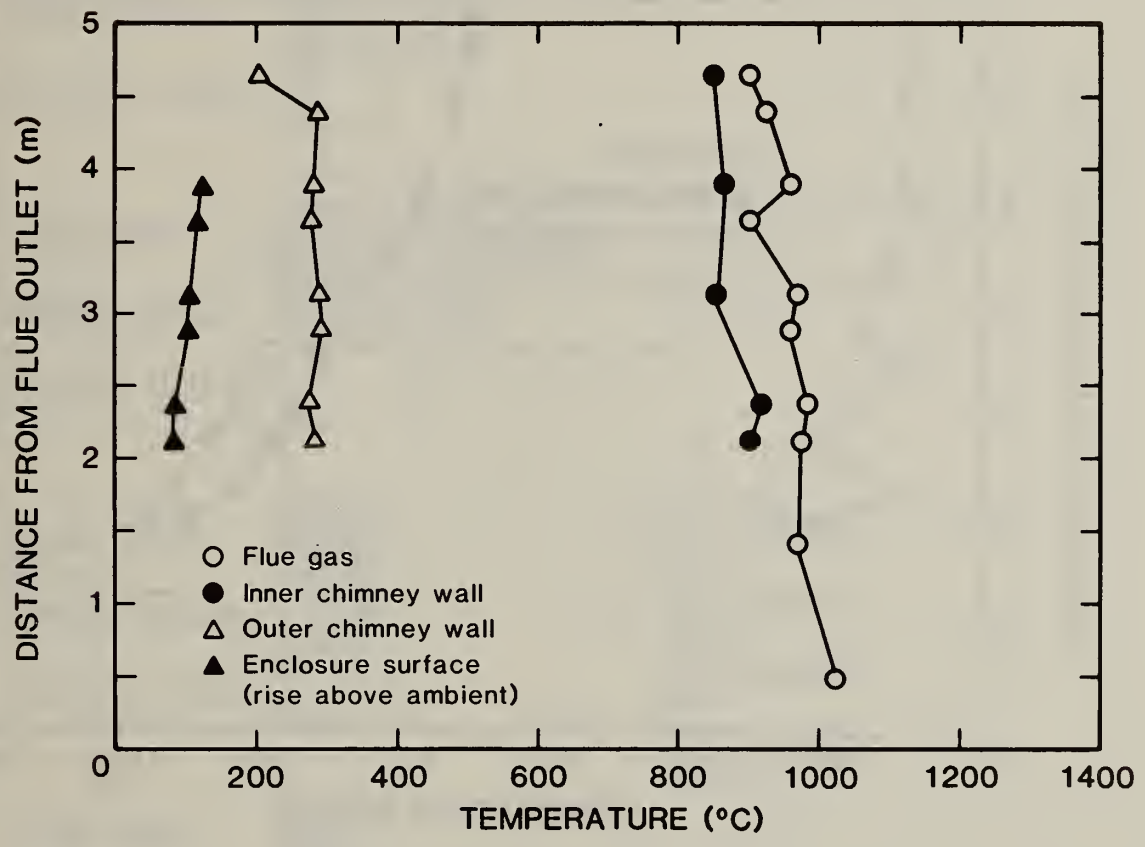


Figure 42. Temperature Profiles During Burnout Test of Chimney 4, Test 11.

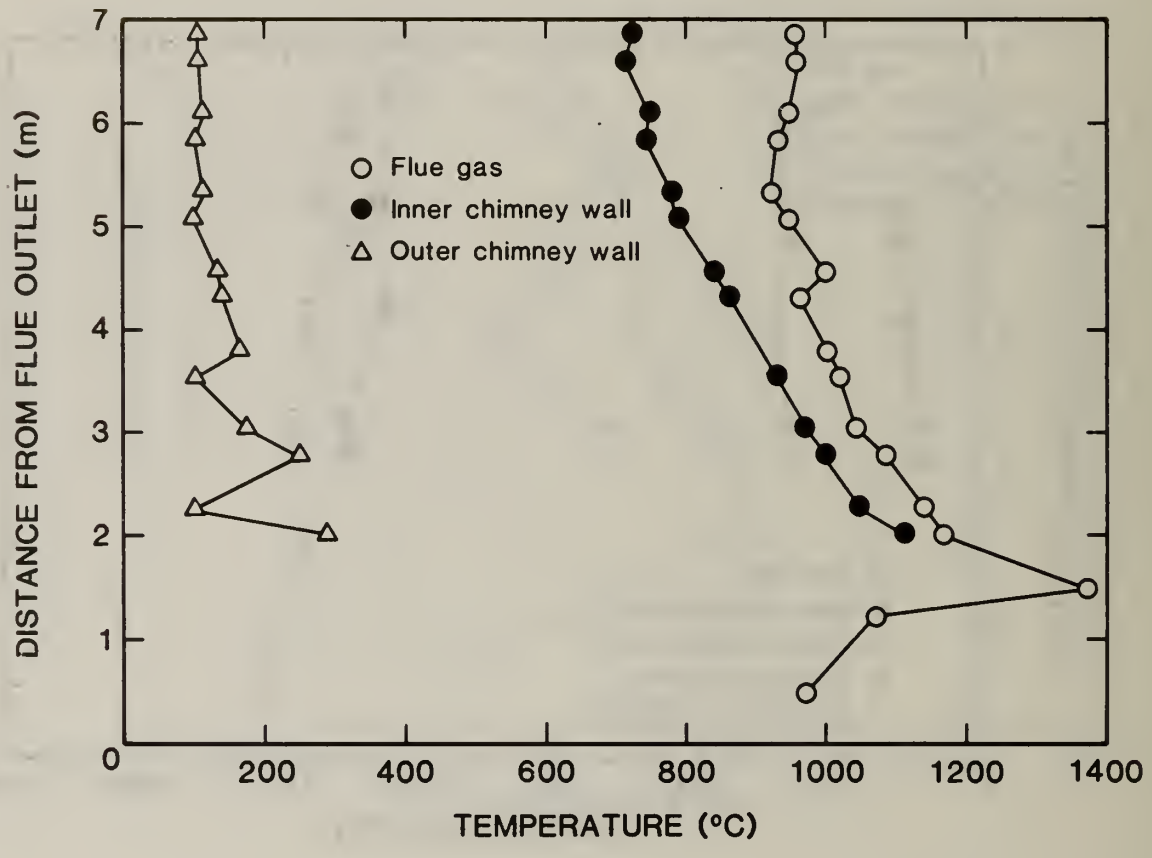


Figure 43. Temperature Profiles During Burnout Test of Chimney 5, Test 12.

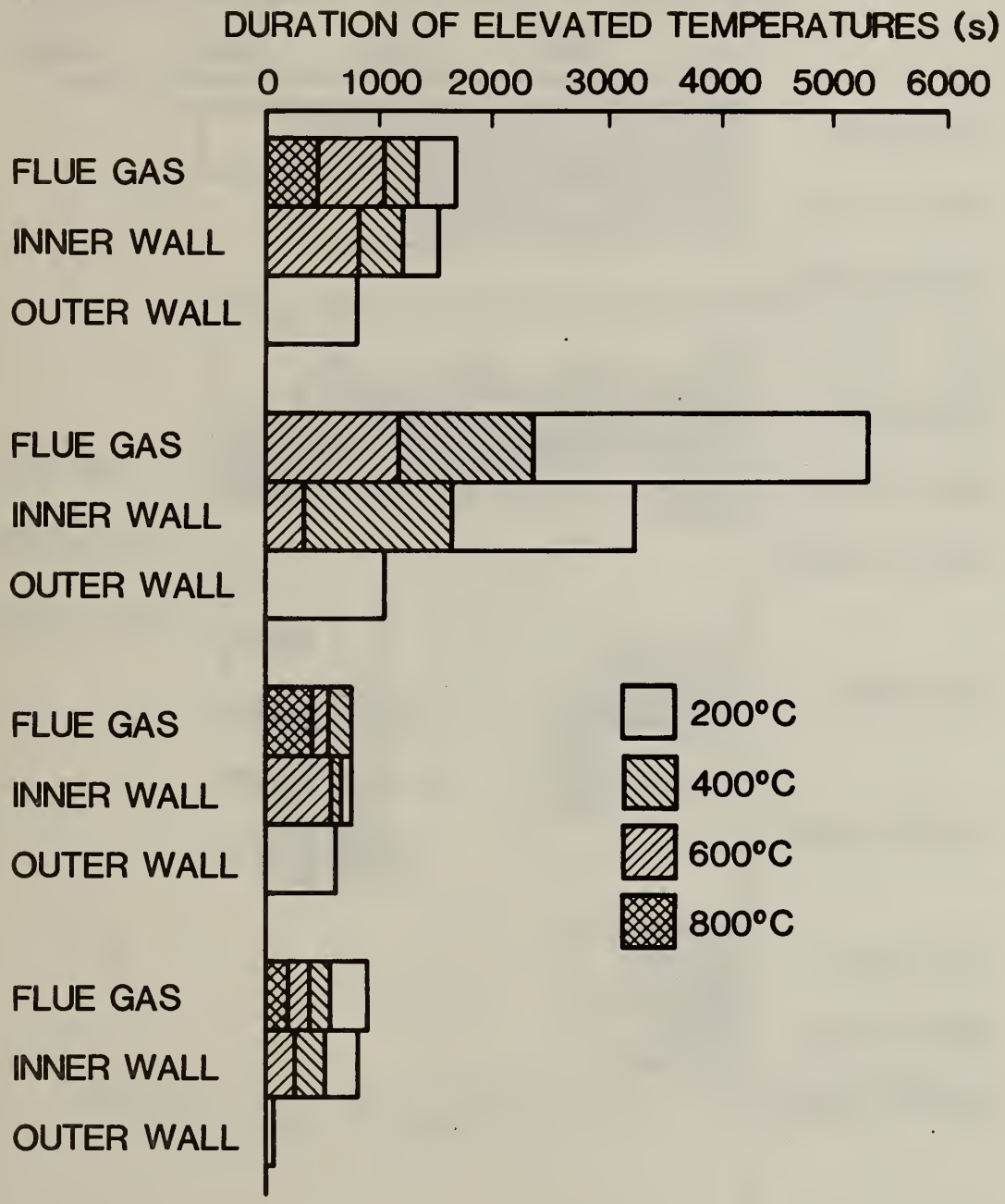


Figure 44. Duration of Elevated Temperatures During Chimney Burnout Tests of Chimney 1.

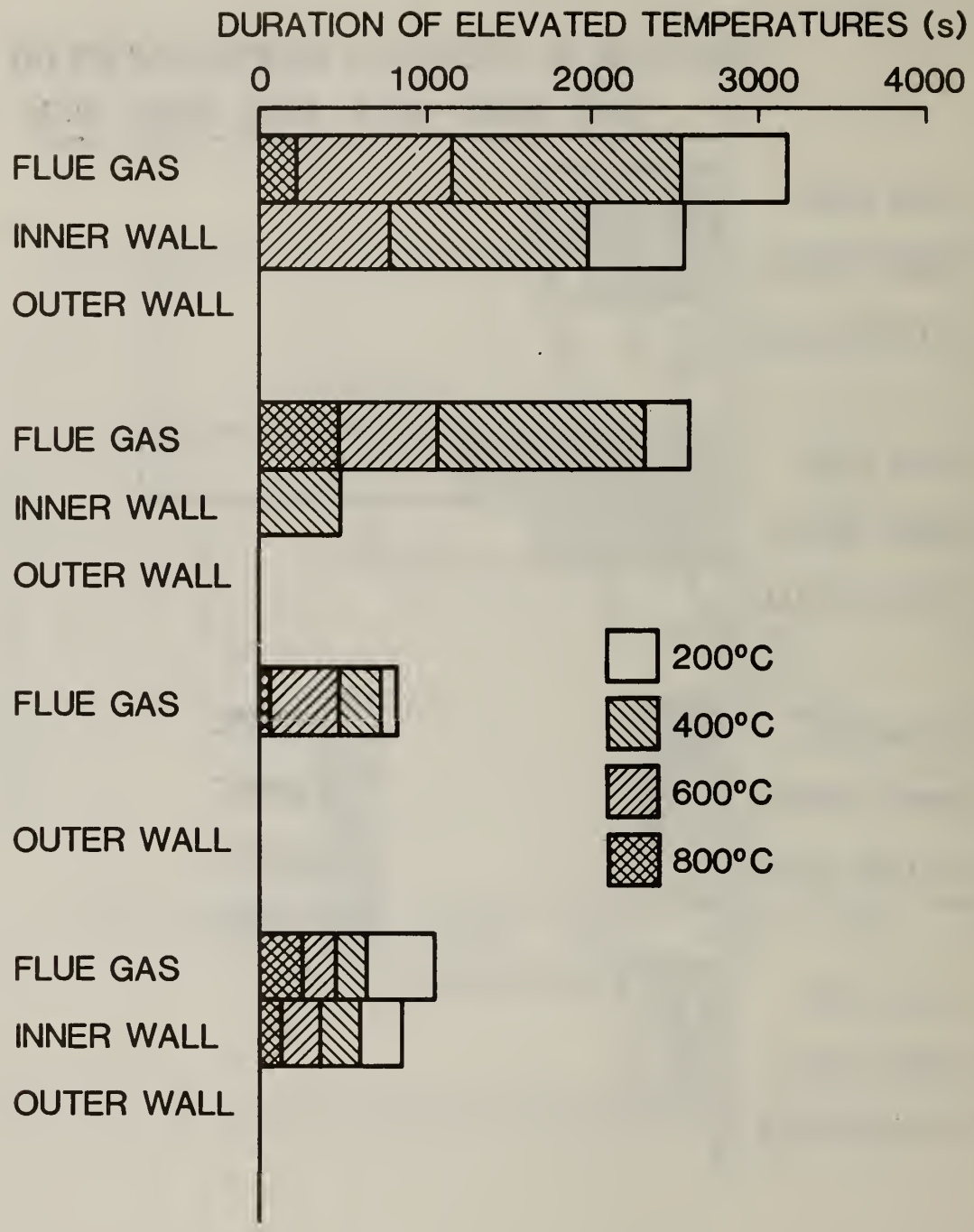


Figure 45. Duration of Elevated Temperatures During Chimney Burnout Tests of Chimney 2.

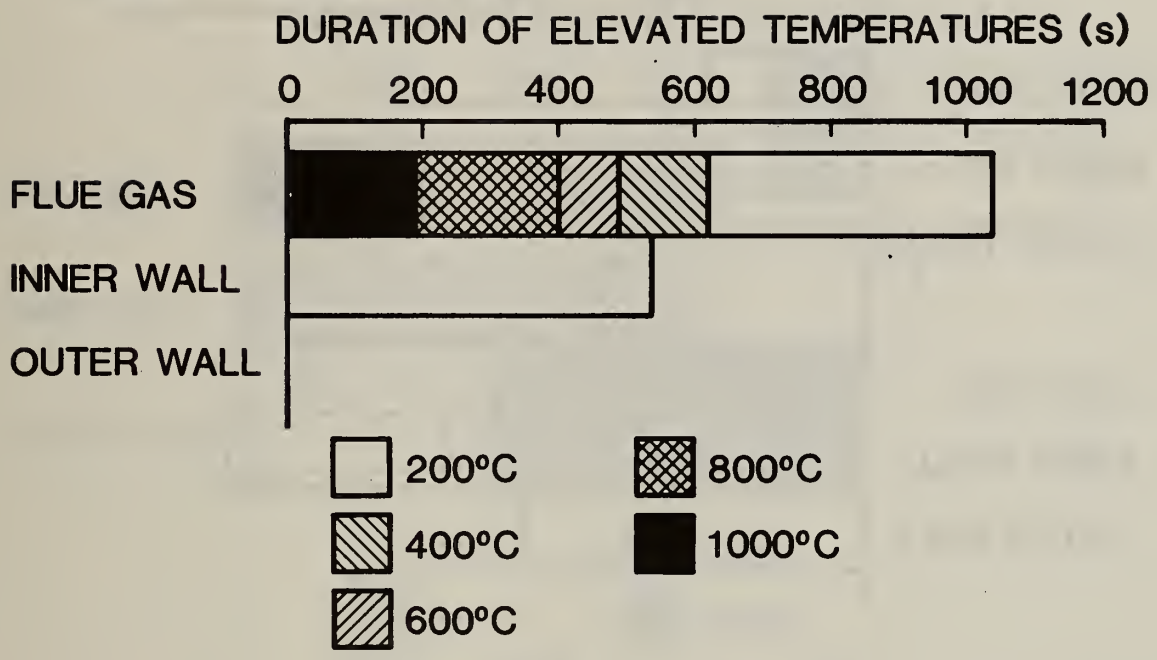


Figure 46. Duration of Elevated Temperatures During Chimney Burnout Tests of Chimney 3.

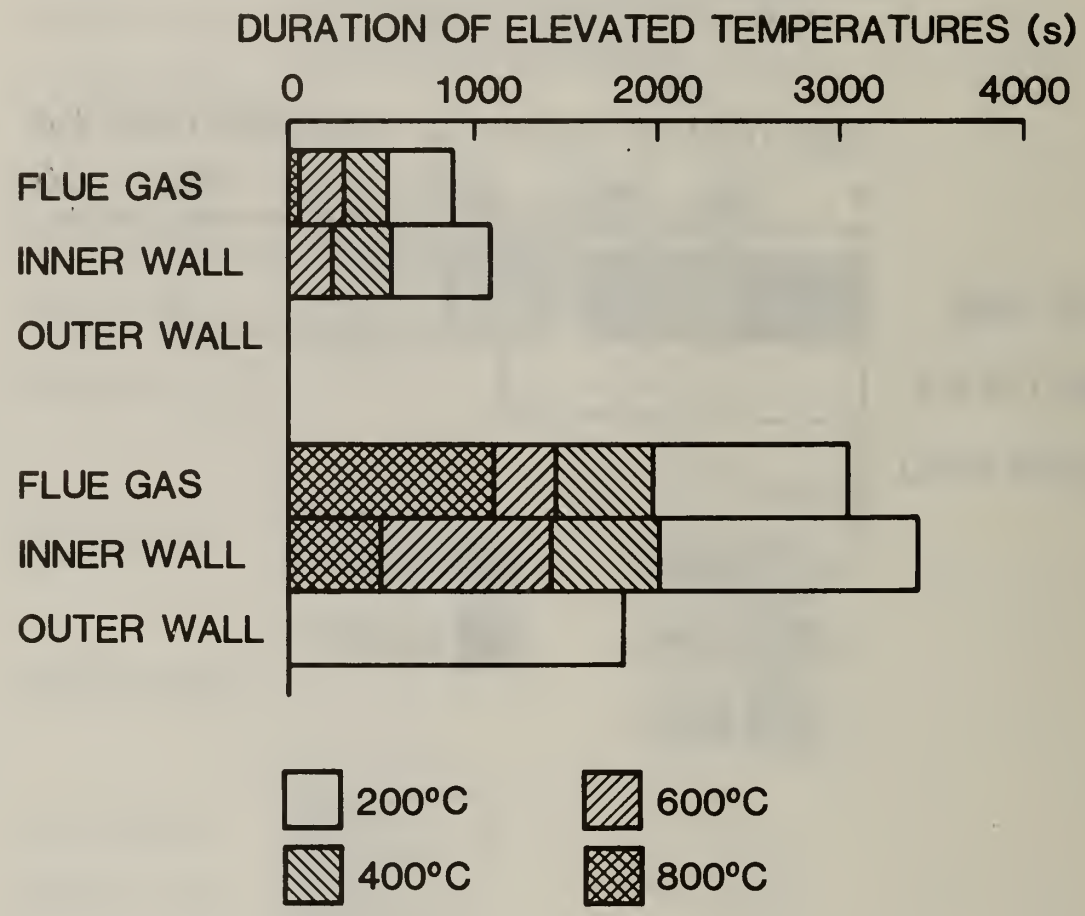


Figure 47. Duration of Elevated Temperatures During Chimney Burnout Tests of Chimney 4.

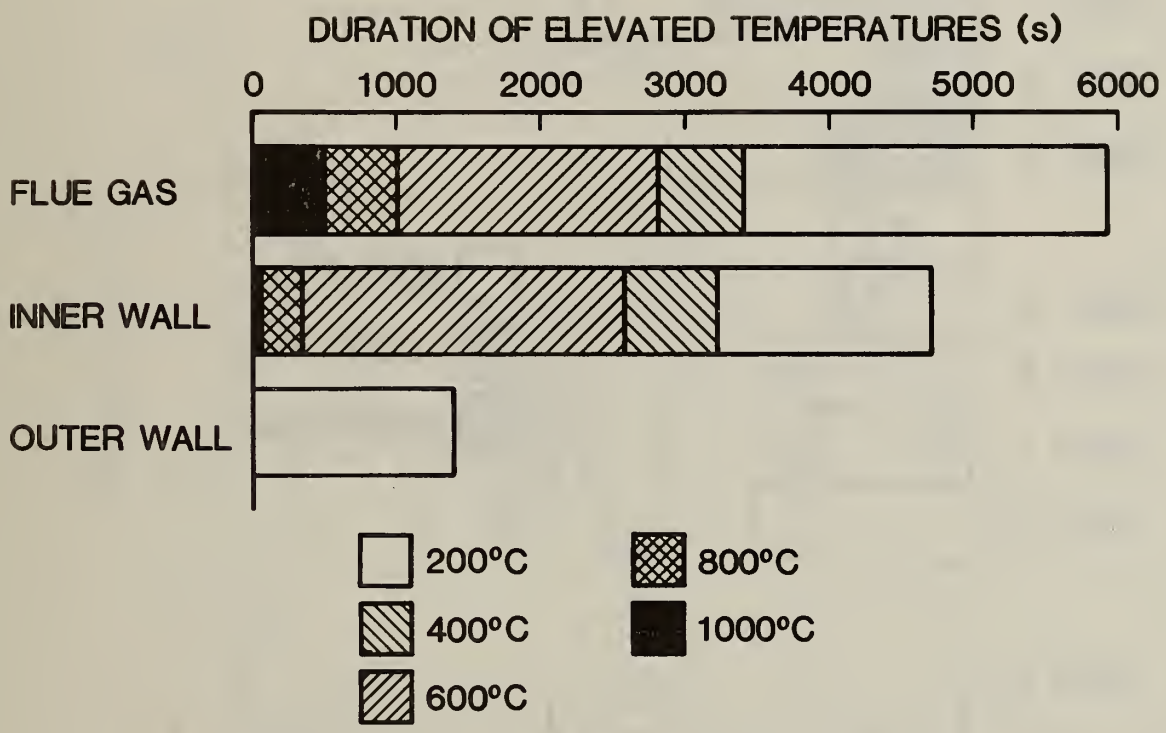


Figure 48. Duration of Elevated Temperatures During Chimney Burnout Tests of Chimney 5.

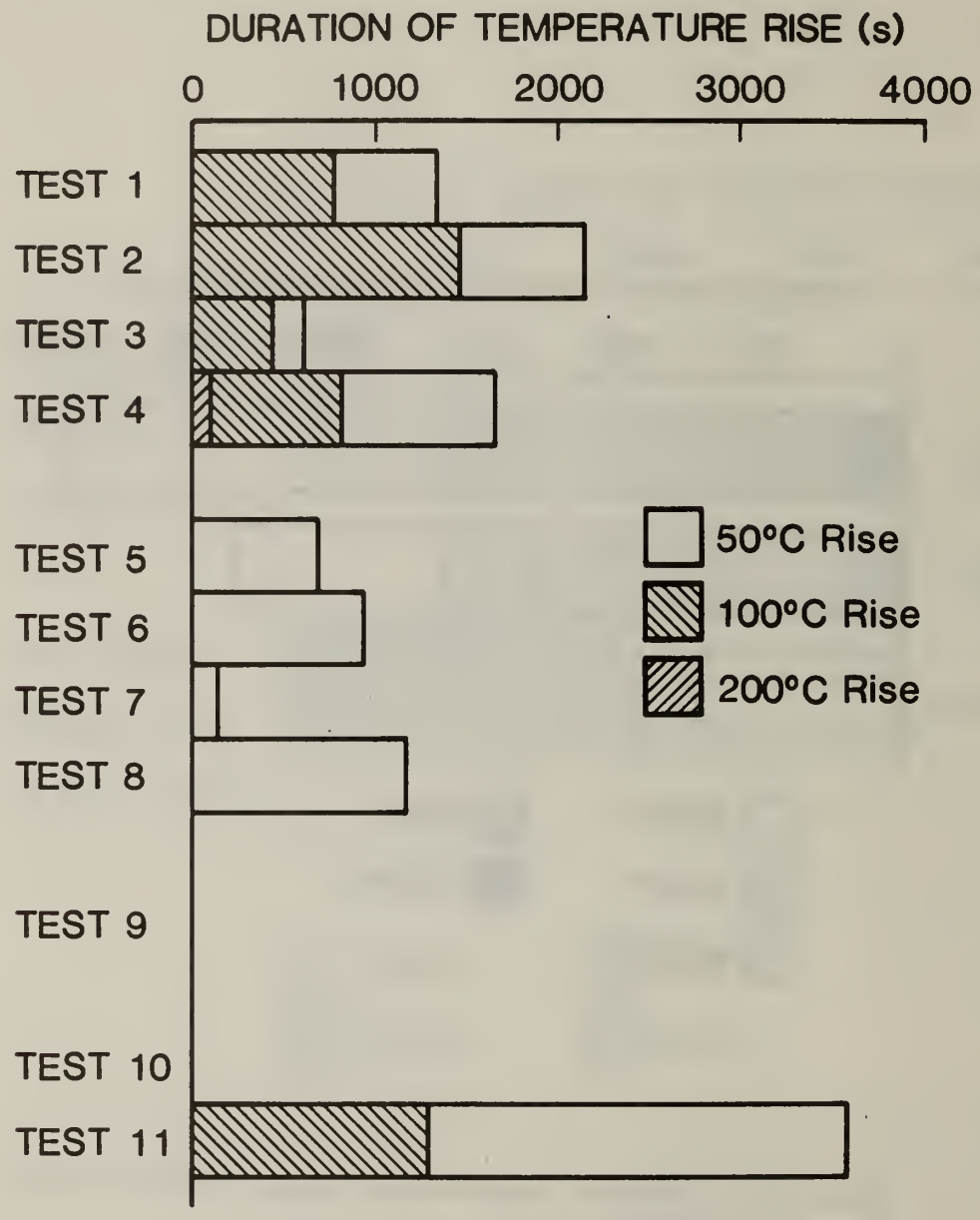


Figure 49. Duration of Temperatures in Excess of 50°C on Enclosure Surfaces During Chimney Burnout Tests.

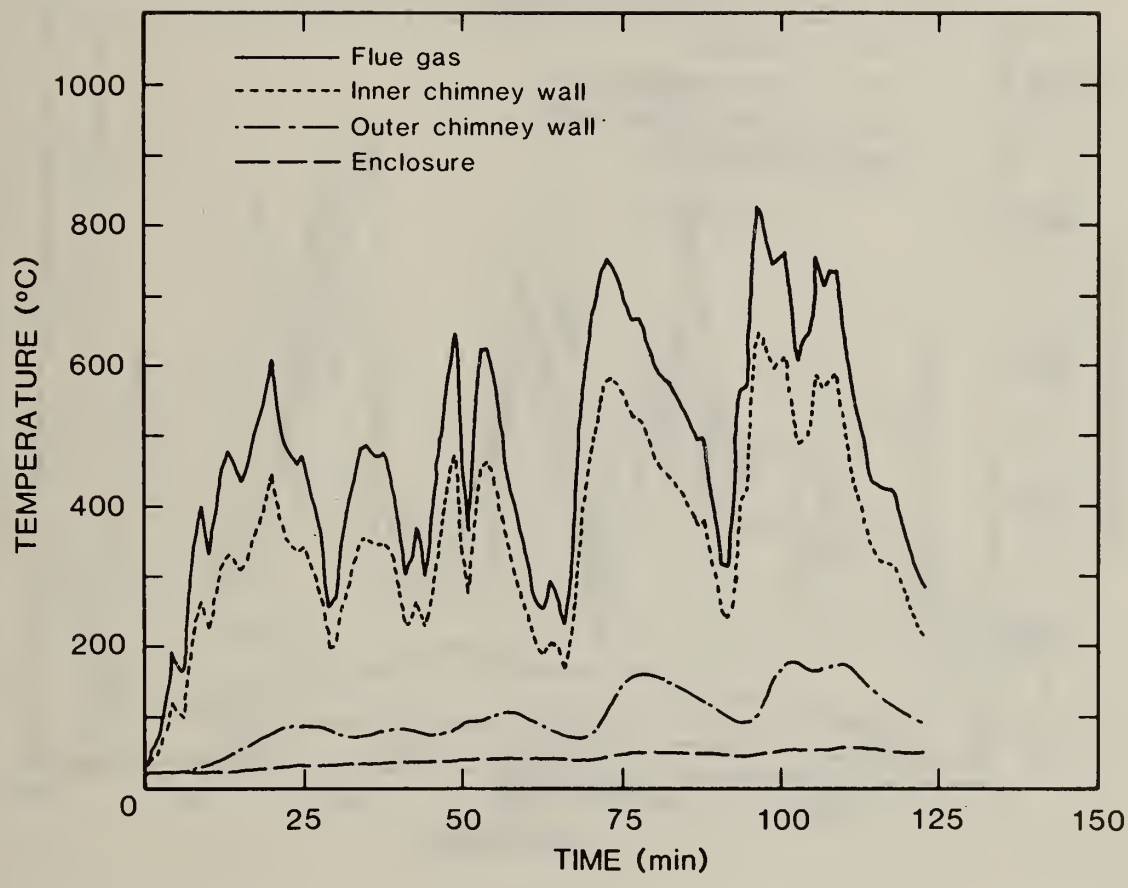


Figure 50. Temperatures at Chimney Base During Overfire Test of Chimney 1.

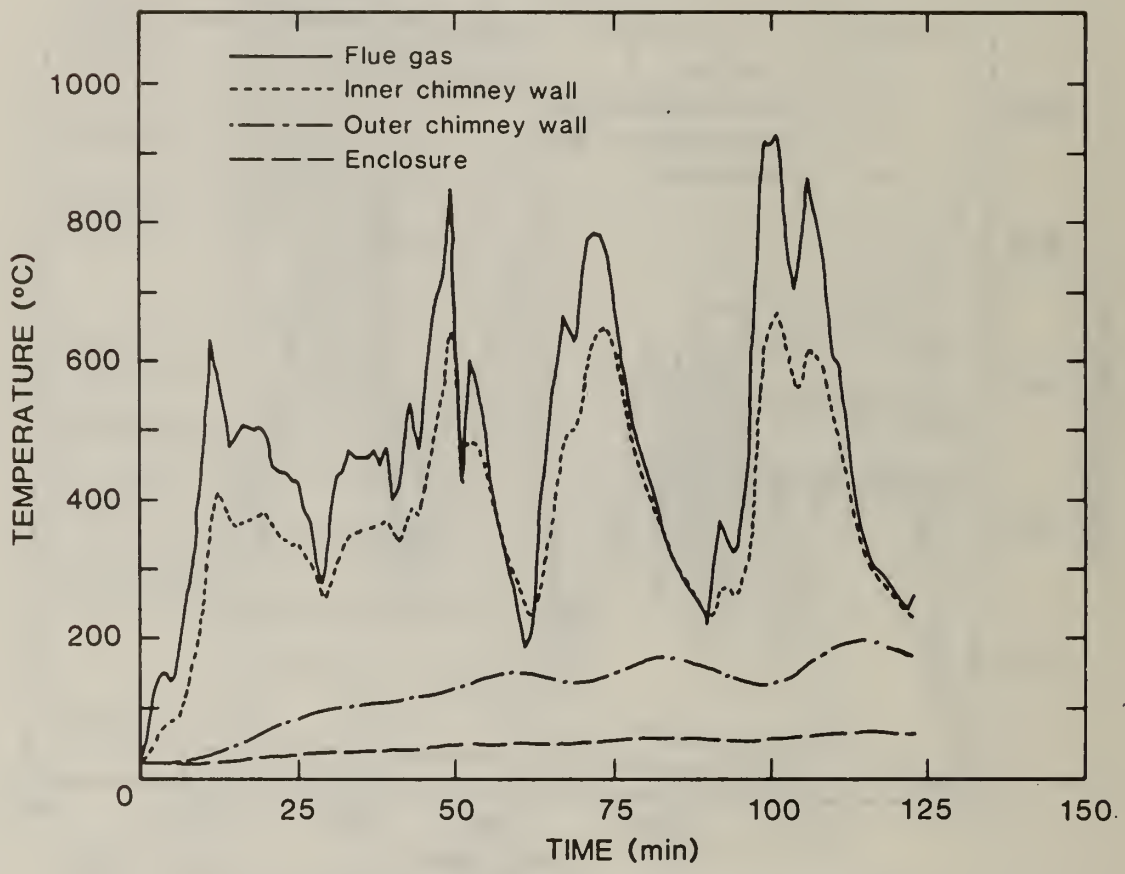


Figure 51. Temperatures at Chimney Base During Overfire Test of Chimney 2.

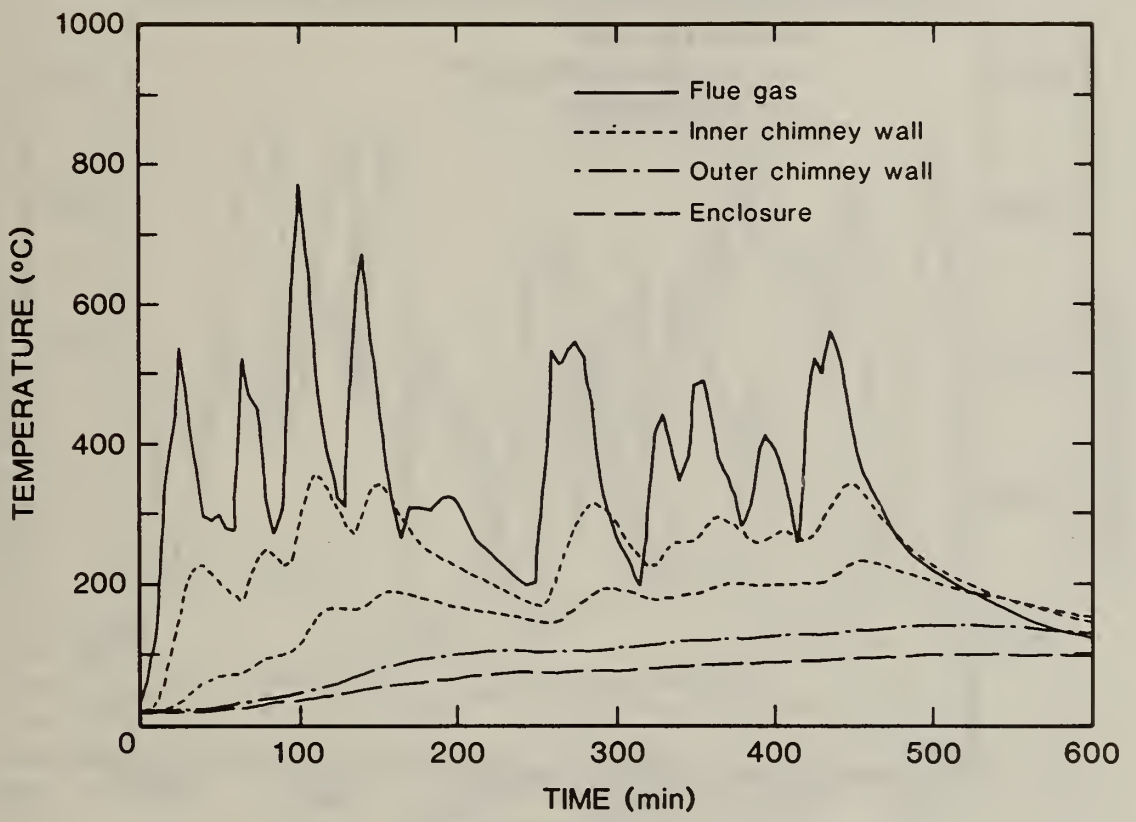


Figure 52. Temperatures at Chimney Base During Overfire Test of Chimney 3.

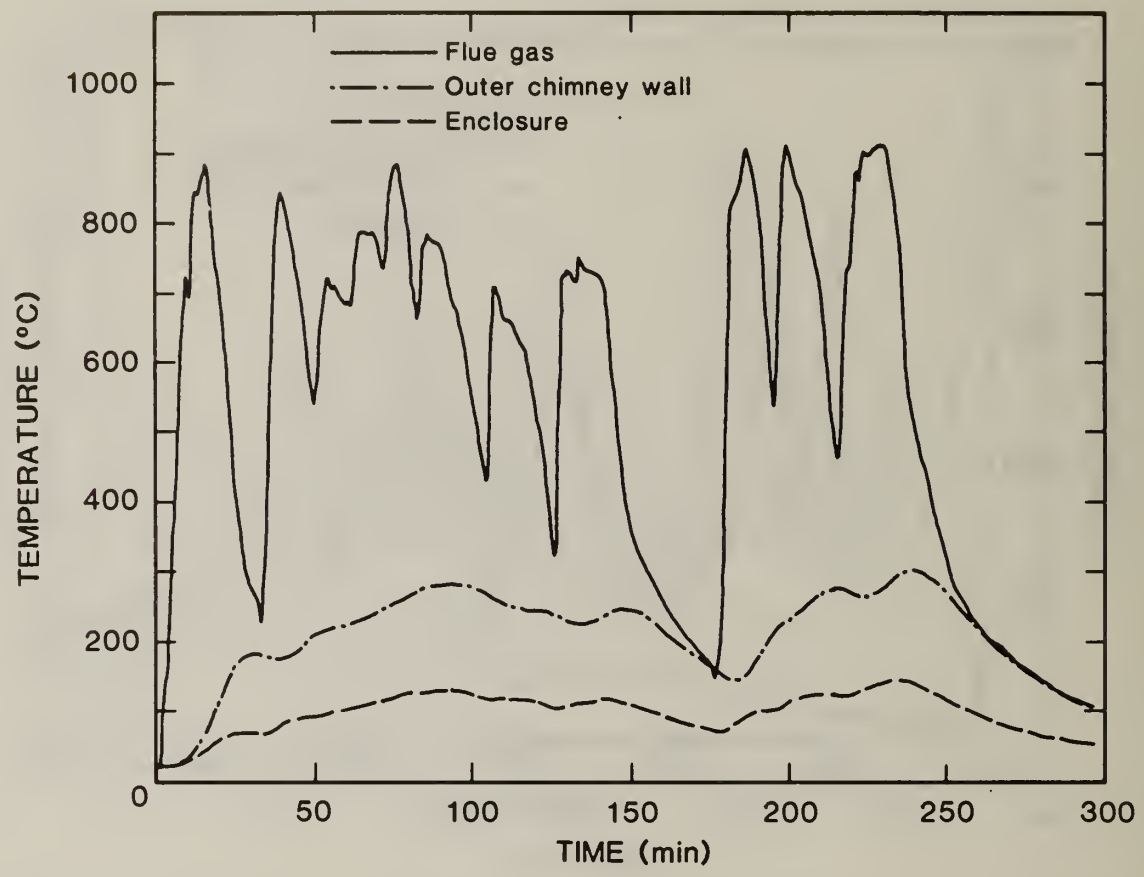


Figure 53. Temperatures at Chimney Base During Overfire Test of Chimney 4.

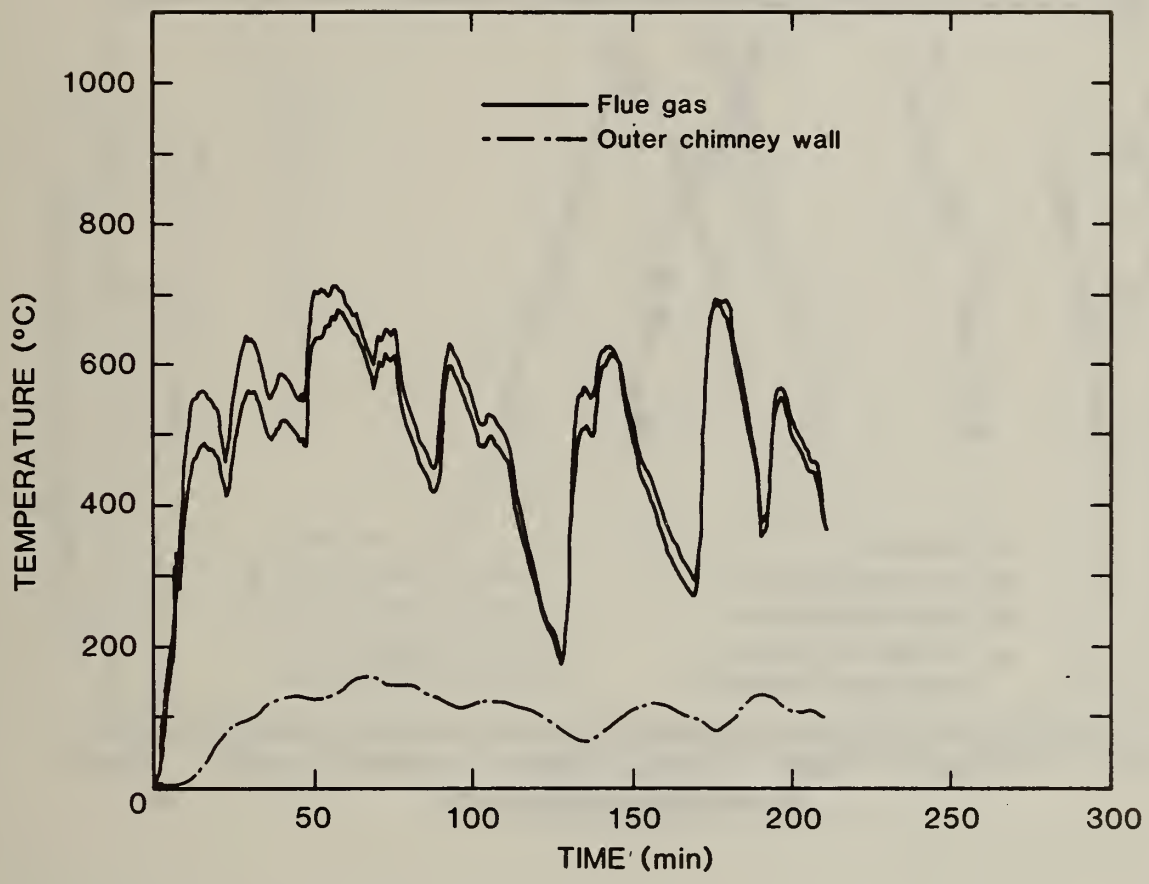


Figure 54. Temperatures at Chimney Base During Overfire Test of Chimney 5.

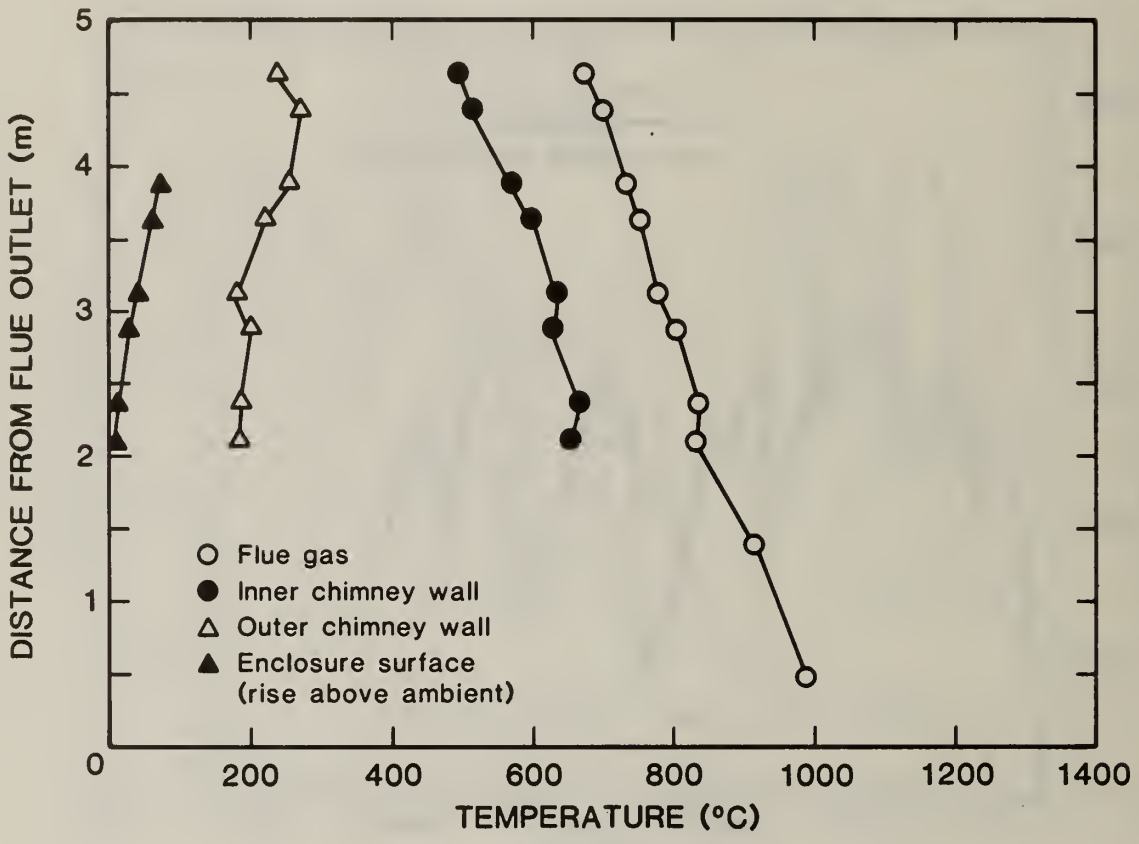


Figure 55. Temperature Profiles During Overfire Test of Chimney 1.

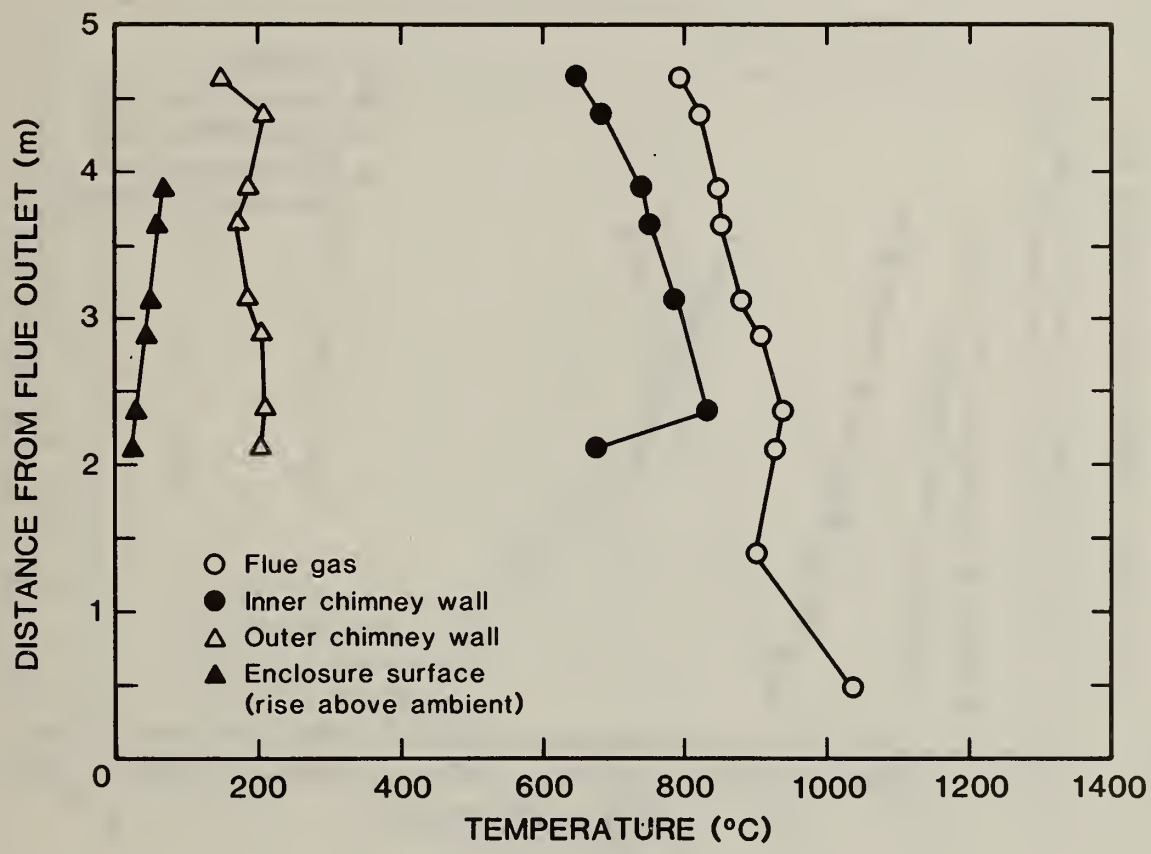


Figure 56. Temperature Profiles During Overfire Test of Chimney 2.

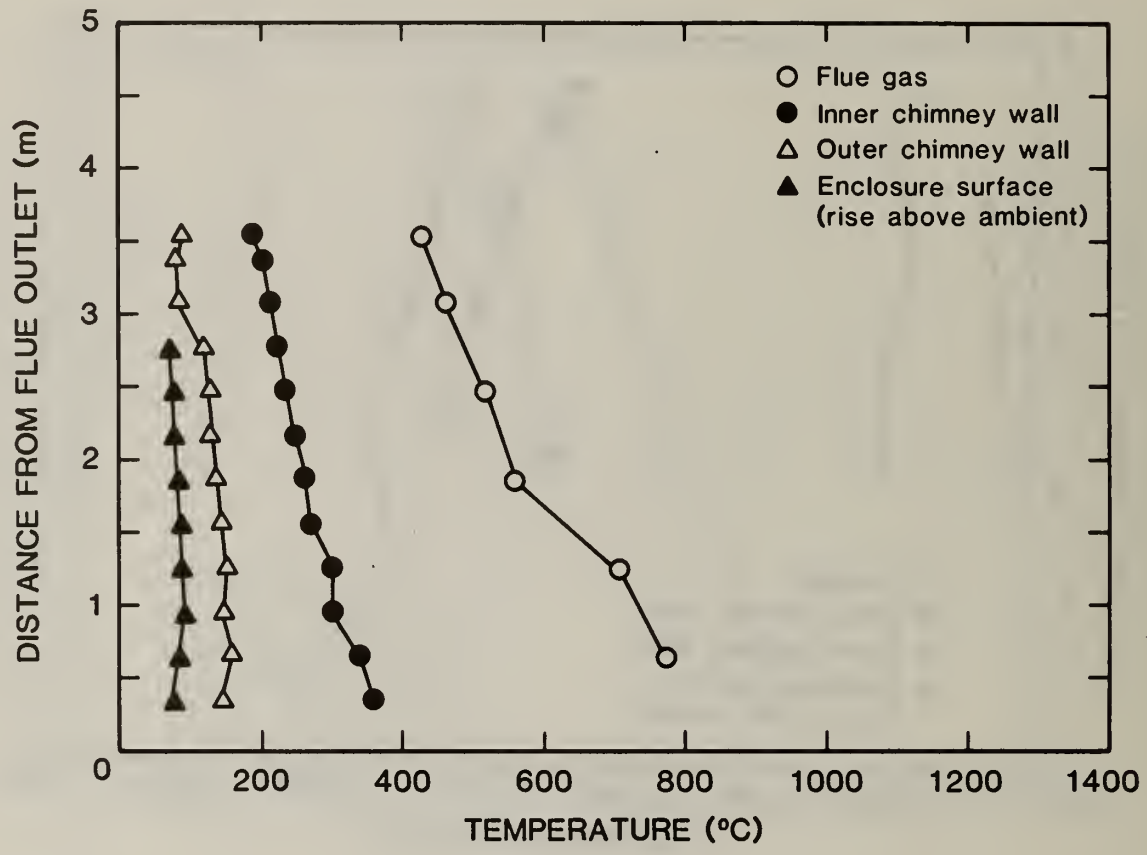


Figure 57. Temperature Profiles During Overfire Test of Chimney 3.

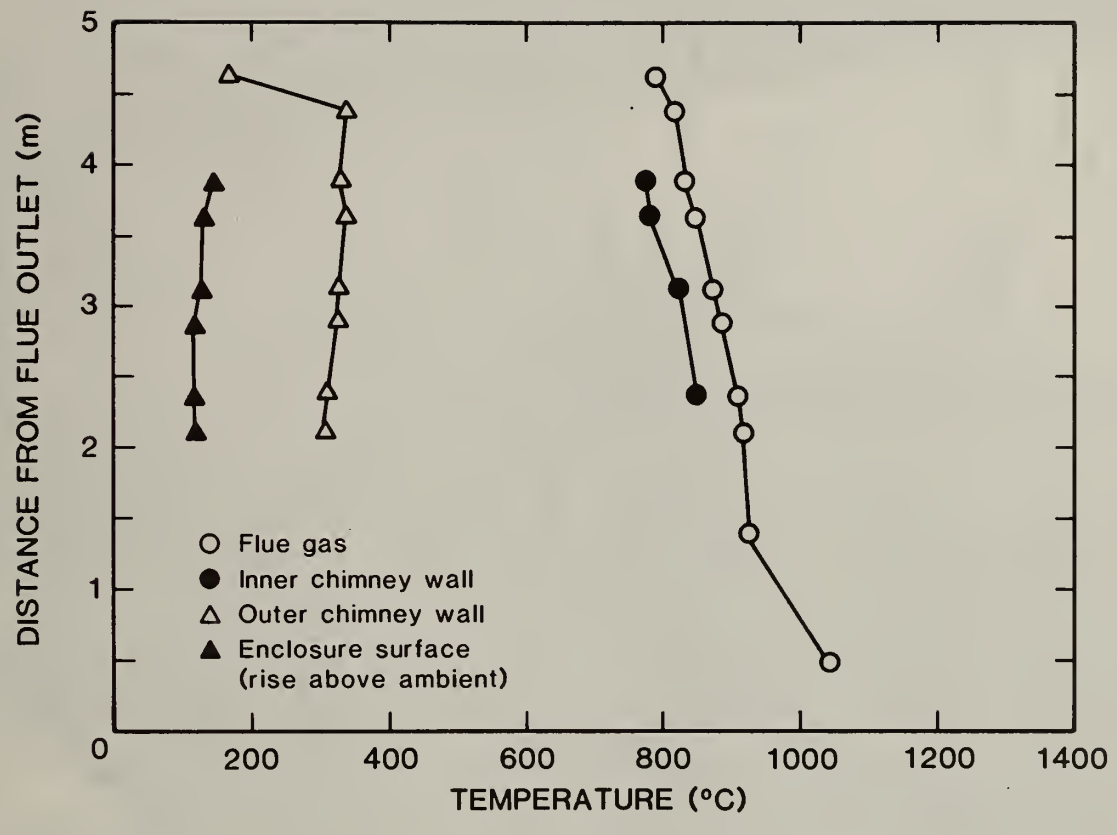


Figure 58. Temperature Profiles During Overfire Test of Chimney 4.

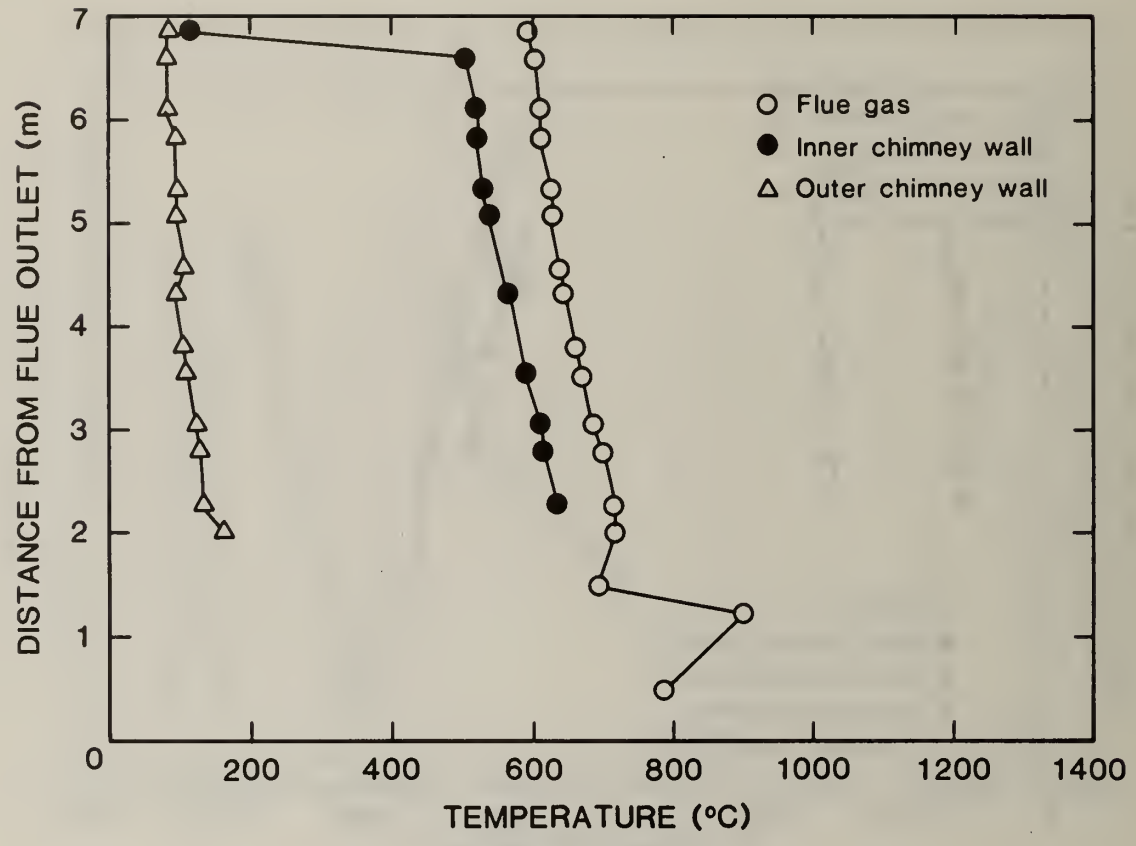


Figure 59. Temperature Profiles During Overfire Test of Chimney 5.

Figure 60. Damage to Masonry Chimney 3 After Chimney Fire.

Figure 61. Damage to Masonry Chimney 3 After Chimney Fire.

Figure 62. Damage to Factory-Built Chimney 5 After Chimney Fire -- Hole in Tee Section at Base of Chimney.

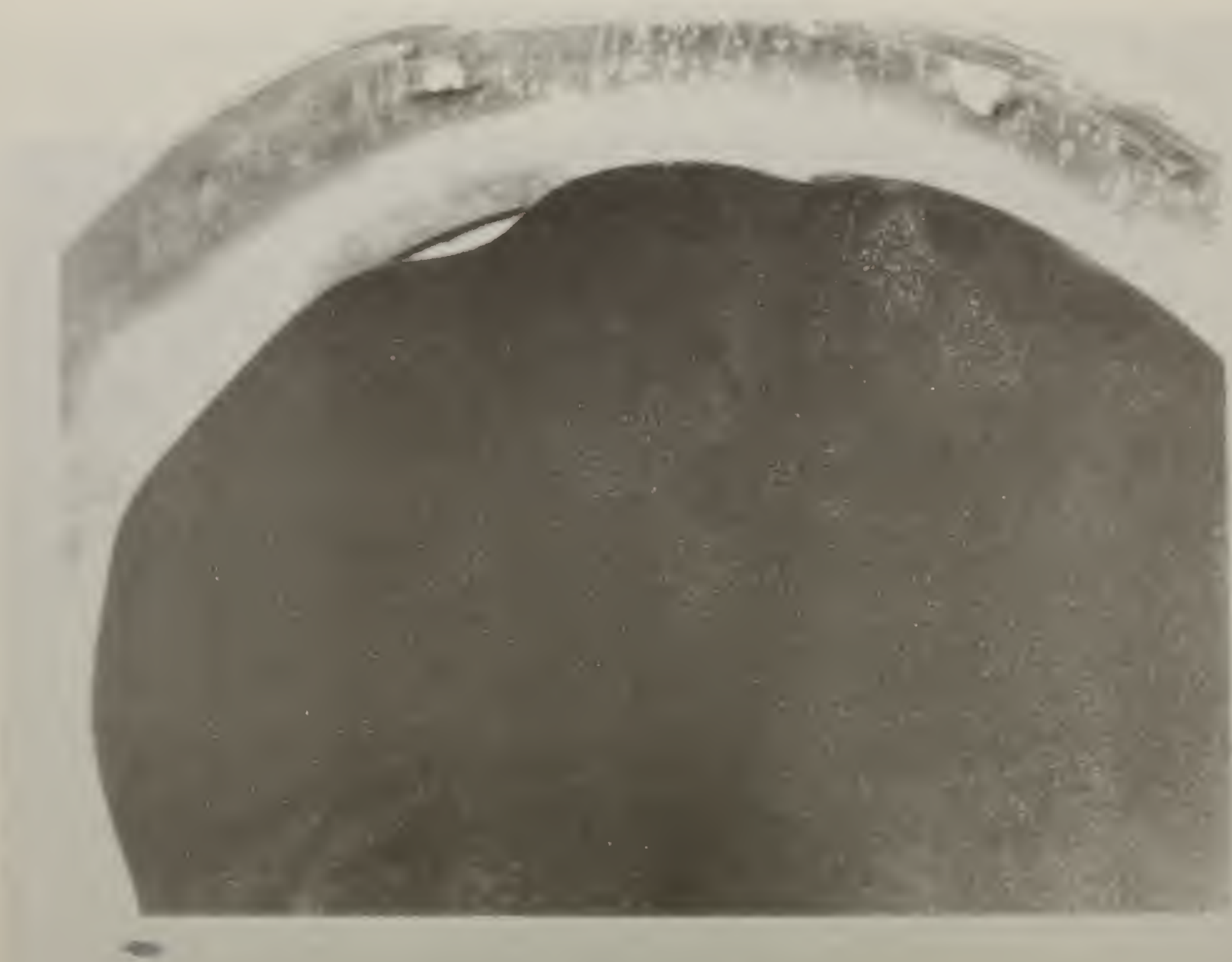


Figure 63. Damage to Factory-Built Chimney 5 After Chimney Fire -- Buckling of Stainless Steel Inner Liner.

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See Instructions)	1. PUBLICATION OR REPORT NO. NBSIR 83-2771	2. Performing Organ. Report No.	3. Publication Date December 1983

4. TITLE AND SUBTITLE

Intensity and Duration of Chimneys Fires in Several Chimneys

5. AUTHOR(S)

Richard D. Peacock

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

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

Final

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

U.S. Department of Energy
Washington, DC 20545

and

U.S. Consumer Product Safety Commission
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)

A series of tests was conducted in four instrumented chimneys to study the intensity and duration of chimney fires due to the ignition and burning of combustible deposits accumulated on the chimney lining over a prolonged period of time. These tests were conducted (1) to establish typical conditions including temperatures in the chimneys and on combustible surfaces nearby, (2) to determine the duration of the burnout as evidenced by elevated temperatures within the chimneys, and (3) to compare these measured values with those obtained during overfire conditions - prolonged firing of the appliances at high rates.

The results of these tests point out some areas where the the codes and standards covering residential wood heating appliances should be modernized to better protect against failure due to chimney fires.

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

Chimney fires; chimneys; creosote; fire safety; fire tests; flues; heating equipment; stoves; wood.

13. AVAILABILITY

☒ Unlimited

☐ For Official Distribution. Do Not Release to NTIS

☐ Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

☒ Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

135

15. Price

$14.50