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Conditions in Corridors and Adjoining Areas Exposed to Post-Flashover Room Fires

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ABSTRACT

This study, conducted for the General Services Administration, examined the effect of a post-flashover room fire on a corridor and attached target room. The burn room was a 2.44 m square with a 2.44 m high ceiling. The corridor was 12.8 m long, 2.44 m wide, and 2.44 m high. The target room was composed of two parts, a rectangular area, 2.6 m by 2.4 m and 2.2 m high, and an entry alcove, 0.8 m long, 1.1 m wide and 2.0 m high. Gas temperatures, wall surface temperatures and concentrations of oxygen, carbon dioxide, and carbon monoxide were measured at selected points in the burn room, corridor, and target room. Various methods of protecting the target room from the effects of the post-flashover room fire were also examined. The target room and its doorway were protected using a simulated "standard" door (with a top cut, a side cut, and an undercut), a reduced leakage door (undercut only), and a commercial accordion fire door. In addition, the target room with the "standard" door was tested using mechanical pressurization. Pressurization of the target room and reduction of the amount of door leakage, below that of a standard door, into the target room were effective methods of reducing temperature rise and the penetration of products of combustion into the target room. Measurements from the study were used to examine a recently proposed model for predicting the flow velocity of the initial gravity wave down the corridor. The measured and predicted values agreed within the limits of uncertainty for the data.

Key words: corridor tests; crib tests; evacuation; fire doors; flashover; large scale fire tests; leakage; life safety; office buildings; refuge; room fires; smoke hazards.

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1. INTRODUCTION

The General Services Administration (GSA) is responsible for 30 million square meters of government owned or leased office space. In addition, it operates one of the largest building construction activities in the nation. As part of its responsibility, the General Services Administration must assure the fire safety of the employees occupying the space under its control. Under the sponsorship of GSA, the Building and Fire Research Laboratory (BFRL) at the National Institute of Standards and Technology (NIST) has been working on a multi-phase research project addressing new technology to enable the analysis and assessment of fire safety in GSA buildings. The General Services Administration has expressed a need for developing a better understanding of the critical factors that determine the impact of a post-flashover fire exposure on exit corridors and on spaces adjacent to these corridors.

In order to evaluate the life safety provided by a specific building design, an estimate of the time required for the "threatened" occupants to reach a "safe area" must be made. This "safe area" has been defined either as the outside of the building or as a protected stairway. However, in today's high-rise structures total building evacuation in the event of fire is impractical. Therefore, the "safe area" is being redefined[1][1], for high-rise fire resistive structures, to be any area other than the fire floor. (Fire floor occupants typically move two floors below the fire.) In addition, the time between the start of the fire and onset of hazardous conditions in the building space must be determined. For a specific fire scenario, a particular building design could be deemed "safe" if it were determined that the time required to reach a "safe area" is less than the time required for the route to the "safe area" to become hazardous.

In many instances, particularly in high rise buildings, designated "safe areas" are established as part of the building fire safety plan. In the event of fire, the occupants would move through the building to these spaces which have been specifically designed to provide an area safe from the effects of the fire and its toxic gases for some period of time. These areas would also serve as "staging areas" for evacuation of people to another part of the building or the outside.

It is generally accepted that relocation to another floor is considered safe, at least as an interim move. However, concern has been raised over the effects of fire exposure on occupants who may be unable to egress readily from the fire floor for a

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

variety of reasons - delayed or unheard alarm, common travel path to exits blocked, mobility impairment, etc. To address this concern, it is necessary to investigate and assess the potential exposure to a corridor and target room from a post-flashover condition in a room off the corridor.

The Building and Fire Research Laboratory conducted a study to assess conditions in a simulation of a significant portion of a building corridor system exposed to a post-flashover fire. The test series, conducted as part of this study, involved exposure of the corridor and a target room, simulating a room off a corridor, to a post-flashover room fire. The post-flashover room fire was allowed to burn for approximately eight minutes. This allowed sufficient time to measure the effects of the fire and its products on the corridor and the target room. At the end of this time, the fire was manually extinguished with a hose stream. Safety of the adjoining compartments was assessed using measurements of toxic gases and state-of-the-art hazard analysis. Various methods of protecting the target room from the effects of the post-flashover room fire were also examined. Finally, measurements from this study are used to evaluate a recently proposed model for predicting the flow velocity of the initial gravity wave down the corridor.

Results of the tests discussed here are being incorporated into an Engineering Fire Hazard Assessment Model being developed separately for GSA by BFRL. While this study does not in itself provide a stand-alone evaluation of rooms off corridors being used as "safe areas" within a building, results of this study in combination with other engineering methods and available programs, including the Engineering Fire Hazard Assessment Model, will allow fire protection engineering professionals to make design decisions for the location of the spaces and specifications for methods to protect building occupants in a variety of situations.

Measurements taken during the extinction of the post-flashover room fire are being used as a basis for evaluation of computer fire models of the suppression process. In particular, Mission Research Corporation, Santa Barbara, California in cooperation with NIST, is comparing the suppression data generated during these tests to predictions obtained using the Fire Demand Model [2]. The fire suppression part of this study is documented in separate reports [3,4].

2. DESCRIPTION OF THE TEST FACILITY

A total of four full scale fire tests were conducted in the burn room-corridor-target room test facility. The first, second, and third tests examined the effect of target room door leakage rates and pressurization on the tenability of the target room. The fourth test utilized a commercial fire door as protection for the target room opening.

Several simulated door configurations between the corridor and the target room were tested. A simulated door, constructed using a 2 m (6.6 ft) by 1 m (3.3 ft) wide sheet of 13 mm (0.5 in) thick calcium silicate board, was used for three of the four tests. For the first and second tests, the simulated door was placed in the target room opening with a 22 mm (0.87 in) undercut, a 6 mm (0.25 in) top cut, and a 6 mm (0.25 in) side cut. The side cut was located along the door edge farthest from the corridor end wall (closest the burn room). These cut dimensions were chosen to be representative of typical door crack sizes [5,6]. The main difference between the first and second tests was the use of room pressurization in the second test. For the third test, all door cracks except the door undercut were sealed. The fourth test utilized a commercial sliding, accordion type fire door. In the remainder of this report, the first test will be referred to as "Typical Door Test", the second test as "Pressurized Room Test", the third test as "Tight Door Test", and the fourth test as "Accordion Door Test".

Before the fire tests, the target room was pressurized to determine the potential leakages across the three different doors. At a pressure difference across the door of 37 Pa (0.15 in H_2O), the simulated typical door had a volume flow leakage of 0.24 m^3/s (8.48 ft^3/s). The measured leakage for the tight door was 0.12 m^3/s (4.24 ft^3/s). When pressure tested, the accordion door bowed outward. This made accurate leakage measurements impossible.

2.1 Details of the Enclosures

The test arrangement and instrumentation locations are shown in Figures 1 and 2. The test enclosure consisted of a "burn room" containing the fire source, a "target room" and a 12.8 m (42 ft) long corridor connecting the two rooms. The "burn room" was a 2.44 m (8 ft) square with a 2.44 m (8 ft) ceiling. The burn room was lined with two layers of calcium silicate board for a total thickness of 25.4 mm (1 in).

The burn room was provided with two door openings. The first opening was 0.76 m (2.5 ft) wide by 1.52 m (5 ft) high. This opening was located between the burn room and an overhead exhaust hood. The other opening, between the burn room and the corridor, was 0.46 m (1.5 ft) by 1.52 m (5 ft) high. Based on calculations using the Fire Demand Model [2], these two door sizes were chosen to provide sufficient exposure of the corridor and target room to fire products while maintaining the fire in a post-flashover state long enough to allow completion of the fire extinguishment study [3].

The total volume of the "target room" was 15 m^3 (528 ft^3). The "target room" was composed of two parts, a rectangular area with dimensions of 2.6 m (8.5 ft) wide, 2.4 m (7.7 ft) deep and 2.2 m (7.1 ft) high and an entry alcove with dimensions of 0.8 m (2.7 ft) long, 1.1 m (3.6 ft) wide and 2 m (6.6 ft) high. The overall dimensions of the door opening between the target room and the corridor were 2 m (6.6 ft) high by 1.1 m (3.6 ft) wide.

Wood cribs were used as the fuel source in all tests. Cribs can be constructed to provide a wide variety of burning rates and once fully ignited, sustain a steady burning rate for a period of time. The cribs were constructed of fir sticks 38 mm (1.5 in) high by 38 mm (1.5 in) wide and 0.61 m (2 ft) long. The sticks were fastened together with 8d common nails at both ends. The overall crib size was 0.61 m (2 ft) wide by 0.61 m (2 ft) deep and 0.30 m (1 ft) high. Each crib contained 6 sticks per layer and was 8 layers high (Figure 3). The cribs had a pretest moisture content of between 5 and 10 percent.

With the exception of the Accordion Door Test, the fuel load consisted of nine cribs arranged in a three by three matrix in the center of the burn room (Figure 4). In the Accordion Door Test, eleven cribs were used and the walls of the burn room were lined with 3.2 mm (0.13 in) plywood paneling. Three cribs were placed near one wall while the remaining eight cribs were located adjacent to the opposite wall. Six of the eight cribs were distributed in a two by three array adjacent to the wall. The other two cribs were placed on top and in the middle of the two by three array (Figure 5). This fuel arrangement was used to determine if a "flashover pulse" could be simulated by adding combustible wall lining and additional fuel load and to determine the effect that the pulse would have on the conditions in the corridor and target room.

Each crib was elevated approximately 0.13 m (5 in) above the floor. The cribs were ignited using pans of heptane centered under each row of three cribs. Each pan was approximately 1.5 m (5 ft) long by 0.13 m (5 in) wide and contained approximately 1.25 ℓ (0.33 gal) of heptane, which burned for about two minutes. The heptane was ignited using an electrically activated match. This technique provided for uniform ignition of all of the cribs.

2.2 Instrumentation and Data Acquisition

Measurements were taken in the burn room, corridor, target room, and exhaust hood. The locations of the measurement devices are shown in Figure 2. Their placement and distribution is summarized in Table 1. All of the thermocouples used for gas temperature measurements were 0.5 mm (0.02 in) chromel-alumel bare bead thermocouples. Calibration of randomly selected thermocouples indicated an accuracy within ± 2°C.

2.2.1 Burn Room

One thermocouple array was located 0.4 m (1.4 ft) out of the northwest corner of the burn room. Gases were sampled from a location adjacent to the thermocouple array and approximately 0.9 m (3 ft) below the ceiling. The horizontal sampling tube was 9.4 mm (0.38 in) I.D. stainless steel. Outside the burn room, the tube was connected to polyethylene tubing, which delivered the gas samples to the oxygen, carbon dioxide, and carbon monoxide gas analyzers via a glass wool filter-moisture cold trap, pump, and flow metering system.

2.2.2 Corridor

In the corridor, floor to ceiling thermocouple arrays were located at 3 m (10 ft) intervals from the burn room doorway on the corridor centerline. Thermocouple pairs (ceiling surface and 51 mm (2 in) below the ceiling) were placed at intermediate 1.5 m (5 ft) intervals. Two additional floor to ceiling thermocouple arrays were added after the first test (typical door) to enhance analysis of corridor flow velocities. The first array was located in the corridor 0.46 m (1.5 ft) from the north corridor wall and 0.46 m (1.5 ft) from the burn room-corridor wall. The other was in the center of the corridor across from the target room doorway. A gas sampling tube was located in the center of the corridor 0.9 m (3 ft) below the ceiling. The concentrations of oxygen, carbon dioxide, and carbon monoxide were measured from gas samples drawn at this location.

2.2.3 Target Room

One gas sampling tube and thermocouple array were located in the target room along the center line of the doorway, in the center of the rectangular portion of the room.

2.2.4 Burn Facility Exhaust Stack

Gas temperature and velocity; and oxygen, carbon dioxide, and carbon monoxide concentrations were monitored in the exhaust stack. These data were used to determine the mass flow through the stack and the total rate of heat production by the fire using oxygen consumption calorimetry [7].

The measurements obtained from the instruments were recorded at a rate of one scan every eleven seconds on a computerized data acquisition system.

3. DISCUSSION OF TEST RESULTS

Immediately prior to each test, the cribs were weighed. The crib weights and their placement in the burn room are presented in Table 2 and Figures 4 and 5, respectively. After the data acquisition system was started and its proper functioning verified, the heptane was ignited. Typically, the fire reached "flashover" in approximately two minutes after ignition. The fire was allowed to burn while conditions in the burn room, corridor, and target room were monitored. After a minimum of 500 seconds, sufficient data for analysis were obtained, and the fire was extinguished.

3.1 Burn Room

Figure 6 presents the heat release rate data for the four tests as determined from oxygen consumption measurements in the stack. Peak heat release rates of approximately 2 MW were obtained for all of the tests. The heat release rate remained at or above 1 MW for the 500 second duration of each test. From the heat release rate graphs, it can readily be seen that "flashover" or total fire involvement of the cribs occurred very quickly (within approximately two minutes after ignition). The heat release rate for the Pressurized Room Test, the dashed line in Figure 6, indicates a lower peak and higher steady heat release rate than any of the other tests. Consequently, all of the corridor measurements (temperatures and combustion product concentrations) are consistently lower for the Pressurized Room Test. The room pressurization system also produced an increased air flow through the corridor from the target room to the burn room. This increased air flow enhanced mixing and diluted the gas in the corridor, contributing further to the lower measured temperatures and combustion product concentrations.

Figure 7 shows the measured concentrations of oxygen and carbon dioxide inside the burn room for the Accordion Door Test. These data are typical of that measured during each test. Figure 7 also shows the oxygen concentration (dry basis) in the exhaust gases just outside the burn room (burn room to exhaust hood opening). There is no measurable oxygen remaining in the gases leaving the burn room, hence the fire is ventilation limited. The excess fuel flows out the door, mixes with additional oxygen, and burns outside the room. The maximum heat release rates, the measured peak gas temperatures, and gas concentrations (minimums for oxygen) are summarized in Tables 3, 4 and 5. A complete set of temperature graphs for all of the tests can be found in Appendix A.

3.2 Corridor

The concentrations of oxygen, carbon dioxide, and carbon monoxide in the corridor are shown in Figures 8 - 11 for the four tests.

Maximum concentrations (minimums for oxygen) are shown in Table 4. The oxygen analyzer in the corridor malfunctioned during the Accordion Door Test, so Figure 11 contains only carbon dioxide and carbon monoxide results. However, the oxygen concentrations should be similar to those in Figures 8 and 10. In all of the tests except the pressurized room test, the oxygen concentration in the corridor had decreased to about 5 percent after 500 seconds. Correspondingly, the concentrations of carbon dioxide and carbon monoxide increased to 15 and 5 percent respectively.

No detectable carbon monoxide increase in the target room was noted in the test where the target room was pressurized. In addition, the oxygen concentration remained at ambient levels for the first two minutes of the test even though the carbon dioxide concentration was increasing. The corridor CO measurement for the pressurized target room test (Figure 9) is not available due to an equipment malfunction. As discussed previously, the increased air flow, produced by the pressurization system, diluted the gas in the corridor. The diluted gas would have a higher oxygen concentration and lower CO_2 and CO concentrations.

The temperatures at 3 m (10 ft) intervals along the centerline of the corridor are shown in Figures 12 - 14 for the Typical Door Test. Figures 15 and 16 depict the temperature profiles, obtained for the Accordion Door Test, in the corridor 0.3 m (1 ft) from the burn room and adjacent to the target room door [10.7 m (35 ft) from burn room]. The temperature histories presented in these figures are representative of those found in the corridor during all tests.

As can be seen in Figures 12 - 16, there are distinct vertical temperature gradients in the corridor. In the case of the Accordion Door Test (Figure 15), the temperatures at the first thermocouple array ranged from a peak of 650°C (1200°F) near the ceiling to 110°C (230°F) at floor level. The latter temperature was attained approximately 4 minutes after ignition; it was maintained for over 12 minutes. The peak temperature (650°C) was the result of flames projecting out the burn room to corridor door during flashover. Once the flames receded back into the burn room, the temperature decreased to 325°C (617°F) and remained there until the start of extinguishment. In all of the other tests, the thermocouples at this location, just outside the burn room, recorded peak temperatures of 325°C (617°F) at the upper positions and about 100°C (212°F) at floor level.

Peak temperatures outside the target room door were in excess of 200°C (390°F). Again, in the case of the Accordion Door Test, the flaming in the corridor produced an initial peak of 275°C (527°F) which reduced back to the 200°C (390°F) level in under a minute. The temperatures at the floor ranged from a low of 80°C (176°F) for the Pressurized Room Test to about 100°C (212°F) for all of the other tests.

3.3 Target Room

The concentrations of oxygen, carbon dioxide, and carbon monoxide in the target room are shown in Figures 17 - 20 for the four tests. The maximum gas concentrations (minimums for oxygen) are presented in Table 5. In the Typical Door Test, concentrations of carbon monoxide and carbon dioxide reached a maximum about five minutes after ignition. The oxygen concentration fell below 10% about the same time. Pressurization of the target room kept the oxygen, carbon dioxide, and carbon monoxide concentrations at nearly ambient levels. In fact, no change was recorded until almost 500 seconds after ignition of the fire.

The temperature profiles in the target room are shown in Figures 21 and 22 for the Typical Door Test and the Accordion Door Test, respectively. The maximum temperature increases were measured in the target room with the simulated typical door. This door had a top cut, a side cut, and an undercut. The maximum temperature in the target room was 110°C (230°F). In the Typical Door Test, approximately one minute was required for the temperatures in the target room to begin to increase in response to the fire.

The tight door with only the undercut open and the accordion door achieved similar results for target room temperature increase. Maximum temperatures inside the target room never exceeded 41°C (106°F). In addition, the temperatures did not begin to rise until over three minutes after ignition of the fire. When the accordion door was used (Figure 22), the temperatures inside the target room did not begin to increase above ambient until approximately four minutes after ignition. The maximum temperature reached in the target room during the test was 34°C (93°F).

For the Pressurized Room Test, the temperatures inside the target room remained at ambient until the pressurization system was shut down.

4.0 ANALYSIS OF TEST RESULTS

4.1 Corridor Flows

Measurements from the study were used to examine a recently proposed model for predicting the flow velocity of the initial gravity wave down the corridor. Steckler has reviewed the literature related to models of fire induced corridor flows [8]. Three events are identified as making up the corridor filling process: a forward gravity current moving away from the fire source, a reflected or return gravity current moving back toward the source below the forward current, followed by uniform filling of the entire corridor. Several models for predicting the velocity, thickness, and temperature profile for the forward gravity wave are presented. The applicability of these engineering formulas varies depending on the rate at which heat and mass are injected into the flow at the source end of the corridor. Some formulations apply only if the injection rate is constant; others are valid for both constant and time varying injection rates.

For typical growing fires, Steckler [8] recommends the use of an equation developed by Heskestad and Hill [9] for predicting the velocity of the initial forward wave front. This equation is:

$$v_f = \left[\frac{g \, \dot{q}_c' \, (1 + \frac{\Delta T_m}{T_\infty})}{2 \, \rho_\infty \, c_p \, T_\infty} \right]^{1/3} \qquad (1)$$

where g - acceleration of gravity,
$\dot{q}_c'$ - convective heat injection rate per unit corridor width into ceiling layer,
ρ_∞ - density of ambient air,
c_p - specific heat of air,
T_∞ - ambient air temperature,
ΔT_m - maximum temperature rise measured in ceiling layer at source - end of corridor, and
v_f - propagation speed of forward gravity wave.

Data obtained from the Tight Door Test will be used to compare with predictions using equation (1).

For two different times, Figure 23 shows the temperature rise 51 mm (2 in) below the ceiling as a function of distance down the corridor. Figure 24 presents the arithmetic average gas temperature profile below the ceiling, 0.3 m from the burn room doorway, calculated from the data measured in two sequential scans 11 seconds apart, at 38 seconds and 49 seconds. For this time period, the 51 mm location corresponds to the location of maximum temperature rise. As suggested in reference [9], Figures 23 and 24 can be used to determine the velocity of the corridor forward wave. The smoke is assumed to have passed a given thermocouple position when the data show a rise in temperature greater than the preceding signal fluctuations (noise) and is followed by increasing temperature. Thirty-eight seconds after ignition, the smoke front is located between the 0.3 m (1 ft) position and the 3.05 m (10 ft) position. At 49 seconds, the smoke front has reached a location between the 6.1 m (20 ft) position and the 7.6 m (25 ft) position.

From the test, these data allow bounds on the gas velocity to be calculated. At 38 seconds, the maximum possible position of the smoke layer in the corridor is 3.05 m. At 49 seconds, the minimum possible position is 6.1 m. These values yield a minimum possible velocity of (6.1 - 3.05)/11 = **0.3 m/s** (1 ft/s). At 38 seconds, the minimum possible position of the smoke layer in the corridor is 0.3 m. At 49 seconds, the maximum possible position is 7.6 m. These values yield a maximum possible velocity of (7.6 - 0.3)/11 = **0.7 m/s** (2 ft/s).

In order to apply equation (1), the convective heat injection rate and the average maximum temperature rise must be estimated for the time interval of interest. From Figure 24, the maximum temperature rise is 30.7 °C (87 °F).

The determination of a mean value of $\dot{q}_c'$ during passage of the smoke front from one station to the next is based on the integral:

$$\dot{q}_c' = \frac{d}{dt} \int c_p \, \rho \, \Delta T \, dV' \tag{2}$$

where the integration in principal extends over the entire instantaneous volume (per unit corridor width) of the ceiling layer, from the burn room end of the corridor to the position of the smoke front. The mean value between the 3.05 m (10 ft) location and the 7.6 m (25 ft) location was obtained as the difference in the integral between the forward position (7.6 m) of the front and the immediately preceding position (3.06 m) of the front, divided by the transit time. The integral was evaluated with the aid of the ideal gas law, the longitudinal gas temperature profiles just under the ceiling as shown in Figure 23, and the assumption of a linear vertical temperature profile.

For each temperature profile, a layer depth, δ, could be determined, defined as the depth of a triangular profile having a maximum $\Delta T = \Delta T_m$ at the ceiling ($y = 0$) and having the same integral $\int_0^h \Delta T dy$ as the actual profile. From the data for Tight Door Test, the layer depth, δ, is calculated to be 1.57 m (5.1 ft). Steckler points out that while being useful for estimating the forward wave velocity, the layer depth determined using this method may be incorrect by a factor of three [8].

The frontal velocity predicted using equation (1) is **0.41 m/s** (1.34 ft/s). Comparison of this value with the possible range of test values (0.3 m/s and 0.7 m/s) is quite positive, with a potential error of about 30 percent. Additional comparisons using data from the other tests yield results with a similar level of agreement (Table 6). Hence the measured and predicted values agreed within the limits of uncertainty for the data.

4.2 Safety of Corridor and Target Room

The effect of combustion products from a post-flashover room fire on an attached corridor and target room was evaluated as part of this study. The temperatures and gas concentrations in the corridor are remarkably similar between tests. The differences occur in the target room and are related to the method or methods chosen to protect it.

As shown in Table 3, the temperatures in the corridor increased 150 to 200 °C. Limited data is available to evaluate the effect of elevated temperature on humans. However, the substantial temperature increases measured in the corridor would certainly be intolerable to unprotected persons[10]. Temperature increases measured in the target room were directly effected by the level of protection provided. The maximum temperature increase was 46 °C measured during the Typical Door Test.

In building fires, a primary concern is the toxic gases produced. The toxicity associated with a given combustion product is related to the concentration of the product and the duration of exposure. Data are available in the literature [10] for assessing the toxic hazard presented by concentrations of oxygen, carbon dioxide, and carbon monoxide. Table 7 lists the LC_{50}s in percent volume for carbon monoxide (based on 5 minute rat exposures [11] and 30 minute human exposures [10]) and carbon dioxide (based on experiments with rats)[10]. The LC_{50}s are those concentrations which would be lethal to 50% of the exposed subjects for the specified time.

Hazardous low oxygen concentration information is also contained in Table 7. Oxygen deprivation is a special case of gas toxicity. Data on oxygen deprivation alone, without any other combined gas effects, suggest that incapacitation occurs when oxygen levels drop to approximately 10% [10]. The concentrations presented in Table 7 do not consider the effect of combinations of these gases.

A comparison of Tables 4 and 7 shows that the gas concentrations measured in the corridor exceed toxic levels within the exposure time in these tests. The concentrations measured in the target room vary substantially depending on the level of room protection. The worst conditions occur when the target room is protected using a simulated typical door. The best protection of the target room was achieved when the typical door is augmented with pressurization of the target room. A pressure differential across the target room door of 36.7 Pa (0.15 in H_2O) prevented any significant infiltration of carbon dioxide or carbon monoxide into the target room. The tight door and the accordion door allow products of combustion penetration into the target room and increased gas temperatures. However, in both cases the rates were substantially reduced from those found using the typical door and are probably not lethal in 5 minutes.

It is readily apparent that the amount of door leakage area has an impact on the rate at which a room or other area becomes hazardous. Changing the leakage position to the bottom of the door and reducing the effective leakage area of the Typical Door by half to 0.12 m^3/s (Tight Door) delays the infiltration of significant amounts of carbon monoxide by approximately 6.5 minutes (see Figure 19). The maximum allowable door leakage is a function of the size of the space being protected. Allowable door leakage should be expressed in terms of maximum numbers of air changes per hour. For the tight door and target room combination used in this study, the air changes per hour were 28.8 at a pressure difference across the doorway of 36.7 Pa (0.15 in H_2O). Further testing is required to determine definite recommendations for maximum allowable door leakage.

5. CONCLUSIONS

For the conditions examined, a fully involved room fire produced high gas temperatures and high concentrations of carbon dioxide and carbon monoxide in an attached corridor. Pressurization of a room attached to the corridor and reduction of the amount of door leakage area into the room were effective methods of reducing temperature rise and the penetration of products of combustion into the target room. Measurements were used to examine a model, proposed by Steckler, for predicting the flow velocity of the initial gravity wave down the corridor. The measured and predicted values agreed within the limits of uncertainty for the data.

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Table 1. Location of Instrumentation

GSA CORRIDOR AND SIMULATED STAGING AREA FIRE TEST SERIES

I. Instrumentation in the Burn Room, Corridor, and Target Room

A. Thermocouple Arrays, Gas Temperature

Array 1 in burn room, Northwest quadrant - 9 thermocouples at 0.26, 0.66, 1.07, 1.47, 1.88, 2.19, 2.34, 2.39, and 2.44 m from floor.

Array 2 in burn room, Northwest quadrant - 7 aspirated thermocouples at 0.66, 1.07, 1.47, 1.88, 2.19, 2.34, and 2.39 m from floor.

Array 3 in doorway between burn room and corridor - 8 thermocouples at 0.51, 0.61, 0.91, 1.22, 1.37, 1.52, 1.83, and 2.29 m from floor.

Array 4 in corridor, Northwest quadrant 0.3 m from burn room doorway - 9 thermocouples at 0.26, 0.66, 1.07, 1.47, 1.88, 2.19, 2.34, 2.39, and 2.44 m from floor (added after the first test).

Array 5 in corridor, 3 m from burn room doorway - 9 thermocouples at 0.26, 0.66, 1.07, 1.47, 1.88, 2.19, 2.34, 2.39, and 2.44 m from floor.

Array 6 in corridor, 4.6 m from burn room doorway - 2 thermocouples at 2.39 and 2.44 m from floor.

Array 7 in corridor, 6.1 m from burn room doorway (center of corridor) - 9 thermocouples at 0.26, 0.66, 1.07, 1.47, 1.88, 2.19, 2.34, 2.39, and 2.44 m from floor.

Array 8 in corridor, 7.6 m from burn room doorway - 2 thermocouples at 2.39 and 2.44 m from floor.

Array 9 in corridor, 9.1 m from burn room doorway - 9 thermocouples at 0.26, 0.66, 1.07, 1.47, 1.88, 2.19, 2.34, 2.39, and 2.44 m from floor.

Array 10 in corridor, 10.7 m from burn room doorway (across from target room door) - 9 thermocouples at 0.26, 0.66, 1.07, 1.47, 1.88, 2.19, 2.34, 2.39, and 2.44 m from floor (added after the first test).

Array 11 in target room, 1.5 m from doorway - 9 thermocouples at 0.22, 0.35, 0.76, 1.16, 1.57, 1.88, 2.03, 2.08, and 2.13 m from floor.

B. Burn room wall thermocouples

North wall, interior - 8 thermocouples at 0.26, 0.66, 1.07, 1.47, 1.88, 2.19, 2.34, and 2.39 m from floor.

North wall, exterior - 8 thermocouples at 0.26, 0.66, 1.07, 1.47, 1.88, 2.19, 2.34, and 2.39 m from floor.

South wall, interior - 3 thermocouples at 1.07, 1.88, and 2.34 m from floor.

South wall, exterior - 3 thermocouples at 1.07, 1.88, and 2.34 m from floor.

C. Differential Pressure Probes

Burn room to corridor doorway - 1 probe at 0.15 m above floor.

Target room to corridor doorway - 2 probes at 0.15 and 1.9 m above floor (probe at 1.9 m added after the first test).

D. Smoke Indicators

Corridor 6.1 m from burn room doorway - 7 horizontal smoke meters at 0.15, 0.61, 0.91, 1.22, 1.52, 1.83, and 2.13 m from floor.

Target room - 2 vertical, 1 m path length smoke meters, top and bottom.

E. Gas Analysis

Burn Room probe, 0.46 m horizontally from the Northwest corner, 1.53 m from the floor - oxygen, carbon dioxide, and carbon monoxide concentrations.

Corridor probe, center of corridor, 1.53 m from the floor - oxygen, carbon dioxide, and carbon monoxide concentrations.

Target Room probe, 0.3 m horizontally from the East and South walls and 1.53 m from the floor - oxygen, carbon dioxide, and carbon monoxide concentrations.

II. <u>Exhaust Hood</u>

1 smoke meter

1 probe for sampling oxygen, carbon dioxide, and carbon monoxide

9 pitot static probes

9 thermocouples

Table 2. Crib Weights

Test	Total Weight of Fuel (kg)
Typical Door	196.1
Pressurized Room	187.9
Tight Door	187.9
Accordion Door	250.4*

* The total weight for the Accordion Door Test includes 31.8 kg of additional wood to account for plywood lining the burn room walls.

Table 3. Maximum Heat Release Rate and Maximum Average Upper Layer Temperature Increase

Test	Maximum Heat Release Rate (MW)	Corridor Temp. Change (°C)	Target Room Temp. Change (°C)
Typical Door	2.2	159	46
Pressurized Room	1.7	149	1
Tight Door	2.3	160	12
Accordion Door	2.5	202	7

Table 4. Corridor Gas Concentrations

Test	% CO (maximum)	% CO_2 (maximum)	% O_2 (minimum)
Typical Door	3.9	14.6	4.5
Pressurized Room	*	11.0	10.0
Tight Door	4.5	14.9	4.3
Accordion Door	4.3	17.2	*

* Not available

Table 5. Target Room Gas Concentrations

Test	% CO (maximum)	% CO_2 (maximum)	% O_2 (minimum)
Typical Door	2.9	11.7	7.7
Pressurized Room	0.0	0.1	20.8
Tight Door	0.2	0.8	20.4
Accordion Door	*	0.6	20.2

* Not available

Table 6. Corridor Smoke Flow Velocities

Test	Velocity Range Determined from Experimental Data		Calculated from Equation (1) (m/s)
	Minimum (m/s)	Maximum (m/s)	
Typical Door	*	*	0.53
Pressurized Room	0.2	0.8	0.39
Tight Door	0.3	0.7	0.41
Accordion Door	0.3	0.8	0.45

* Insufficient data to calculate the velocity.

Table 7. Summary of LC_{50} Data for Common Toxic Products of Combustion

Duration of Exposure	Carbon Monoxide	Carbon Dioxide	Low Oxygen
5 Minutes	1.4 %	> 15 %	< 10 %**
30 Minutes	0.3 %	> 15 %	< 10 %**

** Percentage for incapacitation

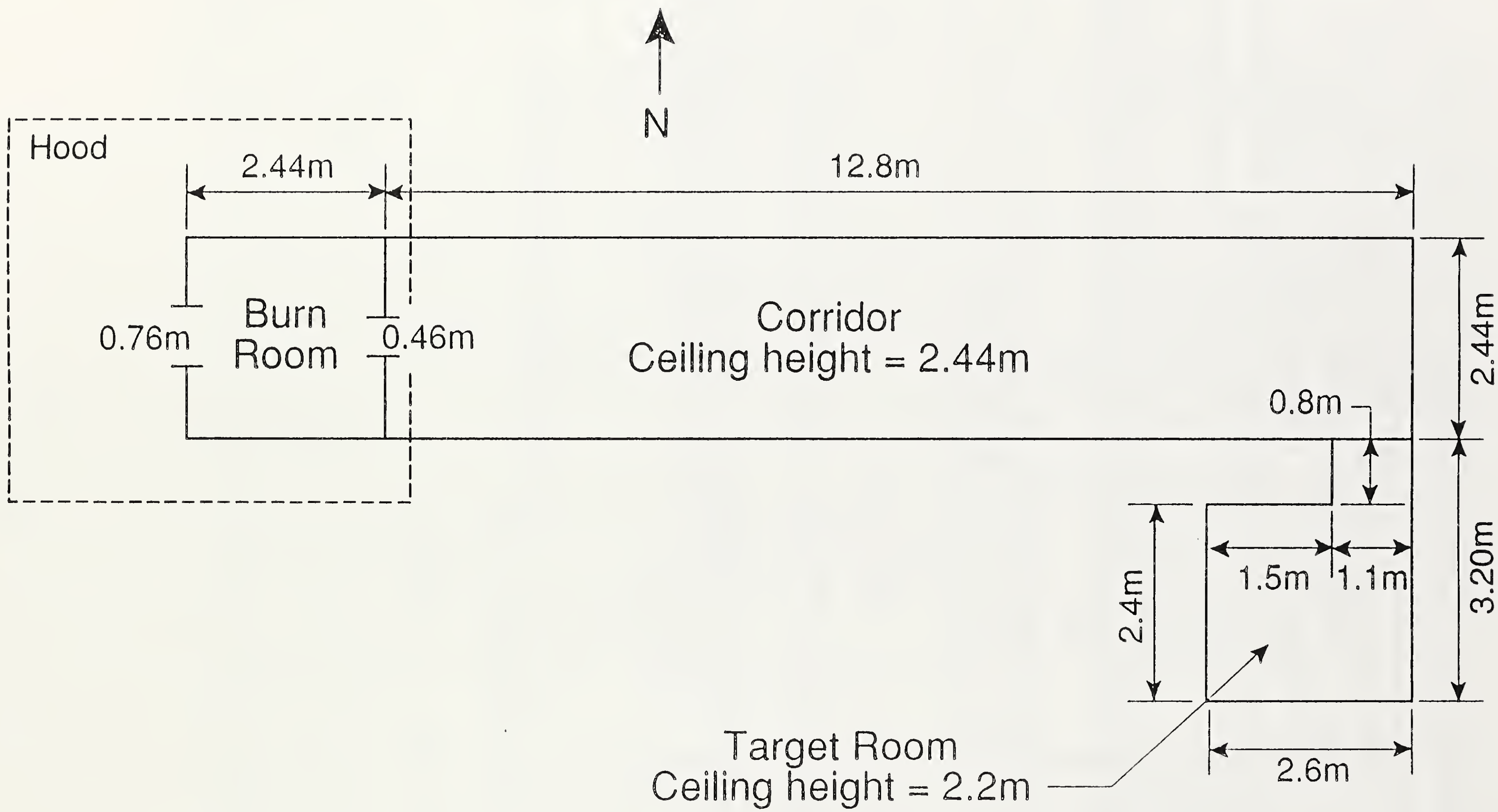

Figure 1. Test Configuration

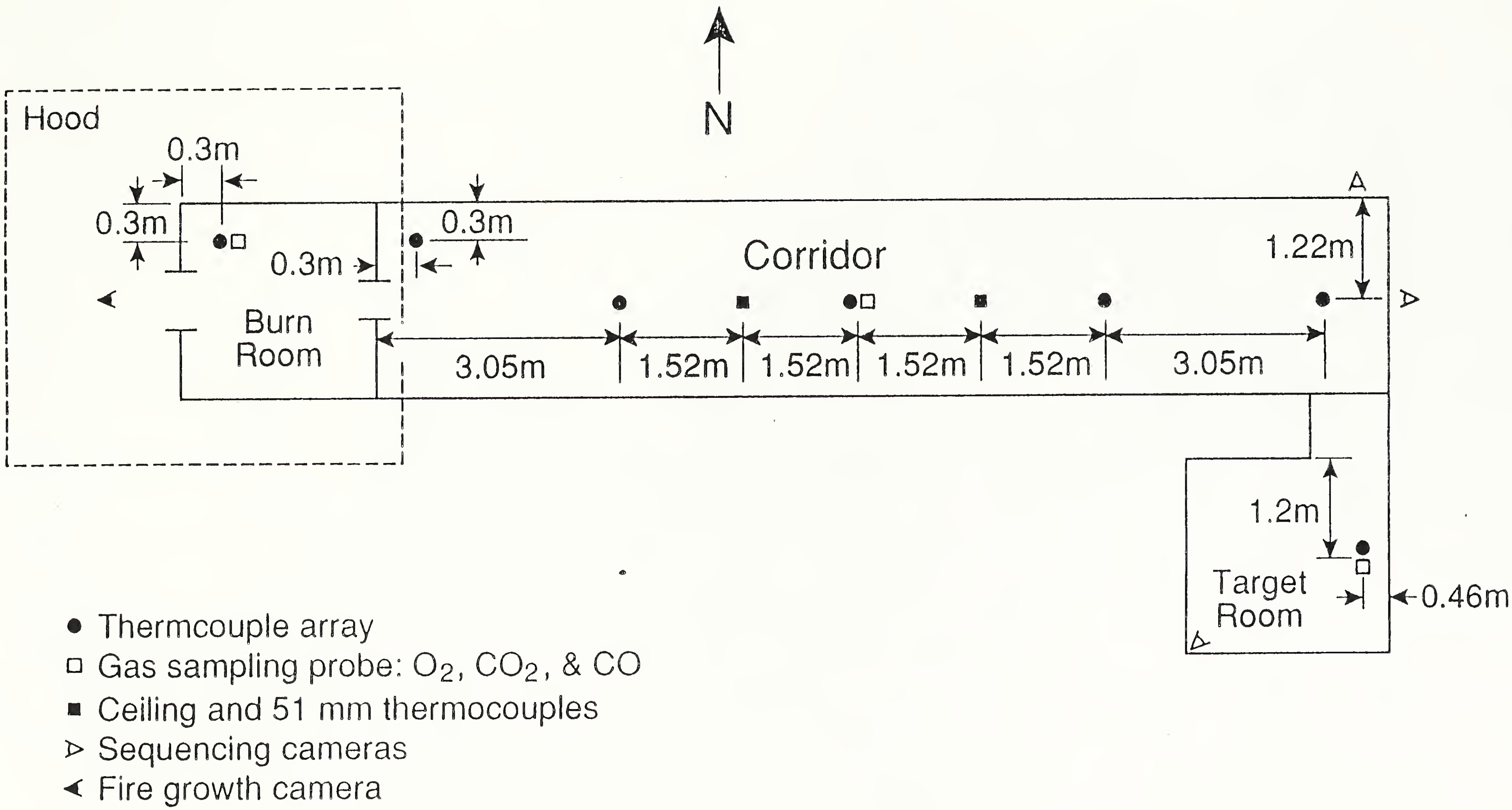

Figure 2. Instrument Locations

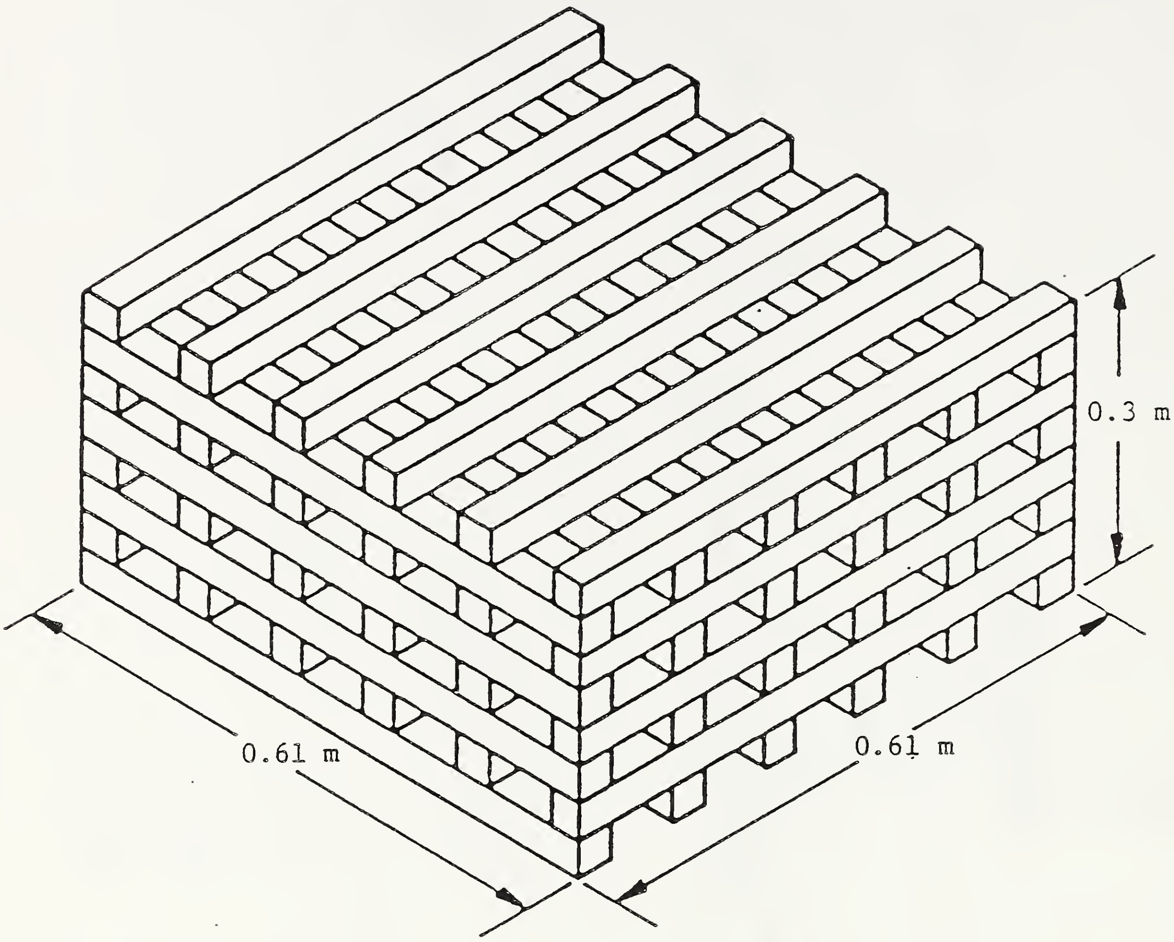

Figure 3. Diagram of Wood Crib used in Test Series

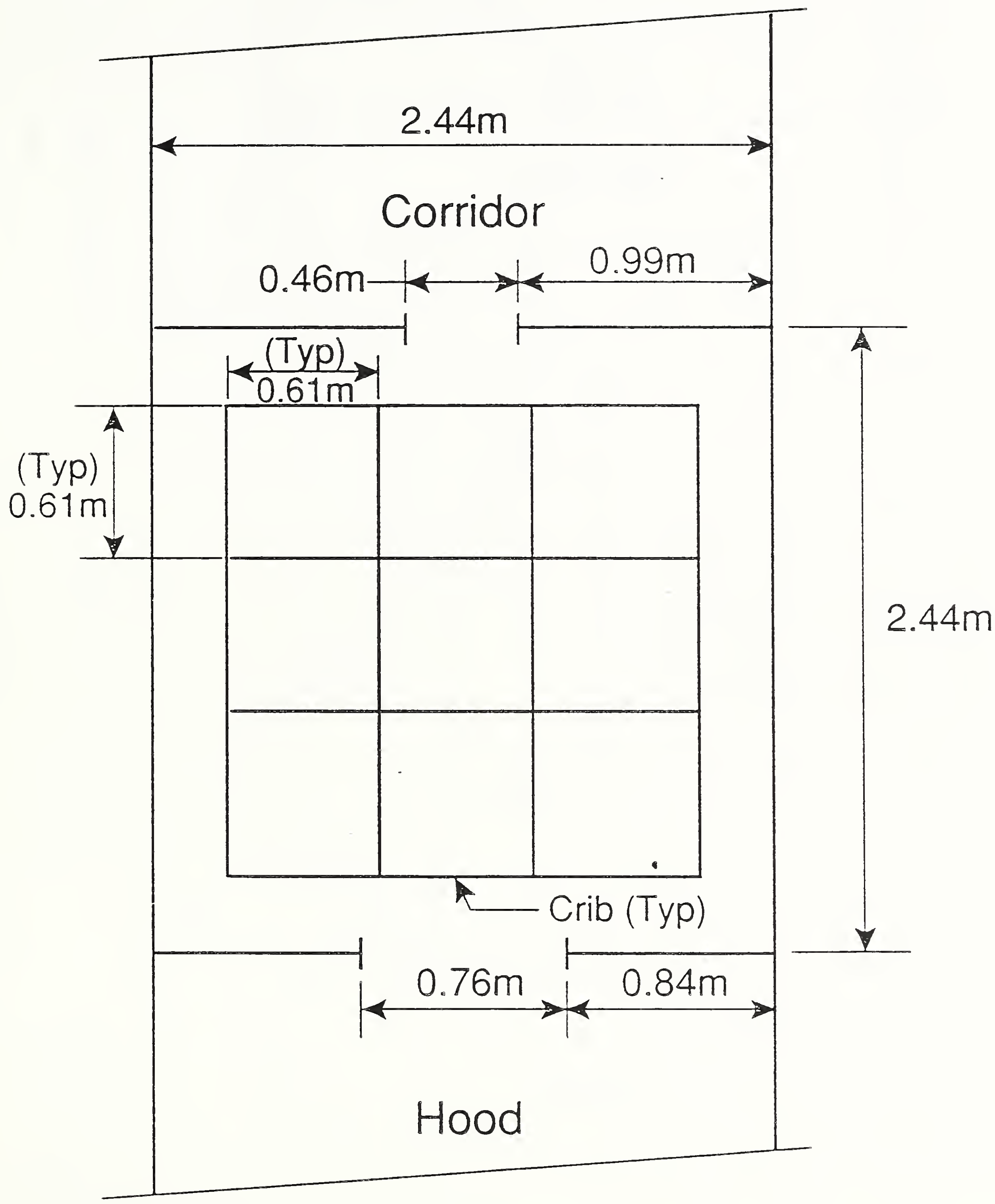

Figure 4. Diagram of Crib Placement in Burn Room (except Accordion Door Test)

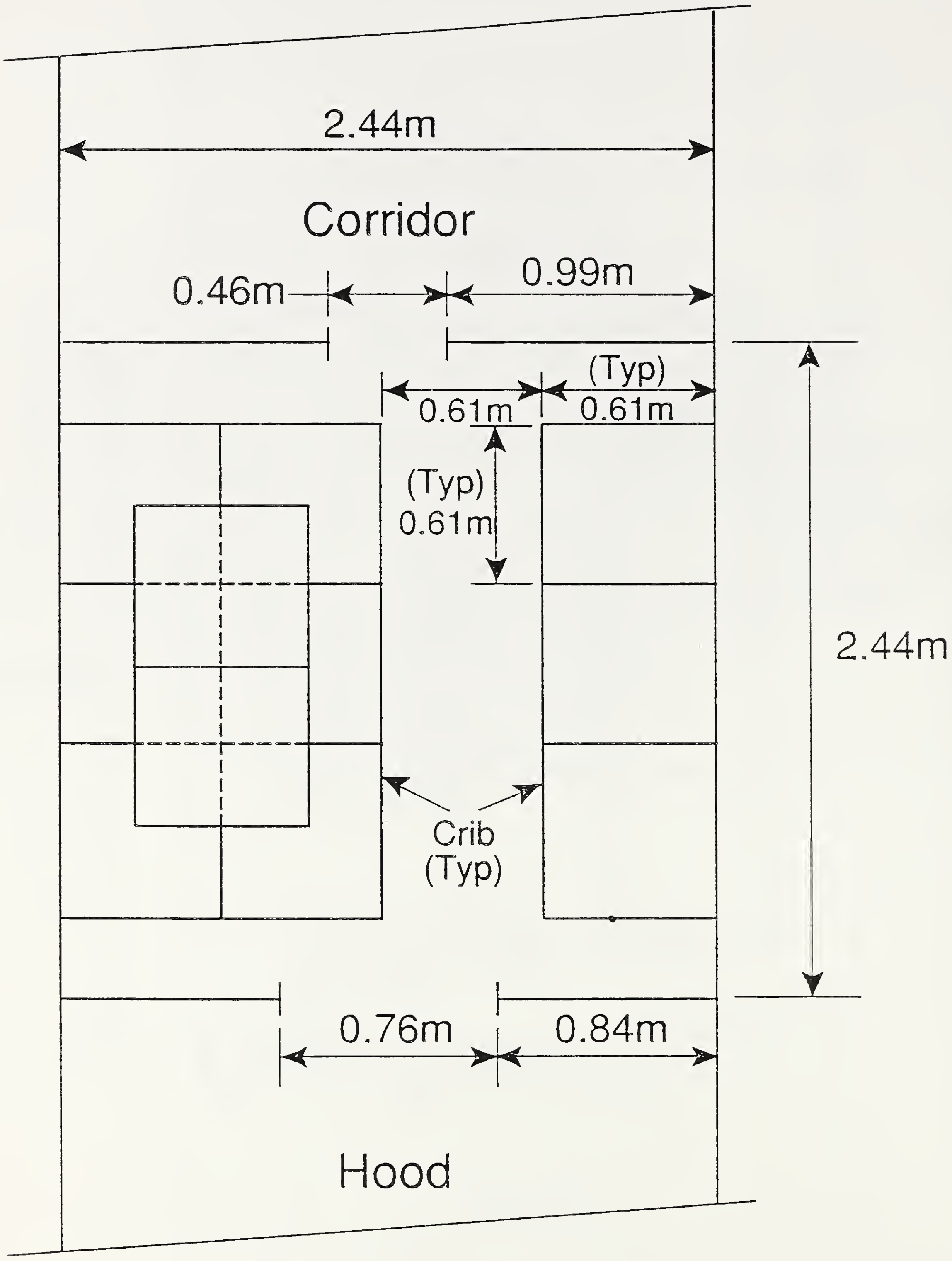

Figure 5. Diagram of Crib Placement in Burn Room (Accordion Door Test)

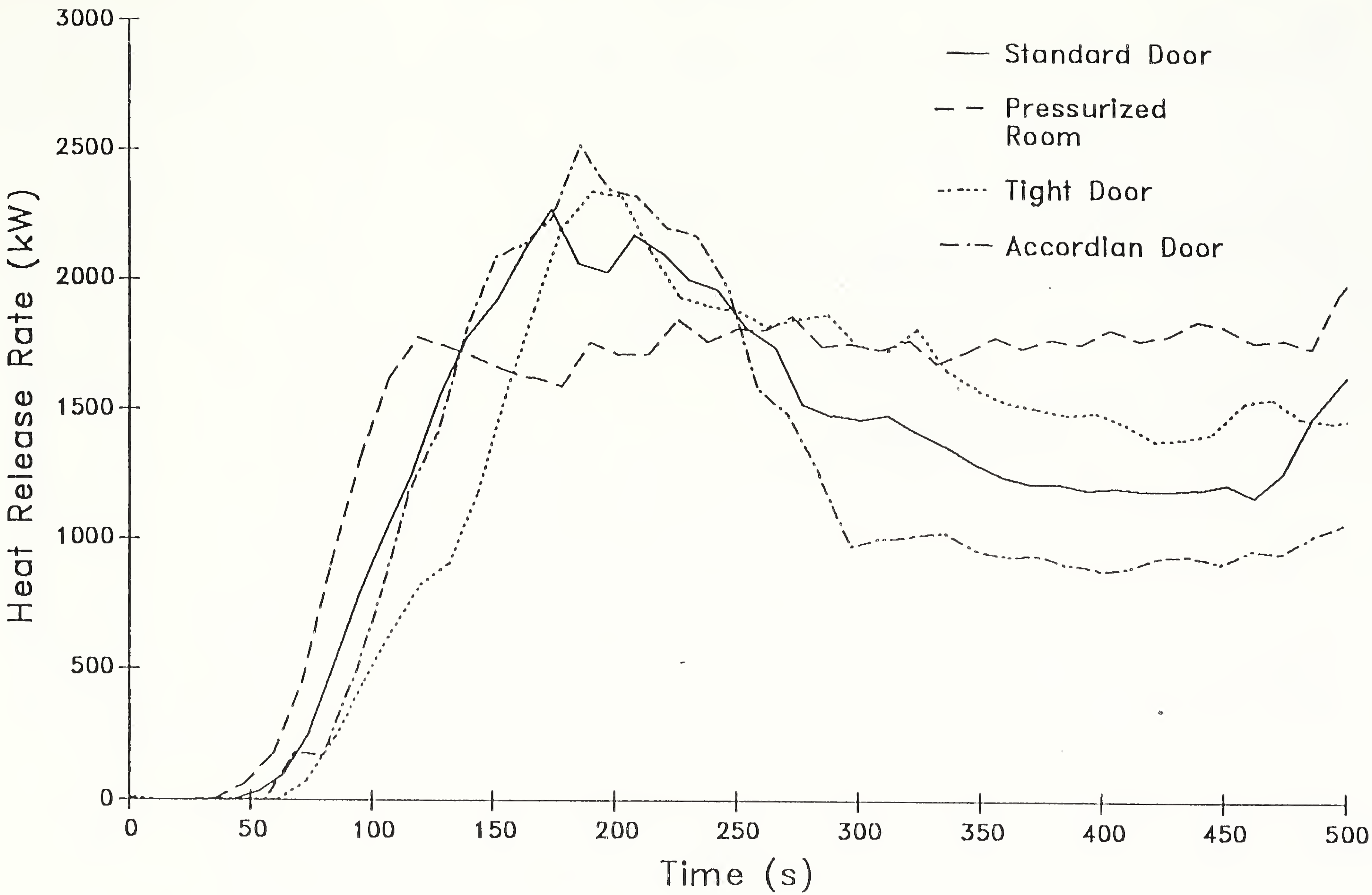

Figure 6. Graph of Heat Release Rates for All Tests

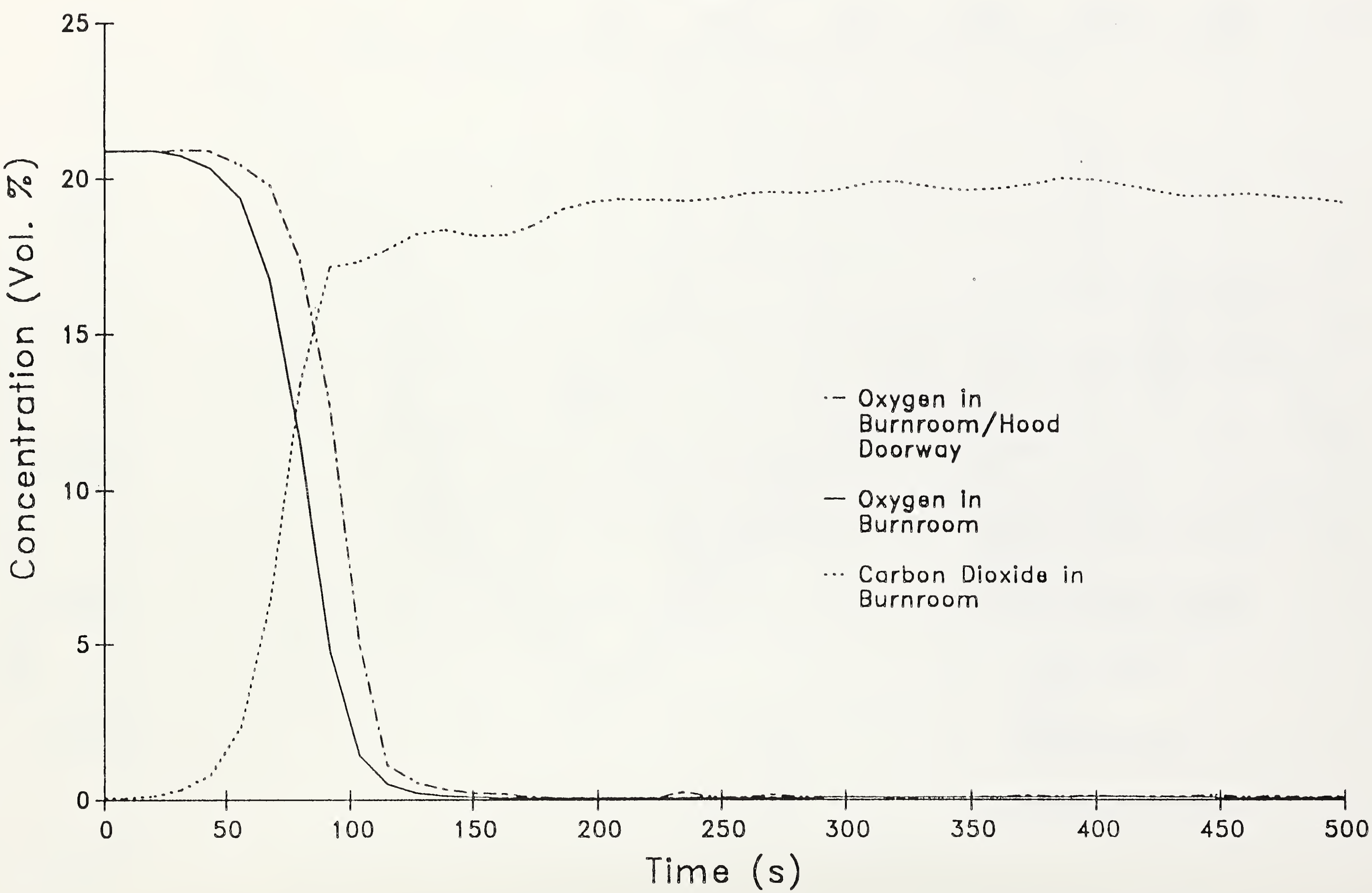

Figure 7. Burn Room Gas Concentrations for Accordion Door Test

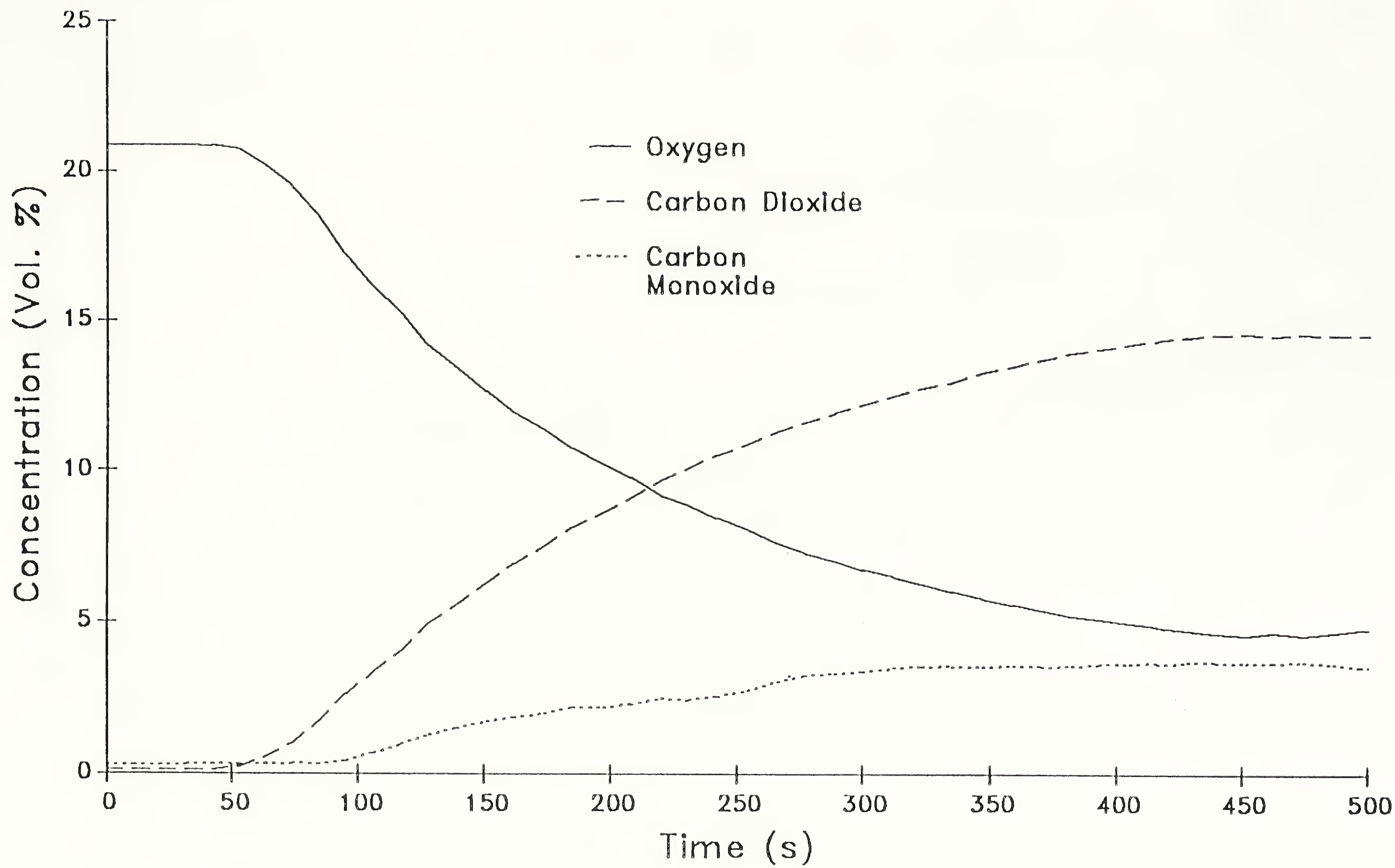

Figure 8. Corridor Gas Concentrations for Typical Door Test

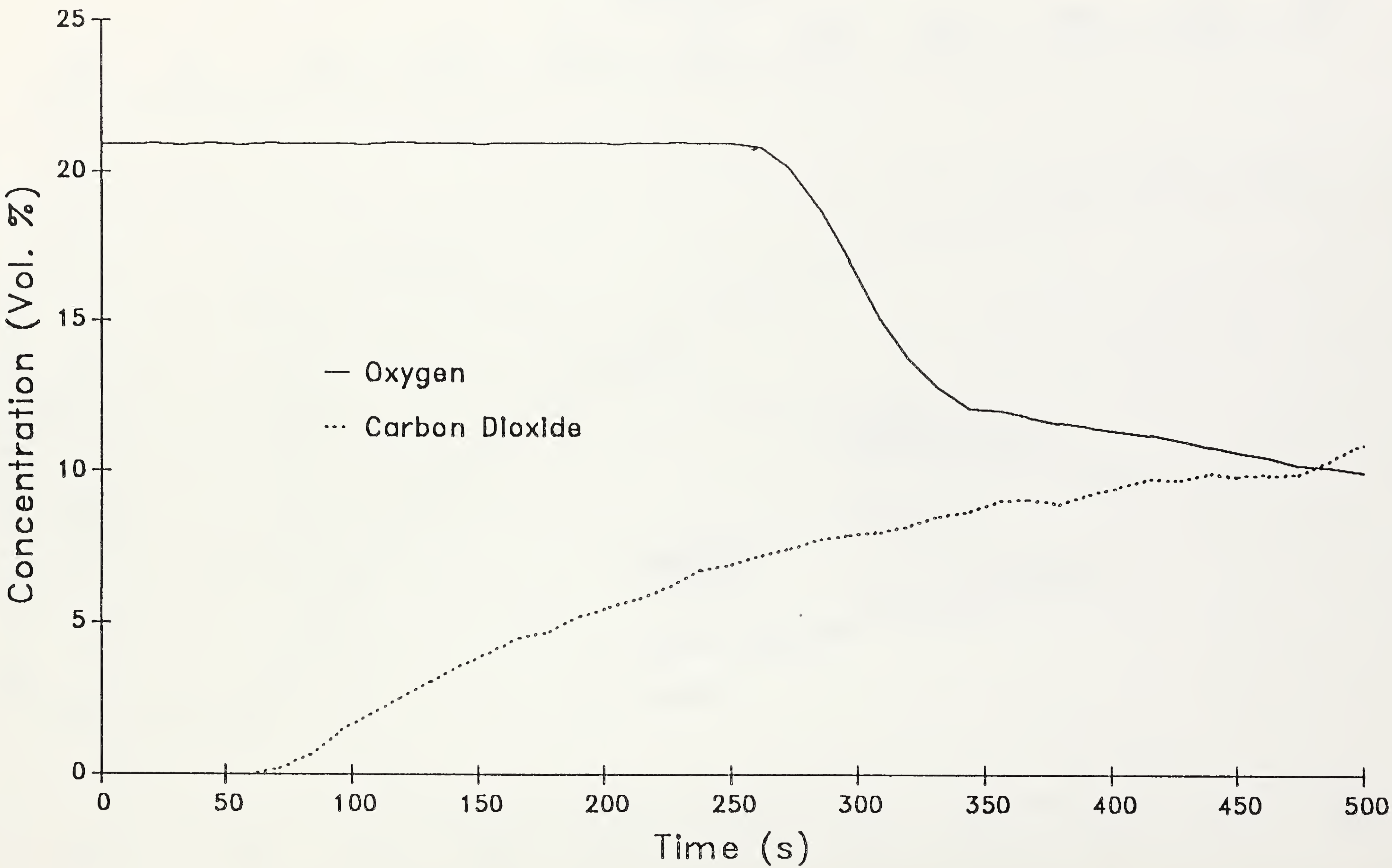

Figure 9. Corridor Gas Concentrations for Pressurized Room Test

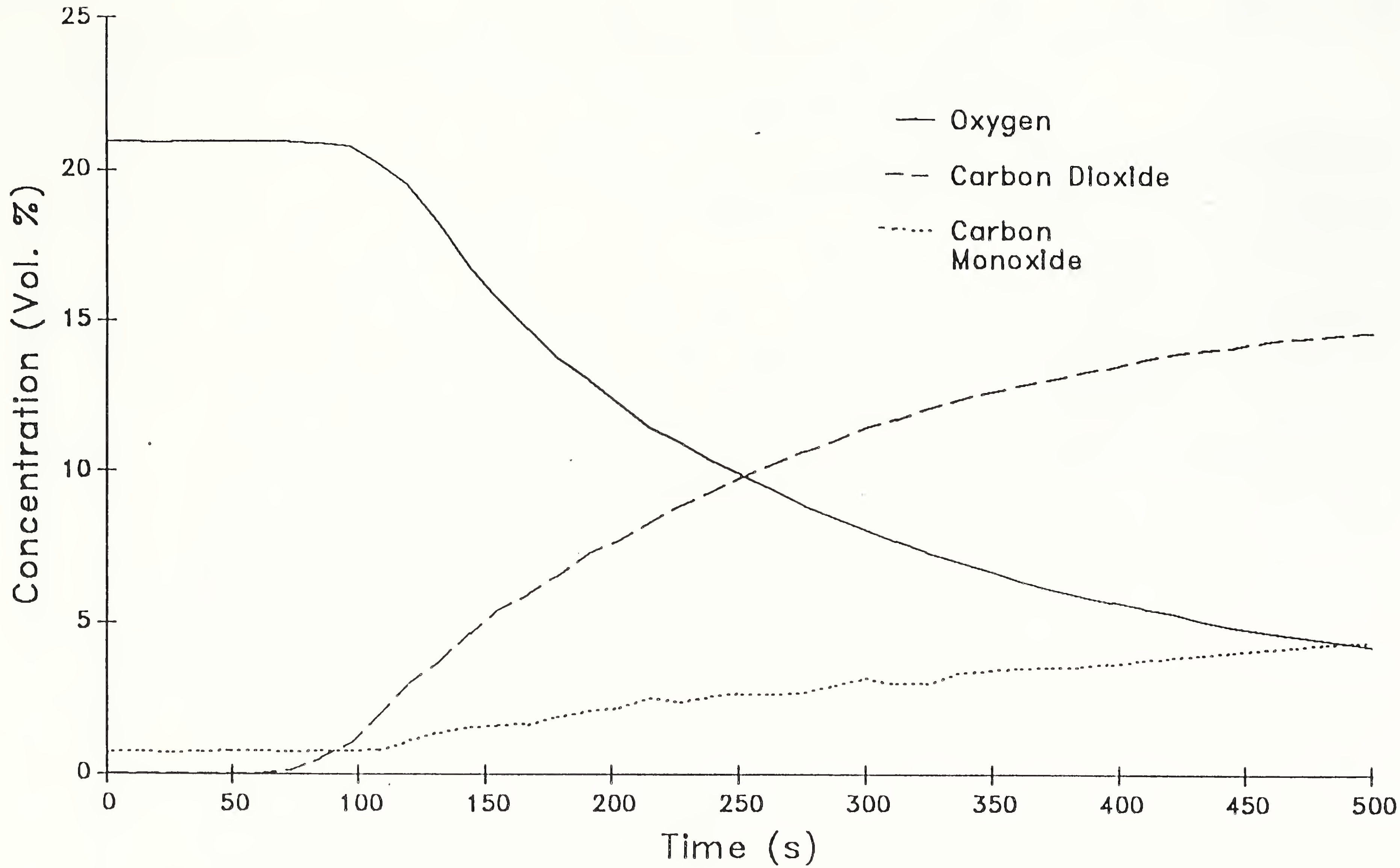

Figure 10. Corridor Gas Concentrations for Tight Door Test

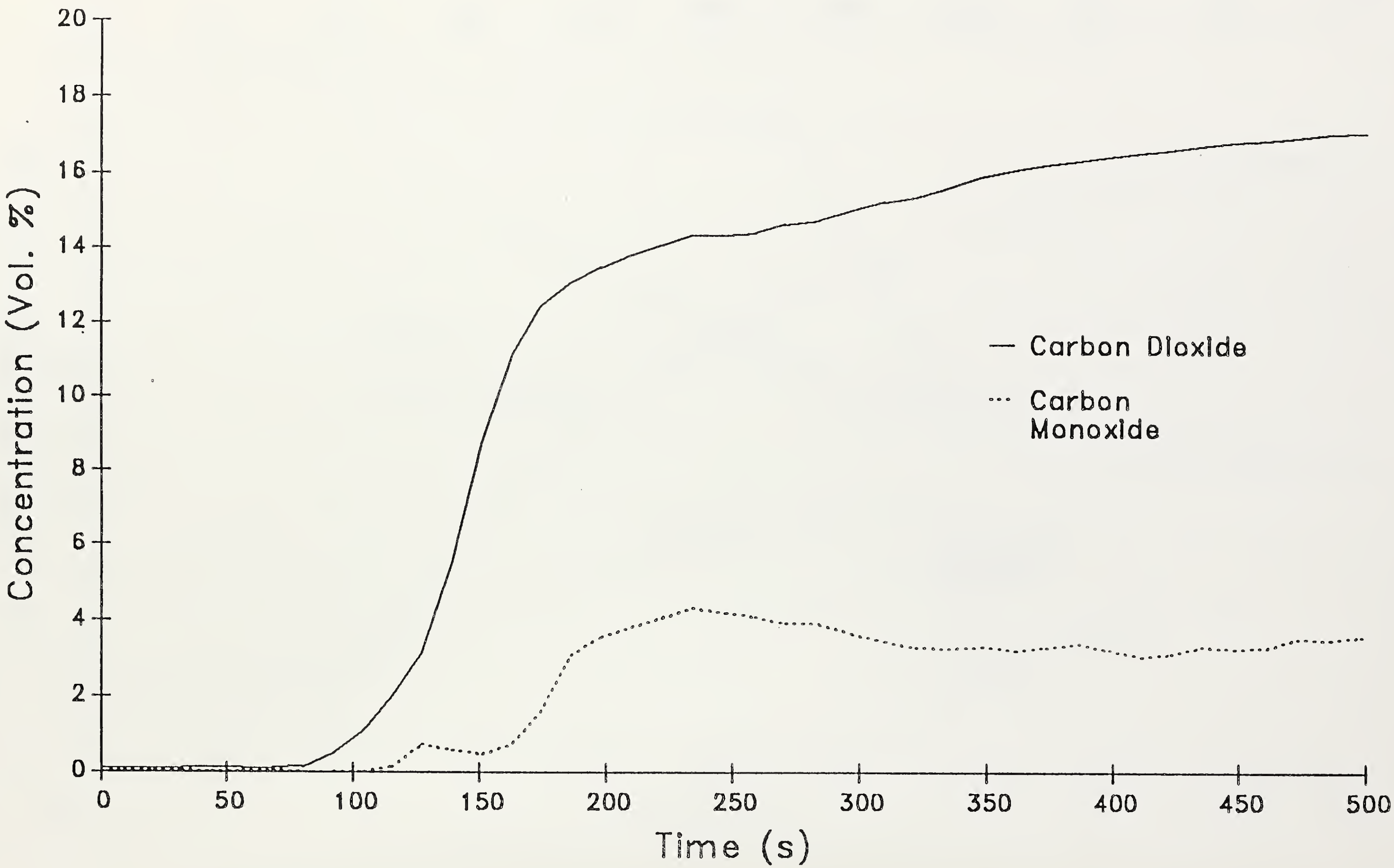

Figure 11. Corridor Gas Concentrations for Accordion Door Test

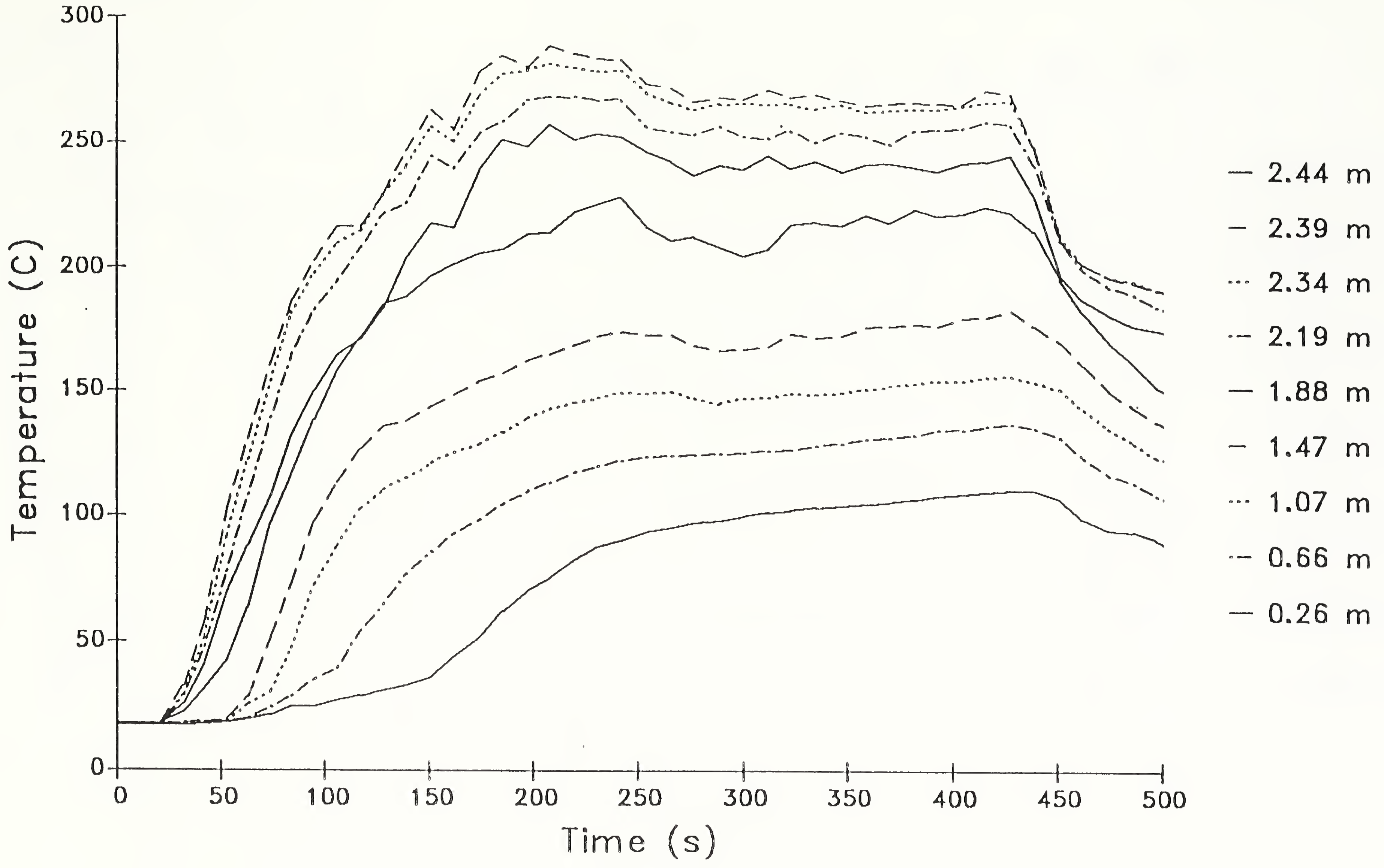

Figure 12. Corridor Temperatures 3.05 m from Burn Room for Typical Door Test

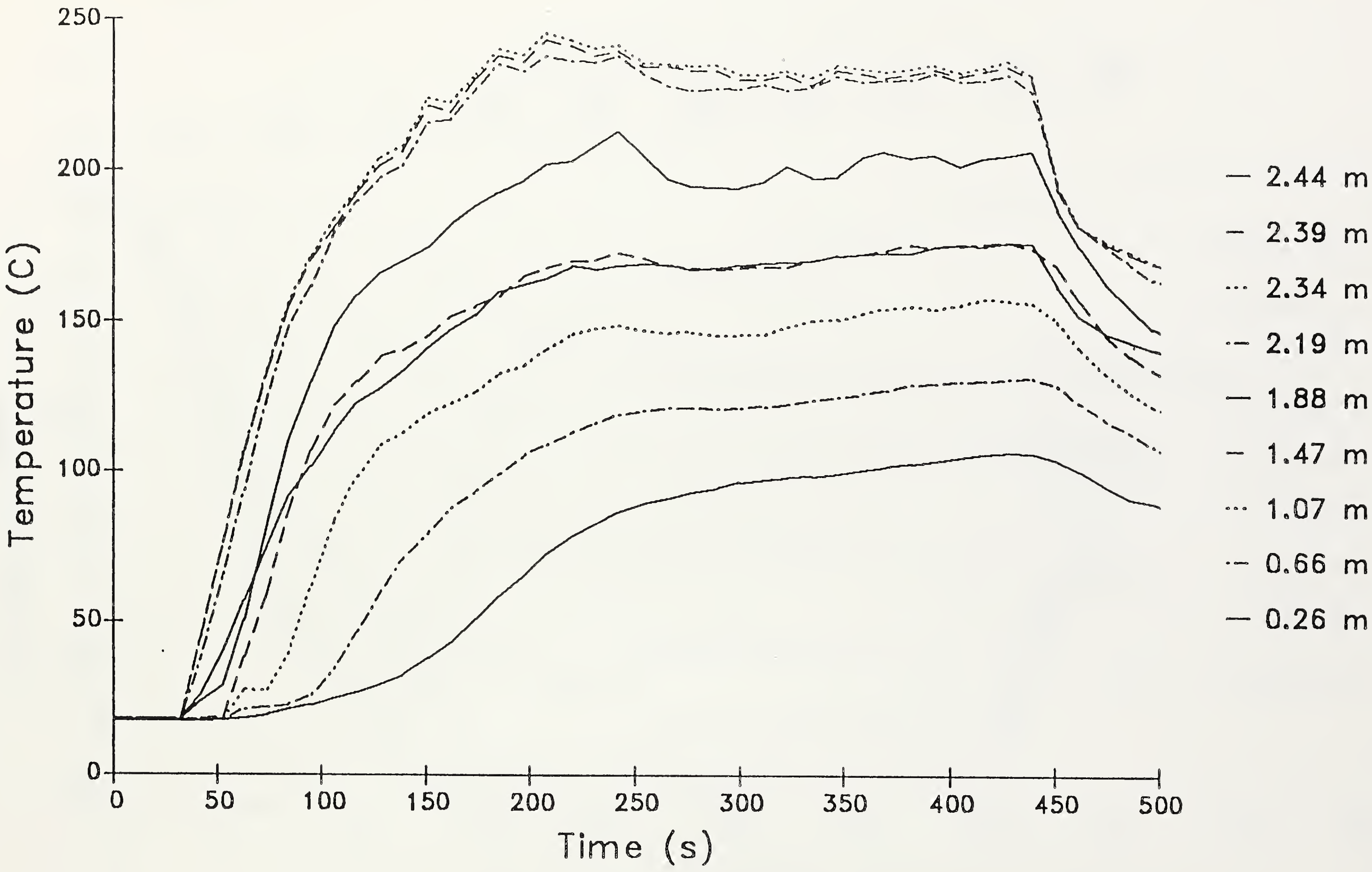

Figure 13. Corridor Temperatures 6.10 m from Burn Room for Typical Door Test

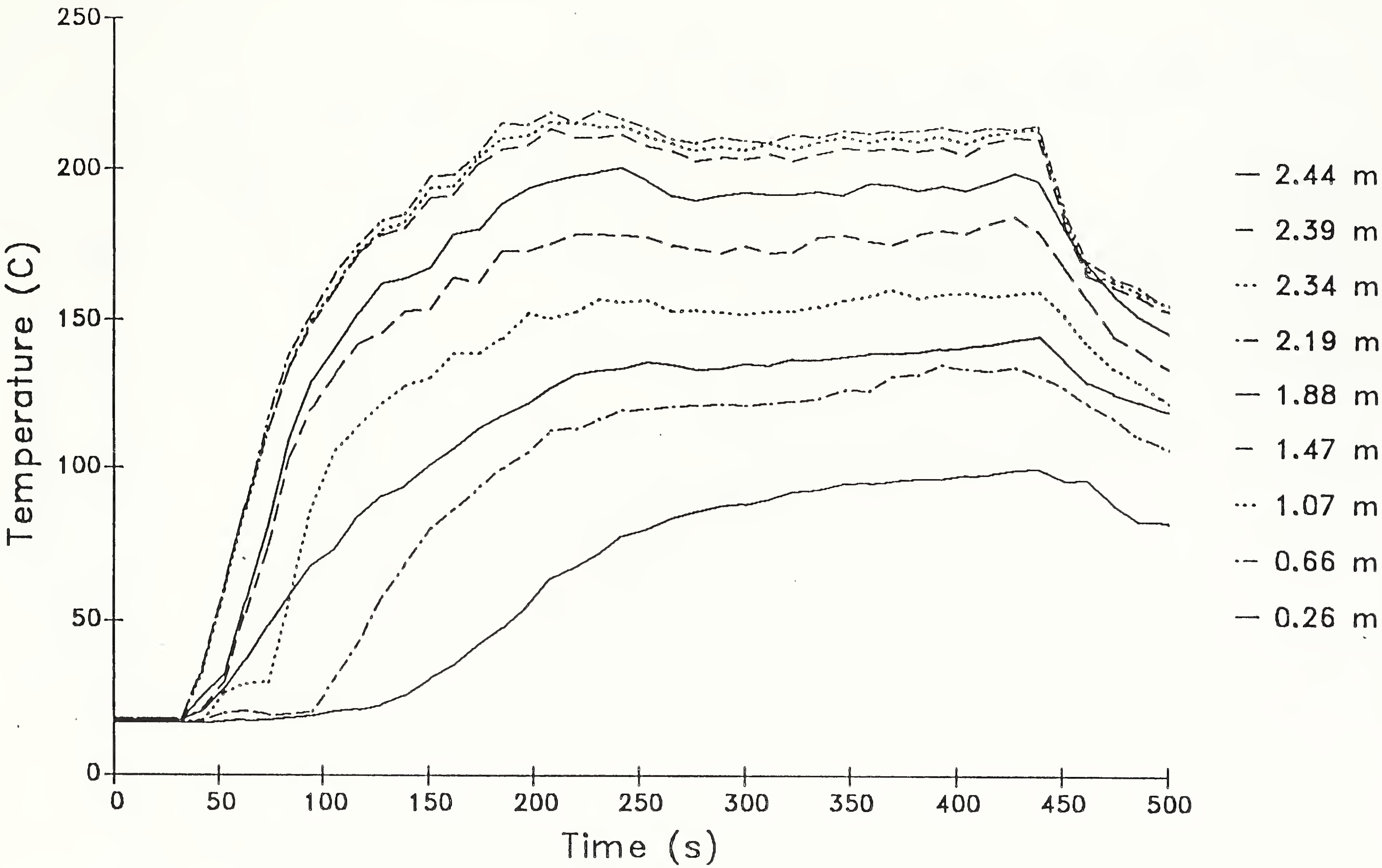

Figure 14. Corridor Temperatures 9.15 m from Burn Room for Typical Door Test

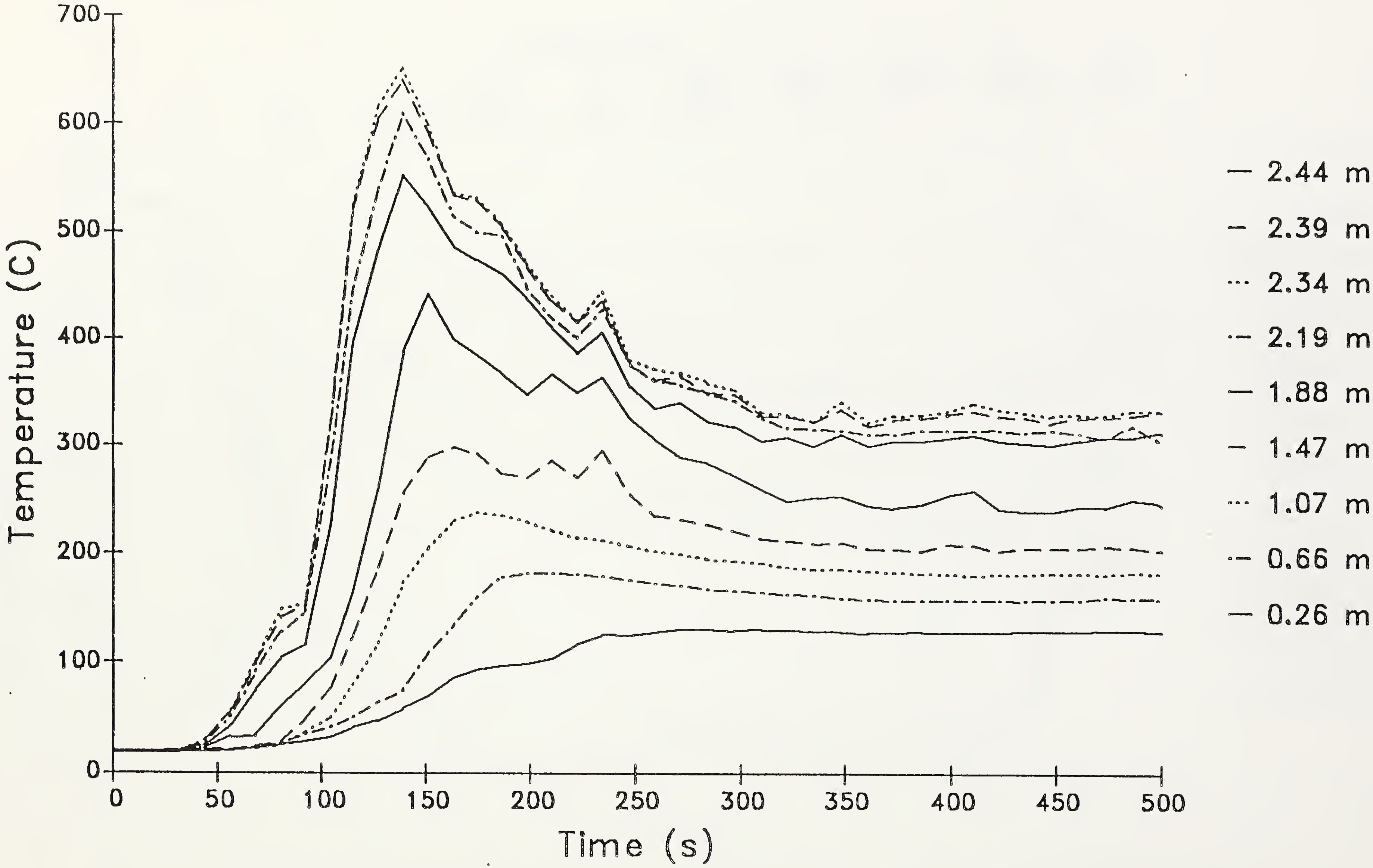

Figure 15. Corridor Temperatures Outside Burn Room Door for Accordion Door Test

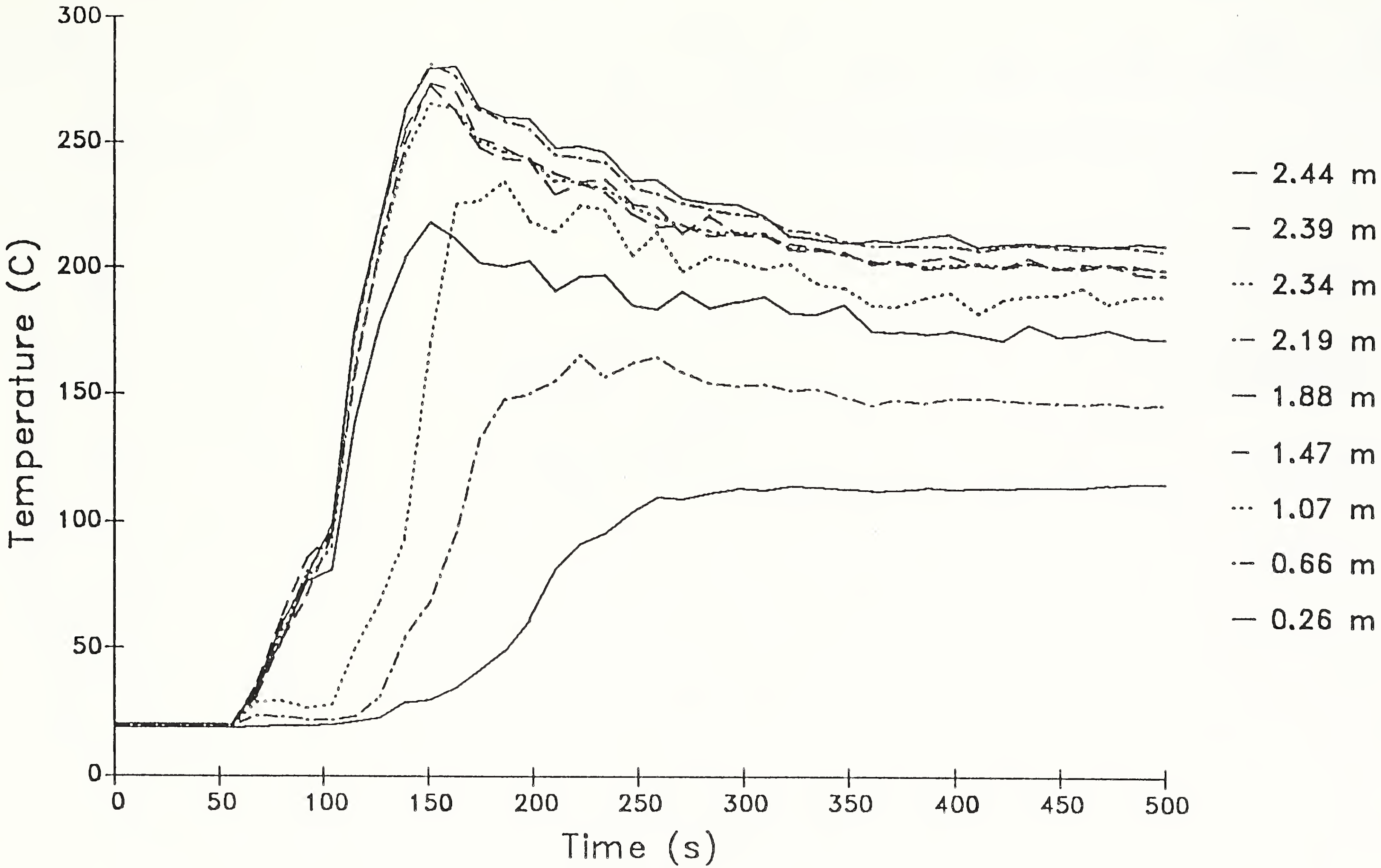

Figure 16. Corridor Temperatures Adj. Target Room Door for Accordion Door Test

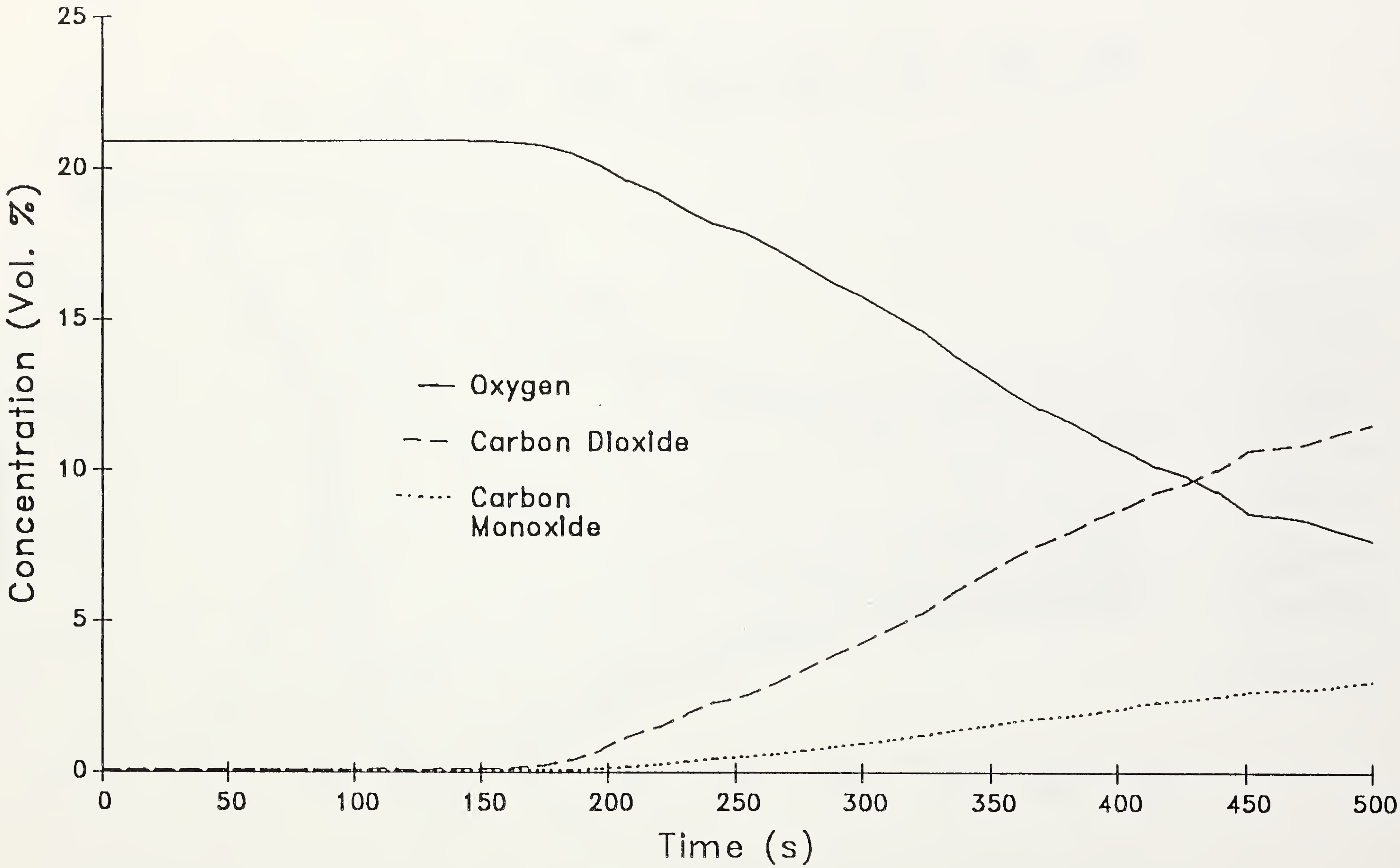

Figure 17. Gas Concentrations in the Target Room for Typical Door Test

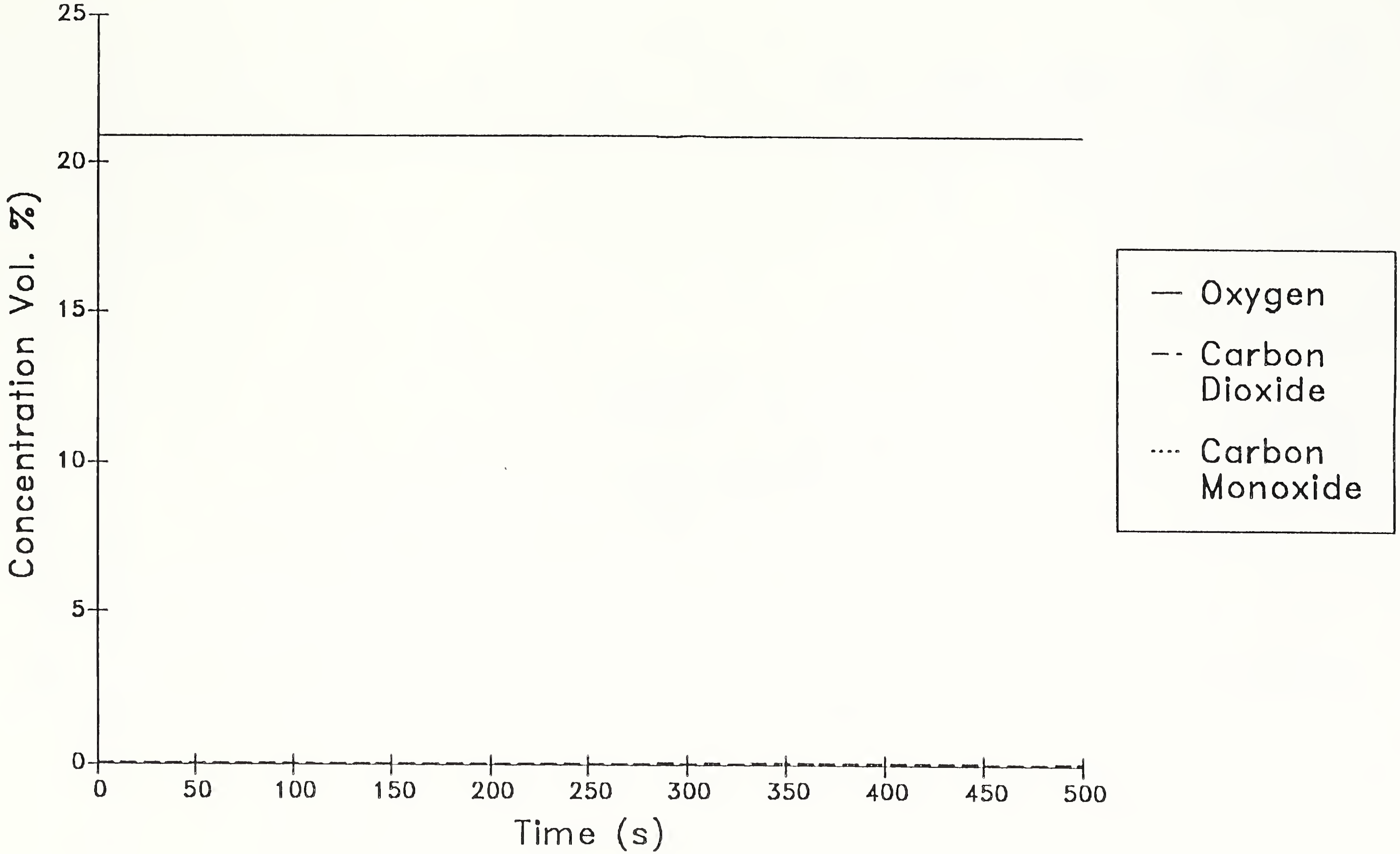

Figure 18. Gas Concentrations in the Target Room for Pressurized Room Test

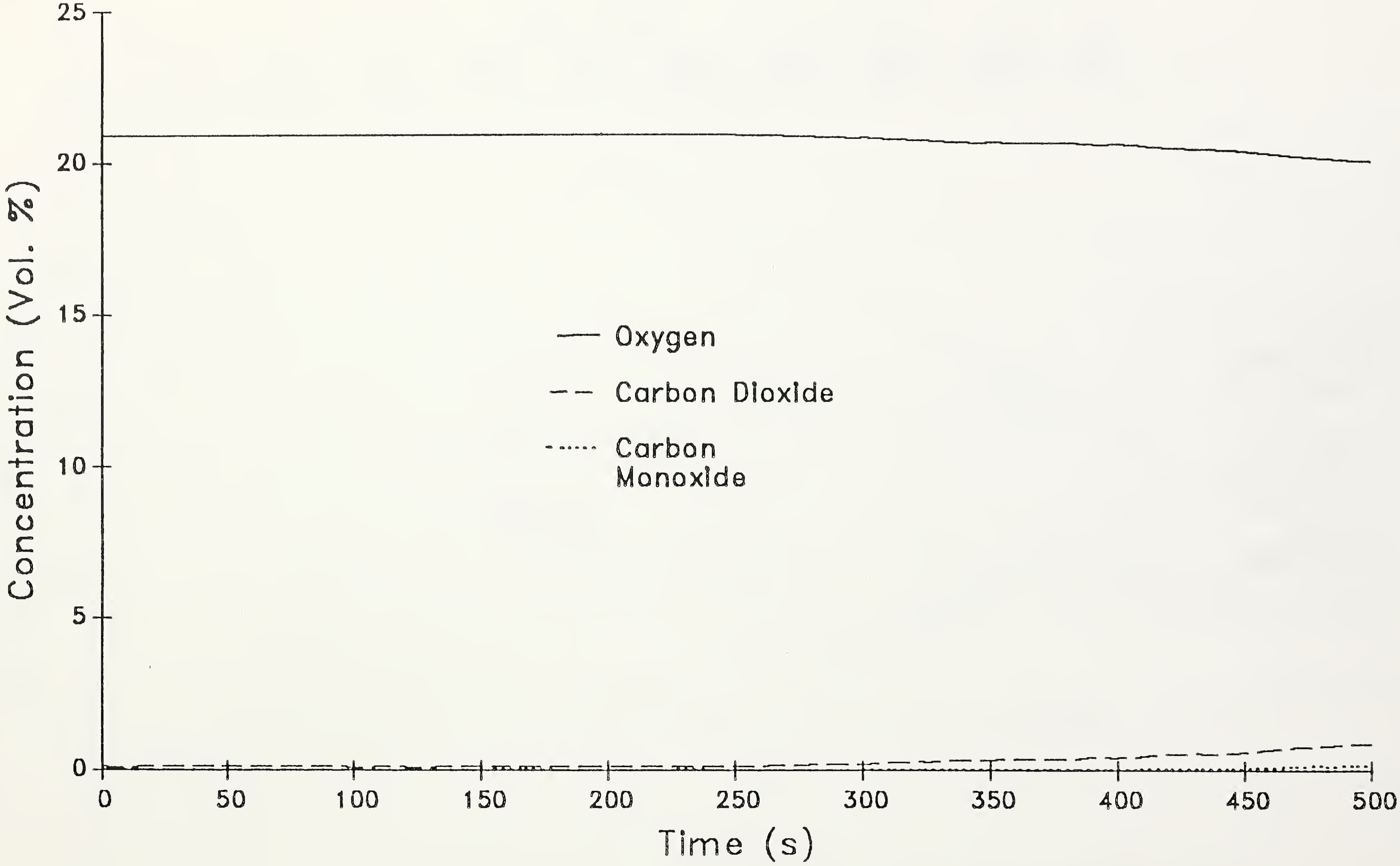

Figure 19. Gas Concentrations in the Target Room for Tight Door Test

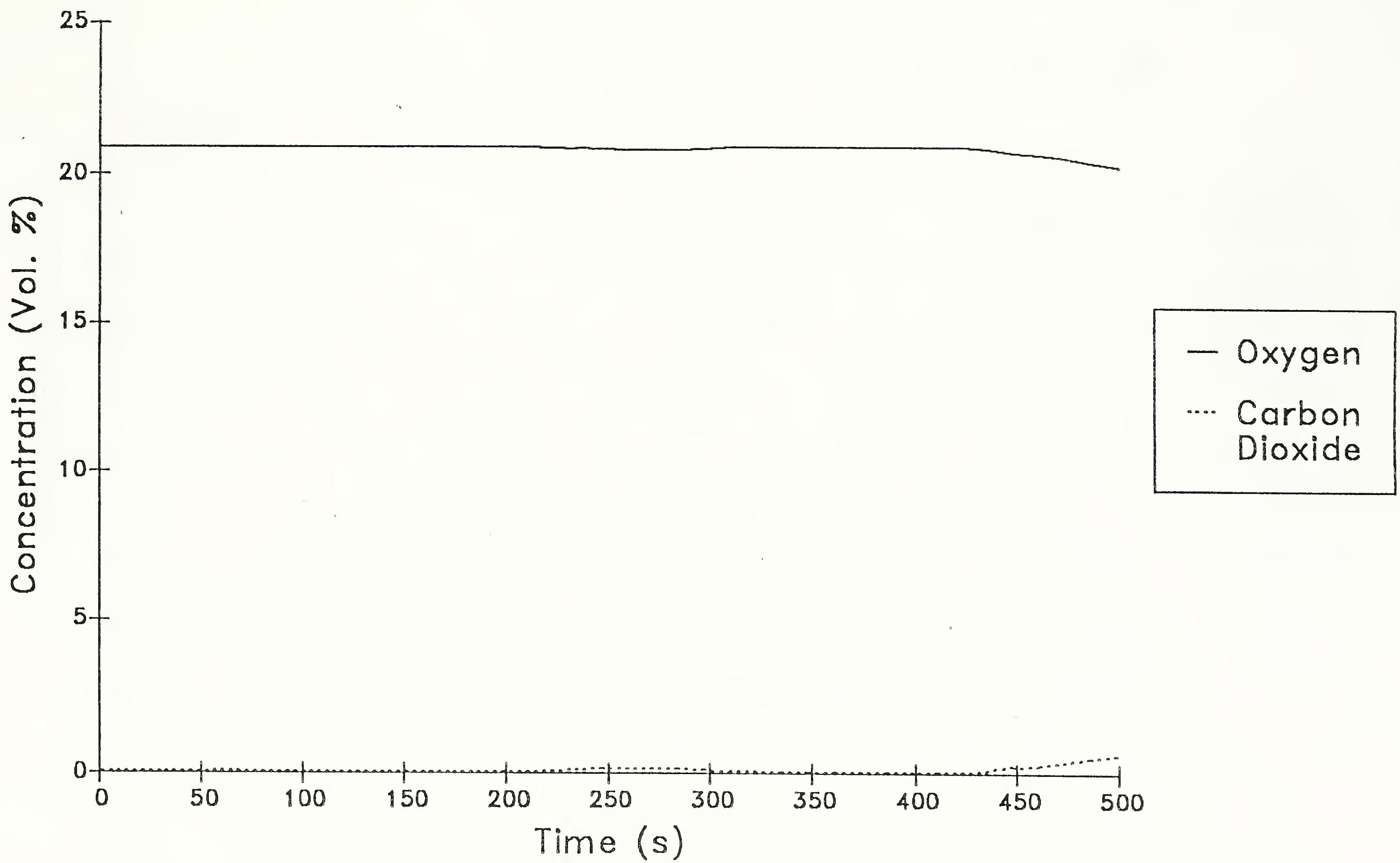

Figure 20. Gas Concentrations in the Target Room for Accordian Door Test

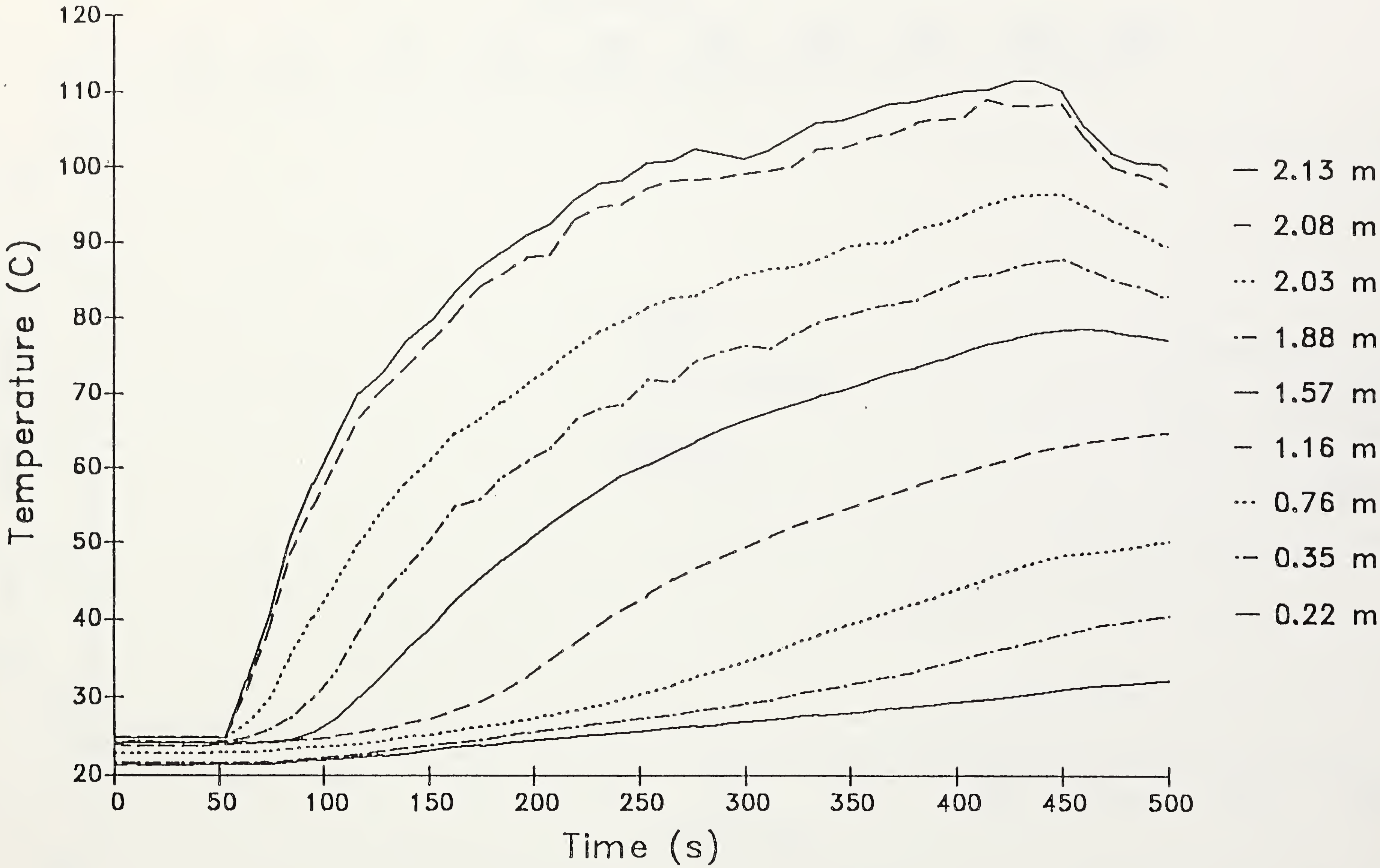

Figure 21. Gas Temperatures in the Target Room for Typical Door Test

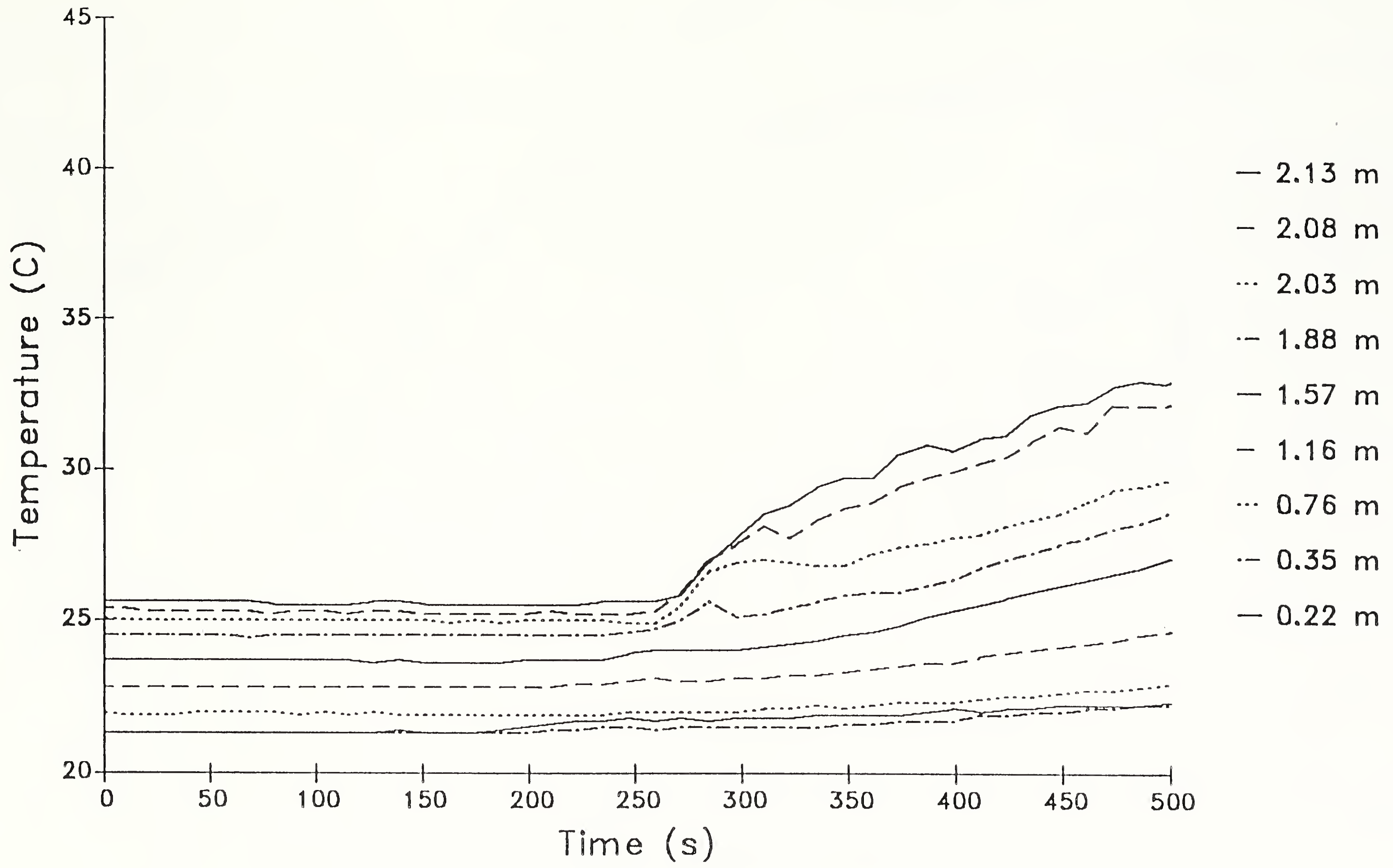

Figure 22. Gas Temperatures in the Target Room for Accordion Door Test

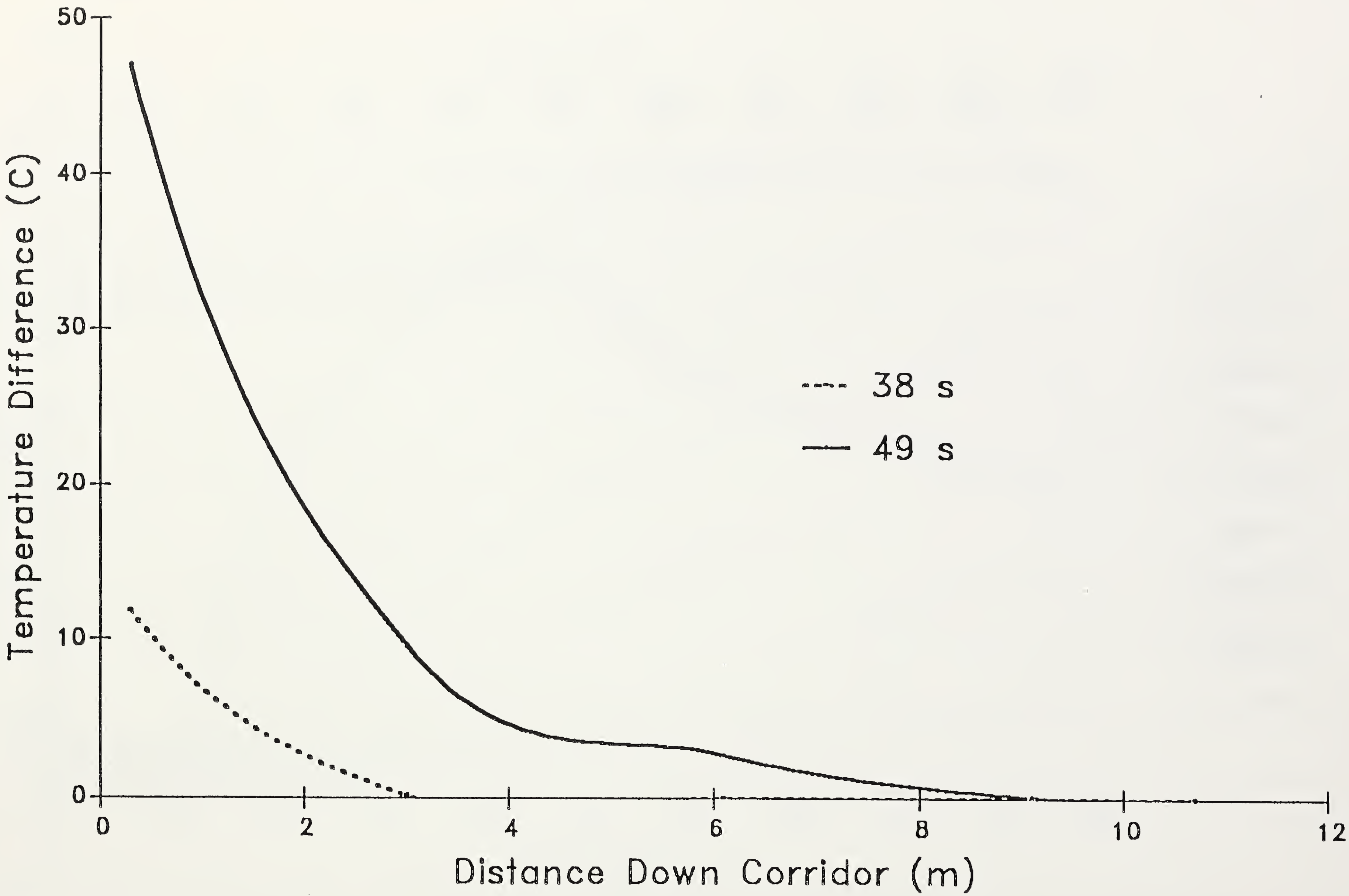

Figure 23. Gas Temperatures in Corridor 51 mm below ceiling at 38 s and 49 s after ignition

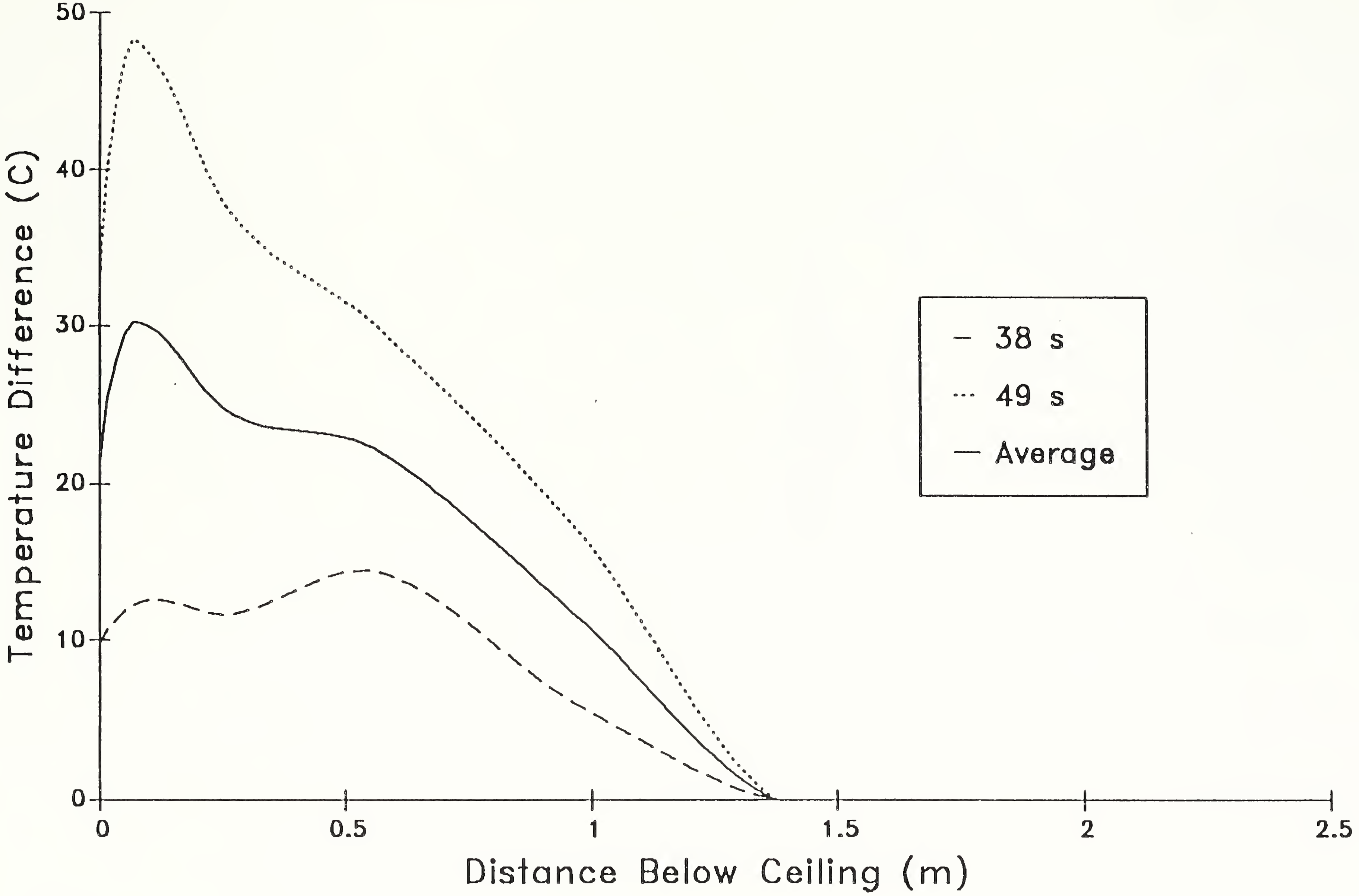

Figure 24. Vertical Temperature Profile in Corridor averaged over the interval between 38 s and 49 s . . . . .

APPENDIX A

TEMPERATURE GRAPHS

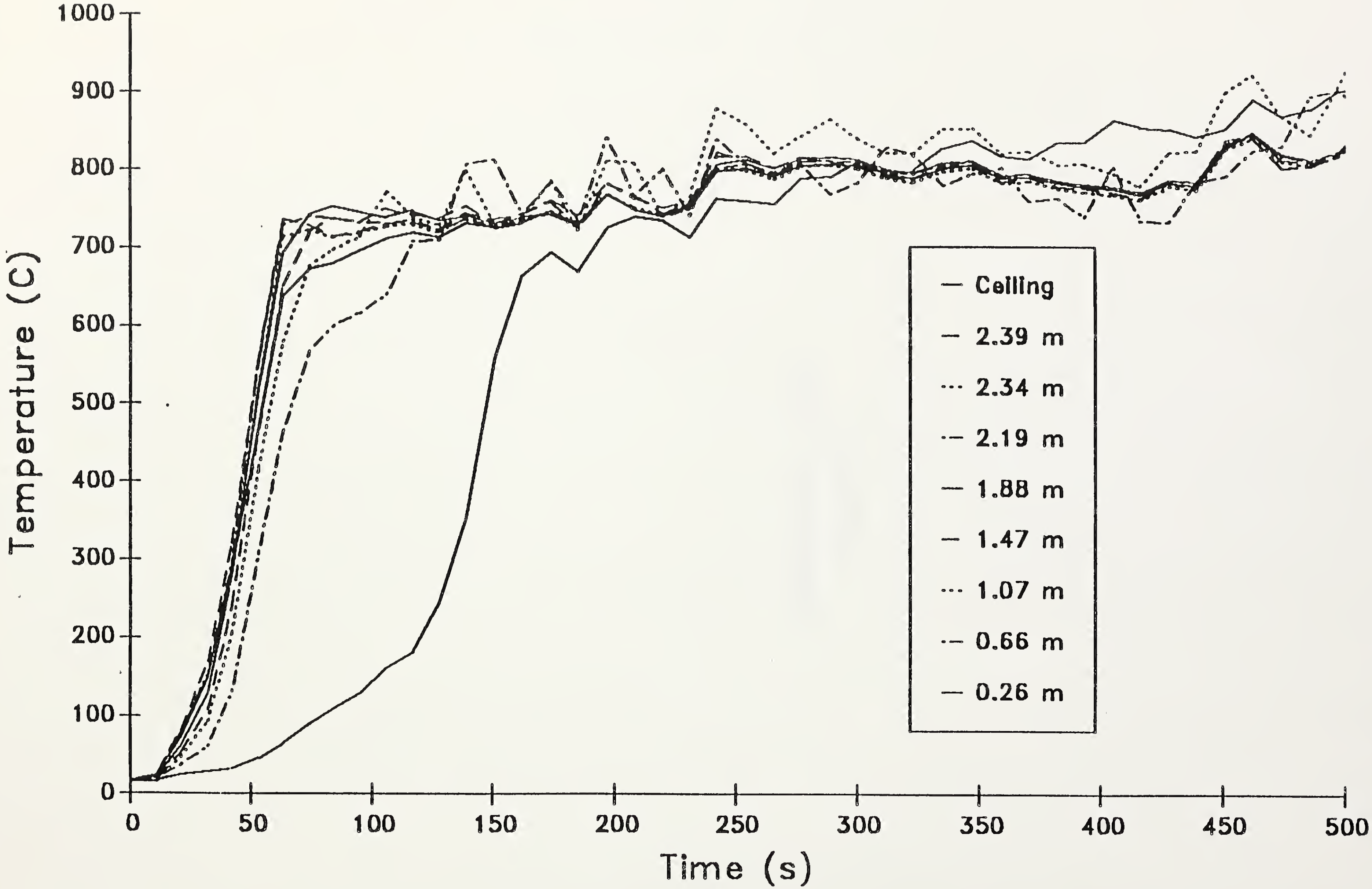

Figure A-1. Typical Door Test - Gas Temperatures in Burn Room

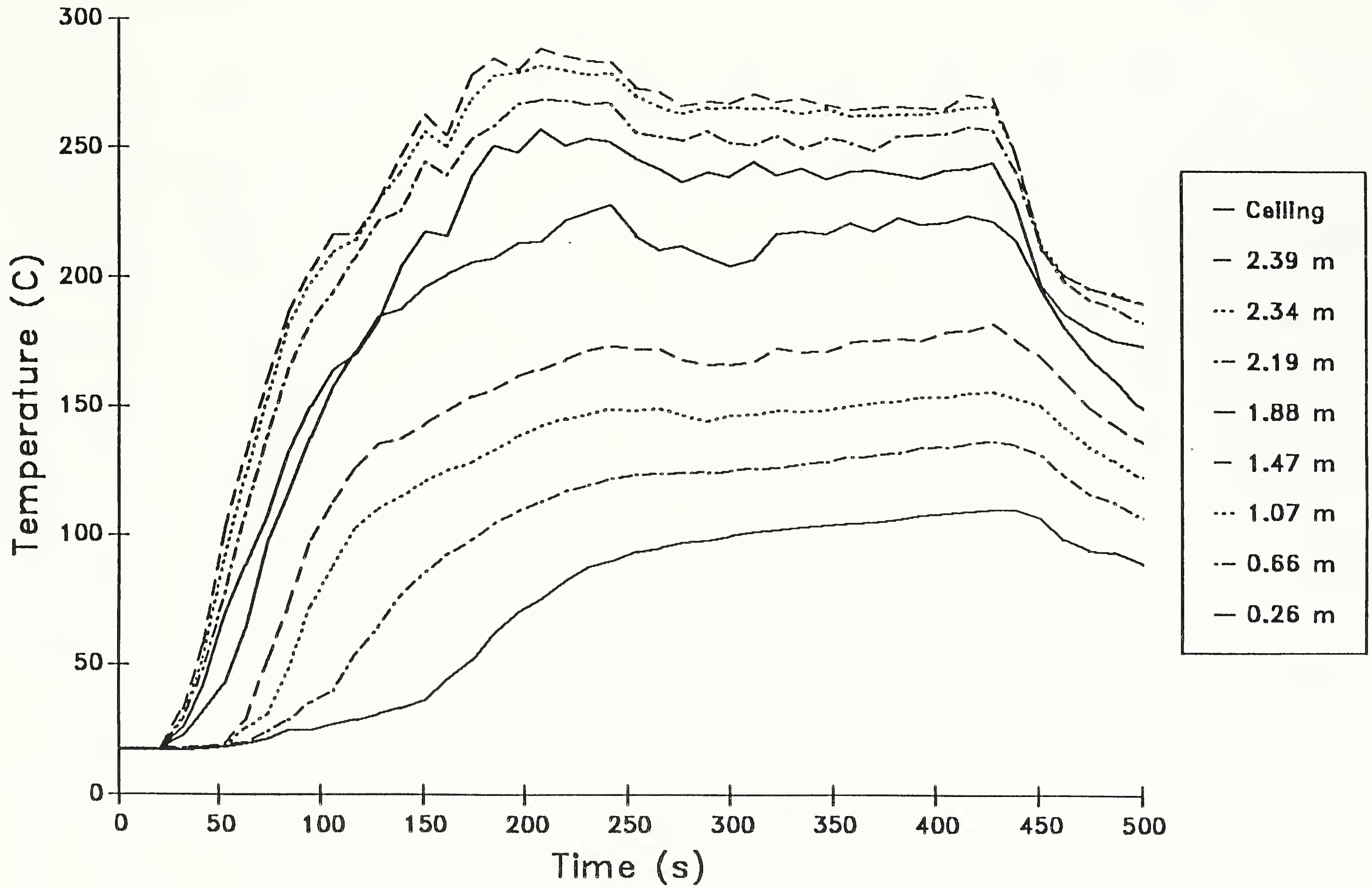

Figure A-2. Typical Door Test - Gas Temperatures in Corridor 3.05 m from Burn Room

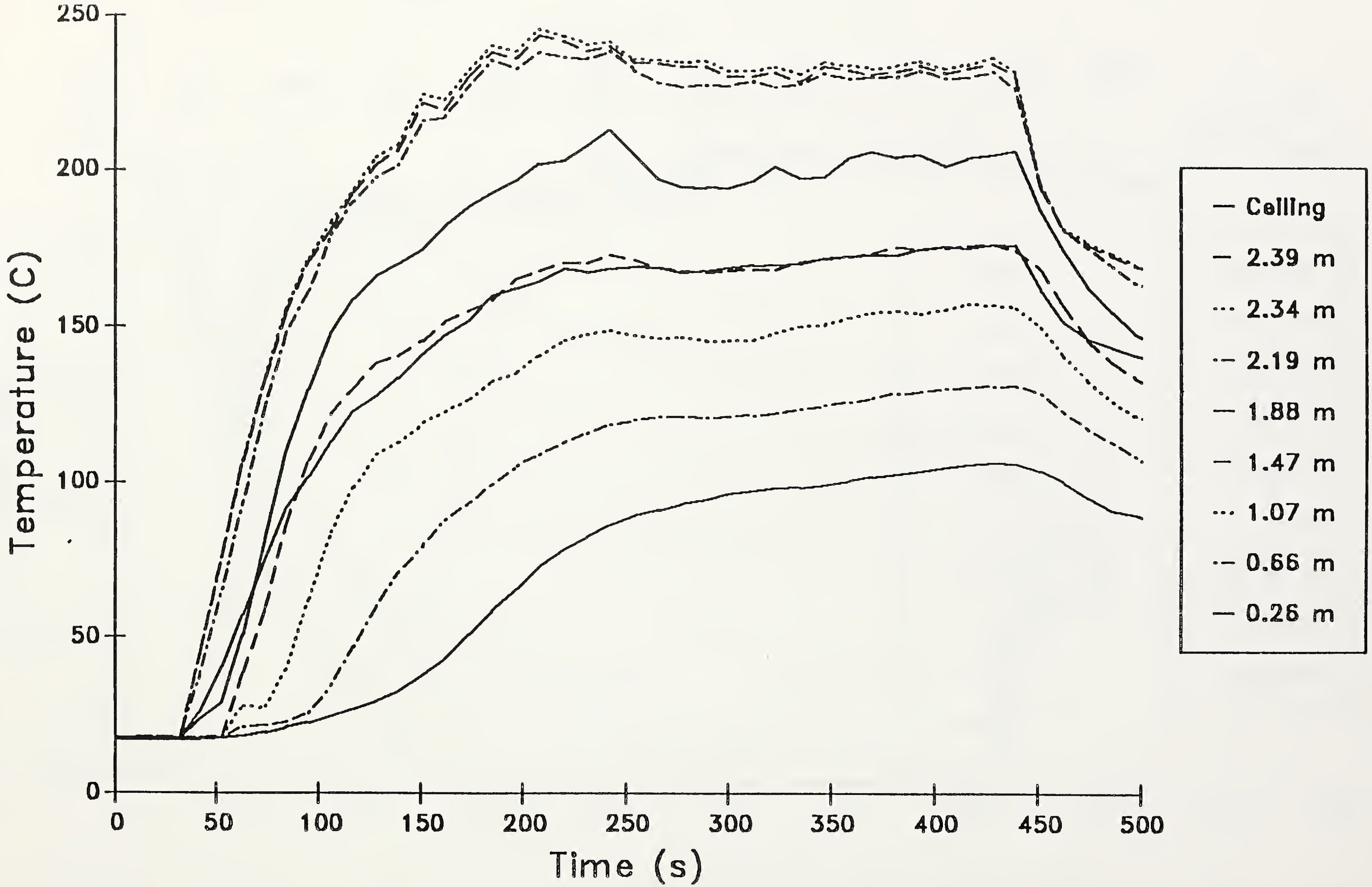

Figure A-3. Typical Door Test - Gas Temperatures in Corridor 6.1 m from Burn Room

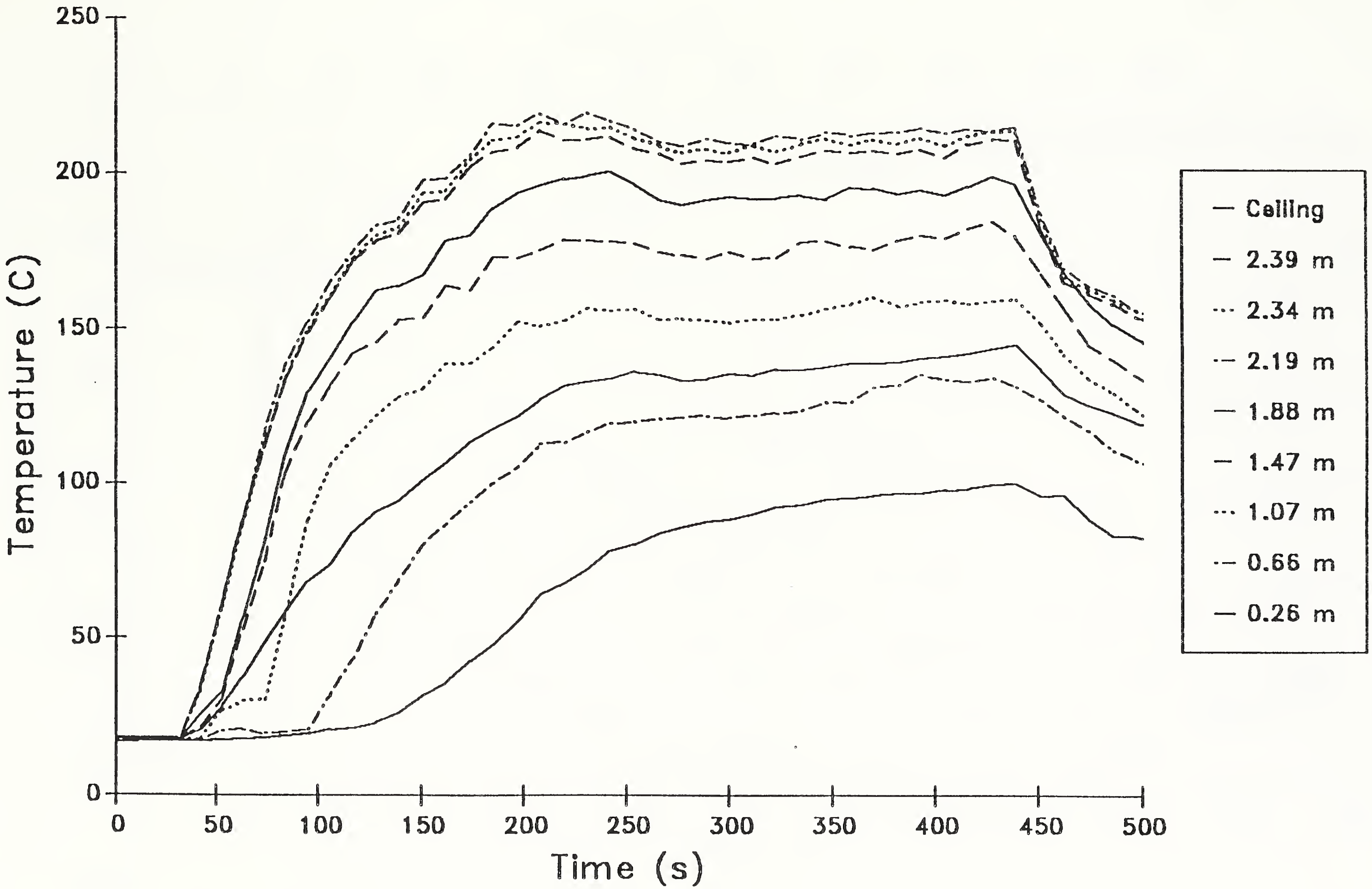

Figure A-4. Typical Door Test - Gas Temperatures in Corridor 9.15 m from Burn Room

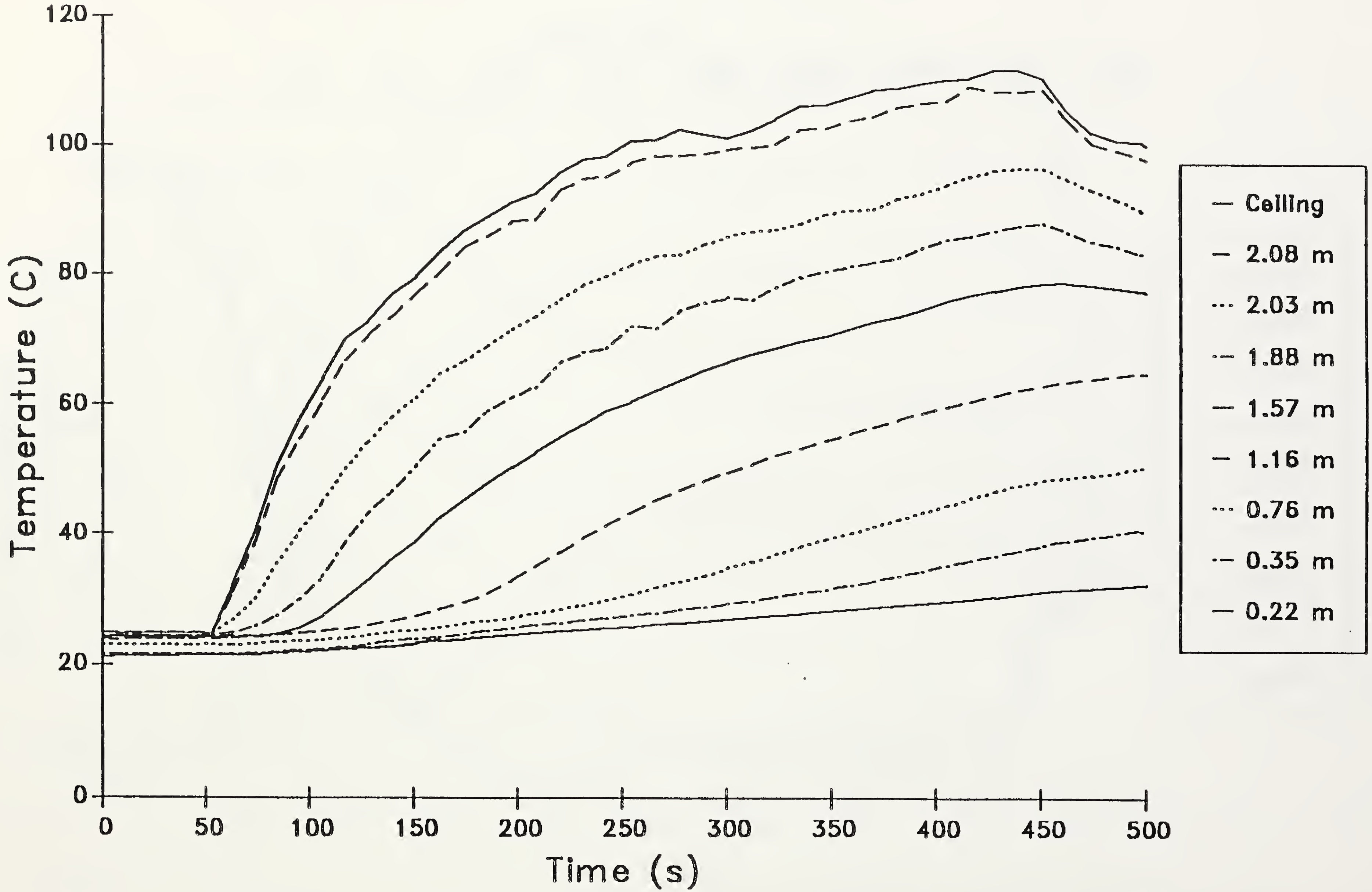

Figure A-5. Typical Door Test - Gas Temperatures in Target Room

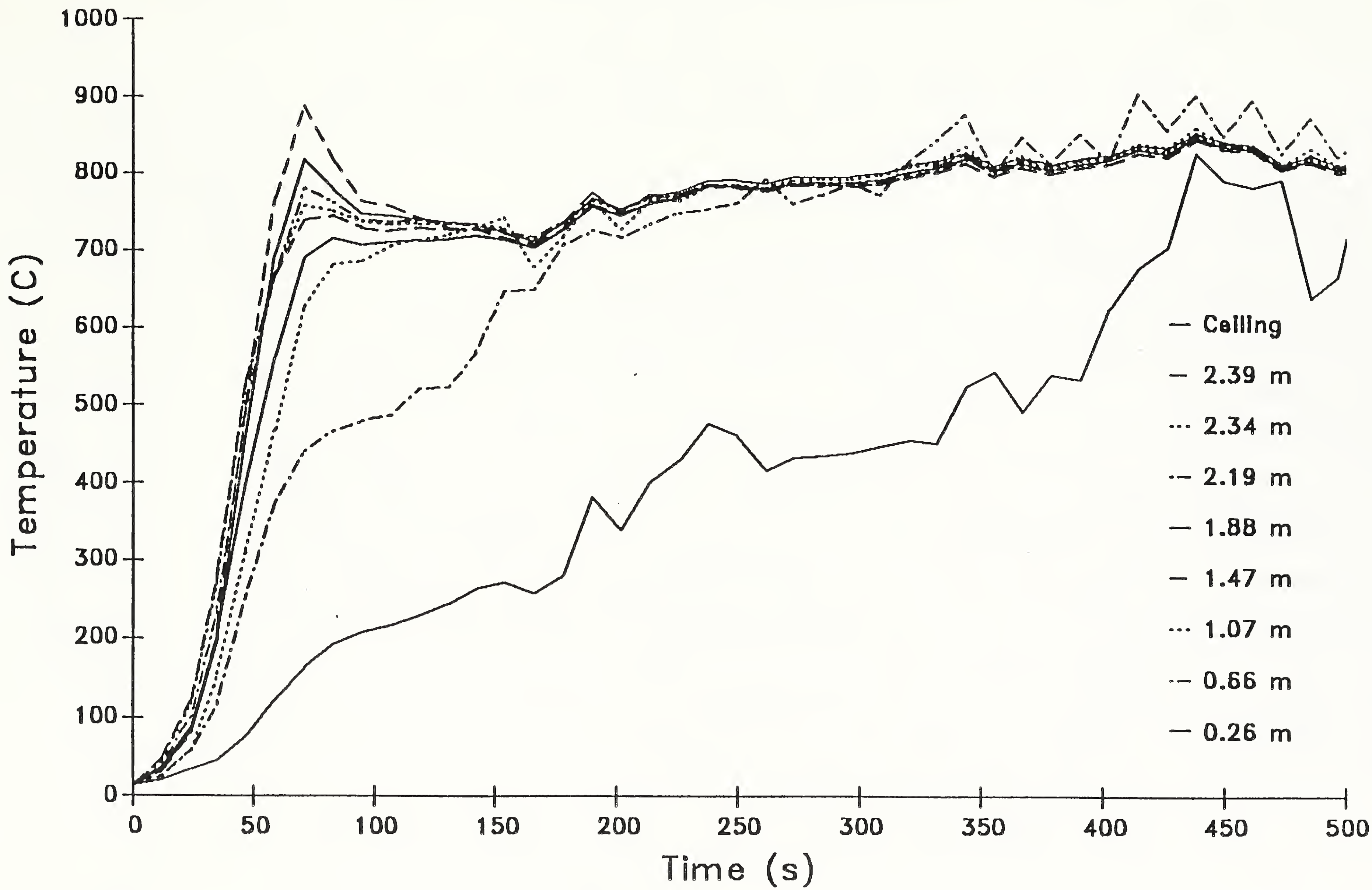

Figure A-6. Pressurized Room Test - Gas Temperatures in Burn Room

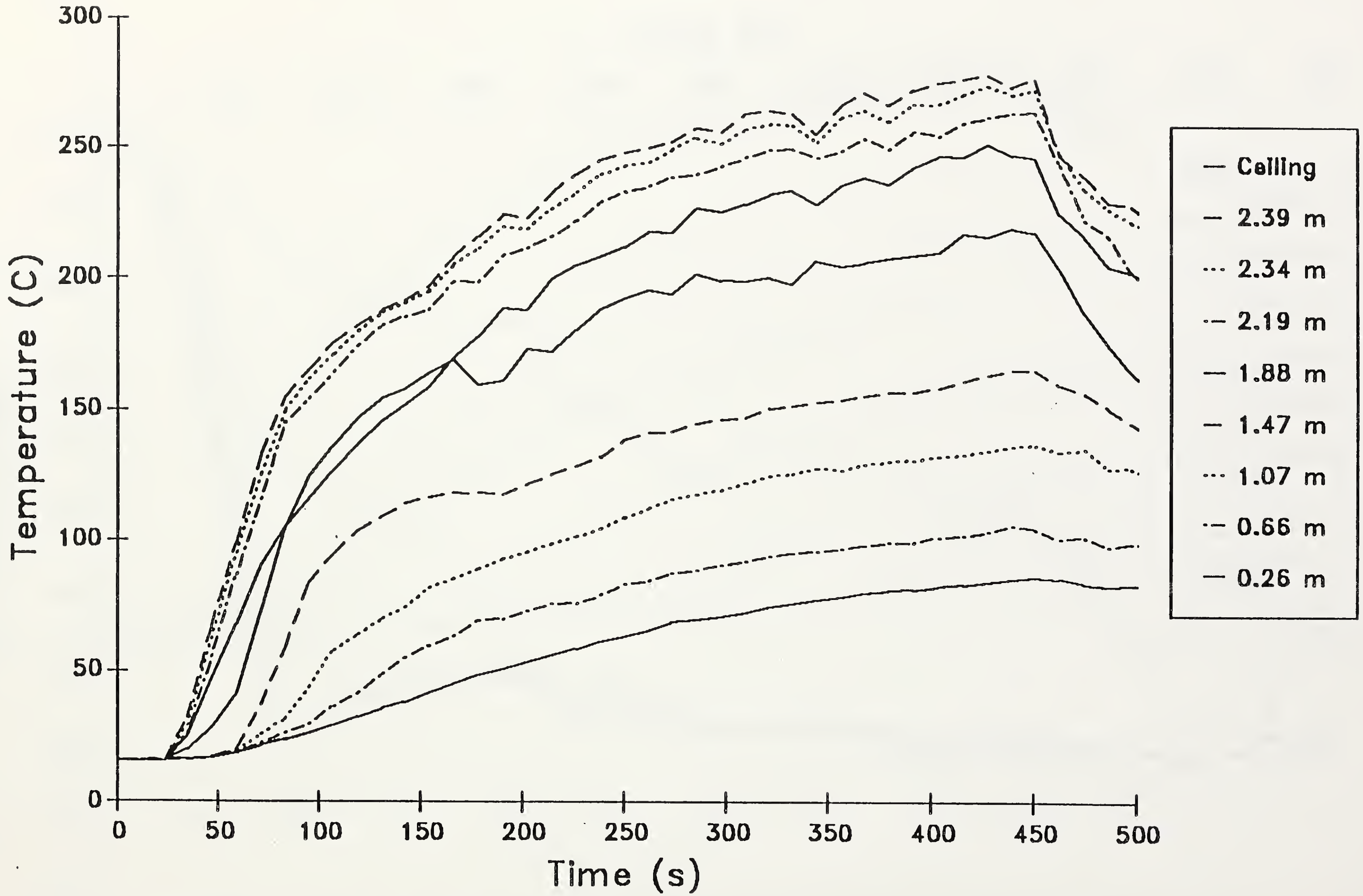

Figure A-7. Pressurized Room Test - Gas Temperatures in Corridor 3.05 m from Burn Room

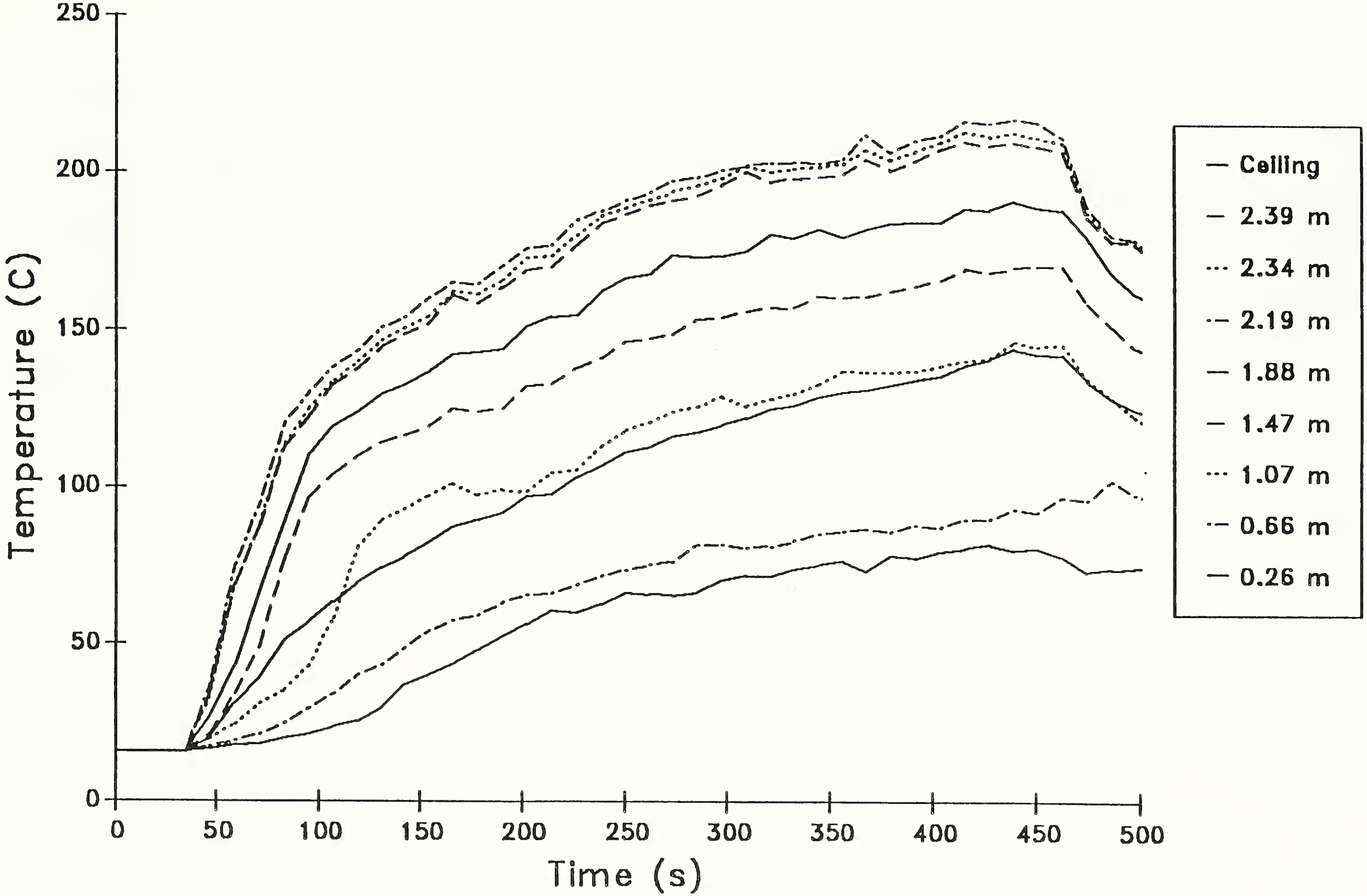

Figure A-8. Pressurized Room Test - Gas Temperatures in Corridor 6.1 m from Burn Room

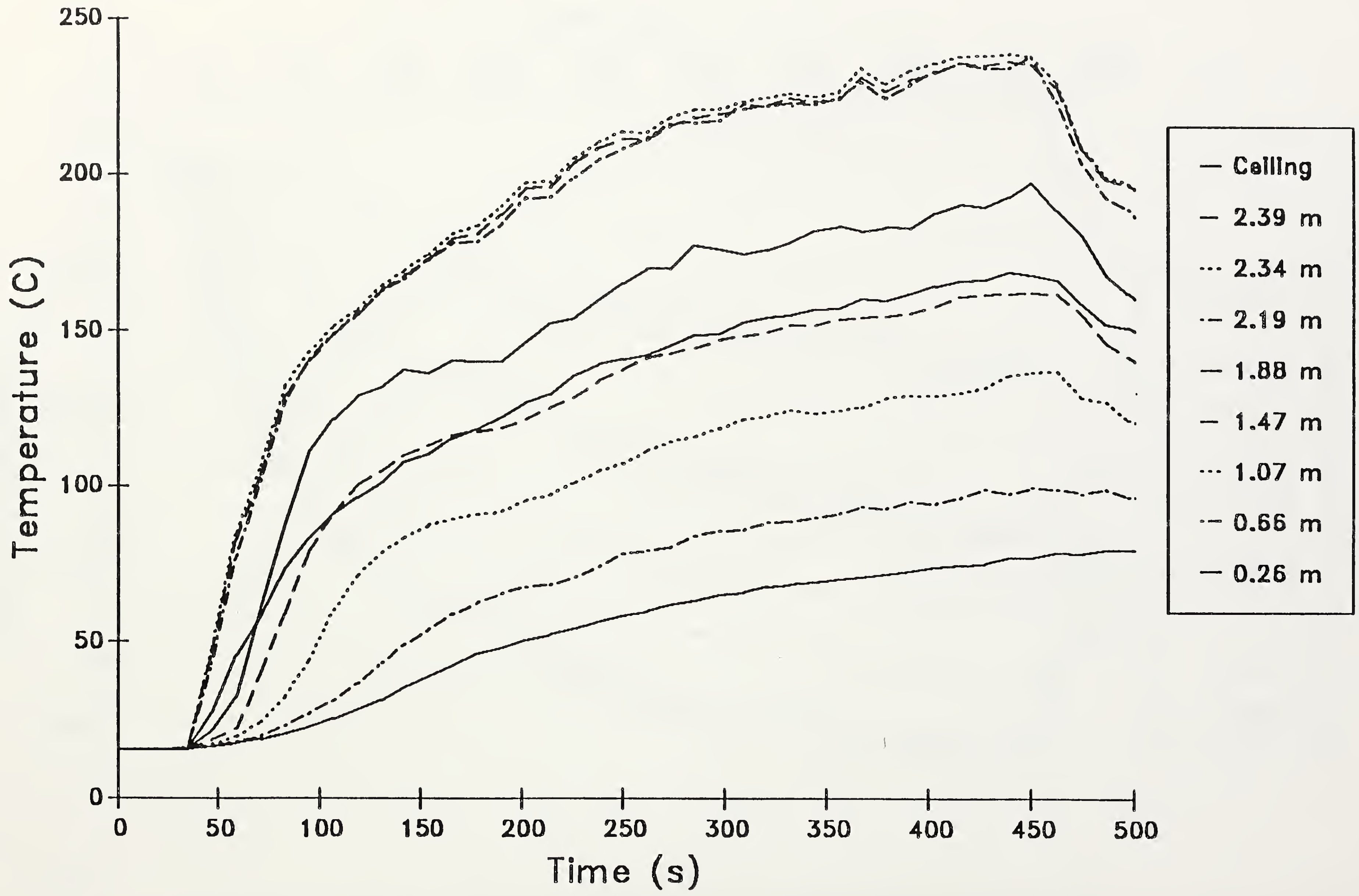

Figure A-9. Pressurized Room Test - Gas Temperatures in Corridor 9.15 m from Burn Room

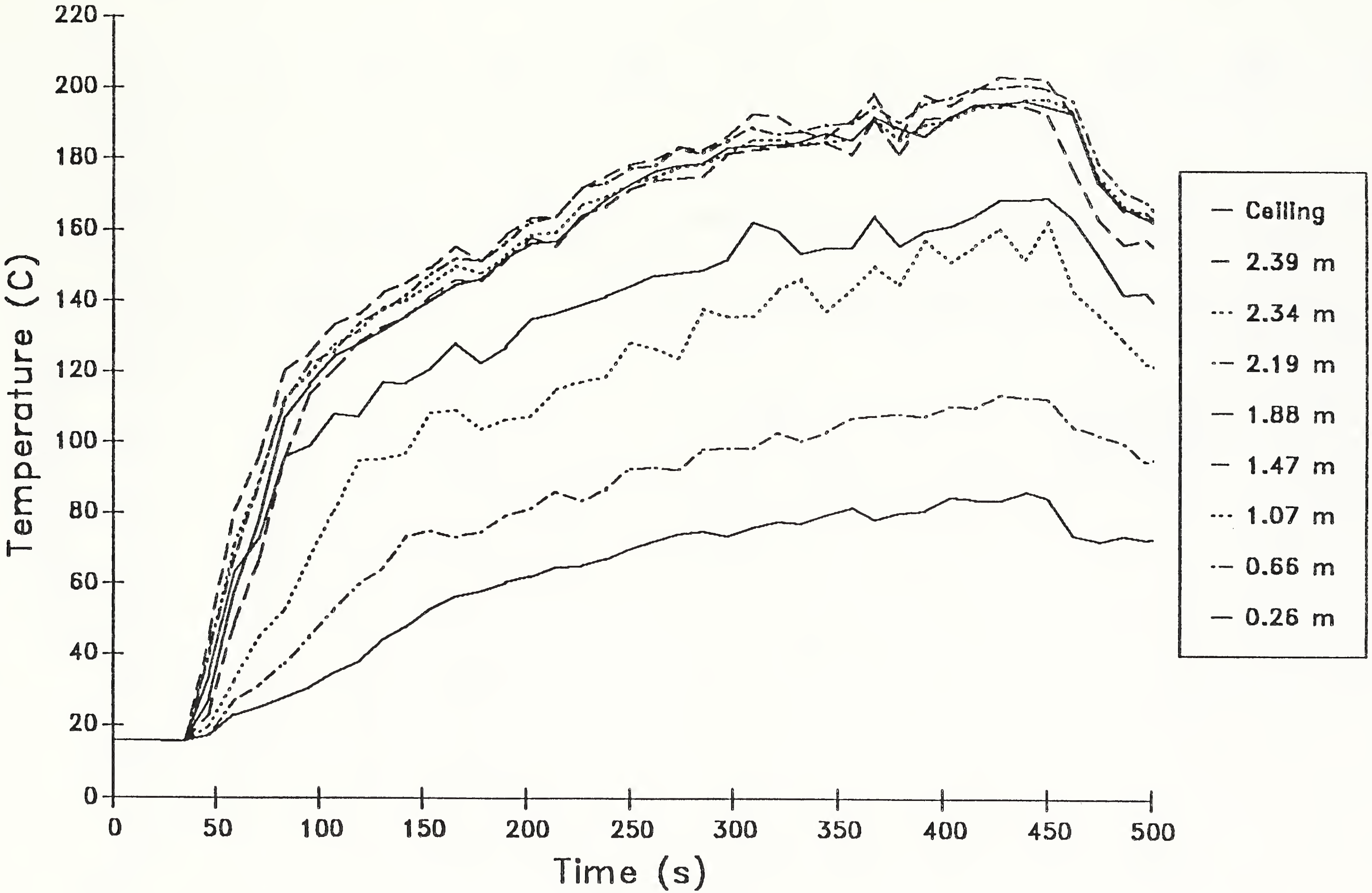

Figure A-10. Pressurized Door Test - Gas Temperatures in Corridor adjacent to Target Room Door

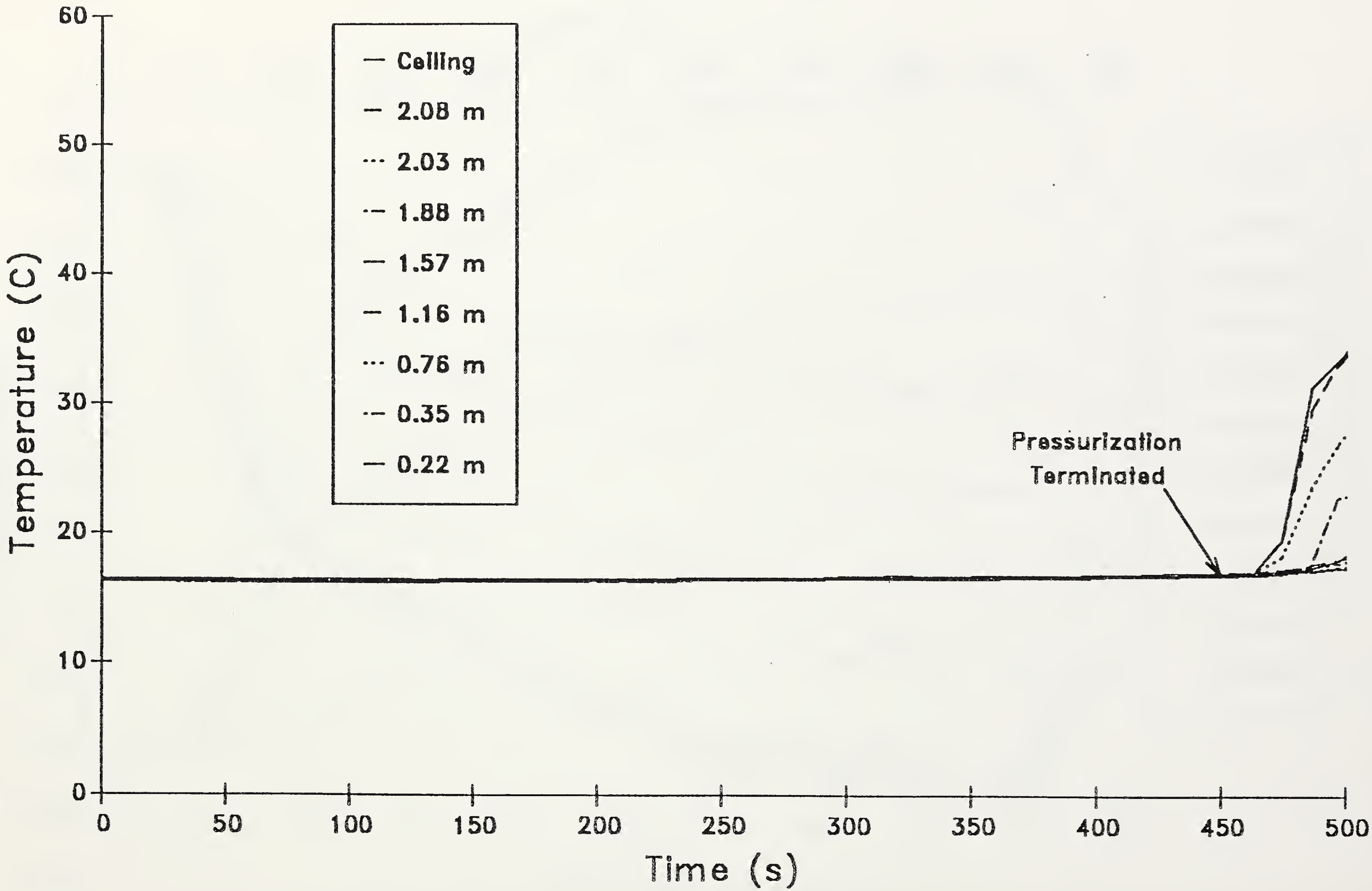

Figure A-11. Pressurized Room Test - Gas Temperatures in Target Room

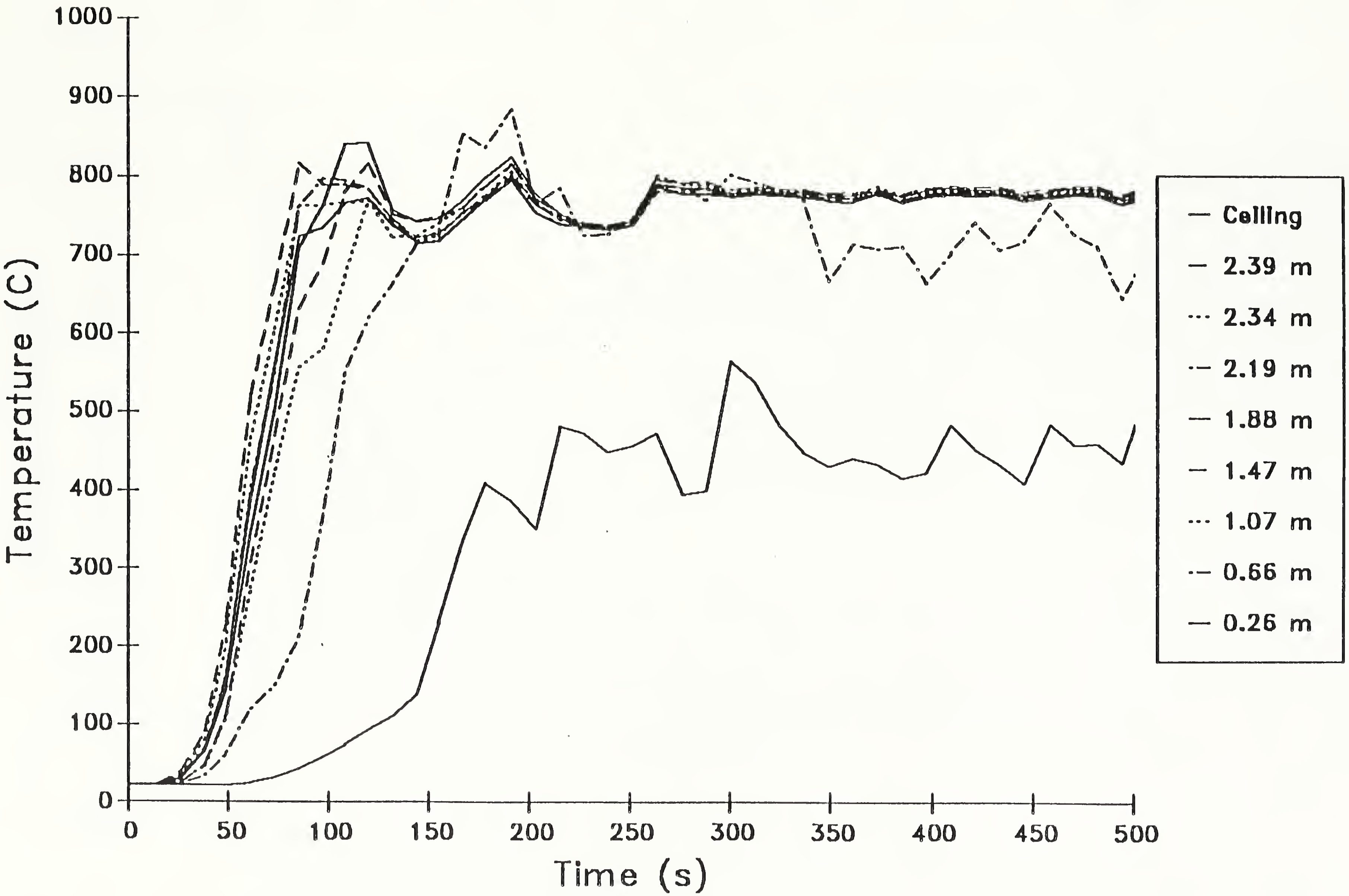

Figure A-12. Tight Door Test - Gas Temperatures in Burn Room

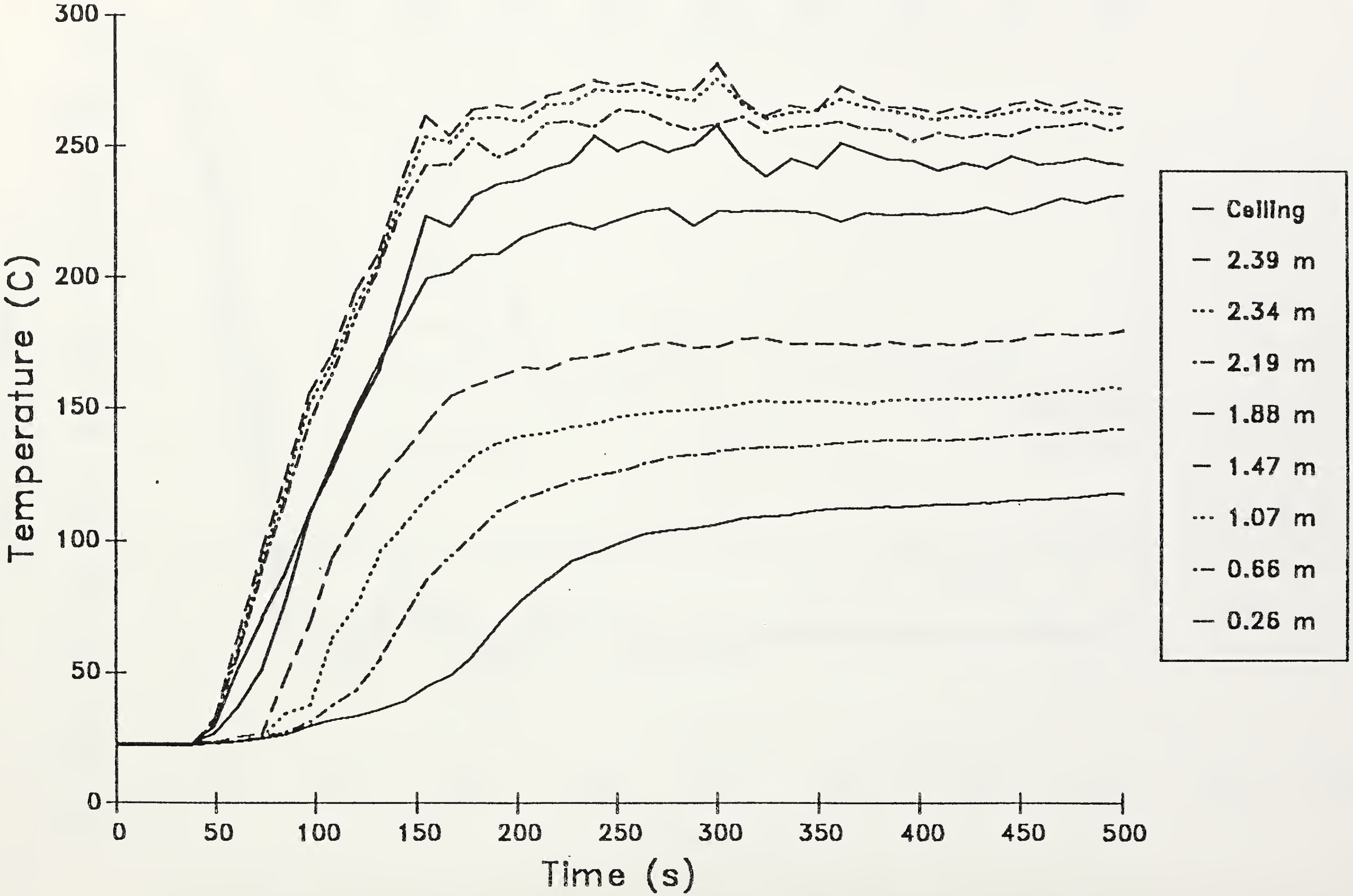

Figure A-13. Tight Door Test - Gas Temperatures in Corridor 3.05 m from Burn Room

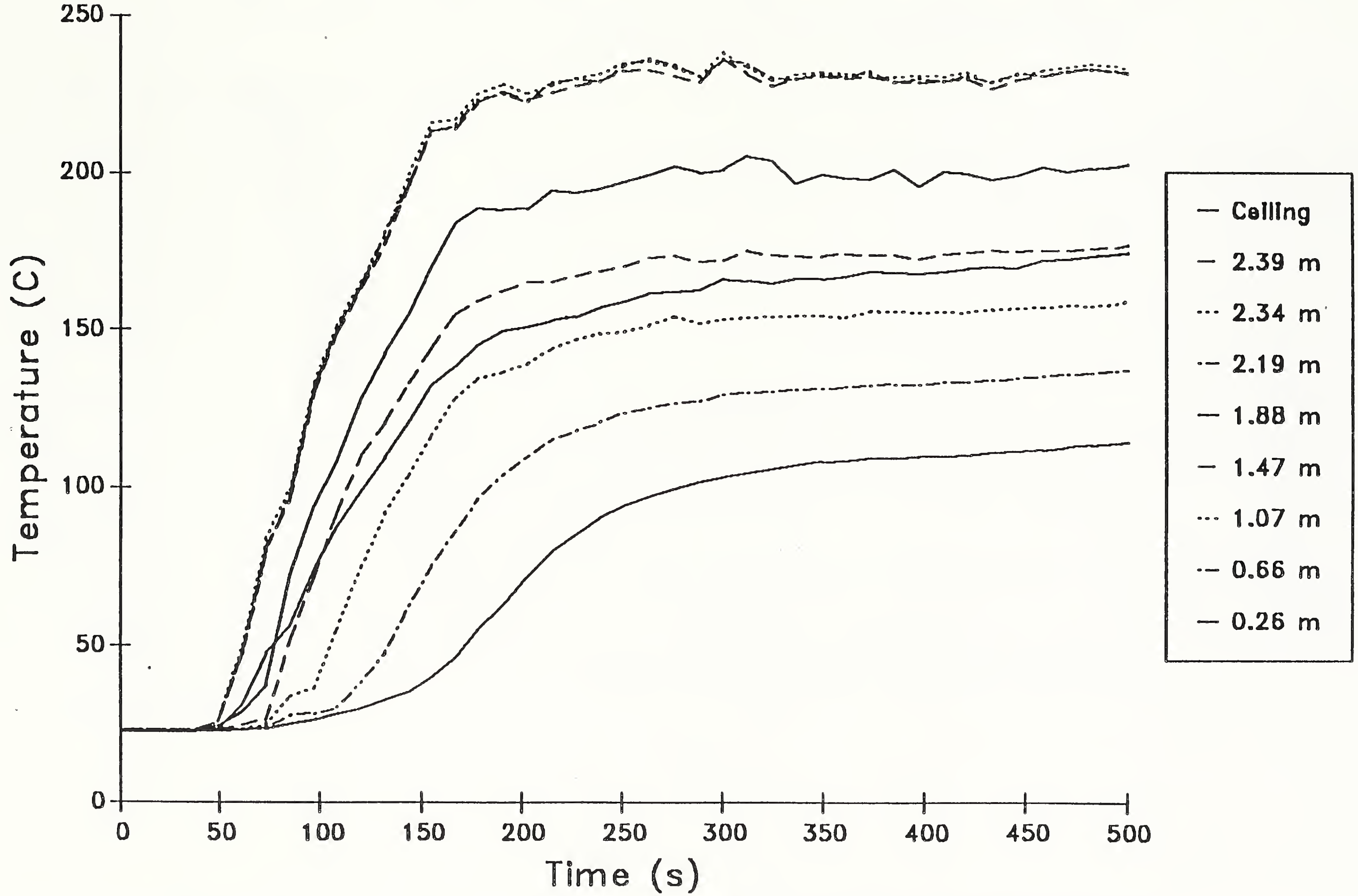

Figure A-14. Tight Door Test - Gas Temperatures in Corridor 6.1 m from Burn Room

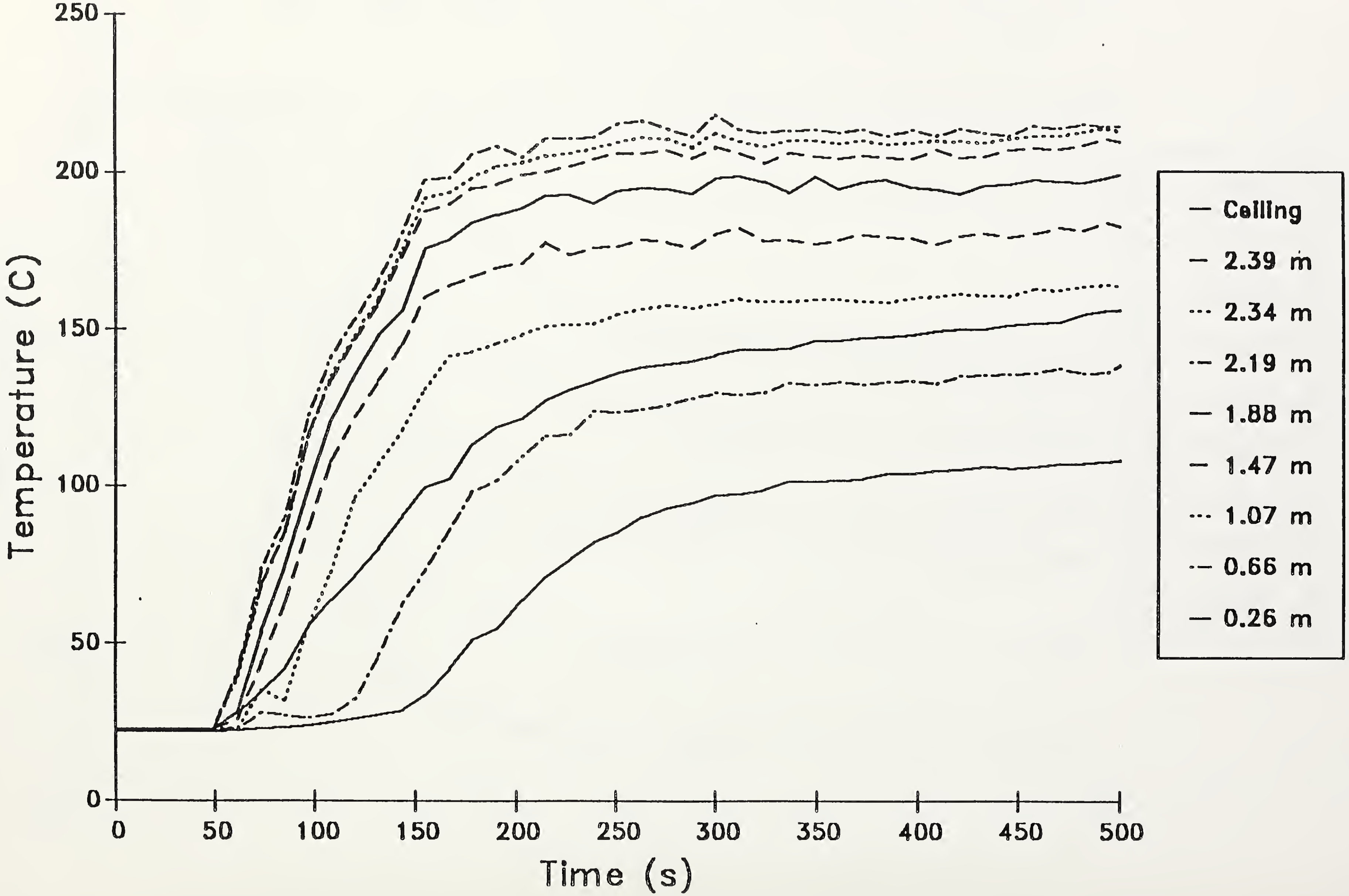

Figure A-15. Tight Door Test - Gas Temperatures in Corridor 9.15 m from Burn Room

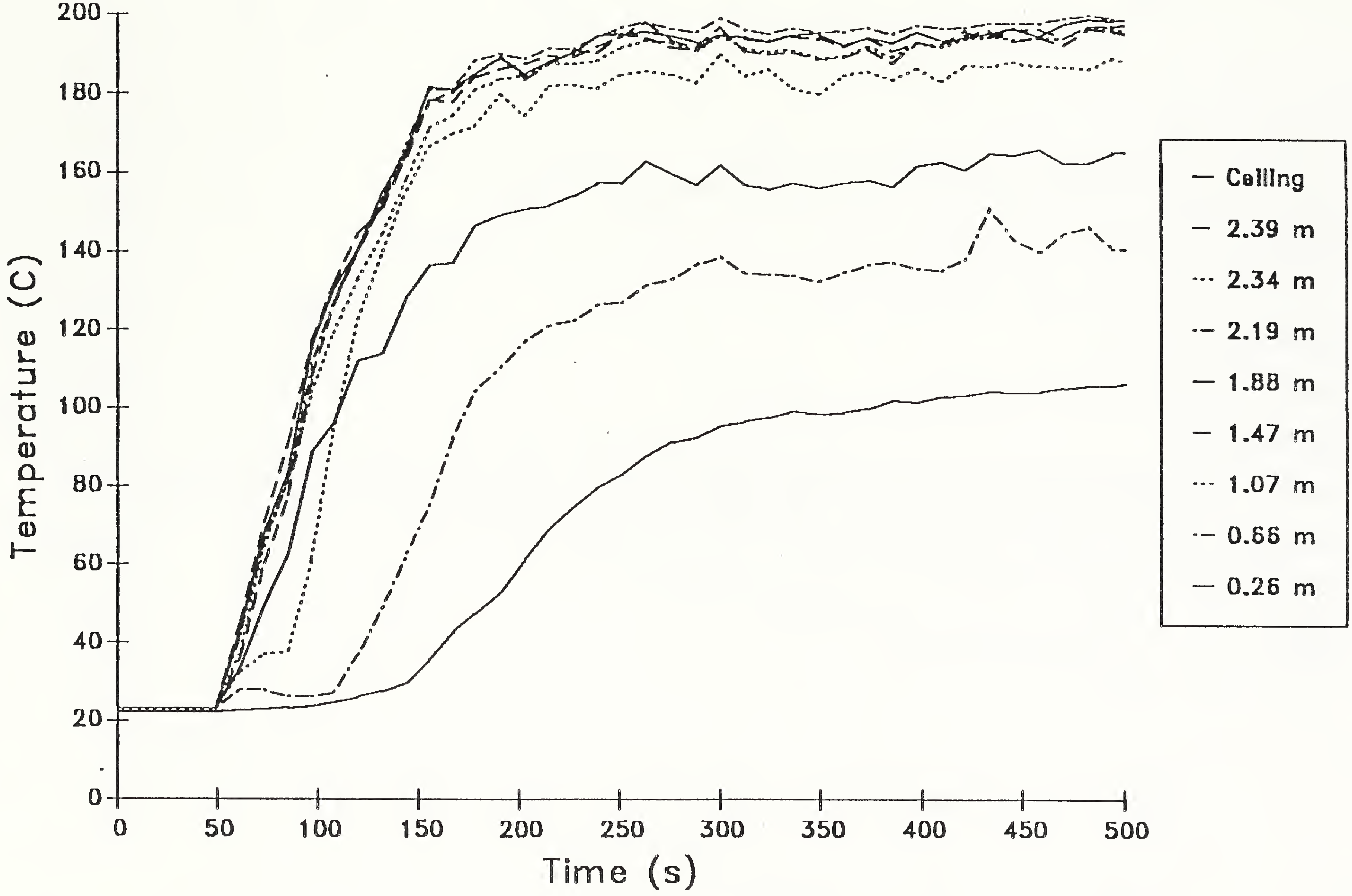

Figure A-16. Tight Door Test - Gas Temperatures in Corridor adjacent to Target Room Door

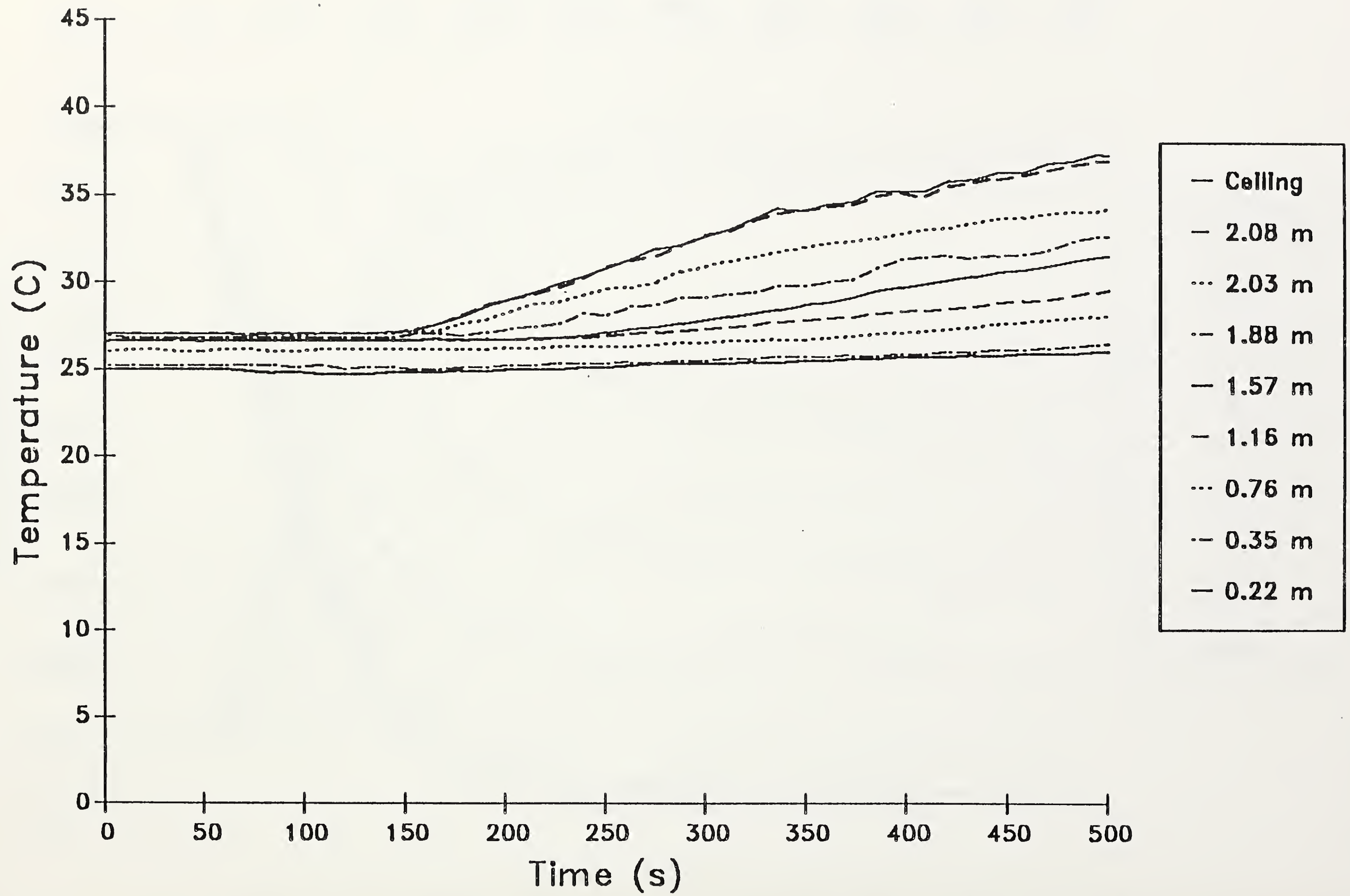

Figure A-17. Tight Door Test - Gas Temperatures in Target Room

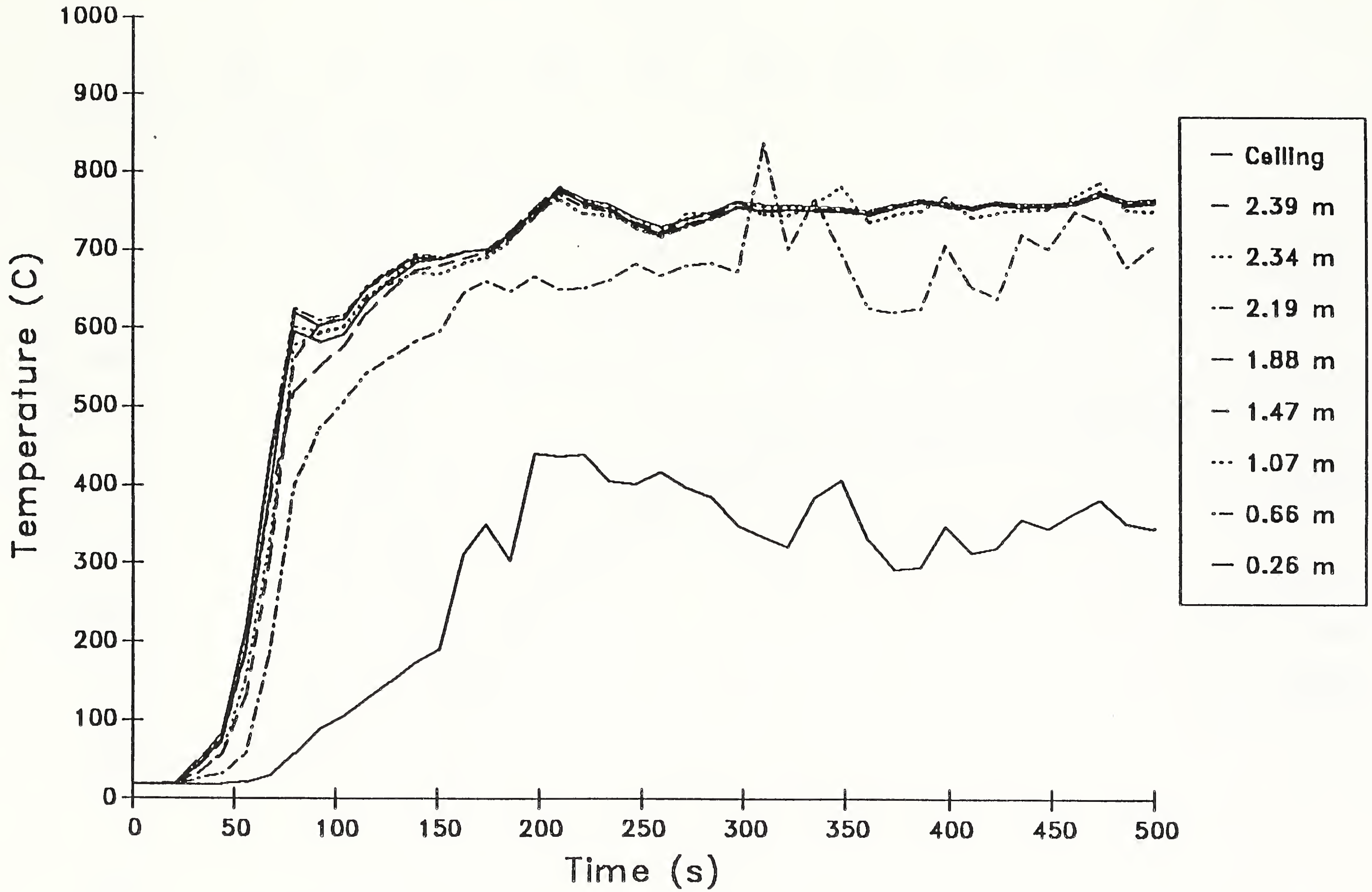

Figure A-18. Accordion Door Test - Gas Temperatures in Burn Room

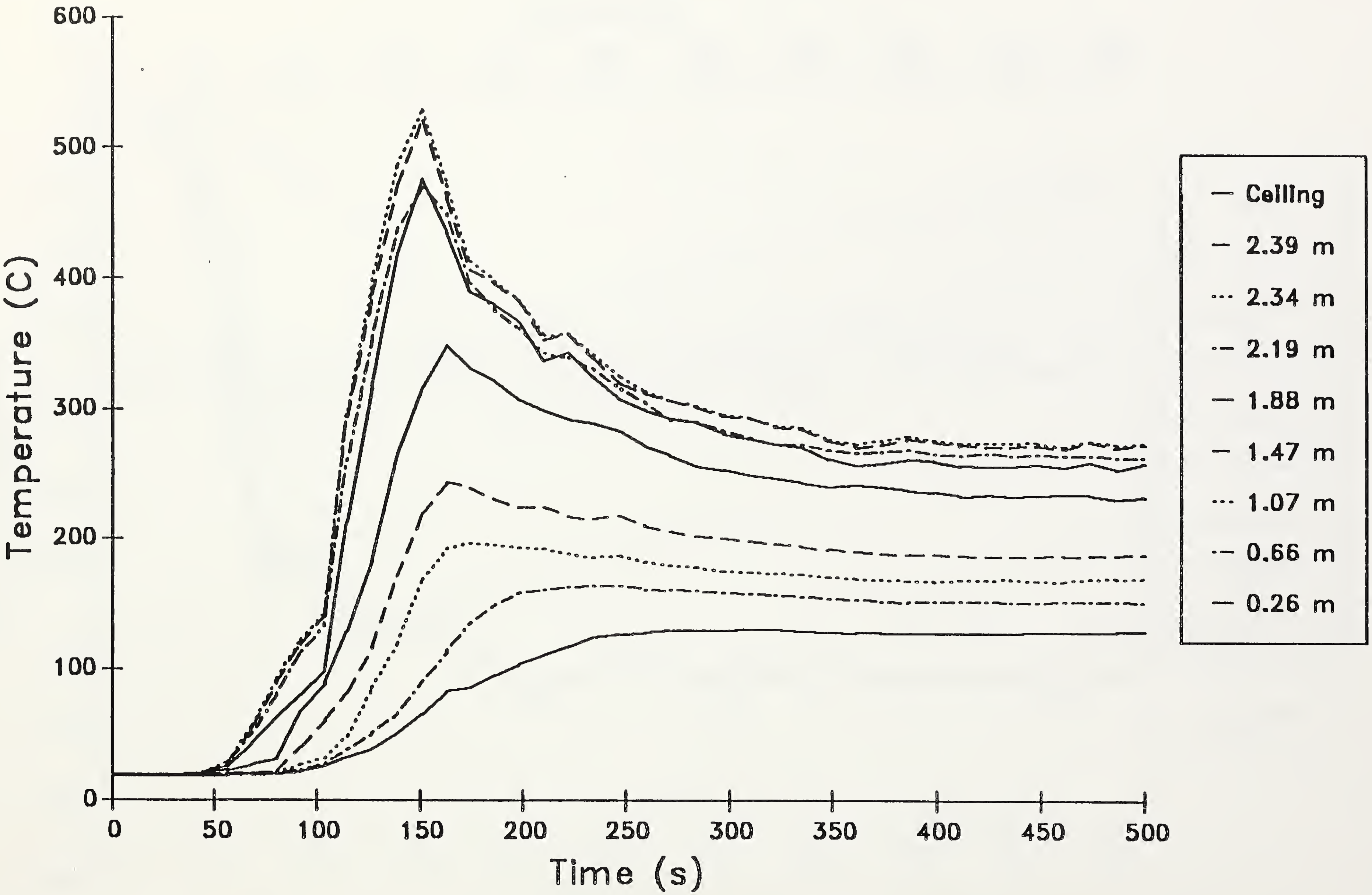

Figure A-19. Accordion Door Test - Gas Temperatures in Corridor 3.05 m from Burn Room

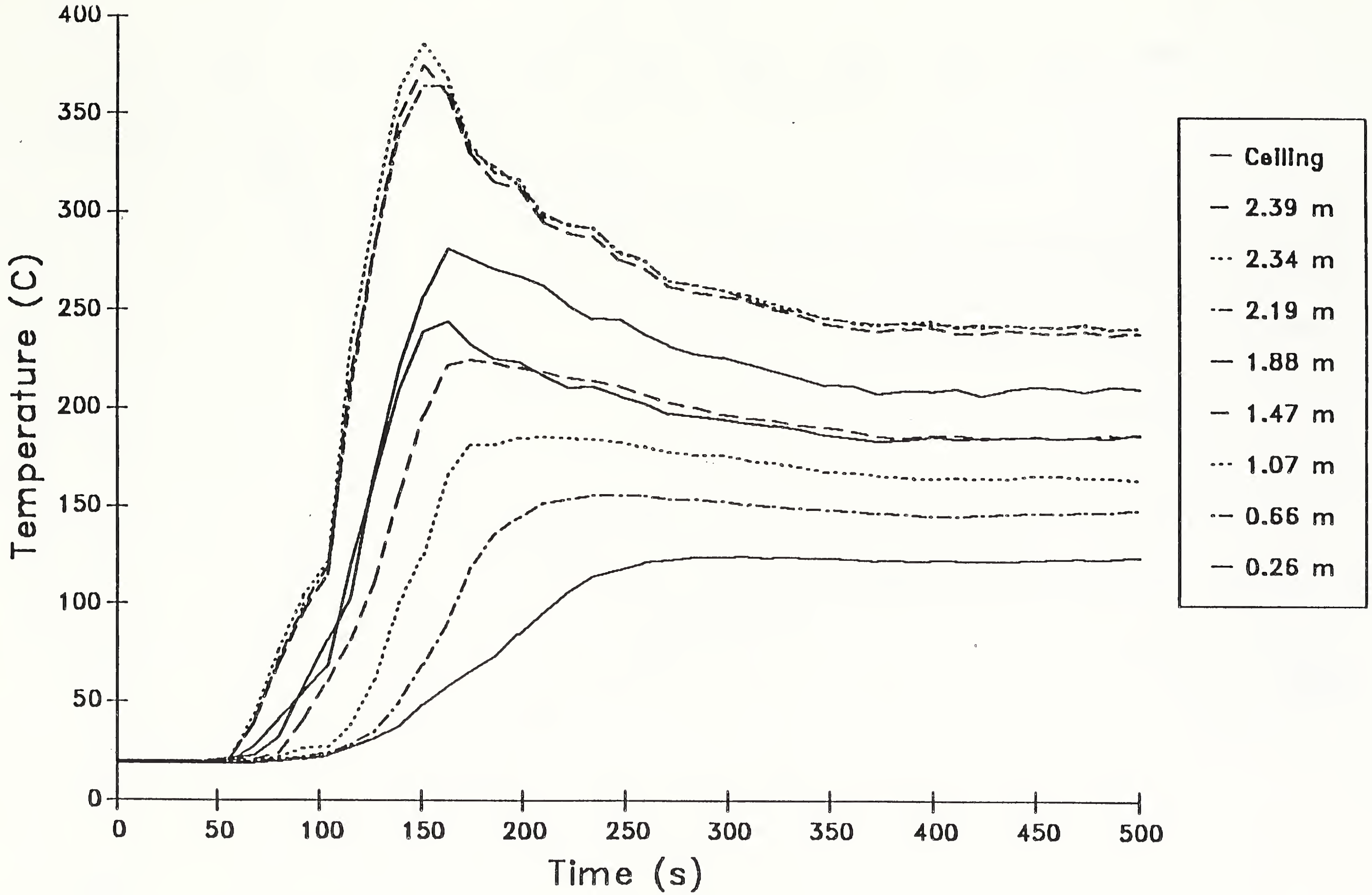

Figure A-20. Accordion Door Test - Gas Temperatures in Corridor 6.1 m from Burn Room

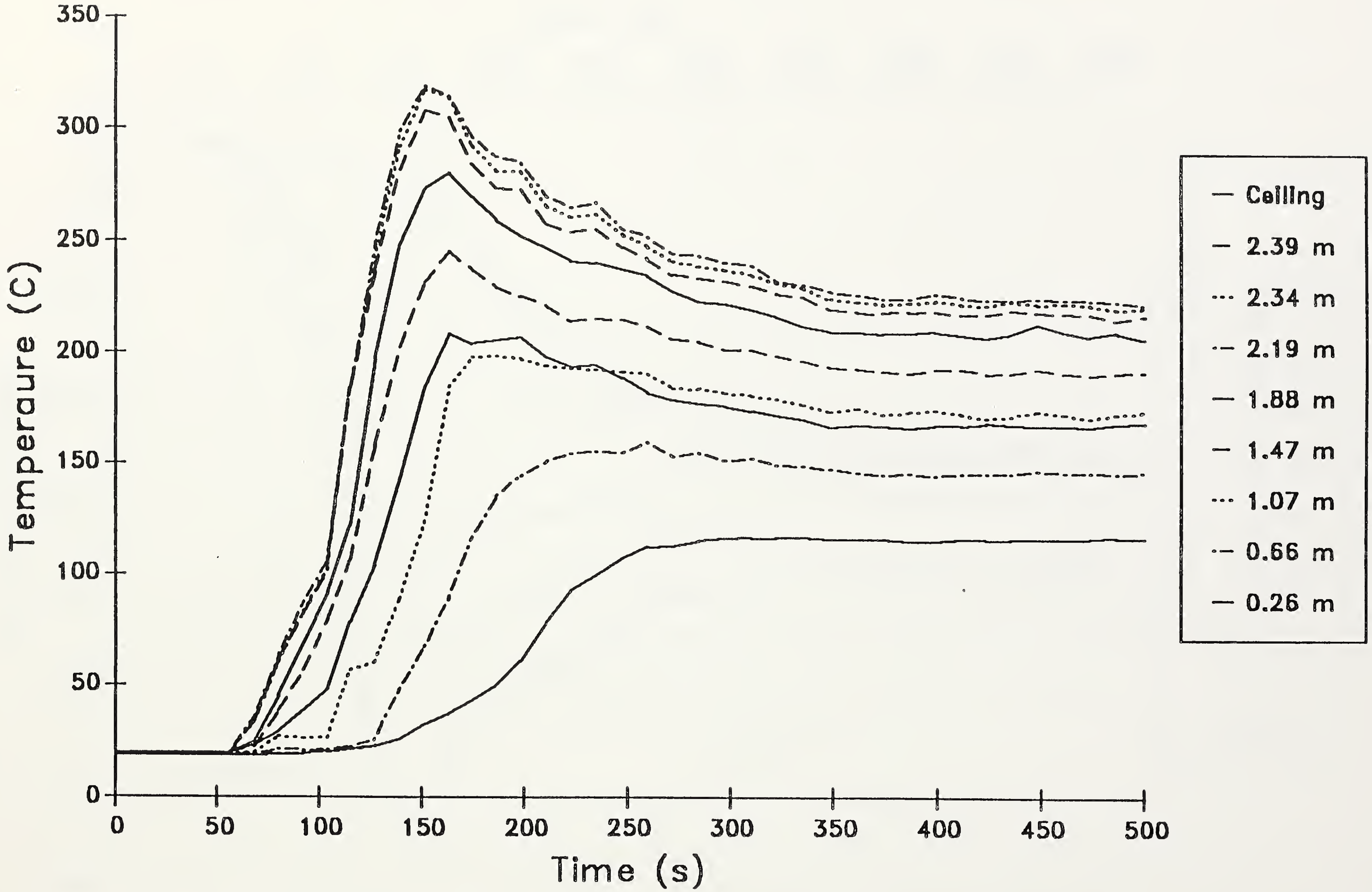

Figure A-21. Accordion Door Test - Gas Temperatures in Corridor 9.15 m from Burn Room

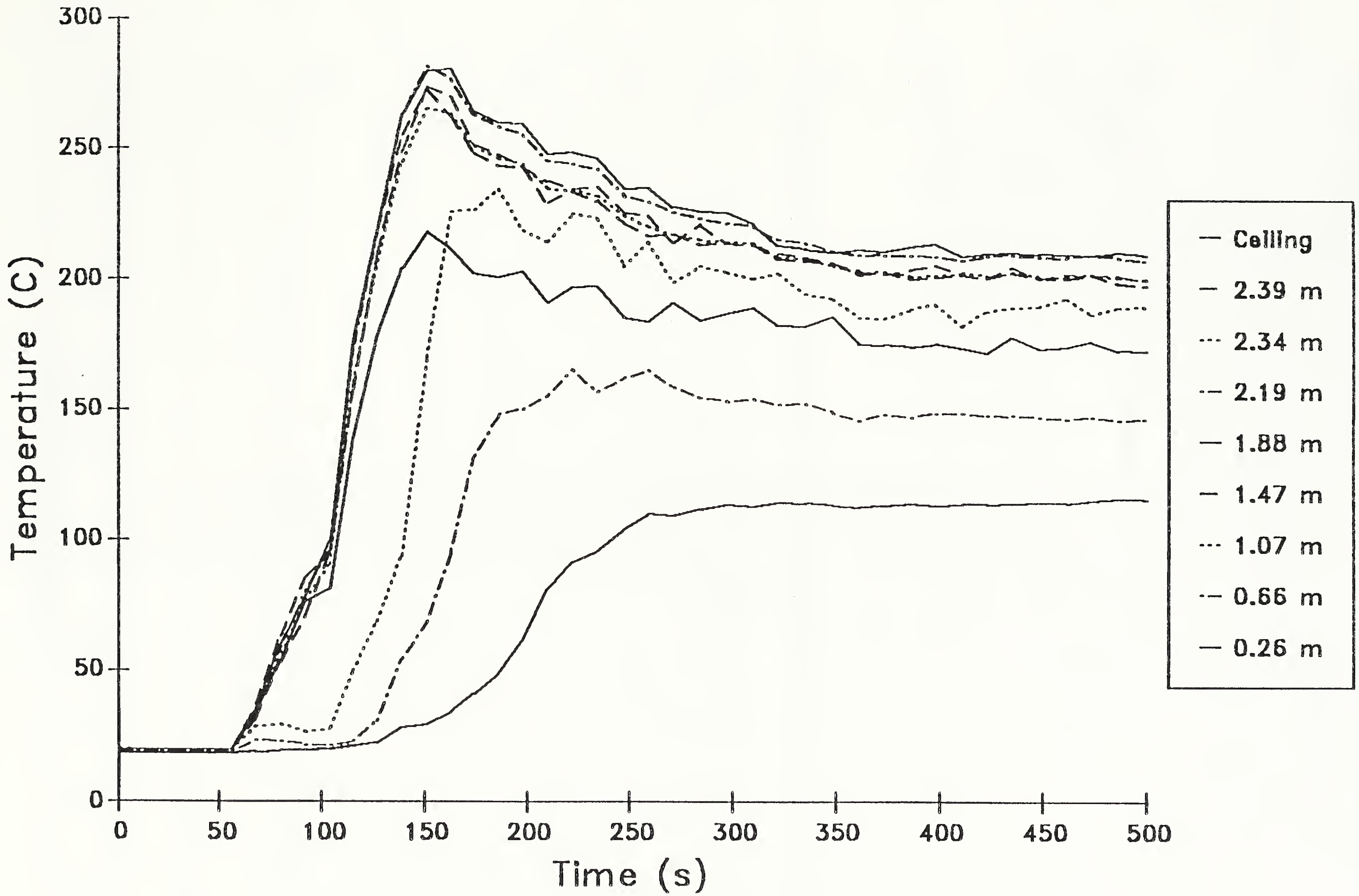

Figure A-22. Accordion Door Test - Gas Temperatures in Corridor adjacent to Target Room Door

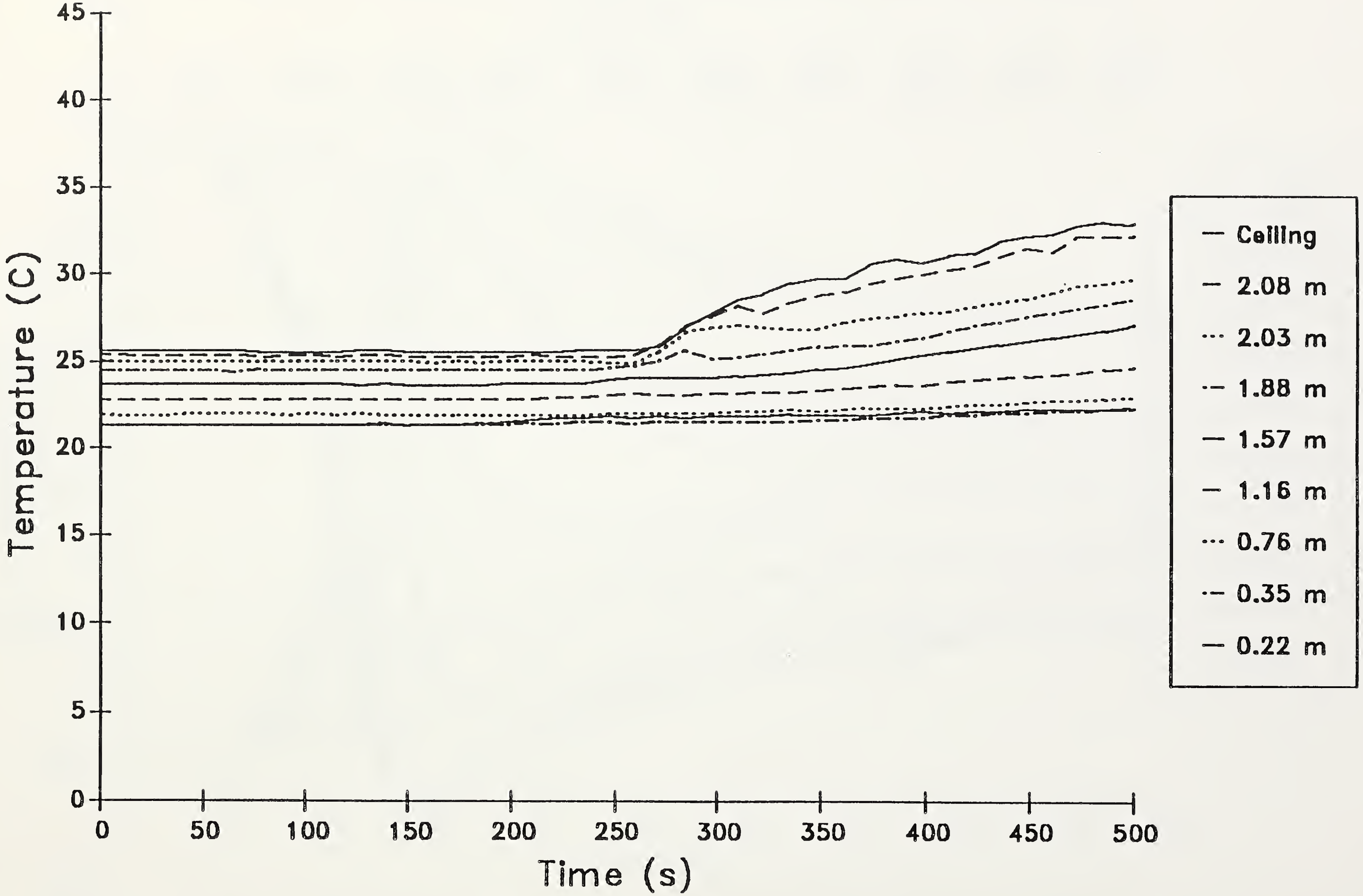

Figure A-23. Accordion Door Test - Gas Temperatures in Target Room

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David W. Stroup and Daniel Madrzykowski

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Office of Real Property Management and Safety
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10. SUPPLEMENTARY NOTES

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.)

This study was conducted for the General Services Administration. The study examined the effect of a post-flashover room fire on a corridor and attached target room. The burn room was a 2.44 m square with a 2.44 m high ceiling. The corridor was 12.8 m long, 2.44 m wide, and 2.44 m high. The target room was composed of two parts, a rectangular area, 2.6 m by 2.4 m and 2.2 m high, and an entry alcove, 0.8 m long, 1.1 m wide and 2.0 m high. Gas temperatures, wall surface temperatures and concentrations of oxygen, carbon dioxide, and carbon monoxide were measured at selected points in the burn room, corridor, and target room. Various methods of protecting the target room from the effects of the post-flashover room fire were also examined. The target room and its doorway were protected using a simulated "standard" door (with a top cut, a side cut, and an undercut), a reduced leakage door (undercut only), and a commercial accordion fire door. In addition, the target room with the "standard" door was tested using mechanical pressurization. Pressurization of the target room and reduction of the amount of door leakage, below that of a standard door, into the target room were effective methods of reducing temperature rise and the penetration of products of combustion into the target room. Measurements from the study were used to examine a recently proposed model for predicting the flow velocity of the initial gravity wave down the corridor. The measured and predicted values agreed within the limits of uncertainty for the data.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

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