NBSIR 79-1915

Investigation of the Effects of Heating and Air Conditioning on the Performance of Smoke Detectors in Mobile Homes

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October 1979

Prepared for:

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Abstract

Since its original promulgation in June 1976, the U.S. Department of Housing and Urban Development's Federal Mobile Home Construction and Safety Standard has required the installation of at least one smoke detector to protect the mobile home occupants. The location of the smoke detector was based on earlier tests in a mobile home conducted by NBS in 1976.

Because of the limited scope of the earlier NBS tests and subsequent improvements in the design of smoke detectors and the construction of mobile homes, a new series of tests was conducted to evaluate the influences of the operation of central forced-air heating and air conditioning systems on the performance of smoke detectors representative of those which are currently being installed. The tests were conducted with upholstered chairs in smoldering and flaming fire modes, representing key residential fire death scenarios. Tests were conducted in both summer and winter weather conditions. The effects of detector location (wall or ceiling and position within the bedroom corridor) and the effects of open and closed bedroom doors were also investigated.

The report concludes that, for the scenarios examined, a properly functioning ionization or photoelectric smoke detector mounted near the ceiling on the inside or outside wall at the living room end of the corridor should provide an alarm in sufficient time for occupant escape.

Key words: Detection time; detector location; fire tests; gas detectors; kitchen fires; mobile homes; smoke detectors; tenability limits; upholstered furniture.

1. BACKGROUND

1.1 Current Requirements

The U.S. Department of Housing and Urban Development (HUD) promulgated the Federal Mobile Home Construction and Safety Standards (FMHCSS) [1][1], effective in June, 1976. Paragraph 280.208 of this standard requires that "at least one smoke detector (which may be a single-station alarm device) shall be installed in each mobile home to protect each separate bedroom area". This paragraph further requires that the detector "be installed in the hallway or space communicating with the bedroom area", specifically "in the hallway between the living area and first bedroom. Mobile homes having bedrooms separated by any one or combination of common use areas such as kitchen, dining room, living room, or family room (but not a bathroom or utility room), shall have at least two smoke detectors, one smoke detector protecting each bedroom area." The standard also states that "smoke detectors shall be installed on an interior wall of the mobile home. The top of the

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

detector shall be five to seven inches from the ceiling." These requirements regarding installation location were based in part on initial work done by the National Bureau of Standards (NBS), Center for Fire Research (CFR) in 1976.

1.2 Basis for Requirements

This initial experimental work, sponsored and conducted by NBS [2], was reported in May of 1976. Some of the conclusions of that report were:

1. It appears as though the best general location for a smoke detector is at the end of the corridor entering the common-use areas of the home.

2. The effect of the HVAC circulating system was more significant than anticipated prior to the study. In each case, the system delayed the response of the smoke detectors regardless of location within the corridor.

3. In the tests conducted under summer conditions without air conditioning, inside and outside wall mounted detectors were not significantly different in response. However, unpublished test data from another source [3] for tests conducted under winter conditions indicated that detectors installed on interior walls responded somewhat faster than those on exterior walls.

4. Relative performance in the case of ceiling versus wall installation related primarily to the type of combustion. That is, smoldering fires seem to be detected more easily by wall mounted detectors and flaming fires by ceiling mounted detectors.

Since (at that time) some studies indicated a higher percentage of home fires were initially smoldering and since inside wall mounted detectors were at least equivalent in response and sometimes faster in response than other locations, that report concluded that inside wall installation would seem preferable.

1.3 Limitations of Initial Work

In order to provide basic technical guidelines for installation of smoke detectors in time for the impending promulgation of the HUD standard in June of 1976, the initial NBS study was somewhat limited in scope. For example, all tests were performed under summer weather conditions. Therefore, the applicability of the report's conclusions under winter weather conditions was uncertain (even though some winter data from an unpublished source was considered when making conclusions). Second, although experiments were conducted under summer conditions, the mobile home used in the tests was not equipped with air conditioning. Third, only photoelectric type smoke detectors were used in the study. The performance of ionization type smoke detectors was not investigated under comparable conditions since, at that time, the large majority of detectors being installed in mobile homes were of the photoelectric type. Fourth, the types of fires used were of the standard laboratory type; that is, cross-piled wood cribs in a smoldering mode and a can of gasoline for flaming fires. The smoldering wood crib fires produced gray/white smoke of larger relative particle size while the gasoline fires resulted in black smoke of smaller relative particle size.

In addition to these limitations, the mobile home used in the initial study was originally purchased by HUD for a disaster relief program. Comparison of construction features in that mobile home with those required under the current Federal Standard revealed differences in thermal insulation which could significantly affect environmental conditions influencing smoke detector response. Environmental conditions include temperature inversions that can cause a weakly bouyant plume of smoke to fail to reach the detector.

A hypothesis made in the 1976 NBS study was that the poorer response of ceiling mounted detectors to smoldering fires and the slower response of outside wall mounted detectors in the unpublished winter tests was at least partially caused by temperature gradients at the inside surface of the exterior wall and ceiling. This type of temperature gradient would be created when the heat from the sun is conducted through the ceiling and outside wall allowing these surfaces to become significantly warmer than the interior air temperature. The resulting boundary layer condition may have been accentuated in the previous studies due to the limited thermal insulation in the ceiling and exterior walls. However, all mobile homes constructed since the promulgation of the standard are required to have a minimum R-7 insulation in walls and floor and R-11 in ceilings. It was felt that the additional insulation might have a significant effect in reducing any thermal gradients which might affect detector performance.

1.4 Experimental Program Objectives

In order to expand upon the scope of the initial study, and to examine the effects of improved construction requirements in the HUD standard on the current smoke detector installation criteria, a follow-up study was conducted. The major emphasis of this study was to (1) incorporate actual rather than simulated ignition sources, (2) test both prevalent detector sensing modes (ionization and photoelectric), (3) vary test conditions to include winter/summer, heating/air conditioning, and (4) conduct tests in a mobile home which was constructed in accordance with the current HUD standard's requirements for thermal insulation.

1.5 Approach

In a 1976 study of fatal residential fires, Clarke and Ottoson [4] identified furnishings (upholstered furniture and mattresses) ignited by smoking materials or by open flames as the top two fire death scenarios. This led to the decision to use smoldering and flaming ignition of upholstered chairs as the primary test scenario for this test program.

In addition, three tests were conducted involving a fire in a pan of cooking oil on the kitchen stove. This scenario was identified as a major type of residential fire in the U.S. Household Fire Survey conducted by the U.S. Fire Administration [5]. Although the kitchen fire scenario does not result in a large number of fire deaths, it was felt that the frequency of occurrence is high enough to warrant study.

Once the test scenarios were established the test variables were assigned. The variables of season (winter/summer), bedroom doors open/closed, HVAC on/off and windows closed/open (summer only) were selected. The experimental design, including a number of repeat tests, resulted in a schedule of 25 tests - 13 summer and 12 winter (see table 1).

Since it was intended to determine the performance of both ionization and photoelectric detectors in these tests as a function of mounting location, a total of 12 detectors was necessary for each test. This would allow the installation of one detector of each type on the inside wall, ceiling, and outside wall at the front and rear of the bedroom hallway. One specific model detector of each type was selected as being representative of the detectors currently being marketed and installed in mobile homes.

A factory preset sensitivity of 0.02 OD/m (1.5% per foot) was selected as representative of the nominal setting of most residential detectors. It was important that all 12 detectors be as close as possible to the same sensitivity to allow direct comparison of response times.

Once these parameters were selected, arrangements were made with the respective detector manufacturers to provide detectors which had the specified sensitivity. In addition, the detectors were electrically modified to allow remote monitoring of their alarm times. This modification in no way affected the sensitivity or response characteristics of the detectors.

2. EXPERIMENTAL PROGRAM

2.1 Description of Mobile Home

The single-wide mobile home purchased for use in this test program was a 4.3 by 17 m (14 by 56 ft), two bedroom unit with front living room, central kitchen, and both bedrooms in the rear (see figures 1 thru 4). The mobile home was equipped with an oil-fired, hot-air furnace and an electric central air conditioning unit. It was constructed and certified in accordance the current edition of the FMHCSS, and included the standard exterior wall and ceiling insulation.

The mobile home was fully carpeted except for the kitchen and bathroom where a vinyl floor covering was used. All interior walls were a 1.0 cm (3/8 in) thick gypsum board with vinyl coating and the ceilings were 1.0 cm (3/8 in) gypsum board finished with rough textured paint. The exterior of the unit was finished with 1.3 cm (1/2 in) exterior grade plywood board. The unit was insulated with 8.9 cm (3-1/2 in) fiberglass batts with foil vapor barrier in the walls and 15.2 cm (6 in) fiberglass batts in the ceiling.

The mobile home was installed on the grounds at the NBS Annex facilities and oriented such that the long exterior wall of the corridor leading to the bedrooms was facing south. Since this exterior wall was painted a dark green color, the southern exposure resulted in maximum heating from the sun during the summer test conditions. This was done to provide the maximum possible temperature difference between the interior wall surface of the outside walls and ceiling and the interior air temperature.

Since the 1976 tests indicated a substantial delay in response to a fire started in the living room from smoke detectors installed on the bedroom side of the furnace cold air return, it was felt to be important that this test program be conducted with detectors again installed on either side of the return. However this particular mobile home had the furnace and its return (figure 4, labeled F) installed immediately in front of the rear bedroom door. Since this arrangement would not permit the installation of detectors beyond the location of the furnace at the remote end of the corridor from the living area, it was necessary to extend the mobile home corridor another 1.2 m (4 ft) into the rear bedroom. This was done by framing in a plywood wall at the original rear bedroom doorway and moving the rear bedroom door to the back of this 1.2 m (4 ft) long extension (see figure 4).

The air return for the air conditioning system was separate from that used by the furnace. This air return was installed in the floor of the corridor almost directly in front of the furnace (figure 4, labeled R). As a result, the return air location was essentially the same for both the summer and winter test conditions.

2.2 Fire Sources

2.2.1 Living Room Fires

Twenty-two identically constructed upholstered chairs were purchased from a furniture manufacturer (see figure 7). The chairs consisted of a hardwood frame with a drop-in spring unit in the base, cotton padding in the arms and back, medium density polyurethane arm and back pads, all covered with a medium weight 0.6 kg/m^2 (18 oz/yd^2) cotton fabric. The seat cushion consisted of a block of polyurethane foam covered with the cotton fabric. Total chair weight was approximately 15.9 kg (35 lbs).

It was requested that all materials used in the chairs be untreated with fire retardant chemicals. Samples of the polyurethane were tested by x-ray fluorescence spectroscopy and only trace amounts of phosphorous and bromine (the usual treatment chemicals) were found. It was not possible to test for boric acid in the cotton, but it appeared from its burning characteristics that the cotton was also not treated.

2.2.2 Kitchen Fires

Tests 23 and 24 were conducted using a 20.3 cm (8 inch) diameter cast iron pan on the right front burner, filled with 5-8 cm (2-3 inches) of vegetable oil and covered with a lid. In test 25, a 17.8 cm (7 inch) diameter stainless steel pan was used, filled with approximately 2.5 cm (1 inch) of oil, and no lid was used.

2.3 Detector Performance Evaluation Criteria

One of the most realistic methods of comparing the performance of different smoke detectors in full-scale fire tests is by comparison of escape times; that is, the amount of time provided by the detector for escape of the occupants from the building. This type of comparison originated in the IITRI/UL report titled "Detector Sensitivity and Siting Requirements for Dwellings" [6]. The escape time is computed by subtracting the individual detector alarm time from the time at which the first of one or more tenability criteria are exceeded. These tenability criteria normally include smoke levels, temperature and carbon monoxide levels and may also include such parameters as radiant flux, oxygen depletion, or carbon dioxide levels.

Previous tests have shown that critical smoke levels are almost always the first of the above mentioned tenability criteria to be exceeded [6]. While some differences of opinion exist over what smoke level is applicable as a limit, values on the order of 0.25 optical density per meter (relating to visibility of about 4 meters (13.3 ft)) appear to be the most often cited [6-9]. The primary reason for the differences in values selected by various experimenters is that the effects of smoke on the ability to escape may be as much or more psychological than they are psysiological. Thus, one might see a rather large variation in effect from individual to individual under similar smoke conditions and that value might be different depending on the distance to be traveled to an exit.

The normally cited 0.25 OD/m level was exceeded in most of the tests. Typical ionization detector response occurred when conditions in the corridor were below or at worst just at this level. Photoelectric detector response occurred prior to reaching this level. But there is also some question about the applicability of the 0.25 OD/m level in the particular case of a mobile home.

In the case of a single family home (particularly multistory) the building occupant must travel a significant distance through the interior of the building in order to reach a point of egress. In a multistory home this might mean traveling through a second floor corridor, down a staircase, through a first floor corridor and living room or kitchen, and finally out the door. This is not the case in a mobile home, where all of the bedrooms are typically located within a few feet of a door and where all bedrooms are required to have an easily accessible secondary means of egress. Based on these factors, it is unjustified to impose this smoke level limit in the mobile home situation. The occupant of a mobile home should be able to escape through significantly greater smoke levels without the attendant psychological effects since the distance to be traveled is so much shorter. Since there is no experimental data upon which to select a critical smoke level for mobile homes as there is for other types of housing, it was decided to compare the smoke detector performance solely on the basis of response time with primary consideration given to carbon monoxide exposure and only subjective observations on visibility.

The effects of carbon monoxide are physiological and there is much less disagreement on critical levels. A level which the Center for Fire Research has used (which takes into account the cumulative nature of CO exposure) is a CO level which would result in a calculated 25% carboxyhemoglobin (COHb) blood concentration using a formula developed empirically by Stewart [10]. This formula takes into account breathing rate and the typical lung volume of a normal adult human.

Stewart conducted a study in 1973 with human volunteers. They were exposed to 35,600 ppm for 3/4 minute, to 15,000 ppm for 2 minutes, to 1,000 ppm for 10 minutes and to other intermediate combinations. The COHb levels were monitored and from the results the following equation was derived.

$$\Delta\%\text{COHb} = (\text{liters breathed}) \times \frac{\text{PPMCO}^{1.036}}{3.01 \times 10^4}$$

Stewart's volunteers averaged a ventilation rate of approximately 7 liters/ minute and exhibited no adverse symptoms beyond a mild frontal headache.

The ventilation rate to be used was obtained from the work of Alarie [11]. He quoted 6 ℓ/minute at rest, 9.5 ℓ/minute for light activity, and 18 ℓ/minute for light work. These figures were compared to Stewart's measurements on his volunteers and a value of 10 ℓ/minute taken as the accelerated rate expected under a fire situation.

2.4 Instrumentation

2.4.1 Chair Tests

Three physical parameters were continuously measured inside the mobile home during the tests; temperatures, smoke levels, and gases (carbon monoxide and carbon dioxide). Figure 4 shows the location of each instrument in the mobile home.

Temperature measurements were taken by means of type K chromel-alumel thermocouples (24 gauge), positioned in 24 locations throughout the test unit. Vertical temperature profiles (thermocouple trees) were taken at three locations: 1) in the living room directly above the chair used as the ignition source (2.5 cm, 0.3 m, 0.6 m, 0.9 m, 1.2 m (1 in, 1 ft, 2 ft, 3 ft and 4 ft) from the ceiling); 2) in the center of the corridor leading to the bedrooms directly in front of the rear door (2.5 cm, 0.3 m, 0.6 m, 0.9 m and 1.2 m (1 in, 1 ft, 2 ft, 3 ft and 4 ft) from the ceiling) and 3) at the front end of the corridor directly in front of the detectors (0.3 cm, 2.5 cm, 5 cm, 7.5 cm, and 10 cm (0.1 in, 1 in, 2 in, 3 in and 4 in) from the ceiling). This latter profile was taken to measure the boundary layer along the ceiling. Additional temperature measurements were taken 2.5 cm (1 in) from the interior wall surface near each group of three detectors in the corridor, at the east and south walls of the living room 20.3 cm (8 in) down from the ceiling, and in the center of the front and rear bedrooms 0.9 m (3 ft) from the floor.

Smoke obscuration measurements were taken at six locations using NBS extinction photometers [12]. These measurements were taking at the ceiling (beam center approximately 6.4 cm (2.5 in) below the ceiling) and at the 1.5 m (5 ft) level at the front and rear of the corridor immediately adjacent to the detectors. Smoke measurements were also taken in the center of the front and rear bedrooms at the 0.9 m (3 ft) level.

Measurements of carbon monoxide and carbon dioxide were made at three and two locations respectively using non-dispersive infrared analyzers. The measurement locations were the 1.5 m (5 ft) level immediately in front of the rear door in the center of the bedroom corridor (both CO and CO_2) and in the center of the front (CO only) and rear (CO and CO_2) bedrooms at the 0.9 m (3 ft) level.

A total of 46 instrument channels were connected to an Acurex Autodata 9, microprocessor controlled data acquisition system located in a building adjacent to the mobile home. This data acquisition system scanned the instrument channels at the rate of 25 channels per second at 10 second intervals and recorded all data on computer compatible magnetic tape for subsequent reduction. The data acquisition system internally converted and recorded all thermocouple outputs in °C. The extinction photometer and non-dispersive infrared gas analyzer outputs were recorded as voltages and then converted to appropriate engineering units for analysis by the data reduction program. The extinction photometers were converted to units of optical density per meter and gas concentrations to percent concentration using a fourth order equation derived from the individual instrument calibration curves.

2.4.2 Kitchen Grease Fire Tests

For the kitchen fires (tests 23, 24 and 25) the thermocouple tree (TC2-TC6) was moved from the center of the living room to the kitchen (see figure 4, labeled alt. tree Ⓐ). All other instrument locations remained the same. The overhead kitchen cabinets were removed and replaced with cabinets fabricated from 1.6 cm (5/8 in) calcium silicate board. The range hood was reinstalled above the cooking range and the wall and ceiling surfaces near the stove were also protected with calcium silicate board.

2.5 Detectors

Twelve samples of one model each of ionization and photoelectric single-station residential smoke detectors considered to be typical of those detectors currently being installed in mobile homes were obtained from their respective manufacturers for the test program. The detectors were modified by the manufacturers to provide an electrical circuit closure upon alarm which facilitated their connection to elapsed time clocks. It was further specified that the test samples be provided at a nominal 0.02 OD/m (1.5 %/ft)[2] obscuration sensitivity level as measured in the UL 217 type test compartment [13].

[2] While the preferred unit of smoke density is OD/m, the %/ft units are shown for the benefit of the readers who might be more familiar with these units.

Prior to installation the calibration of each detector was verified in a UL 217 type test compartment maintained at NBS. The six photoelectric detectors ranged in sensitivity from 0.022 to 0.027 OD/m (1.53 to 1.87 %/ft) obscuration, yielding an average sensitivity of 0.024 OD/m (1.66 %/ft) with a standard deviation of 0.001 OD/m (0.10 %/ft). The six ionization detectors ranged from 0.023 to 0.027 OD/m (1.57 to 1.89 %/ft) yielding an average sensitivity of 0.025 OD/m (1.74 %/ft) and a standard deviation of 0.002 OD/m (0.12 %/ft).

One detector of each type was installed on the inside wall, ceiling, and outside wall of the mobile home at the front (figure 5) and rear (figure 6) of the corridor (see table 3). The front hallway units were installed as close to the front of the corridor as was permitted (representing compliance with current requirements of FMHCSS - see figure 5) and the rear corridor detectors were installed about 0.8 m (2-1/2 ft) past the furnace cold air return in the center of the corridor extension (see figure 6). The wall mounted detectors were located approximately 20.3 cm (8 in) below the ceiling.

All detectors were connected to a suitable source of power and the contact closure circuits were connected to a set of clock timers which measured elapsed time to alarm to the nearest second. The clock timer panel was located in the instrumentation room adjacent to the data acquisition system.

Upon completion of the test program the sensitivity of the smoke detectors was measured with the detectors in place using an NBS smoke detector field test unit [14]. Empirical data on this device indicates that it will measure sensitivity of any smoke detector to within 0.007 OD/m (0.5 %/ft) of the reading obtained in the UL 217 test compartment.

The measured sensitivity of the six photoelectric detectors ranged from 0.029 to 0.051 OD/m (2.0 to 3.5 %/ft) obscuration yielding an average sensitivity of 0.035 OD/m (2.4 %/ft) with a standard deviation of 0.010 OD/m (0.7 %/ft). The sensitivity of the six ionization detectors ranged from 0.029 to 0.036 OD/m (2.0 to 2.5 %/ft) yielding an average sensitivity of 0.032 OD/m (2.2 %/ft) and a standard deviation of 0.004 OD/m (0.3 %/ft).

The only test detectors which shifted significantly in sensitivity (although still remaining within accepted limits) were the two ceiling mounted photoelectric units. These detectors shifted from 0.02 OD/m (1.5 %/ft) to 0.051 and 0.043 OD/m (3.5 and 3.0 %/ft) at the front and rear hall positions respectively. A possible explanation for this shift is that the LED light sources were heat stressed by the repeated temperature exposure (up to 150°C peak), causing their normal, linear light degradation characteristic to be accelerated. A discussion of this light degradation characteristic is contained in reference [15].

In addition to the smoke detectors, five analog output gas sensing detectors were installed adjacent to the smoke detectors (see figures 5 and 6) to provide information on their comparative response. These five units were located at the inside wall, ceiling, and outside wall locations at the front of the corridor and at the ceiling and outside wall locations at the rear of the corridor.

These gas sensing detectors employ a semiconductor gas sensing element which is responsive to oxidizable gaseous material. Detectors employing this type of element are sold in the U.S. as fire detectors. However, previous studies at NBS [16,17] have detailed some problems associated with the use of earlier versions of this sensor as fire detectors. Since improvements/modifications in the sensor used in these analog output detectors have recently been made, some comparative information on their detection capability was desired.

The five test units were provided by the sensor manufacturer and were arranged to provide a continuous analog output in the range of 0 to 3 volts dc. The output of these five units was connected to the data acquisition system. (A problem which developed in the data collection system resulted in the loss of data from the gas detectors for the winter tests.)

2.6 Weather Conditions

All summer tests were conducted in the afternoon on sunny days with outdoor temperatures above 32°C (90°F). All winter tests (except for the kitchen tests) were conducted in the morning on days when the outdoor temperature was below 4°C (39°F).

3. PROCEDURE

3.1 General

A total of 25 experiments were conducted in the test series; 13 under summer test conditions and 12 under winter conditions. The summer series consisted of 7 smoldering tests and 6 flaming tests, all of which used an upholstered chair in the living room. The winter series included 5 smoldering tests and 4 flaming tests with chairs in the living room and three grease (cooking oil) fires on the kitchen stove. Table 1 provides the complete test matrix for the summer and winter test series.

3.2 Experimental Procedure

The upholstered chair was placed in the center of the living room in a large galvanized metal pan to capture the water used in extinguishment, (see figure 7). This prevented wetting the carpets and increasing the interior humidity for subsequent tests. The metal pan was placed on a sheet of 1.6 cm (5/8 in) calcium silicate board to inhibit melting of the living room carpet. In addition, a 1.2 by 1.8 m (4 by 6 ft) sheet of 1.6 cm (5/8 in) calcium silicate board was secured to the ceiling directly above the chair to prevent direct flame impingement on the gypsum board ceiling. A single thermocouple was placed between the calcium silicate board and the ceiling board to allow monitoring of the interface temperature. This was a precautionary measure to preclude possible ignition of the ceiling joists.

Smoldering ignition of the chair was initiated with a 500 watt electric charcoal igniter (cal-rod heater). The igniter was placed in direct contact with the chair back just above the seat cushion and then energized from a source of 120 VAC at time zero. The charcoal igniter was held in contact with the chair for 120 seconds at which point self-sustaining smoldering had begun. The charcoal igniter was then de-energized and removed from the mobile home.

The use of a cal-rod heater to produce self-sustaining smoldering ignition provides an experimentally reproducible means of simulating the characteristics of a smoldering cigarette ignition in terms of temperature rise, gas generation, and smoke production. While there has been some criticism of the lack of true representation of accidental smoldering from a cigarette in using the cal-rod heater [18], work conducted at Factory Mutual Research Corporation indicated that the use of an electric heating coil similar to that described above reasonably simulates the self-sustained smoldering obtained with a cigarette [19]. The only major variation identified in this work was the time required to produce self-sustained smoldering ignition. The resulting measurements for smoke, gases and temperature were similar, indicating comparable conditions.

Flaming ignitions were initiated by placing a small polyethelyne wastebasket adjacent to the chair filled with a specified mix of combustibles as detailed in table 2. The contents of the wastebasket were ignited with a single paper match.

In all cases, the test was allowed to continue until it was felt by the observers that living room window temperatures were such that breakage might occur (on the order of 60°C). At that point, the chair fires were extinguished with a garden hose carried in through the front door.

The number of tests conducted permitted systematic examination of each combination of 1) type of ignition, 2) HVAC system on or off, 3) bedroom doors open or closed, and 4) windows open or closed. Further, at least one repeat test was conducted for each of the smoldering and flaming type conditions.

The winter test series was similar to the summer test series except that no open window tests were conducted. In addition to the chair tests conducted in the winter series, three kitchen grease fires were conducted to provide information on response to a rapidly developing fire with a high heat output and producing black smoke.

At the test start the burner was turned on high. After about 35 minutes in tests 23 and 24 smoke began issuing out around the lid, increasing in rate until at about 40 minutes the lid was removed and auto-ignition of the oil occurred. In test 25 where no lid was used, the oil began to smoke at about 11 minutes and auto-ignition occurred at 16 minutes. All three of these tests were terminated when the oil began to froth and spill out of the pan, spreading flaming oil to the top of the stove and adjacent cabinet top.

4. RESULTS

Graphs of the reduced data from all instruments are presented in Appendices A and B for the summer and winter tests respectively. Groups of instruments such as each thermocouple tree, front corridor smoke measurements, rear corridor smoke measurements, bedroom smoke measurements, carbon monoxide measurements, etc. are plotted together. Each graph is labeled with the instrument channel (corresponding to the channel identification in figure 4) and location.

The elapsed time from ignition to alarm for the smoke detectors is tabulated for each test in table 4. They are tabulated by clock number which is related to detector type and location in table 3.

Table 4 also lists time to appearance of first flames in each test. For the case of flaming ignition tests, this time is zero; for smoldering ignition tests this time reflects the time at which transition to flaming spontaneously occurred.

5. DISCUSSION OF RESULTS

5.1 Smoldering Ignition Chair Fires

The smoldering ignition upholstered chair fires include tests 1 through 7 in the summer series and 14 through 18 in the winter series. Although all of the chairs used were identical and the method of obtaining self-sustained smoldering ignition was identical, the time at which the chairs converted to the flaming mode varied from slightly less than 30 minutes to slightly more than 60 minutes after ignition. Also, the rate of smoke generation during the smoldering phase varied significantly; with some fires producing relatively little smoke (such as test 2, figure A17) and others producing relatively large amounts of smoke (such as test 3, figure A27). Analysis of the results indicated that there were no peculiarities in the procedure and that the variations were most likely a result of the typical vagaries of full-scale fire testing.

As would be expected, the smoldering tests resulted in a very gradual, almost linear increase in ambient temperature until transition to flaming (e.g. see figures A1, A11). Once transition occurred, temperatures throughout the mobile home increased quite rapidly; the duration of the tests being limited by the attainment of high temperatures (est. 60°C) at the living room windows. The peak temperatures observed at test termination in both the smoldering and flaming tests were of the same order of magnitude. However, as would be anticipated, the elapsed time was quite different for the two general types of fires, with the smoldering tests taking 2-3 times longer to reach termination temperatures.

As was mentioned earlier, the rate of smoke generation from the smoldering chairs varied considerably. In test 2, smoke levels in the corridor and bedrooms were quite low ($\leq$ 0.2 OD/m) at the point of transition to flaming (figures A17, A19). Under this condition some ionization detectors did not respond until a few seconds after transition to flaming due to the lack of sufficient smoke at the detector location to cause alarm of the ionization detectors. In most of the tests, however, there was sufficient smoke to result in alarm of the ionization detectors prior to transition to flaming. Since smoldering materials typically produce fairly few numbers of relatively large size smoke particles, it took between 0.15 to 0.23 OD/m (10 to 15 %/ft) obscuration smoke level, measured by an extinction photometer, to result in alarm.

This type of large, white smoke particle is very efficient at scattering light [20]. As a result, the photoelectric type detectors responded faster than the ionization type to this type of smoke. This comparative response difference between ionization and photoelectric detectors to smoke particulate from smoldering sources is well-known and documented [6,7].

Because the generation of carbon monoxide and carbon dioxide is, in general, a function of rate of combustion, the rate of gas generation in the smoldering fires was less than that in the flaming fires. That is, while similar peak values of CO and CO_2 were recorded the respective types of ignition, the rate of increase was lower for the smoldering tests until transition to flaming. Although a critical level of CO exposure based on the criterion established for this study was not reached in any of the tests, the levels of the CO exposure (COHb concentration) were somewhat greater for the smoldering fires than for the flaming fires, primarily due to the cumulative effect. Using the Stewart formula discussed in section 2.3 and assuming a linear increase in CO from 0 to 300 parts per million (ppm) (the highest reading at detector alarm) in 33 minutes (the average alarm time for the slower - ionization detectors in the smoldering tests) the calculated COHb level would be approximately 2%. The same calculation using a linear increase from 0 to 1000 ppm (the highest value attained in any test) over the full 4000 second maximum test duration yields a value of only 14.2%, which is still considerably lower than the threshold of COHb selected for this study.

The peak carbon monoxide concentrations were under 1000 ppm for all tests. Peak concentrations at the time of detector alarm tended to be less than 300 ppm, which is significantly below levels which would be expected to result in adverse physiological effects.

5.2 Flaming Ignition Chair Fires

The flaming ignition chair fires included tests 8 through 13 of the summer series and 19 through 22 of the winter series. Although there was some variation from test to test in the flaming fires, this inter-test variability was not as great as was observed in the smoldering tests prior to transition to flaming.

Temperature measurements throughout the test unit increased exponentially from the time of ignition and peaked at similar values to the smoldering tests (after transition) at test termination. This would be expected since termination of the tests was based on attainment of similar elevated temperature levels at the living room window. It was estimated that about one-third to one-half of the chair was consumed prior to the end of the test.

Smoke levels observed during flaming ignition tests increased more rapidly and the smoke was noticeably darker in color, which is characteristic of flaming combustion. This darker color and typically smaller particle size has some adverse effects on the performance of photoelectric type smoke detectors. That is, the smaller smoke particle size is less efficient at scattering light and the darker color tends to absorb more light and scatter less [20]. The relatively large numbers of the smaller particles produced by flaming combustion is more efficient at producing signal change in the ionization chamber [20]. Therefore, the ionization detectors responded before the adjacent photoelectric type detectors for the flaming fires. Again, this effect is well known and documented [6,7].

As was mentioned earlier, the rate of CO and CO_2 generation was greater for the flaming combustion tests. Similar concentrations were measured at one-half to one-third of the time of the smoldering case. Again, since the time frames are shorter the cumulative effects of the carbon monoxide would not be as great. The peak values at time of detector alarm again tended to be less than 300 ppm. The COHb calculations similar to those discussed in section 5.1 for a linear increase from 0 to 300 ppm for the 6 minutes average response time for the photoelectric detectors to respond gives a calculated COHb level of only 0.37%. Likewise the calculation for the 0 to 1000 ppm increase over the entire 1500 second maximum test duration yields a value of 5.3%. Thus there would be no expected adverse physiological effect from this exposure.

5.3 Kitchen Grease Fires

The kitchen grease fires included tests 23, 24 and 25. While these are listed under the winter series the tests were conducted in the early spring with relatively mild (12°C (54°F)) weather conditions.

Tests 23 and 24 were conducted using covered pans of oil. In both of these tests, the oil began to smoke at about 35 minutes and was allowed to continue for about 5 minutes prior to removal of the lid. Auto-ignition was achieved within two seconds after the lid was removed.

Temperatures recorded in the mobile home were essentially ambient until auto-ignition occurred. The recorded temperatures then increased very rapidly due to the high heat output from the burning oil.

No smoke was observed from the grease fires until about 35 minutes had elapsed. Smoke levels then increased rapidly. The smoke color changed from a white, large particle smoke during the non-flaming stage, to a dark, smaller particle smoke during the flaming stage. The nature of the smoke produced during the pre-ignition stage resulted in the photoelectric detectors responding first in test 23. In test 24 the order was reversed, most probably as a result of the burning of some grease on the outside of the pan and upper surfaces of the stove from the previous test. As this spilled grease burned off the pan and stove surface it may have added significantly to the quantity of small particulate enhancing the response of ionization detectors.

This assumption was reinforced by the results of test 25 which used an uncovered pan and where the photoelectric detectors responded first. This was a different pan than was used in the previous two tests and had no external grease accumulation. Also, every attempt was made to clean the stove, removing the accumulated grease, as best as possible prior to test 25. The time frame to auto-ignition of the grease in test 25 was significantly shorter than 23 and 24, most likely due to the fact that the pan used in test 25 was thin stainless steel and the pan used for tests 23 and 24 was cast iron. The thinner, lower mass stainless steel pan would be expected to heat up faster and would cause the oil temperature to increase faster. Auto-ignition was achieved in test 25 at approximately 16 minutes.

Carbon monoxide and carbon dioxide levels for the kitchen grease fires tended to be significantly lower than those for the previous tests with upholstered chairs. This was attributed to the much smaller amount of fuel being burned in the grease fires as compared to the chair fires. There was almost no CO and CO_2 produced prior to auto-ignition of the oil and, while higher rates of gas generation were evident in the burning oil, the time of flaming was very short, resulting in little gas accumulation. This is demonstrated in the plotted data in the very low levels of CO and CO_2 for all three kitchen fires. (Figures B109, B110, B120, B121, B131 and B132.)

5.4 Performance of Smoke Detectors

The data obtained from these tests provides information not only on the performance of smoke detectors but also on the environmental effects (temperature, smoke, and gas levels) which can be produced in a relatively small volume living unit by the combustion of a single item of furniture.

In general, for this test series the smoke detectors responded in advance of conditions selected to correspond to a point in fire development where occupant escape might be impaired. Although ionization detectors significantly lagged behind photoelectric detectors for smoldering fires, the front hallway mounted units responded prior to transition to open flaming in all but four cases; and in these cases they responded in less than 20 seconds after transition. For the flaming ignition fires, photoelectric detector response lagged ionization response by a lesser amount but again all photoelectric detectors responded before measured conditions approached the thresholds for occupant tenability established for this study.

Table 5 summarizes a comparison of smoke detector response by type of detector, location, and type of ignition for tests 1 through 22. The data from these tests indicate that there was no significant difference in response time between inside and outside wall mounted detectors. The inside wall mounted detectors responded before the outside wall mounted detectors in about half the tests and vice versa. However, the differences between front and rear hall mounted detectors were more significant, particularly in light of the much greater range of values for earliest and longest response times for the rear hall units.

Table 5 also compares wall mounted (upper portion of table) and the ceiling mounted detectors (lower portion of table). This table shows that the fastest and most consistent detector response was attained by wall mounted detectors located at the front end of the corridor. The slowest and least consistent were ceiling mounted detectors at the rear end of the hall. The reason for the inconsistency and slower response of the ceiling mounted detectors was not a result of thermal inversion layers at the exterior surfaces as was found in the 1976 NBS study [2], but rather was a function of the smoke flow. Figure A33 shows that there was only a very small thermal gradient at the ceiling, which would not account for this effect.

Looking at the data in table 5, it can be seen that the ceiling mounted detectors respond at approximately the same time as the wall mounted detectors for flaming fires. But in the smoldering ignition tests elapsed time to alarm of the ceiling mounted detectors was significantly greater than for the wall mounted detectors. The explanation of this phenomenon is that flaming fires produce significant thermal lift forming a dense smoke layer at the ceiling. This was observed to be 45 to 60 cm (18 to 24 inches) thick and of fairly uniform density. This effect can be seen by comparing the smoke levels at the ceiling to that at the 1.5 m (5 ft) level and noting that they are almost equivalent for all of the flaming ignition tests (e.g. figure A97). For the smoldering tests, however, there was much less thermal lift to the smoke and, as the smoke moves along the ceiling, it begins to fall away with increasing distance from the fire source. By the time the smoke reaches the first set of detectors in the front end of the corridor it is often significantly more dense at the 1.5 m (5 ft) level than at the ceiling level (e.g. figure A37). Therefore, the wall mounted detectors installed 20.3 cm (8 in) below the ceiling on the side walls are exposed to higher smoke levels earlier in the test, and respond faster.

The HVAC system demonstrated some interesting effects. Earlier reports have documented significant effects of central forced air HVAC systems on smoke transport in dwellings [6,7]. These effects, however, are most critical to the vertical transport of smoke up stairways. Since stairways do not exist in mobile homes, the effects of the HVAC system on smoke transport and therefore on detector response are minimal. There is, however, a significant effect on the environment to which the mobile home occupants are exposed.

Looking at the graphs of temperature at the 0.9 m (3 ft) level in the front and rear bedrooms it can be seen that the temperature levels increase with increasing fire intensity if the bedroom doors are open, but remain fairly constant with the bedroom doors closed. This phenomenon appears to be independent of whether the HVAC system is on or off, or whether it is heating or air conditioning. Therefore, a closed bedroom door provides an effective barrier to the initial temperatures being generated by a fire.

Such is not true, however, of the smoke levels. Comparing the graphs of smoke levels in the bedrooms for various tests it can be seen that these levels remain low only when the bedroom doors are closed and the HVAC system is off. If the doors are closed and the furnace blower is on, a significant increase in the smoke levels in the bedrooms occurs; particularly for smoldering fires. If the furnace blower is off and the bedroom doors are open, a slight increase in smoke levels occurs in the bedrooms over the case where the blower is on and doors are closed; and the worst case is for the blower on and the bedroom doors open. The same general results are seen for the flaming tests although the magnitude of the difference is not as high.

The mechanism for smoke entering the bedroom with the bedroom doors open is direct flow through the open door. In the case where the bedroom doors are closed and furnace blower on, the smoke entering the bedroom is pulled into the cold air return at the furnace location and forced into the bedroom through the heating vents. Since the data on smoke levels show that there is more visible smoke in the smoldering test than in the flaming test and that the smoke in the smoldering test tends to be denser at lower levels in the corridor, it follows that more smoke is distributed through the heating vents in the smoldering case than in the flaming case. The results of the smoldering and flaming tests under the various conditions support this argument.

While increases in the carbon monoxide and carbon dioxide levels in the bedrooms are somewhat analogous to the development of smoke conditions, distribution of carbon monoxide through the heating vents is somewhat less since CO is more naturally buoyant than the smoke in the smoldering tests. The test results do not indicate a significant variation in accumulation of CO under the various conditions discussed above.

5.5 Analog Gas Detectors

The output voltage for the five combustible gas detectors appeared to follow more closely the general shape of the carbon monoxide curves rather than the smoke curves; this would be expected of a gas sensing device. Since measurable smoke precedes measurable gas concentrations for most fires this is of no advantage to an early warning fire detection device. To determine if a detector employing this type of gas sensing element could provide a response to these test fires at least as quickly as either the ionization or photoelectric detectors, the output voltage range of the gas detector with the greatest output was taken from the test data over the time period when the conventional detectors responded.

For a typical smoldering chair fire (test 4, figure A40) the maximum gas detector output ranged from 0.004 to 0.5 volts during the time that the front hallway detectors operated (fastest-ionization to slowest-photoelectric respectively). The maximum output at the time the last smoke detector alarmed (rear hall-photoelectric) was 0.9 volts.

Similarly, for a typical flaming fire (test 10, figure A100) the maximum gas detector output ranged from 0.002 to 0.04 volts during the time that the front hallway detectors responded (fastest-ionization to slowest-photoelectric respectively). The maximum output at the time of the last smoke detector alarm (rear hall-photoelectric) was 0.06 volts.

From these data it would appear that a fire detector utilizing a gas sensing element of this type would need to be set to alarm at an output voltage level of approximately 0.04 volts or less in order to provide response for both fire types at least as fast as the slowest of the conventional smoke detectors. This represents an alarm level of only 1.3% of the full-scale output.

To properly determine if this alarm setting is feasible, it would be necessary to monitor the variation in output voltage in a normal household environment for a period of time. This would allow a determination of the false alarm potential of the device under normal use. While this data is not currently available, it would appear from general engineering considerations that an alarm point of 1.3% of full-scale output would lead to an unacceptable number of false alarms due to a poor signal to noise ratio.

6. LIMITATIONS OF THIS STUDY

There are certain assumptions and limitations which must be considered when conclusions are drawn from the data. The important assumptions and limitations of this series of tests are:

1. The mobile home used represented only one specific floor-plan/interior geometry. While this was a fairly common floor plan, room arrangements which are radically different might produce different detector response characteristics. For example, a seemingly minor change such as the use of several HVAC system returns or location of the single return at a different height could have a major effect on the results obtained.

2. The mobile home used had a non-combustible interior finish and the tests were arranged such that the fire never spread from the initial item ignited. If fire spread to other furnishing items and/or to the interior finish were permitted, the results could be significantly different. Under some conditions of sufficiently rapid fire spread, smoke detectors might have been ineffective.

3. Only two specific fire types and locations were tested; i.e. chairs in the living room and cooking oil fires in the kitchen. Thus the effects of other fire scenarios, such as a mattress fire in the bedroom, are unknown.

4. Only one specific model of ionization and of photoelectric detectors were used in these tests. The performance of other models from the same or other manufacturers might be different although the models used should be representative of most detectors now being produced.

7. CONCLUSIONS

Based on the data obtained in these tests and given the limitations discussed in section 6, the following conclusions can be drawn:

1. Thermal inversion layers at the ceiling and outside wall which might have a detrimental effect on smoke detector response appear to be insignificant in mobile homes constructed in accordance with the current Federal standard.

This conclusion is based upon both the boundary layer temperature measurements and on the recorded performance of ceiling and wall mounted detectors.

This also assumes that the mobile home in question will have at least the minimum R value insulation as specified in the current FMHCSS. While the mobile home tested had insulation sized for this particular geographical area it should be safe to assume that increased insulation provided in mobile homes for colder climates should exhibit roughly equivalent performance in terms of development of thermal gradients.

2. The smoke detectors included in this test series demonstrated similar performance when installed on either outside or inside walls. The response time for ceiling mounted detectors may be significantly longer for smoldering type fires.

The slower response for ceiling mounted detectors appears to be more a function of the movement of the smoke and does not appear to be caused by thermal effects due to pre-existing thermal inversion.

3. Detector performance can be adversely affected by forced air HVAC systems operating during the fire if the return air register is between the detector and the fire.

The primary reason for the slower response of the rear hall detectors is a combination of the increased transport time necessary to move the smoke from the front to the rear of the corridor and also the dilution effect of the cold air return pulling the smoke down and into the air duct system.

4. Closed bedroom doors provide effective barriers to heat from a fire resulting from the burning of incidental combustibles such as an upholstered chair or pan of grease, prior to spread beyond the initial item.

The heated air tends to be near the ceiling in the hallway during the initial fire buildup prior to detector alarm, such that the high temperature air is not pulled into the HVAC system return.

5. With forced-air HVAC systems, significant quantities of smoke can be distributed into the bedrooms if the HVAC system is operating during the fire, even if the door is closed.

This effect is most severe under smoldering conditions when the smoke is denser and tends to be lower in the corridor. It is, however, noticeable even in the flaming type fires.

6. Based on the series of fire tests conducted in this program and the evaluation criteria discussed in section 2.3, a properly functioning smoke detector of either the ionization or photoelectric type should provide an alarm in sufficient time to permit an alert and mobile occupant to escape from the mobile home. While either type detector provided enough time for escape, the use of a detector which combines both ionization and photoelectric sensors in the same unit (or one of each) could provide significant improvement in alerting the occupants of a mobile home to either a flaming or smoldering fire. This potential improvement in response appears, based on the data, to be more significant than response improvement based on location of the detectors, for the locations examined.

This latter statement can be seen in the data in table 5 by examining the response of the photoelectric detectors under smoldering conditions and the response of the ionization detectors under flaming conditions. The ideal average response of a combination detector which is wall mounted at the front end of the hall should be on the order of 16.8 minutes for smoldering fires and 1.7 minutes for flaming fires (assuming a combination detector exhibiting the same performance characteristics as the two detectors used mounted side-by-side).

8. RECOMMENDATIONS

Based on the results of these tests and on revisions of the approval standards promulgated since the adoption of the Federal Mobile Home Construction and Safety Standards, the following changes to the FMHCSS are recommended.

<u>Intent of recommended change to Paragraph 280.208(c)</u>:

The intent of the following recommendation is to reference UL 217 which replaced UL 167 and UL 168 as the approval standard for single and multiple station smoke detectors on January 2, 1976.

<u>Recommended wording for Paragraph 280.208(c)</u>:

(c) Smoke Detectors

Smoke detectors shall be either the ionization chamber or the photoelectric type approved for wall mounting and shall comply with all the requirements of Underwriters Laboratories Standard No. UL 217 for Single and Multiple Station Smoke Detectors. Detectors shall bear the label of a testing and approval laboratory that indicates the smoke detectors have been tested and approved under the requirements of UL 217. The testing and approval laboratory shall be one which maintains a periodic follow-up service of the labeled devices to ensure compliance with the original approval.

Intent of recommended change to Paragraph 280.208(d):

The intent of the following recommendation is to allow installation of smoke detectors on either inside or outside walls of mobile homes (based on the findings reported herein) and to make the mounting dimension below the ceiling consistant with other nationally recognized installation standards. Also, prohibition of connection to a branch circuit controlled by a ground-fault circuit interruptor (GFCI) is intended to preclude loss of power to the smoke detector from a false trip of the GFCI.

Recommended wording for Paragraph 280.208(d):

(d) Installation

Smoke detectors shall be installed on an interior or exterior wall of the mobile home. The top of the detector shall be 4 to 12 inches from the ceiling. The detector mounting shall be attached to an electrical outlet box and the detector connected by a permanent wiring method into a general electrical circuit. There shall be no switches in the circuit to the detector other than the overcurrent protective device protecting the branch circuit. The branch circuit to which the detector is connected shall not be controlled by a ground-fault circuit interruptor.

9. REFERENCES

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Figure 1. Mobile home test unit, north and west exposures (living room end)

Figure 2. Mobile home test unit showing south wall of living room

Figure 3. Mobile home showing southern exposure of corridor and bedroom end

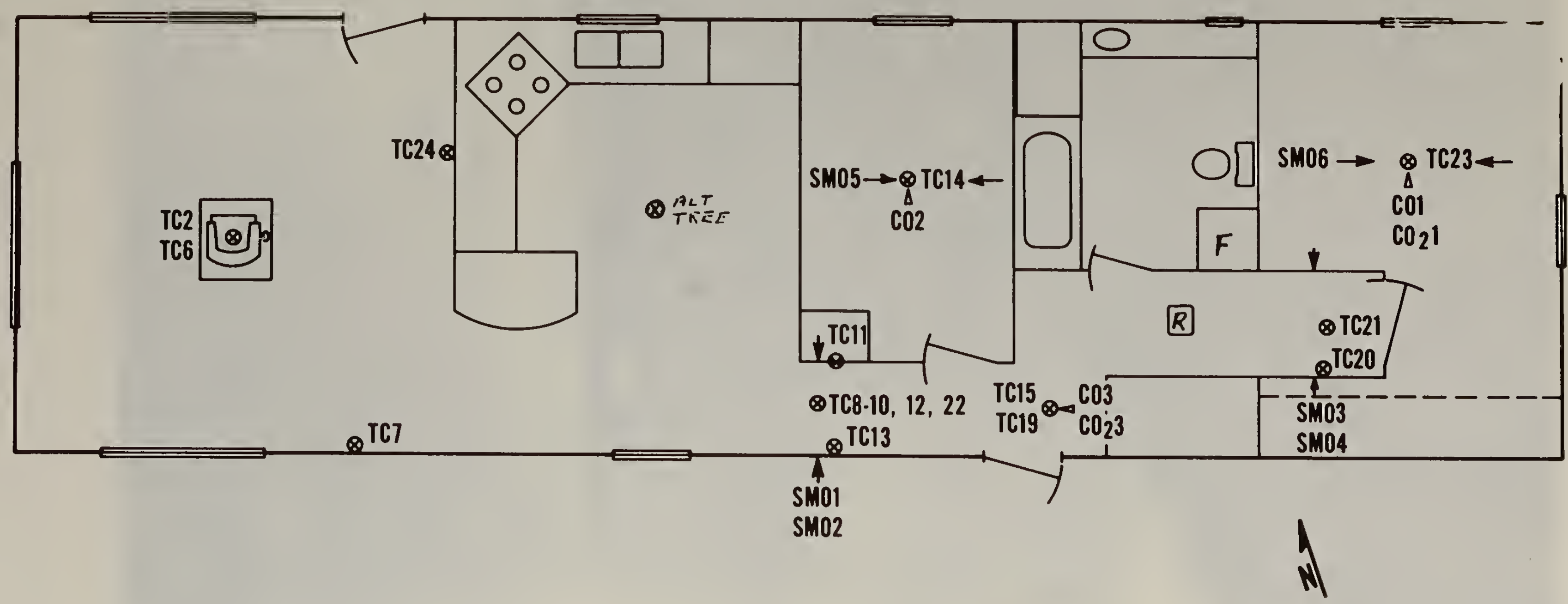

Figure 4. Mobile home floor plan and instrumentation locations

Figure 5. Test detectors and boundary layer probe at front end of corridor

Figure 6. Test detectors mounted in hallway extension at rear of corridor

Figure 7. Upholstered chair and wastebasket in test position in living room

Table 1. Test variables

Test No.	Ignition	HVAC	Bedroom Doors	Windows
		Summer Tests		
1	S	On	Open	Closed
2	S	On	Open	Closed
3	S	Off	Open	Closed
4	S	On	Closed	Closed
5	S	Off	Closed	Closed
6	S	On	Open	Closed
7	S	Off	Open	Open
8	F	On	Open	Closed
9	F	Off	Open	Closed
10	F	On	Open	Closed
11	F	On	Closed	Closed
12	F	Off	Closed	Closed
13	F	Off	Open	Open
		Winter Tests		
14	S	On	Open	Closed
15	S	Off	Open	Closed
16	S	On	Closed	Closed
17	S	Off	Closed	Closed
18	S	On	Open	Closed
19	F	On	Open	Closed
20	F	Off	Open	Closed
21	F	On	Closed	Closed
22	F	Off	Closed	Closed
23*	F	On	Open	Closed
24*	F	Off	Closed	Closed
25*	F	Off	Closed	Closed

*Kitchen grease fires
Flaming = F
Smoldering = S

Table 2. Wastebasket and contents flaming fire ignition source

Waste Can - 6.4 ℓ (1.7 gal) (polyethlyene)
1 - polyethylene bag (liner)
16 - full sheets of newspaper (black ink only)
3 - 3 oz. paper cups, crumpled
3 - sheets 8-1/2 x 11 writing paper, crumpled
5 - facial tissues, crumpled
2 - cigarette packages, crumpled
1 - 1/2 pint milk carton

Table 3. Detector type and location

Clock No.	Type Detector*	Mounting Position*	Location in Corridor
1	P	IW	Front
3	P	C	Front
5	P	OW	Front
2	I	IW	Front
4	I	C	Front
6	I	OW	Front
7	P	IW	Rear
13	P	C	Rear
9	P	OW	Rear
8	I	IW	Rear
12	I	C	Rear
10	I	OW	Rear

*P = Photoelectric, I = Ionization
IW = Inside wall, C = Ceiling, OW = Outside wall

Table 4. Detector alarm times (sec)

Test \ Clock No.	Time to First Flames	1	2	3	4	5	6	7	8	9	10	12	13
Summer tests													
1	1870	315	1105	337	1272	259	1039	648	1313	474	1396	1542	882
2	2180	864	2200	1369	2197	805	2174	1595	2212	1090	2218	2213	1699
3	3430	621	1644	846	1665	903	1698	973	1726	1055	1778	1745	1105
4	3380	1361	1781	1560	2038	1337	1743	1610	2179	1552	2198	2413	1637
5	2790	293	1439	333	1635	280	1488	340	1552	1069	1560	1569	1116
6	3770	1079	2519	1166	2811	1036	2478	1719	2679	1604	2803	3438	1938
7	1720	786	1316	856	1308	880	1340	878	1351	882	1378	1356	866
8	0	444	164	450	139	435	139	479	221	462	218	219	467
9	0	292	84	289	98	292	84	352	168	323	155	170	333
10	0	436	136	373	132	370	167	555	252	466	260	244	436
11	0	470	139	460	146	452	143	578	436	500	250	523	561
12	0	322	69	326	69	317	67	350	129	342	140	121	358
13	0	336	113	339	113	335	104	370	149	367	153	149	365
Winter tests													
14	2120	557	1831	652	2132	513	1790	823	2149	755	2155	2149	1877
15	2780	1763	2161	1528	2162	1434	2203	1338	2223	1310	2189	2300	1703
16	3230	2541	3249	3248	3245	2553	3244	2900	3264	2717	3263	3265	3020
17	1760	1135	1730	1028	1730	958	1763	946	1354	972	1407	1637	1131
18	2960	942	2849	1321	2969	993	2929	1404	2981	1246	2987	2981	2523
19	0	319	98	422	87	389	86	486	151	433	153	114	427
20	0	367	73	436	69	389	66	473	125	438	207	117	492
21	0	292	97	433	79	294	83	453	190	426	150	289	492
22	0	265	92	351	85	261	80	325	156	328	149	132	327
23	2480	2367	2451	2374	2455	2336	2445	2495	2492	2452	2494	2492	2496
24	2470	2298	2070	2327	1972	2299	2007	2387	2321	2377	2489	2487	2432
25	1070	856	1035	955	1032	836	1028	940	1053	949	1067	1053	984

Table 5. Detector average response time (min)

Wall mounted units only						
	Front Hall		Rear Hall		Difference	
	P	I	P	I	P	I
Smold.	16.8	33.1	20.8	34.9	4.0*	1.8**
Flam.	5.9	1.7	7.1	3.2	1.2	1.5

*Ranges to 10 minutes
**Ranges to 7 minutes

Ceiling Mounted Units						
	Front Hall		Rear Hall		Difference	
	P	I	P	I	P	I
Smold.	19.8	34.9	27.1	37.0	7.3*	2.1**
Flam.	6.5	1.7	7.1	3.5	0.6	1.8

*Ranges to 20 minutes
**Ranges to 10.4 minutes

Average variation between inside wall, outside wall detector = 45 seconds front, 74 seconds rear.

Average variation between inside wall, ceiling, outside wall detector = 108 seconds front, 164 seconds rear.

APPENDIX A - GRAPHS OF REDUCED DATA FROM SUMMER TESTS

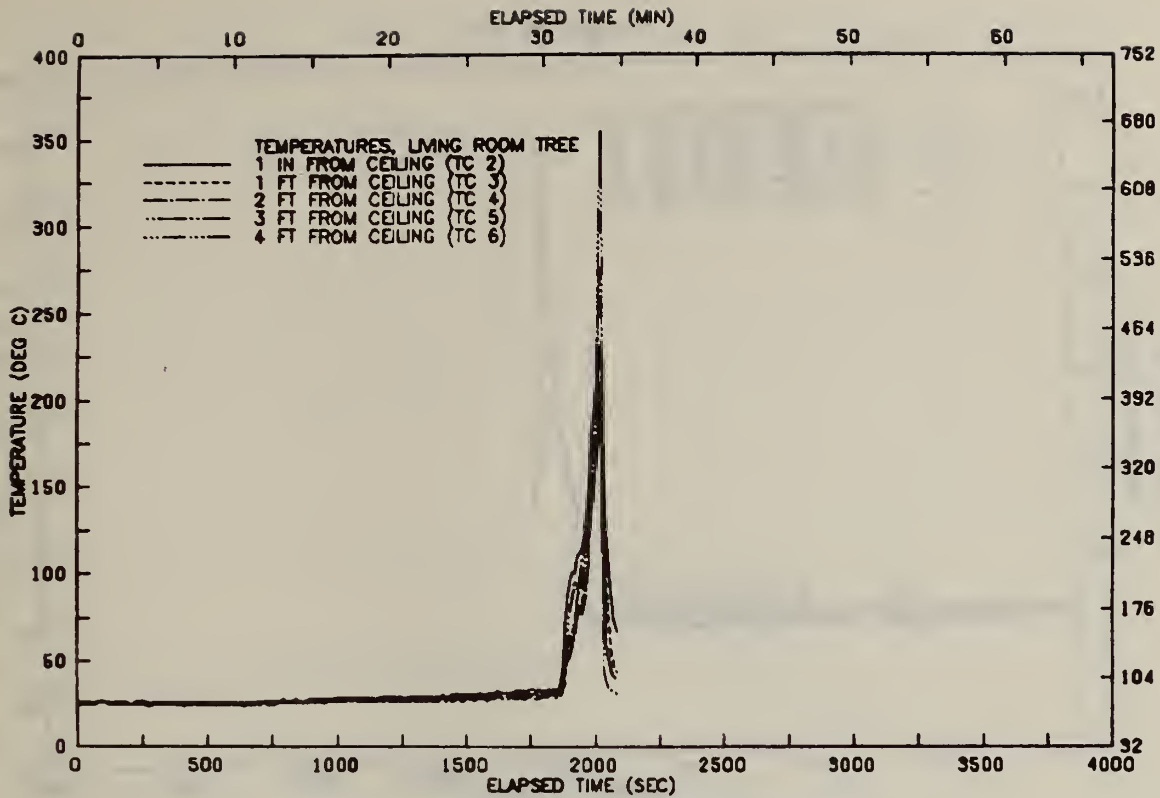

FIGURE A1 VERTICAL TEMP. PROFILE ABOVE CHAIR-TEST 01

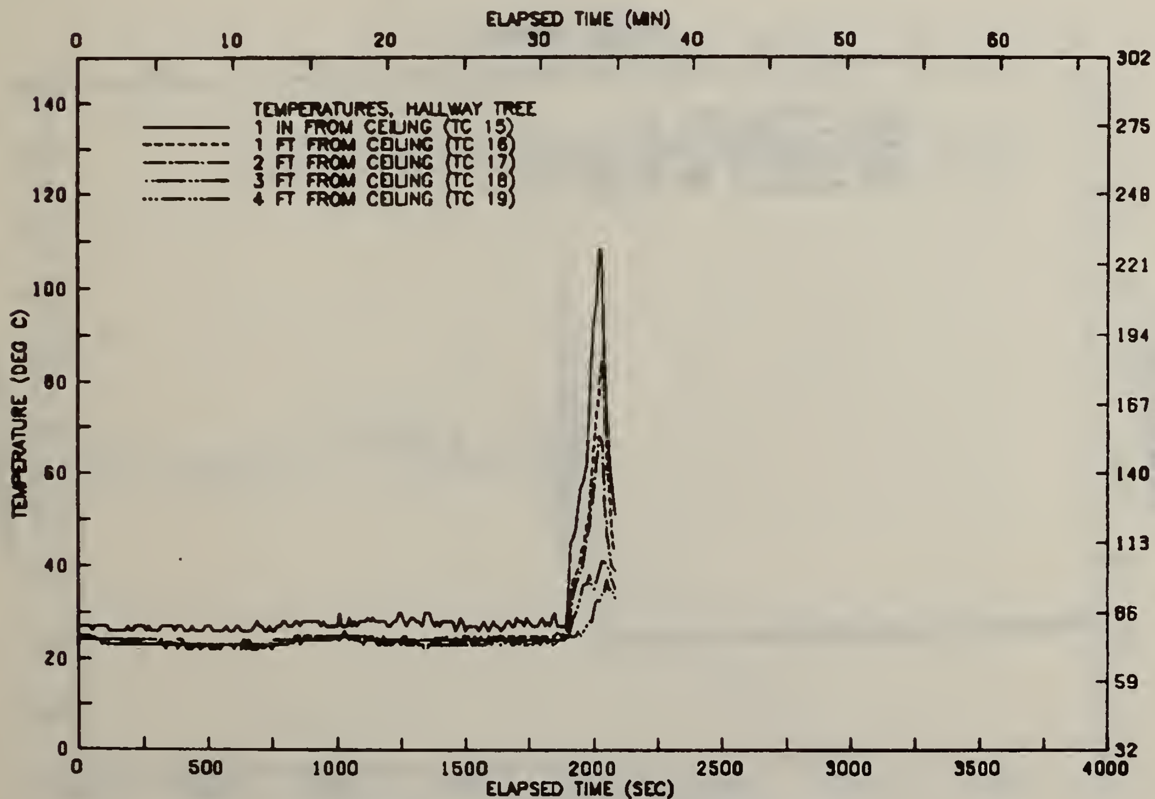

FIGURE A2 VERTICAL TEMP. PROFILE IN HALLWAY-TEST 01

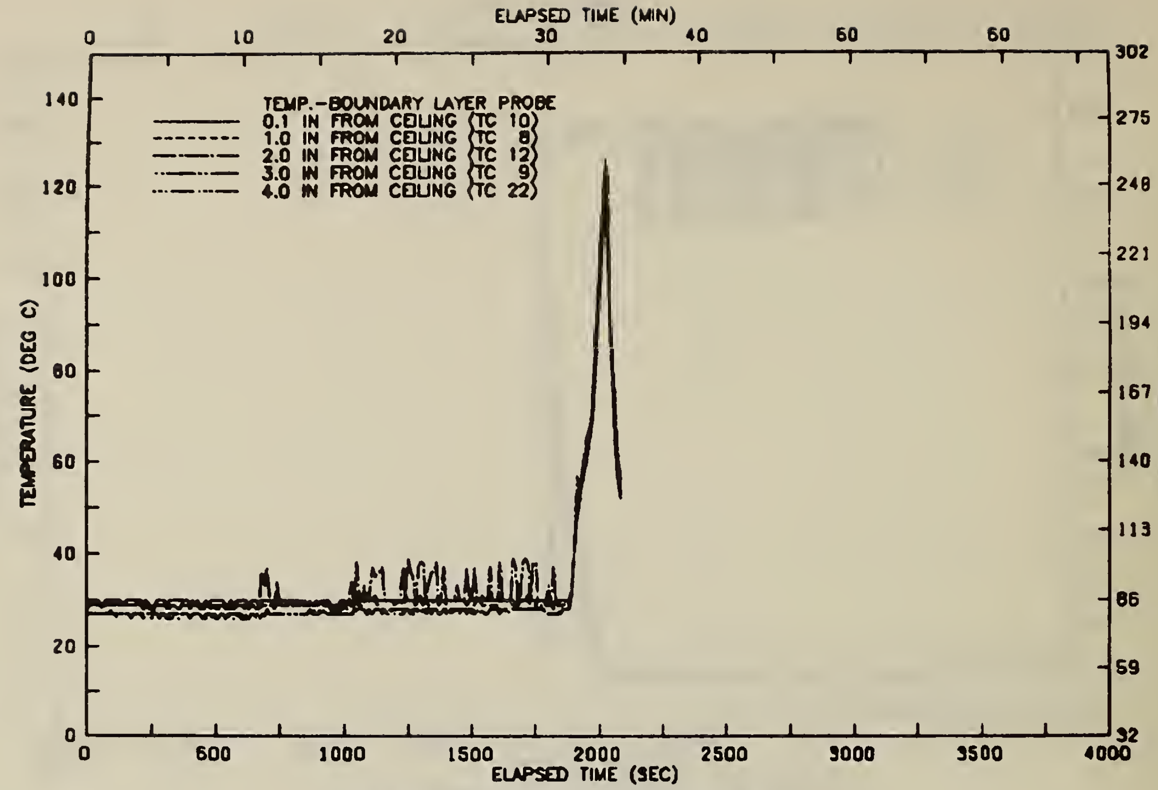

FIGURE A3 VERTICAL TEMP. PROFILE
CEILING BOUNDARY LAYER-TEST 01

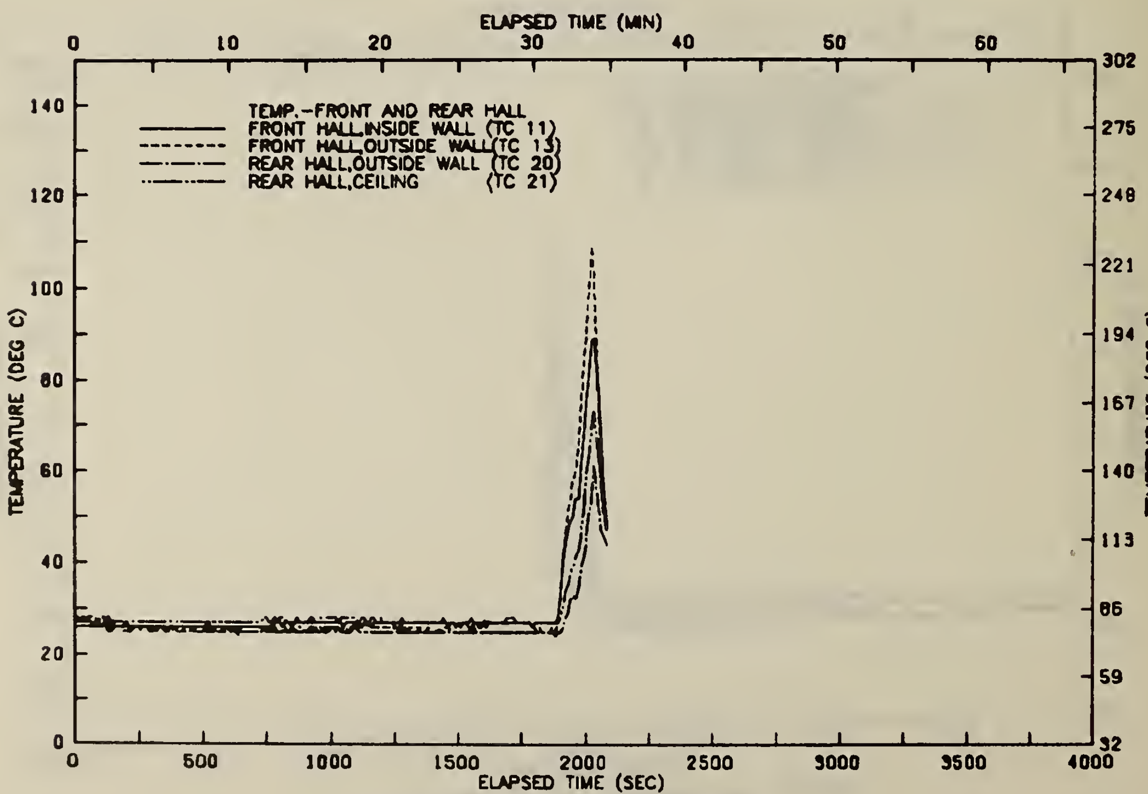

FIGURE A4 TEMP. IN HALLWAY
NEAR DETECTORS-TEST 01

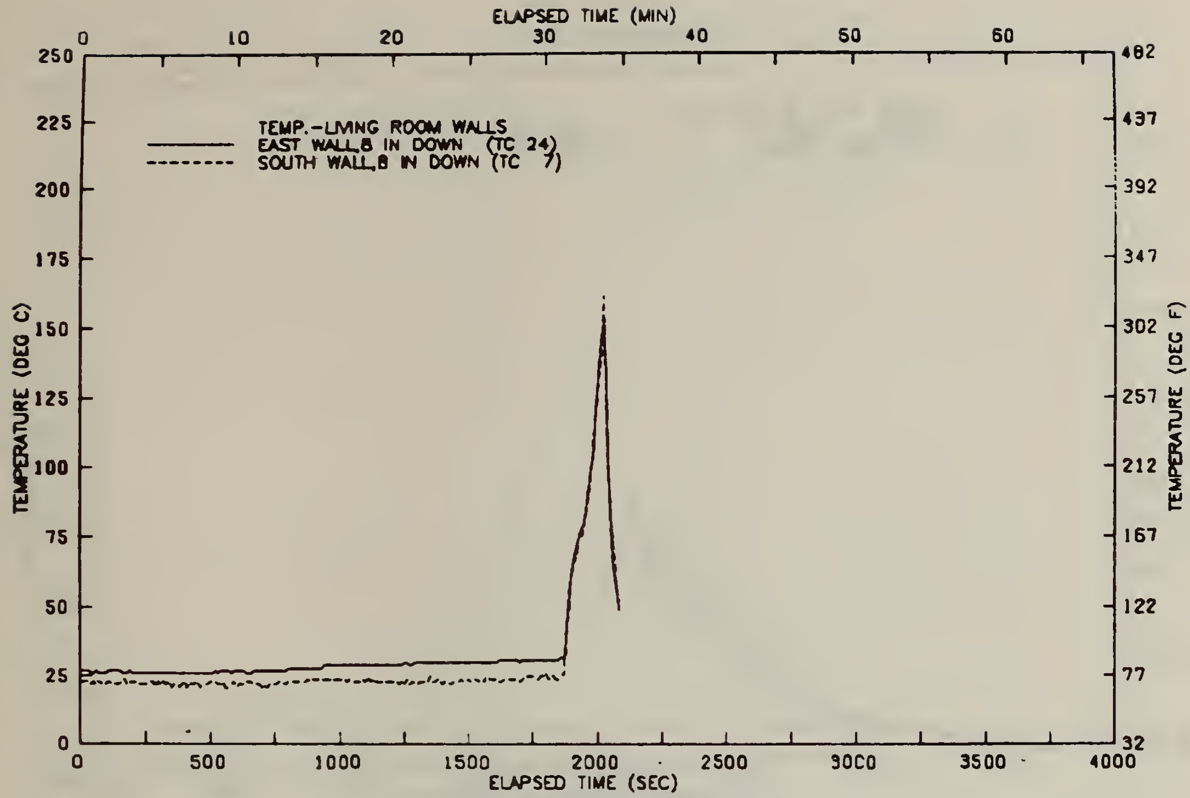

FIGURE A5 TEMPERATURE AT LIVING ROOM WALLS-TEST 01

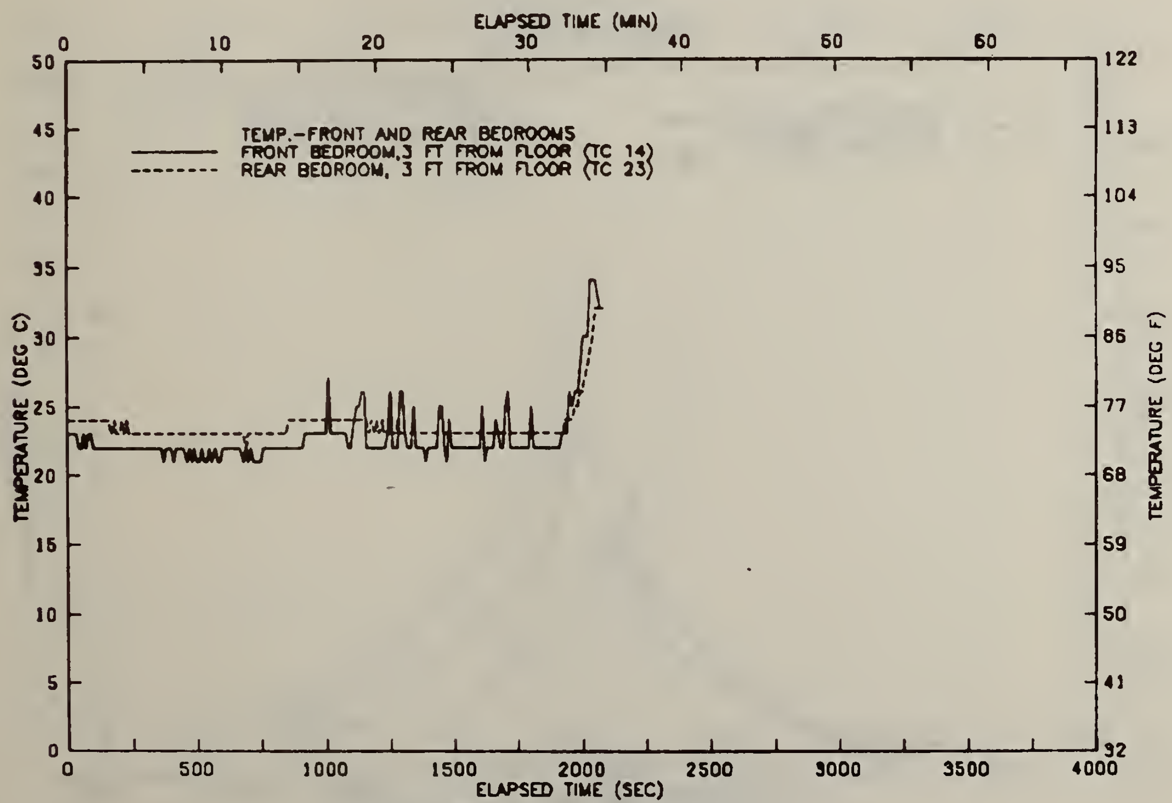

FIGURE A6 TEMP. IN FRONT AND REAR BEDROOMS-TEST 01

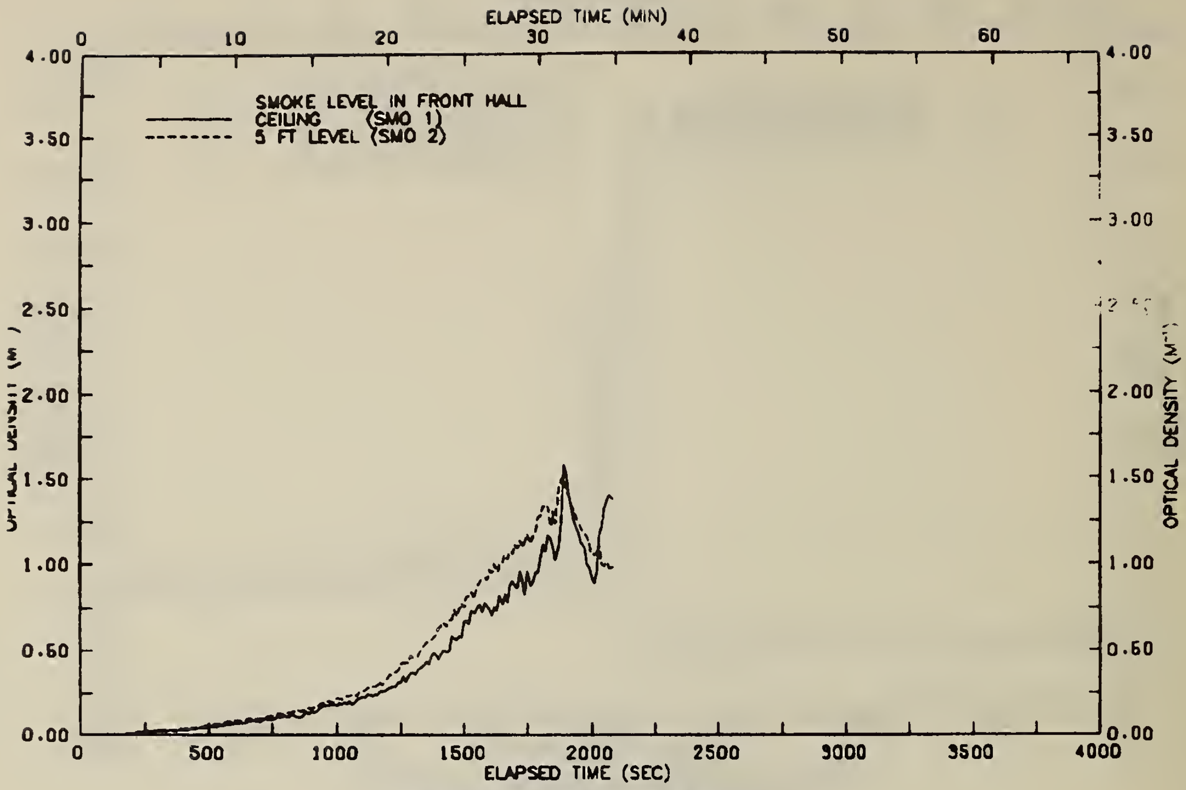

FIGURE A7 SMOKE LEVELS IN FRONT HALLWAY-TEST 01

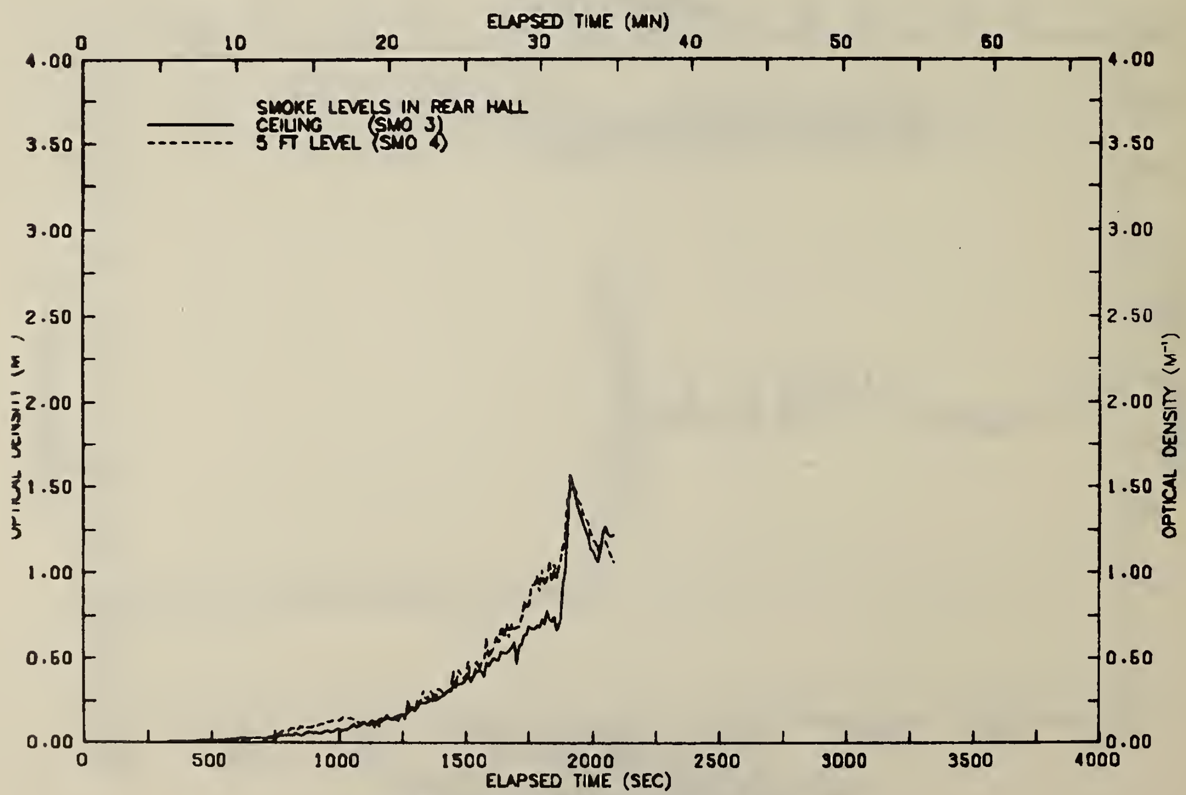

FIGURE A8 SMOKE LEVELS IN REAR HALLWAY-TEST 01

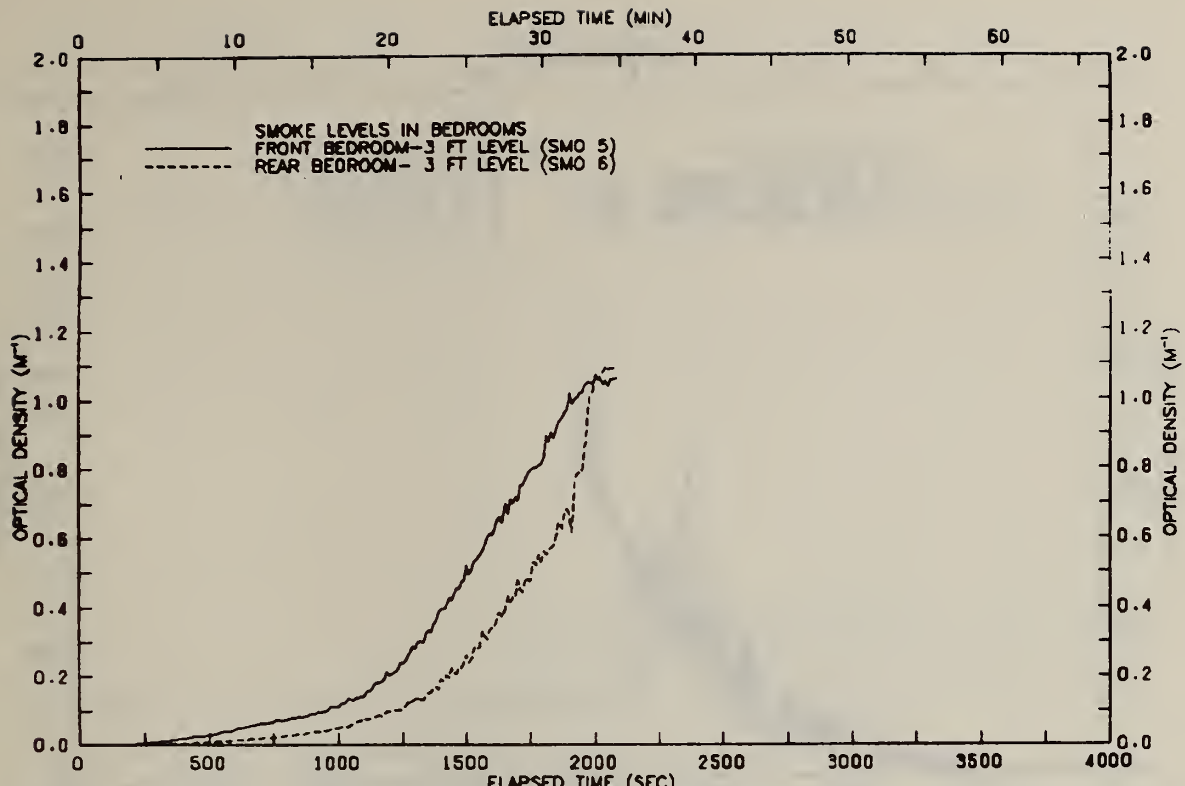

FIGURE A9 SMOKE LEVELS IN BEDROOMS-TEST 01

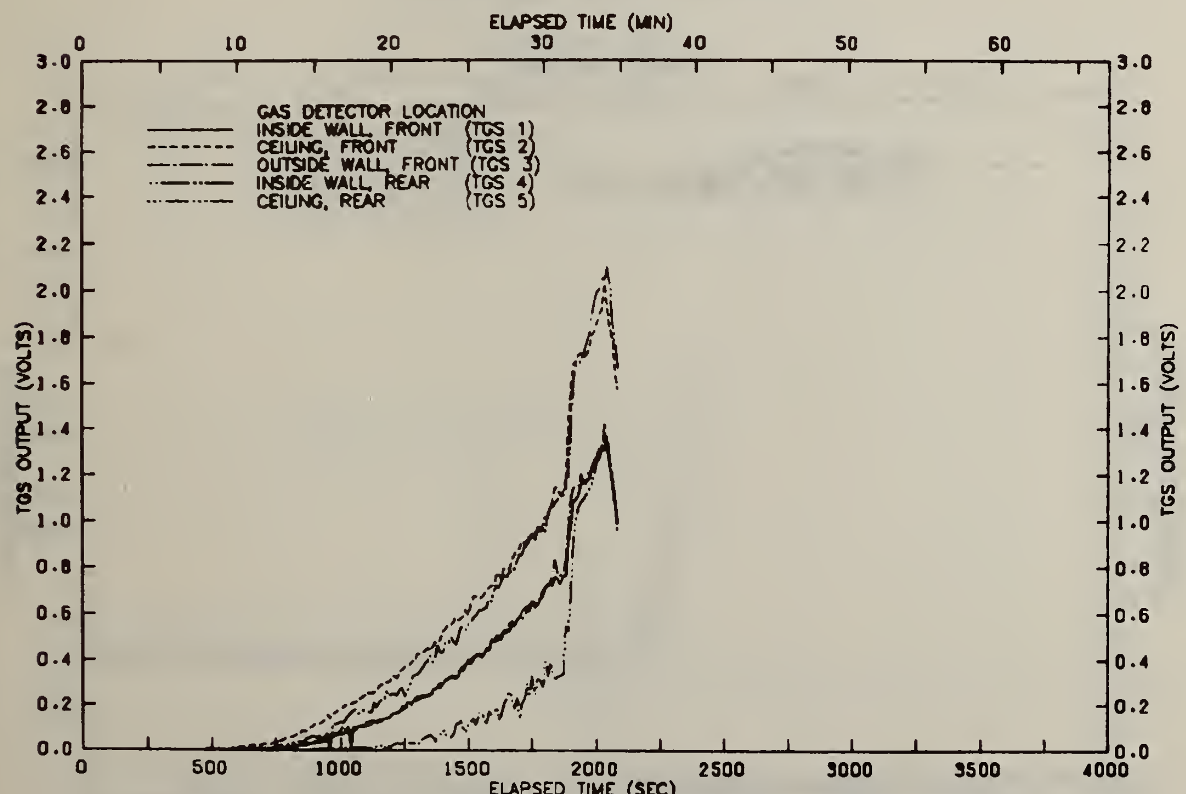

FIGURE A10 GAS DETECTOR OUTPUT VOLTAGE BY LOCATION-TEST 01

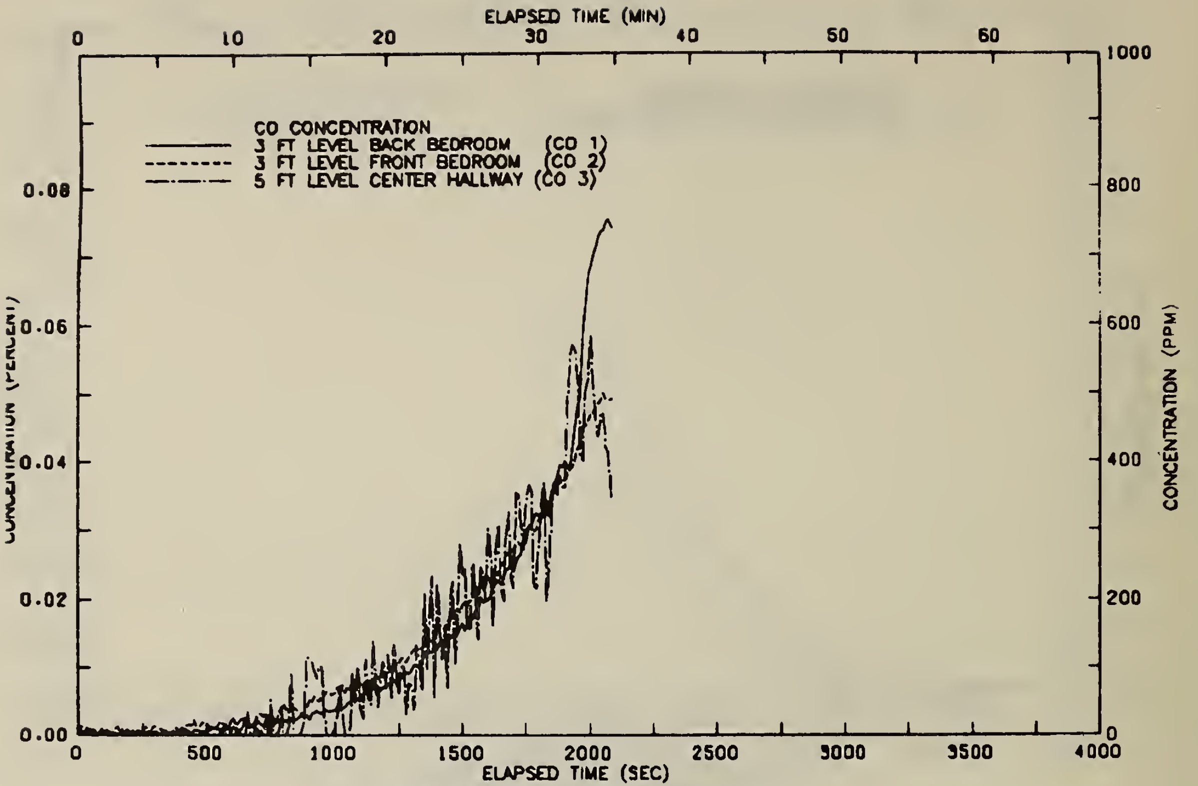

FIGURE A10A CARBON MONOXIDE CONCENTRATION-TEST 01

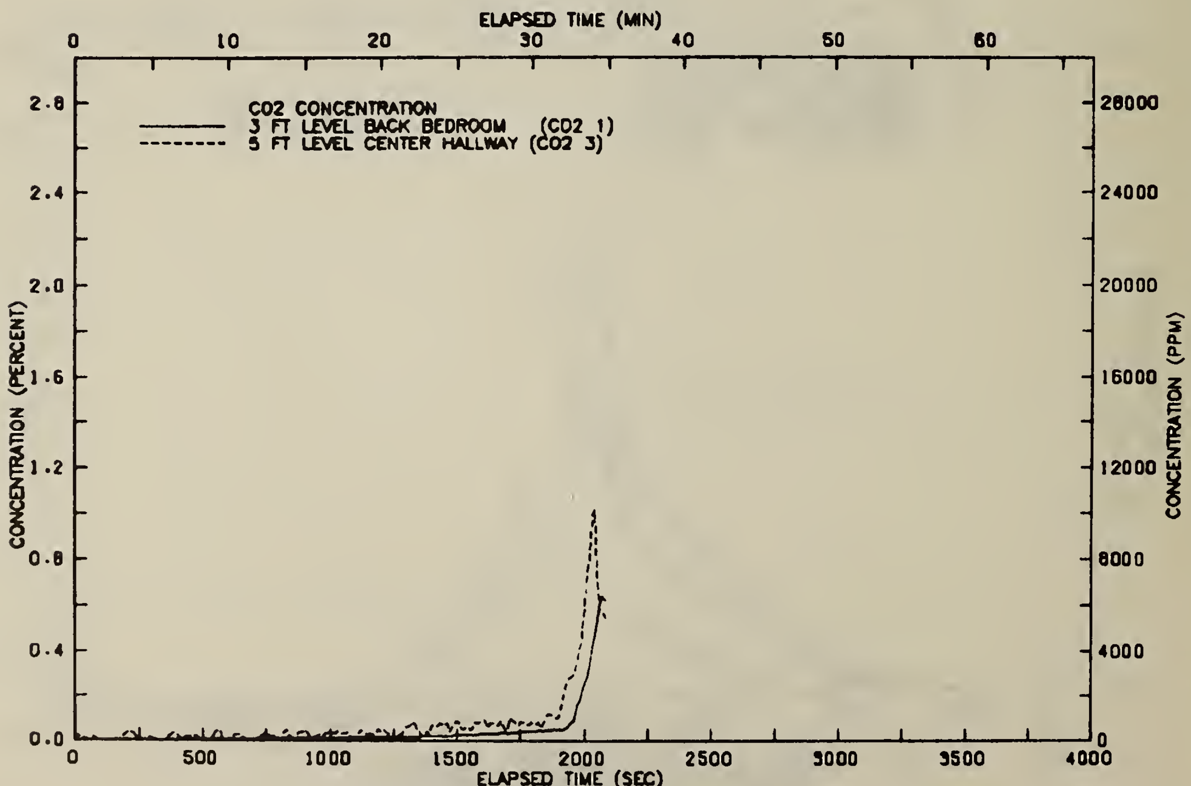

FIGURE A10B CARBON DIOXIDE CONCENTRATION-TEST 01

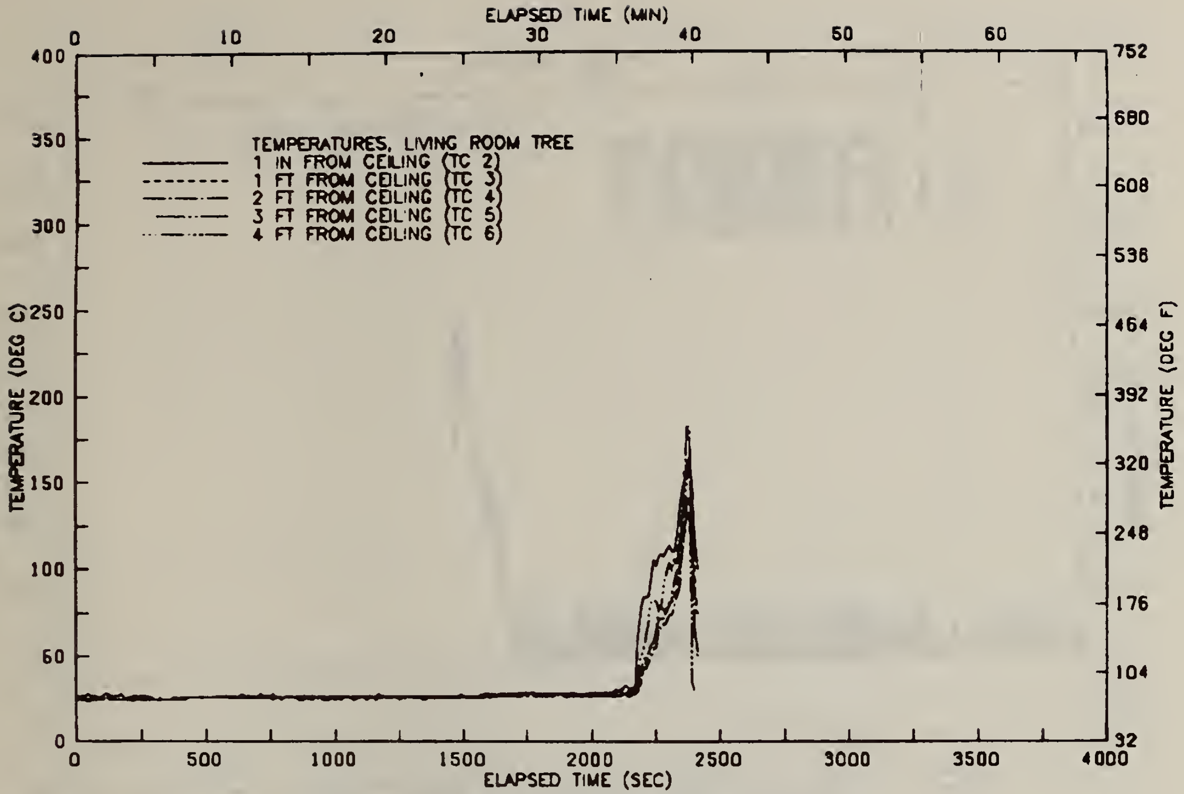

FIGURE A11 VERTICAL TEMP. PROFILE
ABOVE CHAIR-TEST 02

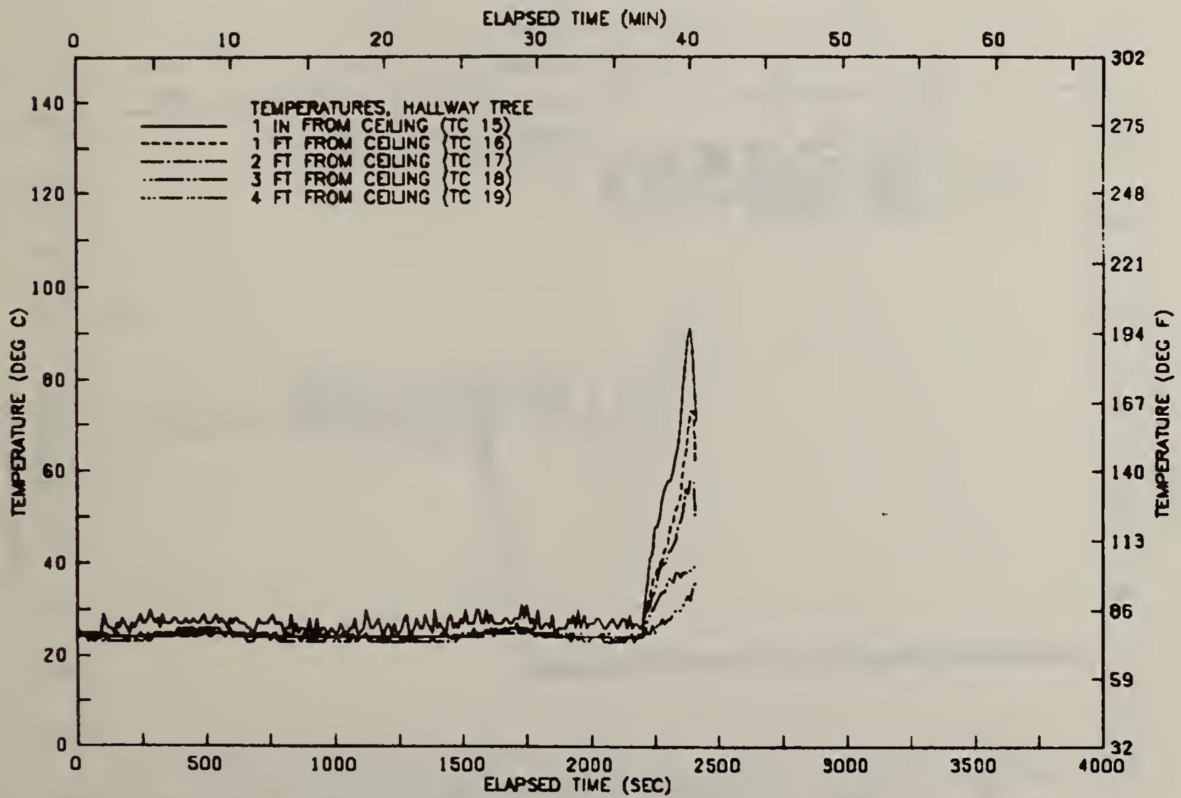

FIGURE A12 VERTICAL TEMP. PROFILE
IN HALLWAY-TEST 02

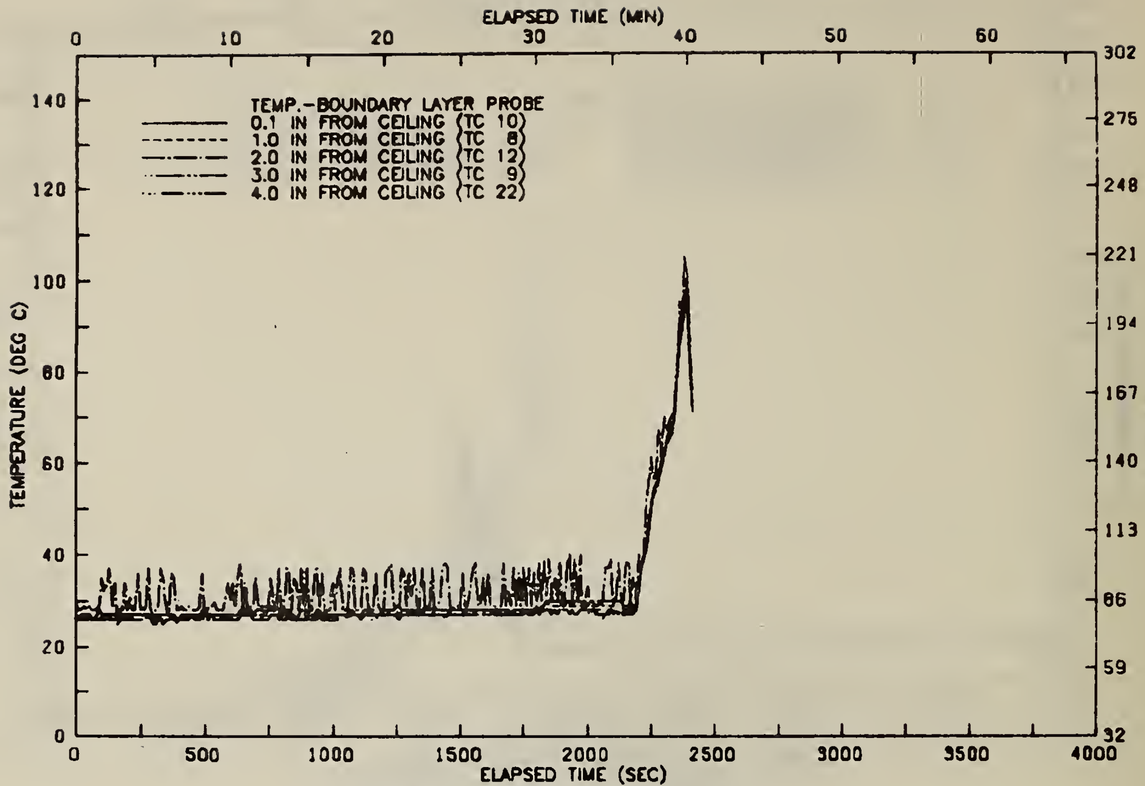

FIGURE A13 VERTICAL TEMP. PROFILE
CEILING BOUNDARY LAYER-TEST 02

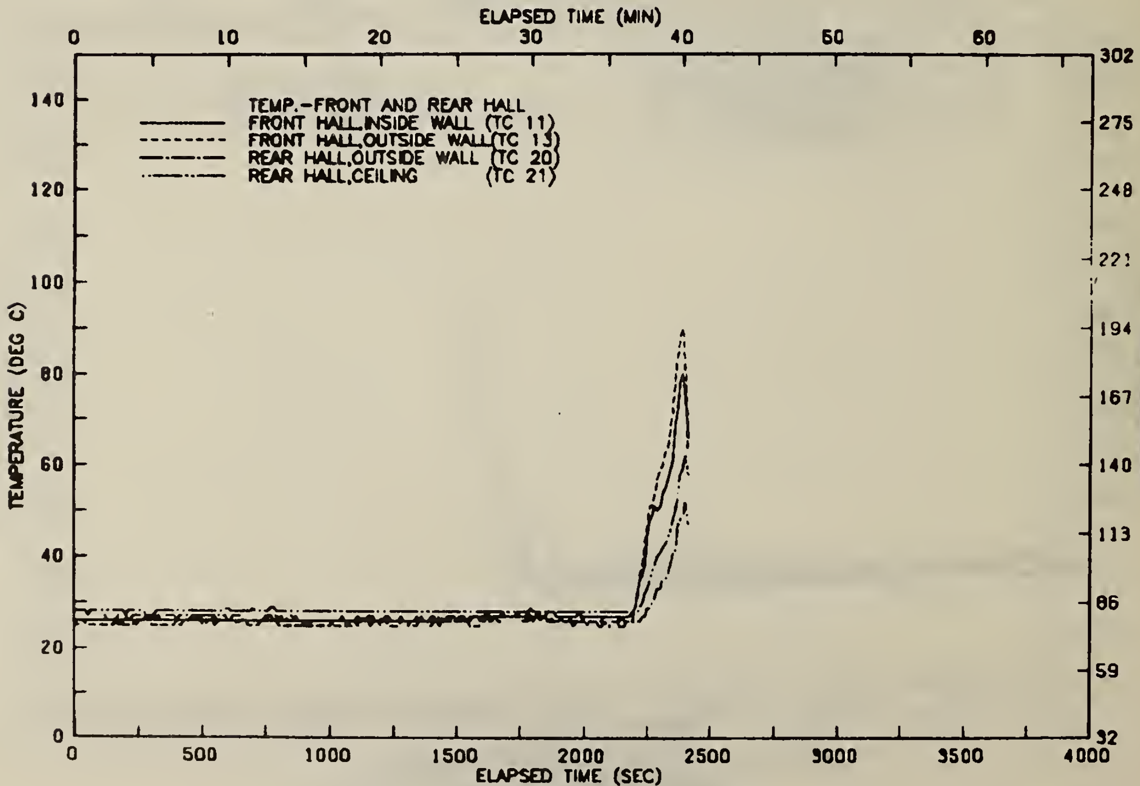

FIGURE A14 TEMP. IN HALLWAY
NEAR DETECTORS-TEST 02

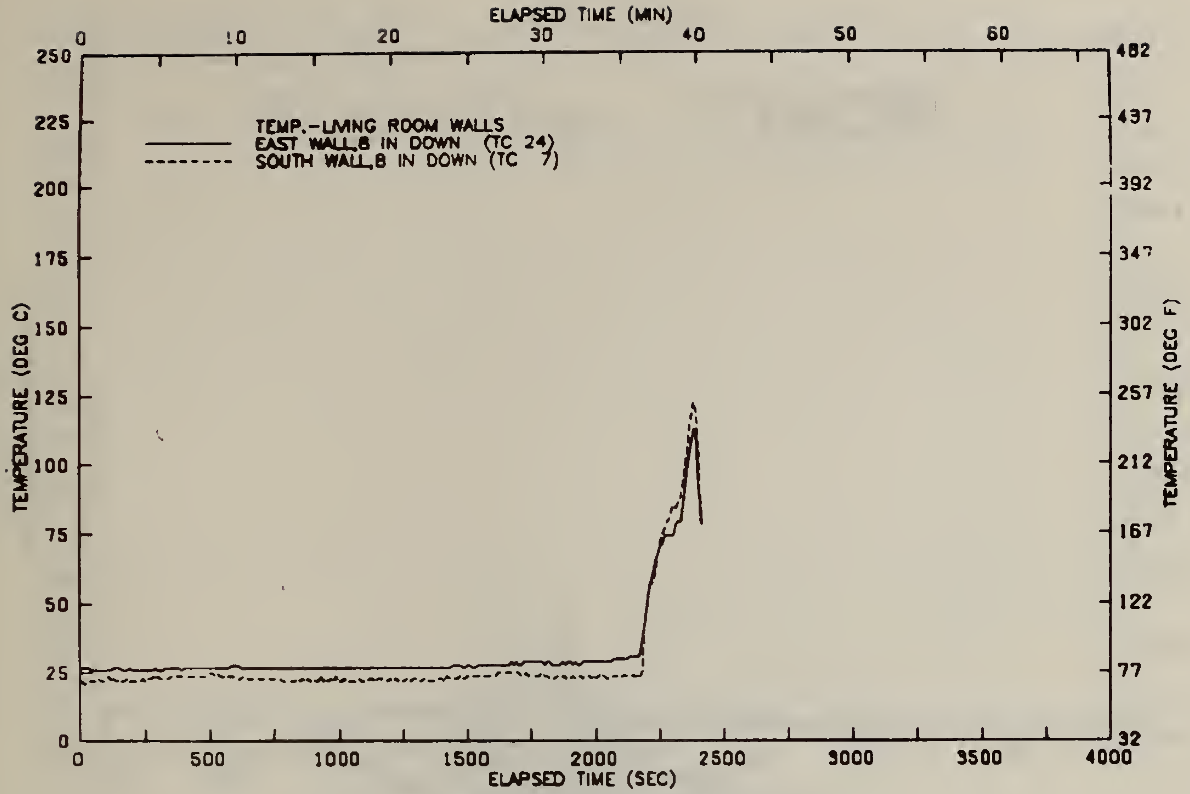

FIGURE A15 TEMPERATURE AT LIVING ROOM WALLS-TEST 02

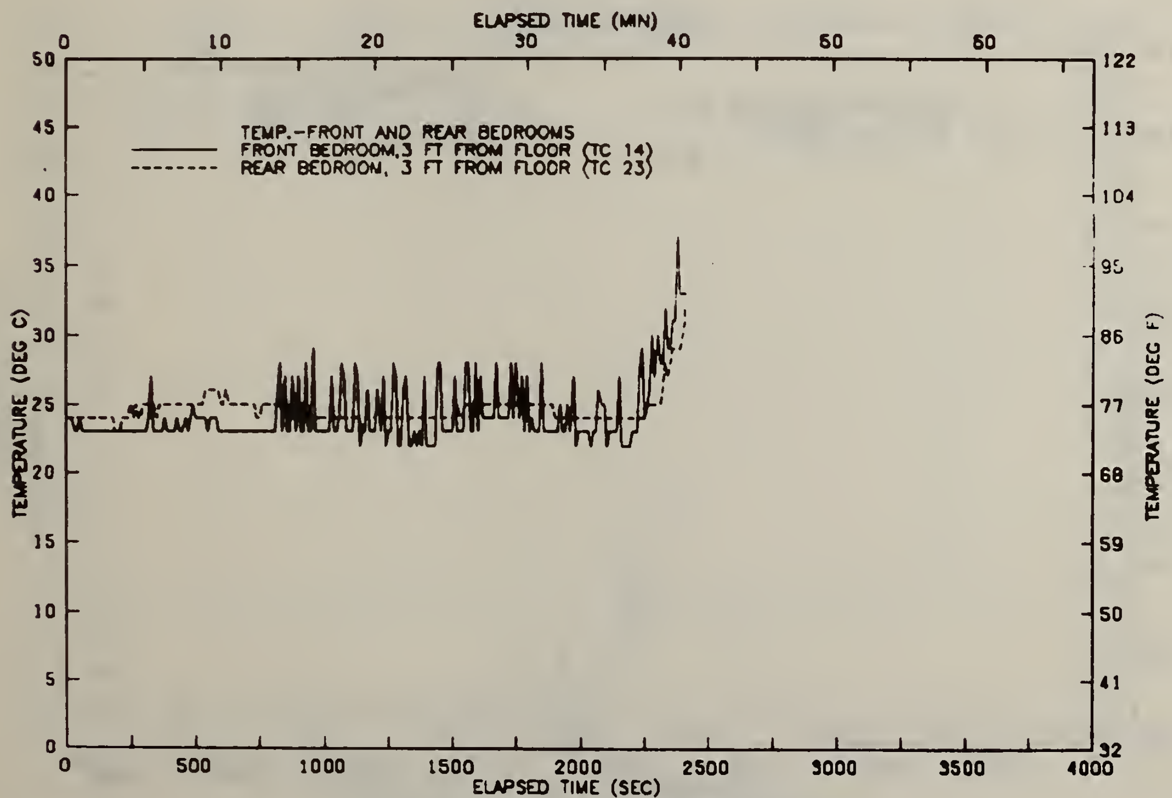

FIGURE A16 TEMP. IN FRONT AND REAR BEDROOMS-TEST 02

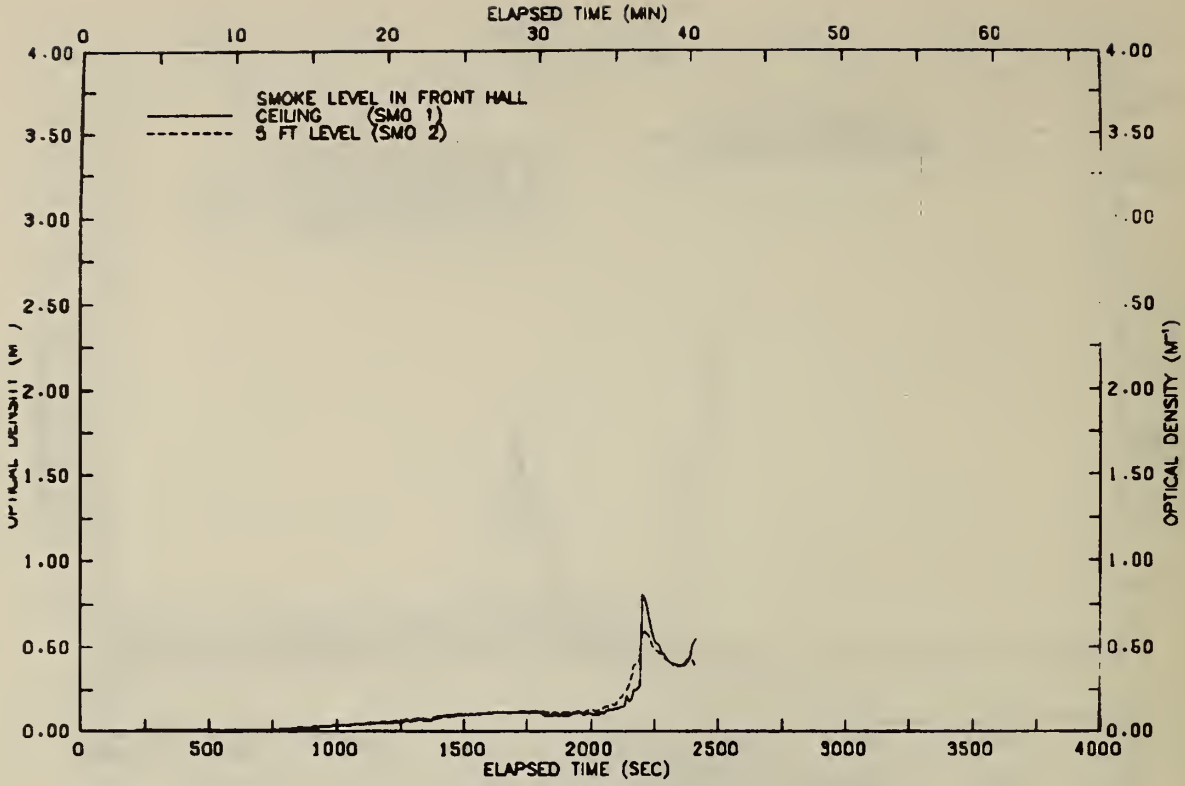

FIGURE A17 SMOKE LEVELS IN FRONT HALLWAY-TEST 02

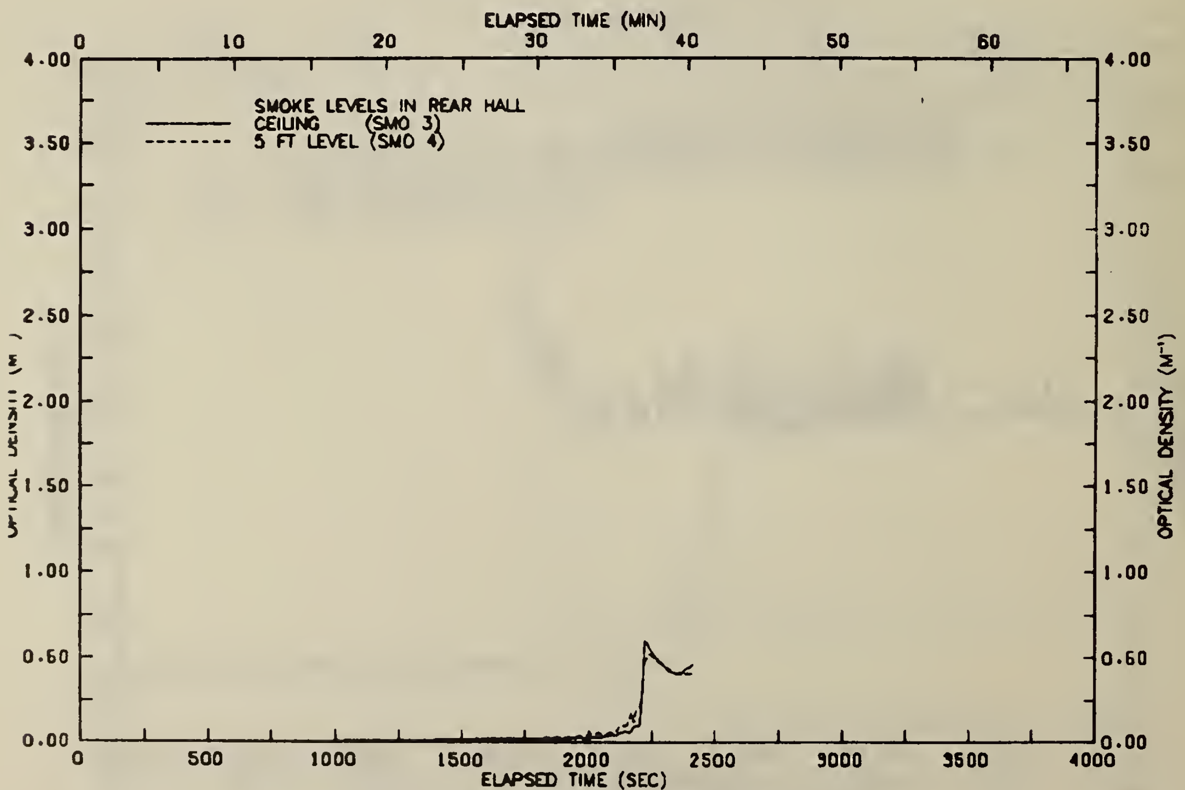

FIGURE A18 SMOKE LEVELS IN REAR HALLWAY-TEST 02

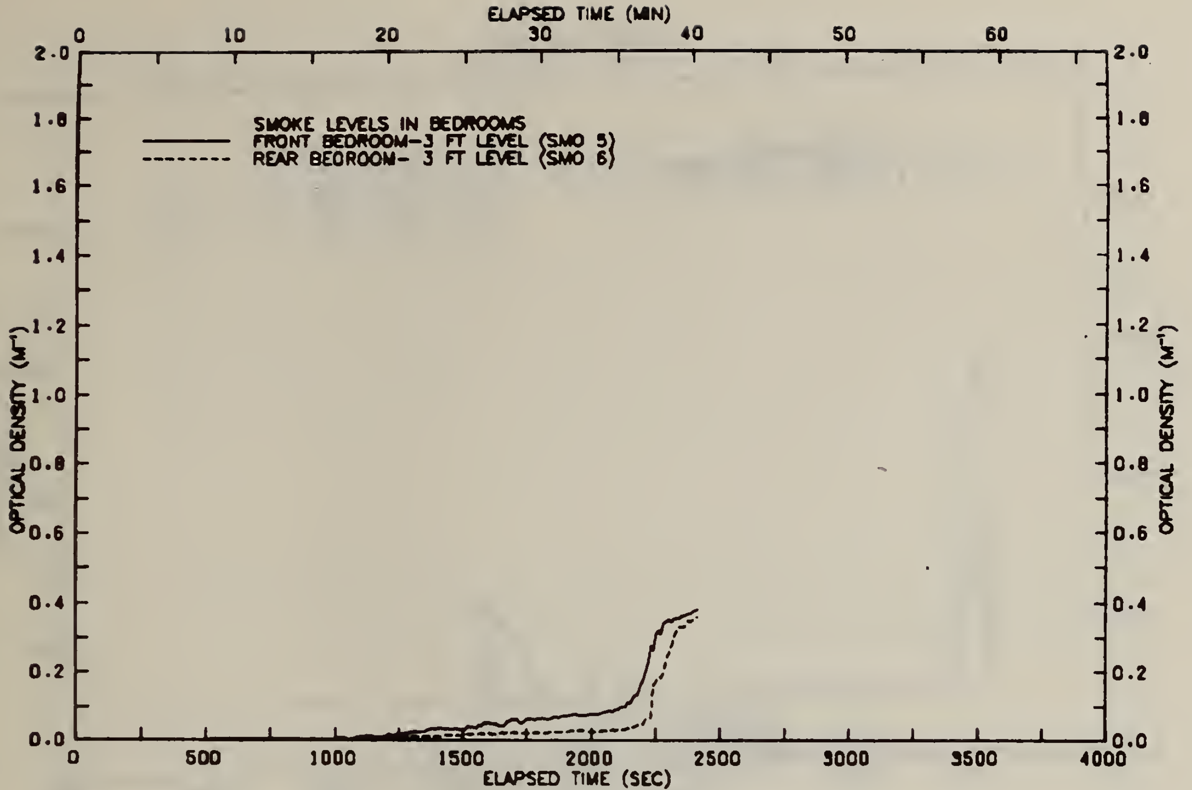

FIGURE A19 SMOKE LEVELS IN BEDROOMS-TEST 02

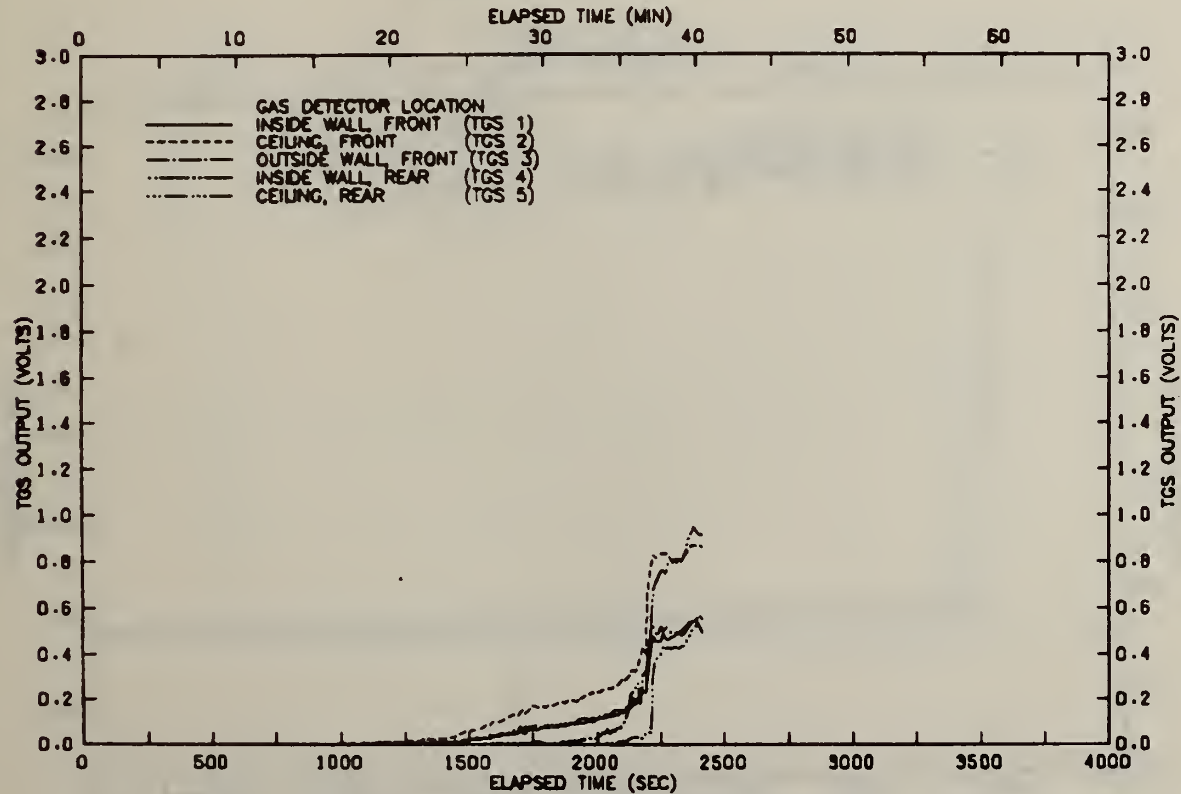

FIGURE A20 GAS DETECTOR OUTPUT VOLTAGE BY LOCATION-TEST 02

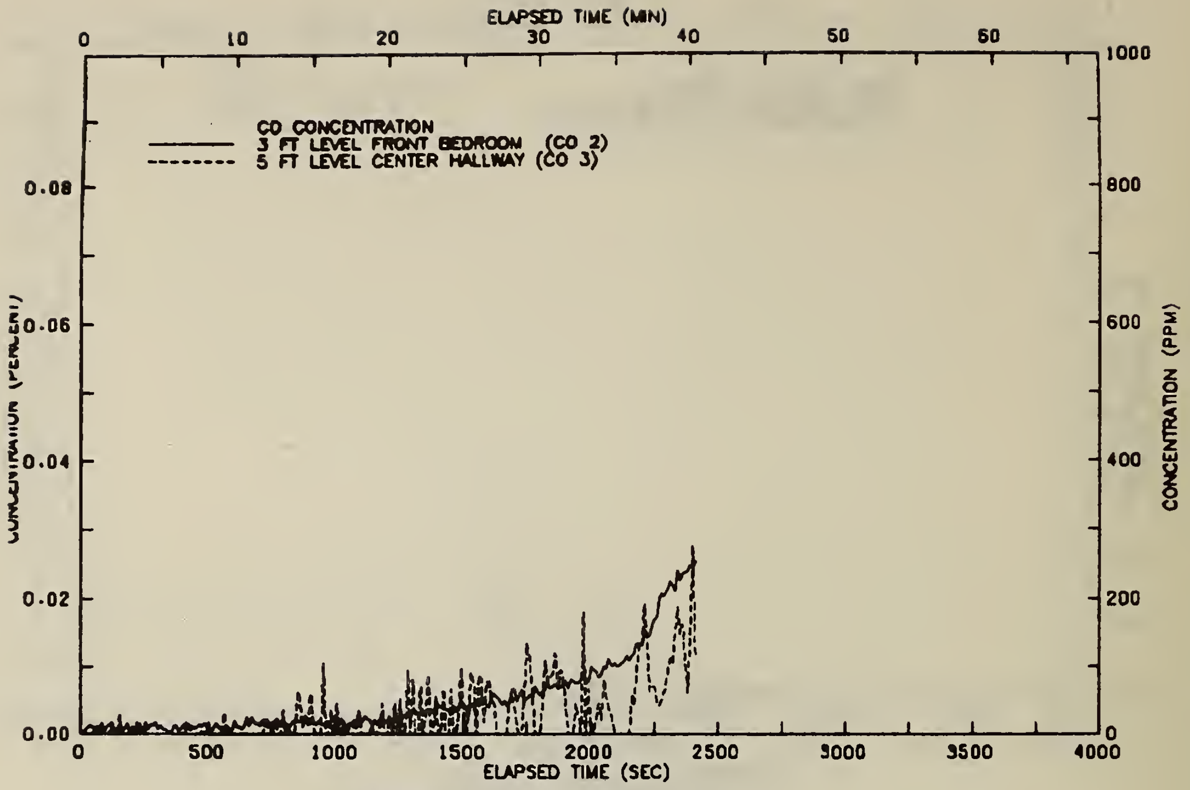

FIGURE A20A CARBON MONOXIDE
CONCENTRATION–TEST 02

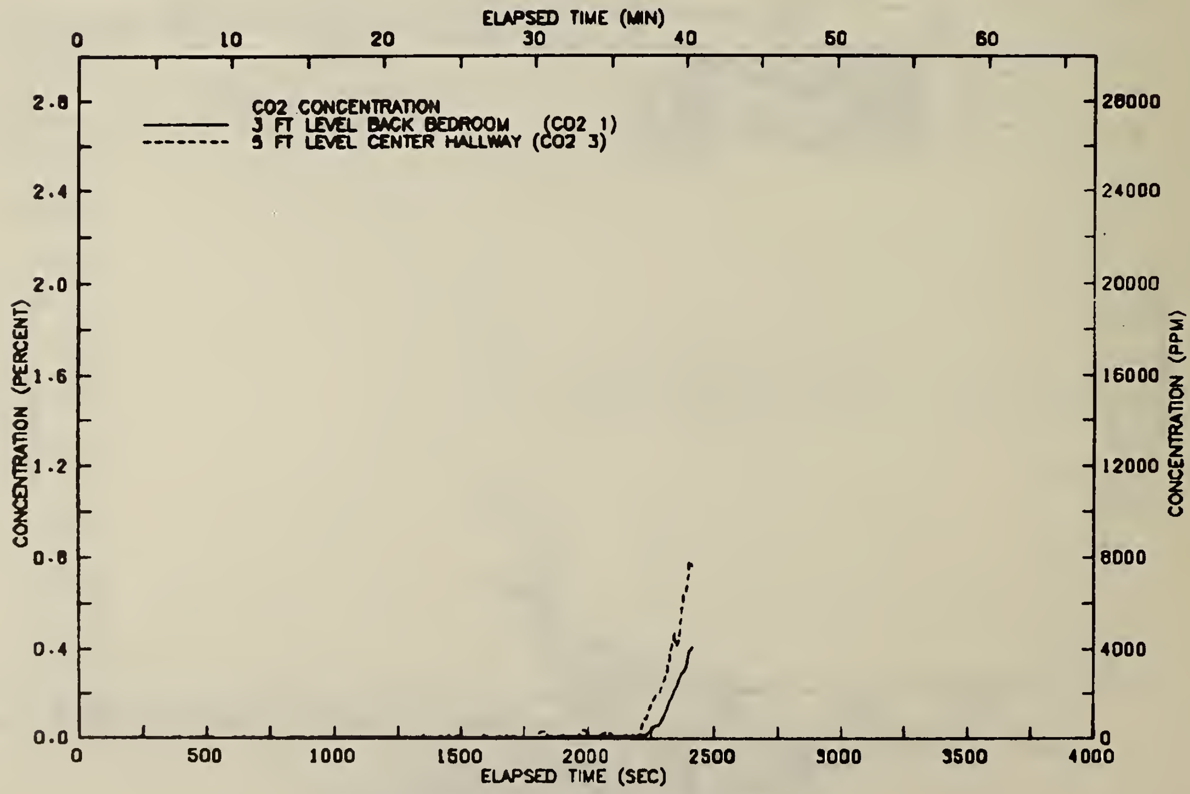

FIGURE A20B CARBON DIOXIDE
CONCENTRATION–TEST 02

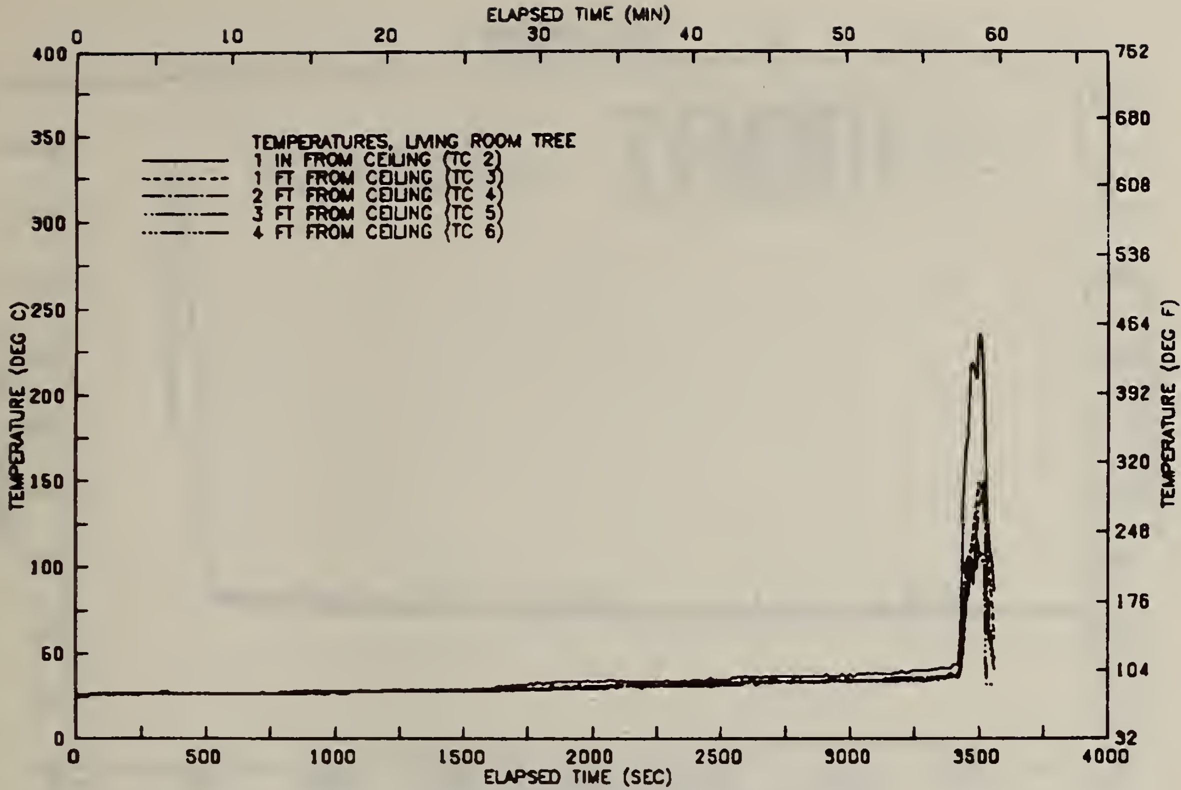

FIGURE A21 VERTICAL TEMP. PROFILE ABOVE CHAIR-TEST 03

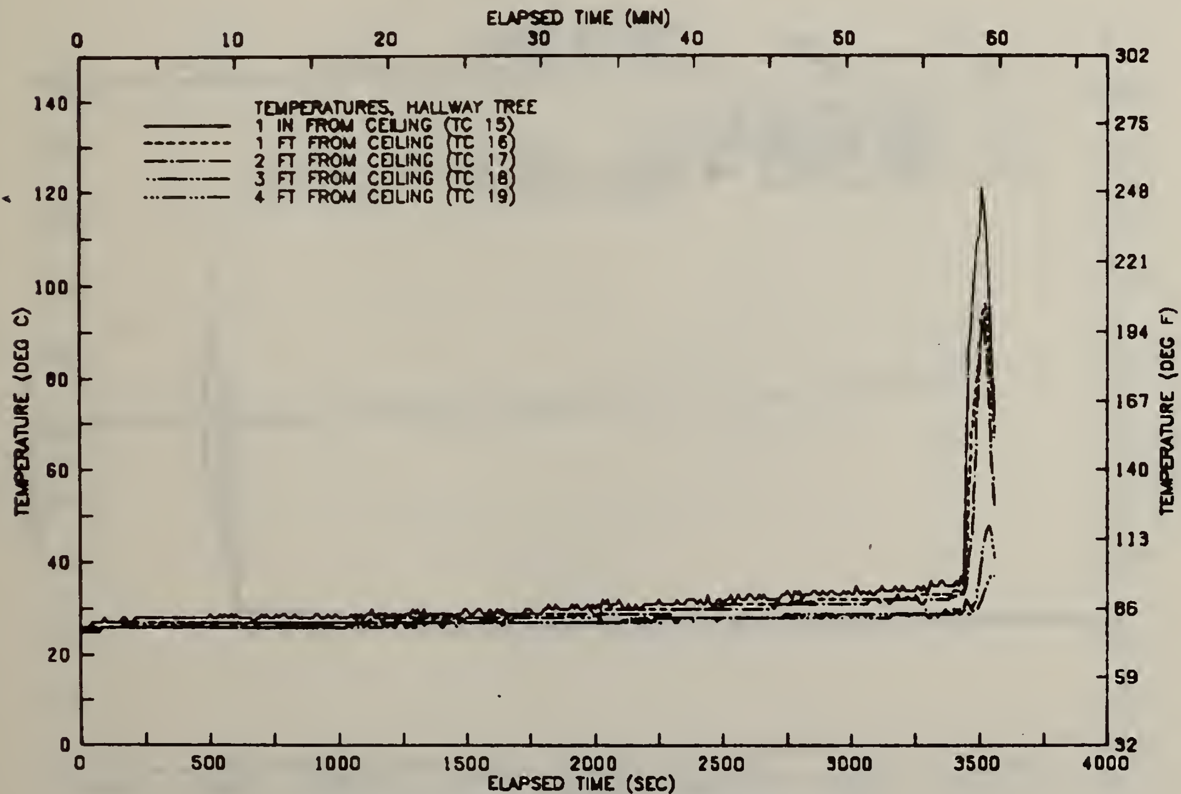

FIGURE A22 VERTICAL TEMP. PROFILE IN HALLWAY-TEST 03

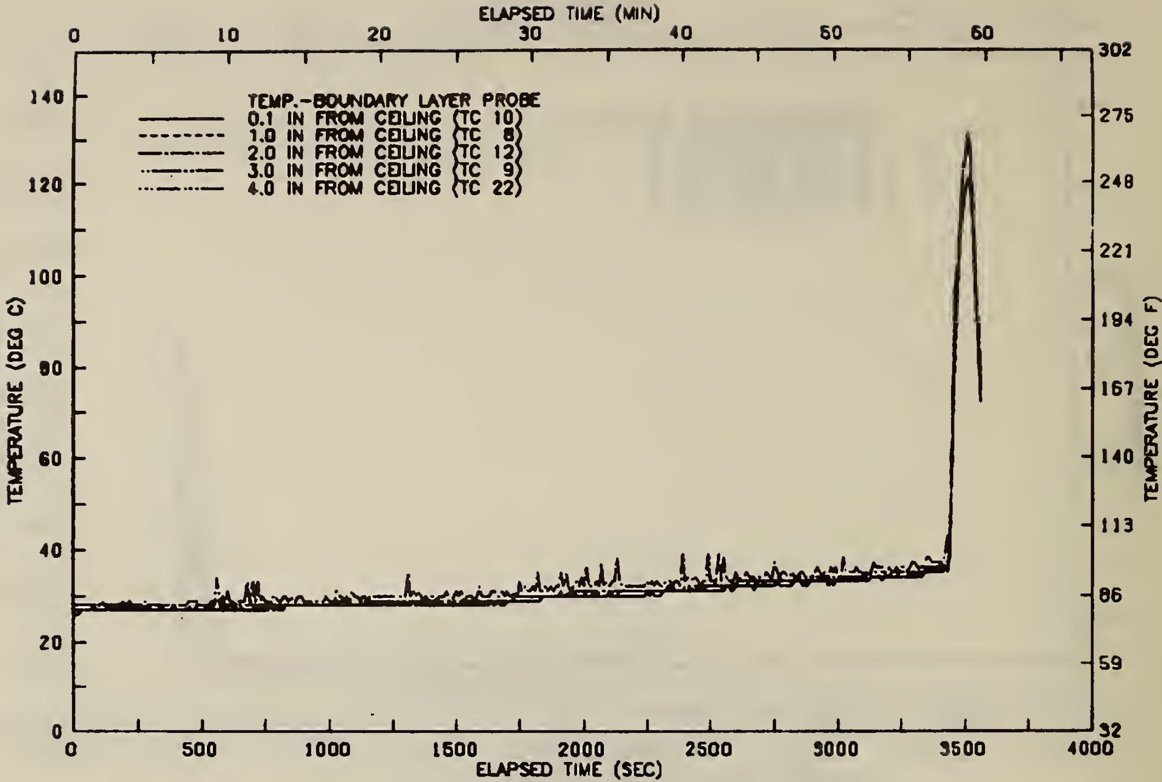

FIGURE A23 VERTICAL TEMP. PROFILE
CEILING BOUNDARY LAYER-TEST 03

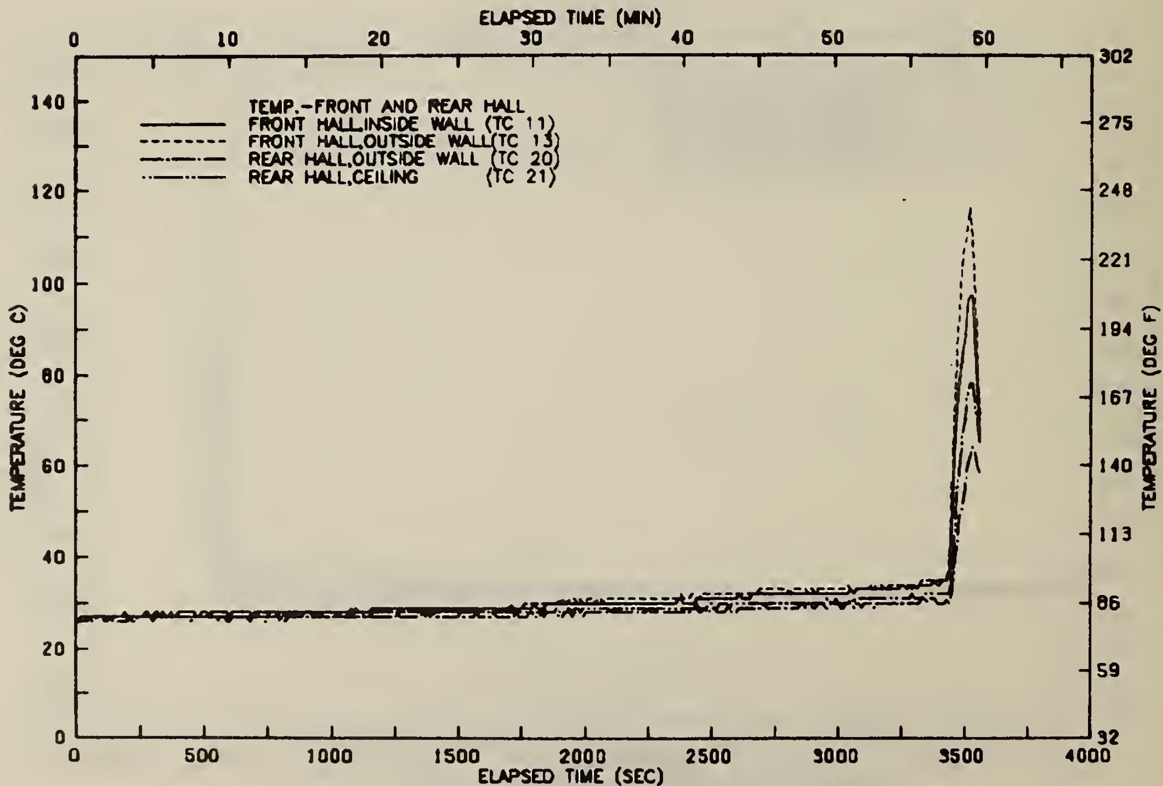

FIGURE A24 TEMP. IN HALLWAY
NEAR DETECTORS-TEST 03

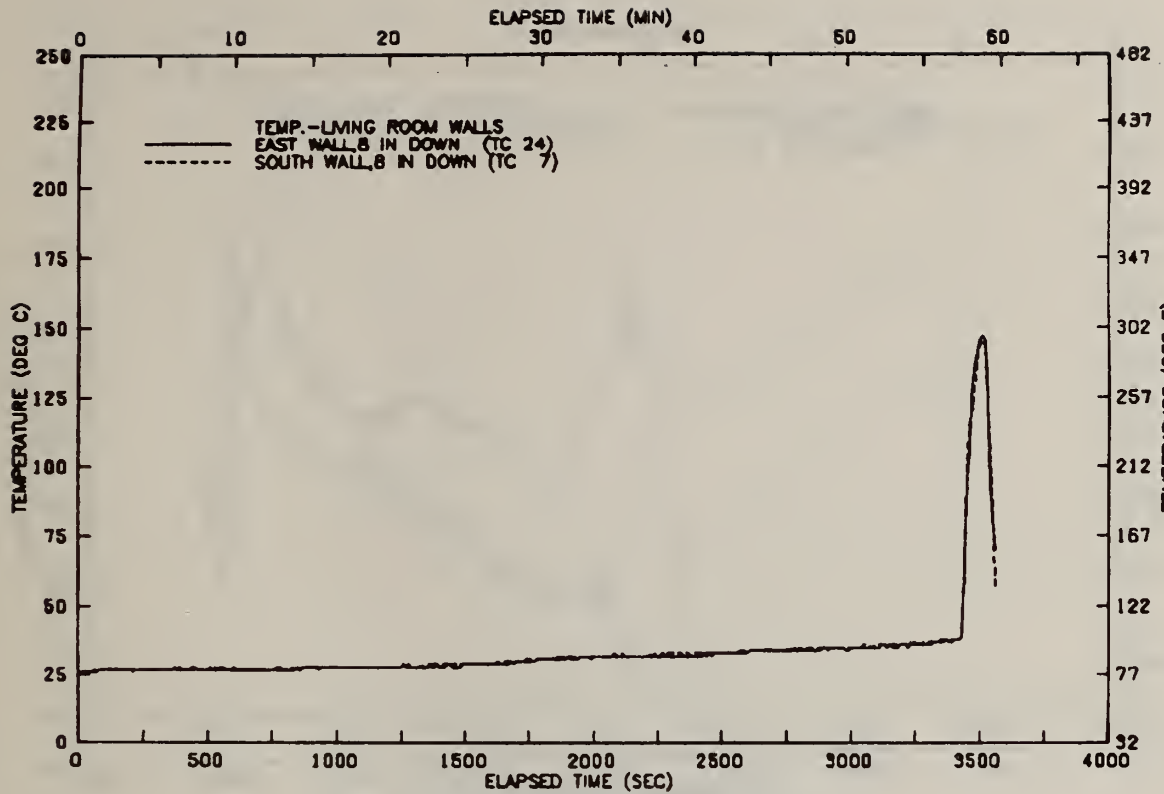

FIGURE A25 TEMPERATURE AT LIVING ROOM WALLS-TEST 03

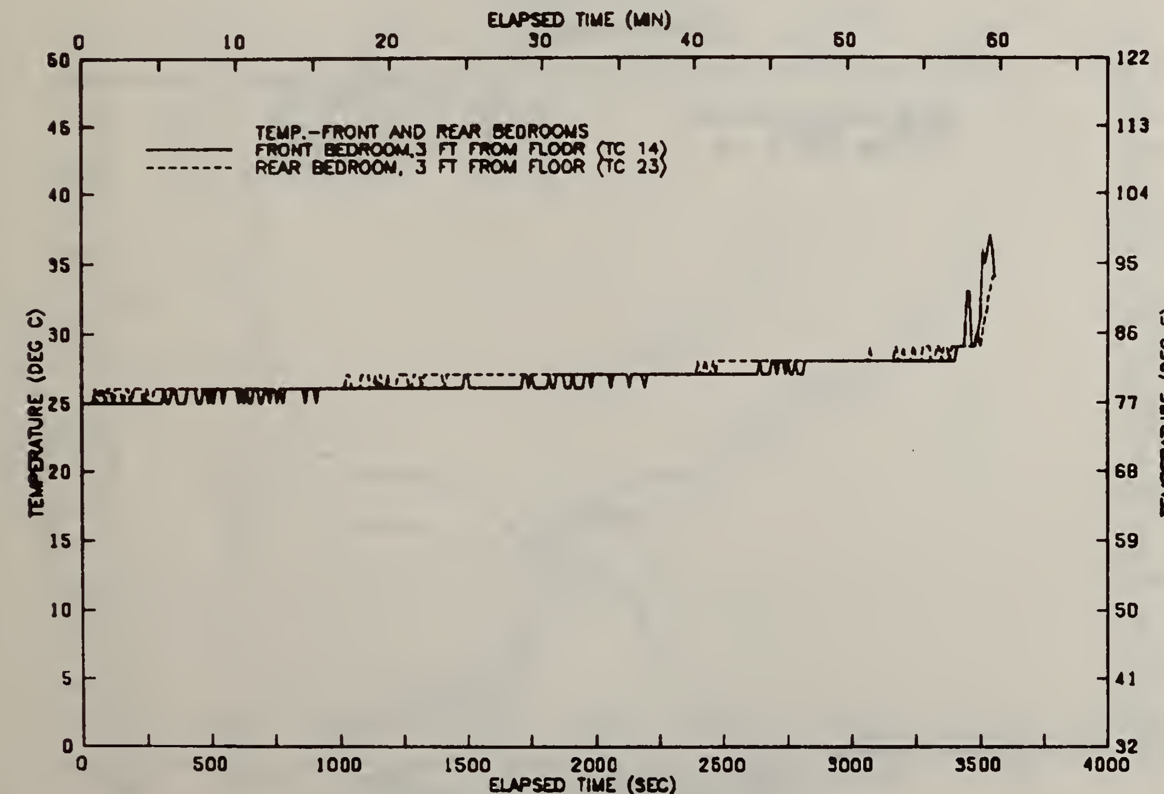

FIGURE A26 TEMP. IN FRONT AND REAR BEDROOMS-TEST 03

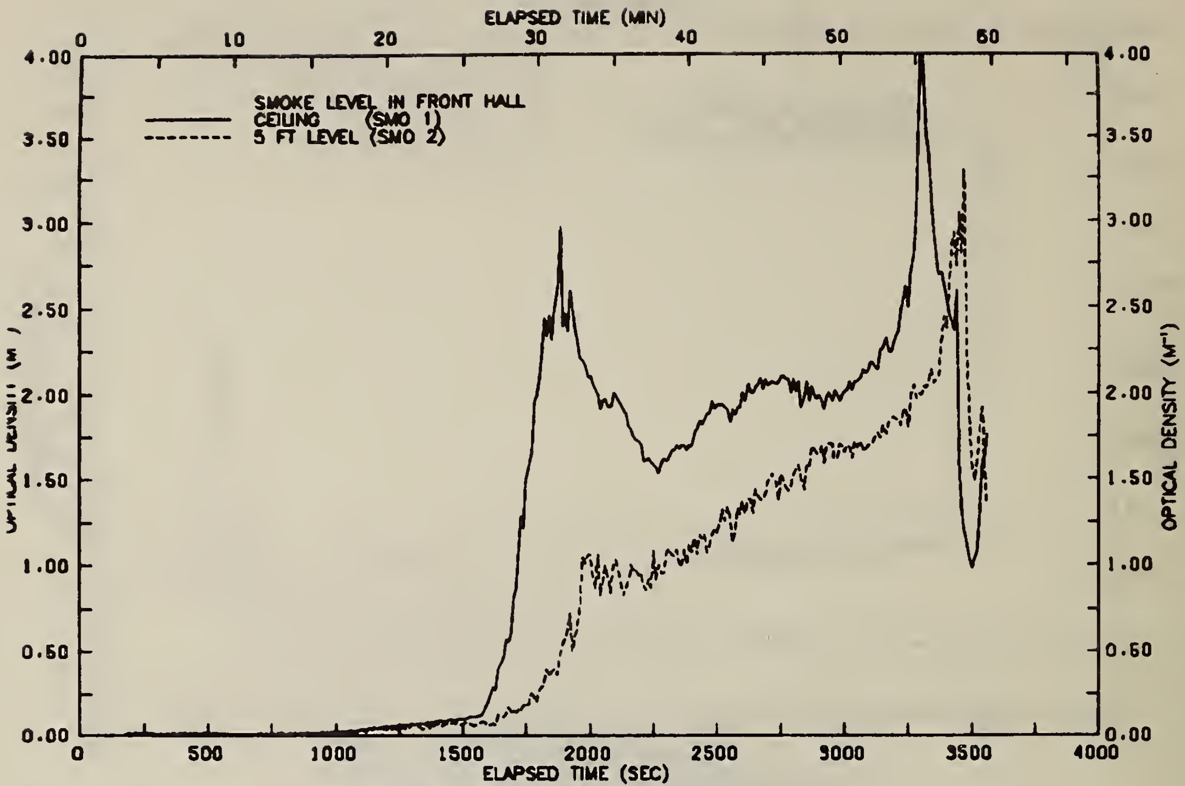

FIGURE A27 SMOKE LEVELS IN FRONT HALLWAY-TEST 03

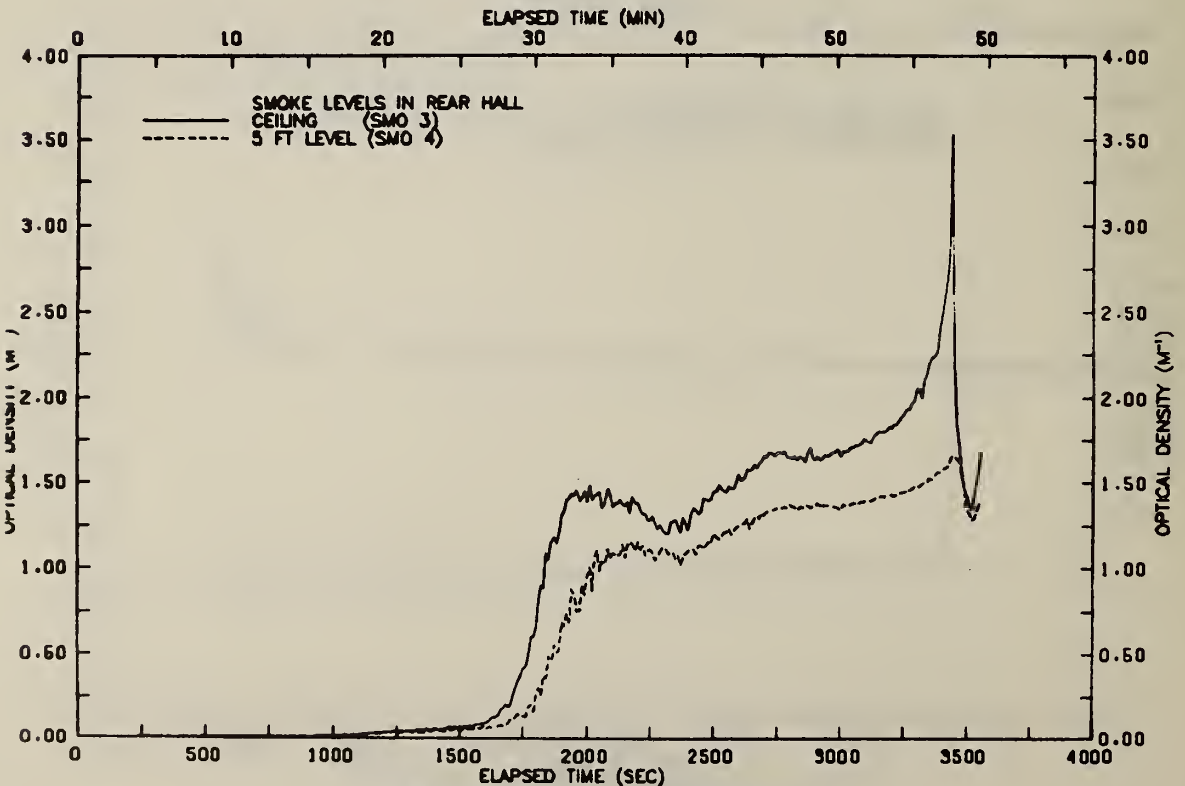

FIGURE A28 SMOKE LEVELS IN REAR HALLWAY-TEST 03

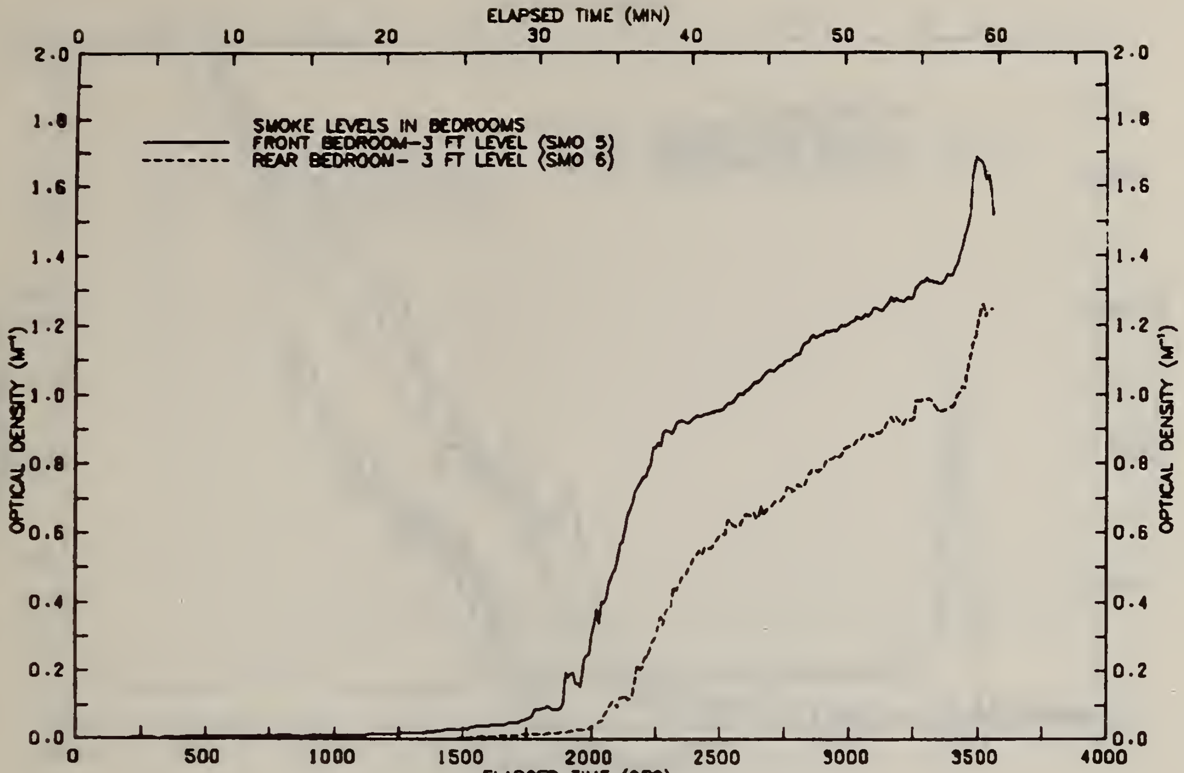

FIGURE A29 SMOKE LEVELS IN BEDROOMS-TEST 03

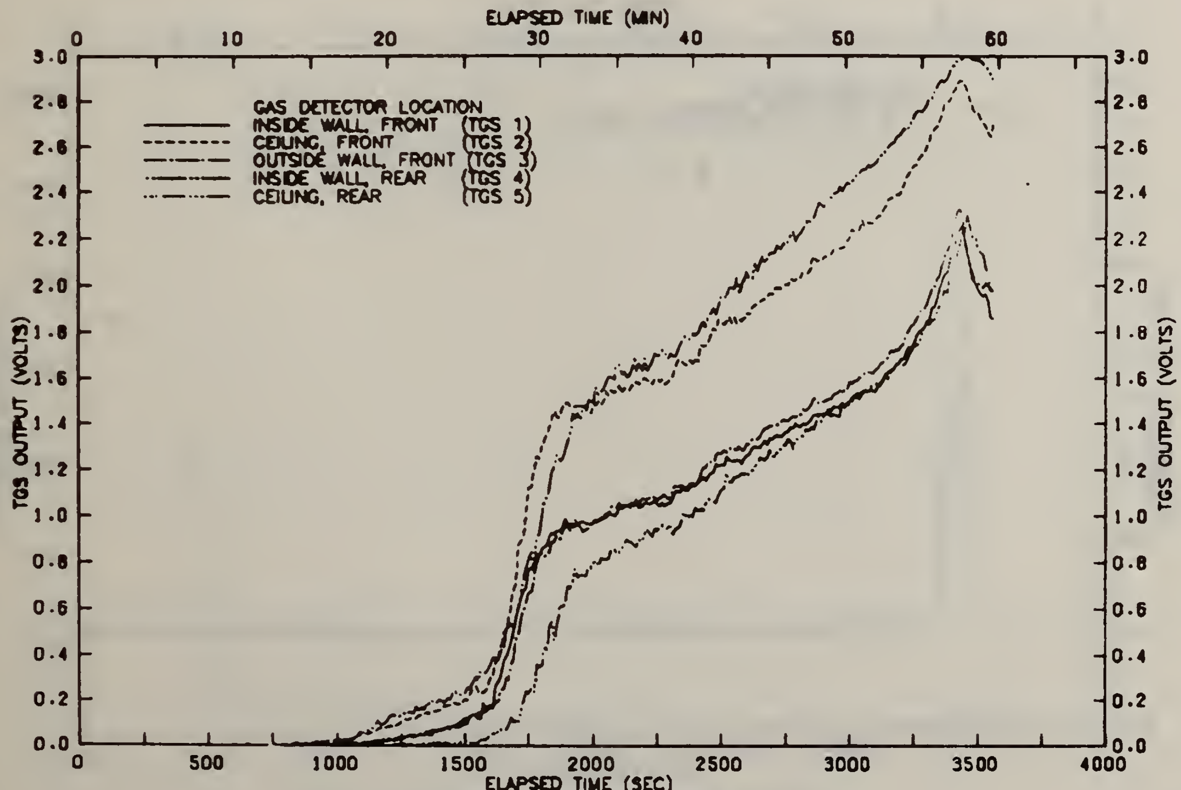

FIGURE A30 GAS DETECTOR OUTPUT VOLTAGE BY LOCATION-TEST 03

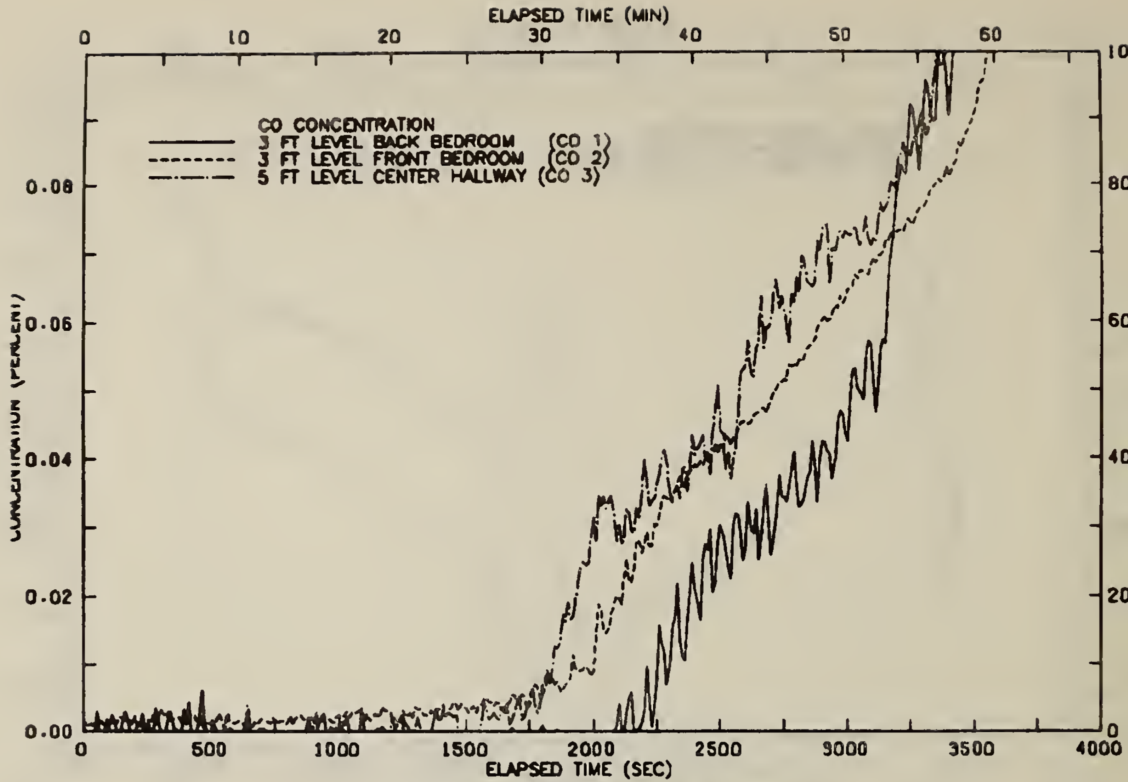

FIGURE A30A CARBON MONOXIDE CONCENTRATION-TEST 03

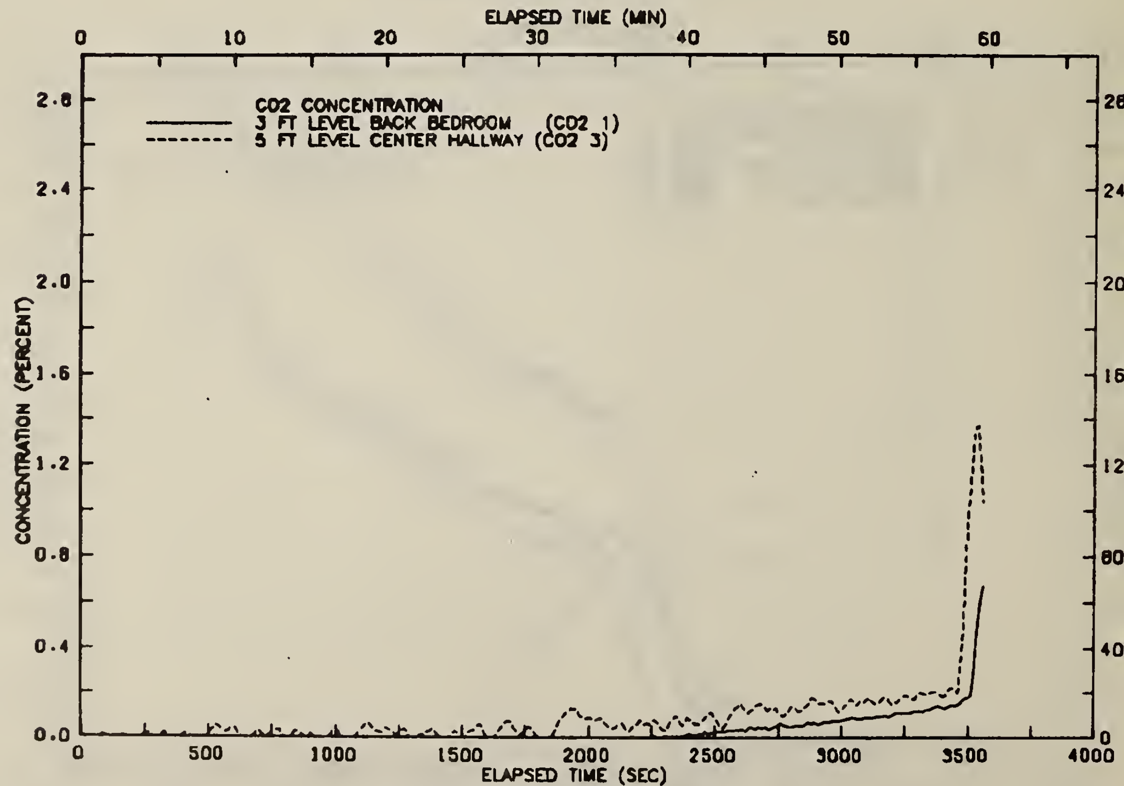

FIGURE A30B CARBON DIOXIDE CONCENTRATION-TEST 03

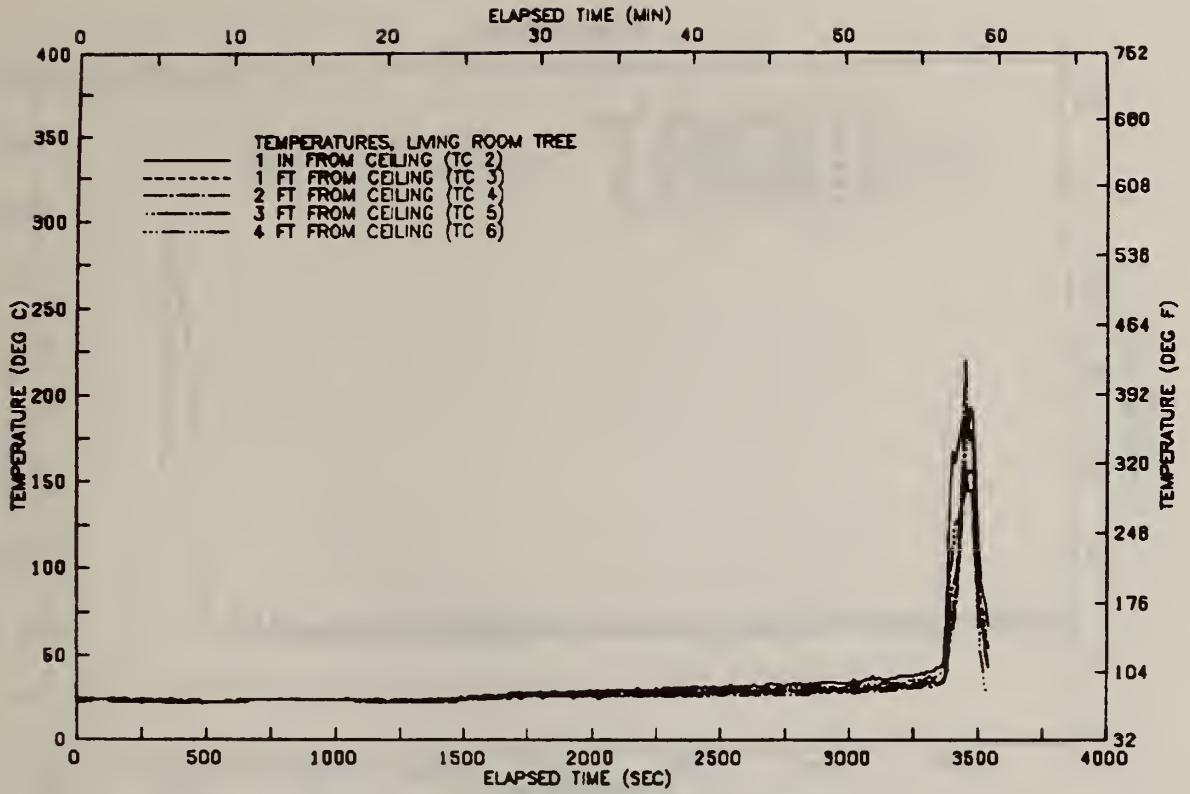

FIGURE A31 VERTICAL TEMP. PROFILE
ABOVE CHAIR-TEST 04

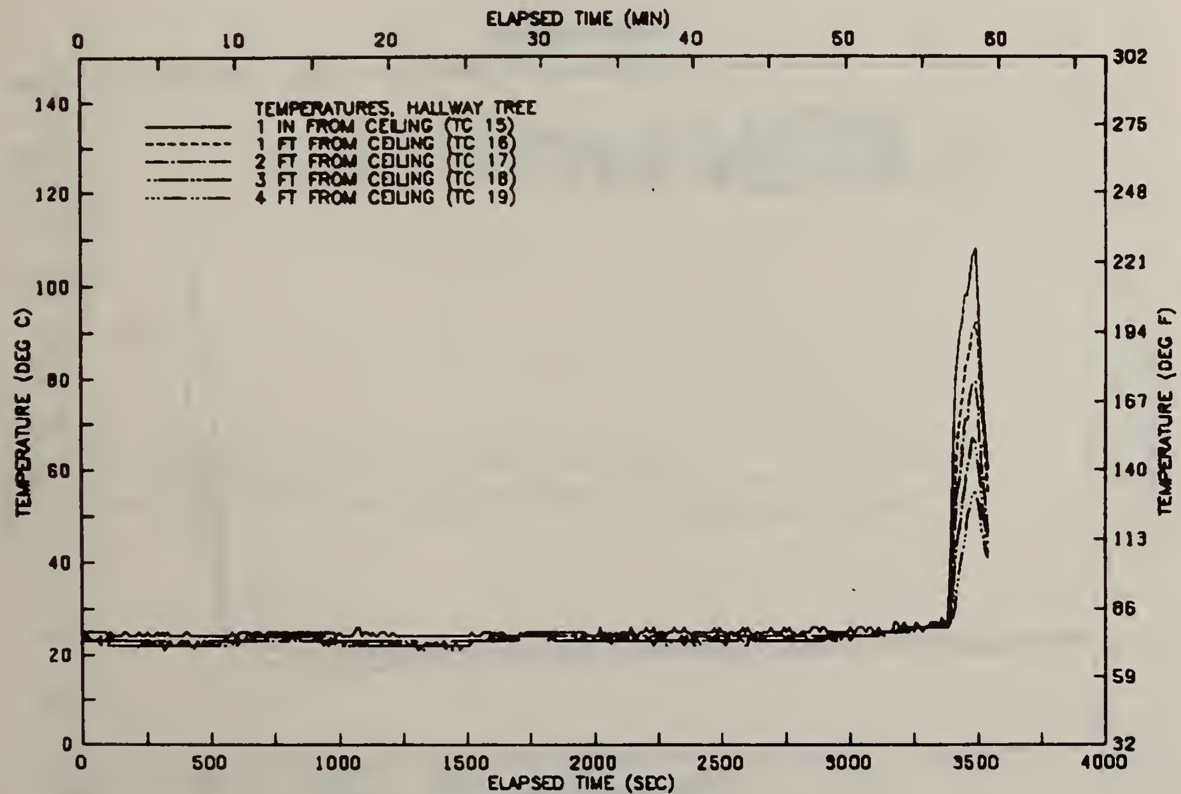

FIGURE A32 VERTICAL TEMP. PROFILE
IN HALLWAY-TEST 04

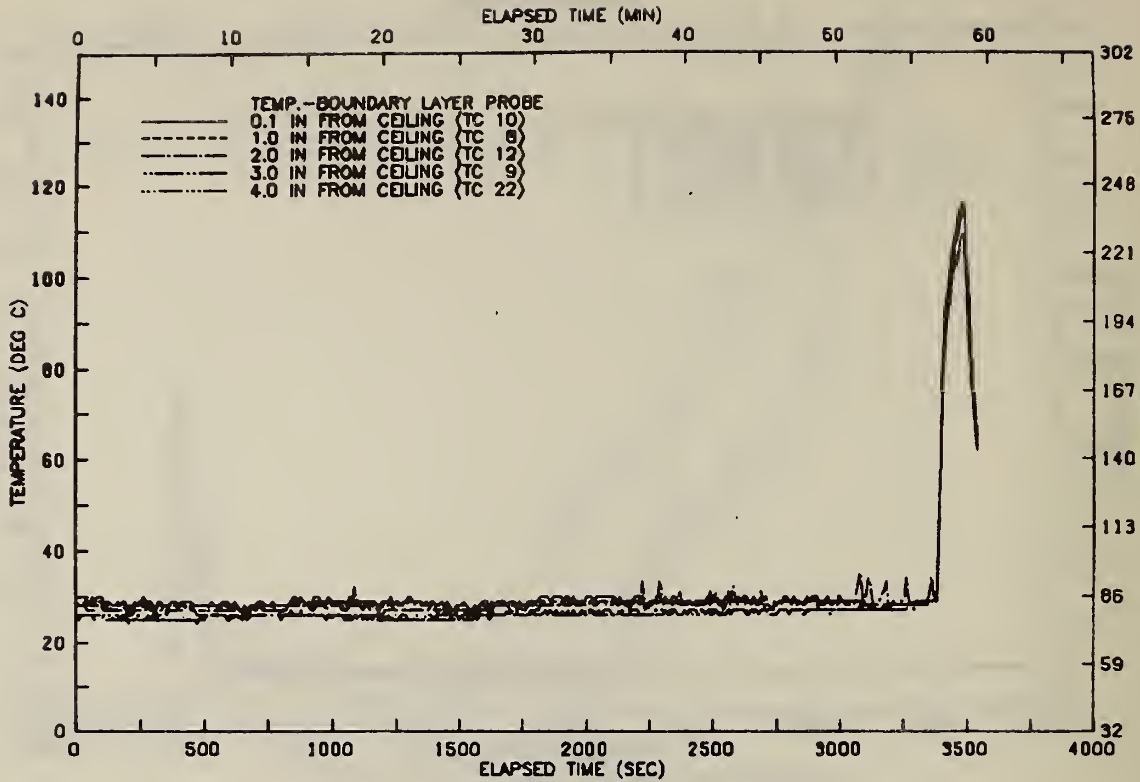

FIGURE A33 VERTICAL TEMP. PROFILE
CEILING BOUNDARY LAYER-TEST 04

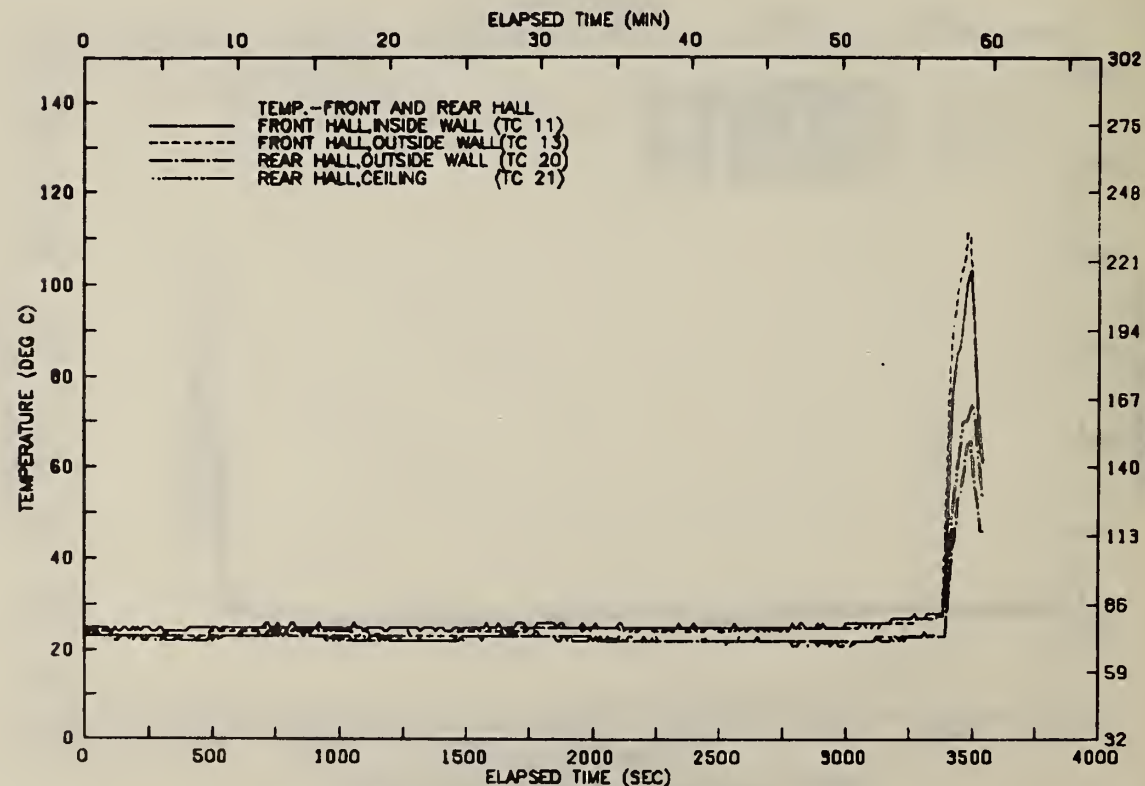

FIGURE A34 TEMP. IN HALLWAY
NEAR DETECTORS-TEST 04

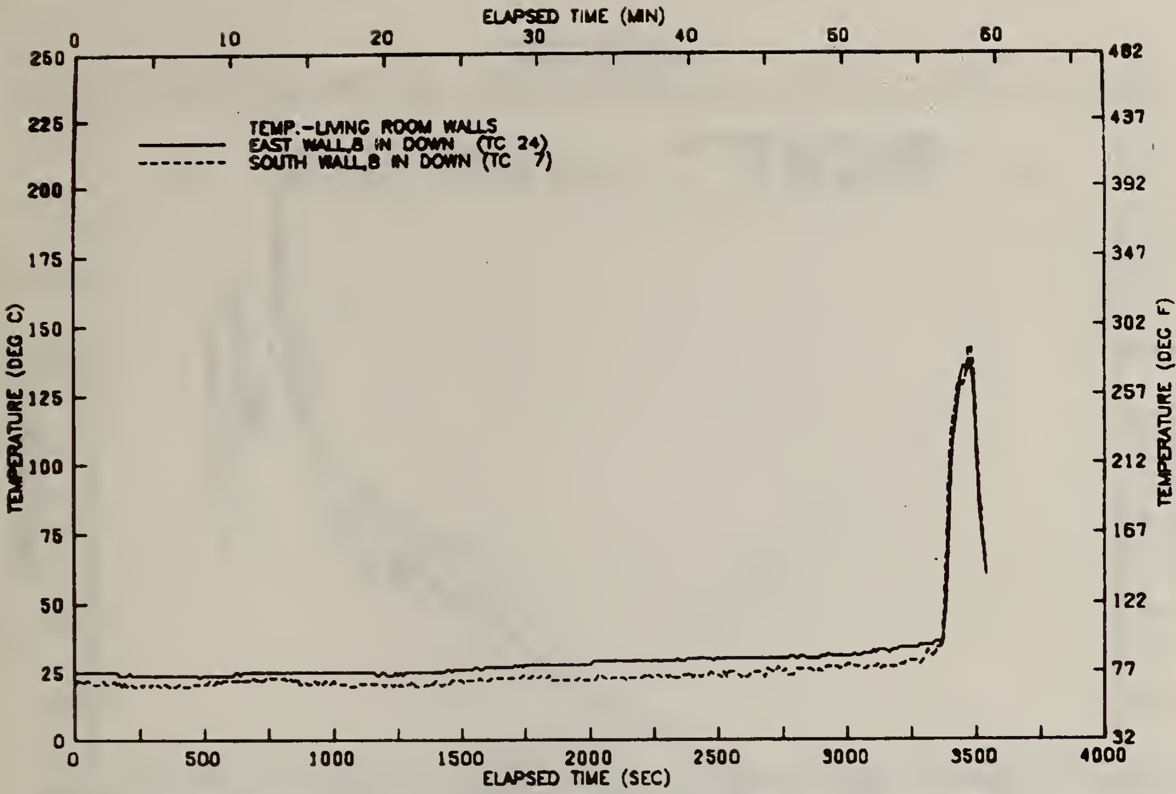

FIGURE A35 TEMPERATURE AT LIVING ROOM WALLS-TEST 04

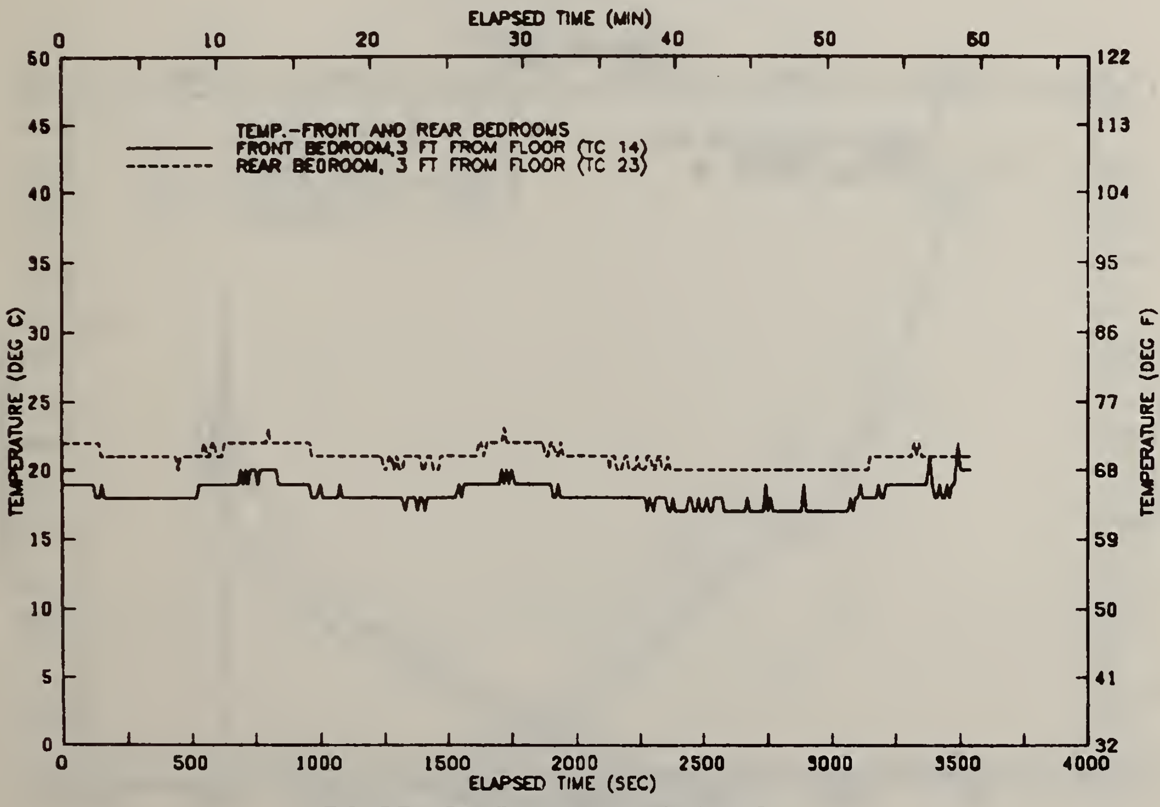

FIGURE A36 TEMP. IN FRONT AND REAR BEDROOMS-TEST 04

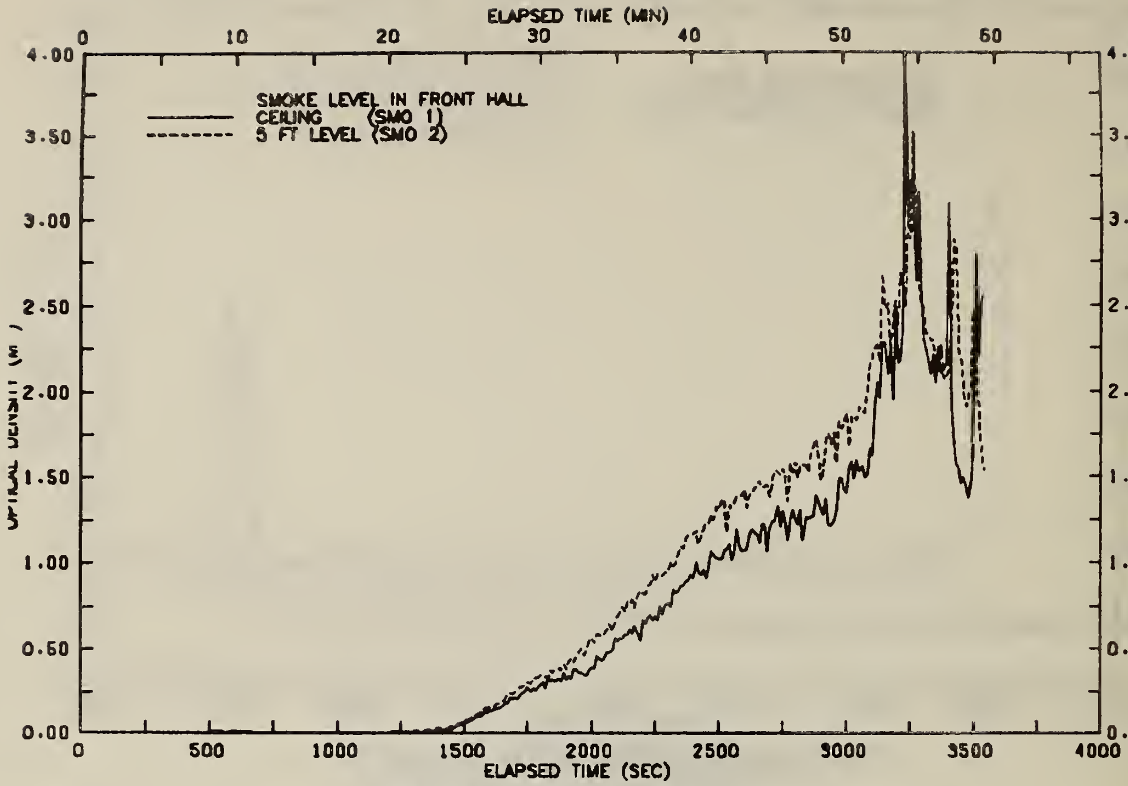

FIGURE A37 SMOKE LEVELS IN FRONT HALLWAY-TEST 04

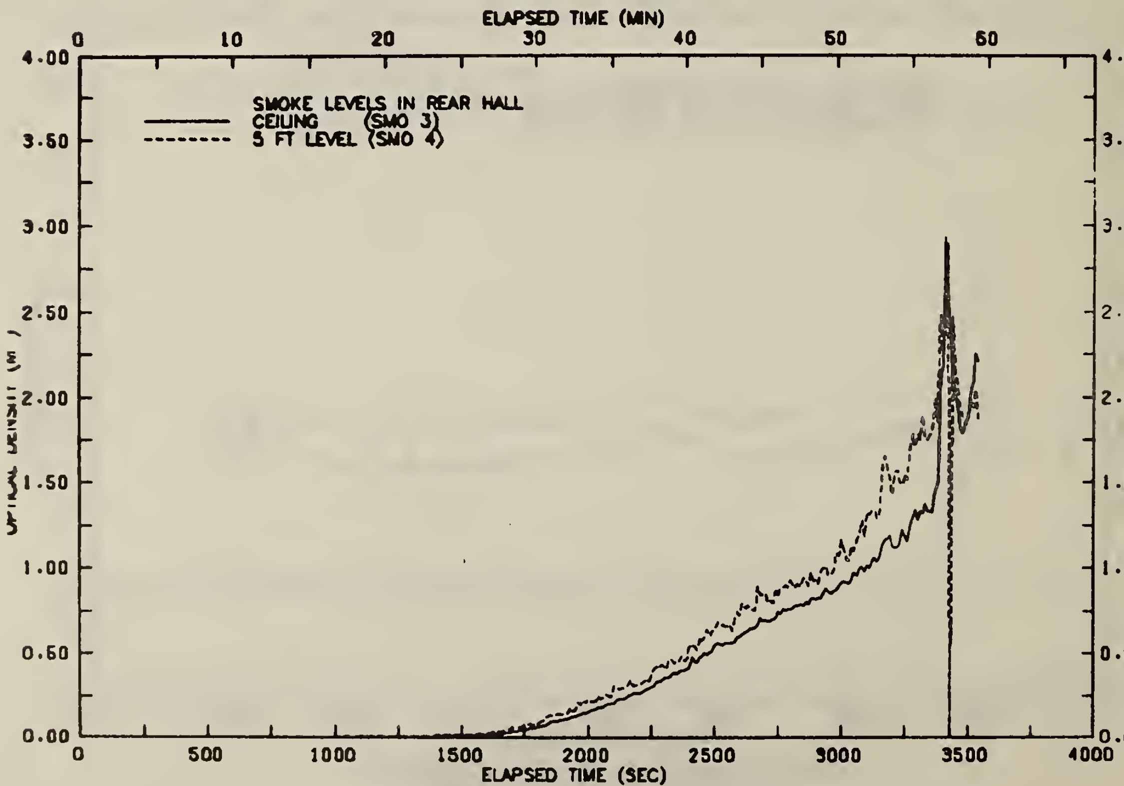

FIGURE A38 SMOKE LEVELS IN REAR HALLWAY-TEST 04

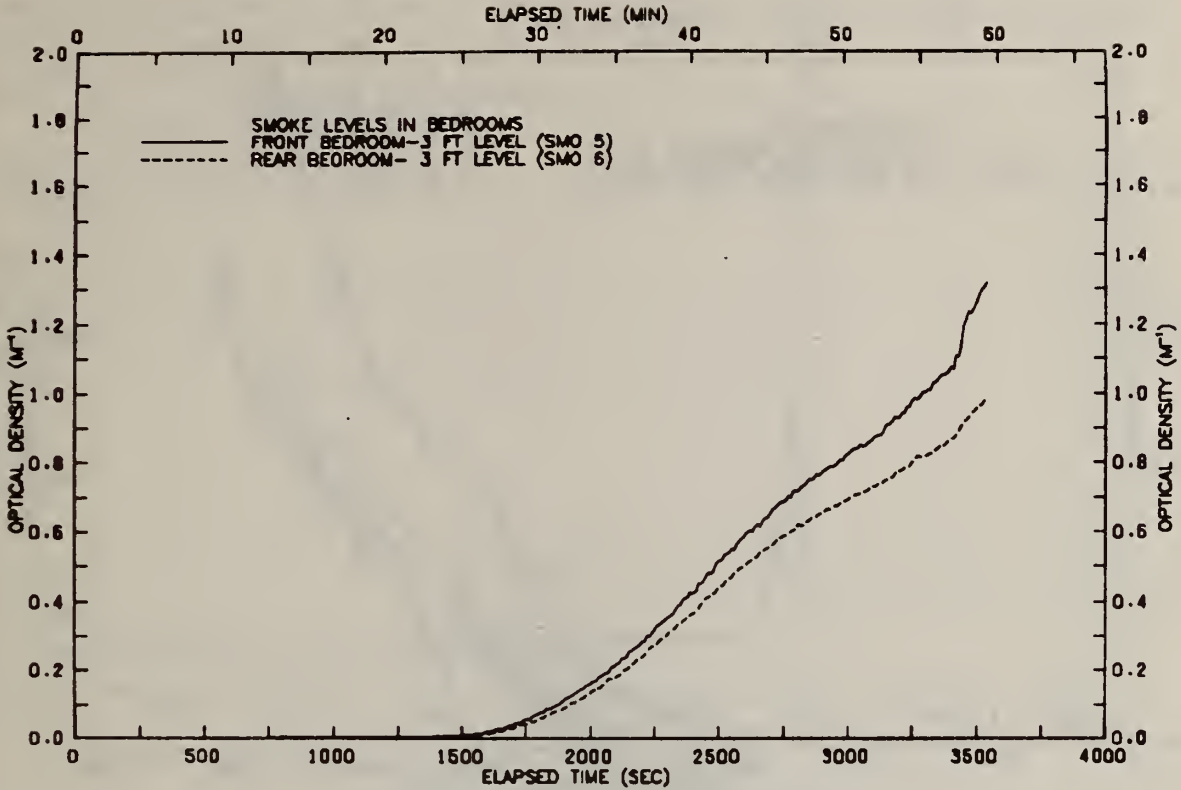

FIGURE A39 SMOKE LEVELS IN BEDROOMS-TEST 04

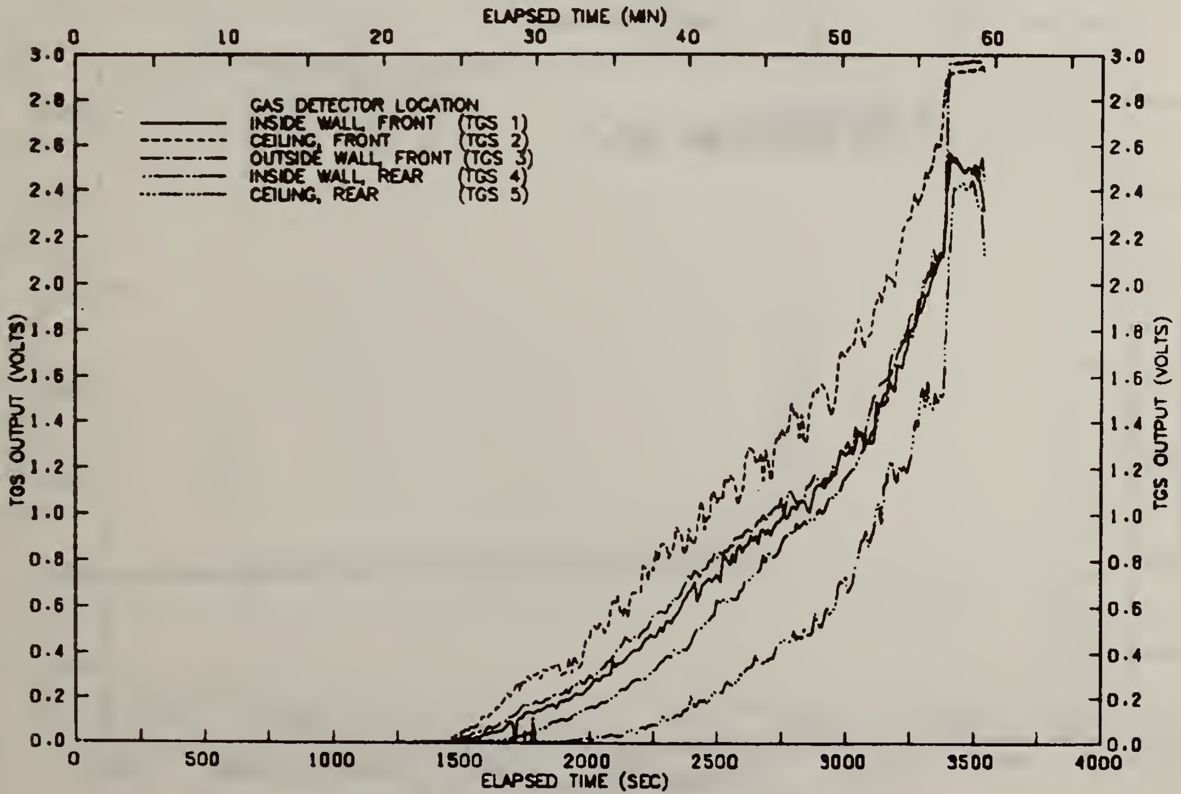

FIGURE A40 GAS DETECTOR OUTPUT VOLTAGE BY LOCATION-TEST 04

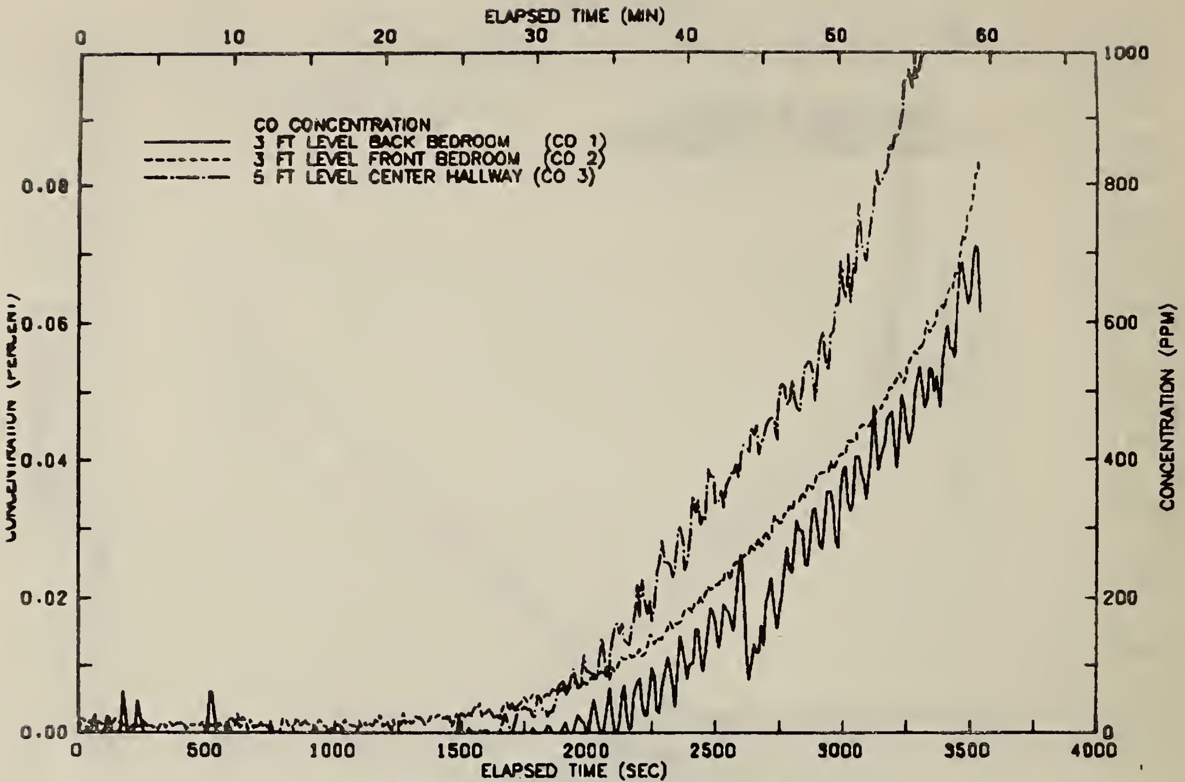

FIGURE A40A CARBON MONOXIDE CONCENTRATION-TEST 04

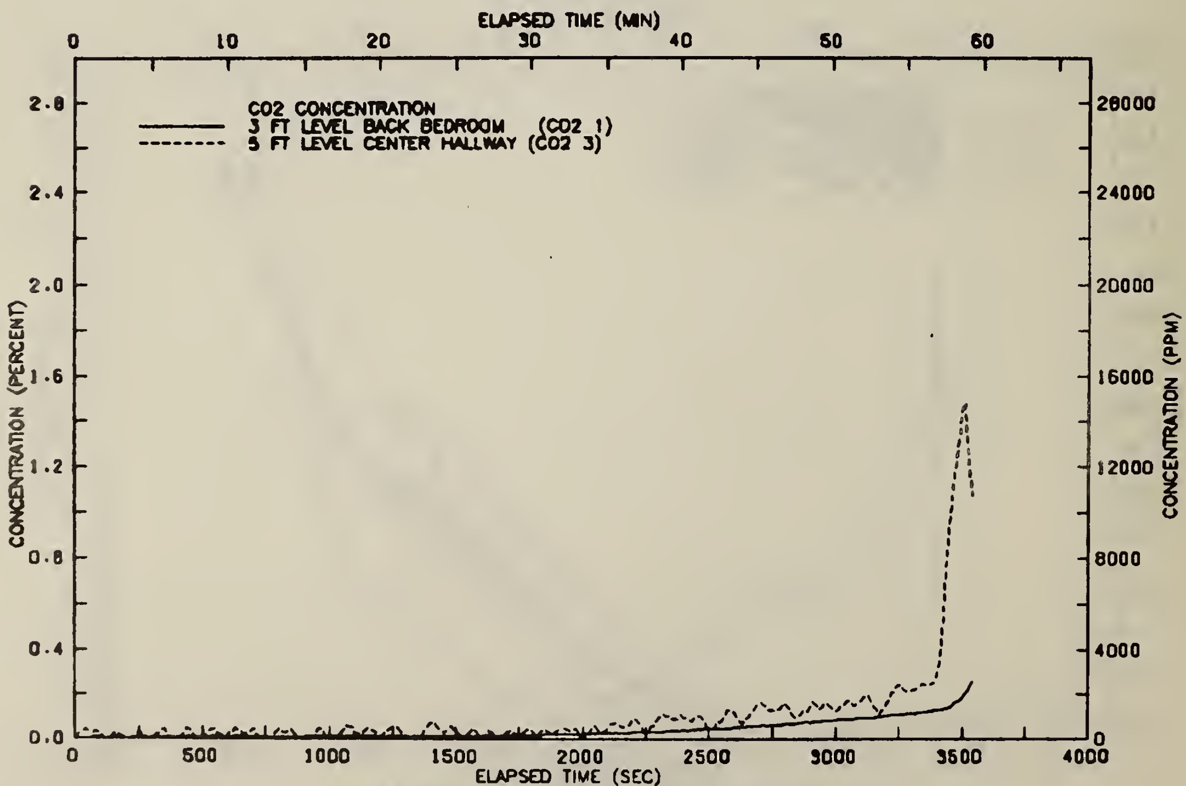

FIGURE A40B CARBON DIOXIDE CONCENTRATION-TEST 04

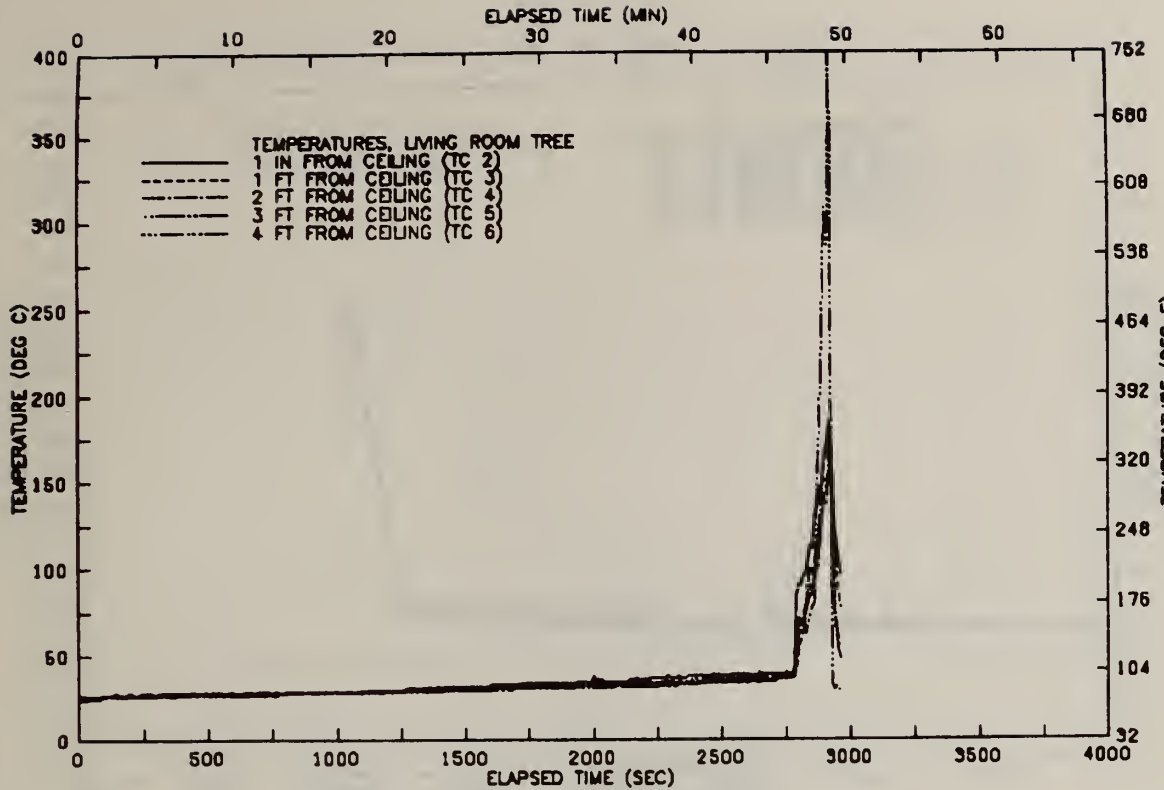

FIGURE A41 VERTICAL TEMP. PROFILE
ABOVE CHAIR-TEST 05

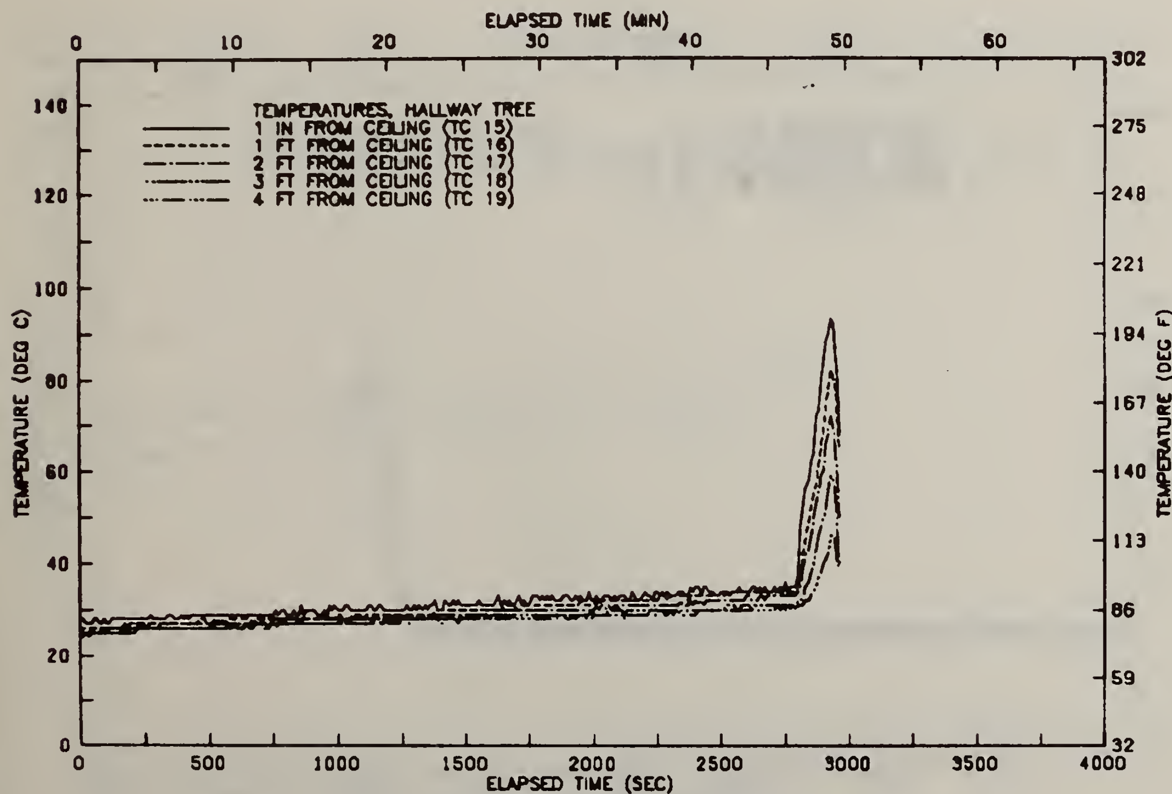

FIGURE A42 VERTICAL TEMP. PROFILE
IN HALLWAY-TEST 05

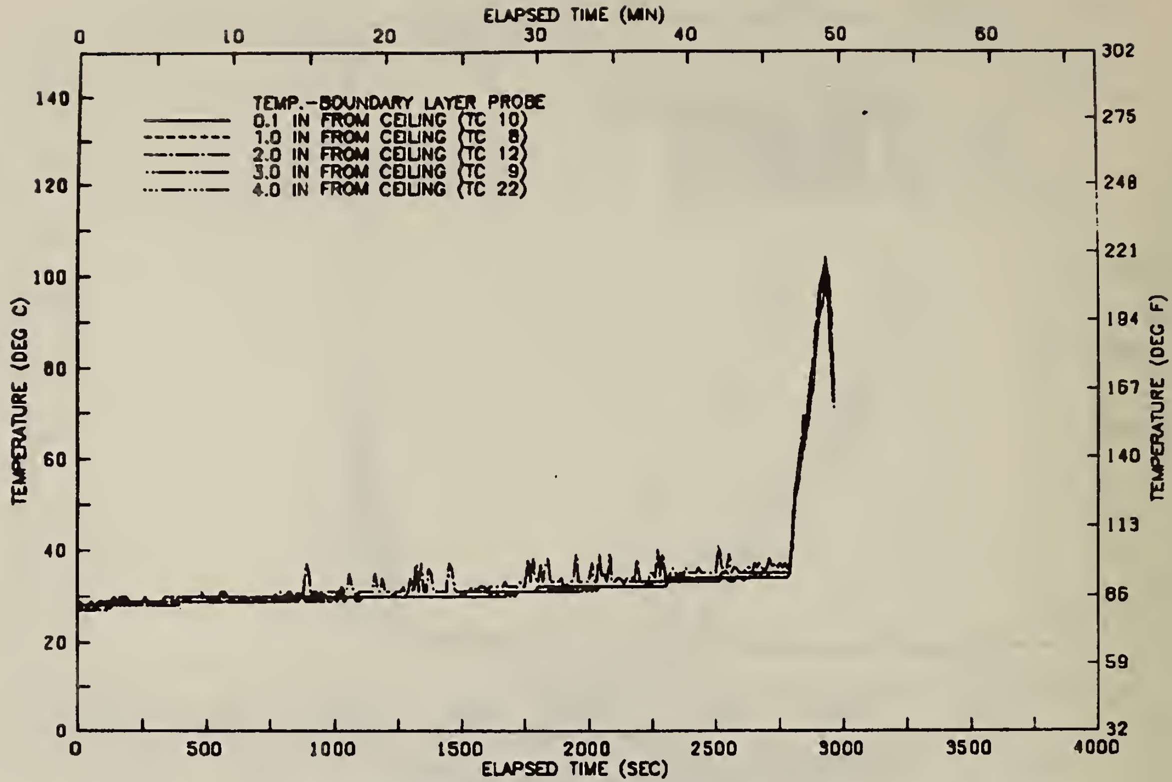

FIGURE A43 VERTICAL TEMP. PROFILE
CEILING BOUNDARY LAYER–TEST 05

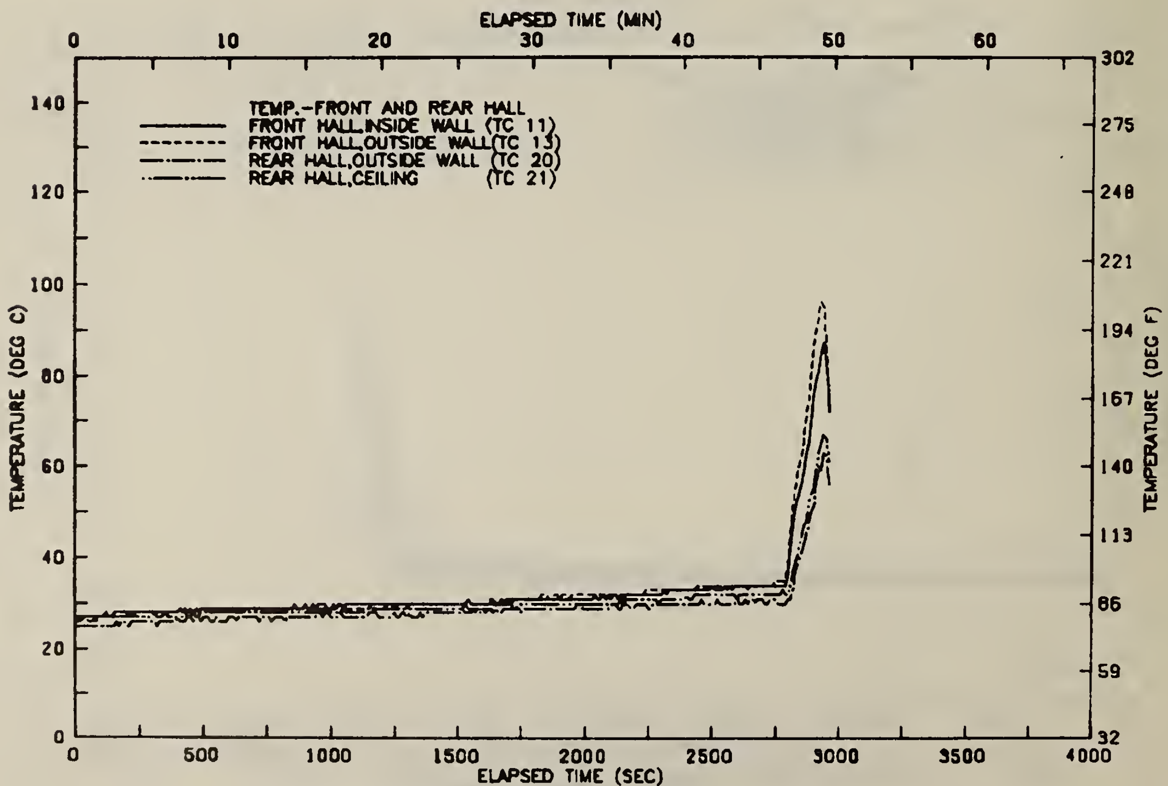

FIGURE A44 TEMP. IN HALLWAY
NEAR DETECTORS–TEST 05

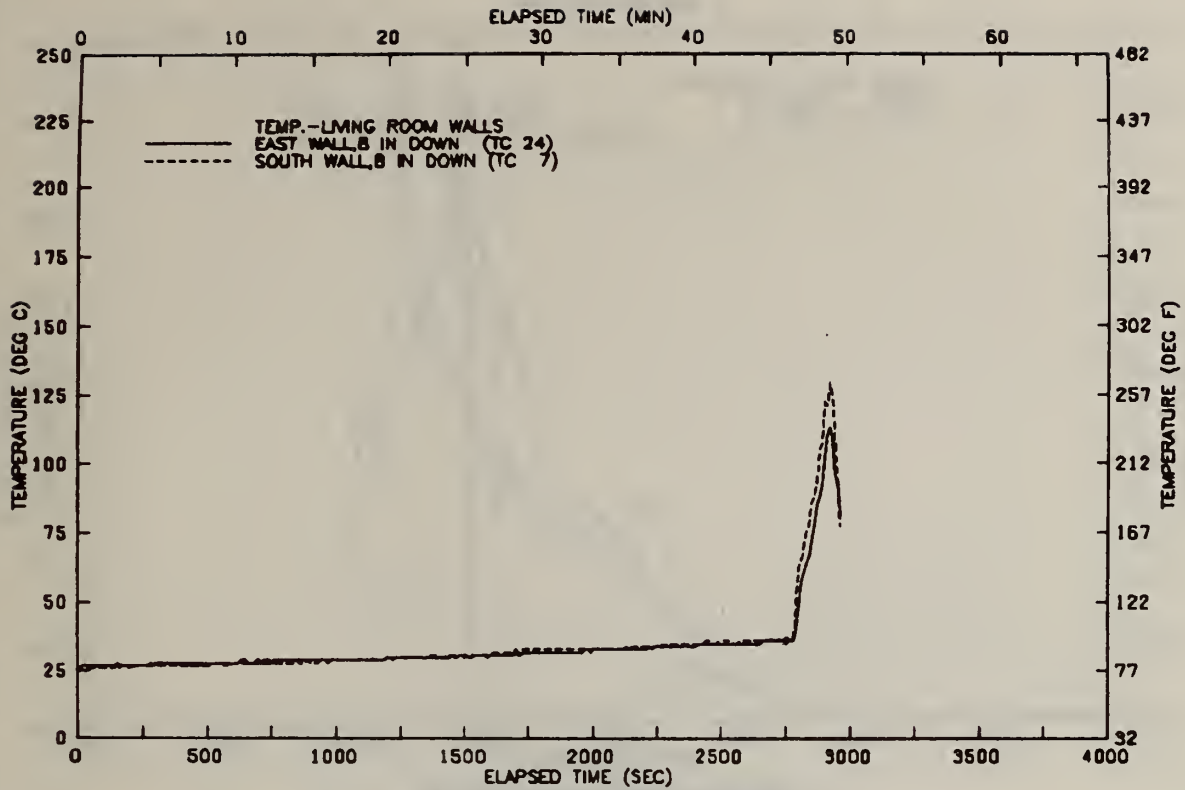

FIGURE A45 TEMPERATURE AT LIVING ROOM WALLS-TEST 05

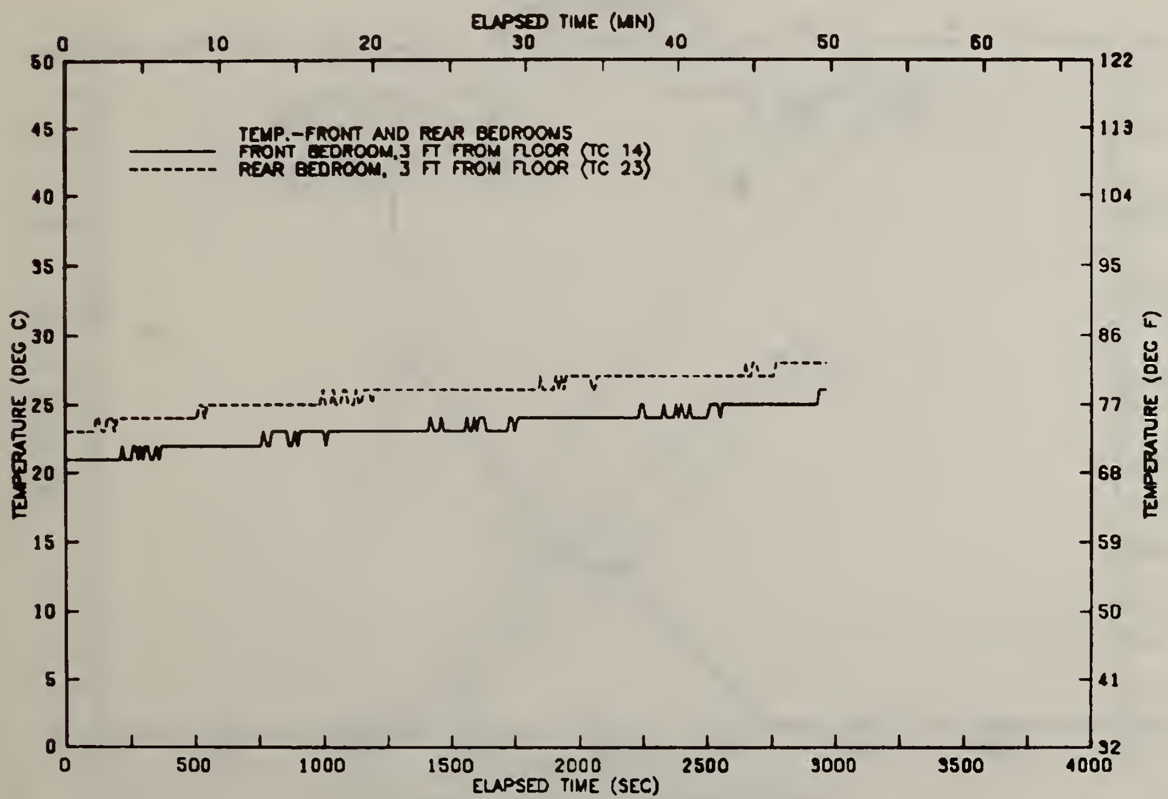

FIGURE A46 TEMP. IN FRONT AND REAR BEDROOMS-TEST 05

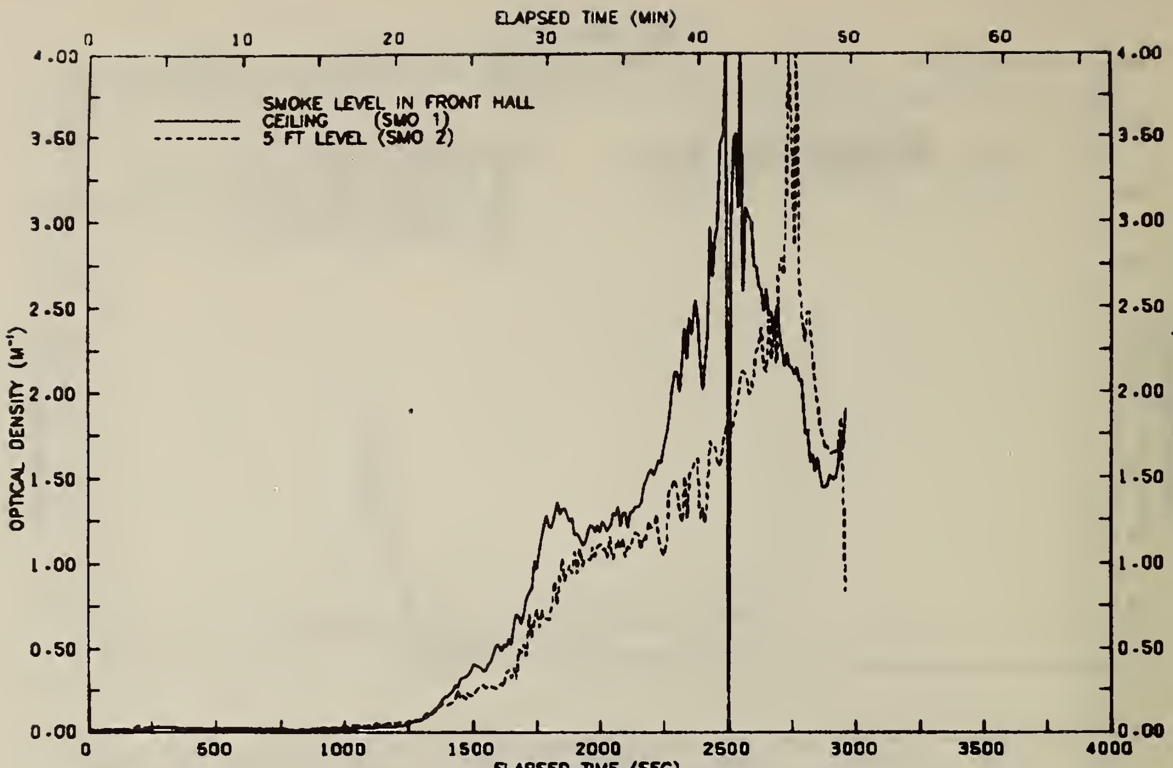

FIGURE A47 SMOKE LEVELS IN FRONT HALLWAY-TEST 05

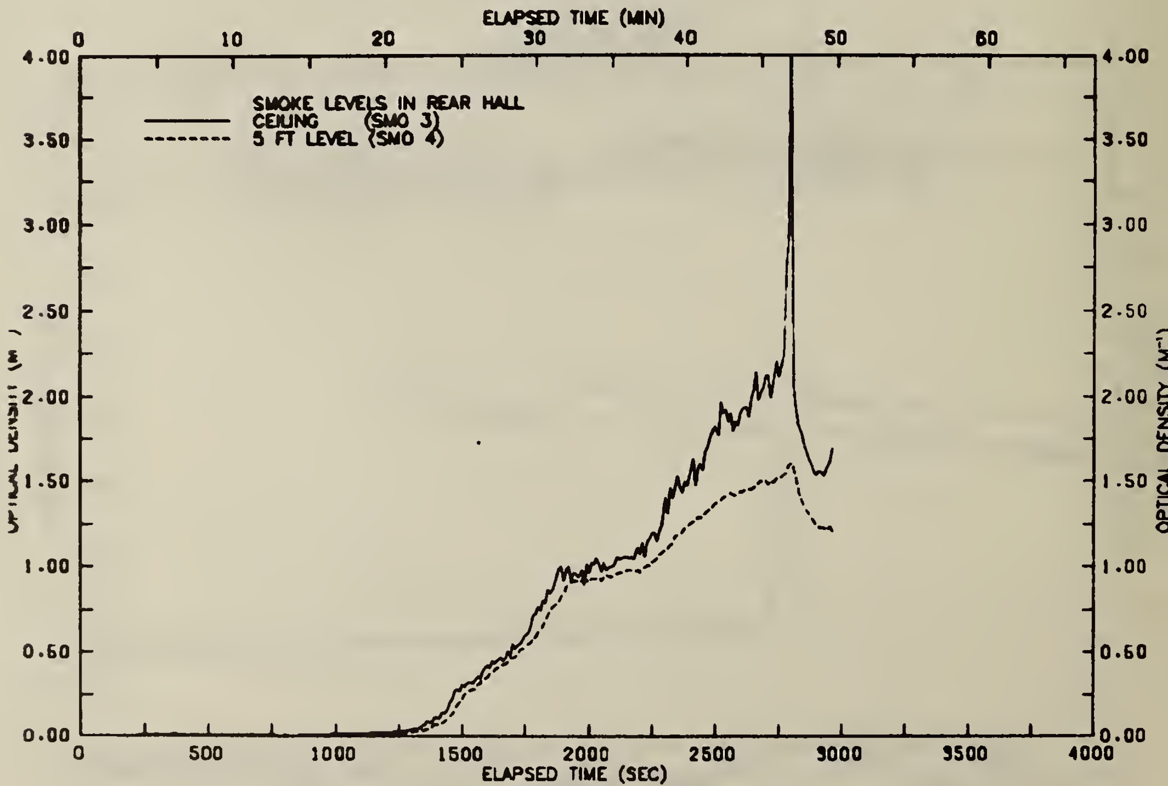

FIGURE A48 SMOKE LEVELS IN REAR HALLWAY-TEST 05

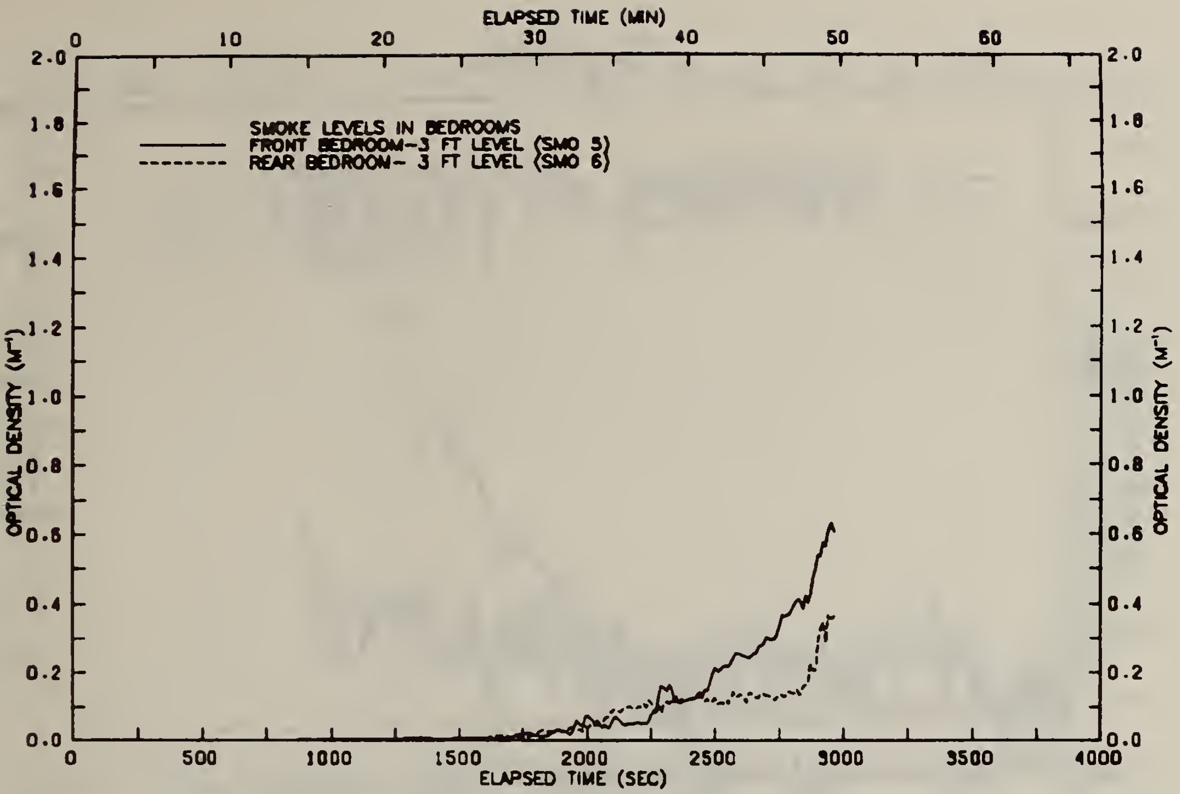

FIGURE A49 SMOKE LEVELS IN BEDROOMS-TEST 05

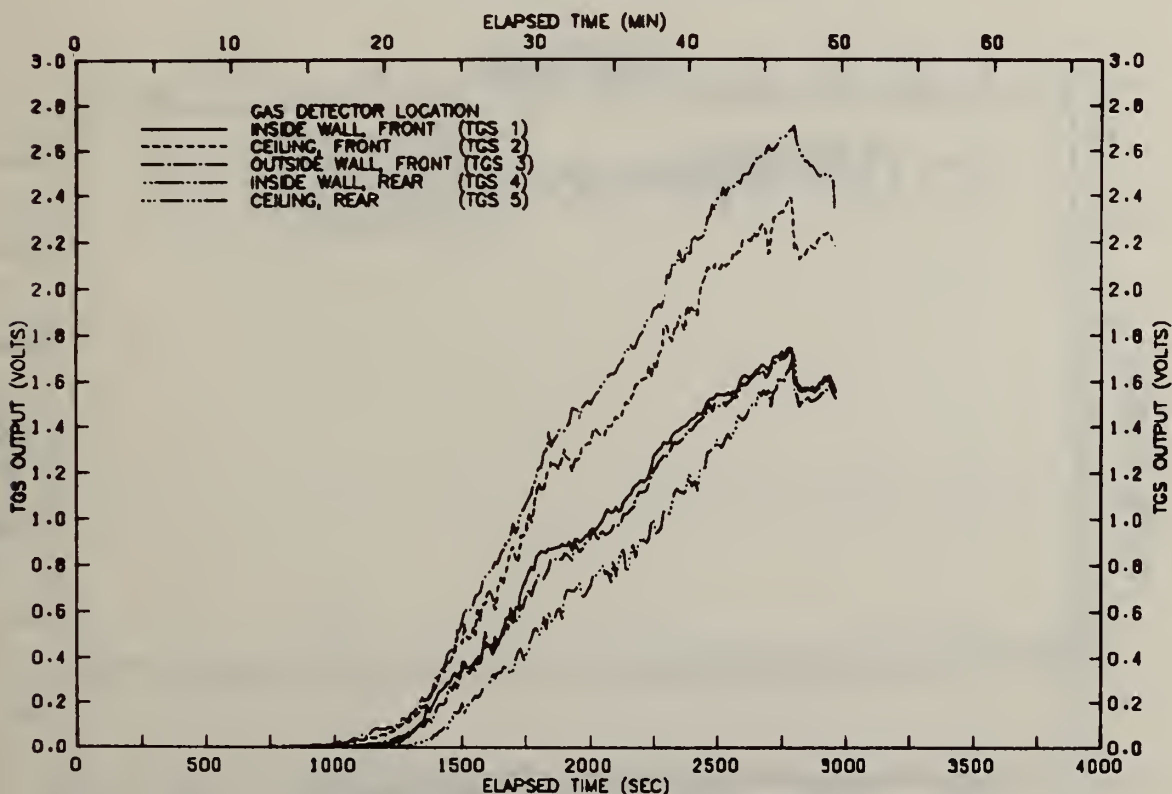

FIGURE A50 GAS DETECTOR OUTPUT VOLTAGE BY LOCATION-TEST 05

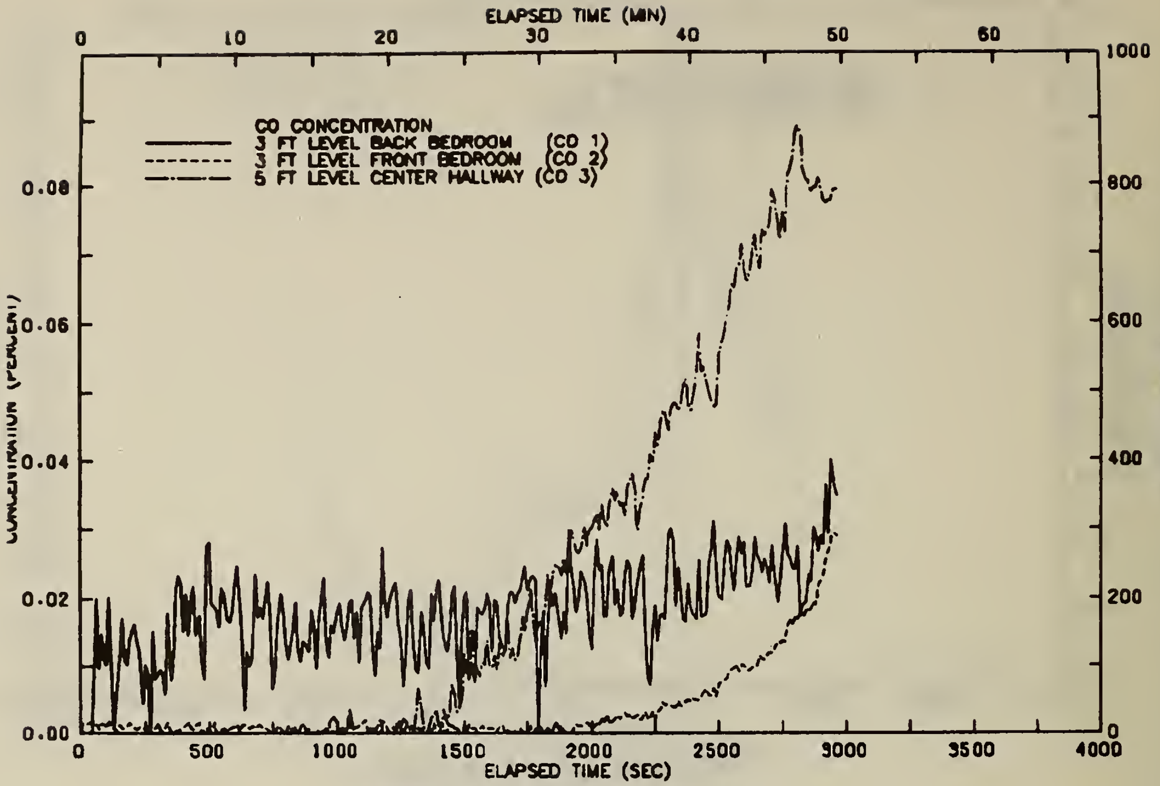

FIGURE A50A CARBON MONOXIDE CONCENTRATION-TEST 05

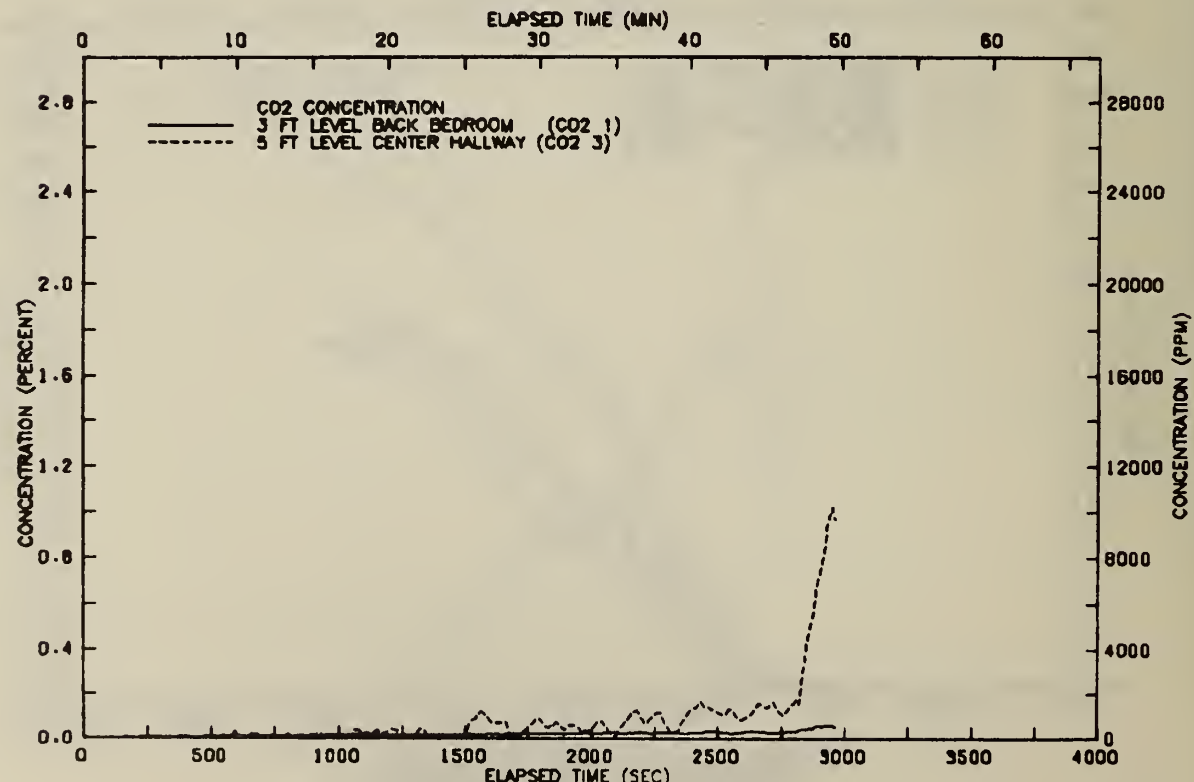

FIGURE A50B CARBON DIOXIDE CONCENTRATION-TEST 05

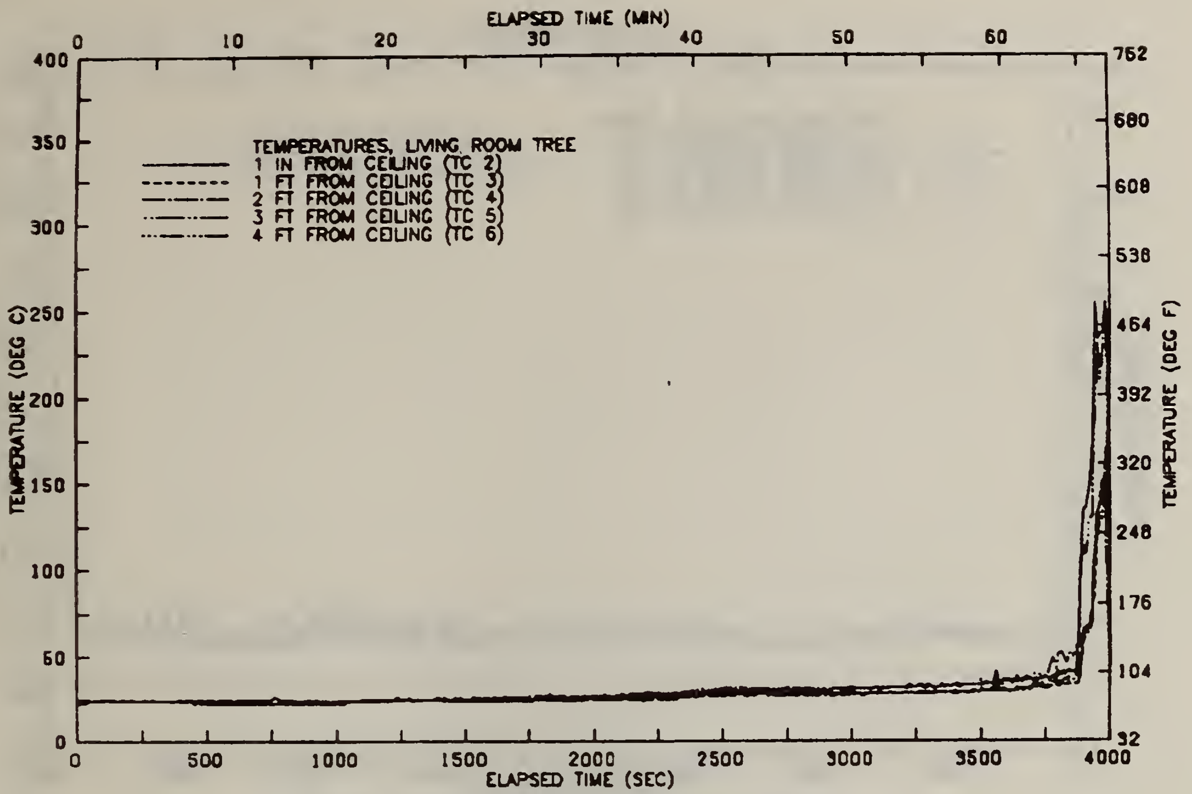

FIGURE A51 VERTICAL TEMP. PROFILE
ABOVE CHAIR-TEST 06

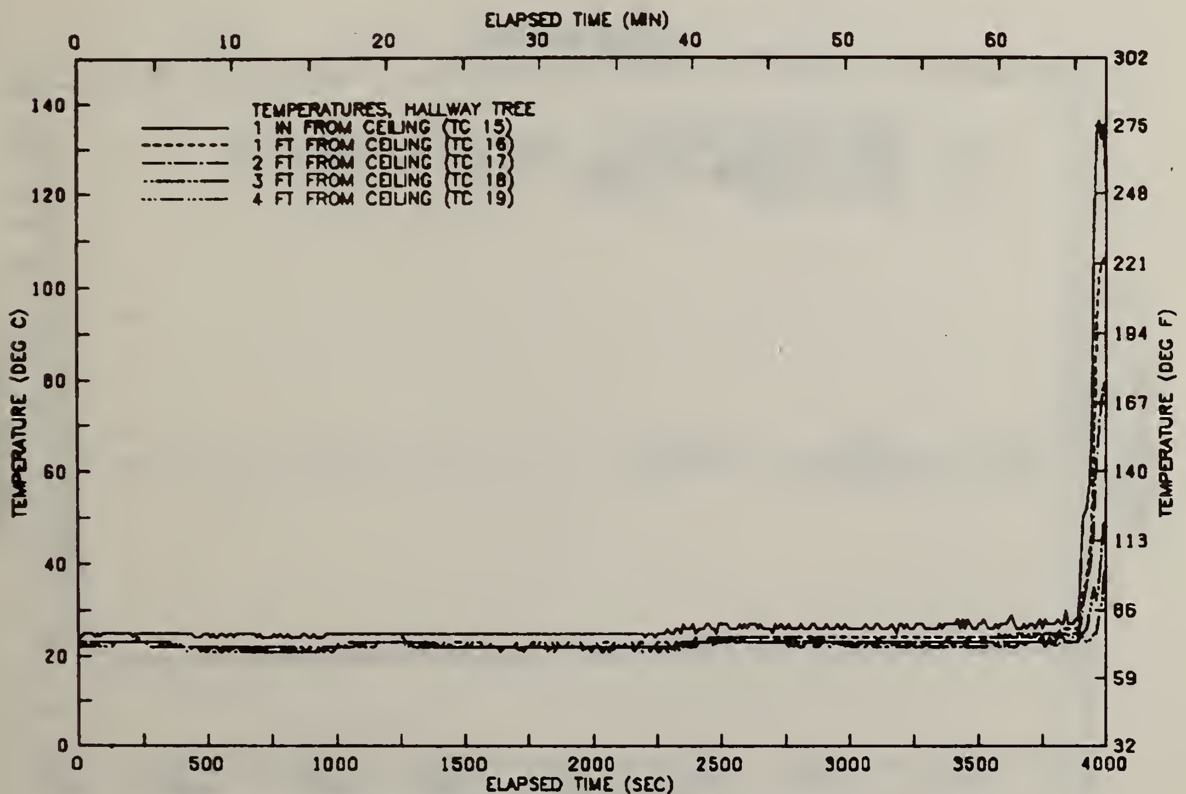

FIGURE A52 VERTICAL TEMP. PROFILE
IN HALLWAY-TEST 06

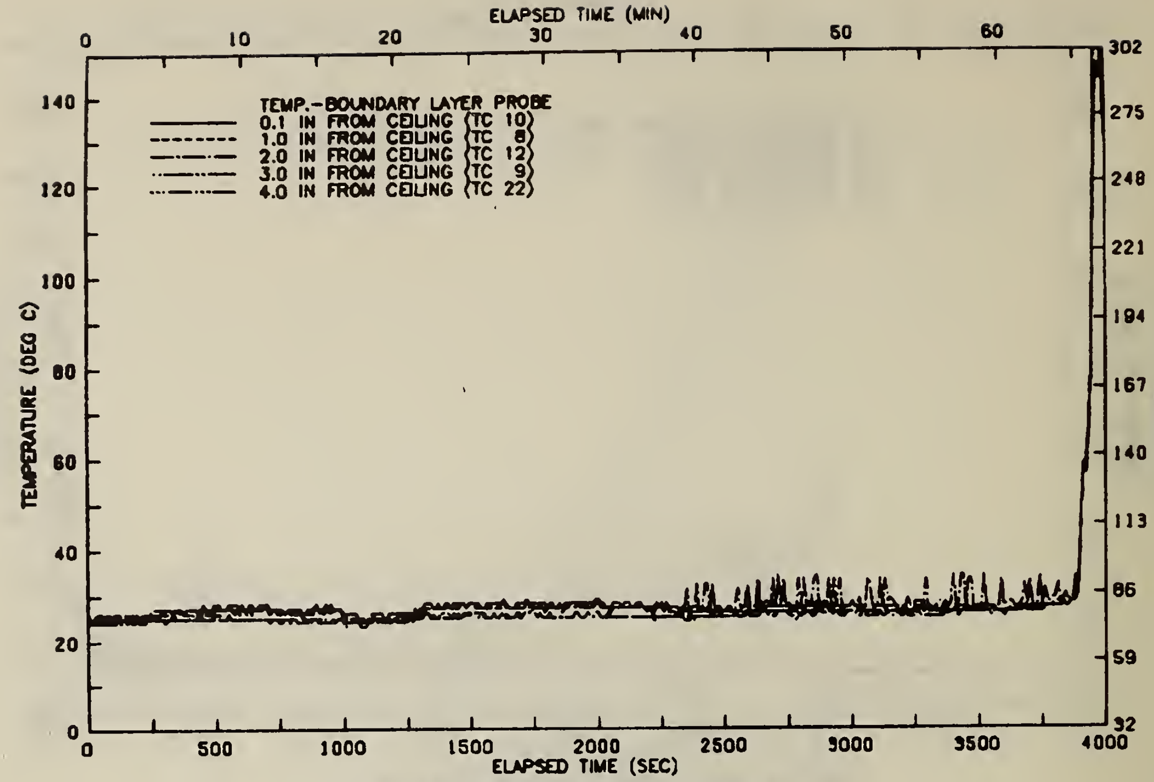

FIGURE A53 VERTICAL TEMP. PROFILE
CEILING BOUNDARY LAYER-TEST 06

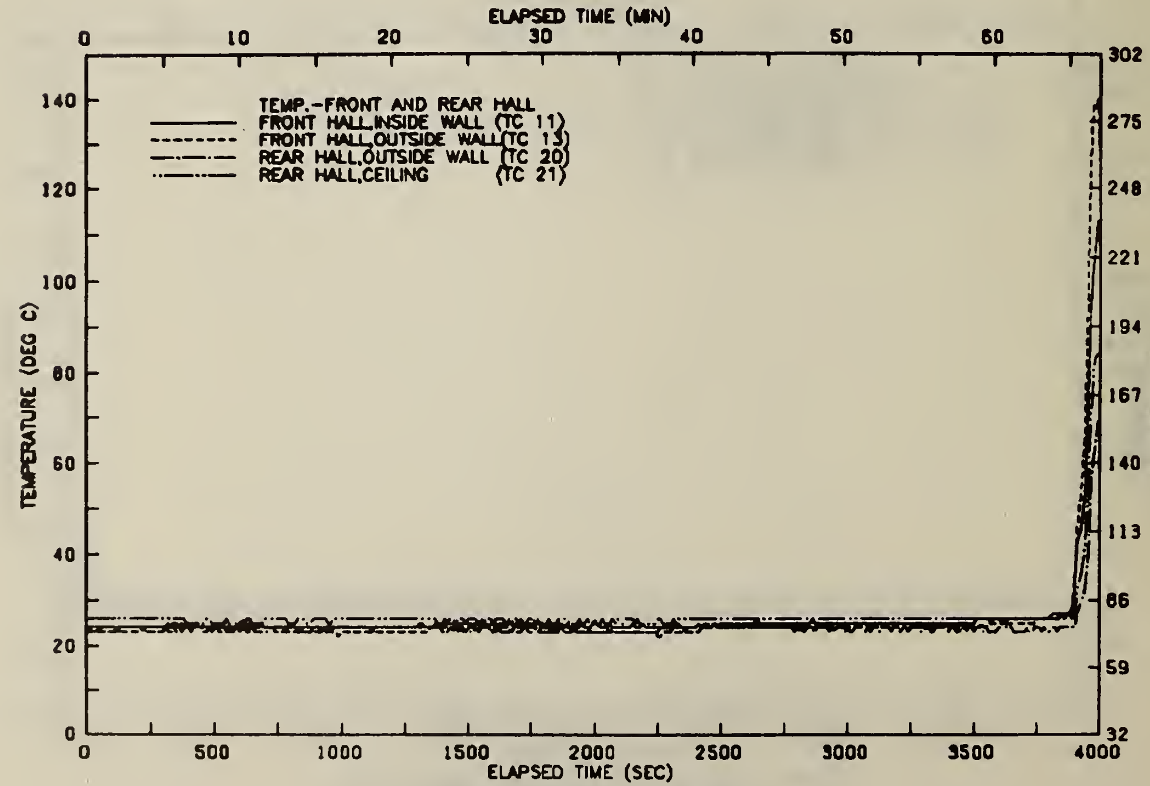

FIGURE A54 TEMP. IN HALLWAY
NEAR DETECTORS-TEST 06

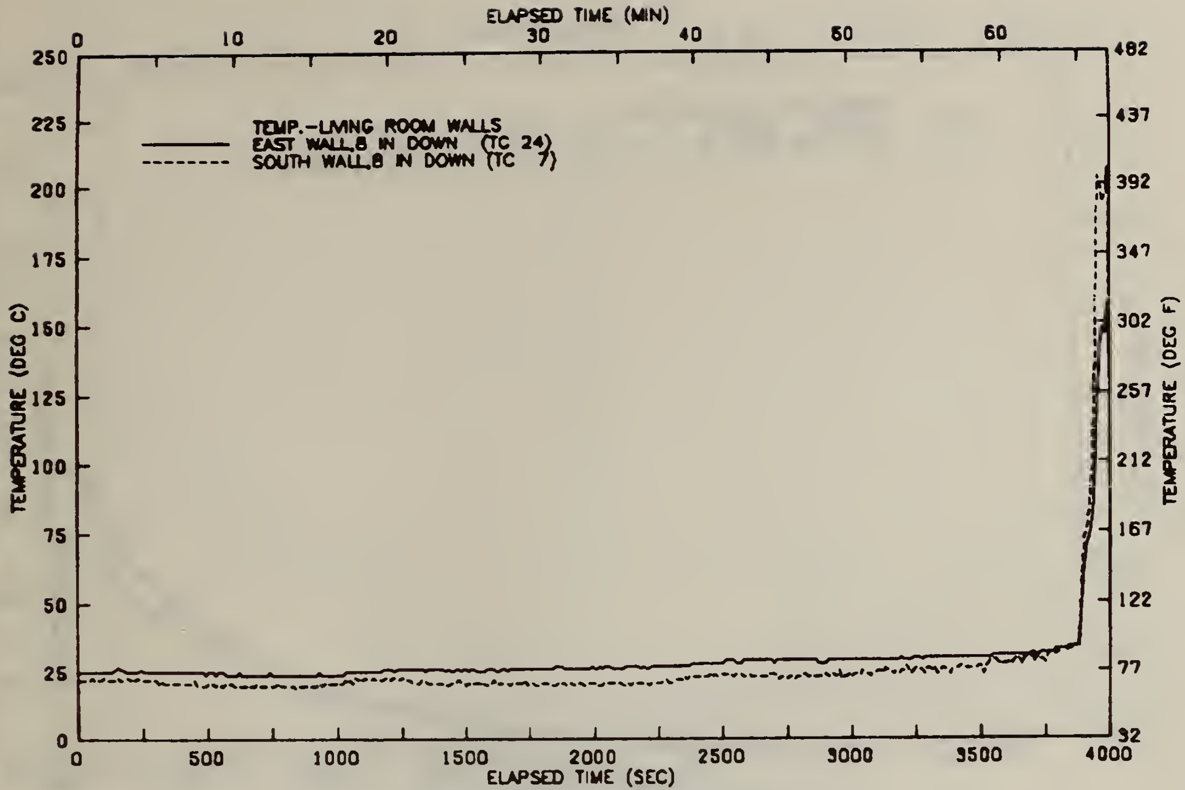

FIGURE A55 TEMPERATURE AT LIVING ROOM WALLS-TEST 06

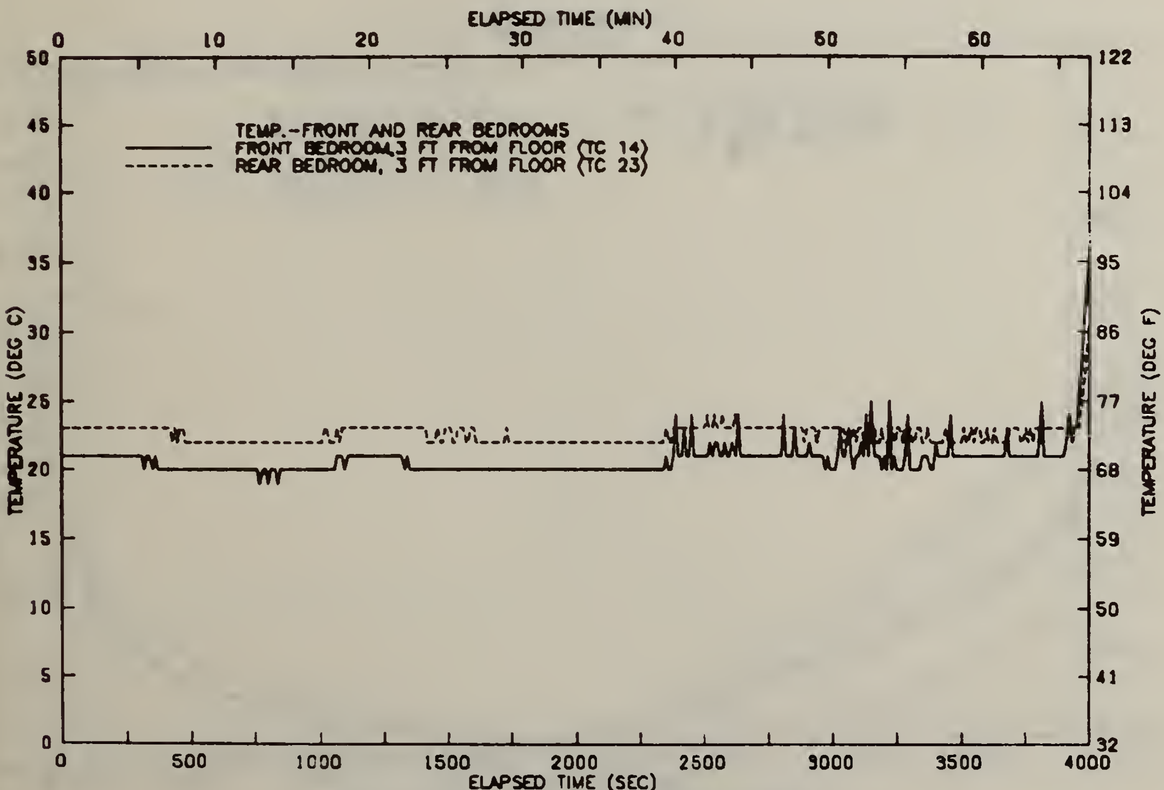

FIGURE A56 TEMP. IN FRONT AND REAR BEDROOMS-TEST 06

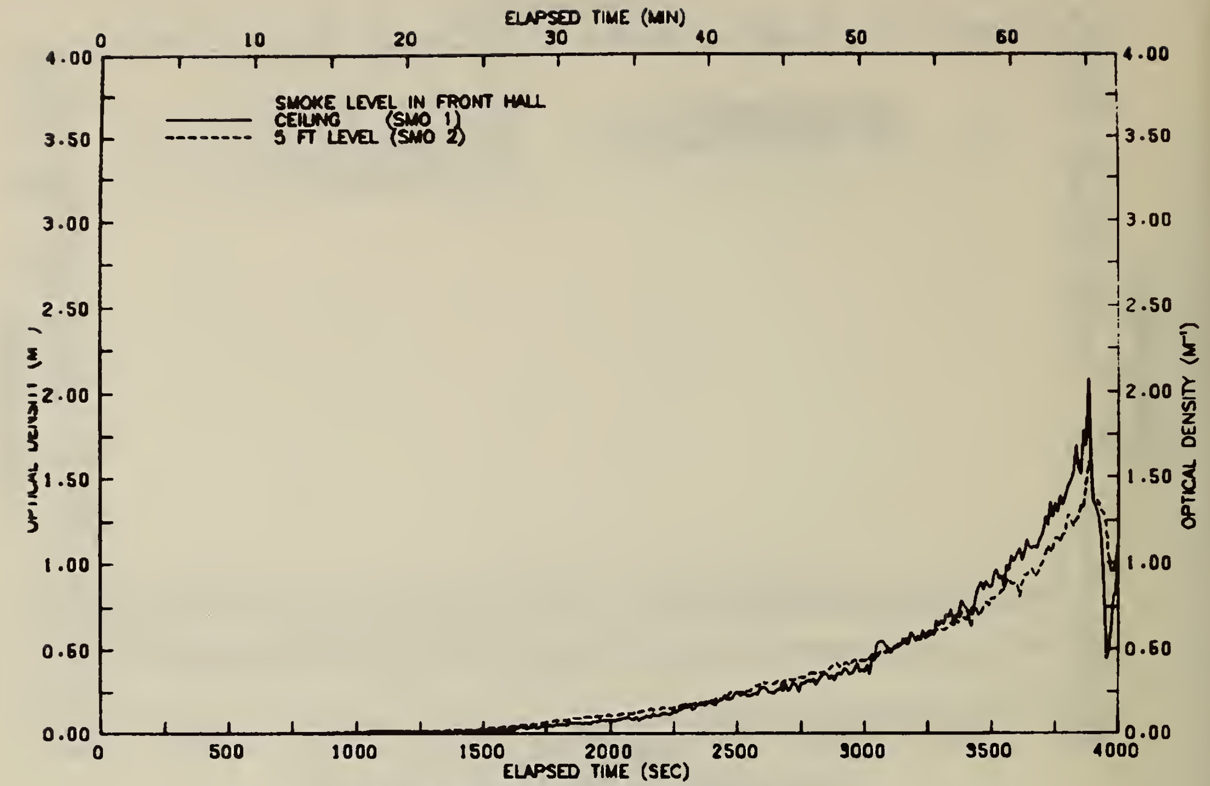

FIGURE A57 SMOKE LEVELS IN FRONT HALLWAY-TEST 06

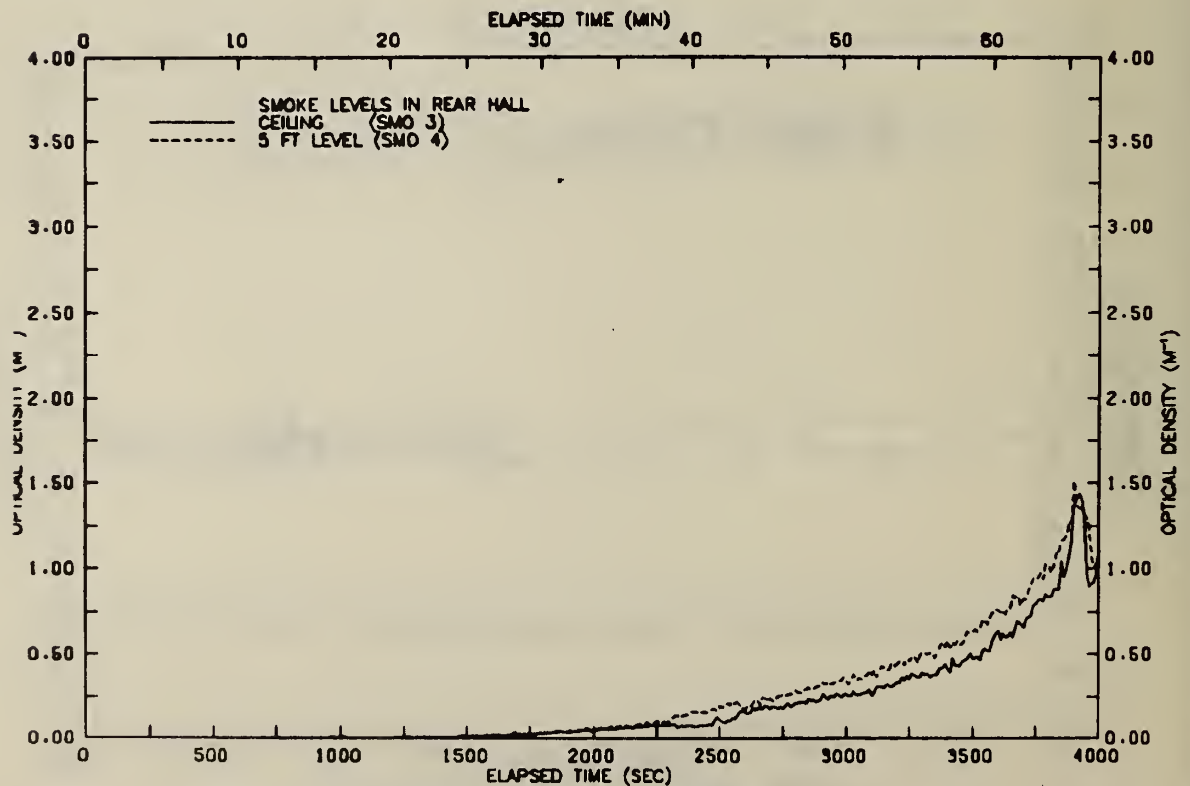

FIGURE A58 SMOKE LEVELS IN REAR HALLWAY-TEST 06

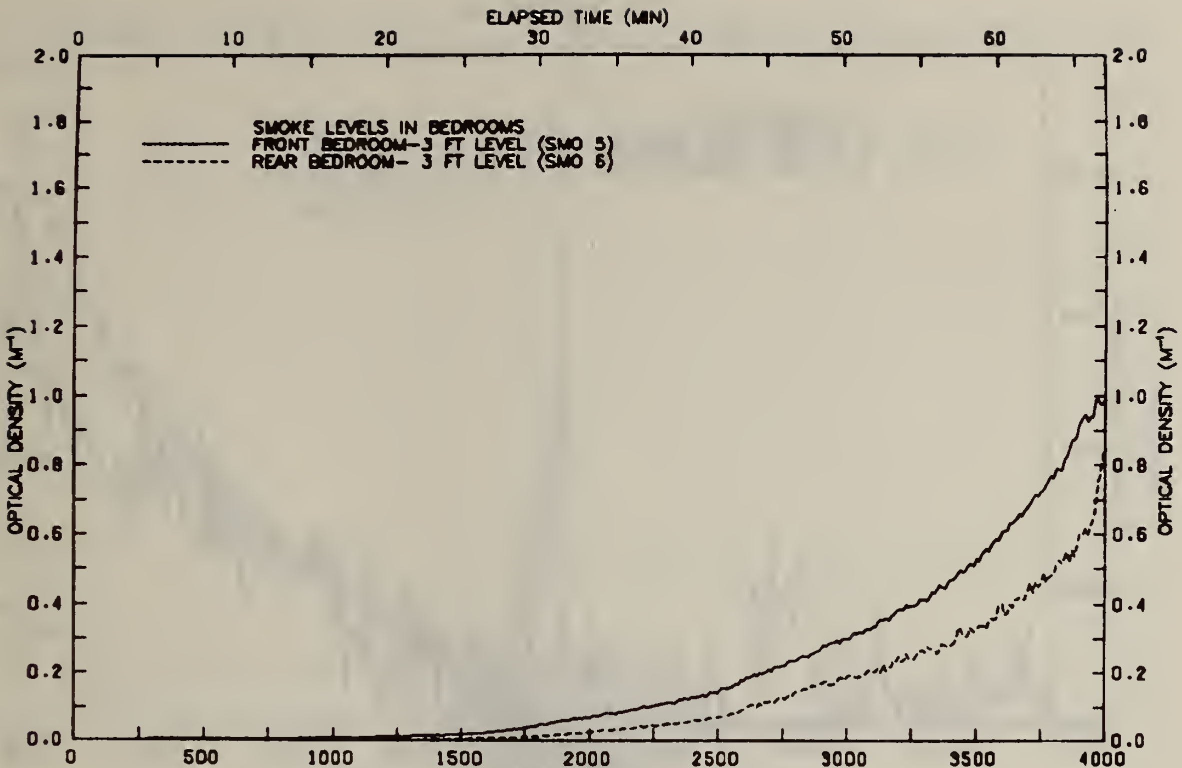

FIGURE A59 SMOKE LEVELS IN BEDROOMS-TEST 06

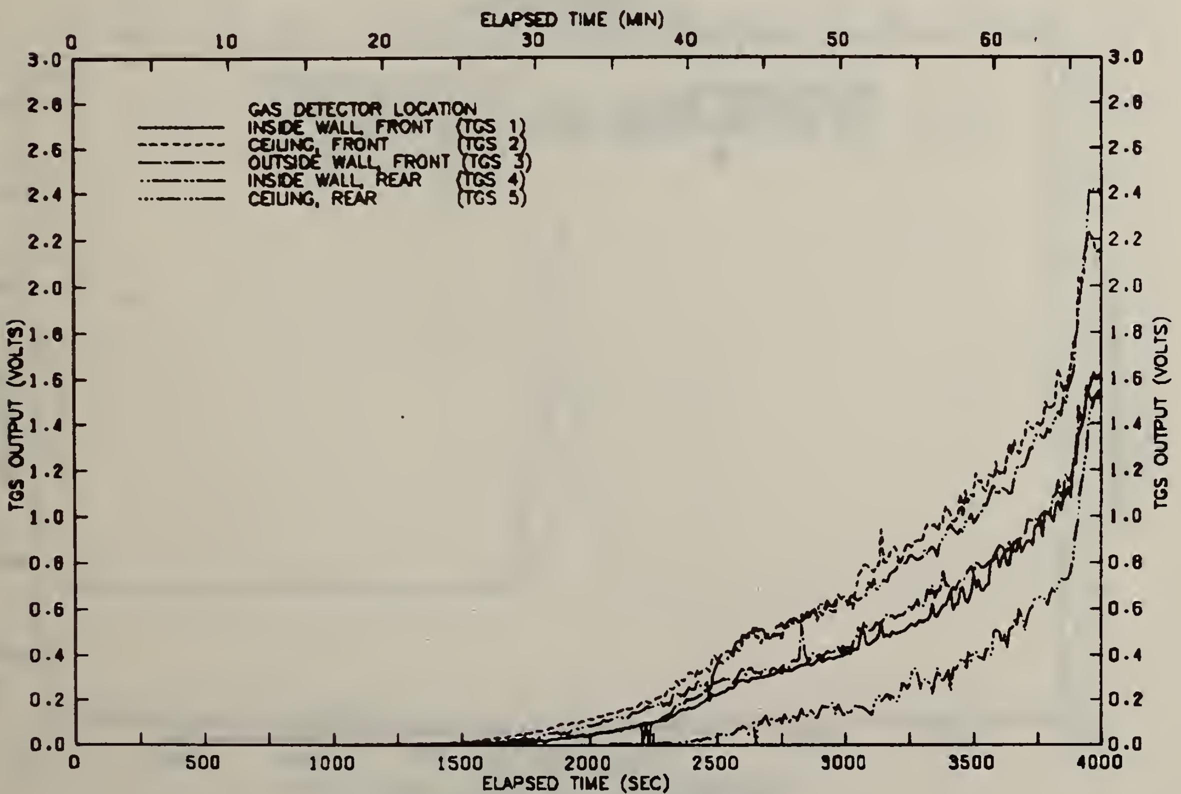

FIGURE A60 GAS DETECTOR OUTPUT VOLTAGE BY LOCATION-TEST 06

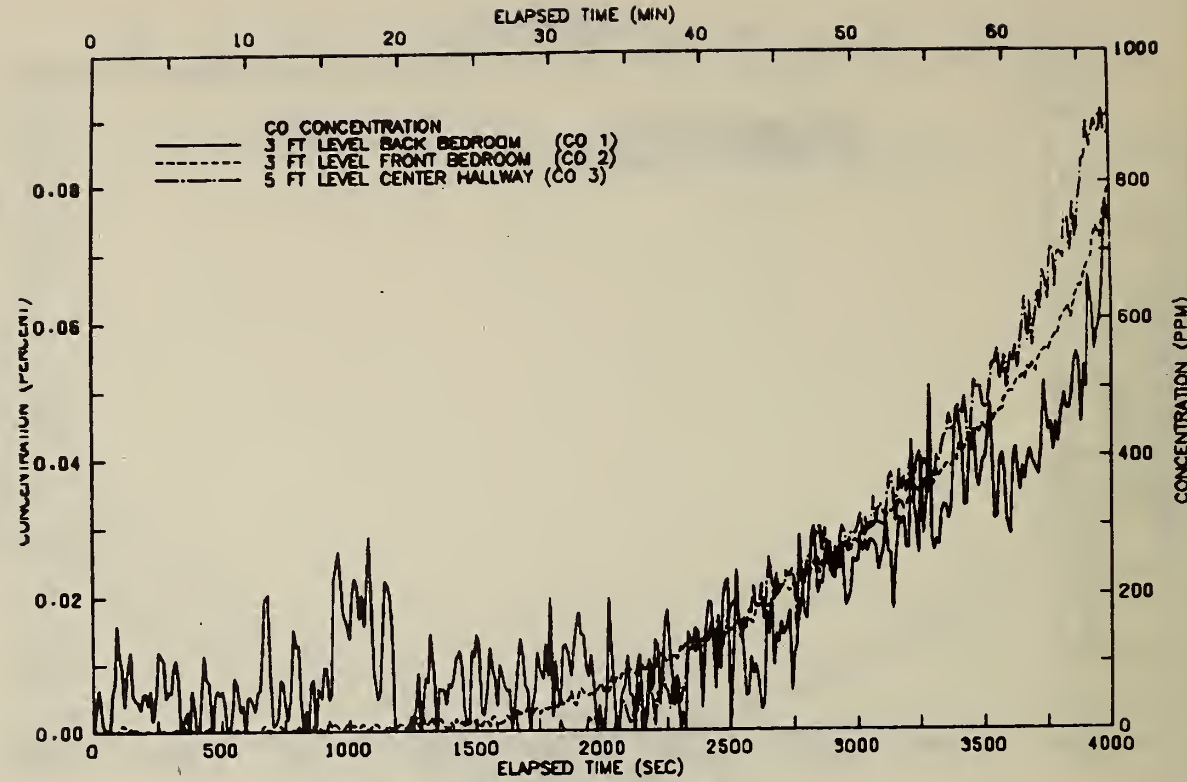

FIGURE A60A CARBON MONOXIDE CONCENTRATION–TEST 06

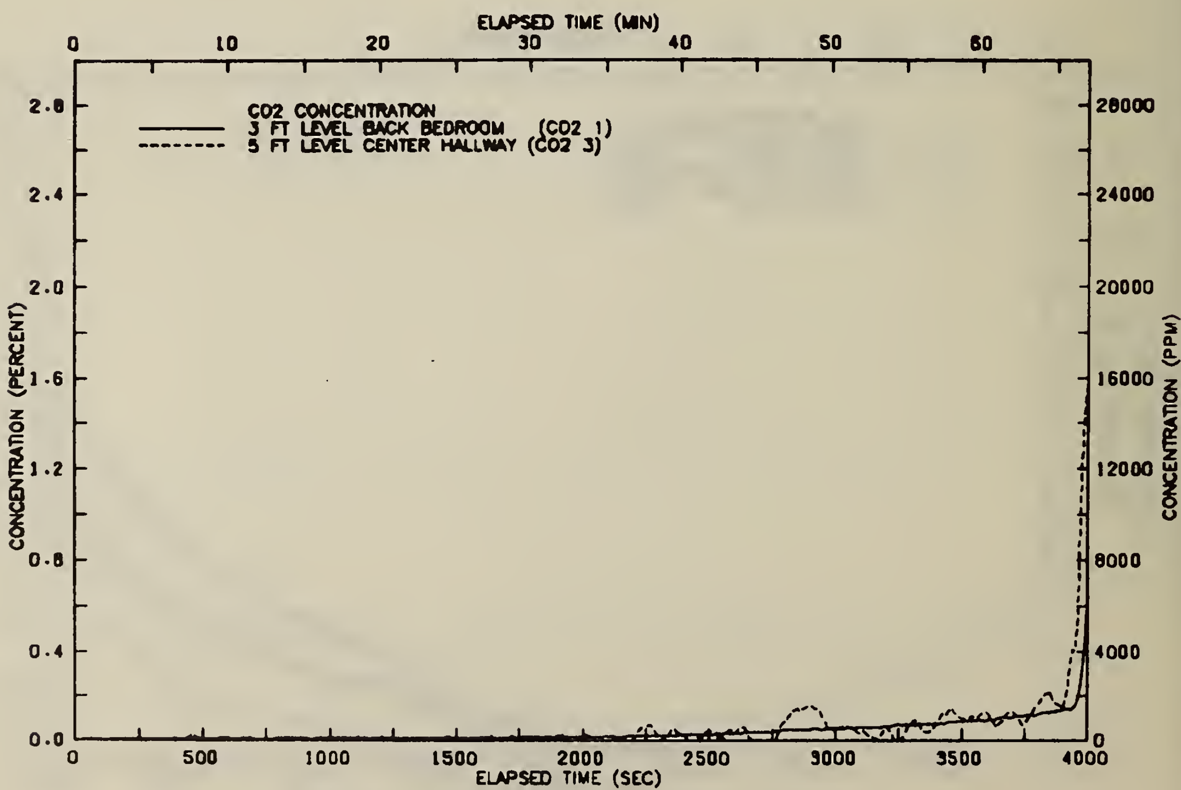

FIGURE A60B CARBON DIOXIDE CONCENTRATION–TEST 06

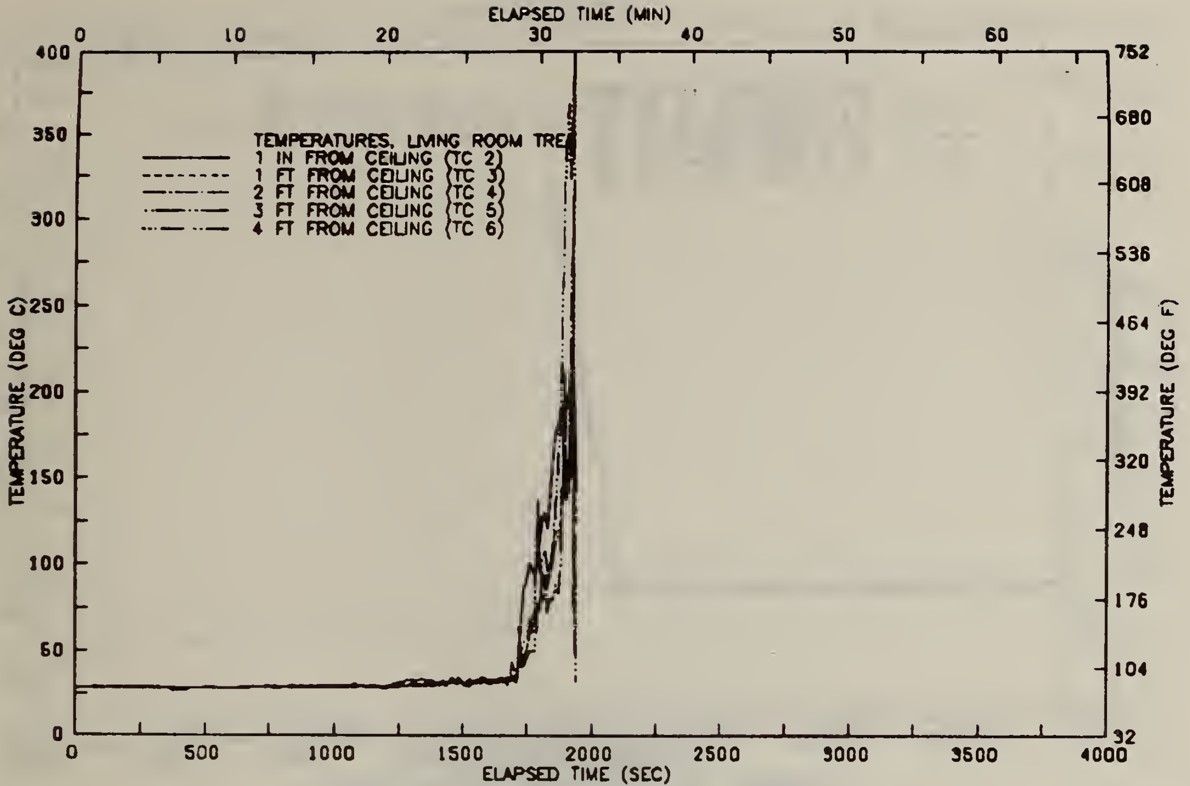

FIGURE A61 VERTICAL TEMP. PROFILE ABOVE CHAIR-TEST 07

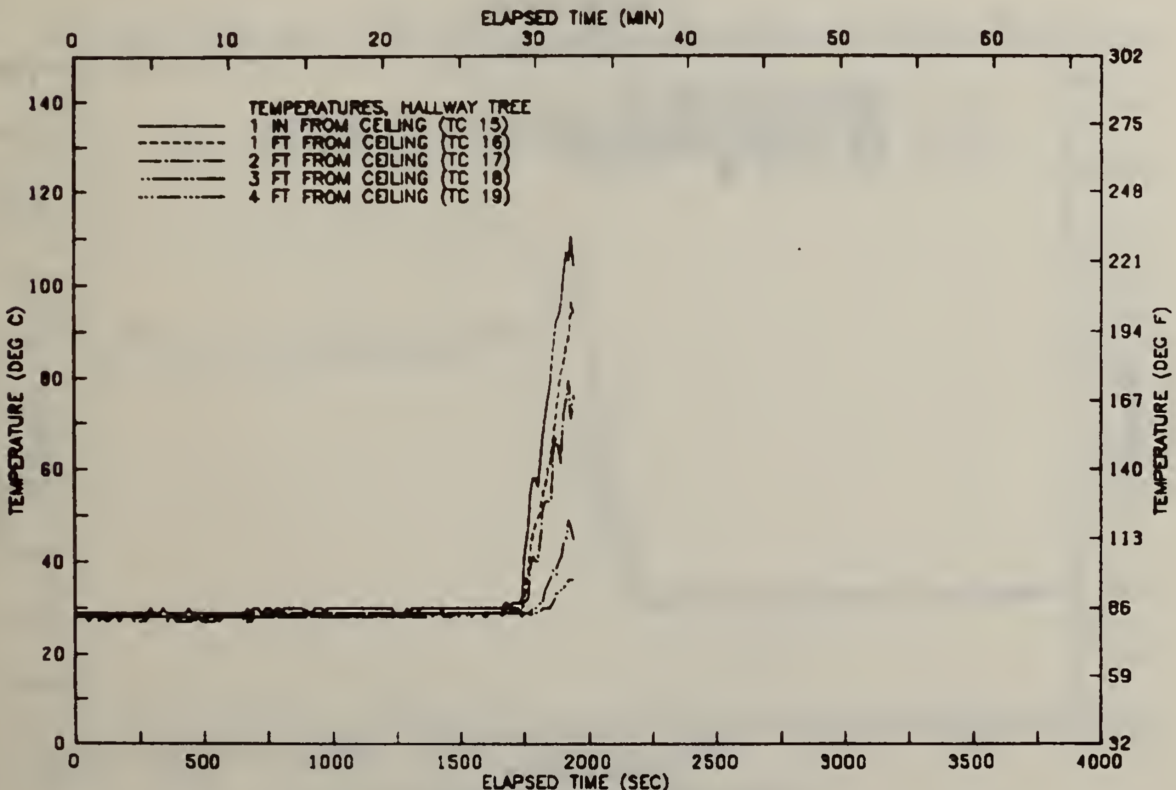

FIGURE A62 VERTICAL TEMP. PROFILE IN HALLWAY-TEST 07

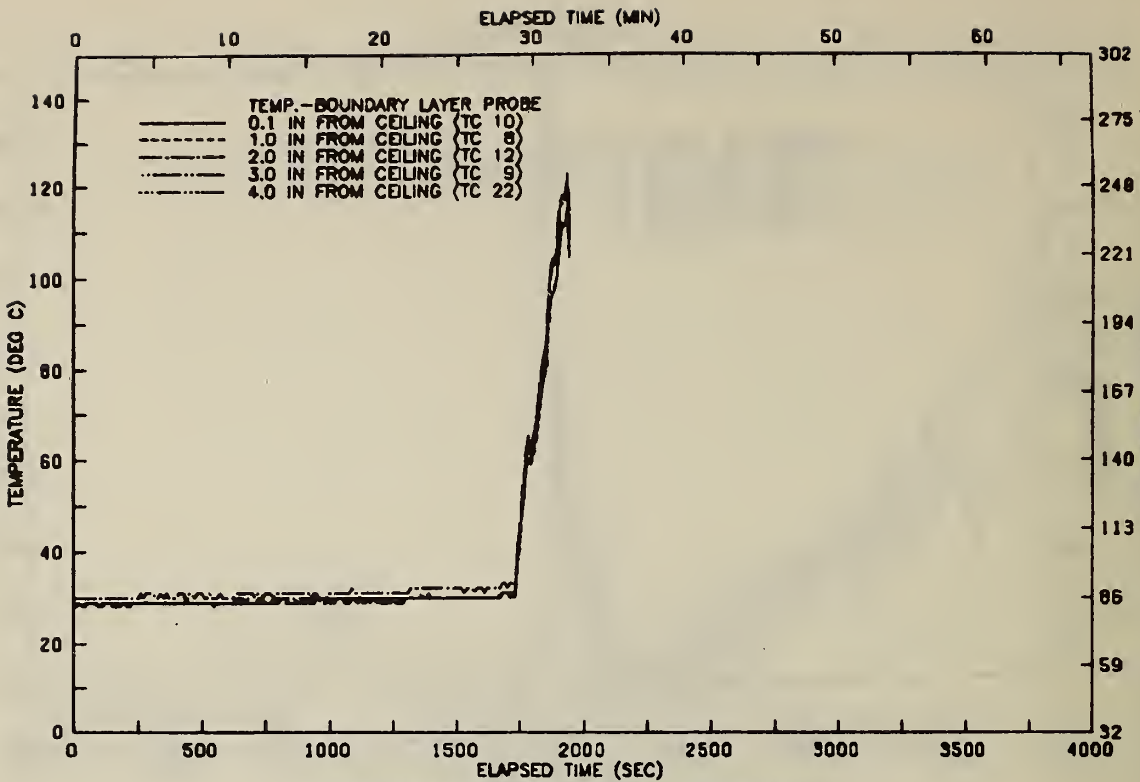

FIGURE A63 VERTICAL TEMP. PROFILE
CEILING BOUNDARY LAYER-TEST 07

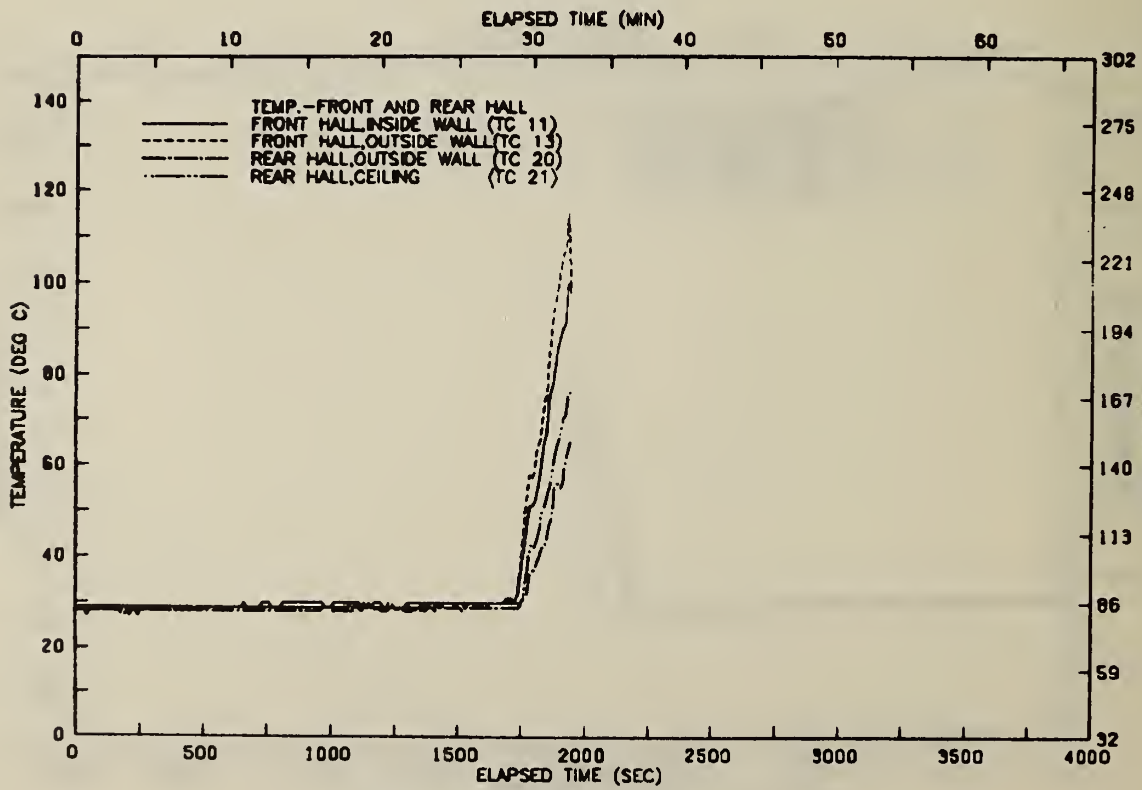

FIGURE A64 TEMP. IN HALLWAY
NEAR DETECTORS-TEST 07

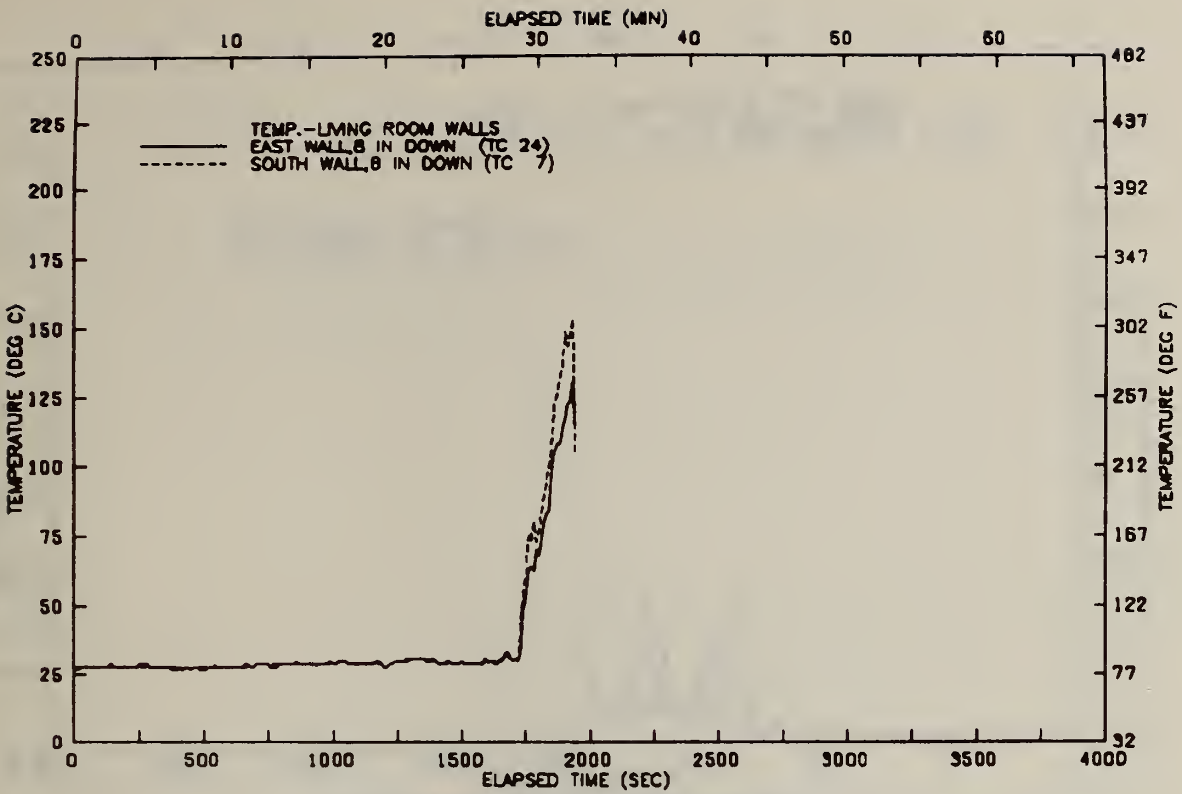

FIGURE A65 TEMPERATURE AT LIVING ROOM WALLS—TEST 07

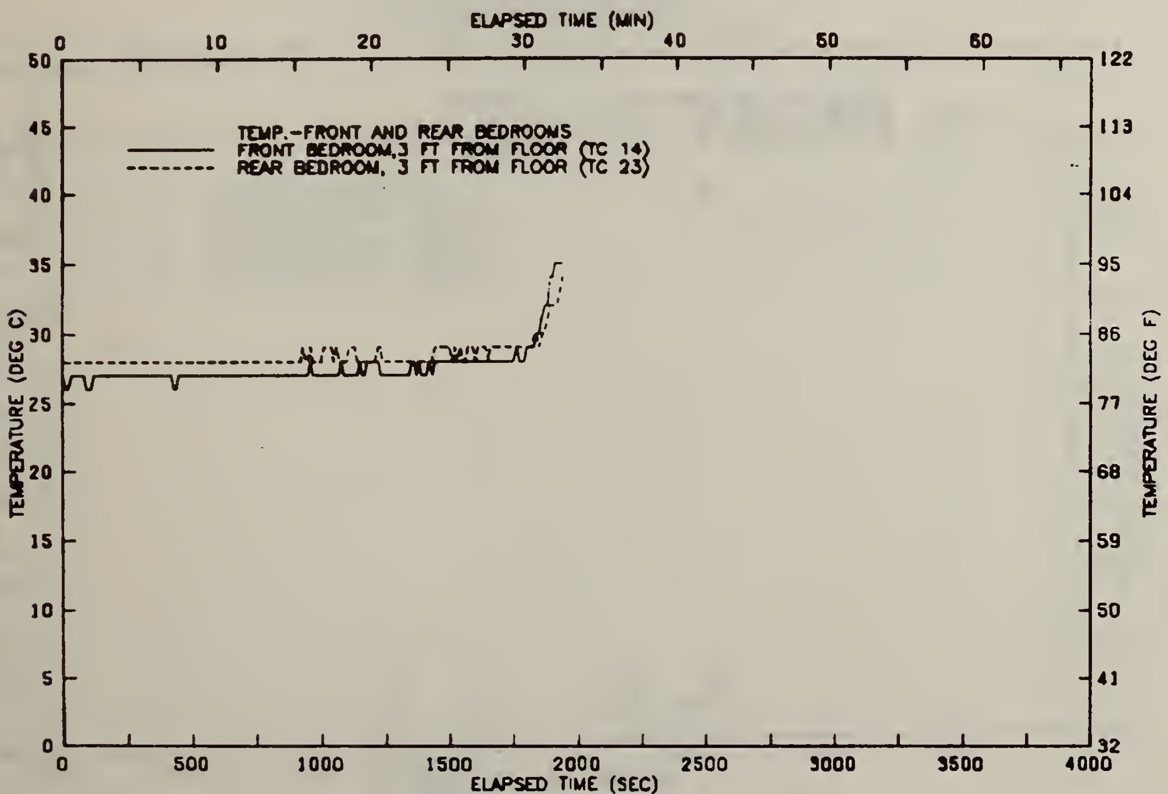

FIGURE A66 TEMP. IN FRONT AND REAR BEDROOMS—TEST 07

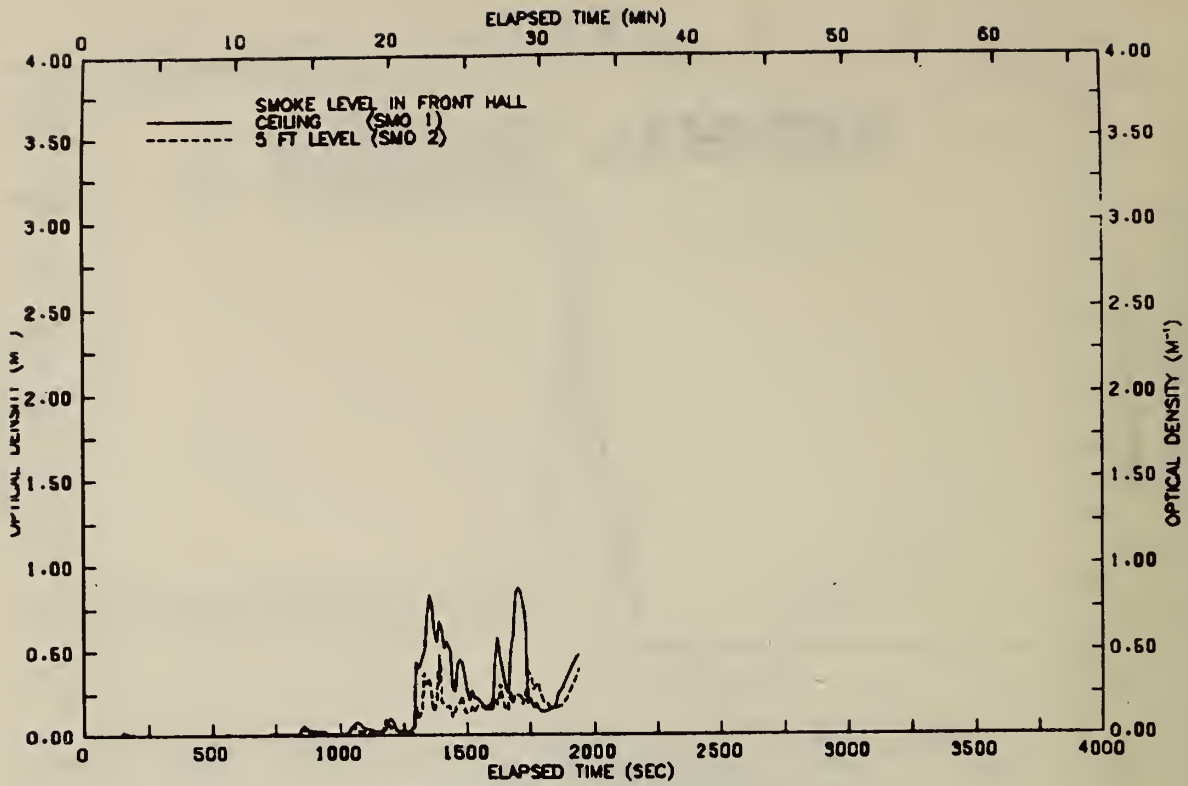

FIGURE A67 SMOKE LEVELS IN FRONT HALLWAY-TEST 07

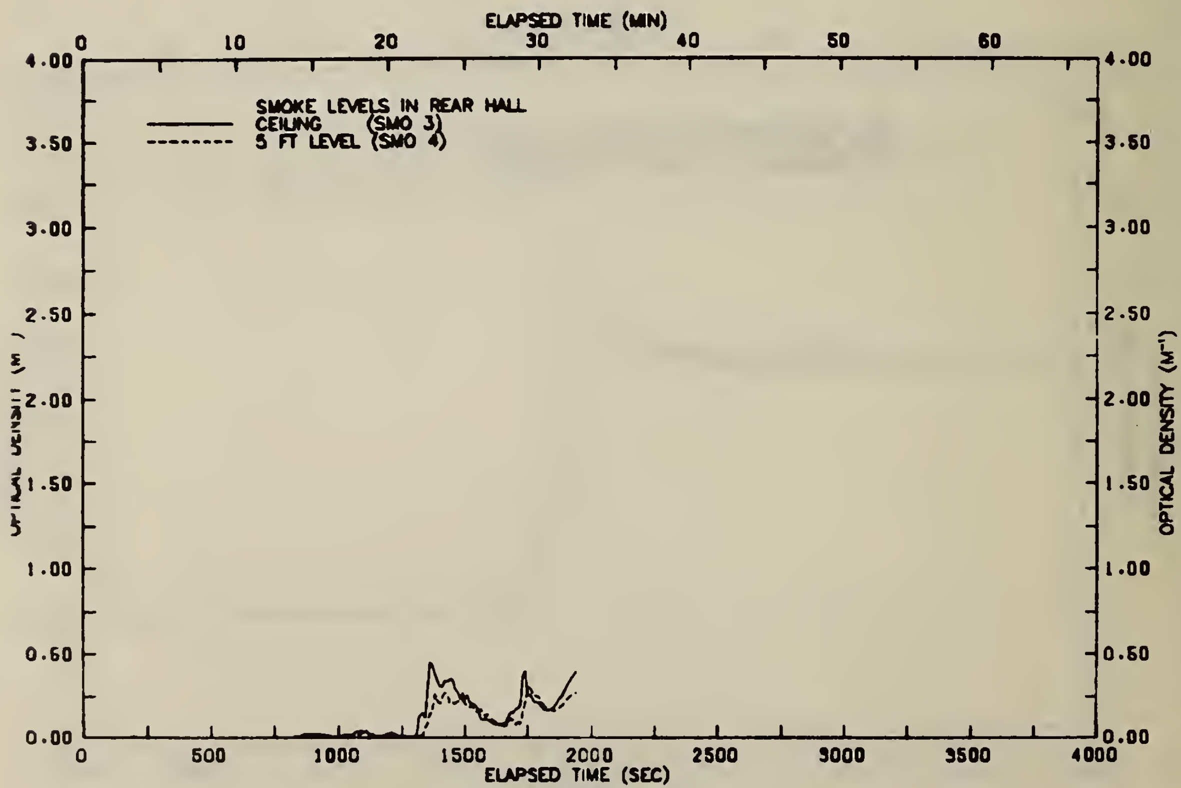

FIGURE A68 SMOKE LEVELS IN REAR HALLWAY-TEST 07

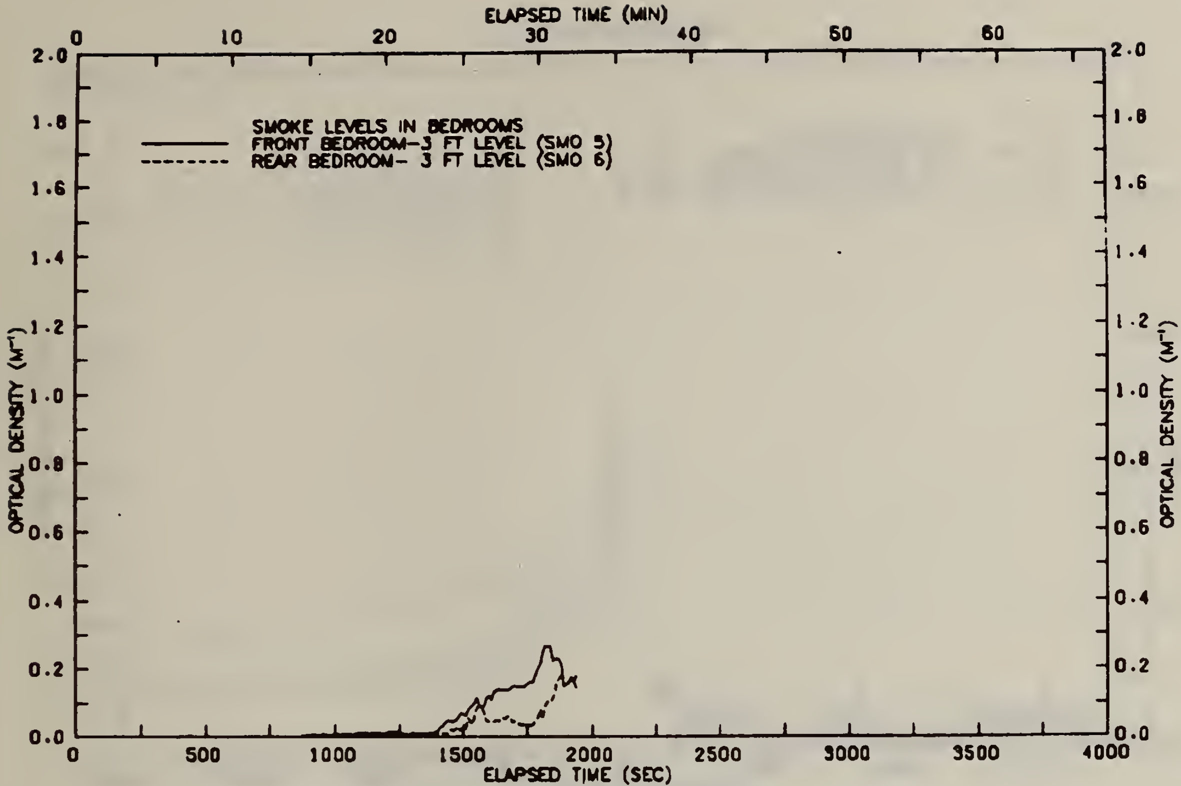

FIGURE A69 SMOKE LEVELS IN BEDROOMS-TEST 07

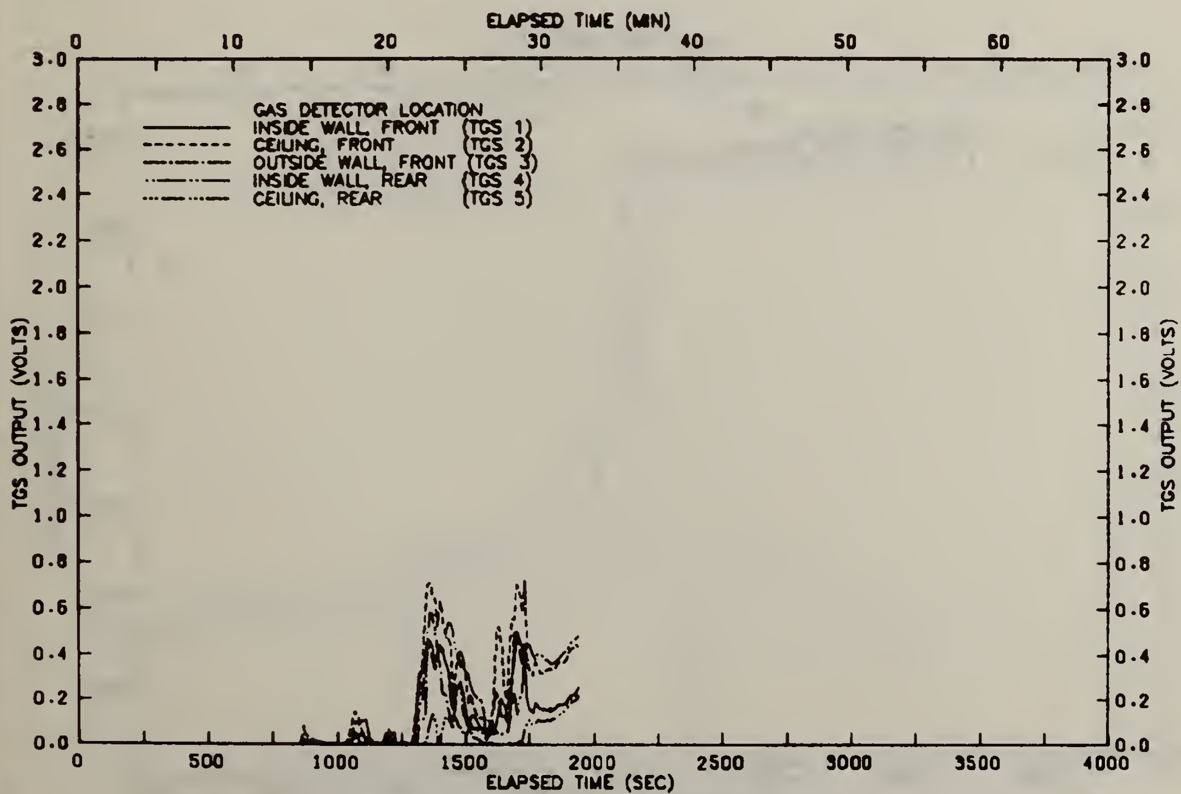

FIGURE A70 GAS DETECTOR OUTPUT VOLTAGE BY LOCATION-TEST 07

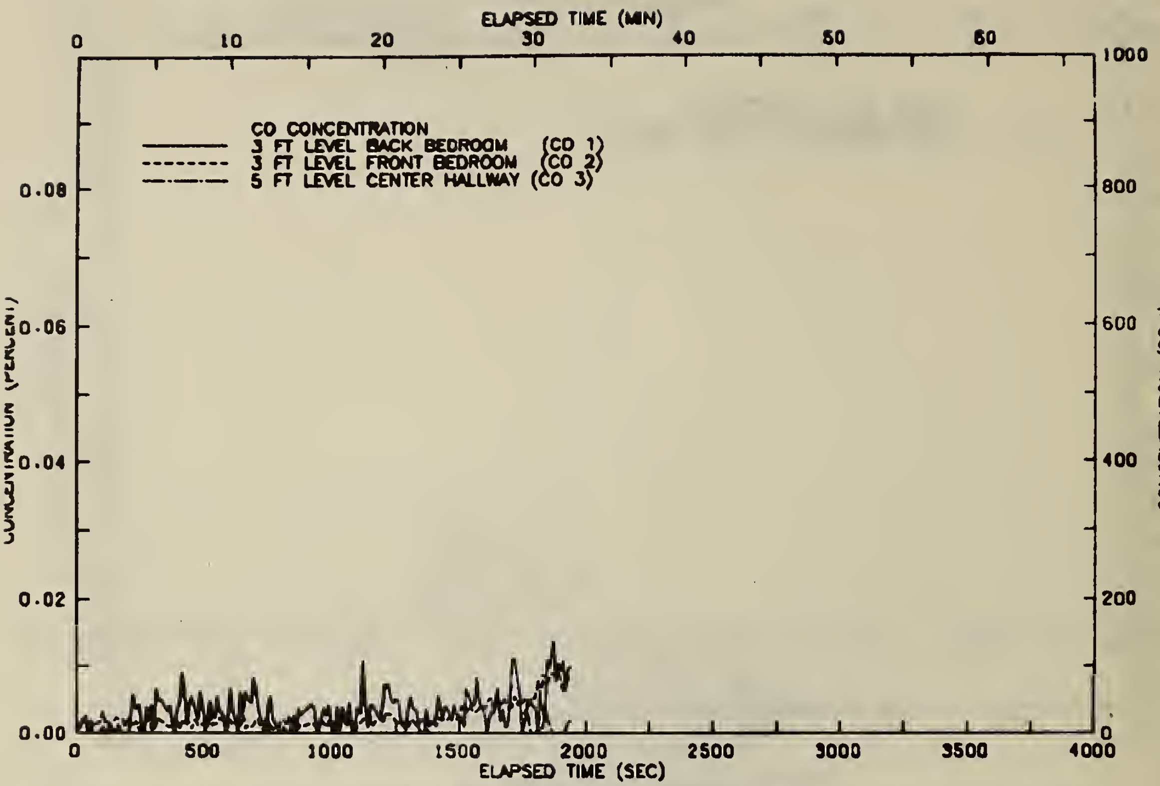

FIGURE A70A CARBON MONOXIDE CONCENTRATION-TEST 07

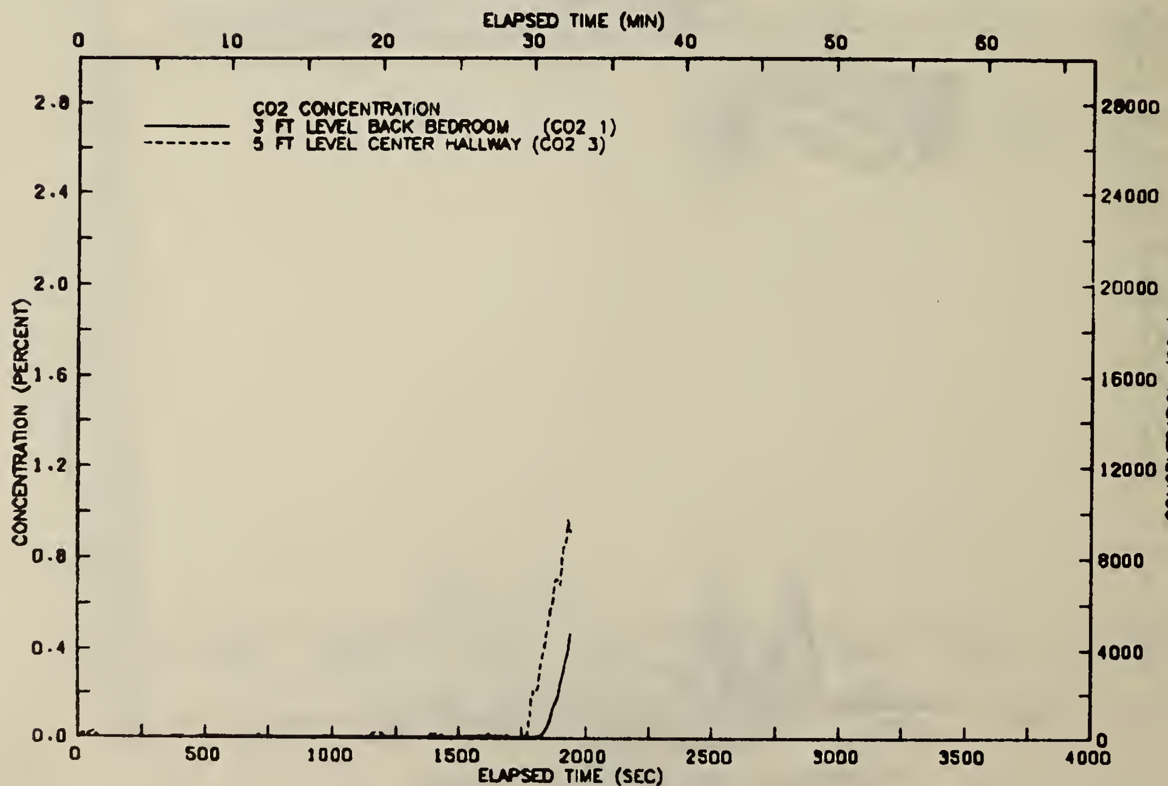

FIGURE A70B CARBON DIOXIDE CONCENTRATION-TEST 07

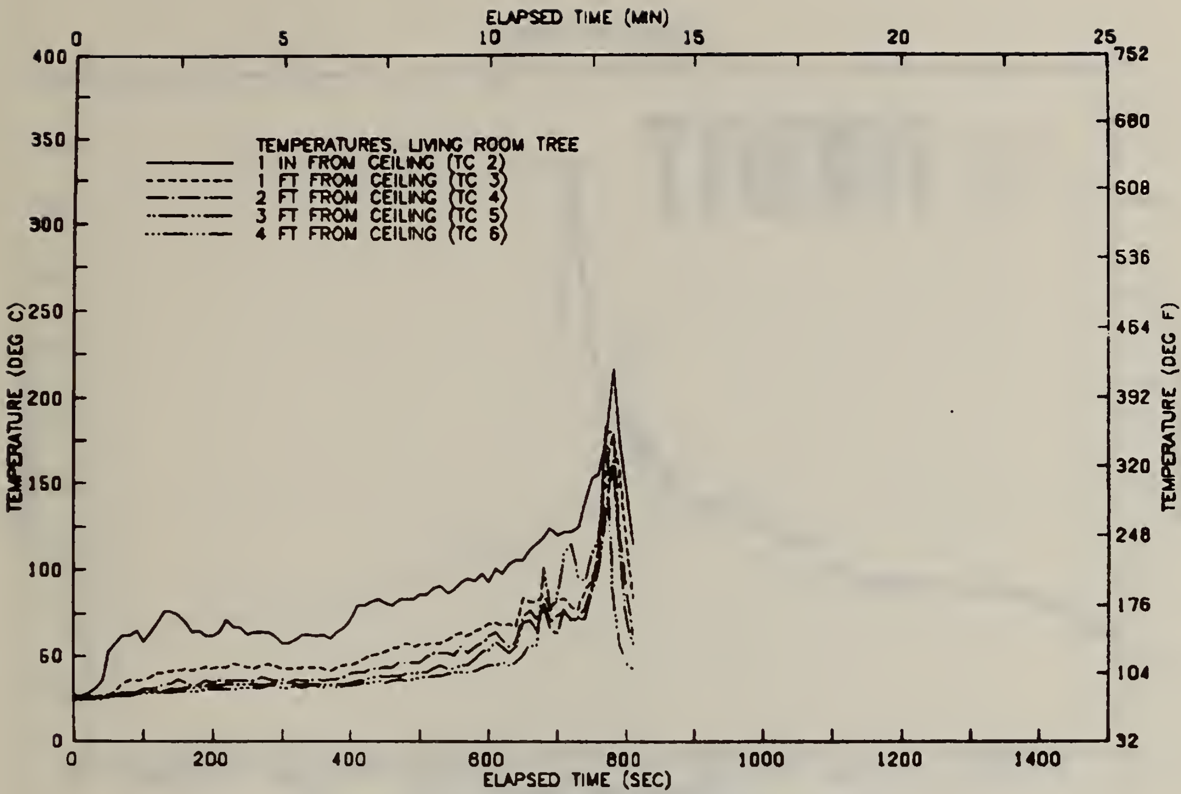

FIGURE A71 VERTICAL TEMP. PROFILE
ABOVE CHAIR-TEST 08

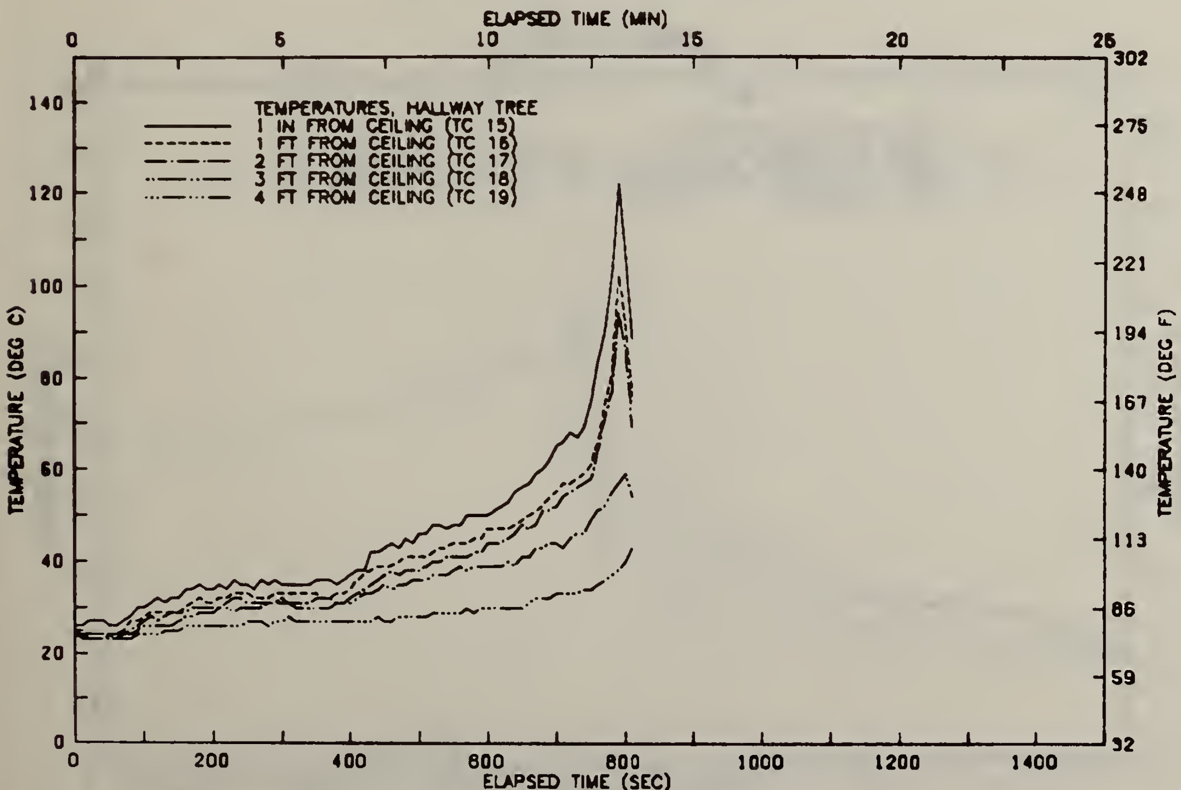

FIGURE A72 VERTICAL TEMP. PROFILE
IN HALLWAY-TEST 08

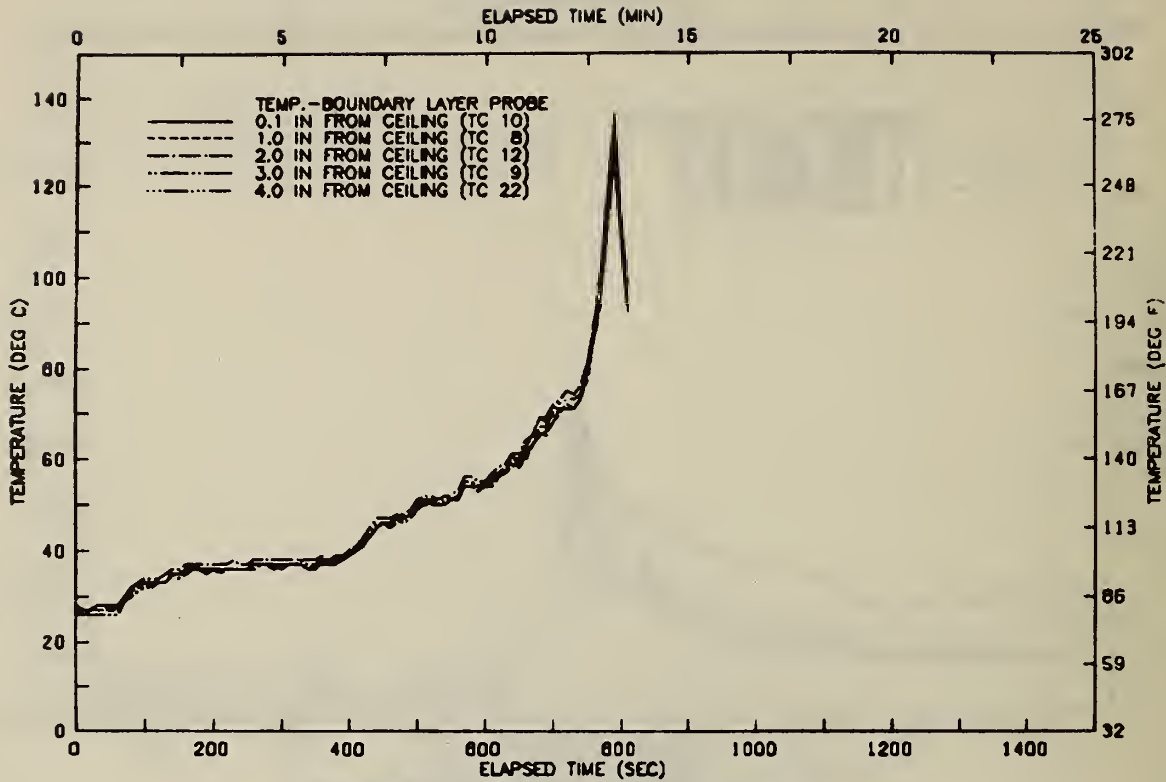

FIGURE A73 VERTICAL TEMP. PROFILE
CEILING BOUNDARY LAYER-TEST 08

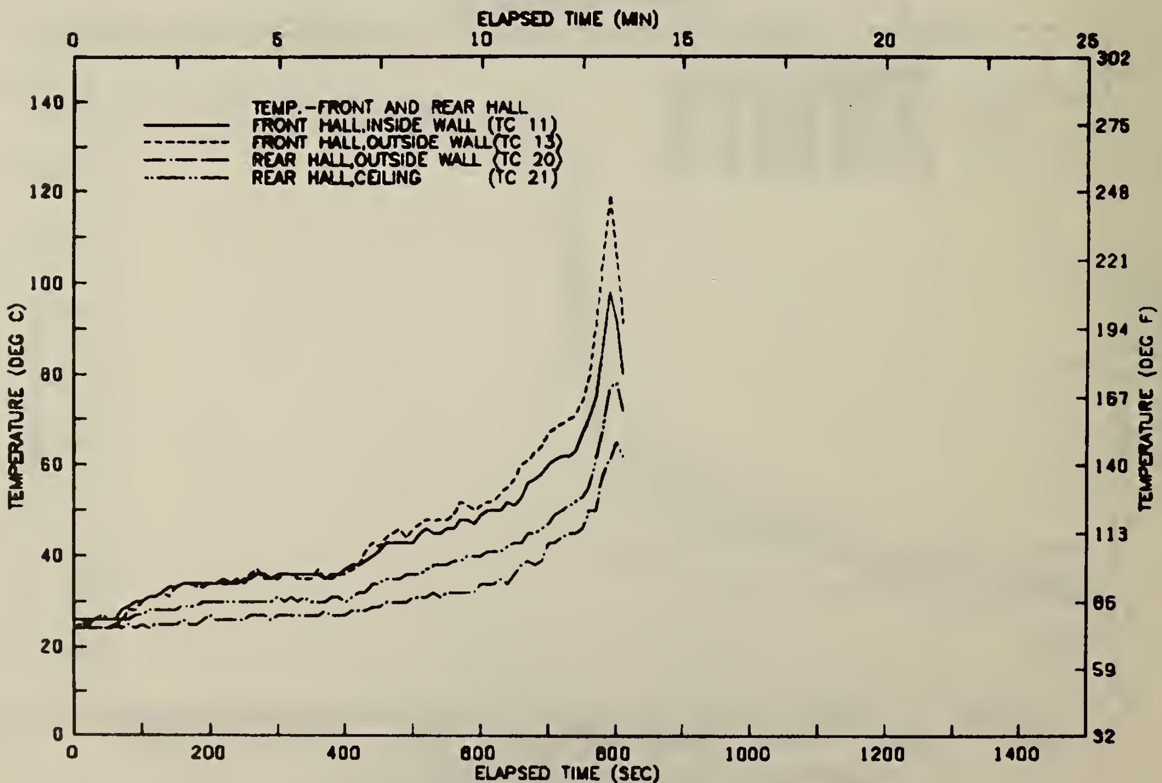

FIGURE A74 TEMP. IN HALLWAY
NEAR DETECTORS-TEST 08

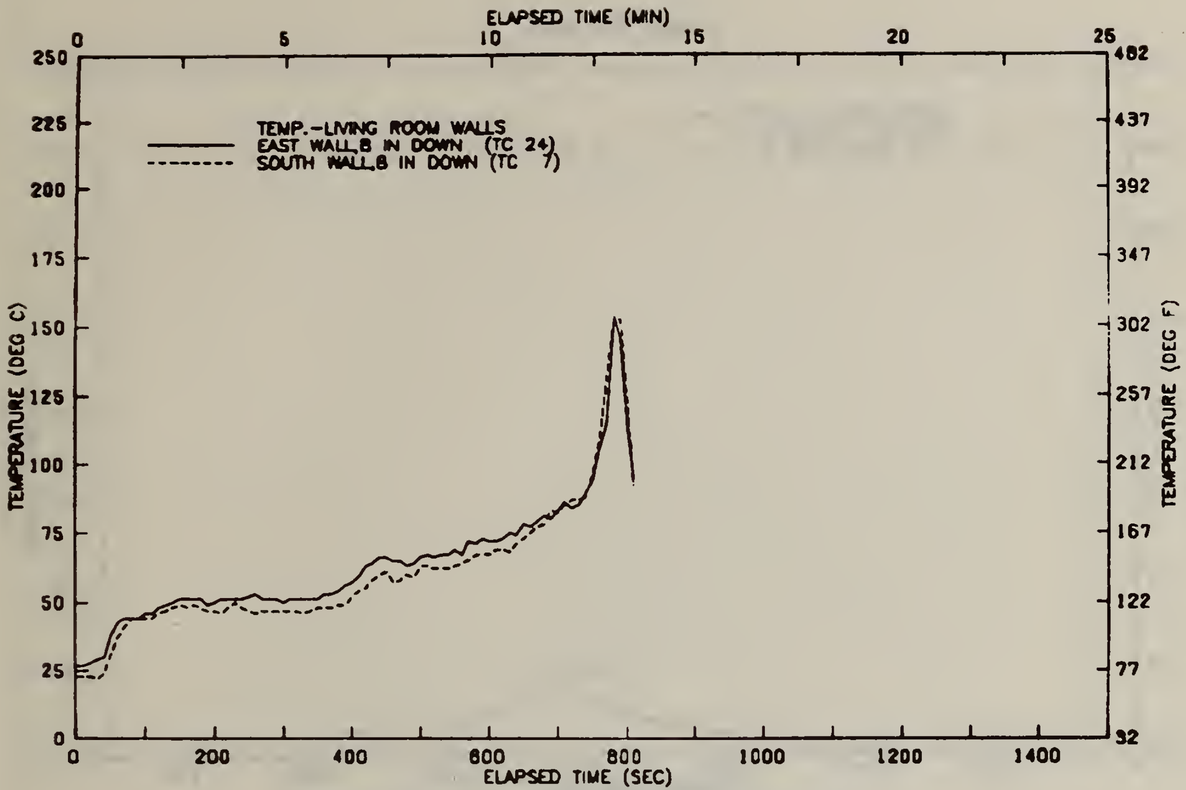

FIGURE A75 TEMPERATURE AT LIVING ROOM WALLS-TEST 08

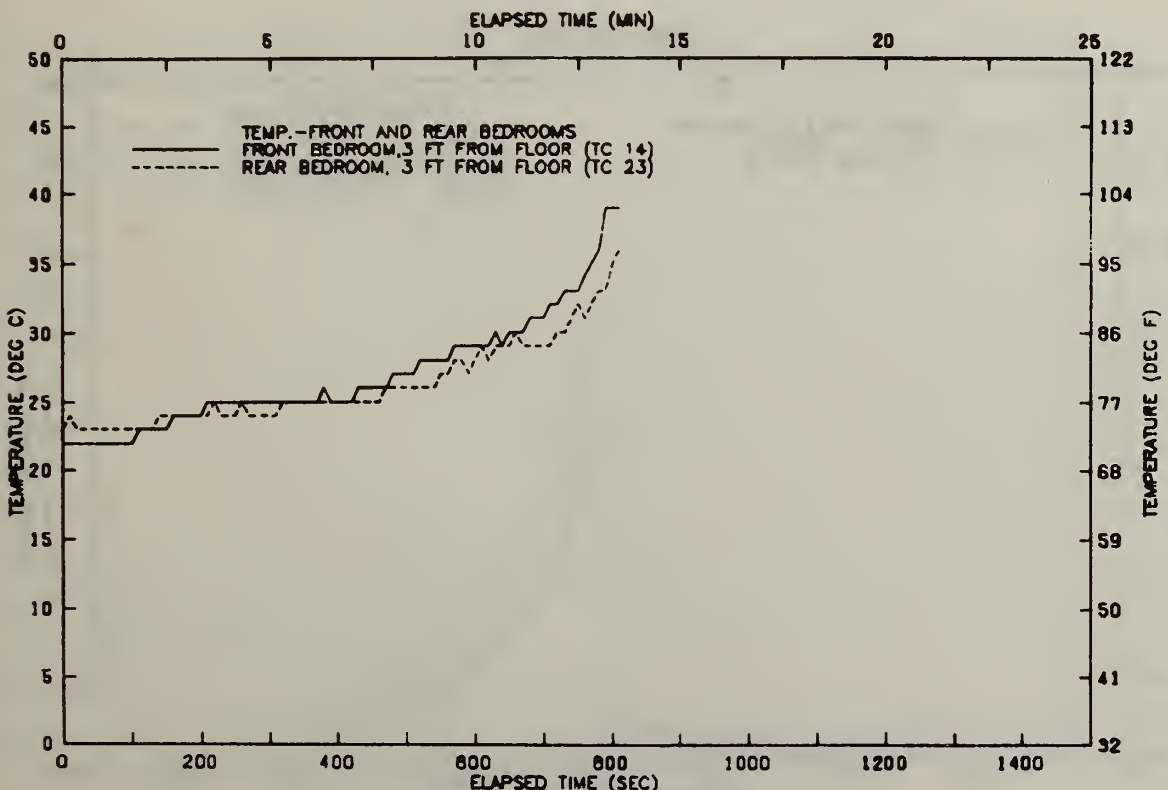

FIGURE A76 TEMP. IN FRONT AND REAR BEDROOMS-TEST 08

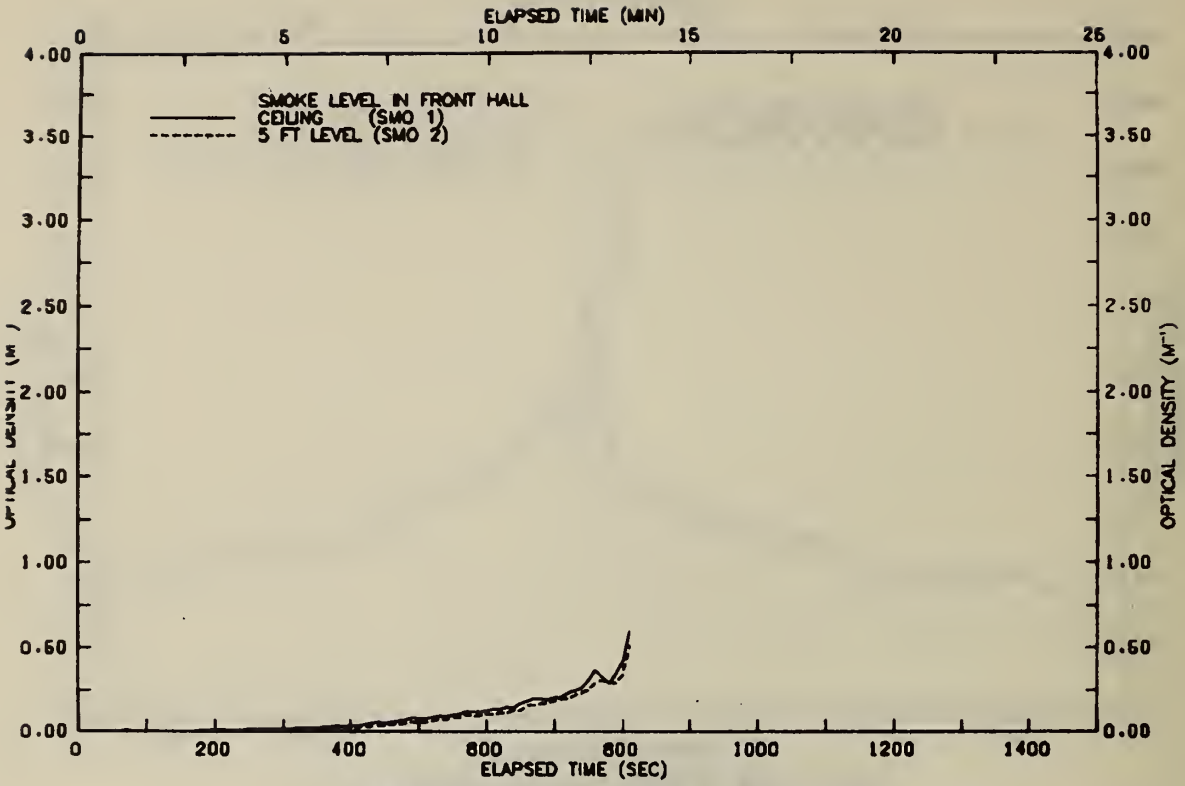

FIGURE A77 SMOKE LEVELS IN FRONT HALLWAY-TEST 08

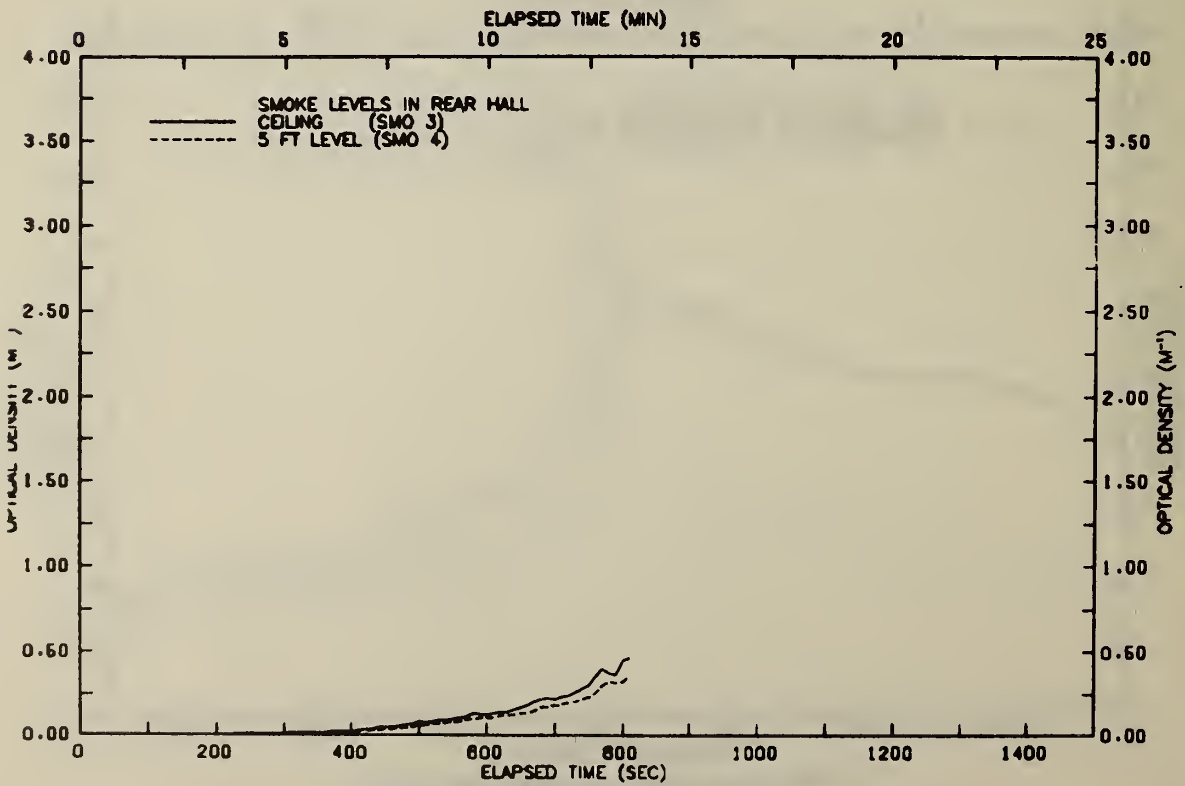

FIGURE A78 SMOKE LEVELS IN REAR HALLWAY-TEST 08

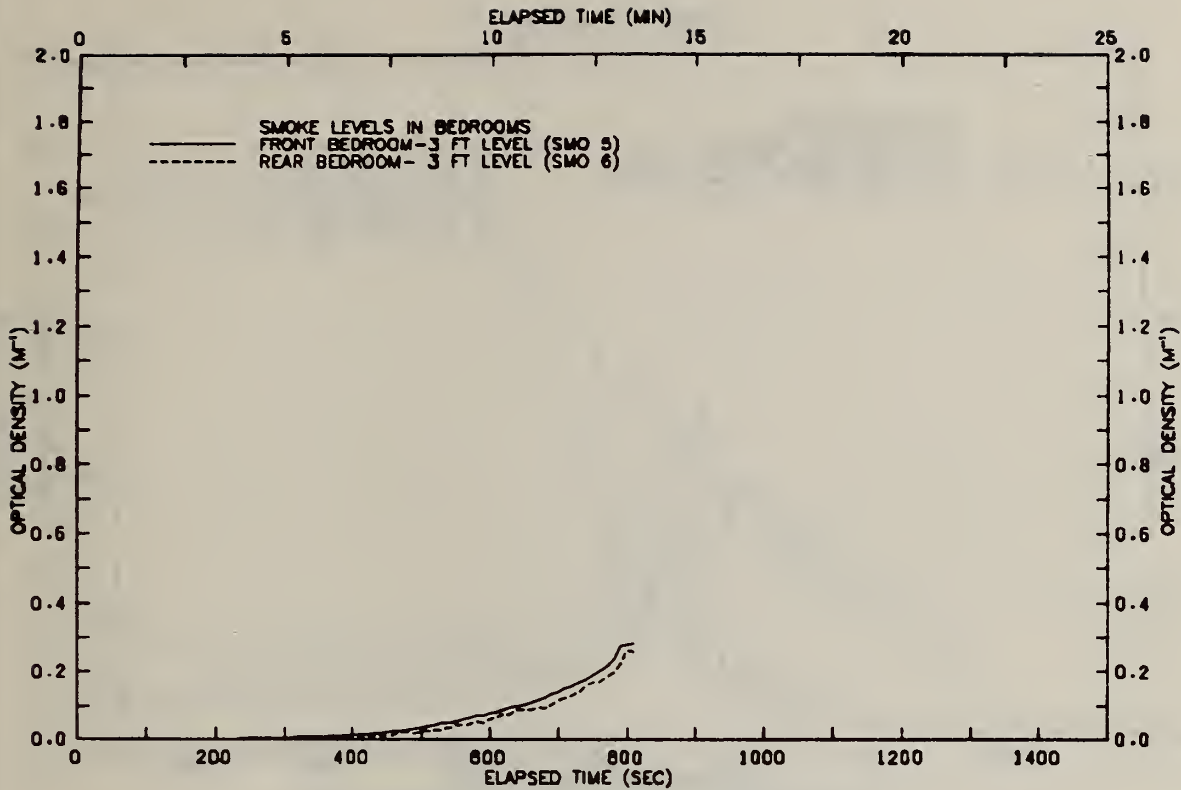

FIGURE A79 SMOKE LEVELS IN BEDROOMS-TEST 08

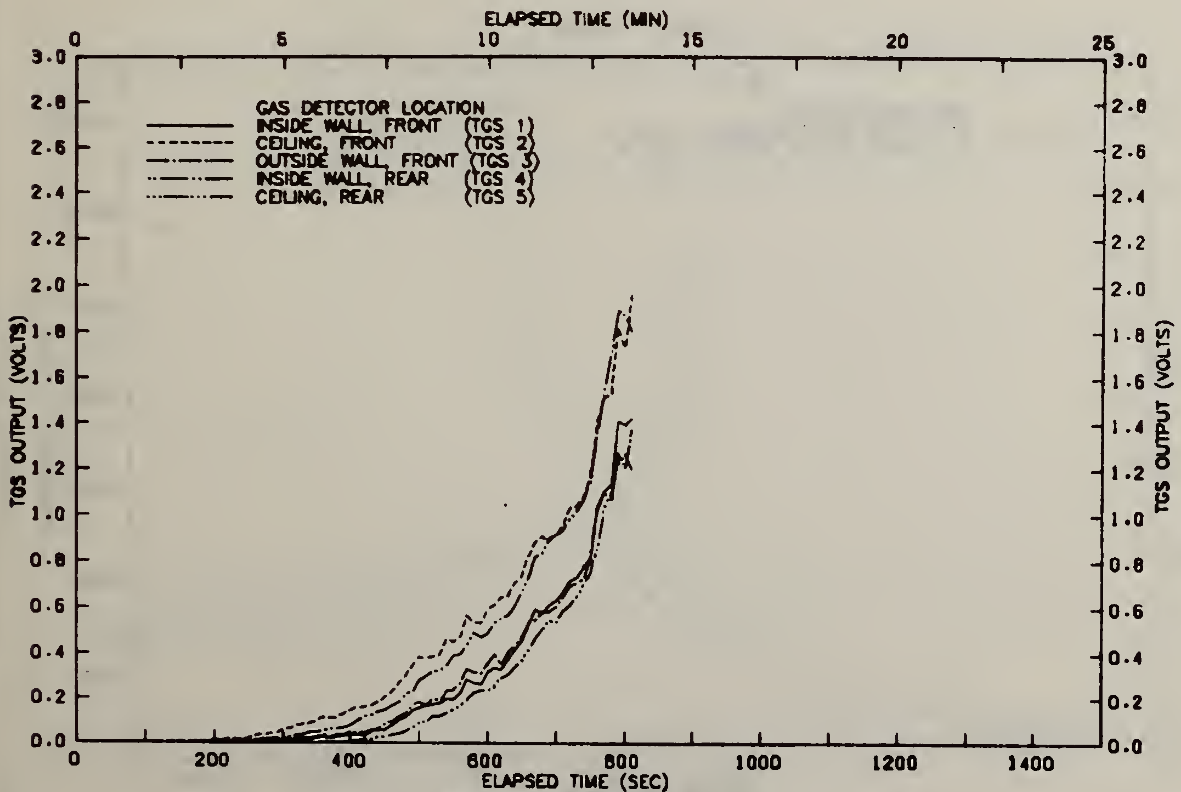

FIGURE A80 GAS DETECTOR OUTPUT VOLTAGE BY LOCATION-TEST 08

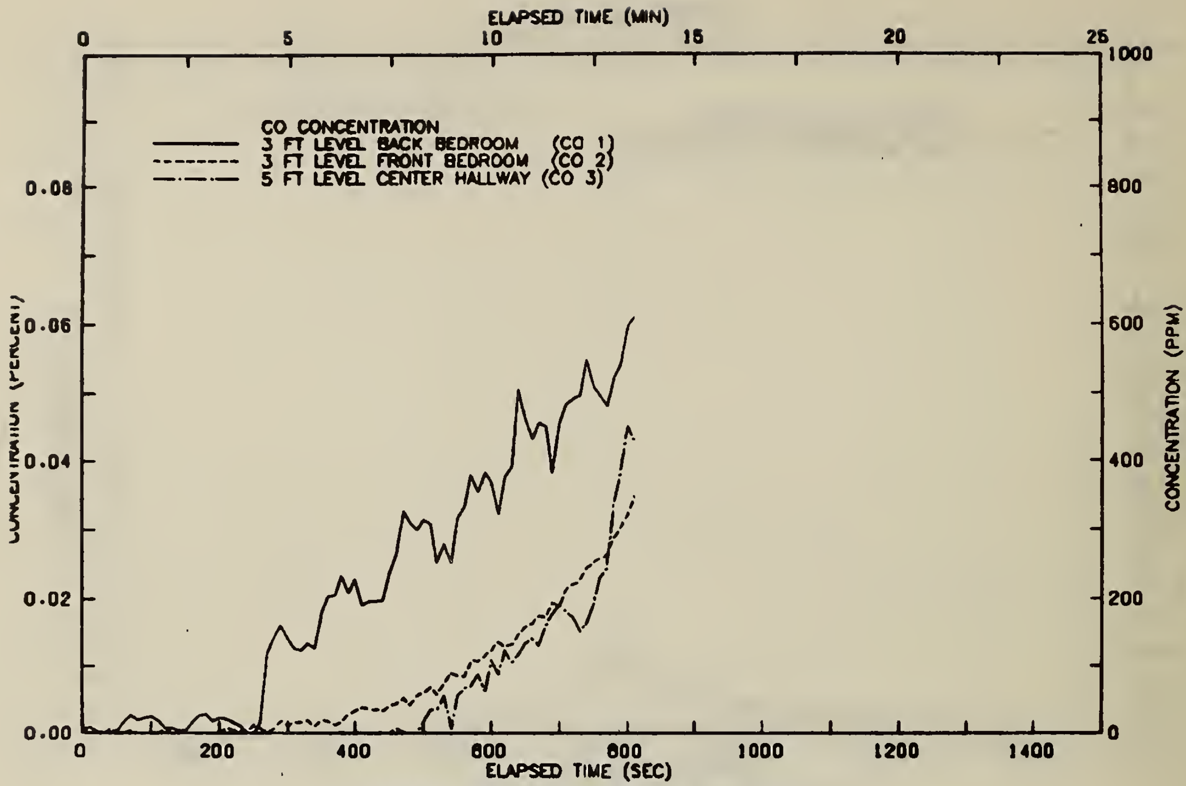

FIGURE A80A CARBON MONOXIDE CONCENTRATION–TEST 08

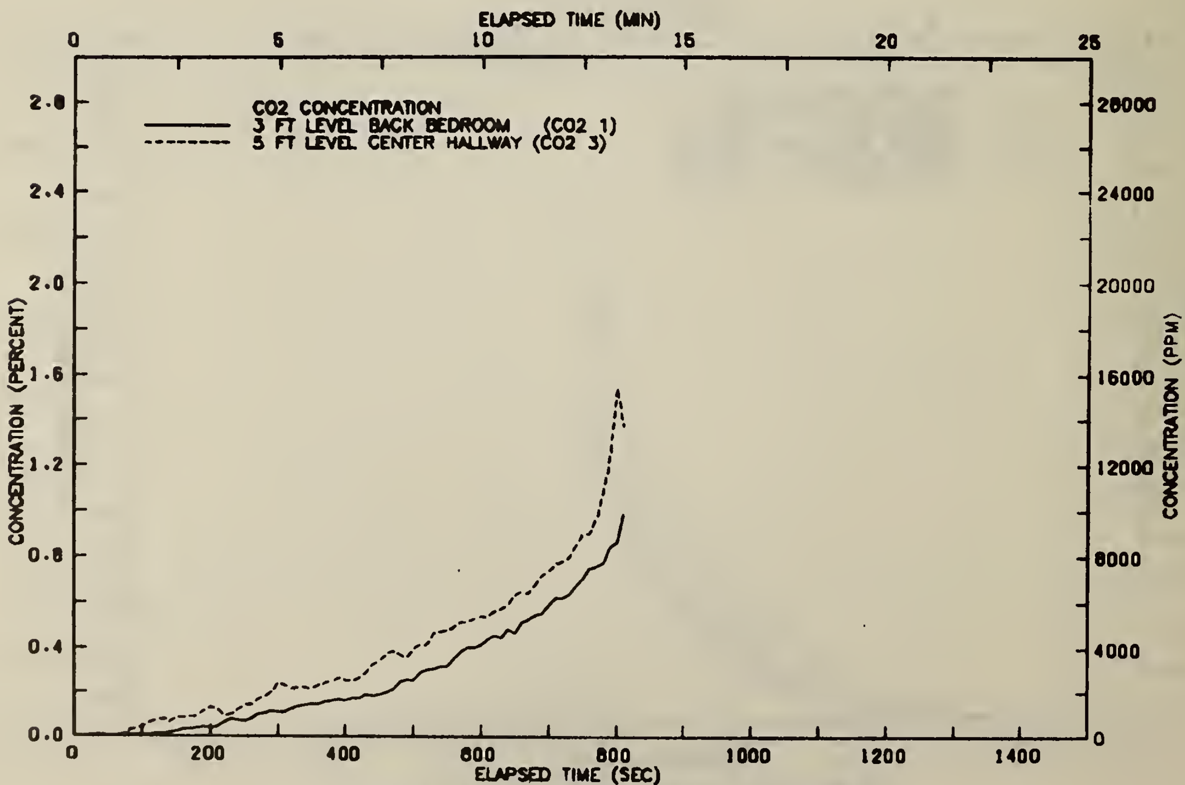

FIGURE A80B CARBON DIOXIDE CONCENTRATION–TEST 08

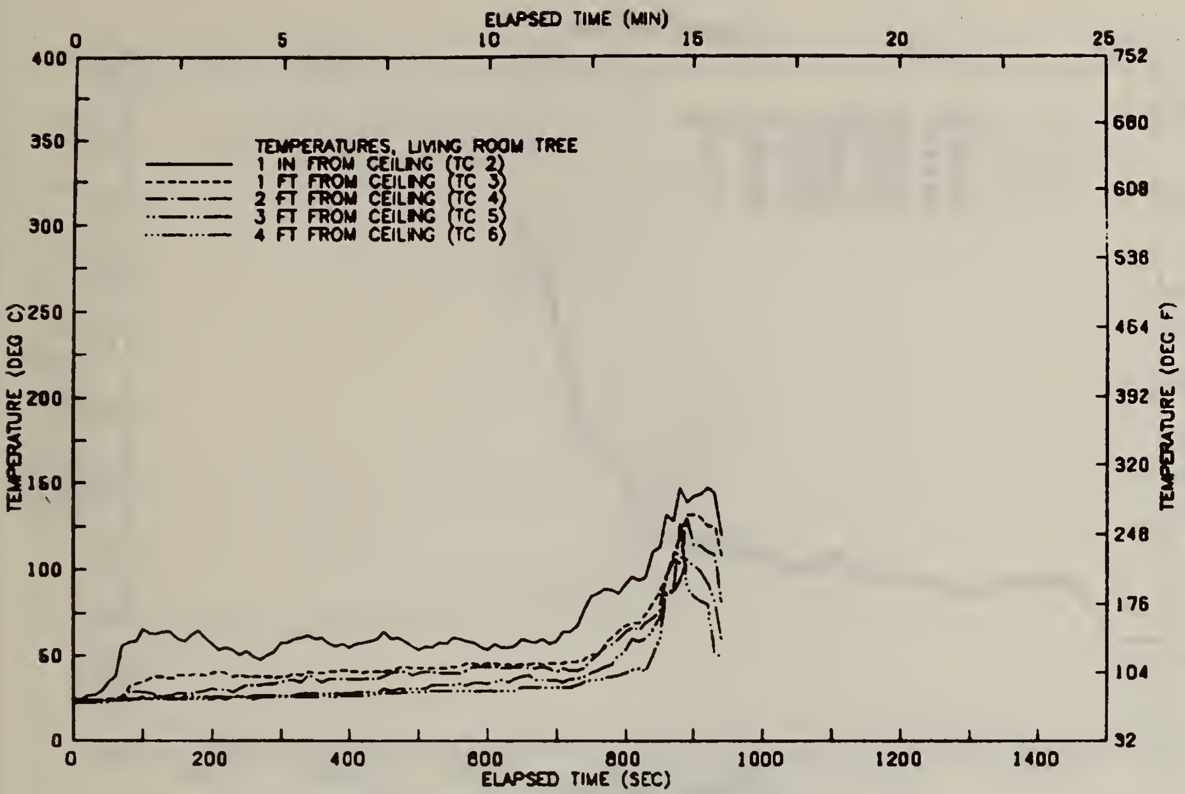

FIGURE A81 VERTICAL TEMP. PROFILE
ABOVE CHAIR-TEST 09

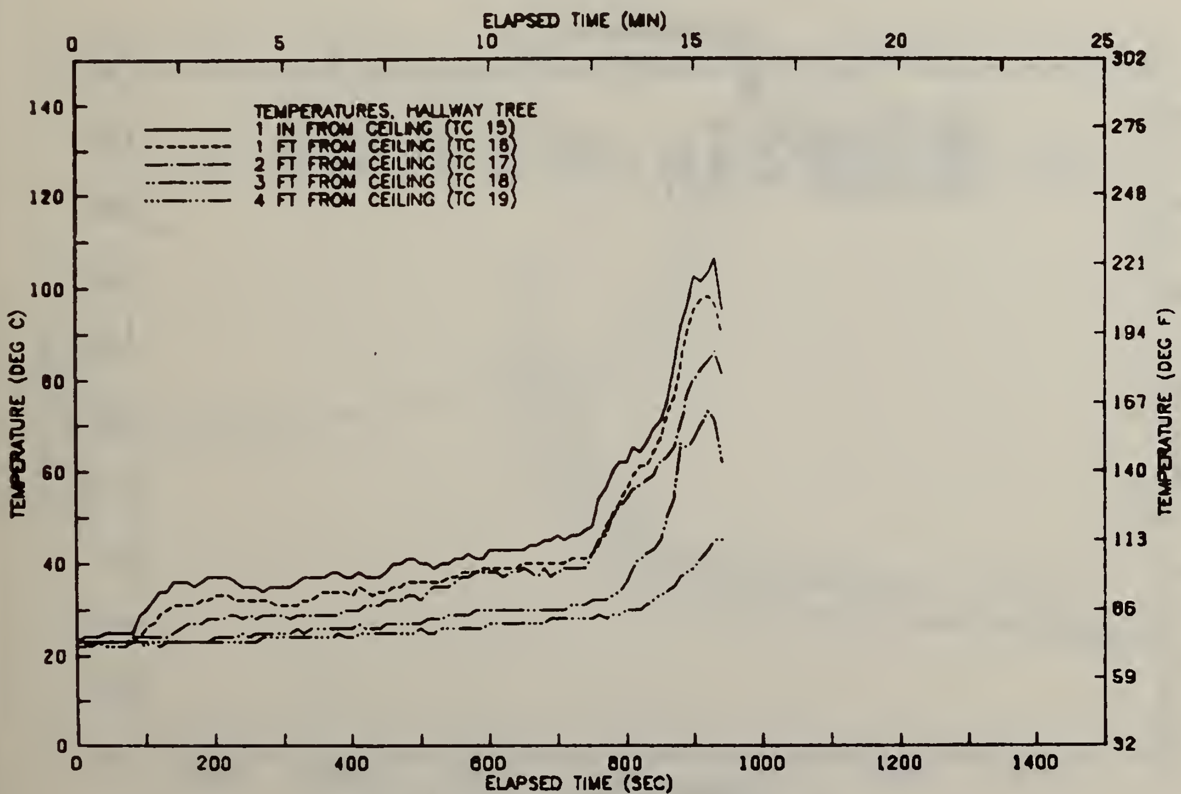

FIGURE A82 VERTICAL TEMP. PROFILE
IN HALLWAY-TEST 09

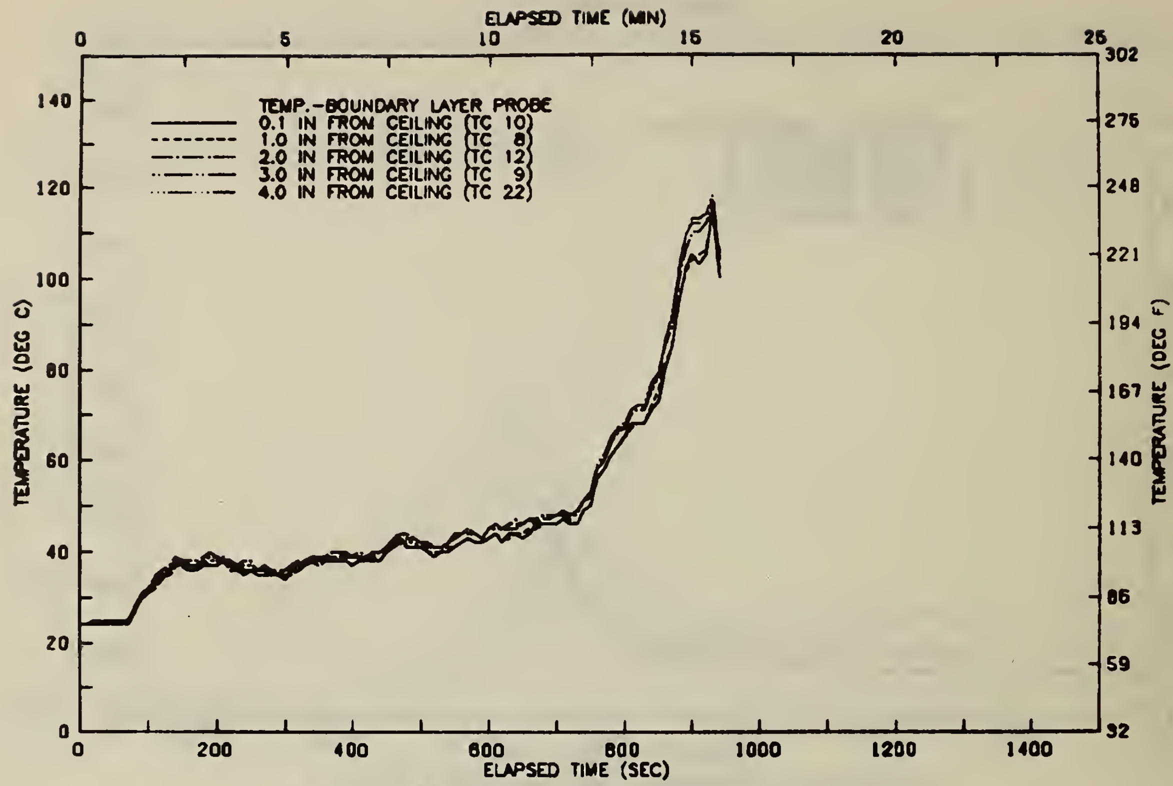

FIGURE A83 VERTICAL TEMP. PROFILE
CEILING BOUNDARY LAYER-TEST 09

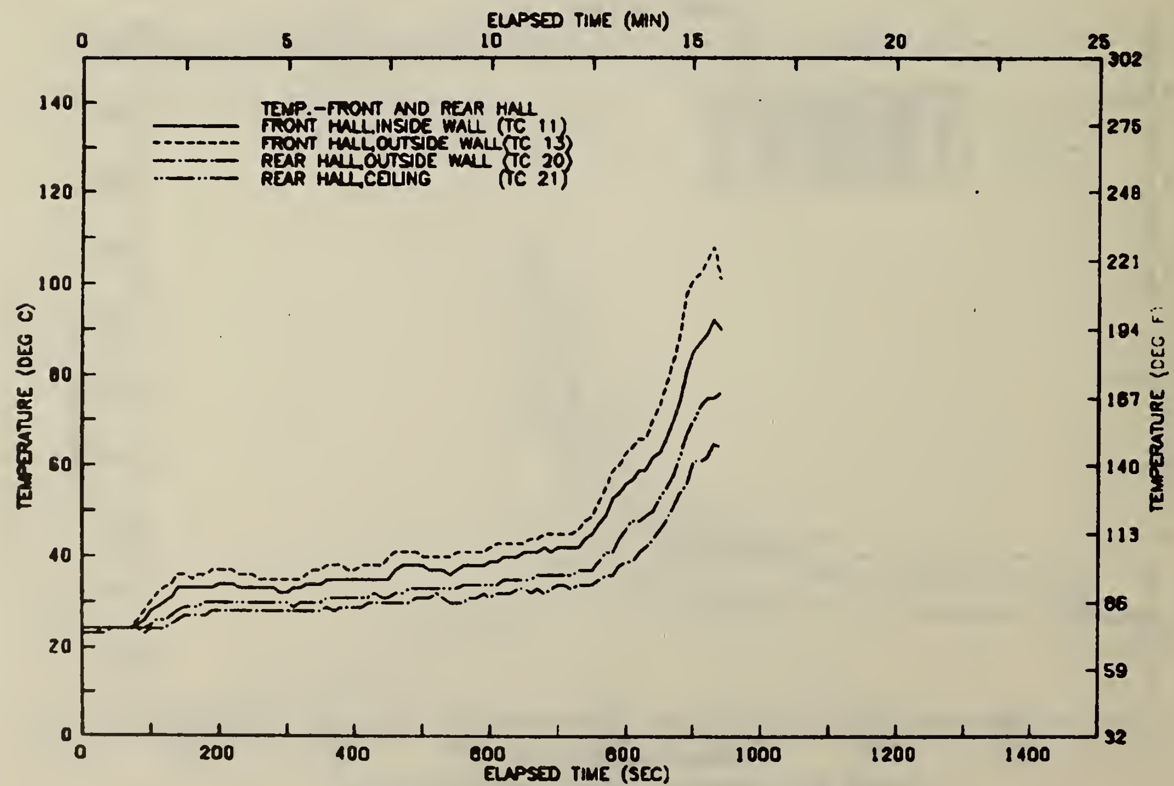

FIGURE A84 TEMP. IN HALLWAY
NEAR DETECTORS-TEST 09

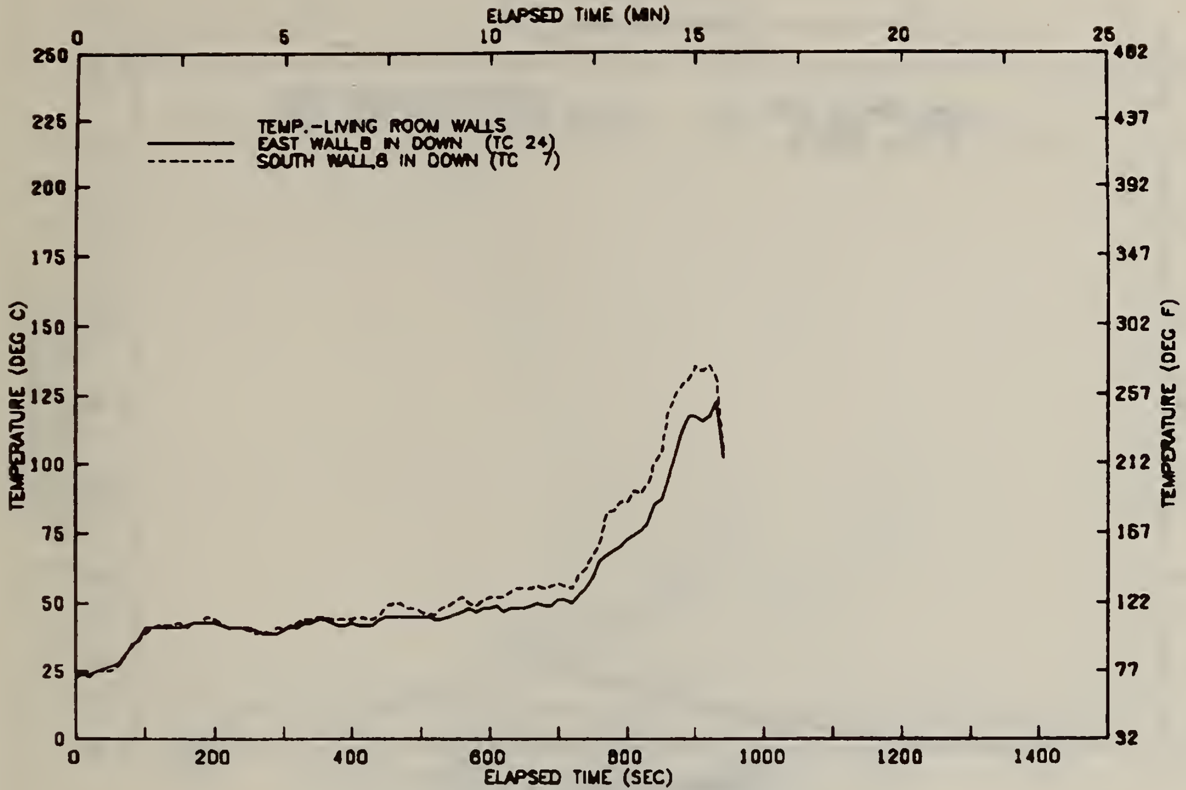

FIGURE A85 TEMPERATURE AT LIVING ROOM WALLS-TEST 09

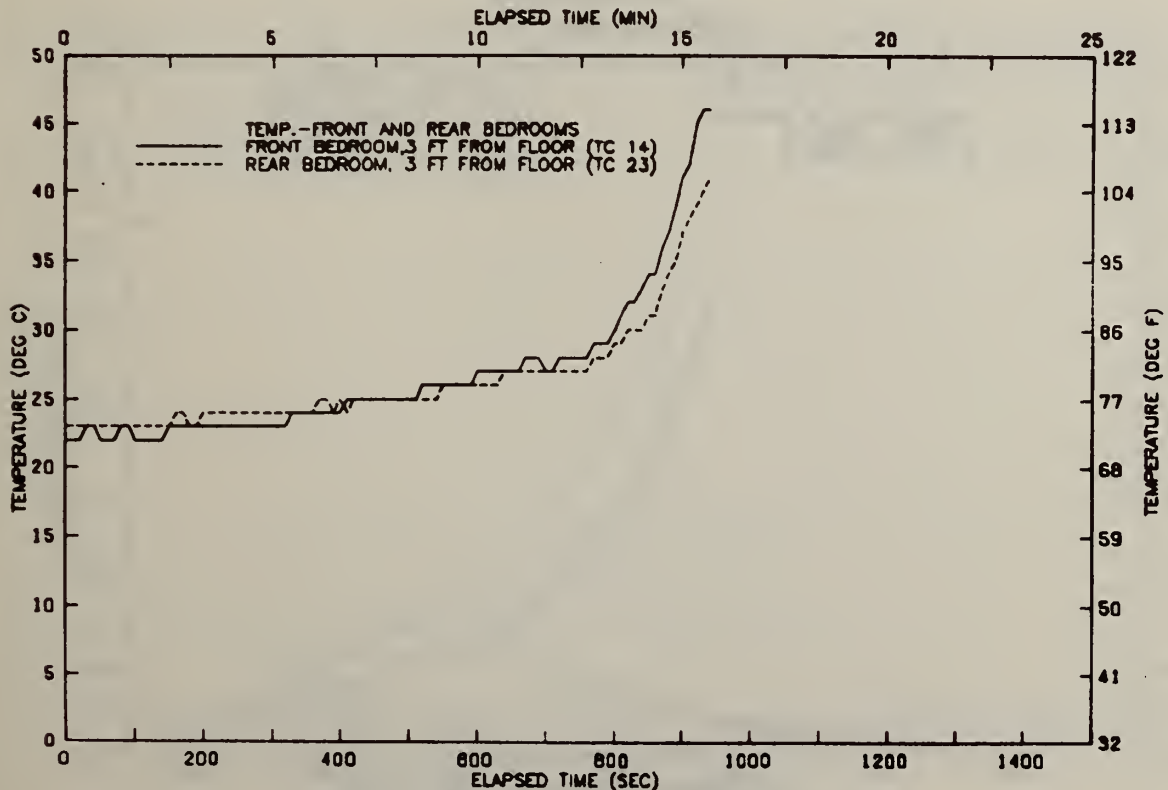

FIGURE A86 TEMP. IN FRONT AND REAR BEDROOMS-TEST 09

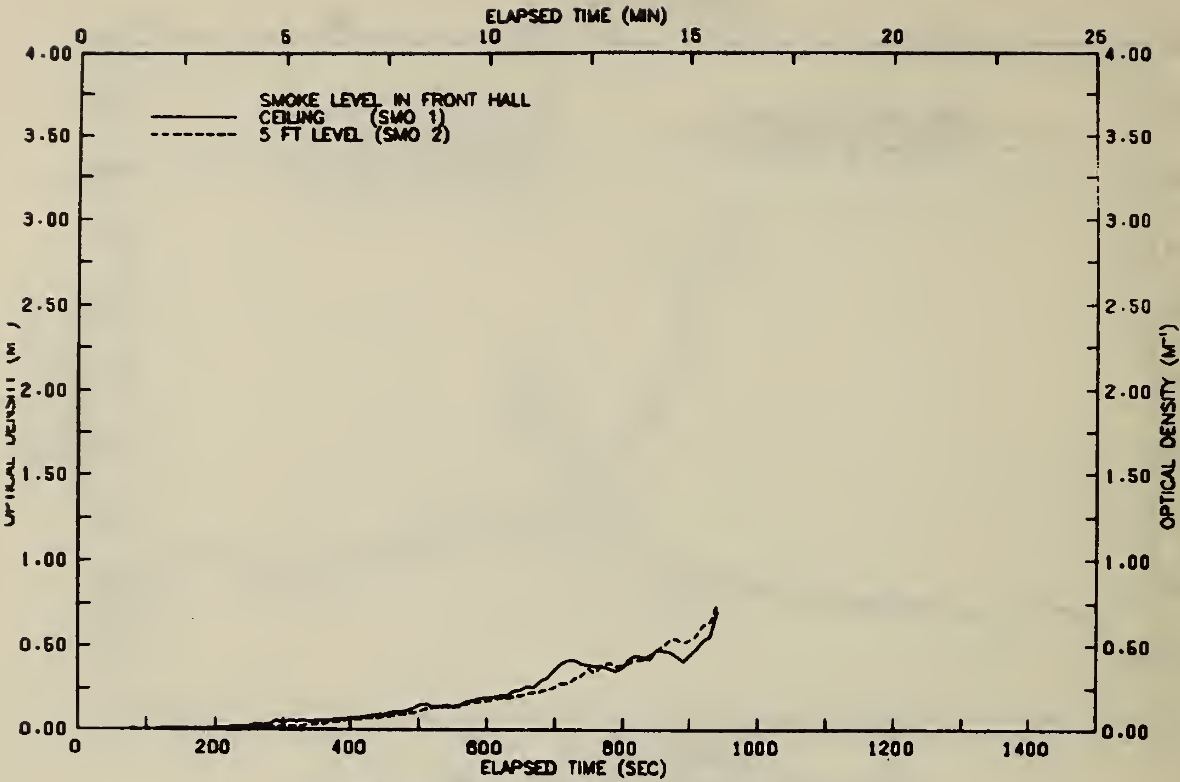

FIGURE A87 SMOKE LEVELS IN FRONT HALLWAY-TEST 09

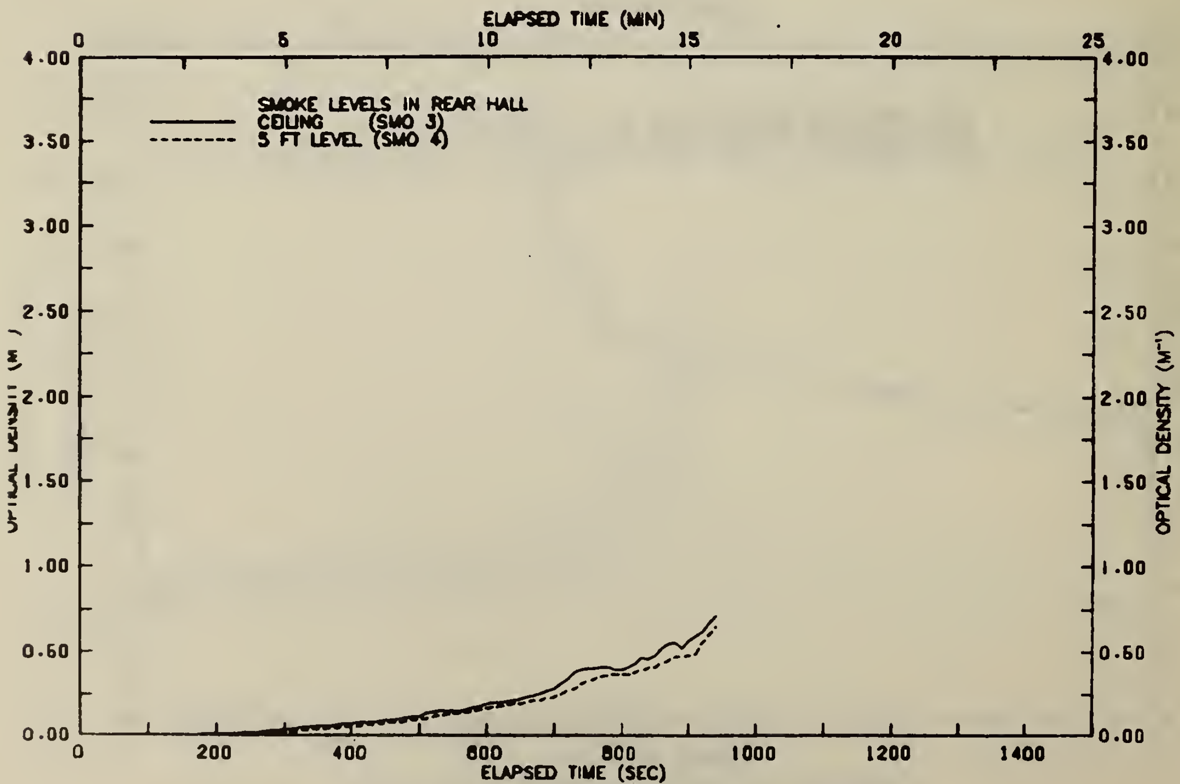

FIGURE A88 SMOKE LEVELS IN REAR HALLWAY-TEST 09

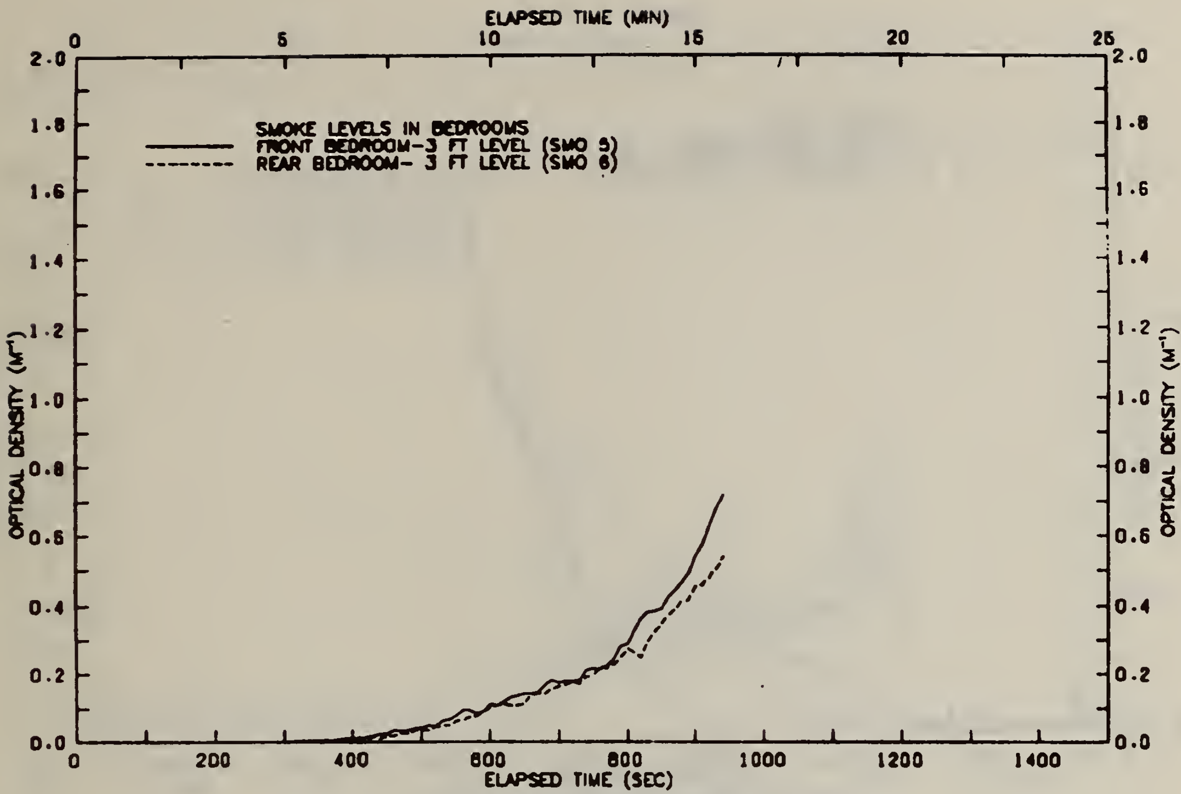

FIGURE A89 SMOKE LEVELS IN BEDROOMS-TEST 09

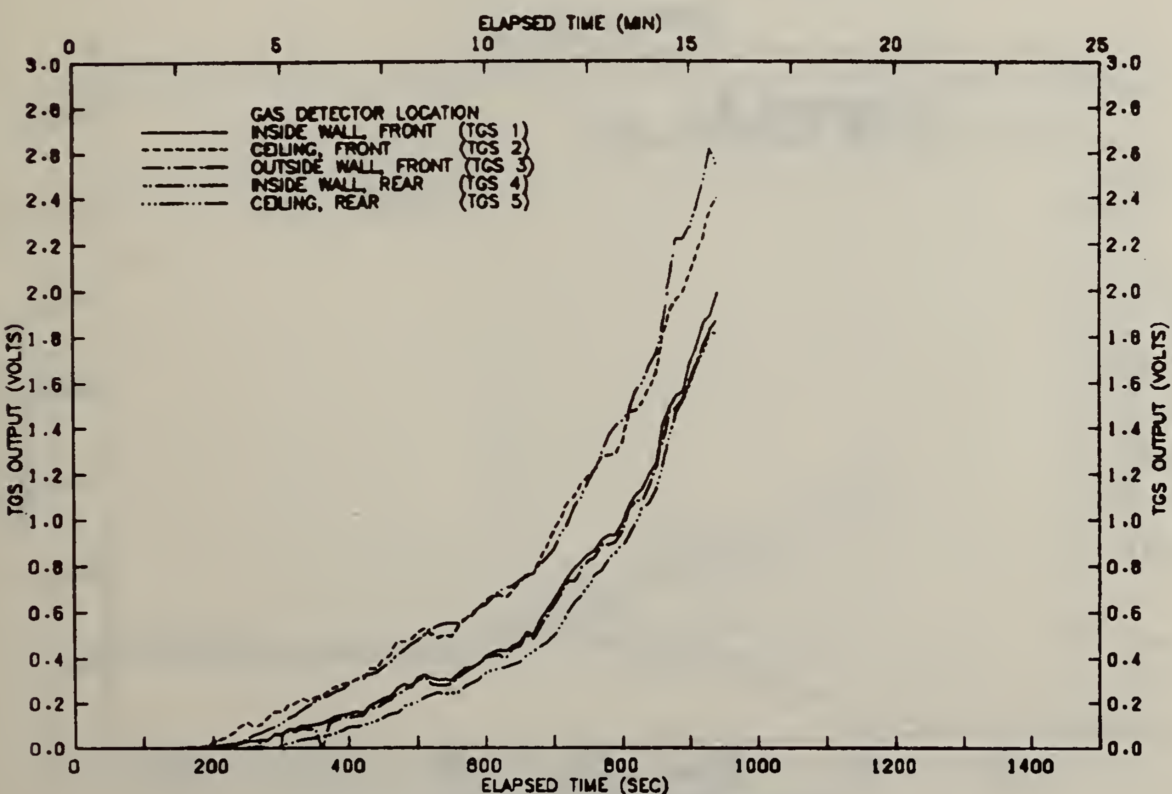

FIGURE A90 GAS DETECTOR OUTPUT VOLTAGE BY LOCATION-TEST 09

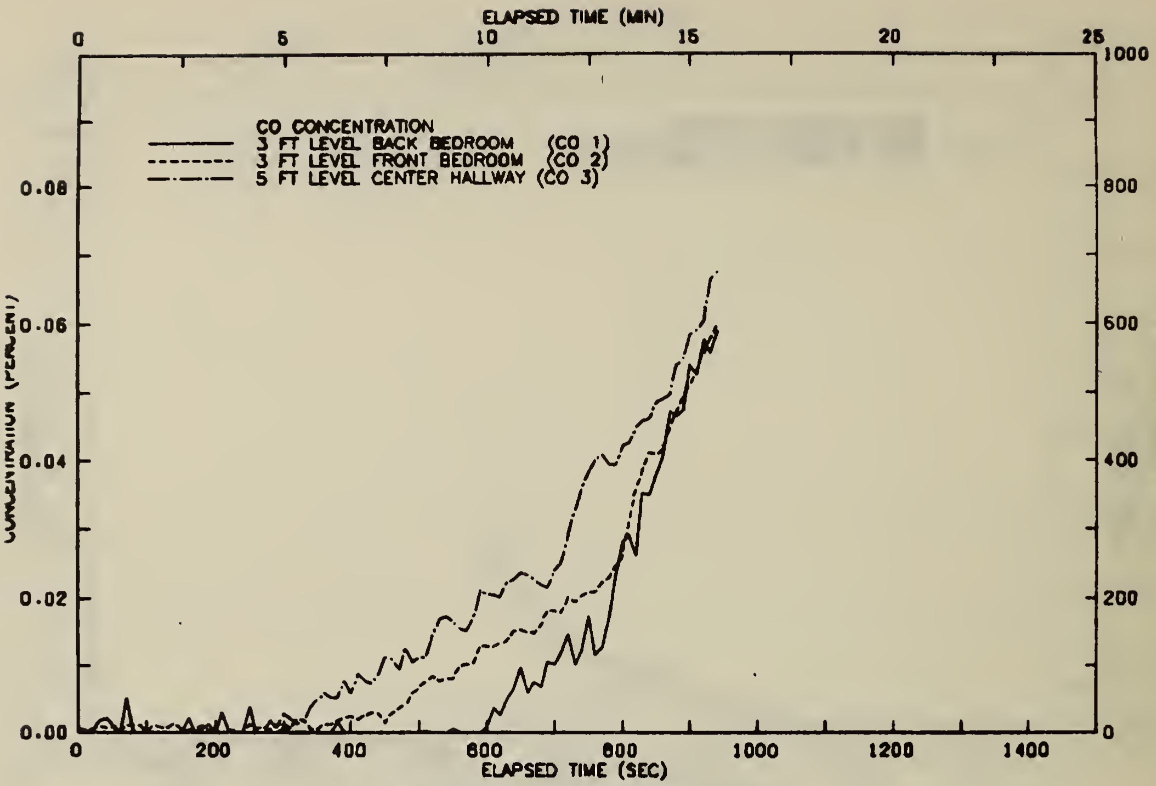

FIGURE A90A CARBON MONOXIDE CONCENTRATION-TEST 09

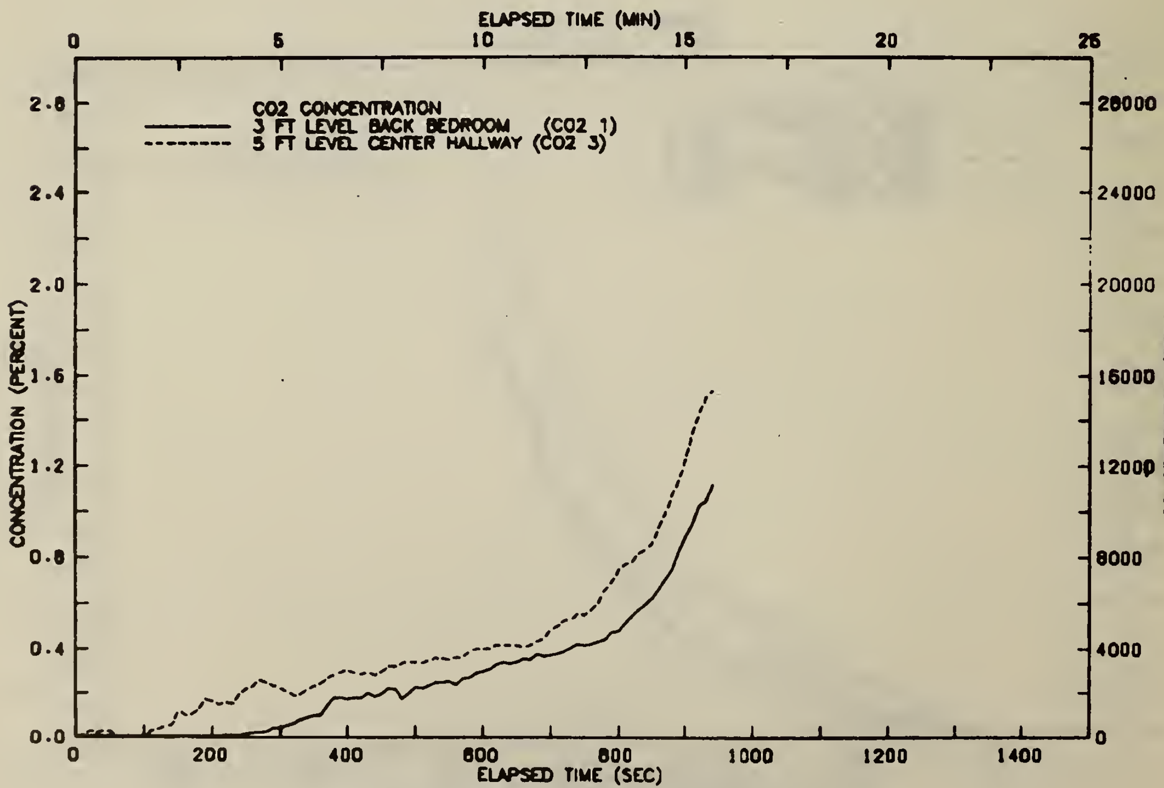

FIGURE A90B CARBON DIOXIDE CONCENTRATION-TEST 09

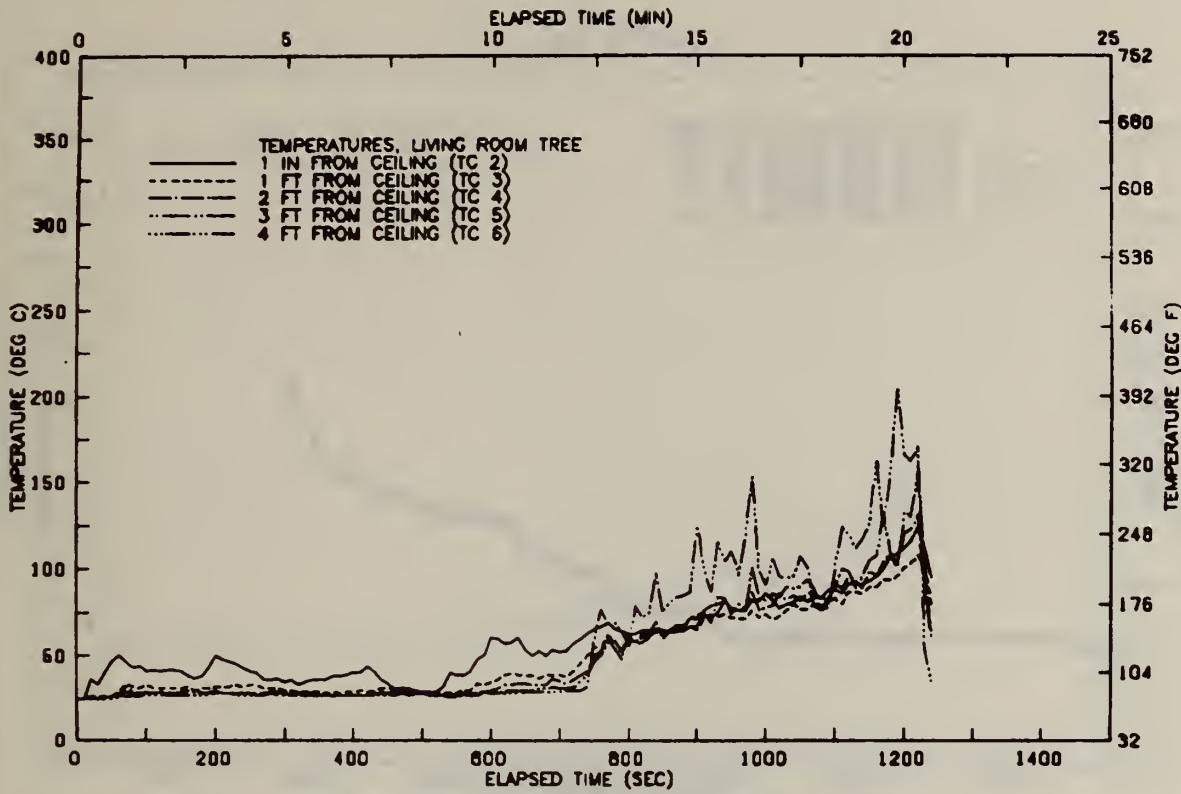

FIGURE A91 VERTICAL TEMP. PROFILE ABOVE CHAIR-TEST 10

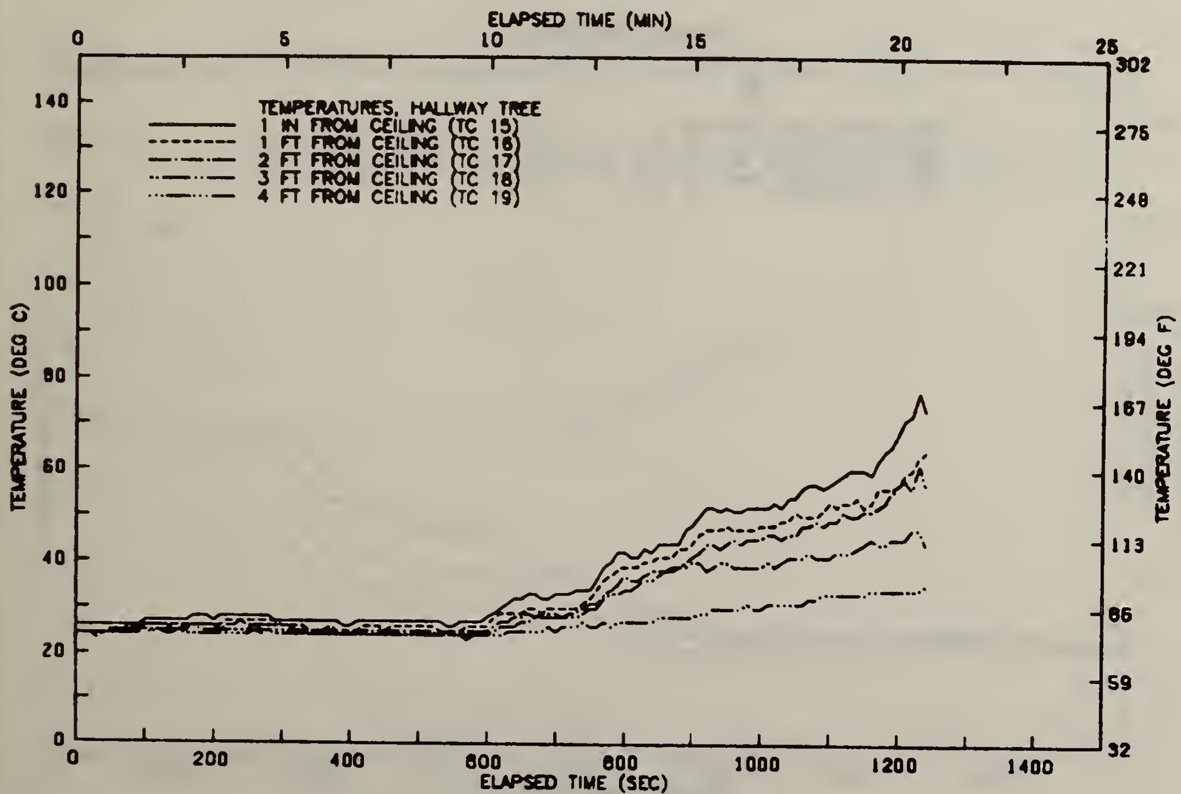

FIGURE A92 VERTICAL TEMP. PROFILE IN HALLWAY-TEST 10

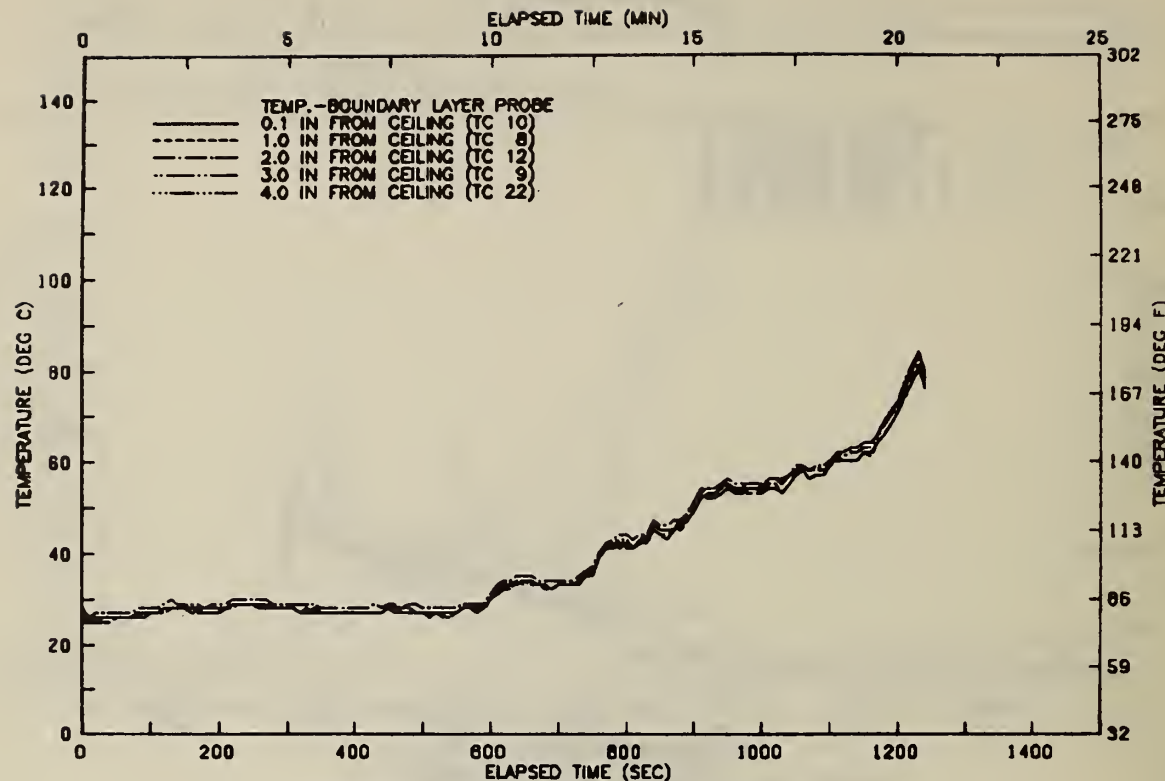

FIGURE A93 VERTICAL TEMP. PROFILE
CEILING BOUNDARY LAYER-TEST 10

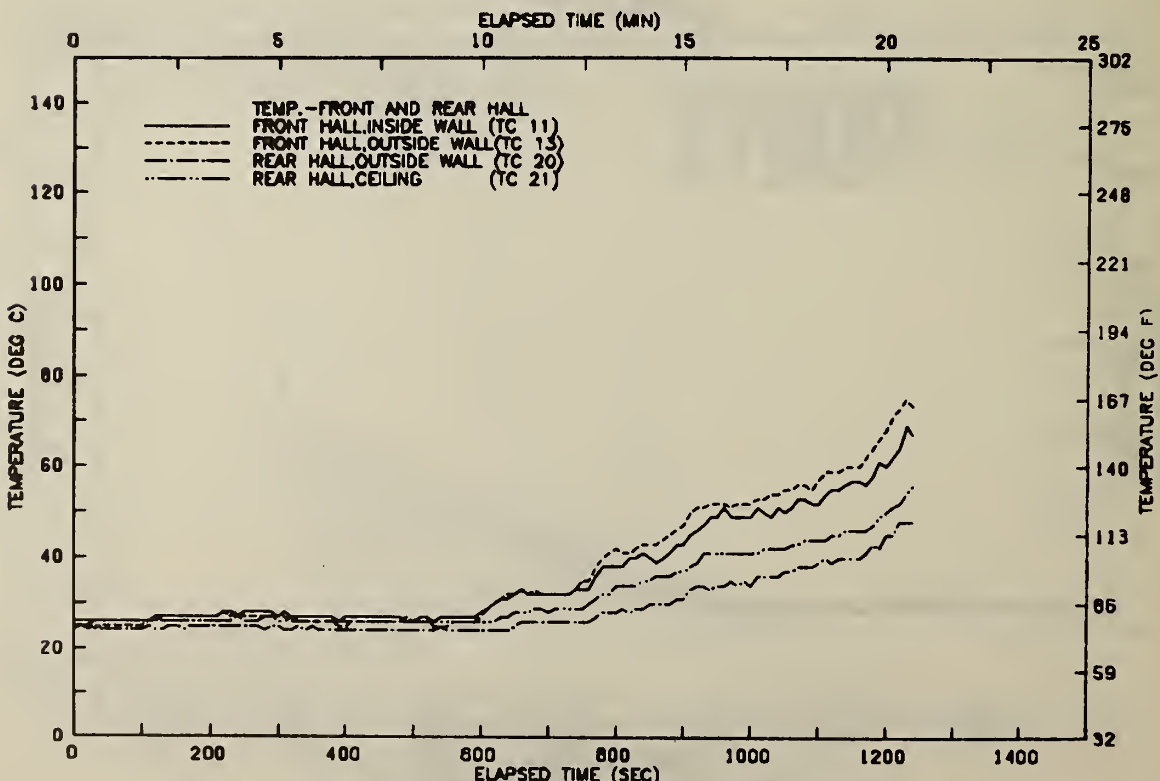

FIGURE A94 TEMP. IN HALLWAY
NEAR DETECTORS-TEST 10

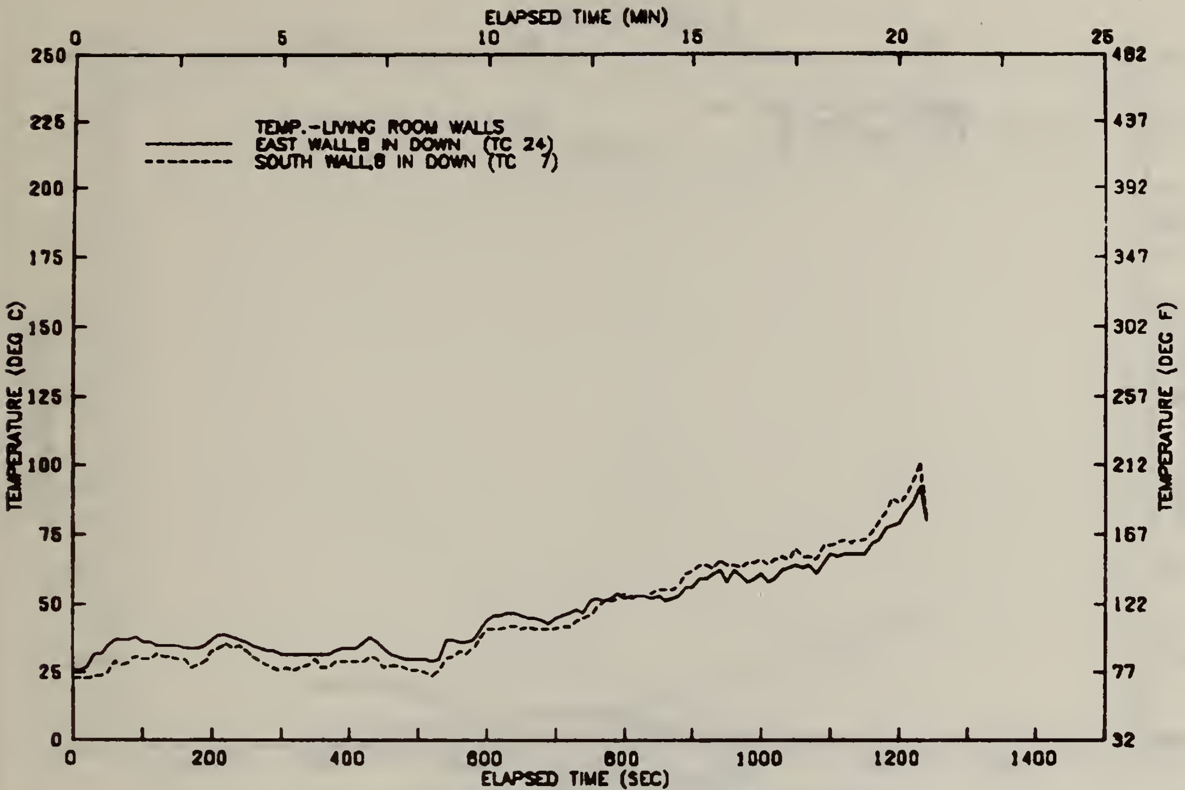

FIGURE A95 TEMPERATURE AT LIVING ROOM WALLS-TEST 10

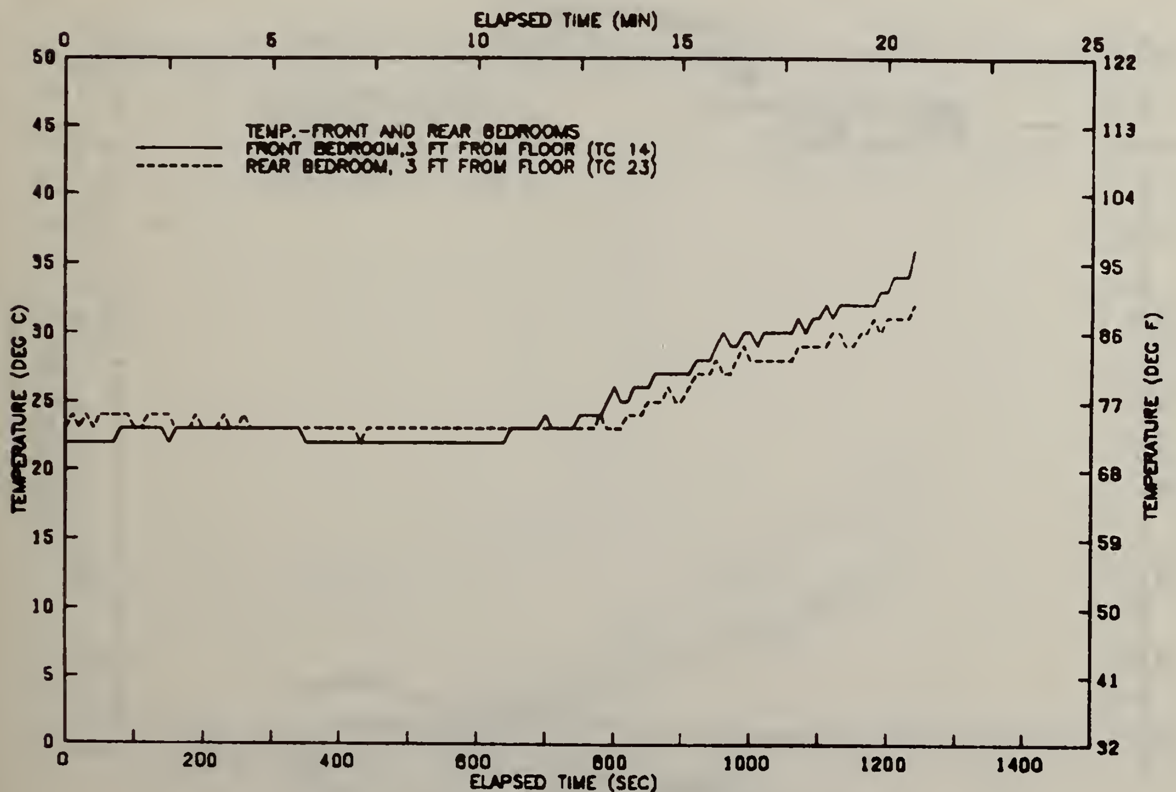

FIGURE A96 TEMP. IN FRONT AND REAR BEDROOMS-TEST 10

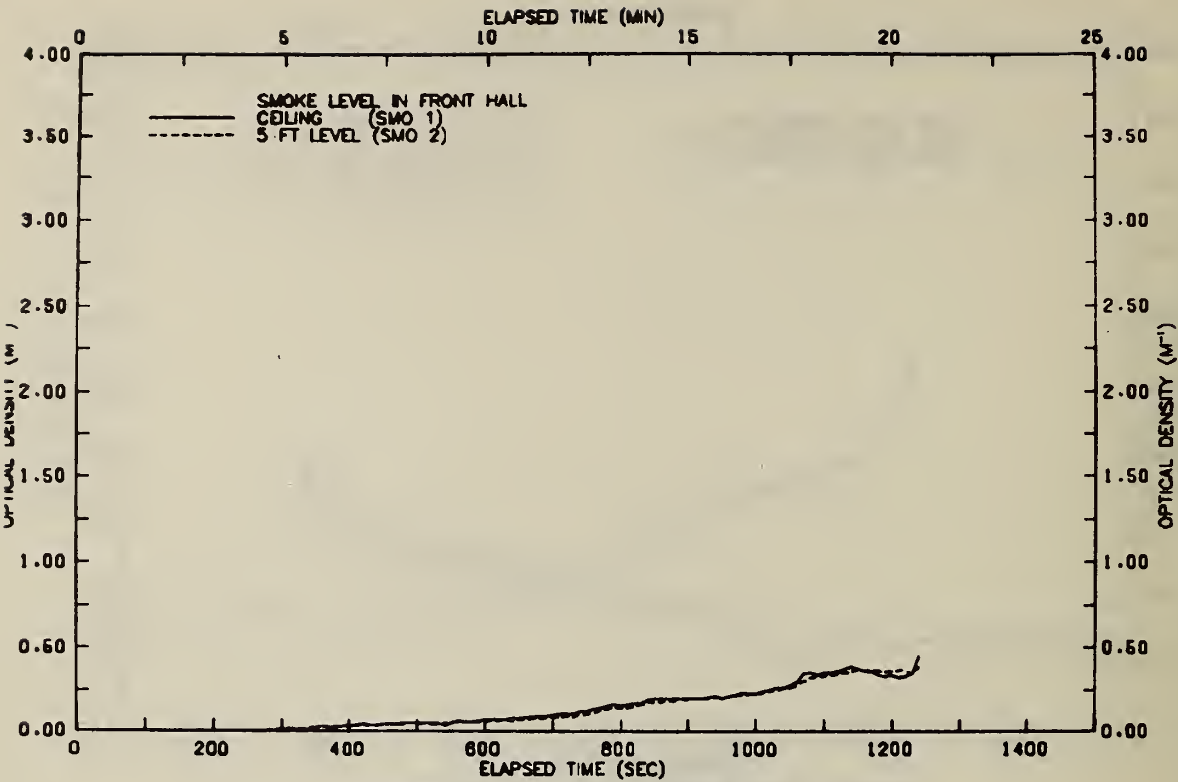

FIGURE A97 SMOKE LEVELS IN FRONT HALLWAY-TEST 10

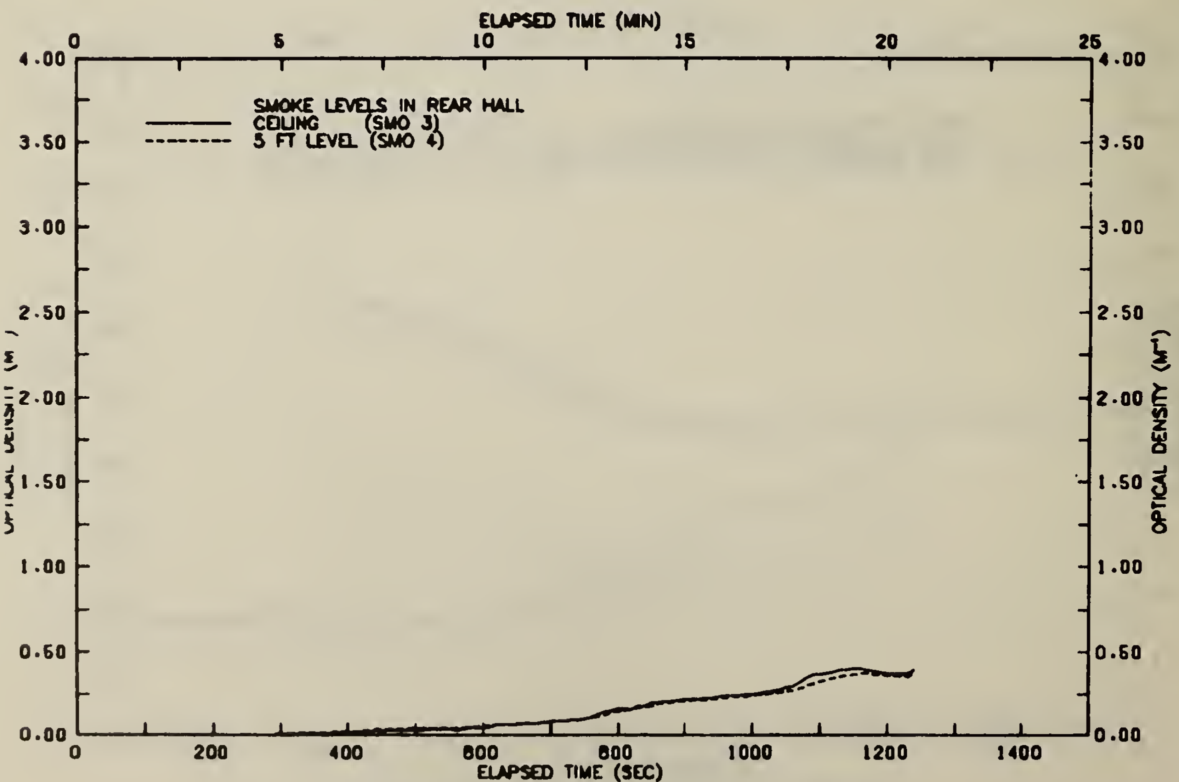

FIGURE A98 SMOKE LEVELS IN REAR HALLWAY-TEST 10

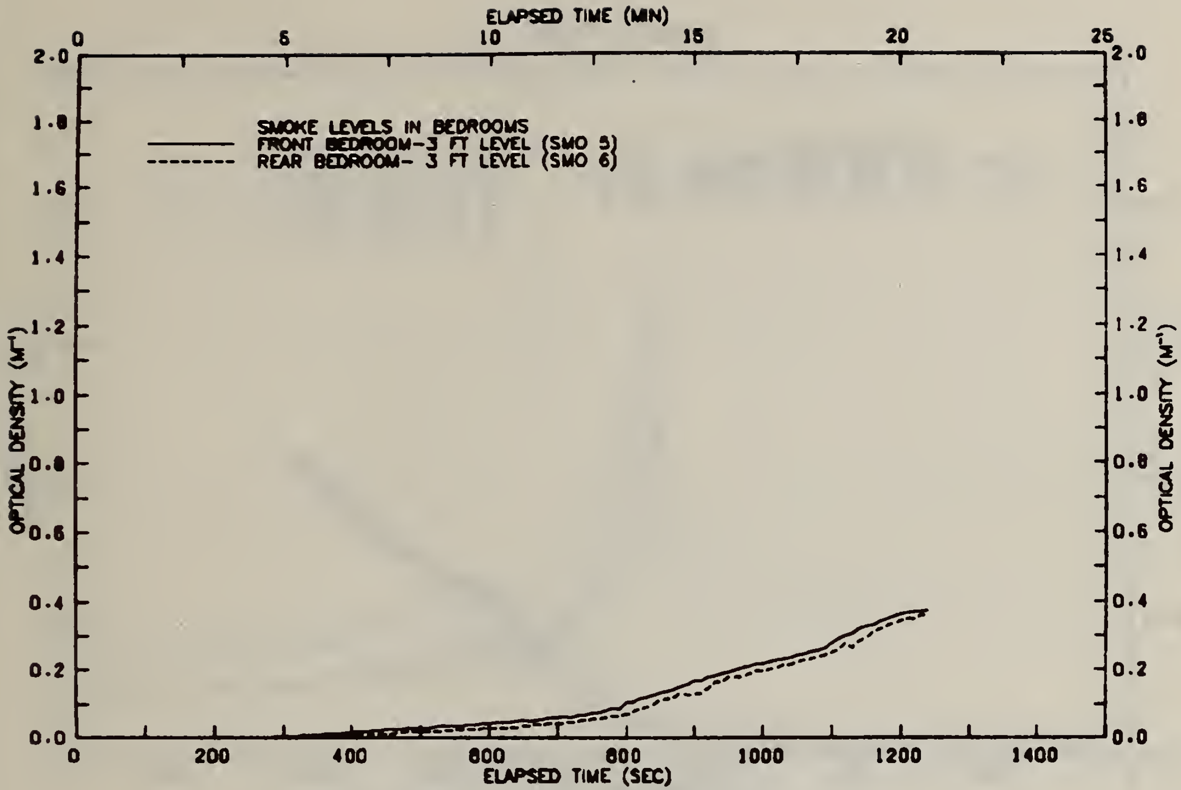

FIGURE A99 SMOKE LEVELS IN BEDROOMS-TEST 10

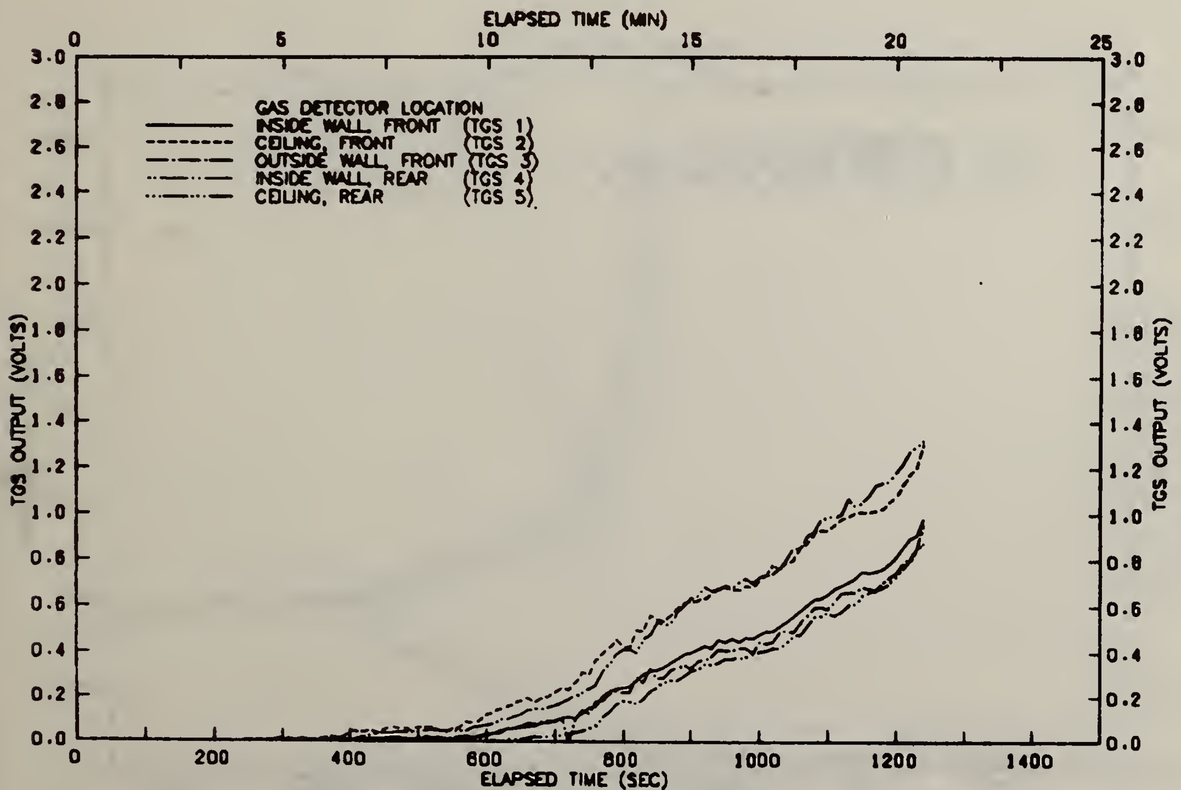

FIGURE A100 GAS DETECTOR OUTPUT VOLTAGE BY LOCATION-TEST 10

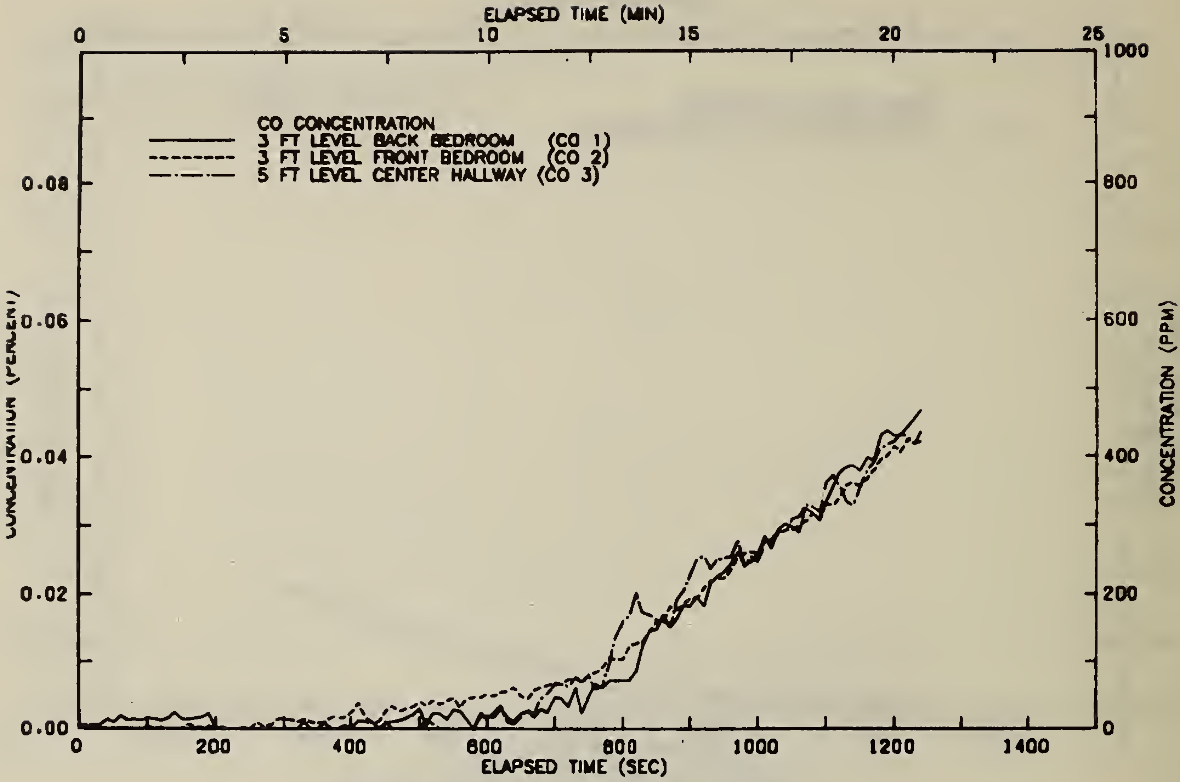

FIGURE A100A CARBON MONOXIDE CONCENTRATION–TEST 10

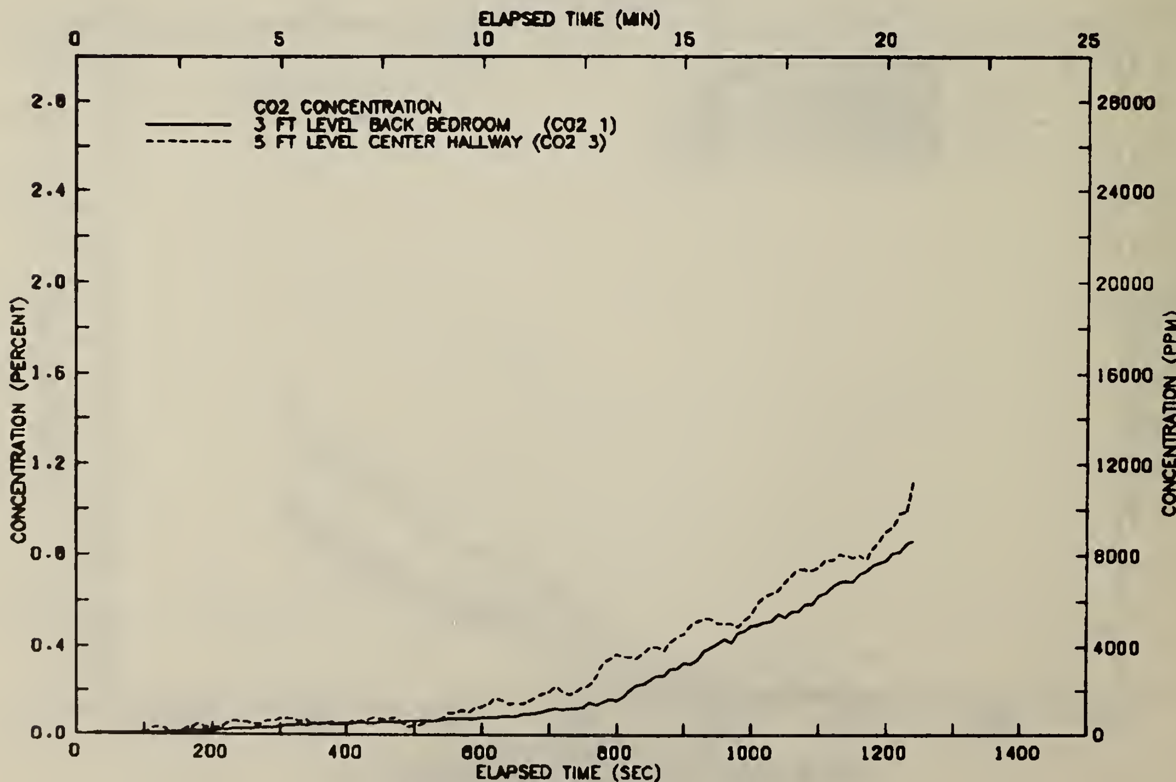

FIGURE A100B CARBON DIOXIDE CONCENTRATION–TEST 10

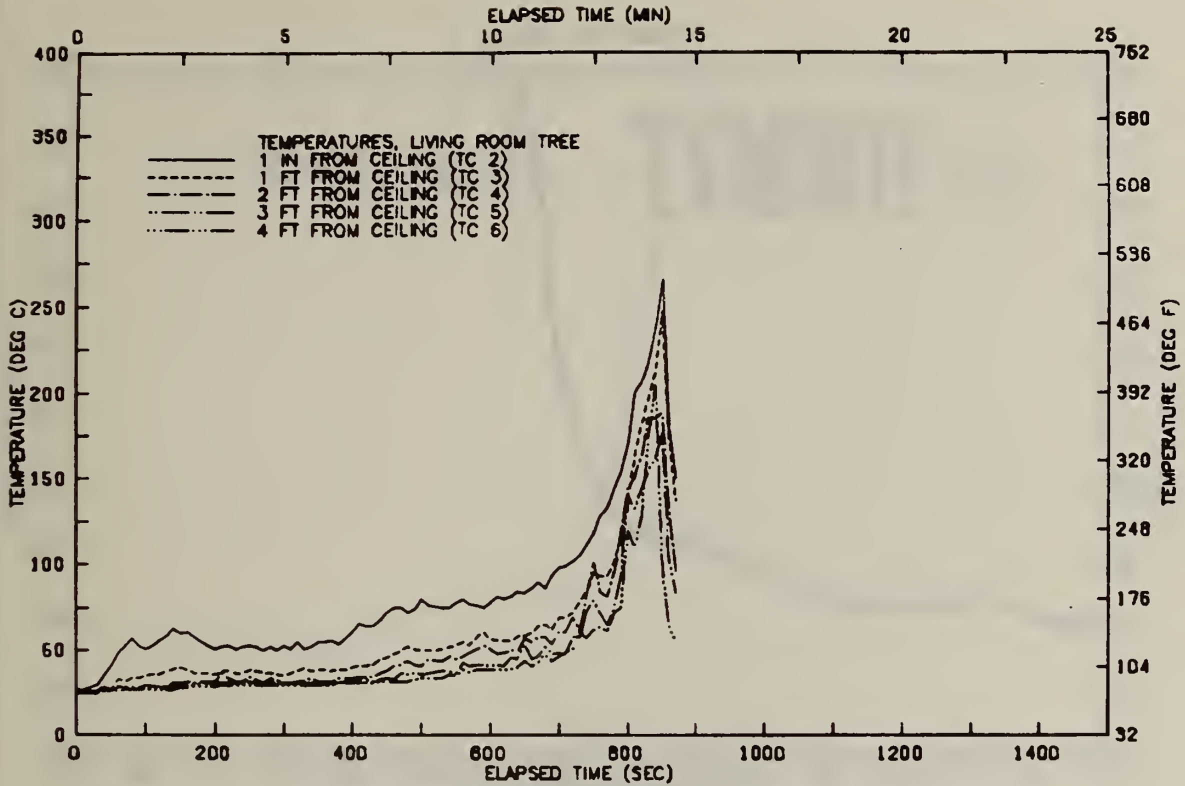

FIGURE A101 VERTICAL TEMP. PROFILE
ABOVE CHAIR-TEST 11

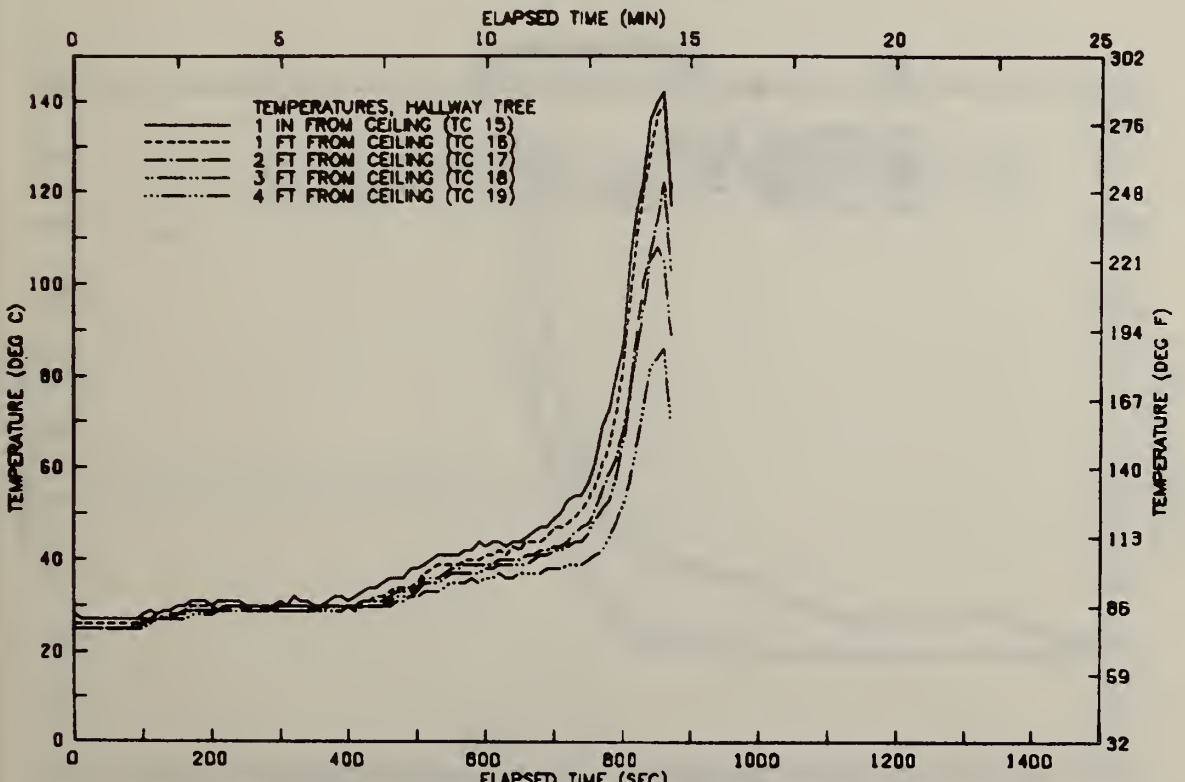

FIGURE A102 VERTICAL TEMP. PROFILE
IN HALLWAY-TEST 11

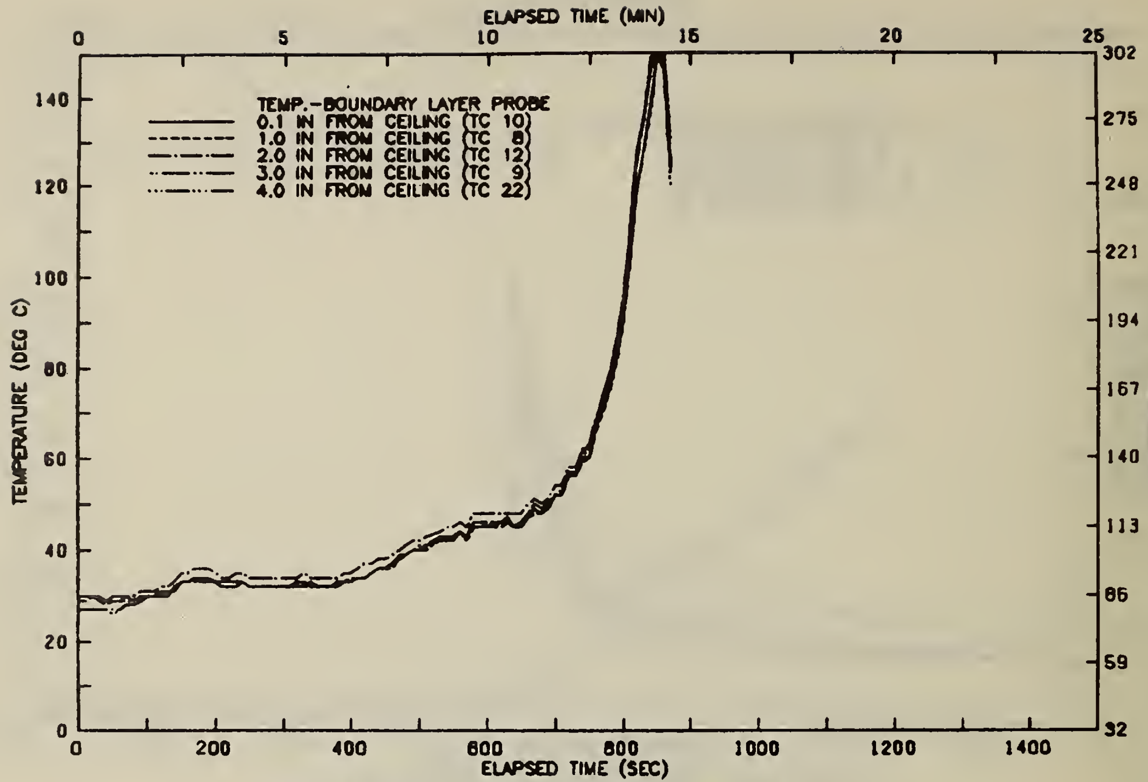

FIGURE A103 VERTICAL TEMP. PROFILE
CEILING BOUNDARY LAYER-TEST 11

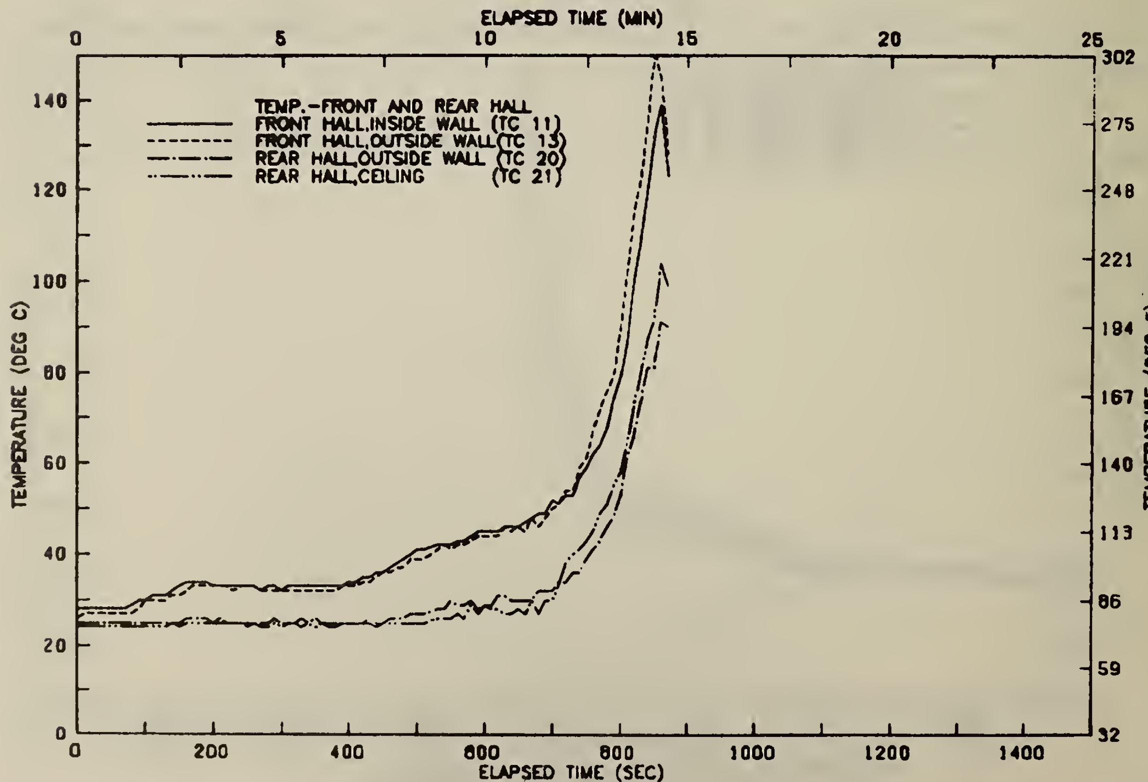

FIGURE A104 TEMP. IN HALLWAY
NEAR DETECTORS-TEST 11

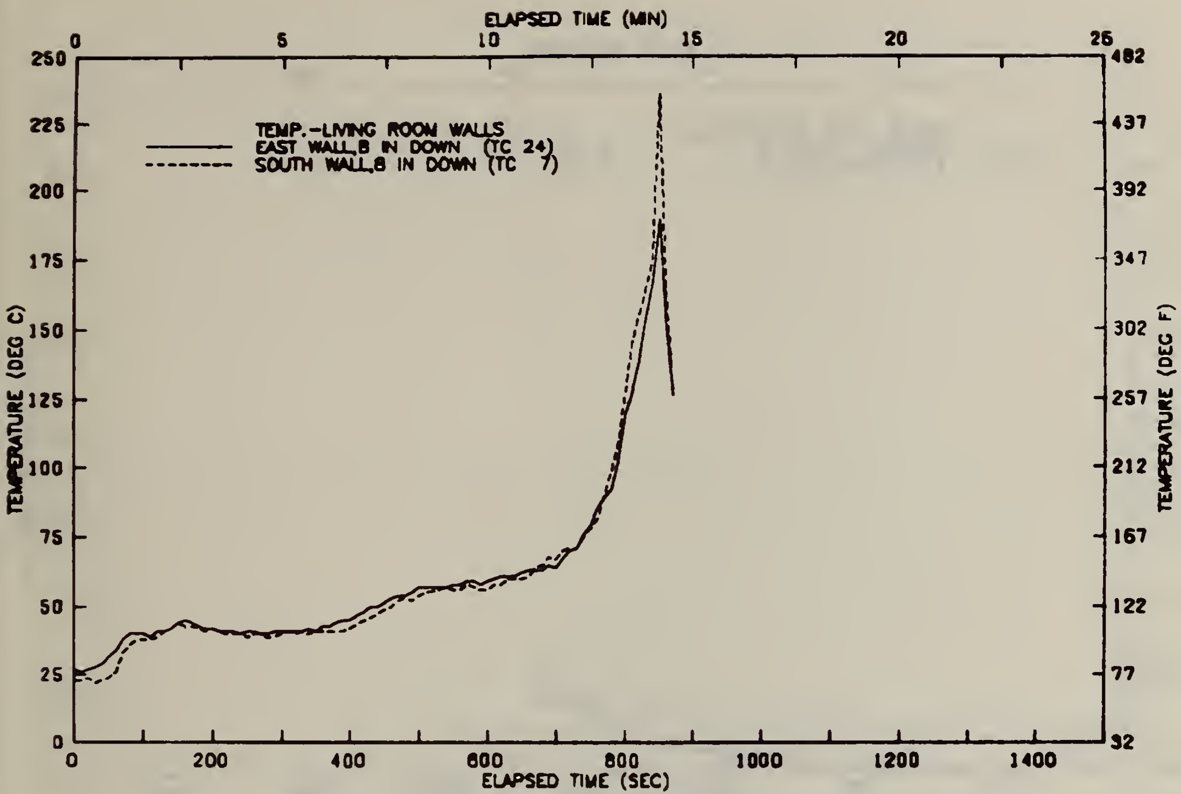

FIGURE A105 TEMPERATURE AT LIVING ROOM WALLS-TEST 11

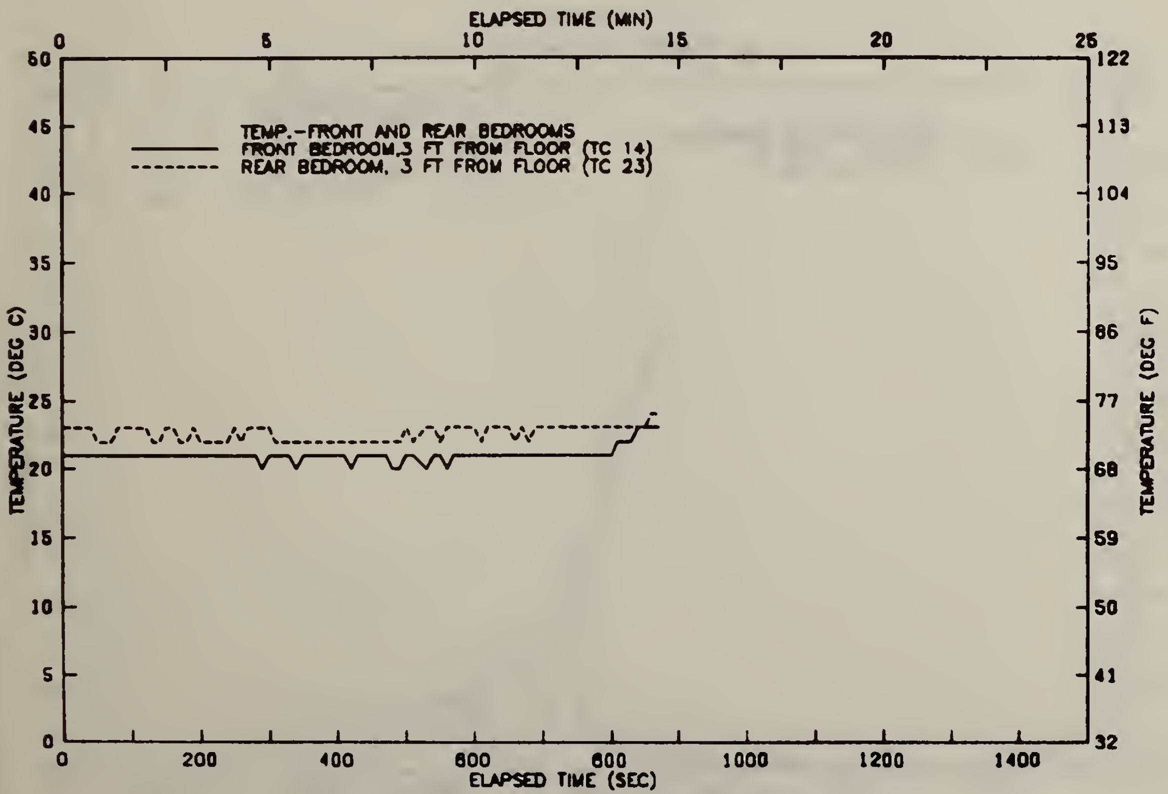

FIGURE A106 TEMP. IN FRONT AND REAR BEDROOMS-TEST 11

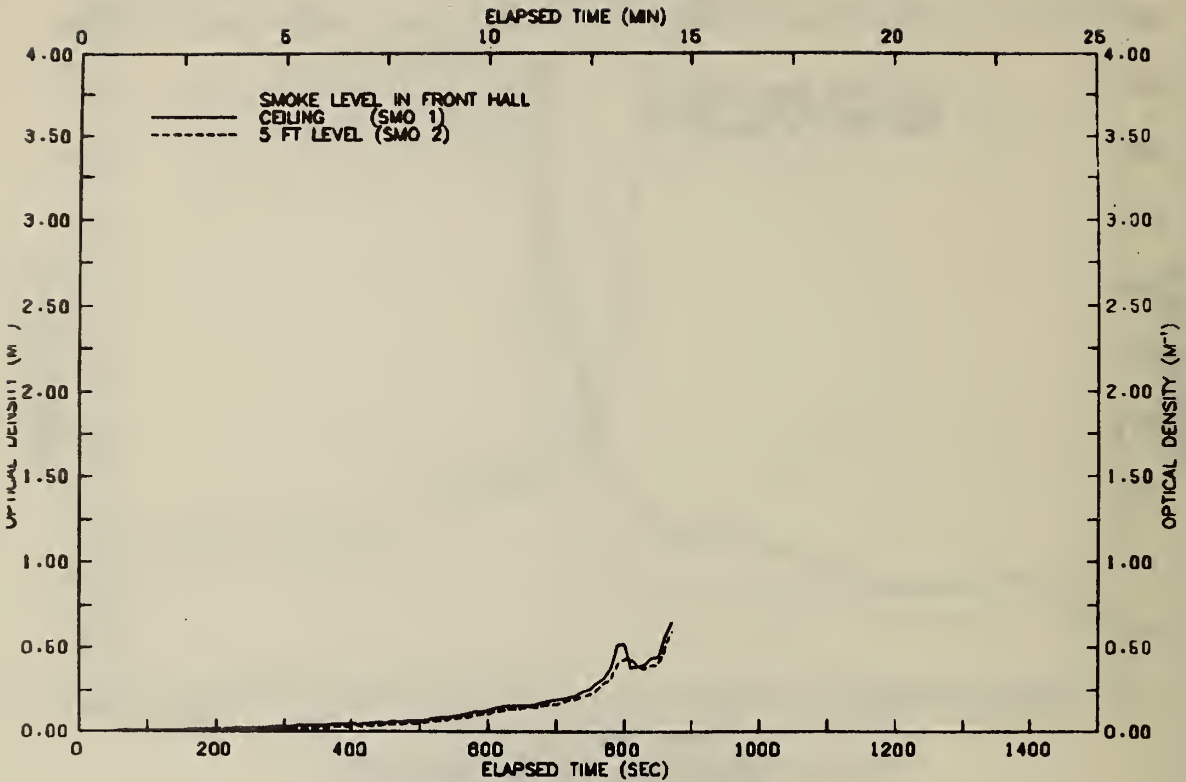

FIGURE A107 SMOKE LEVELS IN FRONT HALLWAY—TEST 11

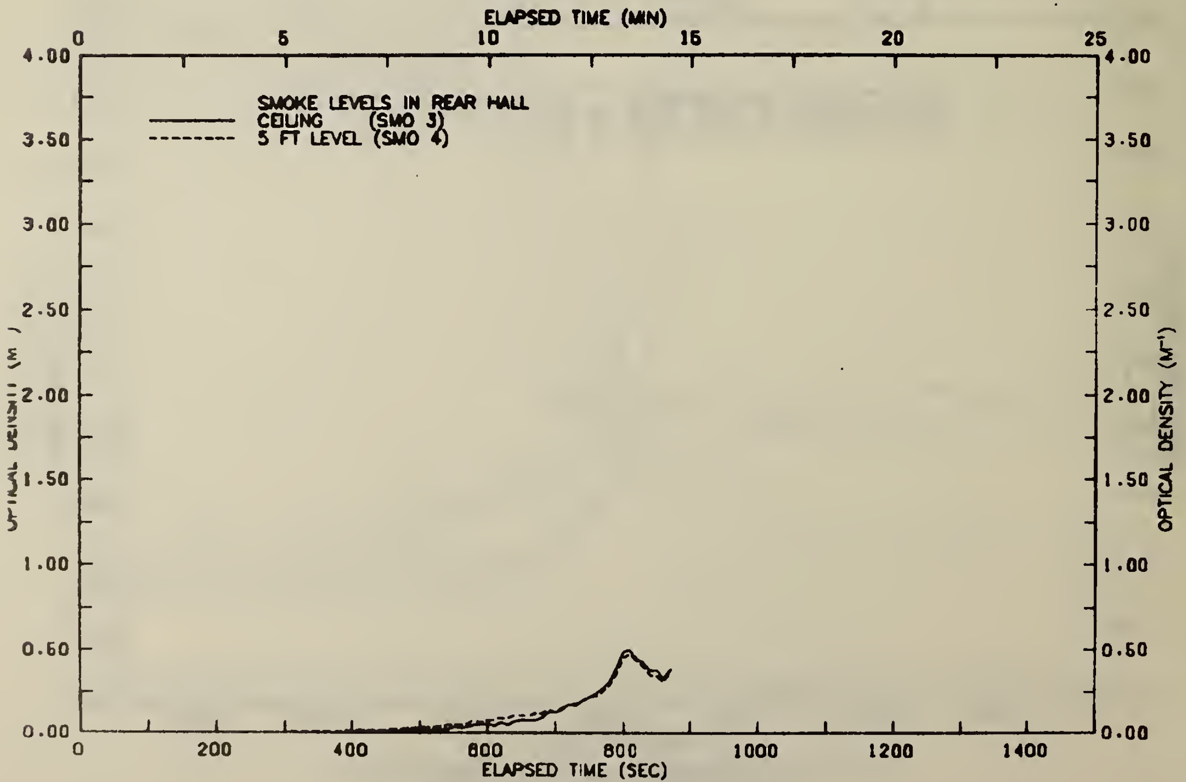

FIGURE A108 SMOKE LEVELS IN REAR HALLWAY—TEST 11

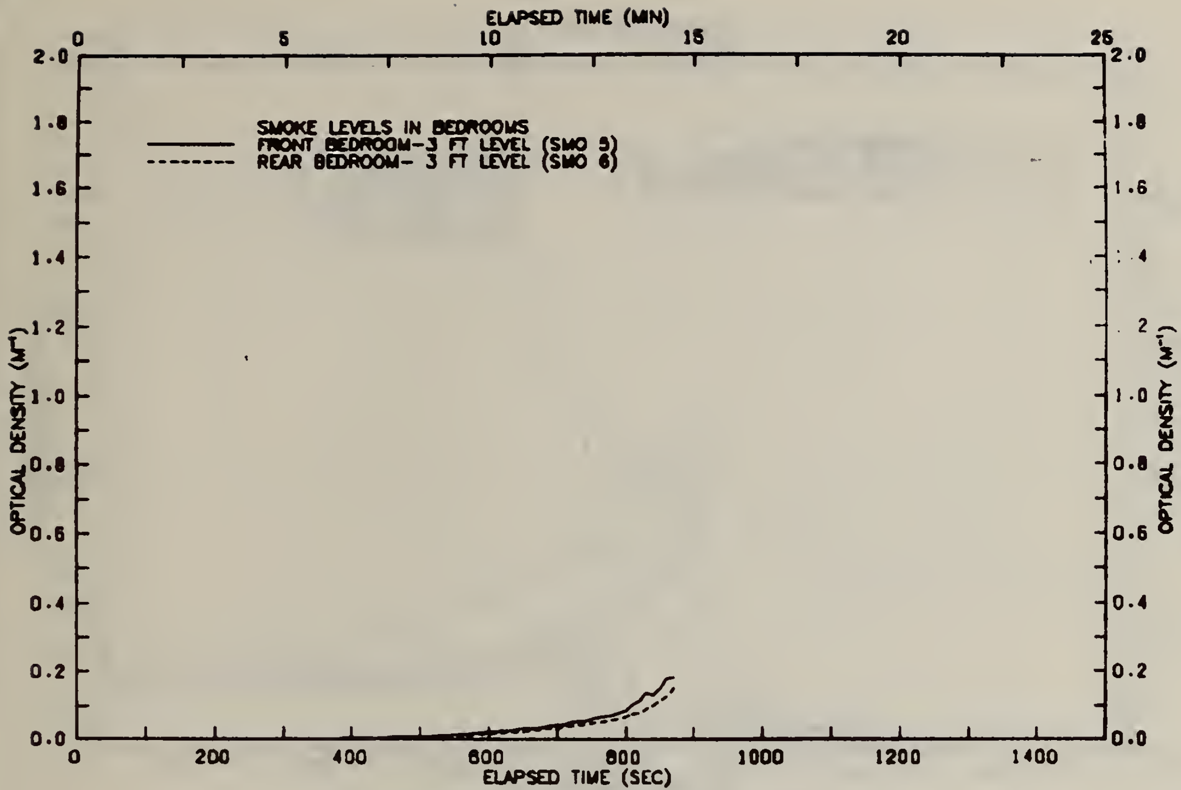

FIGURE A109 SMOKE LEVELS IN BEDROOMS-TEST 11

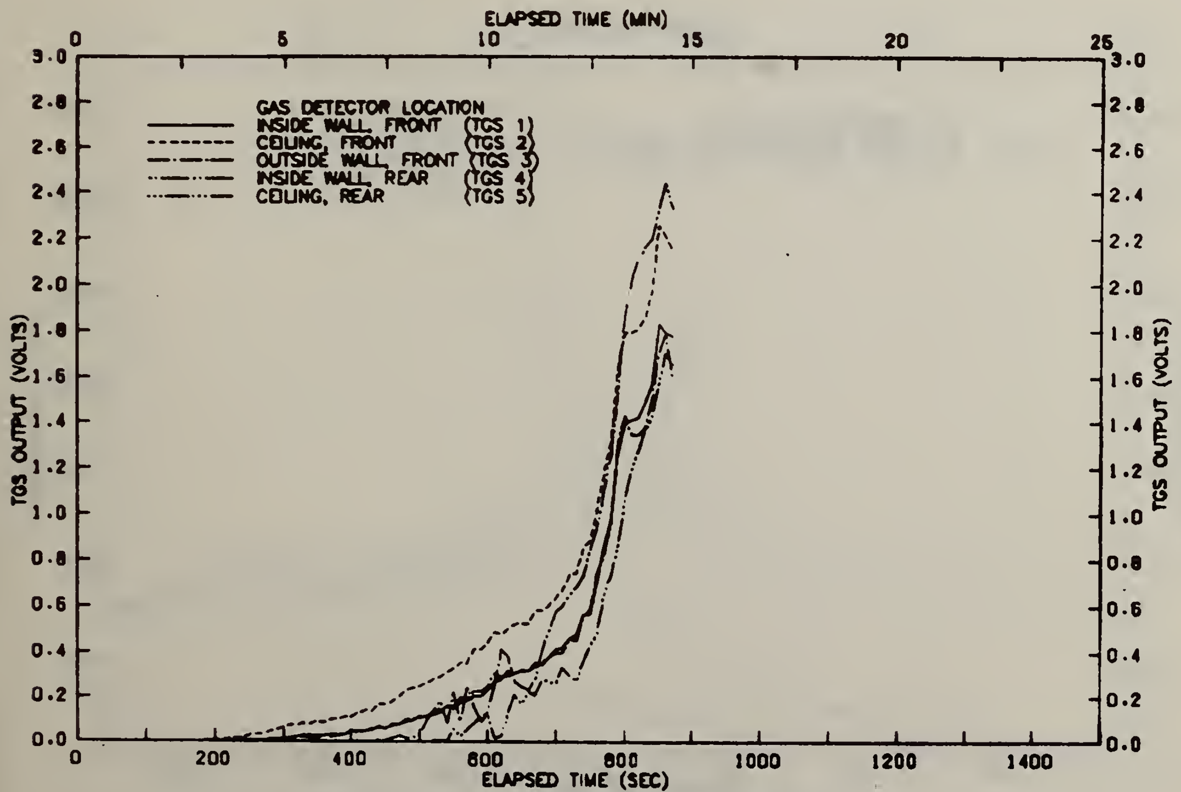

FIGURE A110 GAS DETECTOR OUTPUT VOLTAGE BY LOCATION-TEST 11

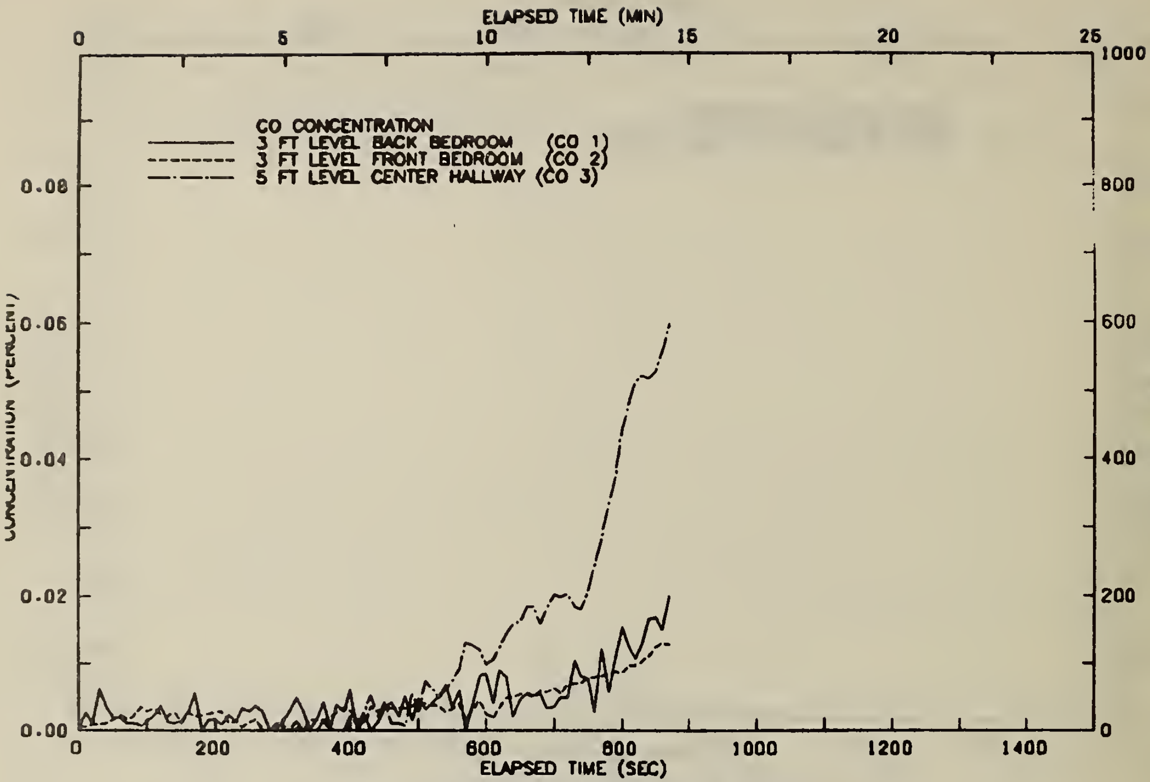

FIGURE A110A CARBON MONOXIDE CONCENTRATION-TEST 1

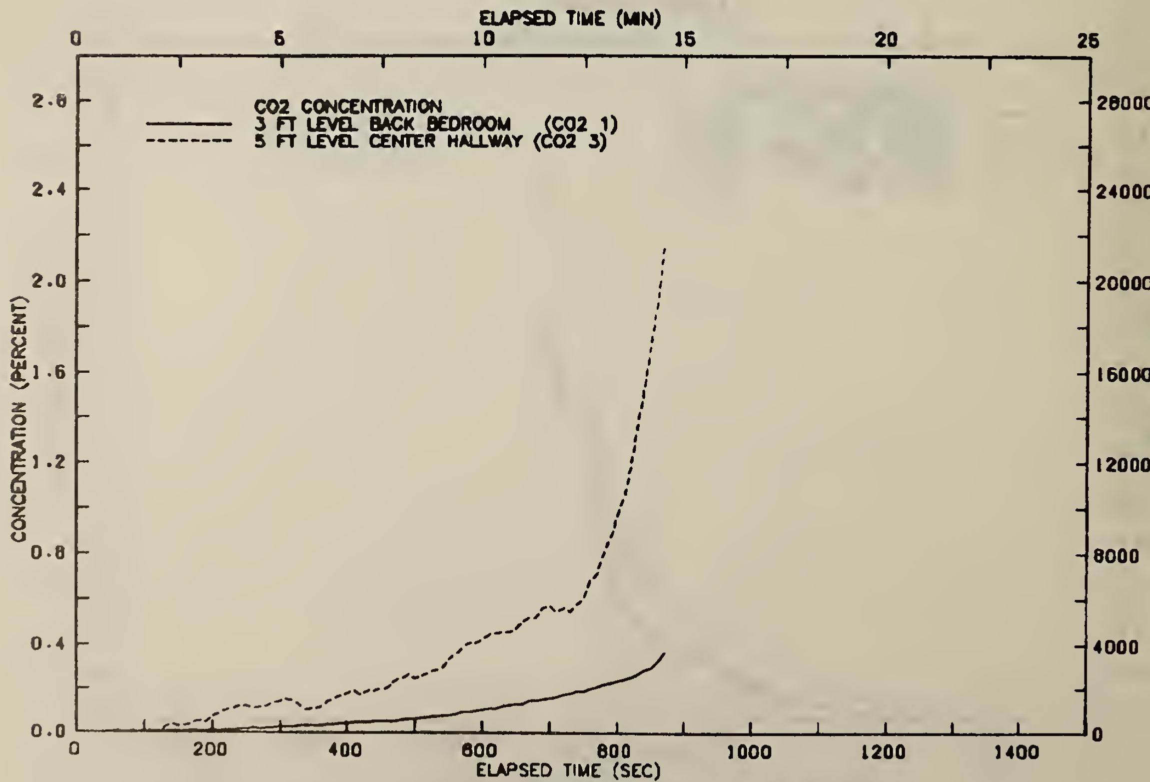

FIGURE A110B CARBON DIOXIDE CONCENTRATION-TEST 11

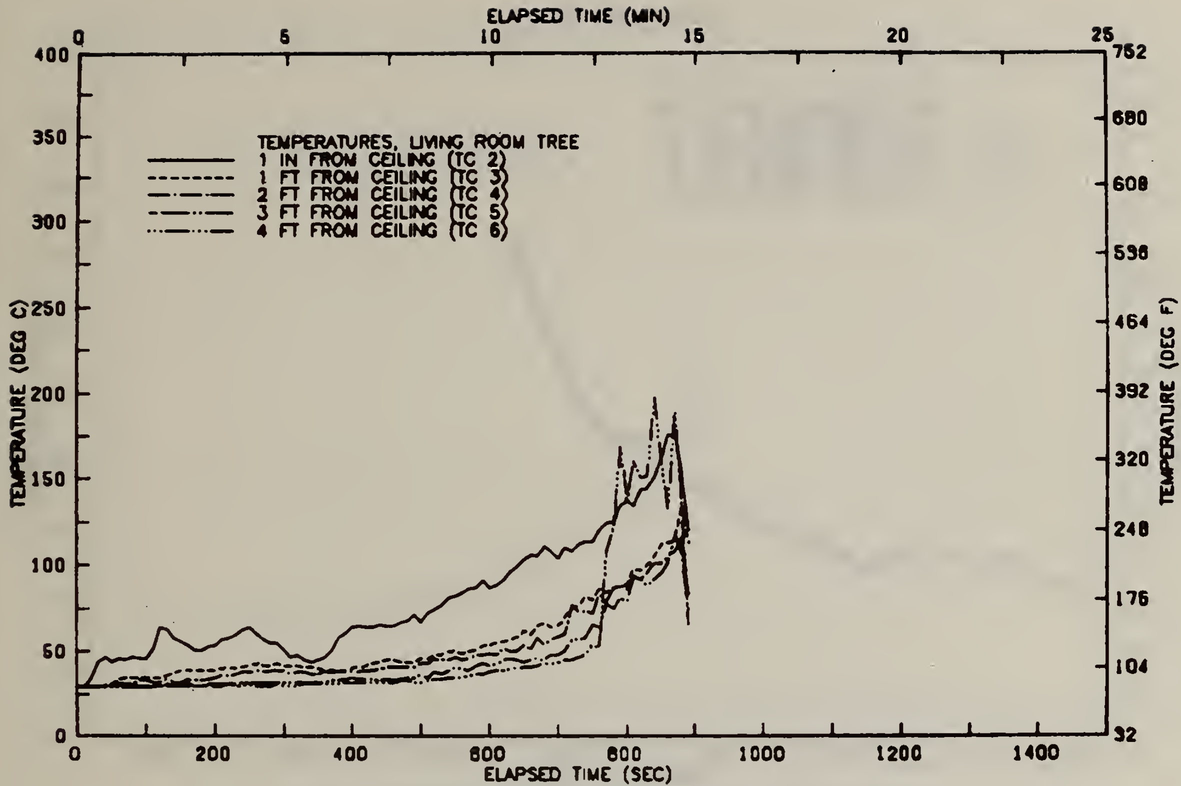

FIGURE A111 VERTICAL TEMP. PROFILE
ABOVE CHAIR-TEST 12

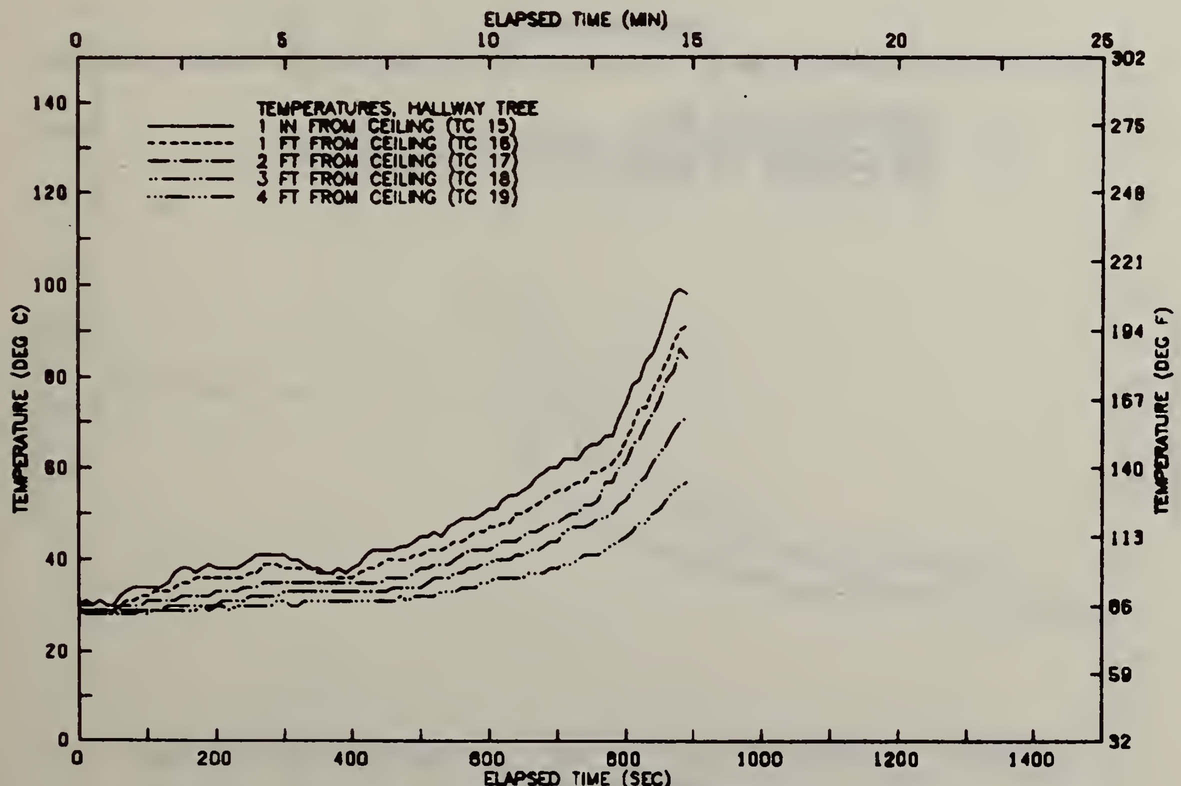

FIGURE A112 VERTICAL TEMP. PROFILE
IN HALLWAY-TEST 12

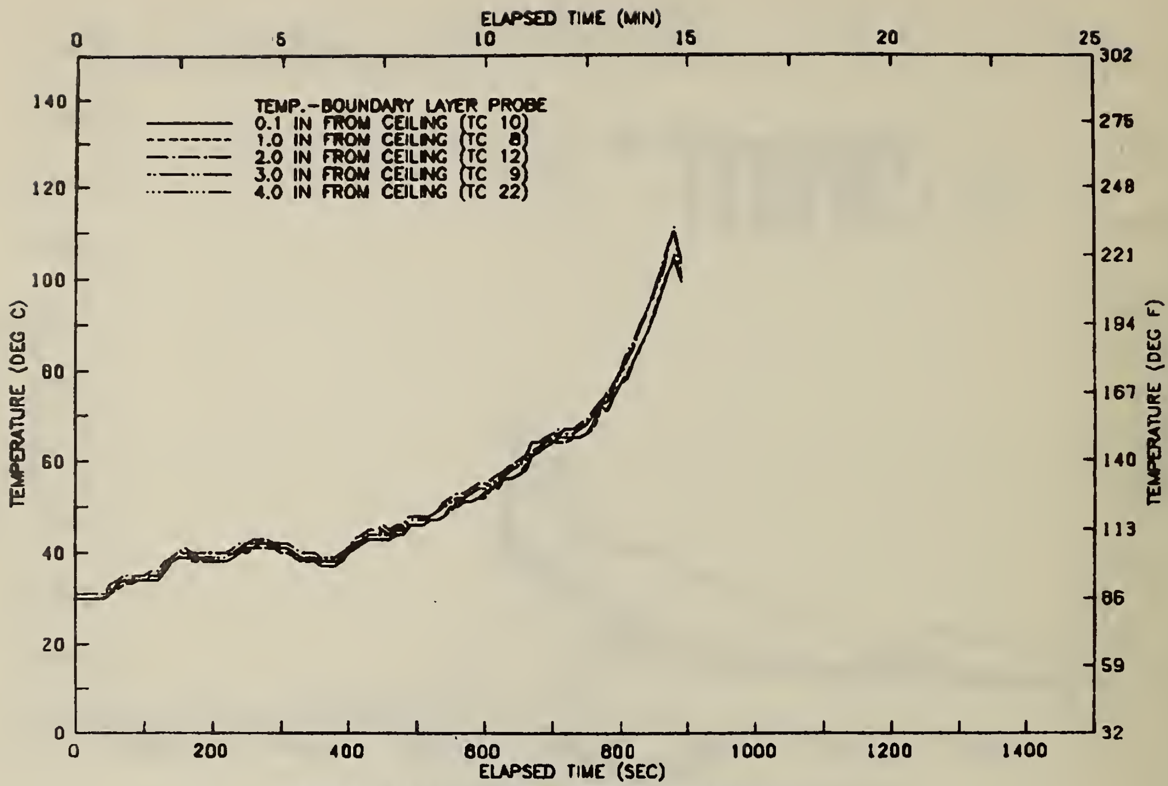

FIGURE A113 VERTICAL TEMP. PROFILE
CEILING BOUNDARY LAYER-TEST 12

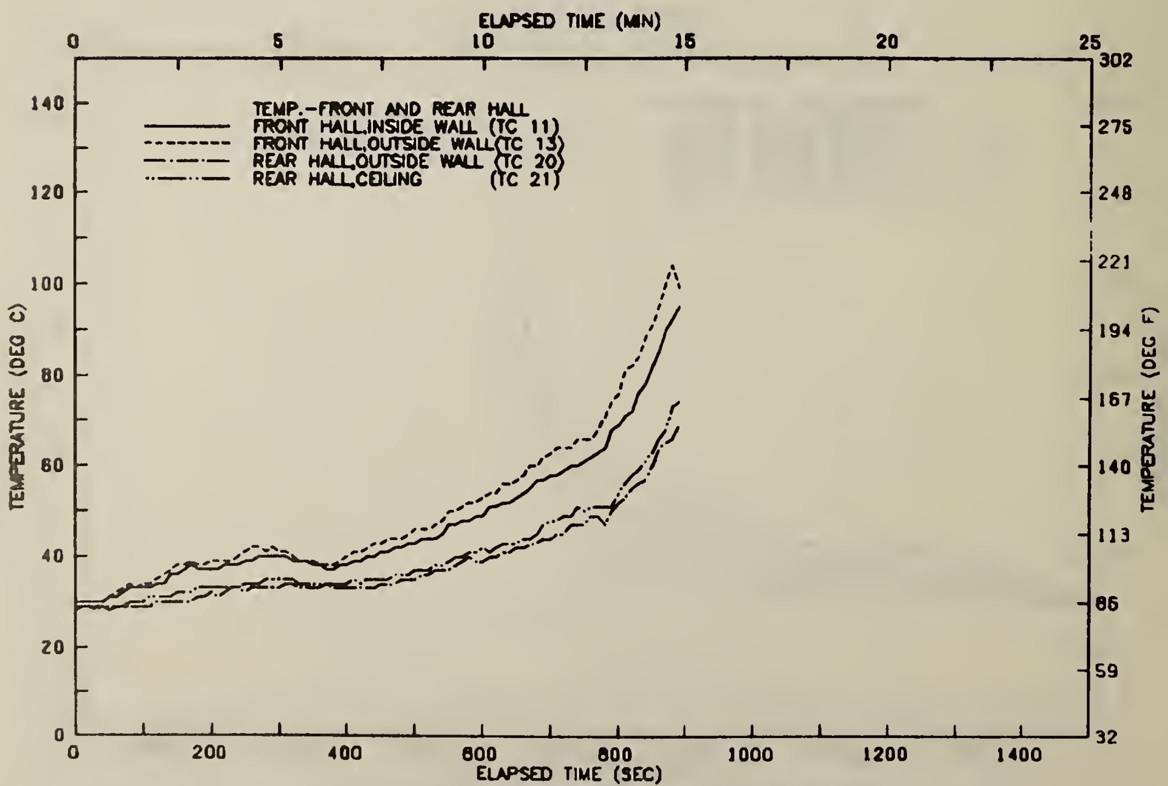

FIGURE A114 TEMP. IN HALLWAY
NEAR DETECTORS-TEST 12

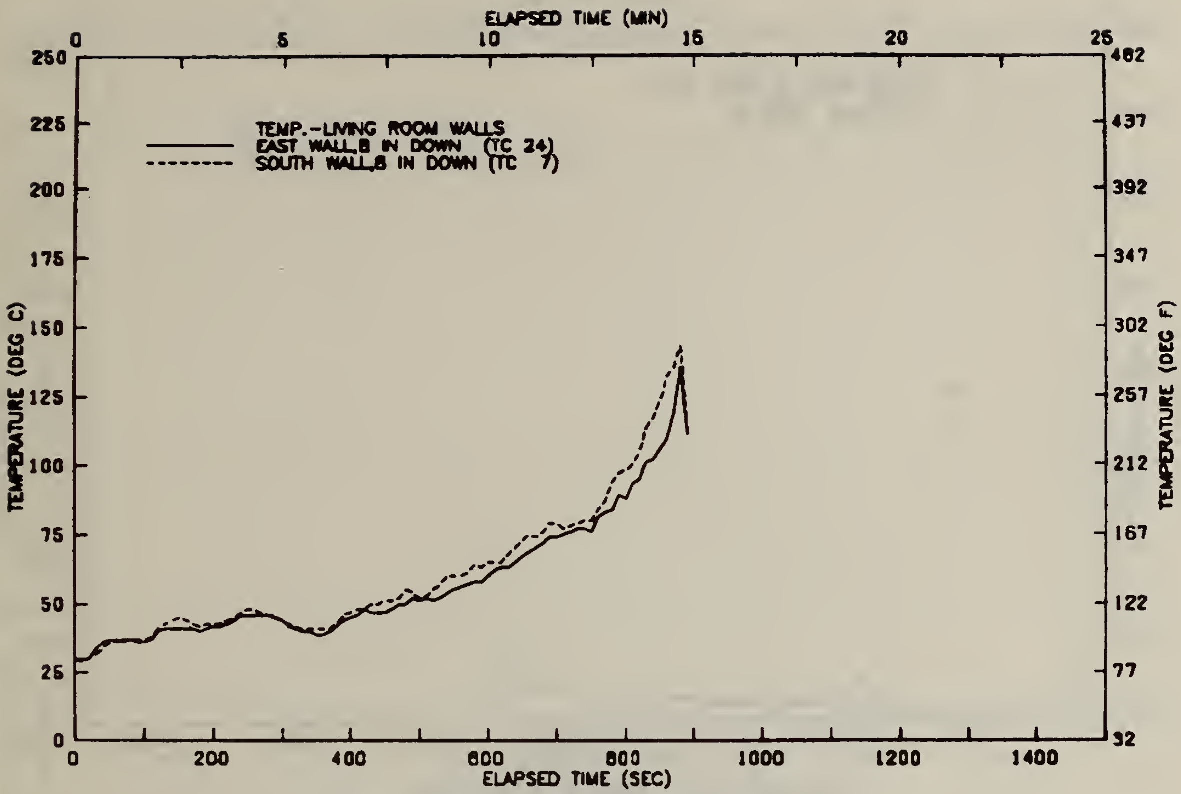

FIGURE A115 TEMPERATURE AT LIVING ROOM WALLS-TEST 12

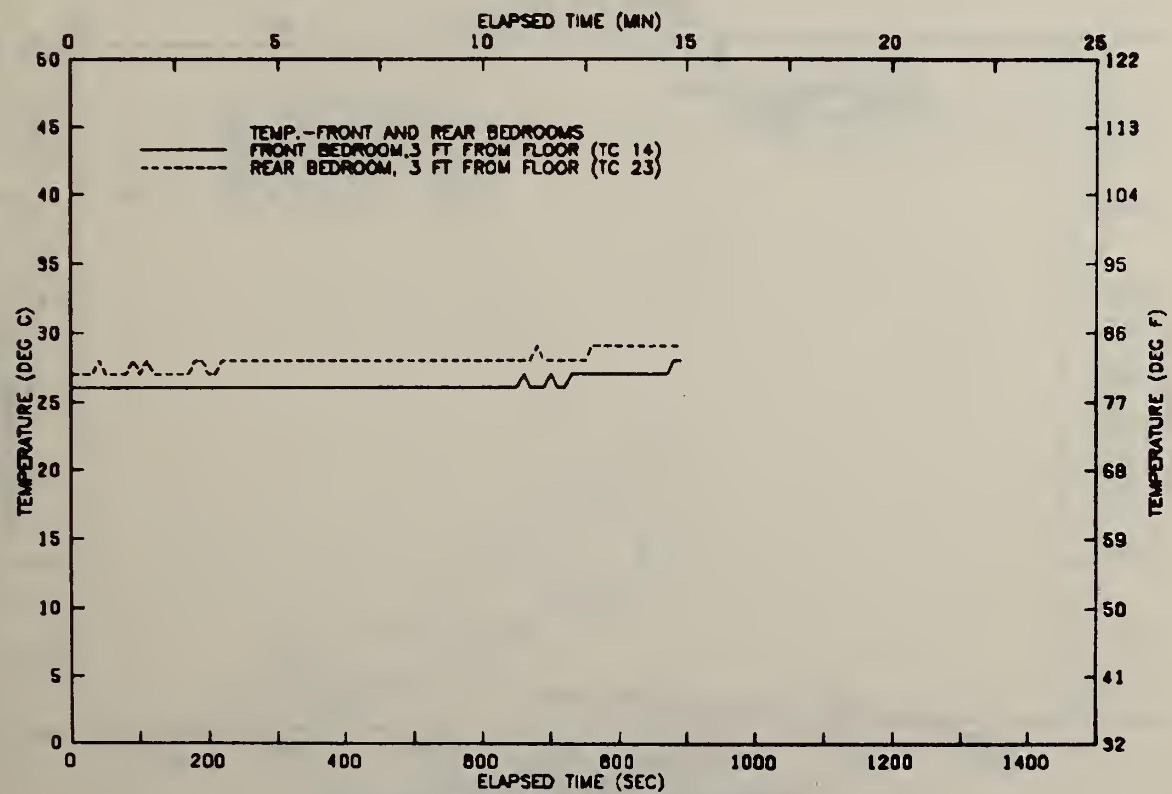

FIGURE A116 TEMP. IN FRONT AND REAR BEDROOMS-TEST 12

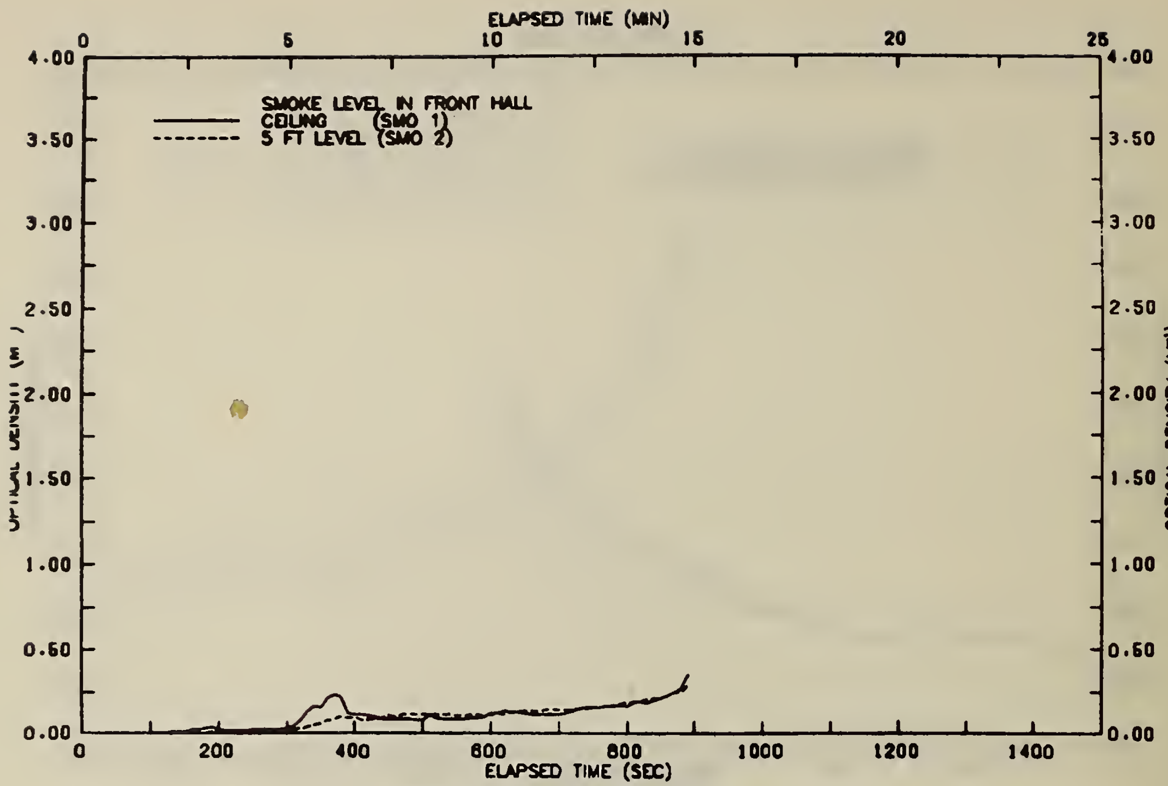

FIGURE A117 SMOKE LEVELS IN FRONT HALLWAY-TEST 12

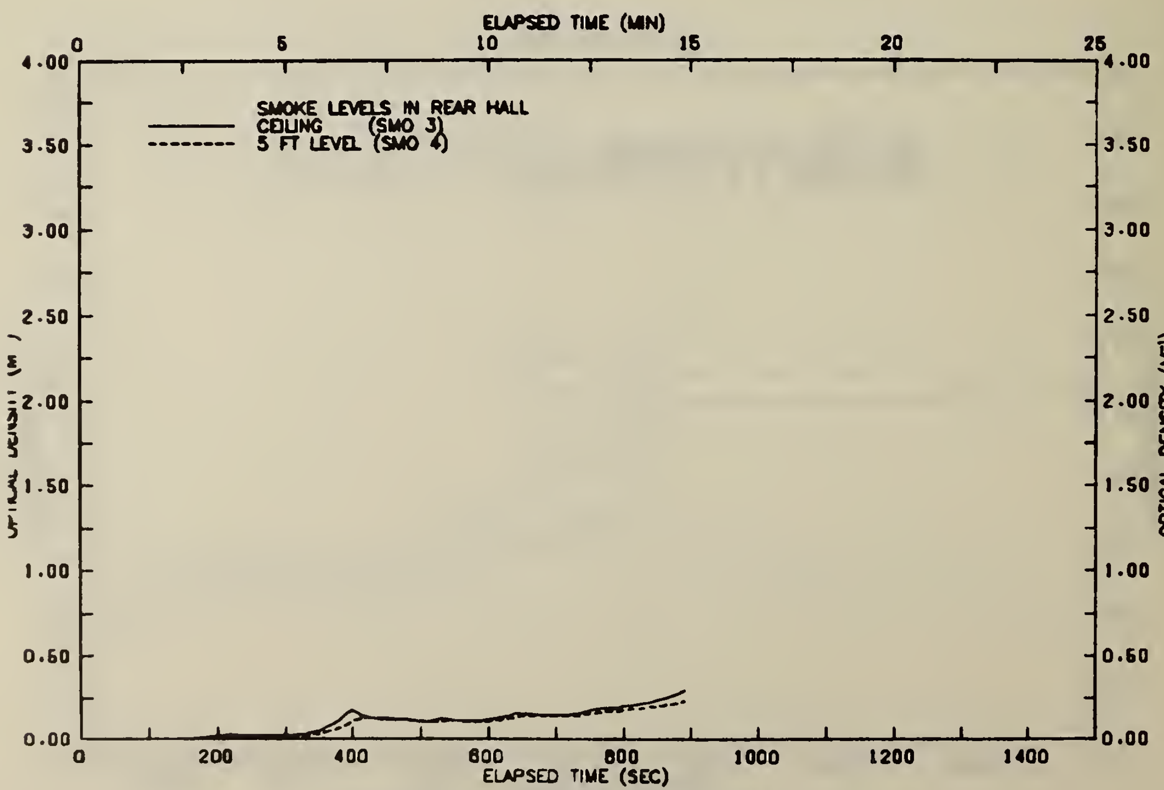

FIGURE A118 SMOKE LEVELS IN REAR HAL_WAY-TEST 12

FIGURE A119 SMOKE LEVELS IN BEDROOMS-TEST 12

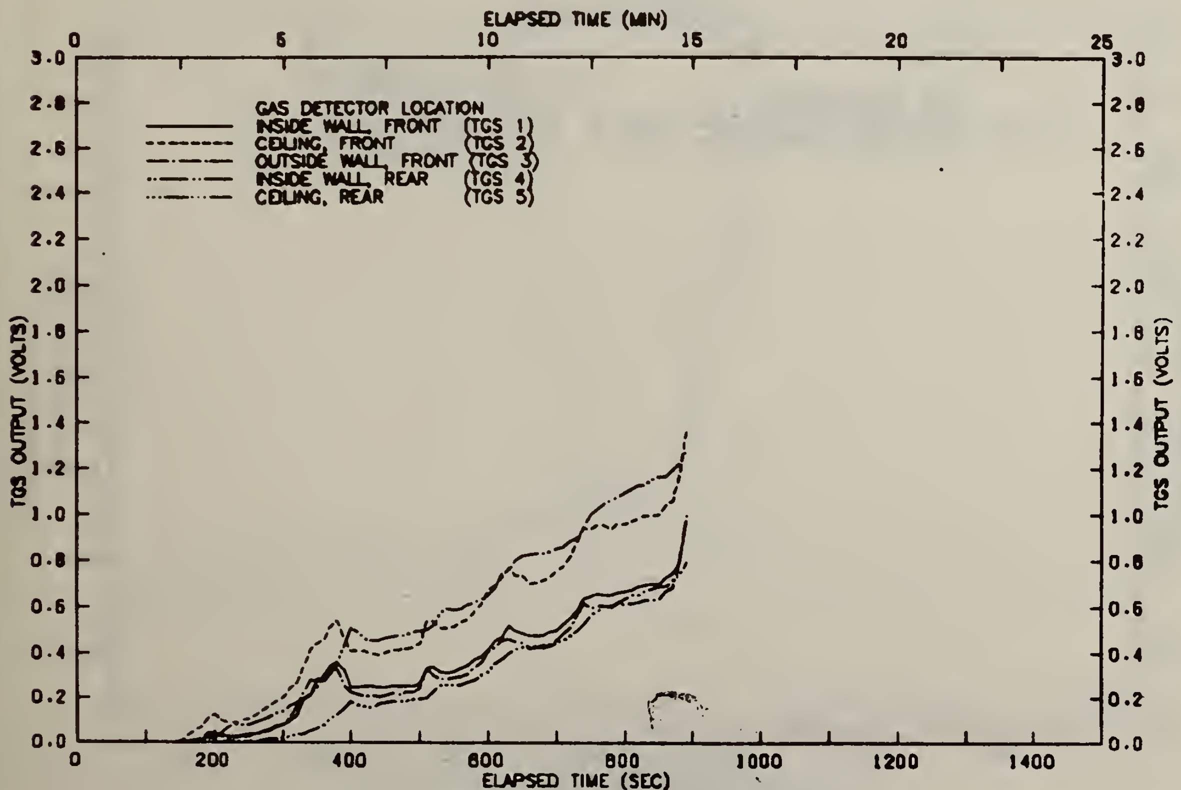

FIGURE A120 GAS DETECTOR OUTPUT VOLTAGE BY LOCATION-TEST 12

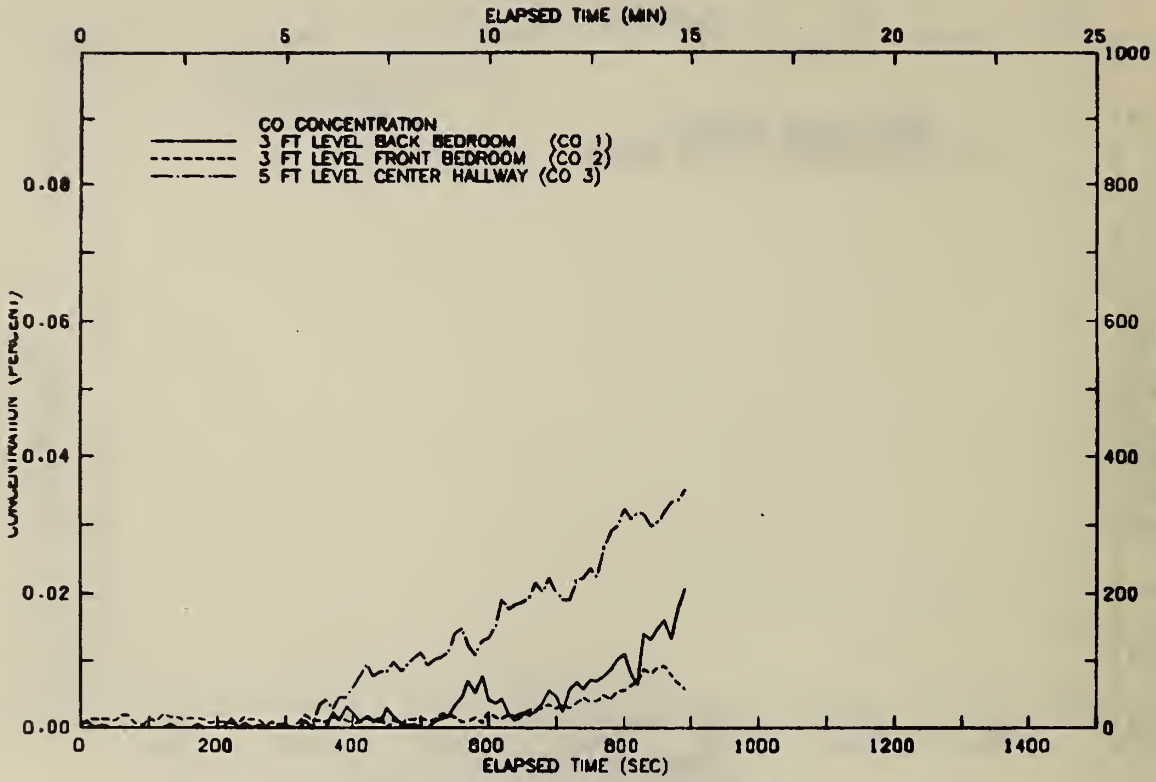

FIGURE A120A CARBON MONOXIDE CONCENTRATION–TEST 12

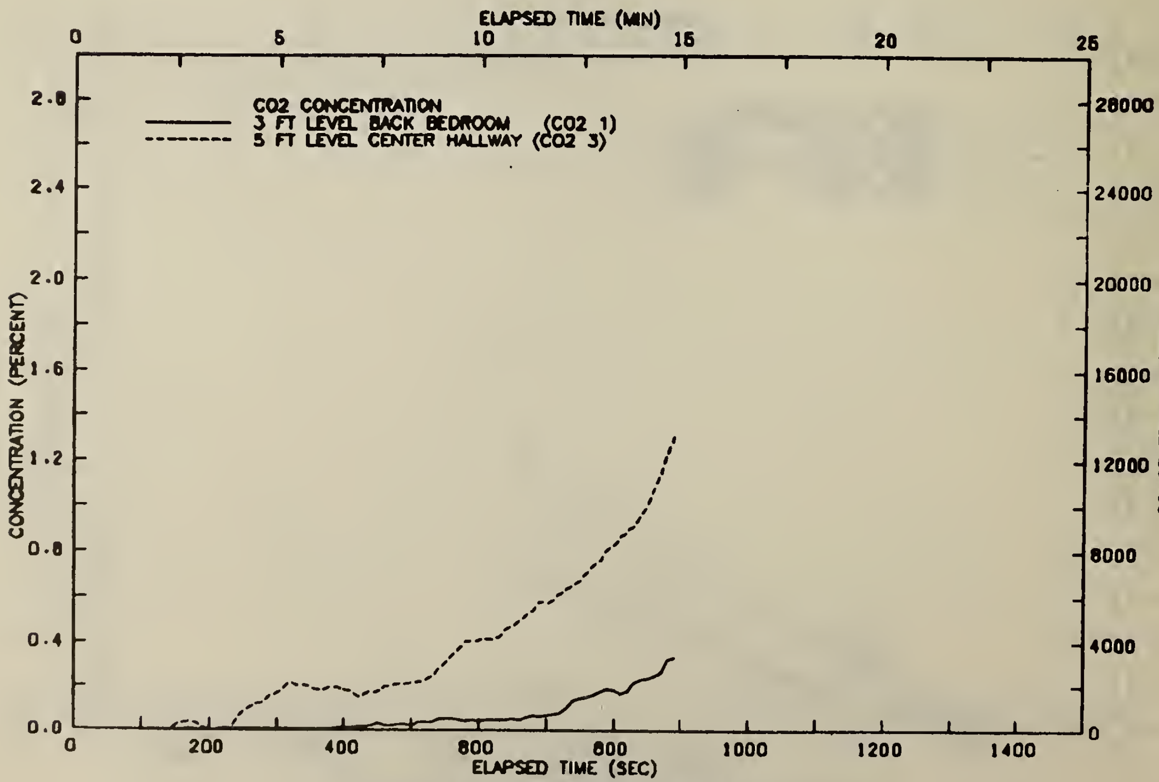

FIGURE A120B CARBON DIOXIDE CONCENTRATION–TEST 12

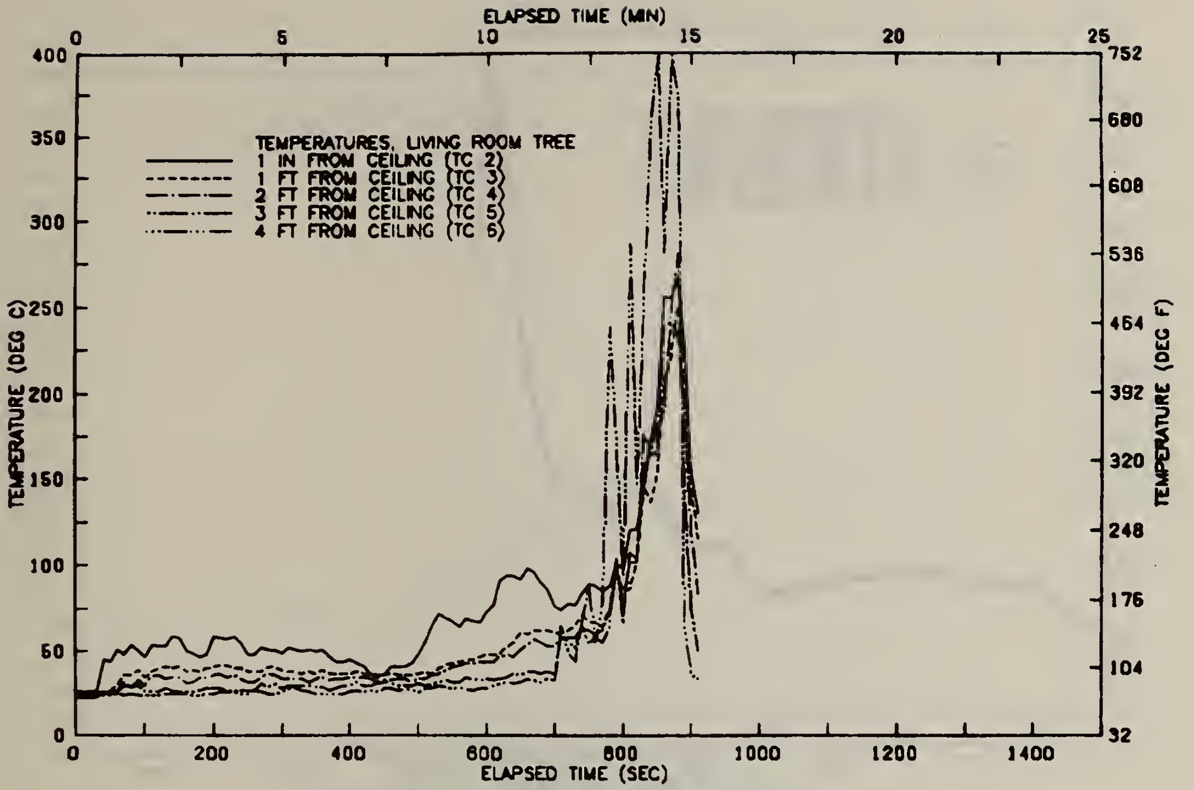

FIGURE A121 VERTICAL TEMP. PROFILE
ABOVE CHAIR-TEST 13

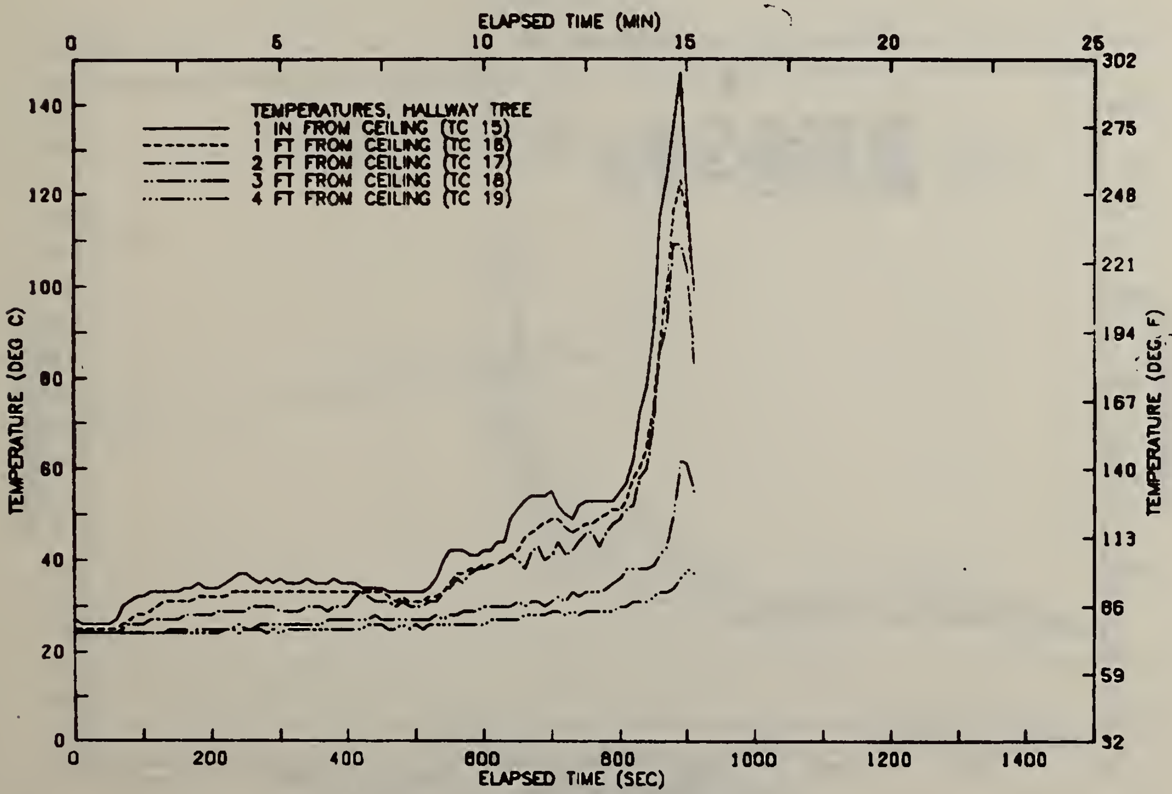

FIGURE A122 VERTICAL TEMP. PROFILE
IN HALLWAY-TEST 13

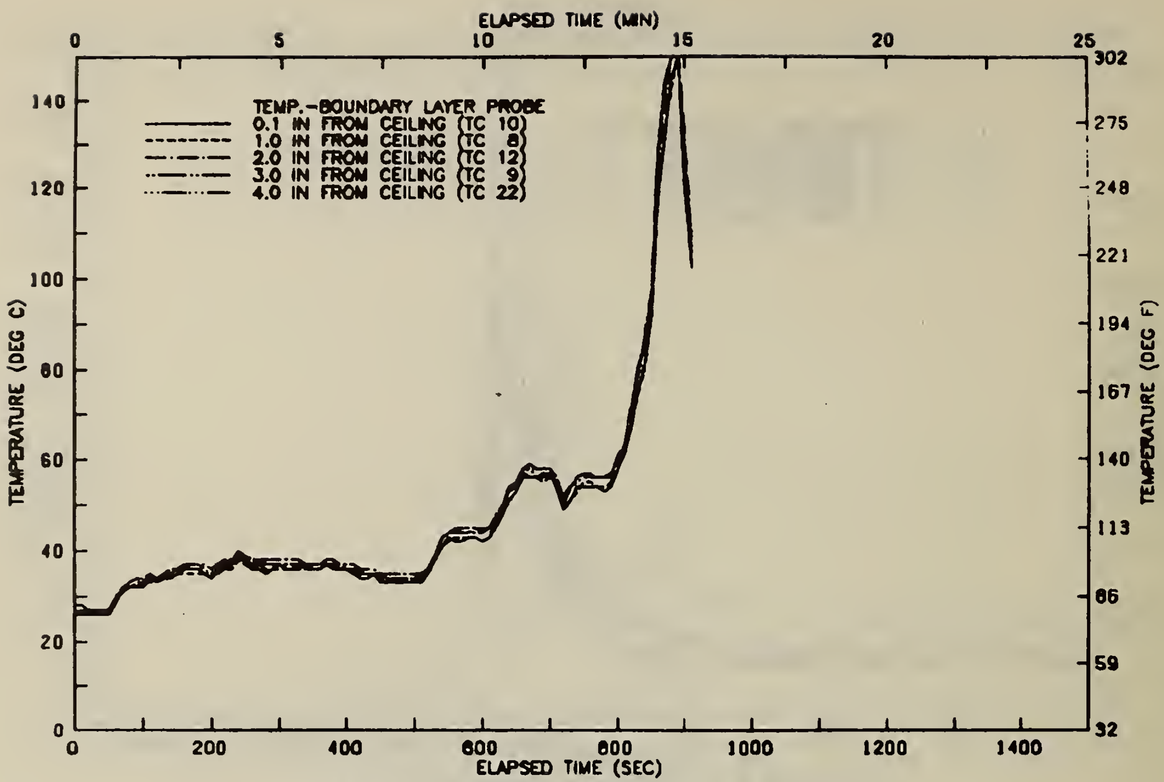

FIGURE A123 VERTICAL TEMP. PROFILE CEILING BOUNDARY LAYER-TEST 13

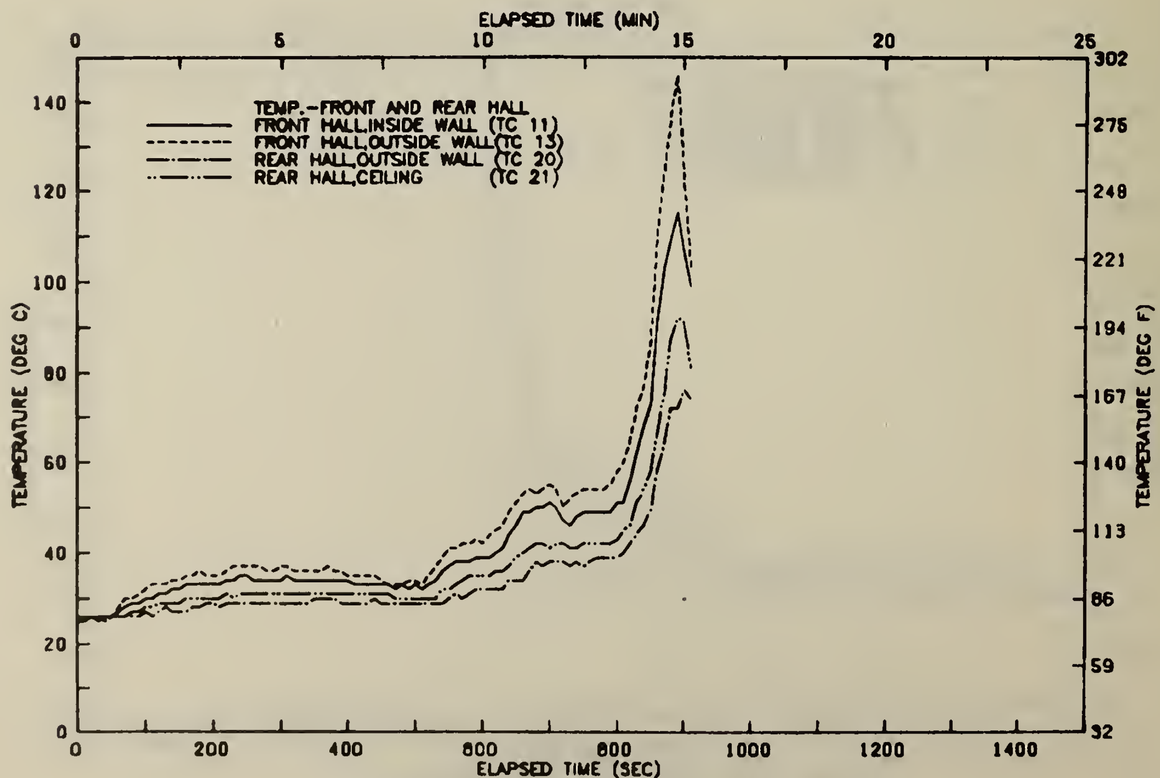

FIGURE A124 TEMP. IN HALLWAY NEAR DETECTORS-TEST 13

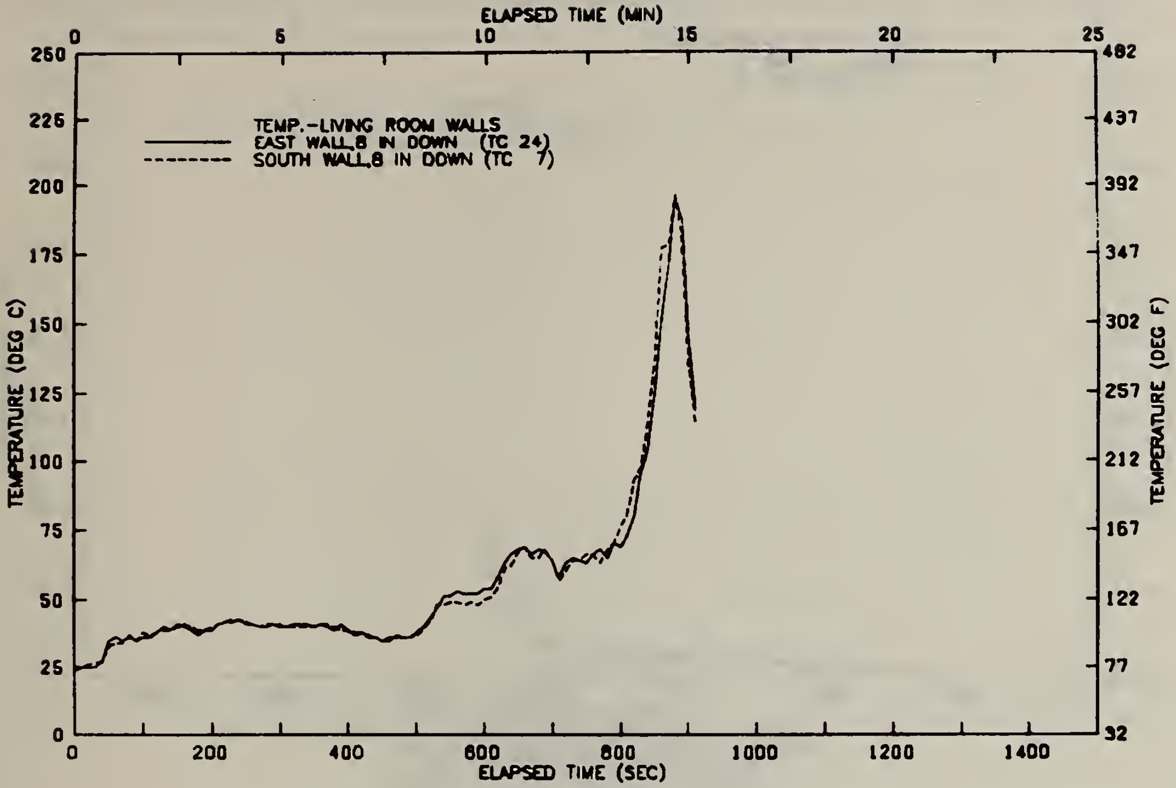

FIGURE A125 TEMPERATURE AT LIVING ROOM WALLS-TEST 13

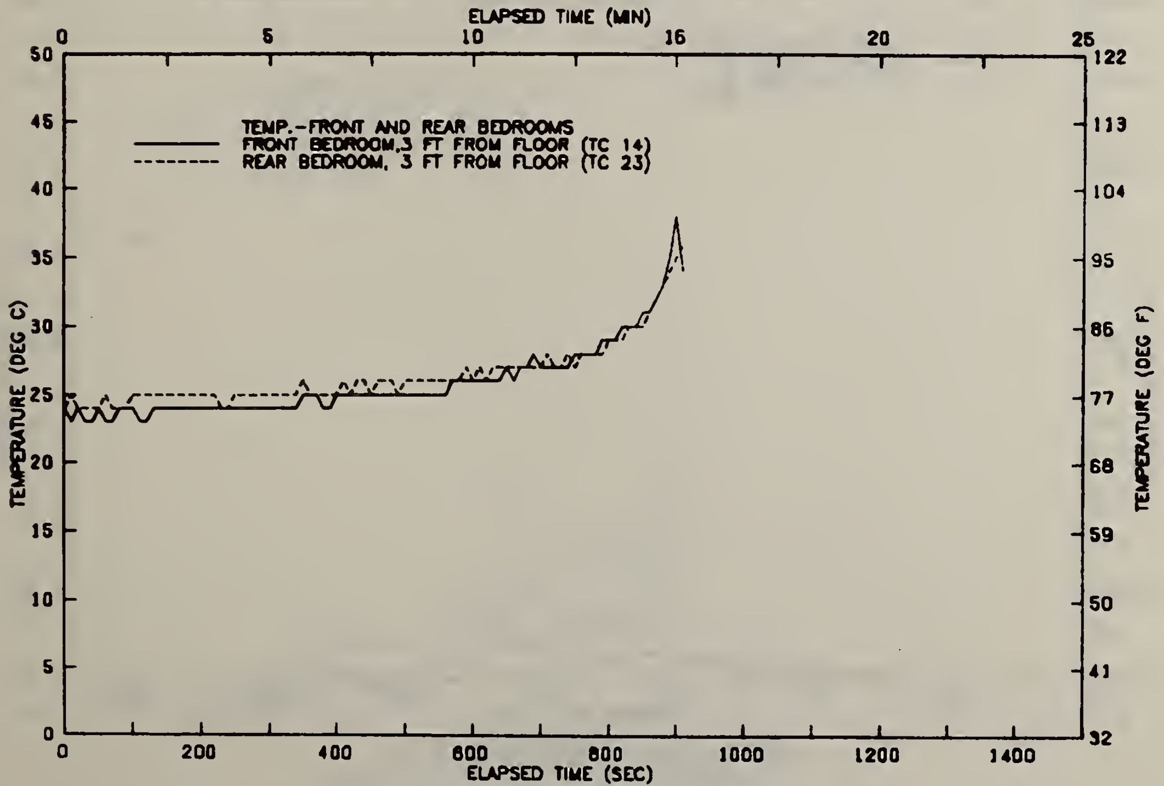

FIGURE A126 TEMP. IN FRONT AND REAR BEDROOMS-TEST 13

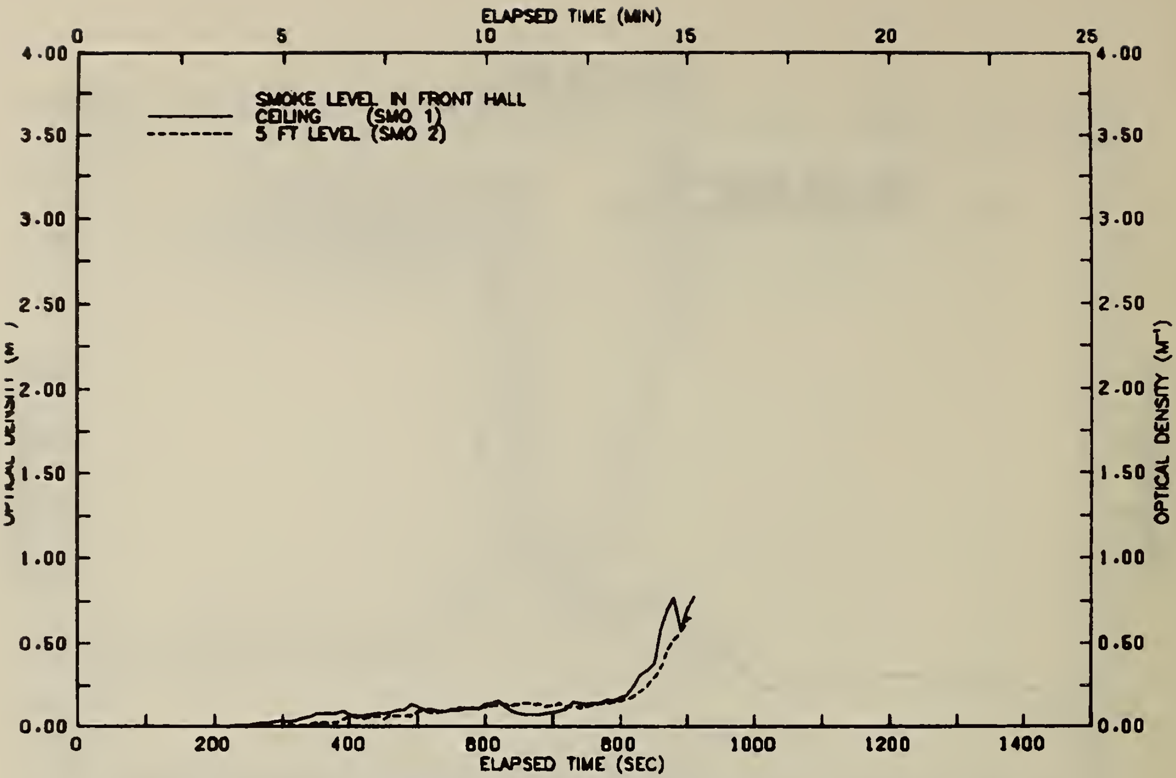

FIGURE A127 SMOKE LEVELS IN FRONT HALLWAY-TEST 13

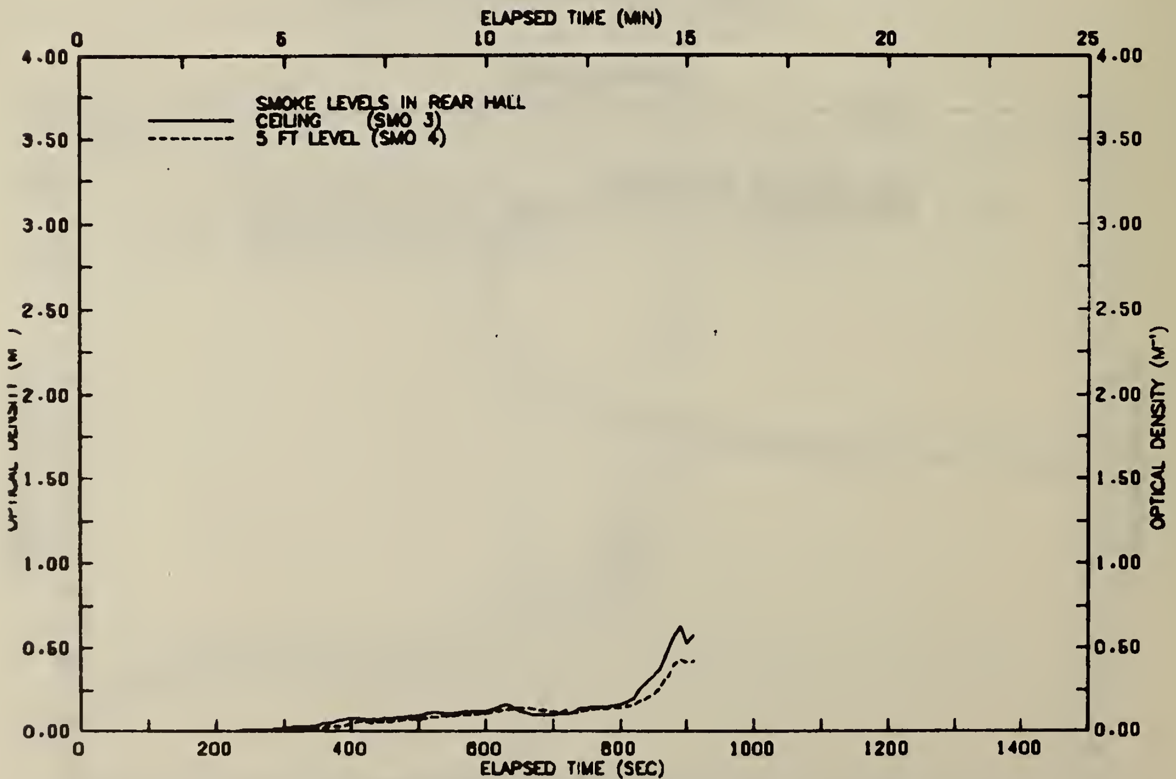

FIGURE A128 SMOKE LEVELS IN REAR HALLWAY-TEST 13

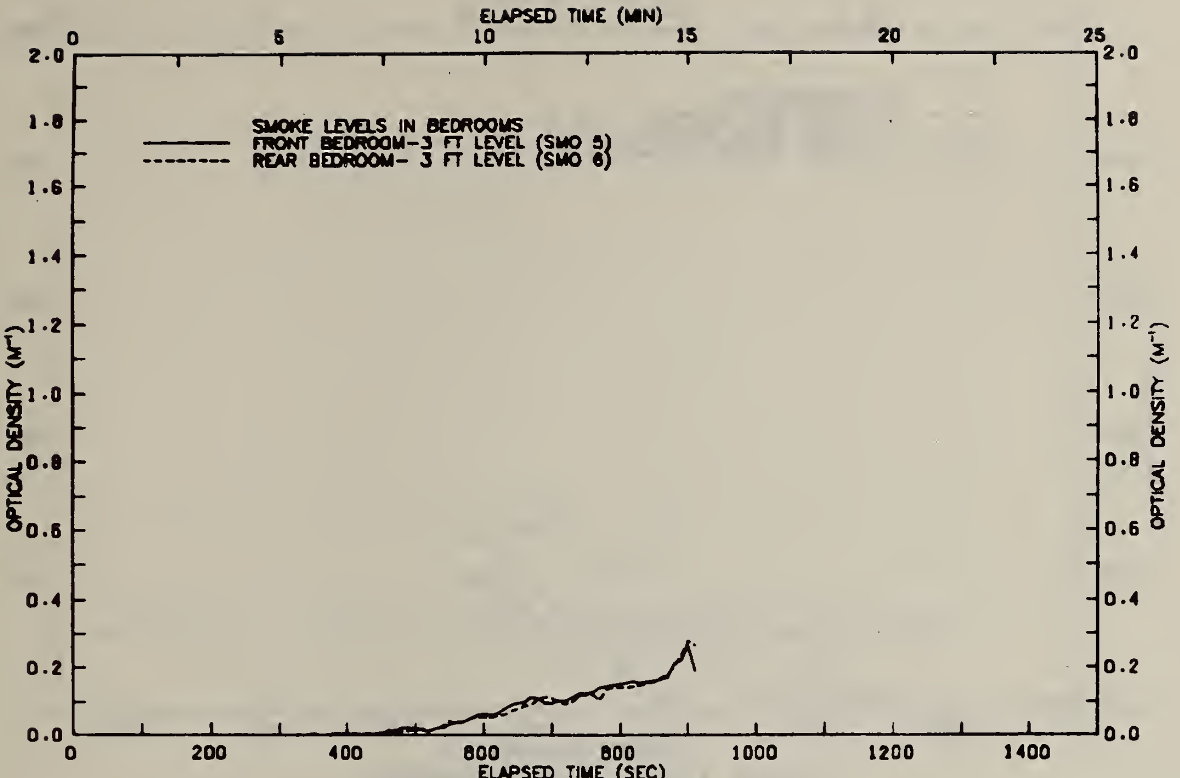

FIGURE A129 SMOKE LEVELS IN BEDROOMS-TEST 13

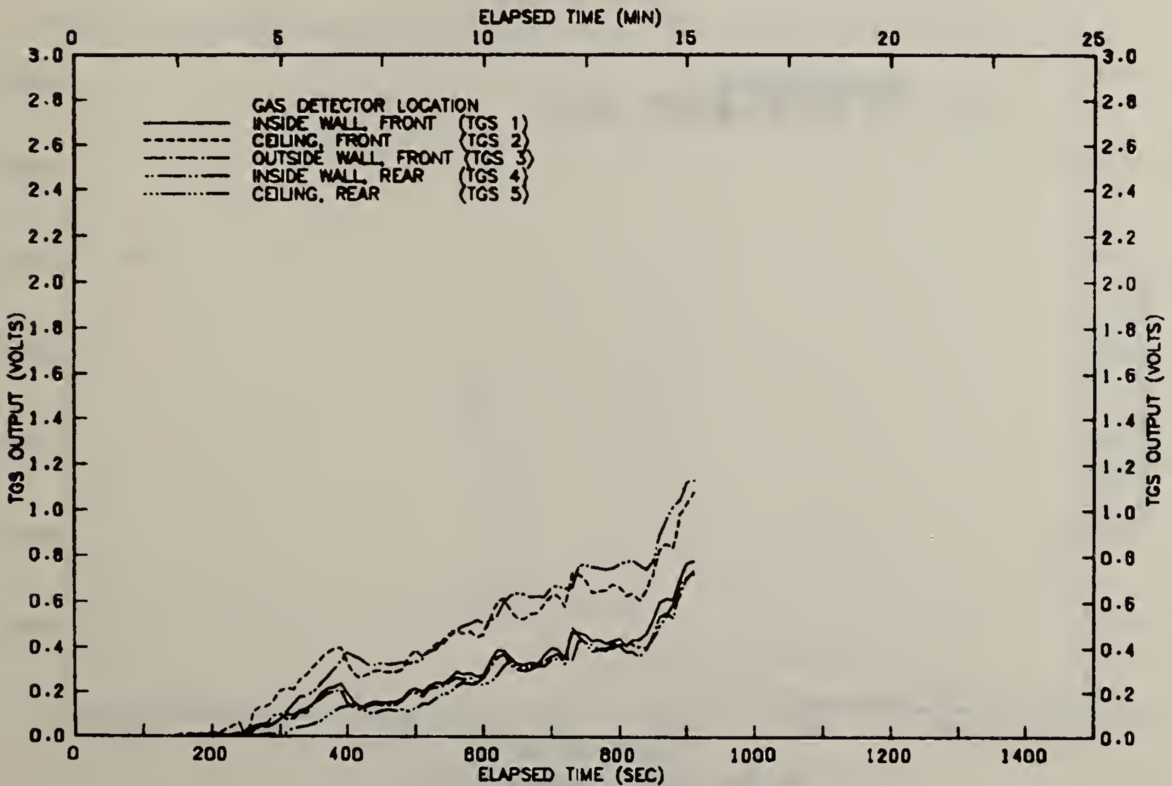

FIGURE A130 GAS DETECTOR OUTPUT VOLTAGE BY LOCATION-TEST 13

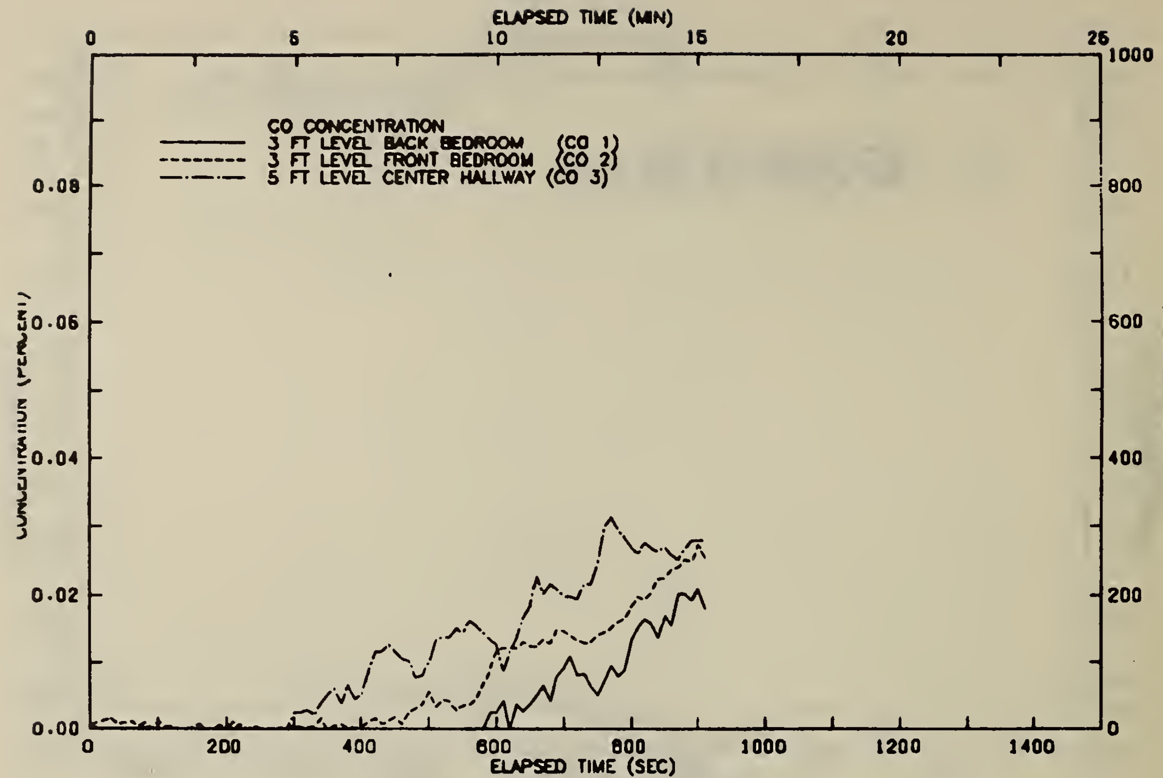

FIGURE A130A CARBON MONOXIDE CONCENTRATION–TEST 13

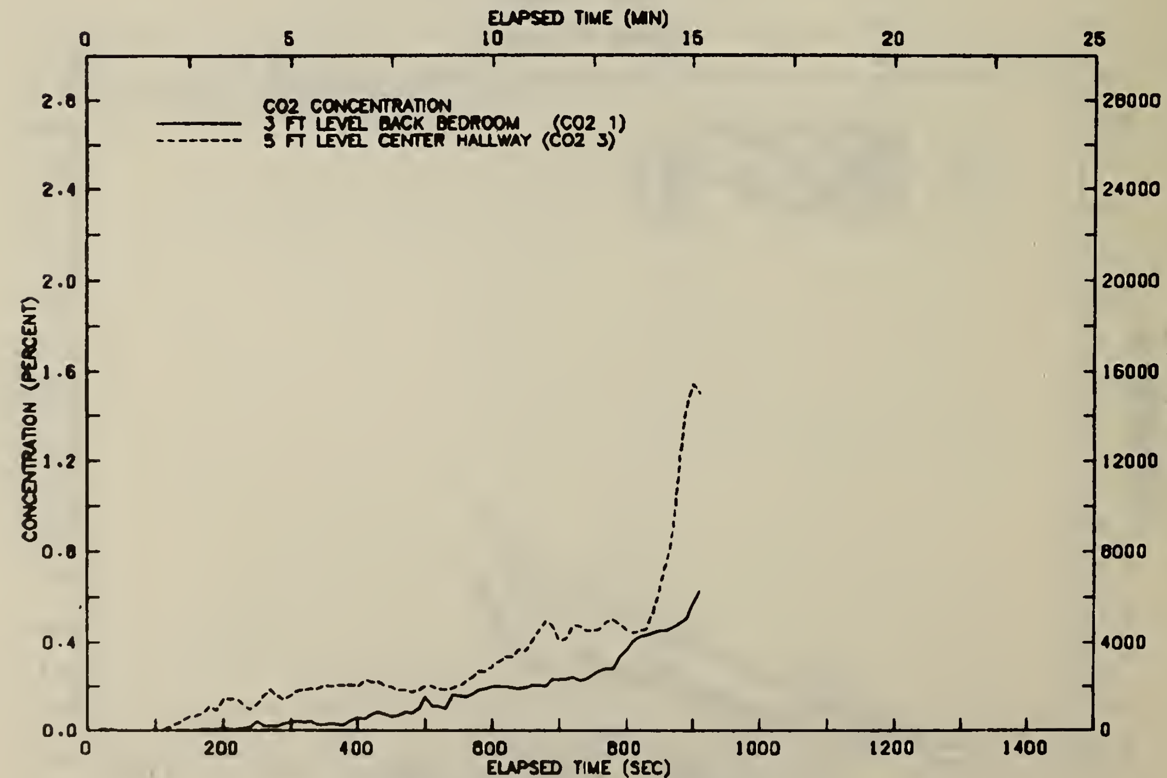

FIGURE A130B CARBON DIOXIDE CONCENTRATION–TEST 13

APPENDIX B - GRAPHS OF REDUCED DATA FROM WINTER TESTS

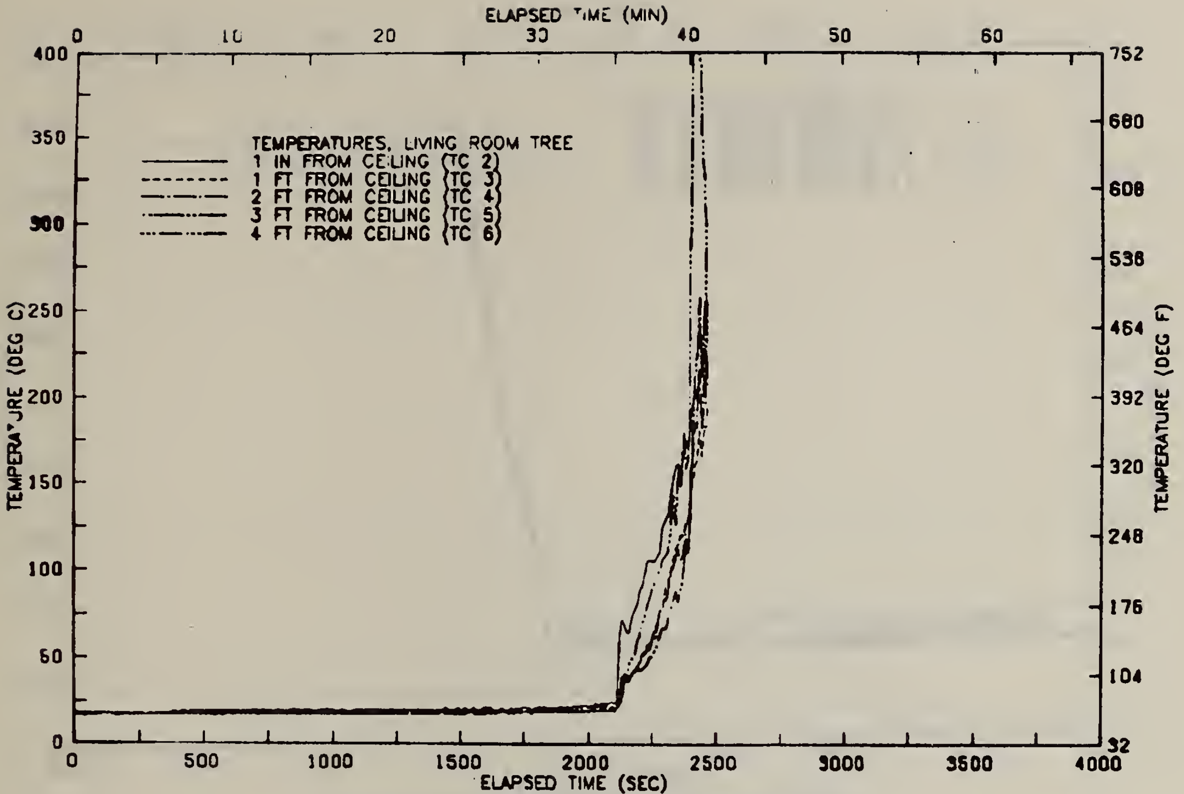

FIGURE B1 VERTICAL TEMP. PROFILE ABOVE CHAIR-TEST 14

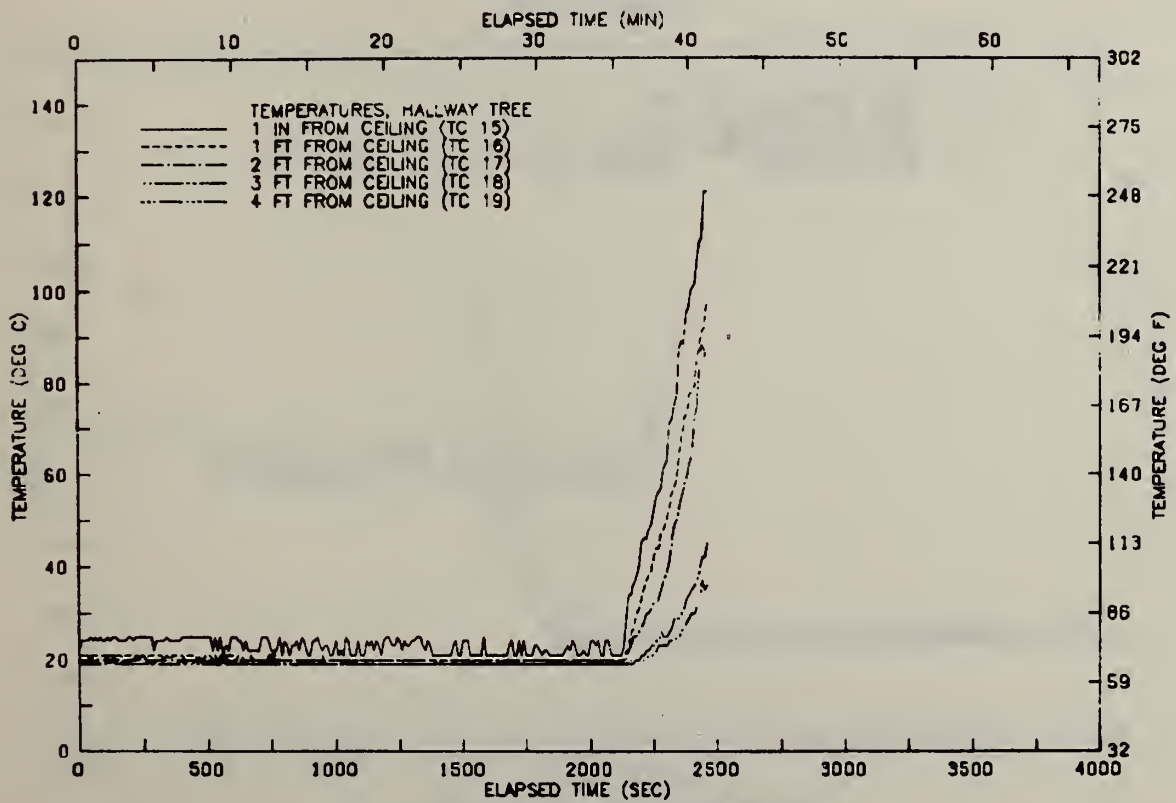

FIGURE B2 VERTICAL TEMP. PROFILE IN HALLWAY-TEST 14

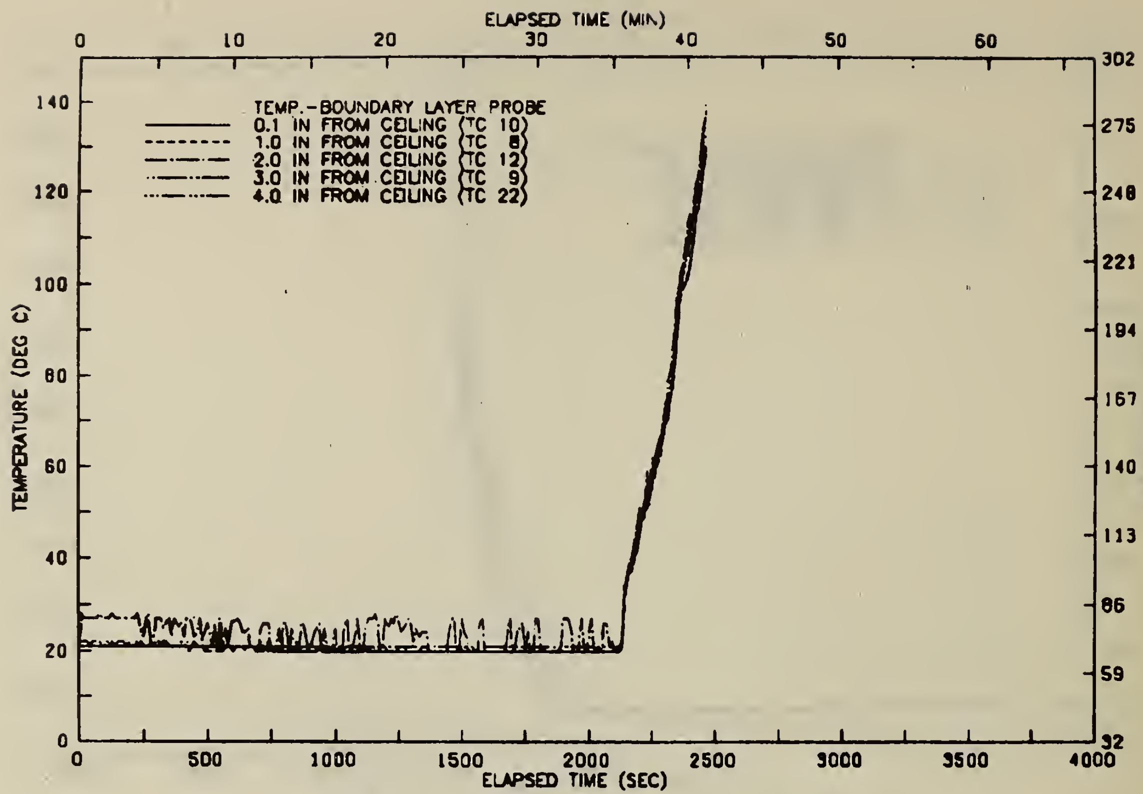

FIGURE B3 VERTICAL TEMP. PROFILE
CEILING BOUNDARY LAYER-TEST 14

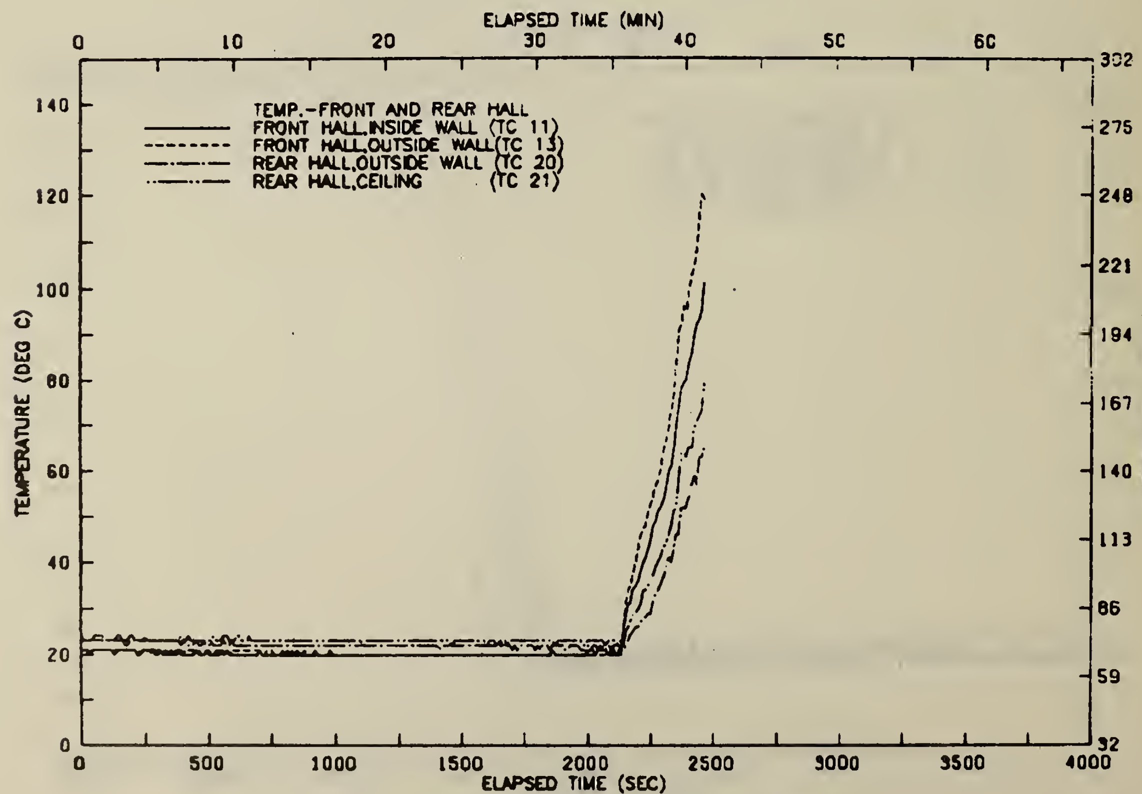

FIGURE B4 TEMP. IN HALLWAY
NEAR DETECTORS-TEST 14

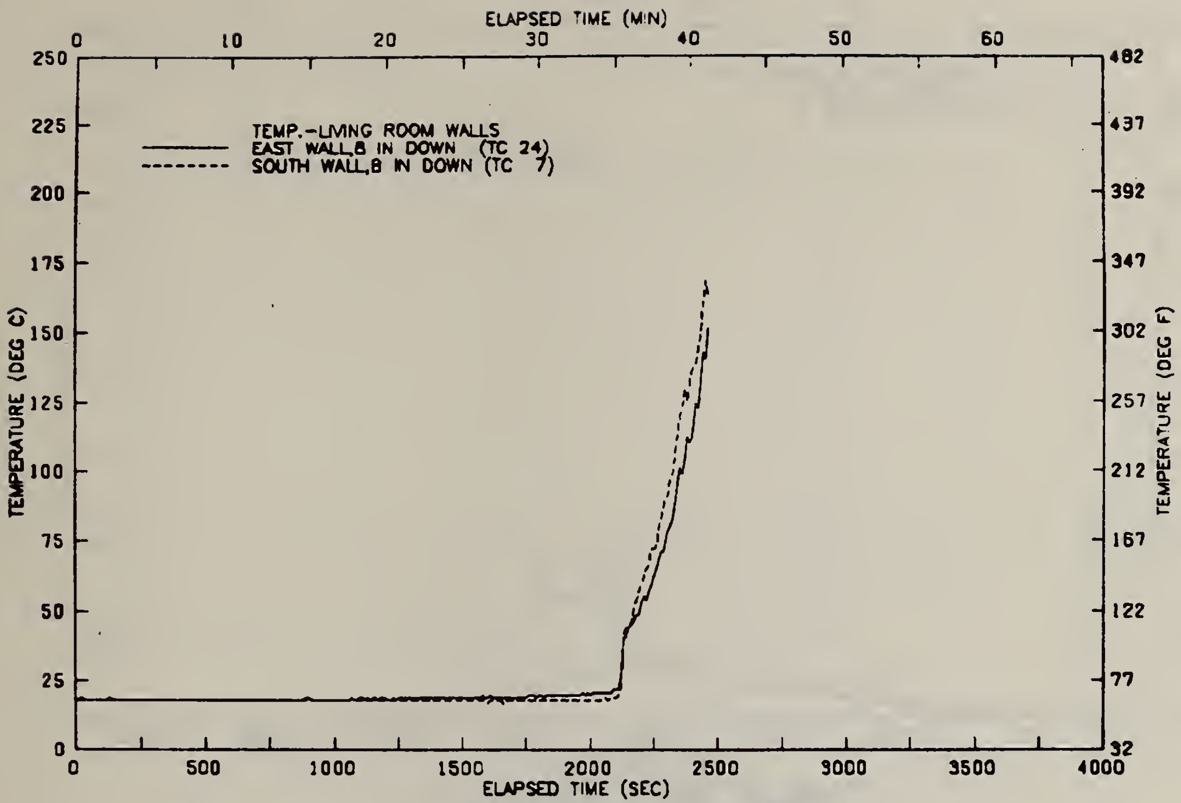

FIGURE B5 TEMPERATURE AT LIVING ROOM WALLS-TEST 14

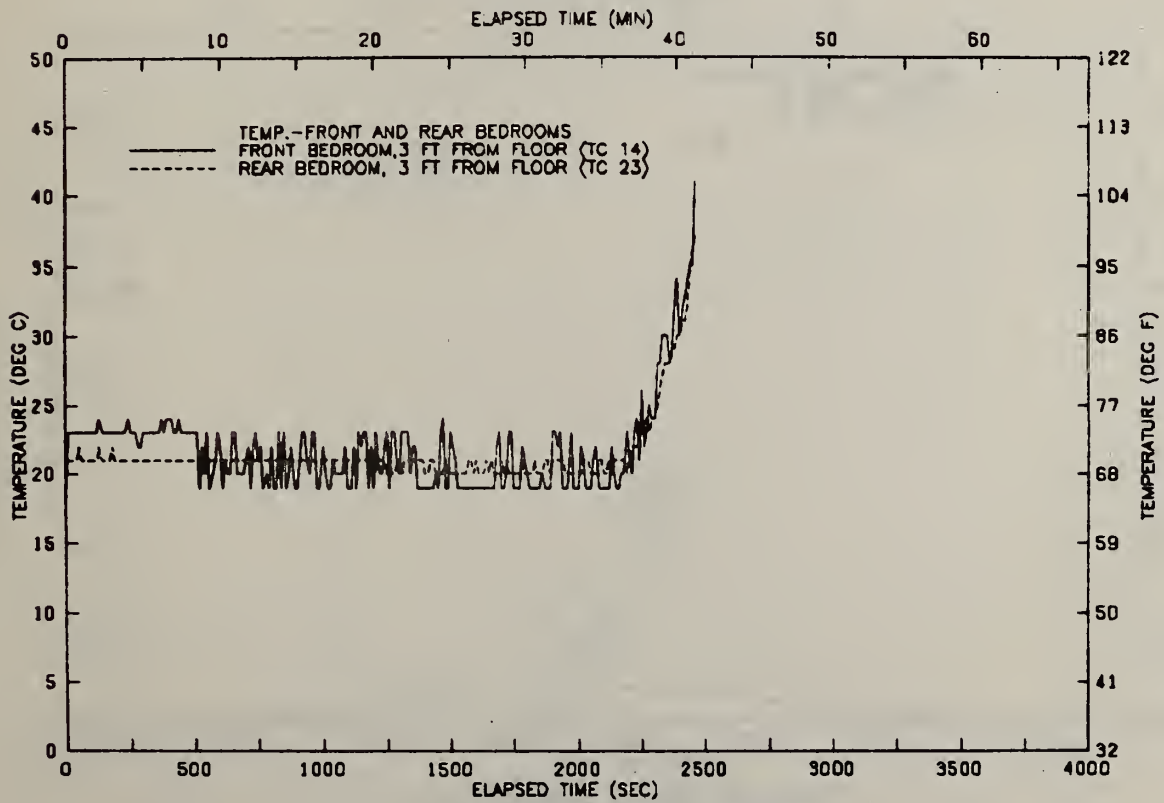

FIGURE B6 TEMP. IN FRONT AND REAR BEDROOMS-TEST 14

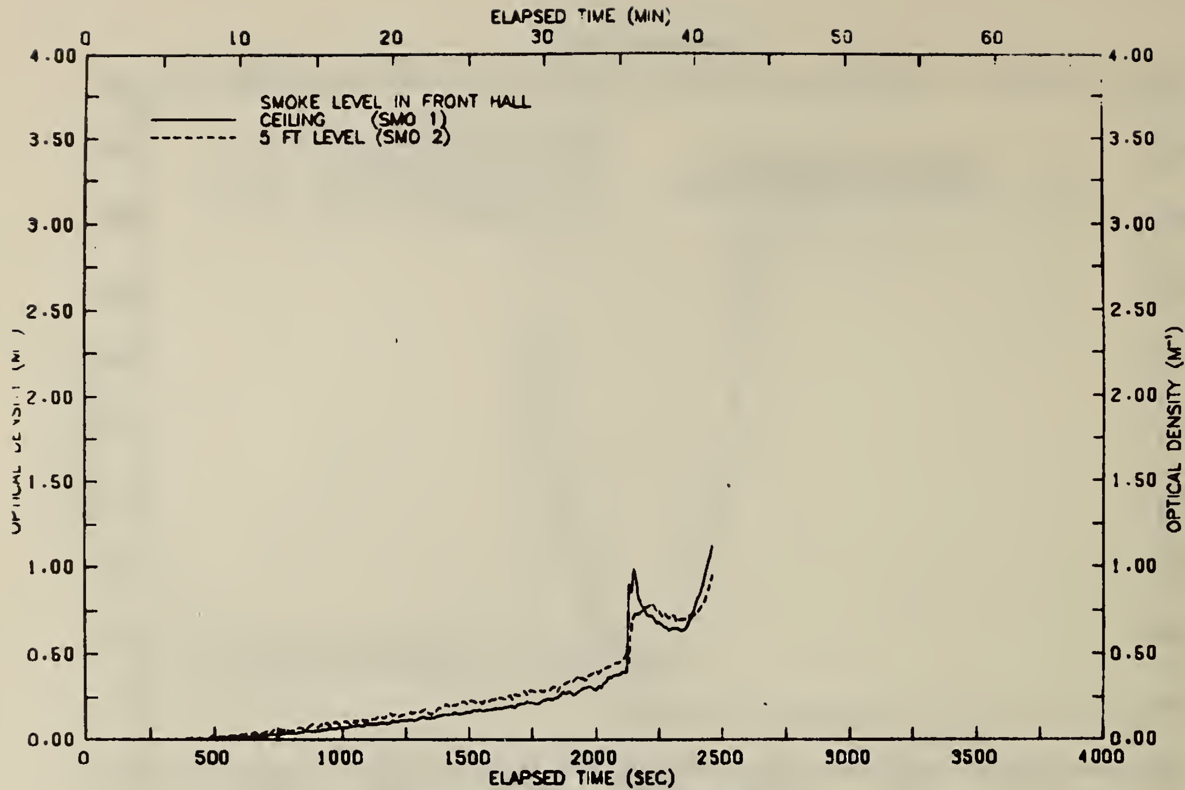

FIGURE B7 SMOKE LEVELS IN FRONT HALLWAY-TEST 14

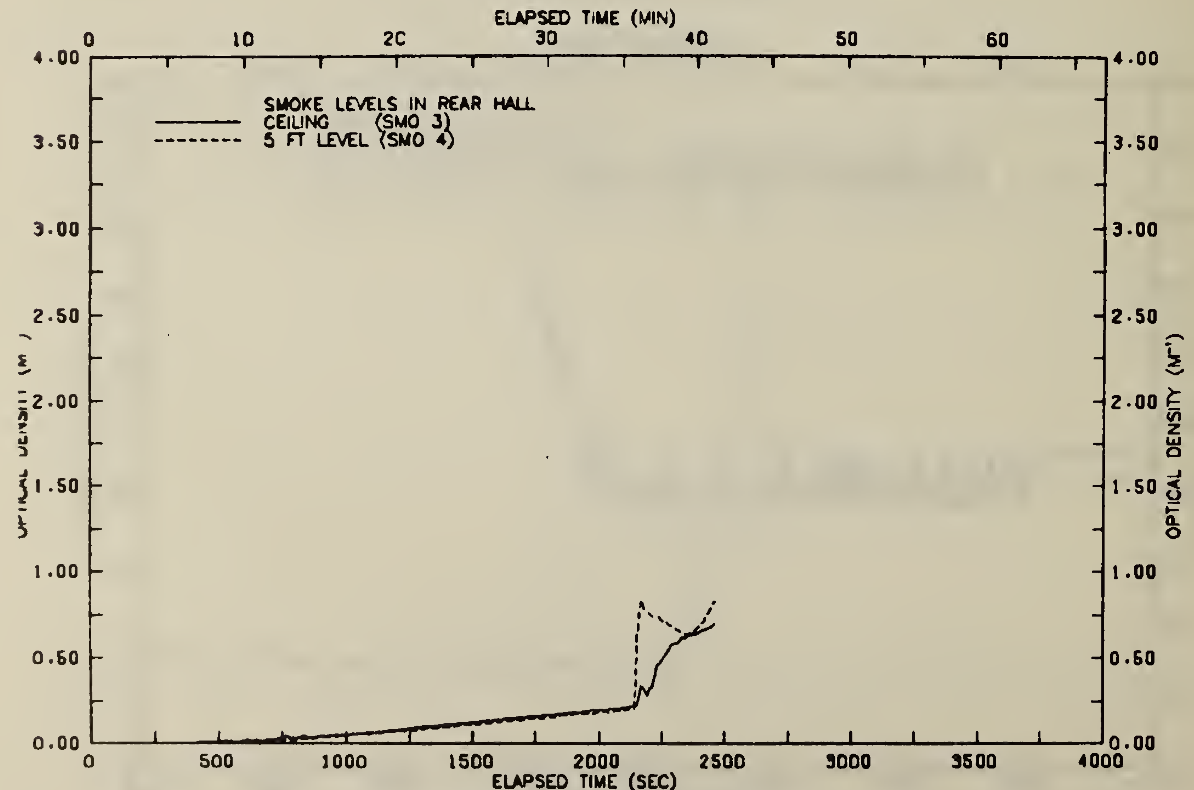

FIGURE B8 SMOKE LEVELS IN REAR HALLWAY-TEST 14

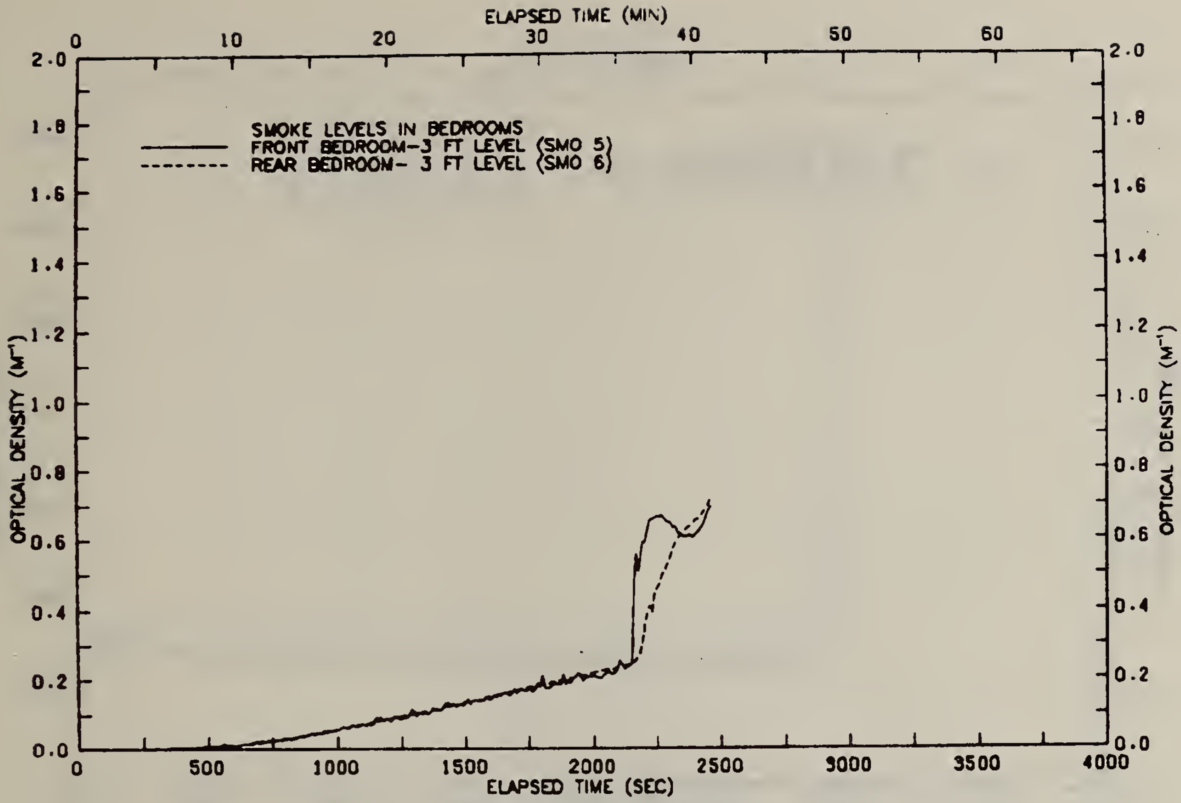

FIGURE B9 SMOKE LEVELS IN BEDROOMS-TEST 14

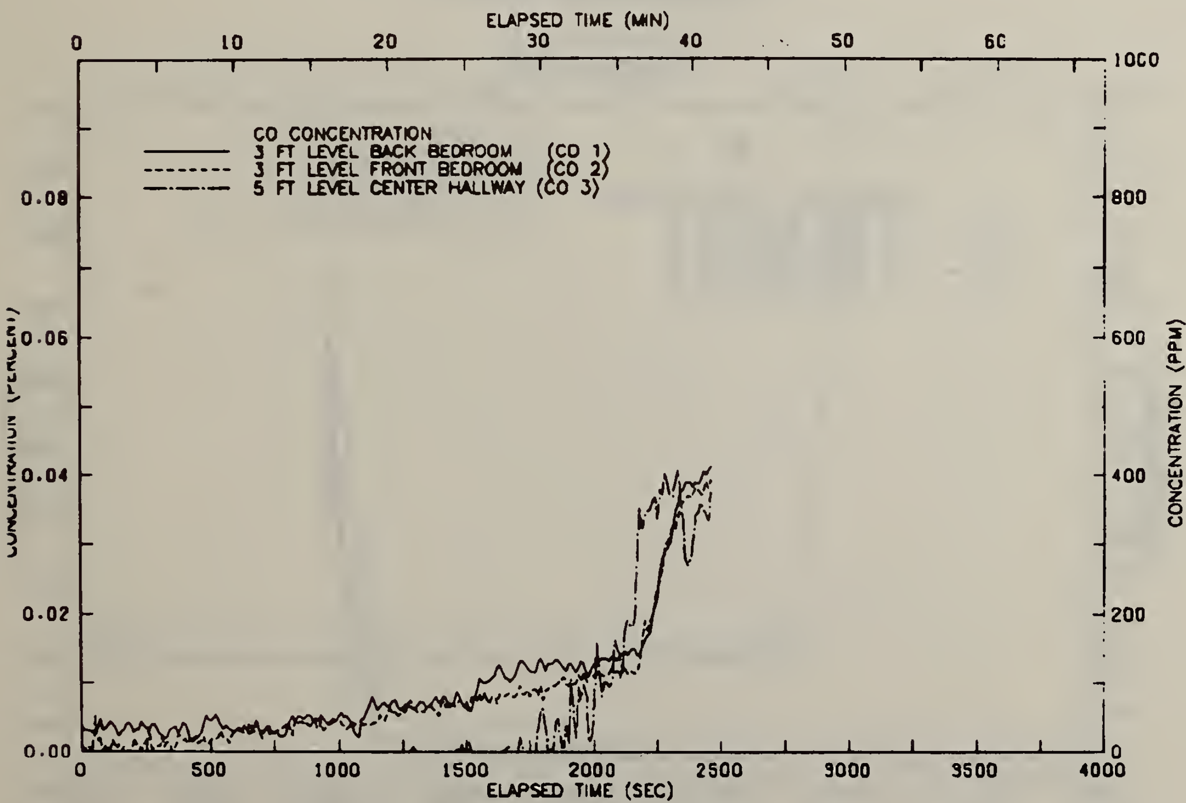

FIGURE B10 CARBON MONOXIDE CONCENTRATION-TEST 14

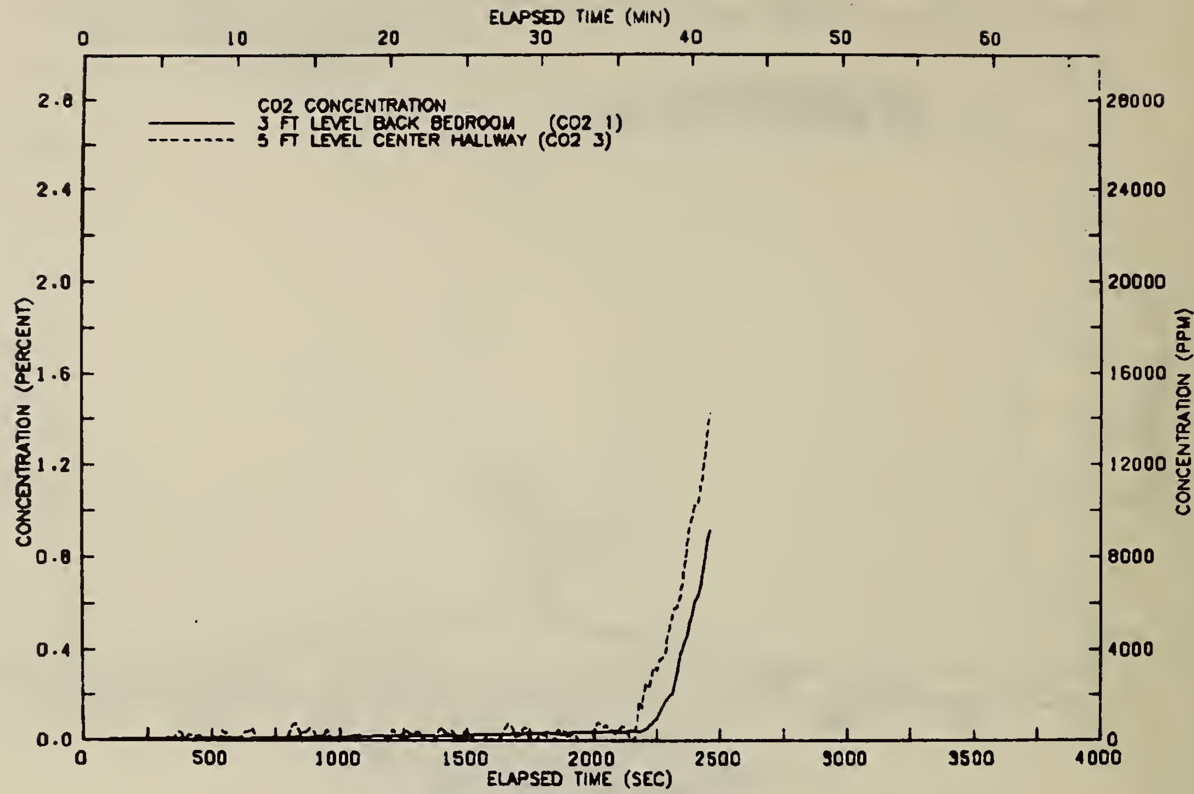

FIGURE B11 CARBON DIOXIDE CONCENTRATION–TEST 14

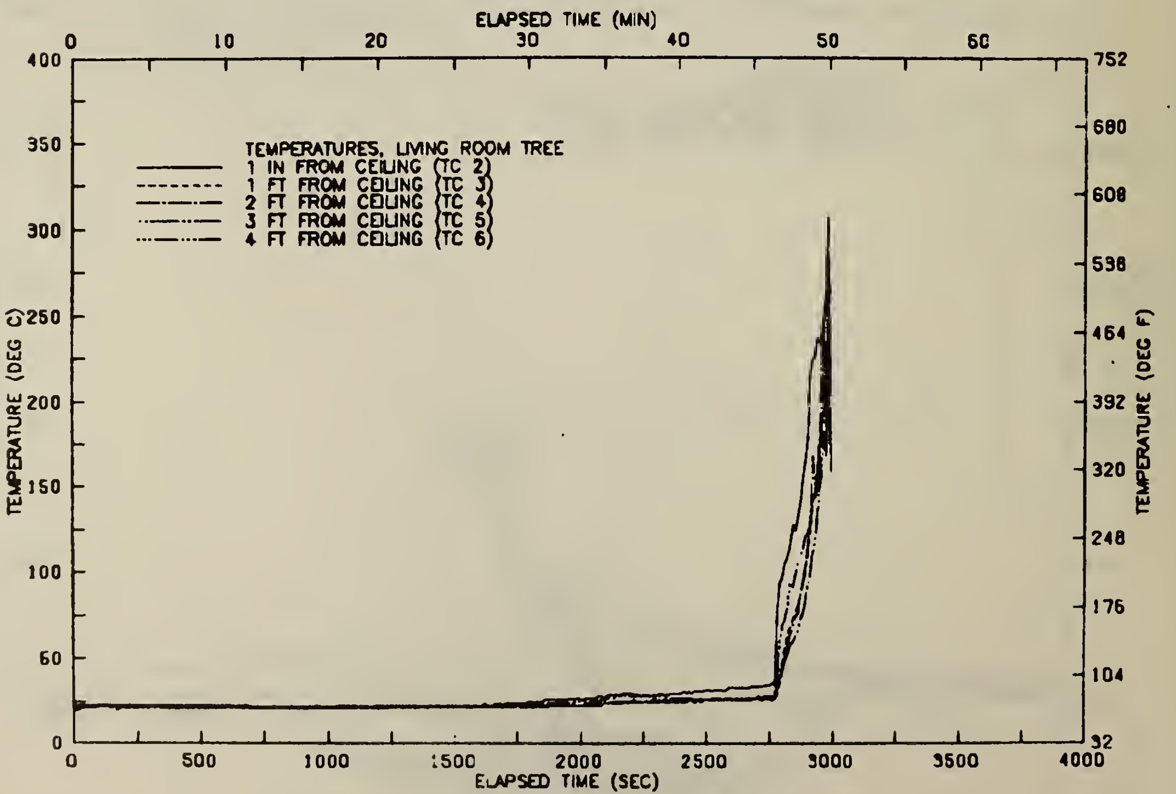

FIGURE B12 VERTICAL TEMP. PROFILE ABOVE CHAIR–TEST 15

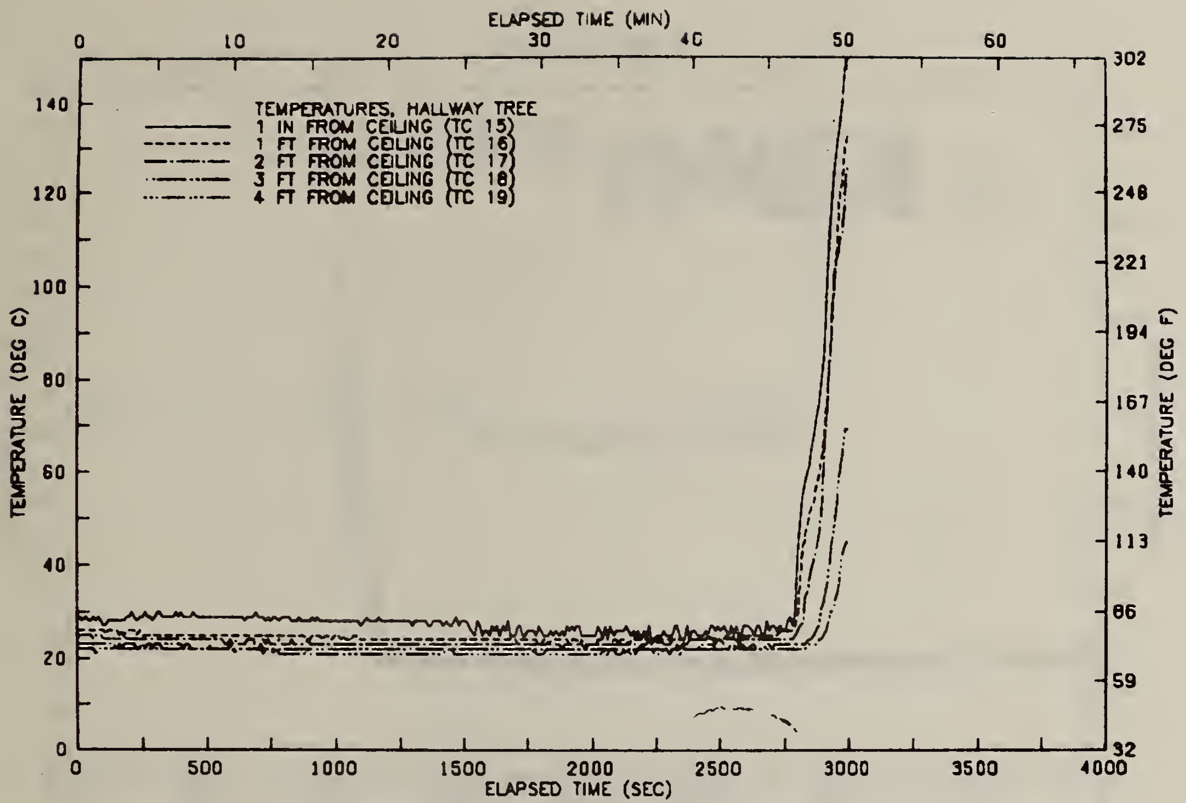

FIGURE B13 VERTICAL TEMP. PROFILE
IN HALLWAY-TEST 15

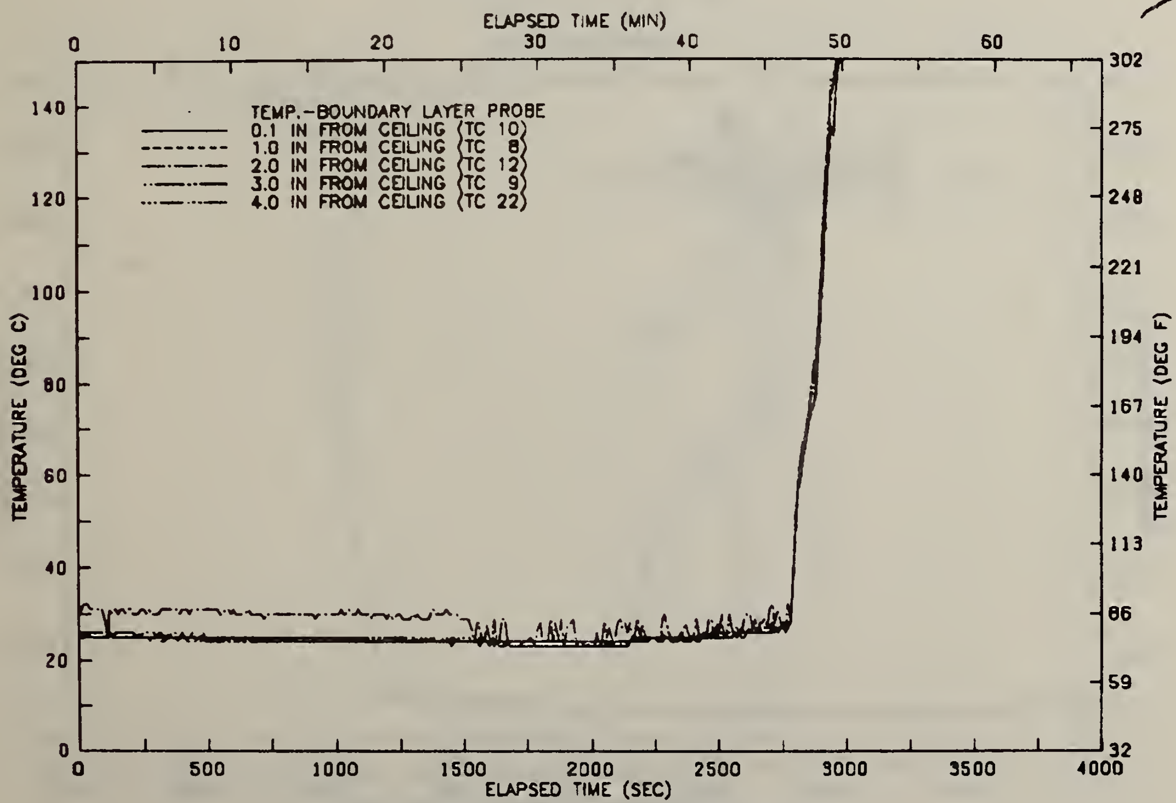

FIGURE B14 VERTICAL TEMP. PROFILE
CEILING BOUNDARY LAYER-TEST 15

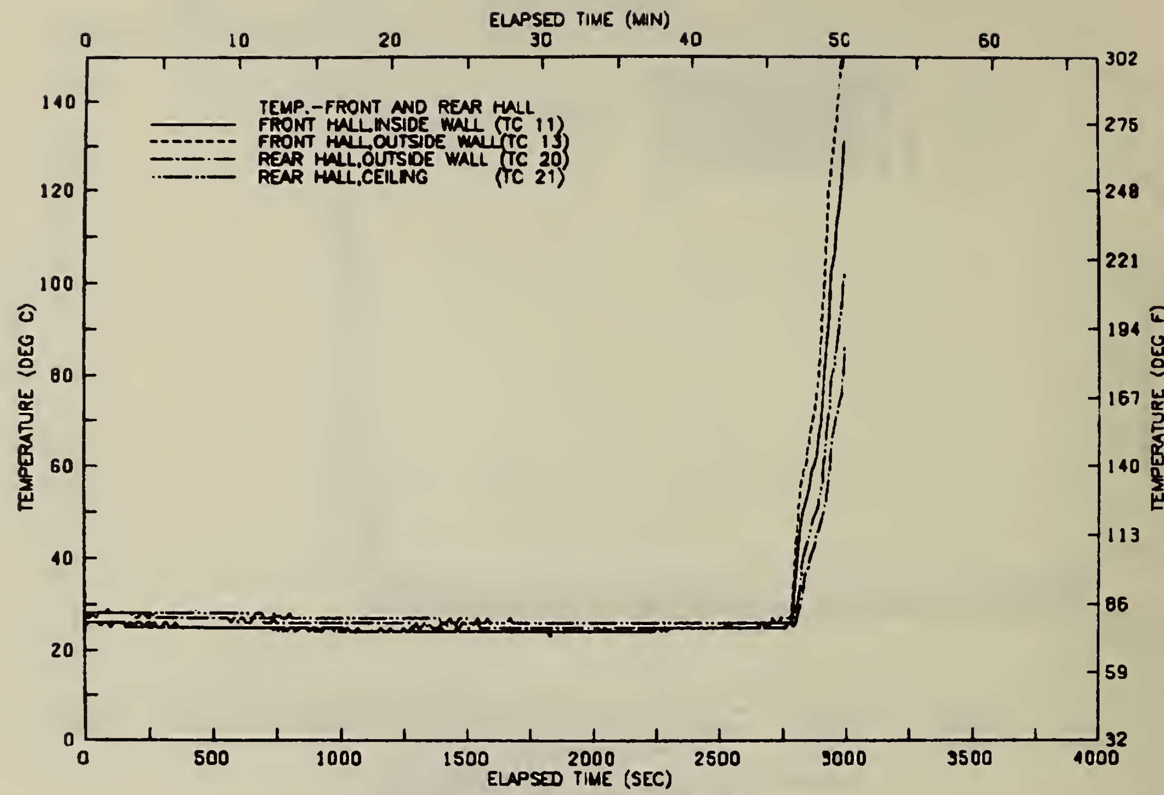

FIGURE B15 TEMP. IN HALLWAY NEAR DETECTORS-TEST 15

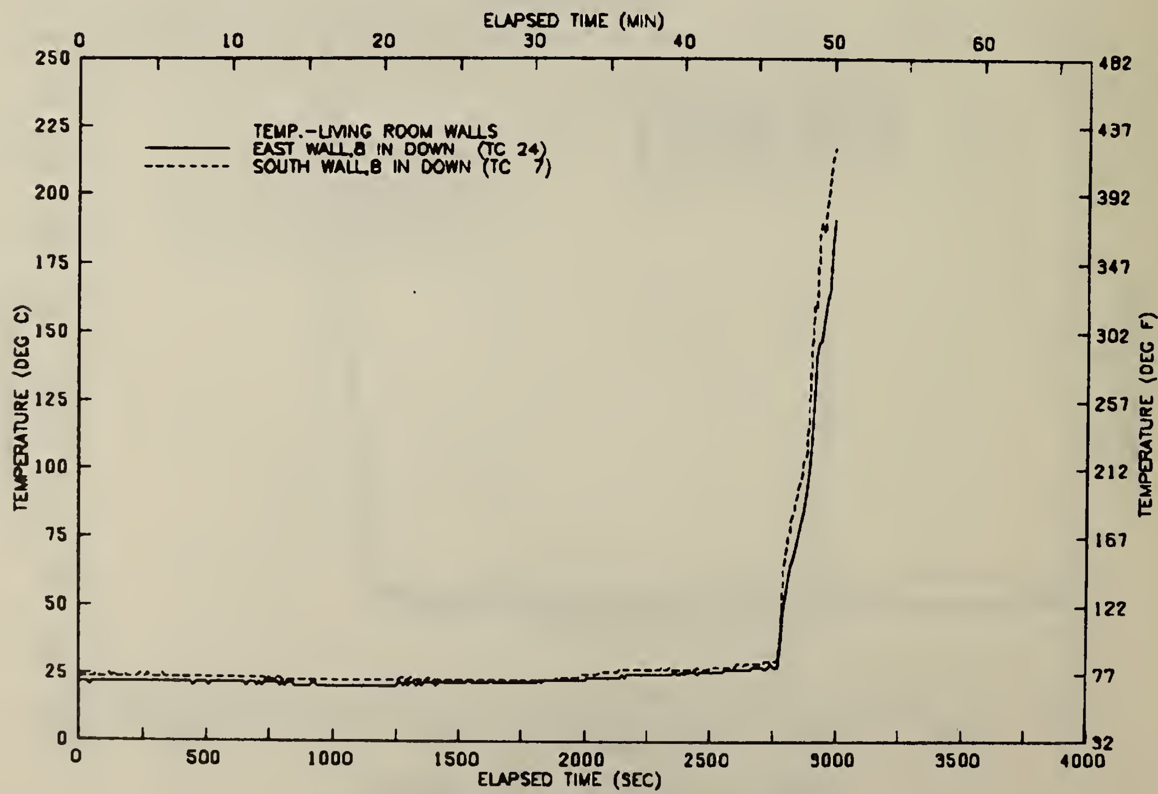

FIGURE B16 TEMPERATURE AT LIVING ROOM WALLS-TEST 15

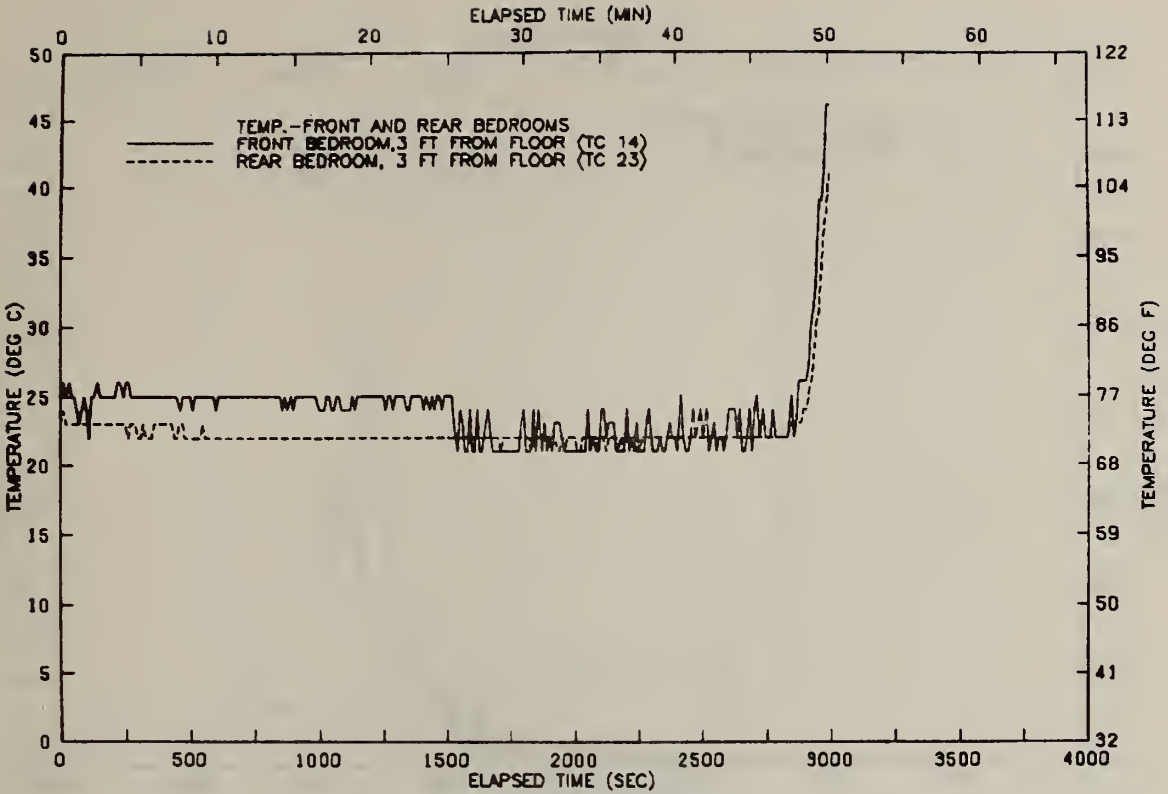

FIGURE B17 TEMP. IN FRONT AND REAR BEDROOMS-TEST 15

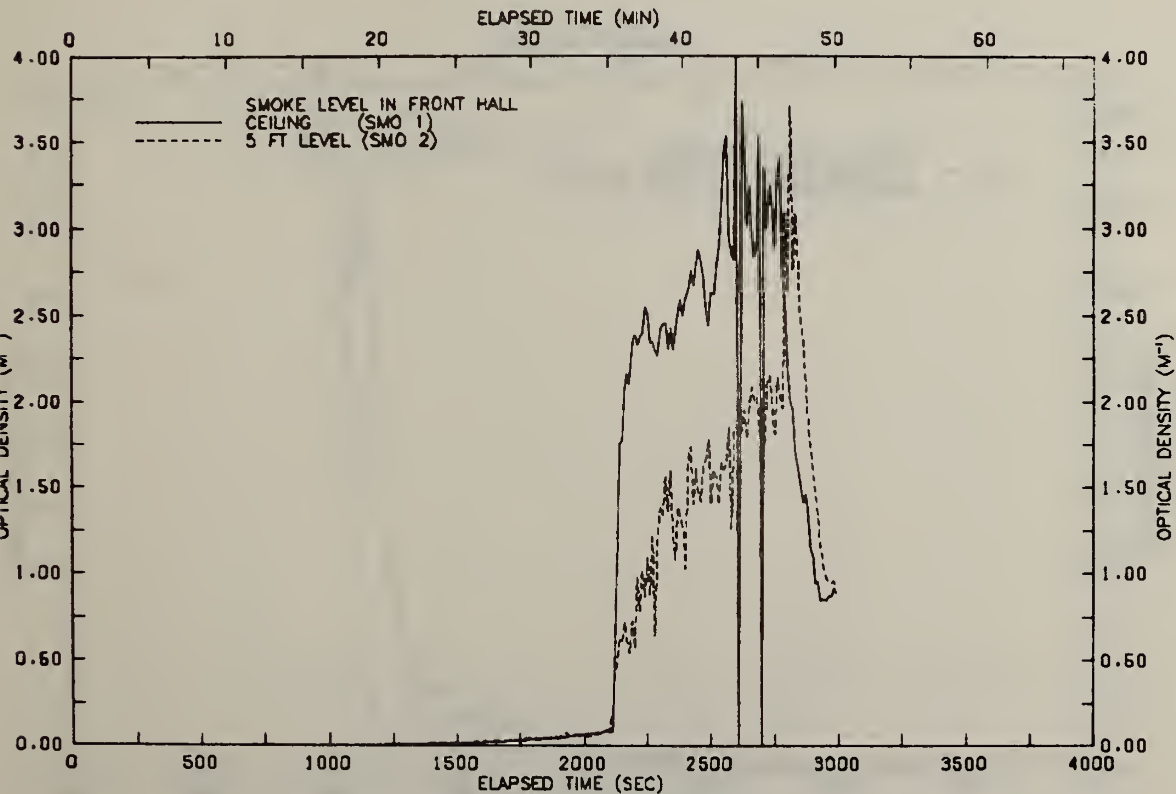

FIGURE B18 SMOKE LEVELS IN FRONT HALLWAY-TEST 15

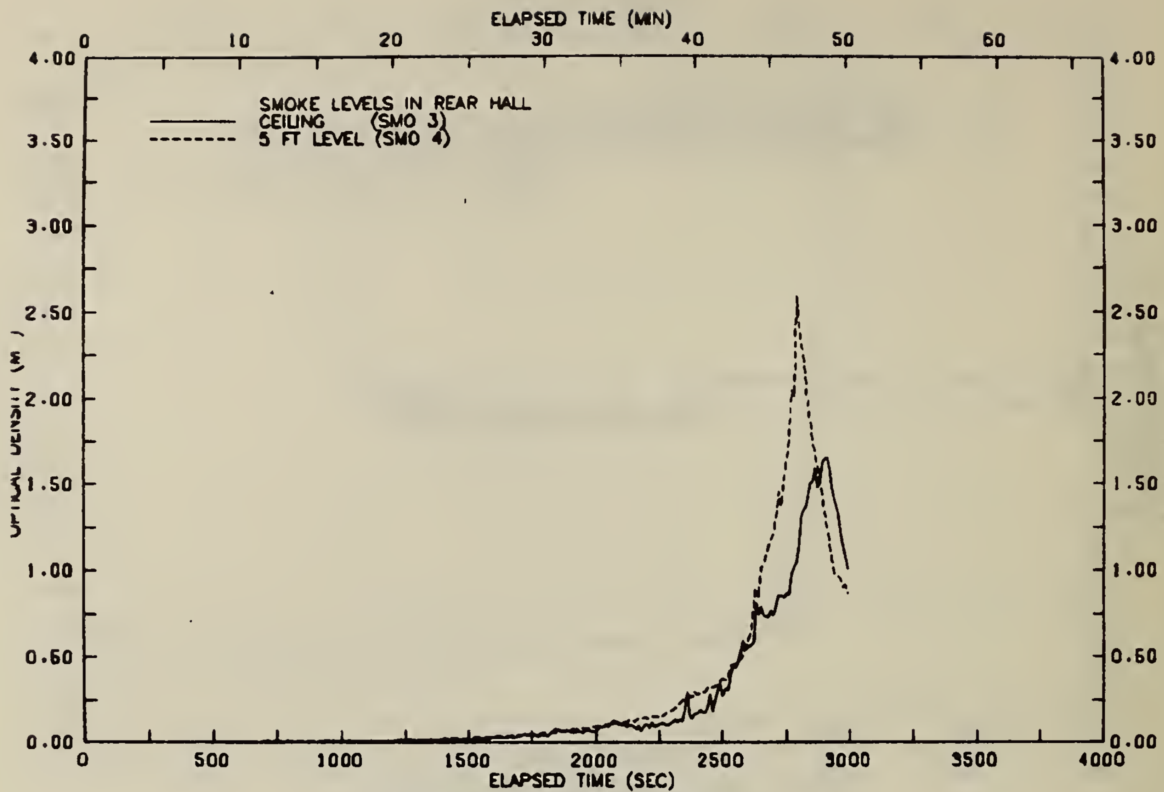

FIGURE B19 SMOKE LEVELS IN REAR HALLWAY-TEST 15

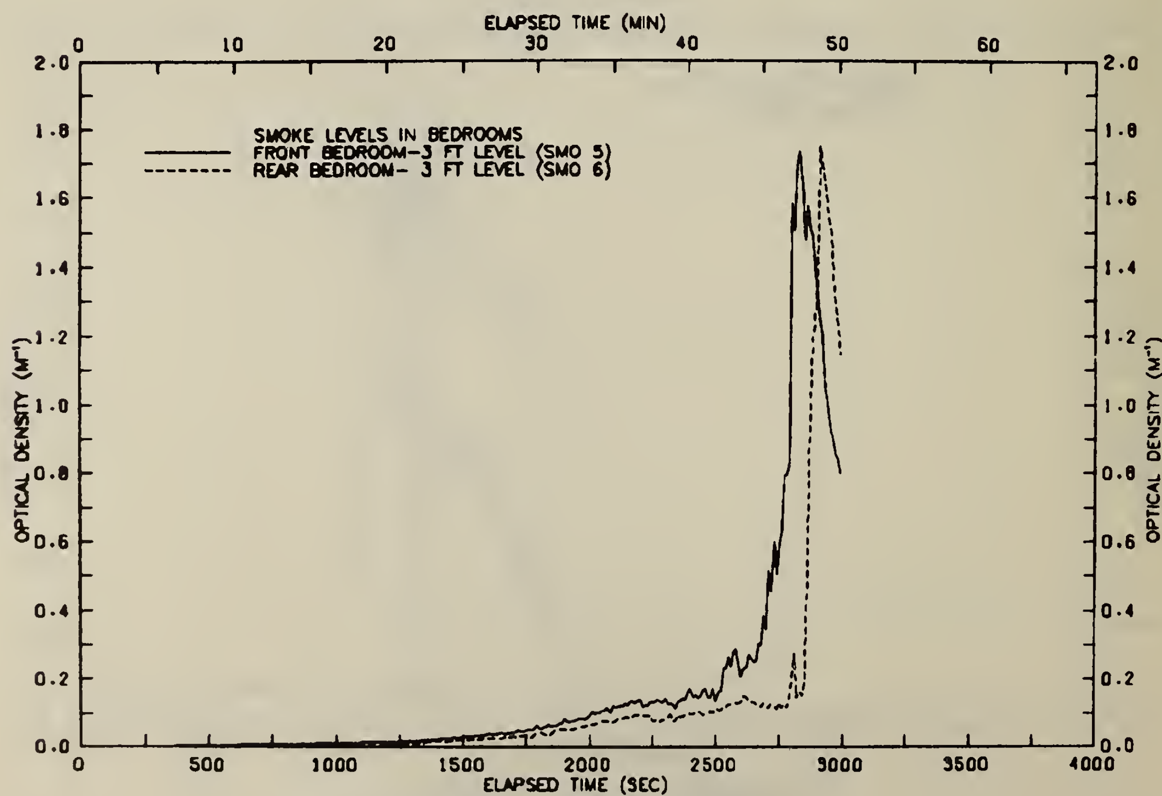

FIGURE B20 SMOKE LEVELS IN BEDROOMS-TEST 15

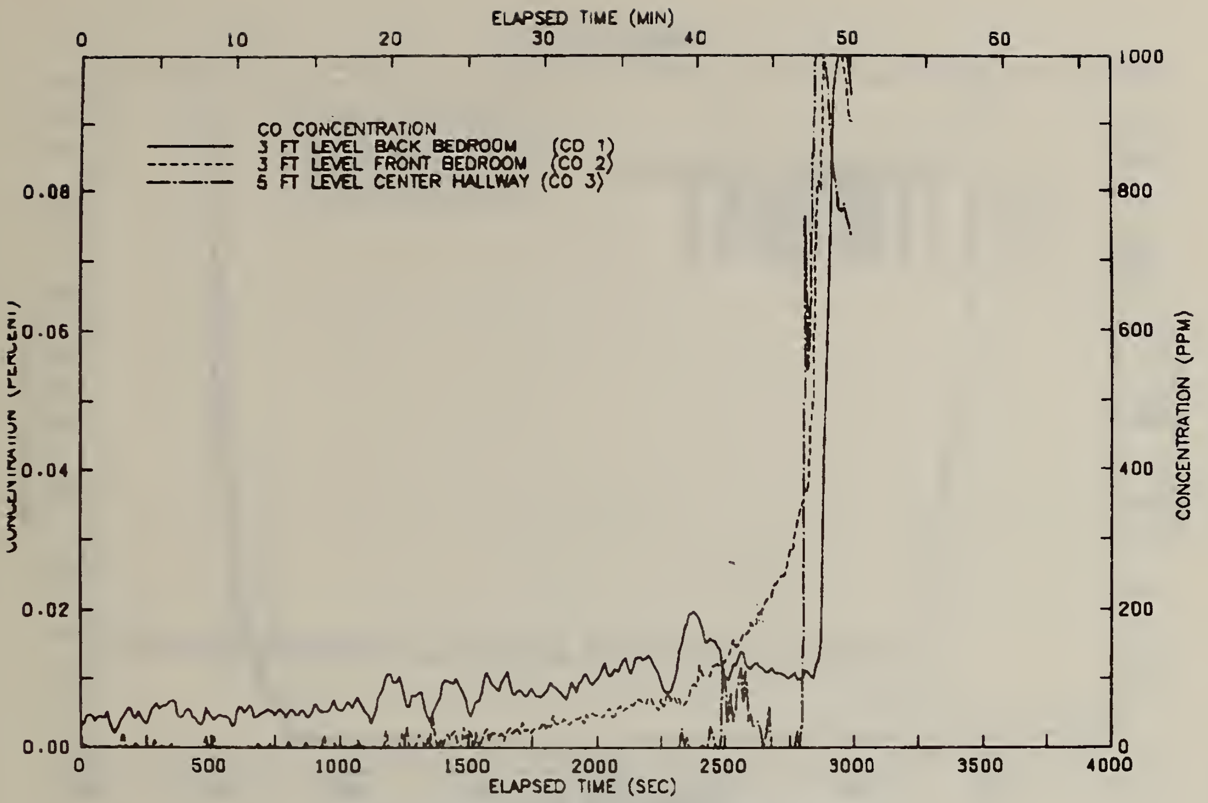

FIGURE B21 CARBON MONOXIDE CONCENTRATION-TEST 15

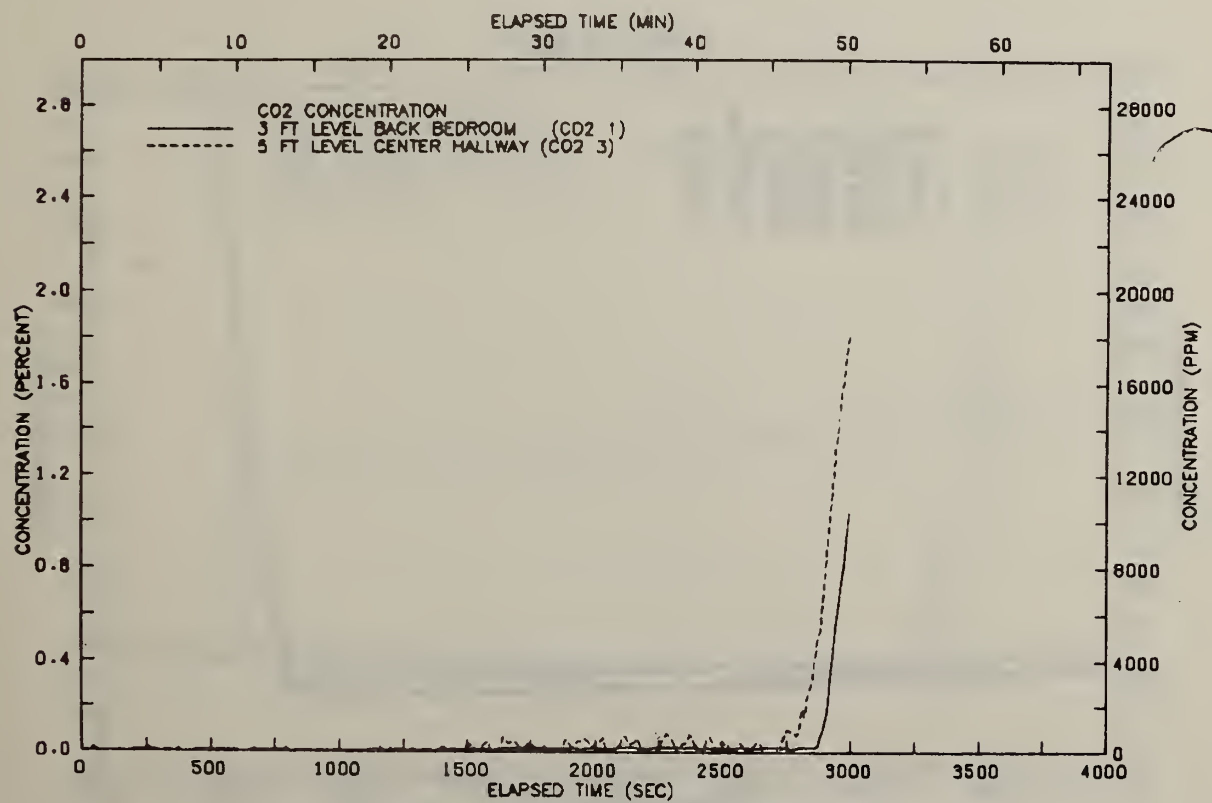

FIGURE B22 CARBON DIOXIDE CONCENTRATION-TEST 15

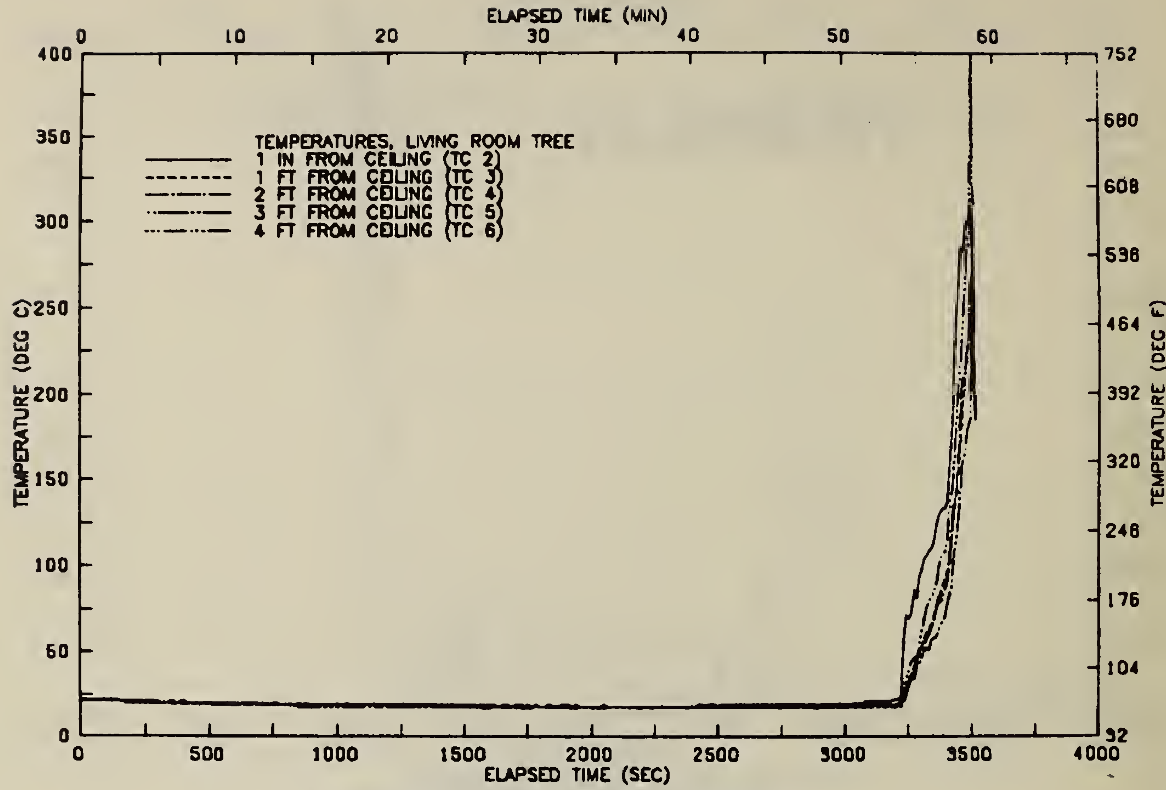

FIGURE B23 VERTICAL TEMP. PROFILE ABOVE CHAIR-TEST 16

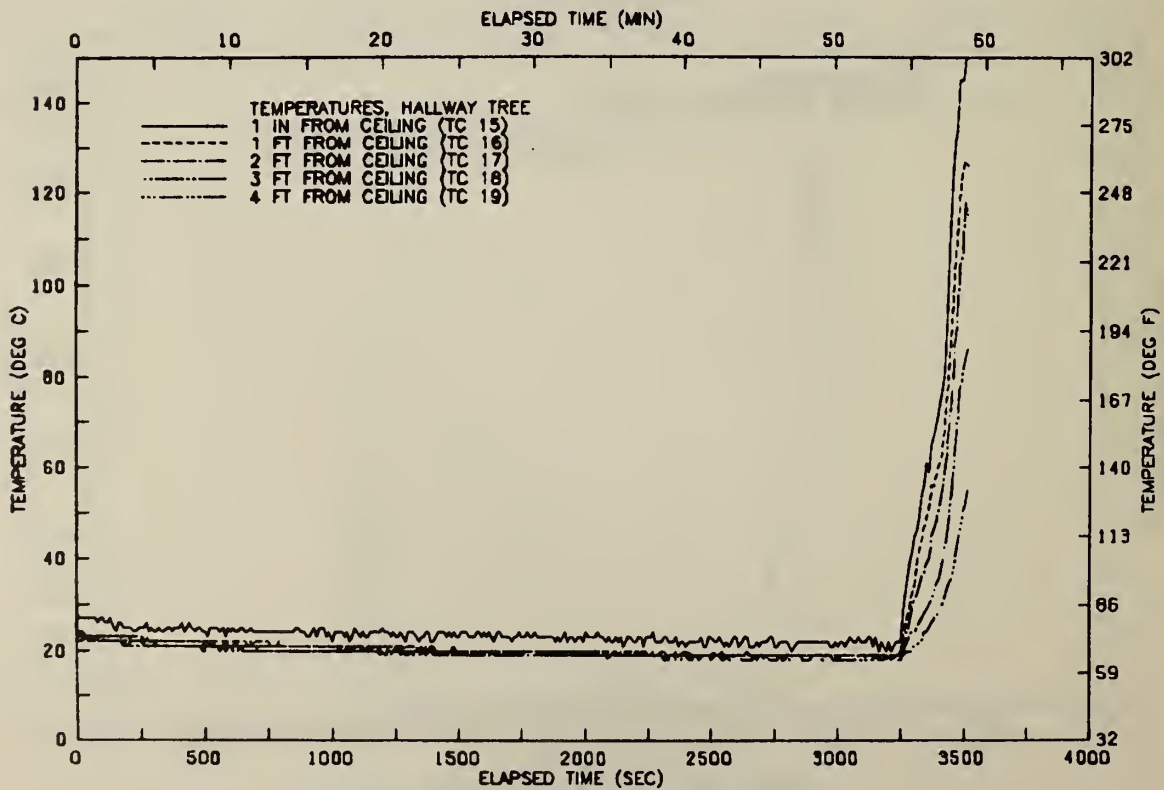

FIGURE B24 VERTICAL TEMP. PROFILE IN HALLWAY-TEST 16

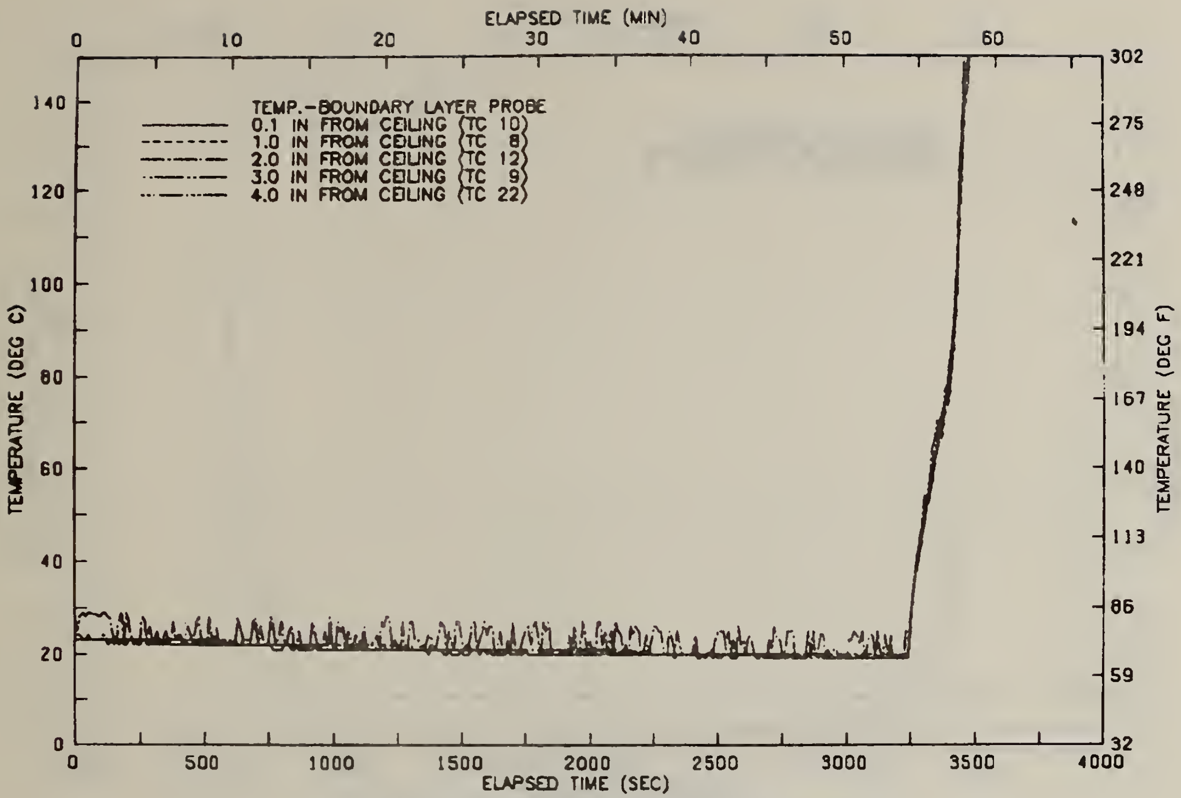

FIGURE B25 VERTICAL TEMP. PROFILE
CEILING BOUNDARY LAYER-TEST 16

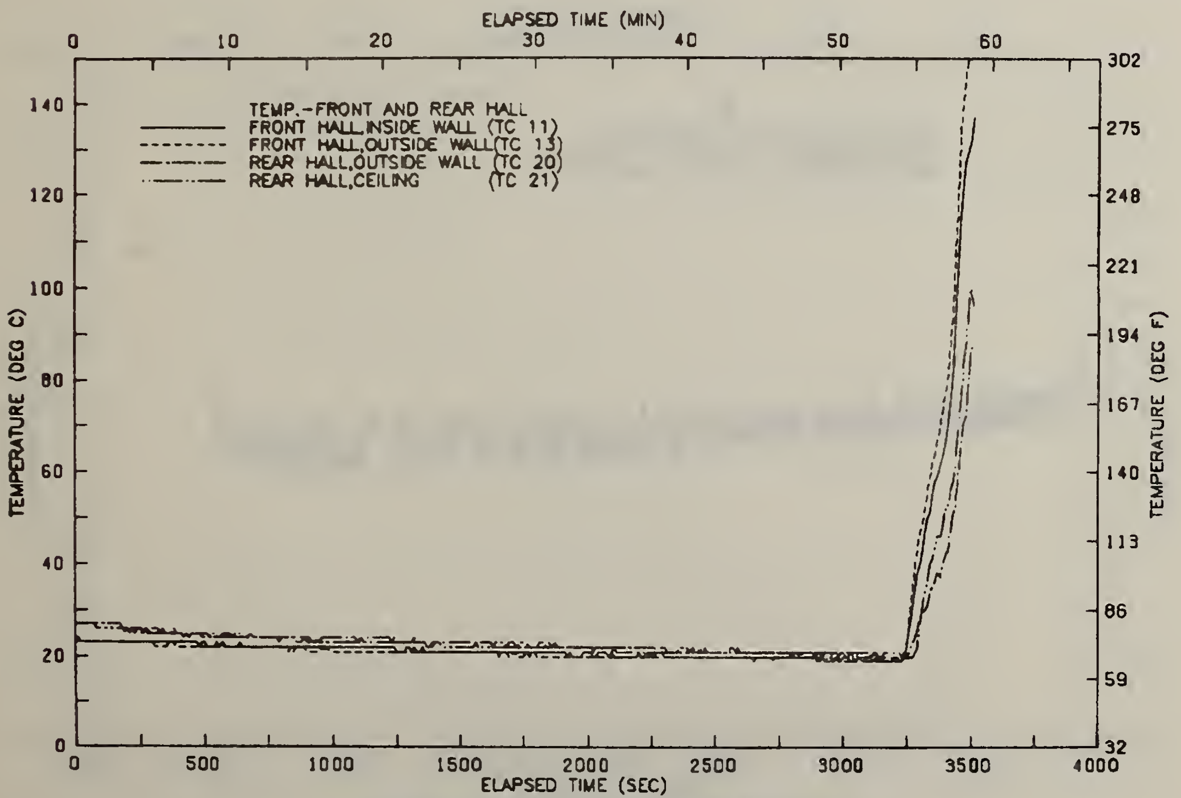

FIGURE B26 TEMP. IN HALLWAY
NEAR DETECTORS-TEST 16

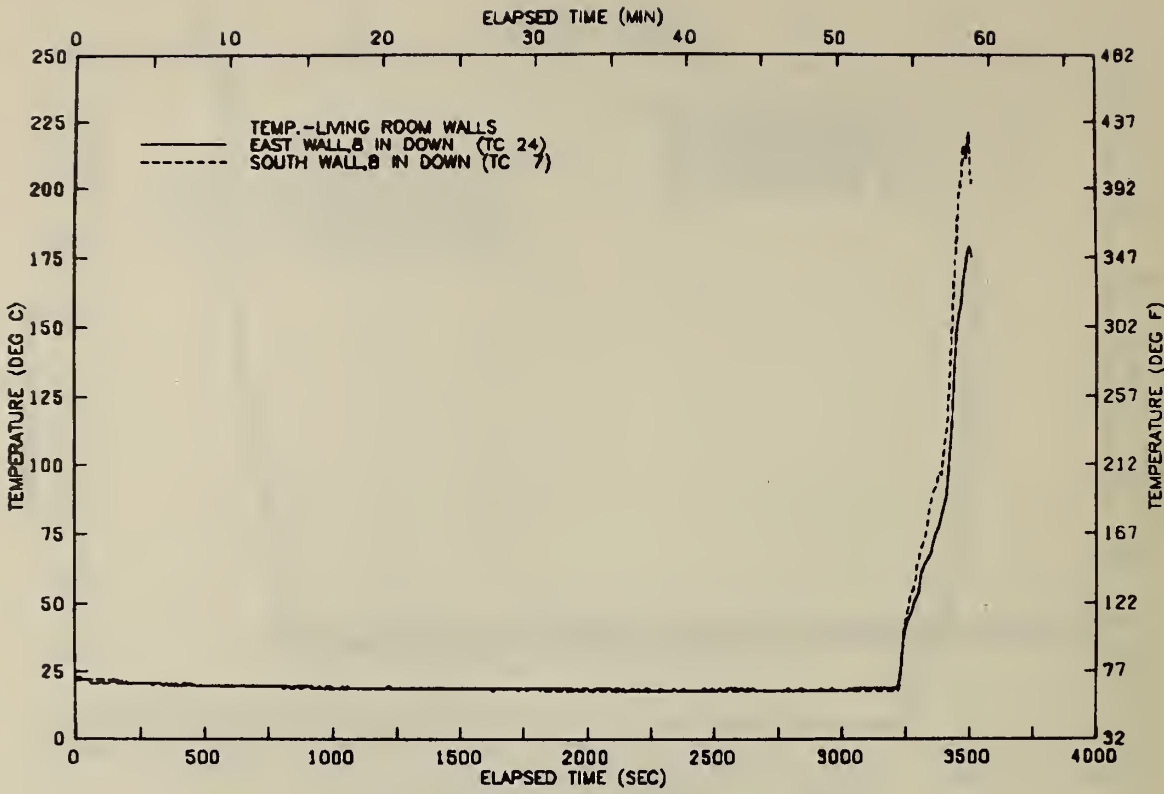

FIGURE B27 TEMPERATURE AT LIVING ROOM WALLS-TEST 16

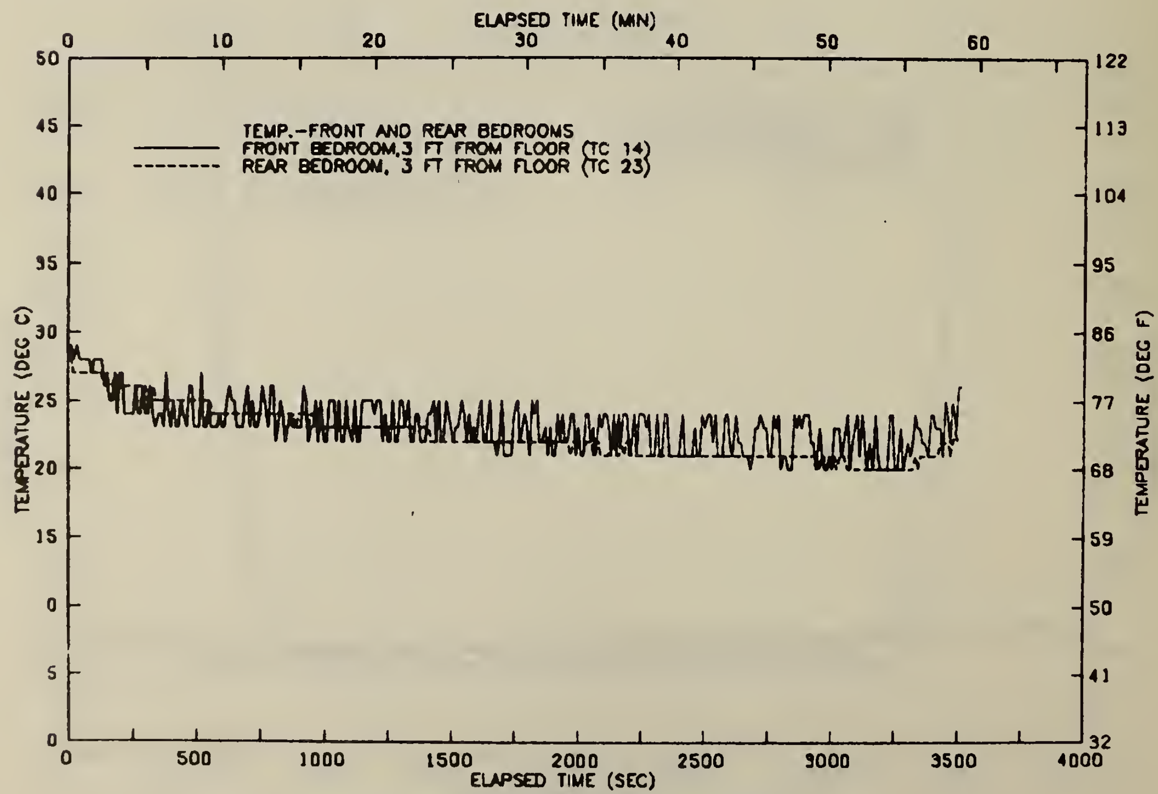

FIGURE B28 TEMP. IN FRONT AND REAR BEDROOMS-TEST 16

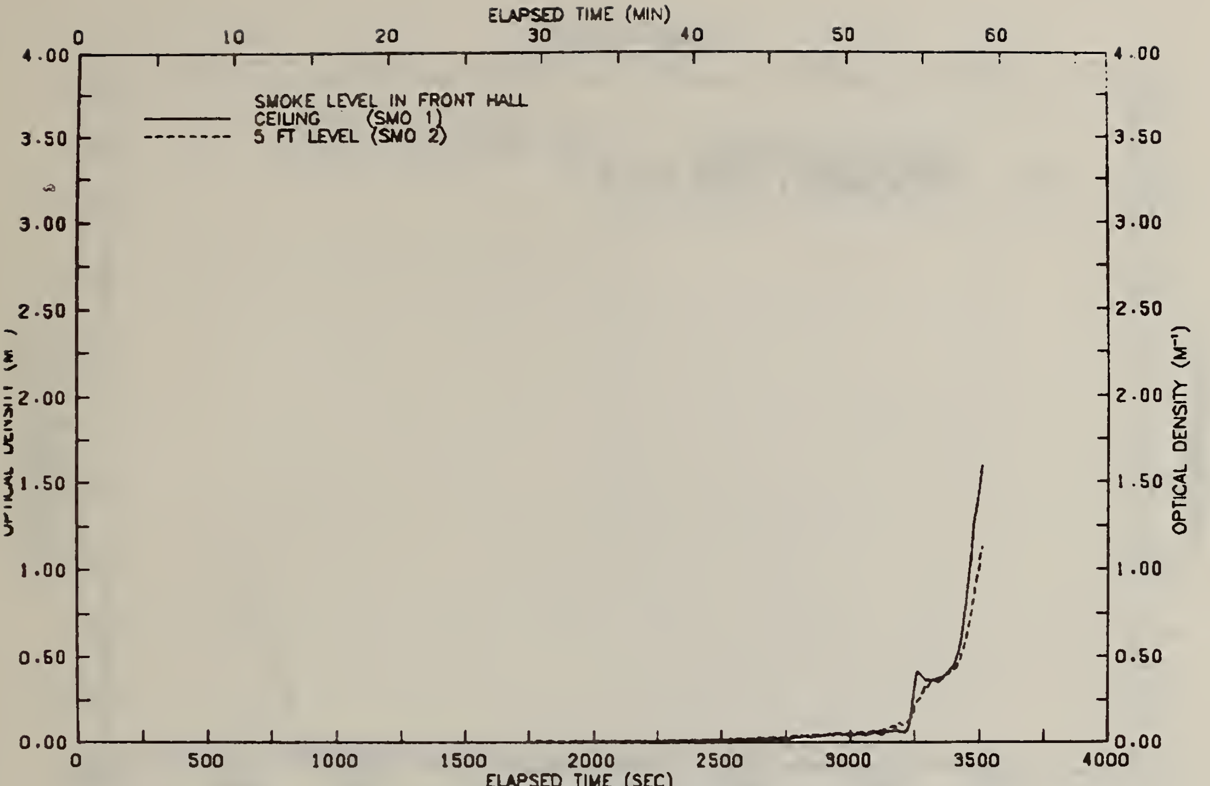

FIGURE B29 SMOKE LEVELS IN FRONT HALLWAY-TEST 16

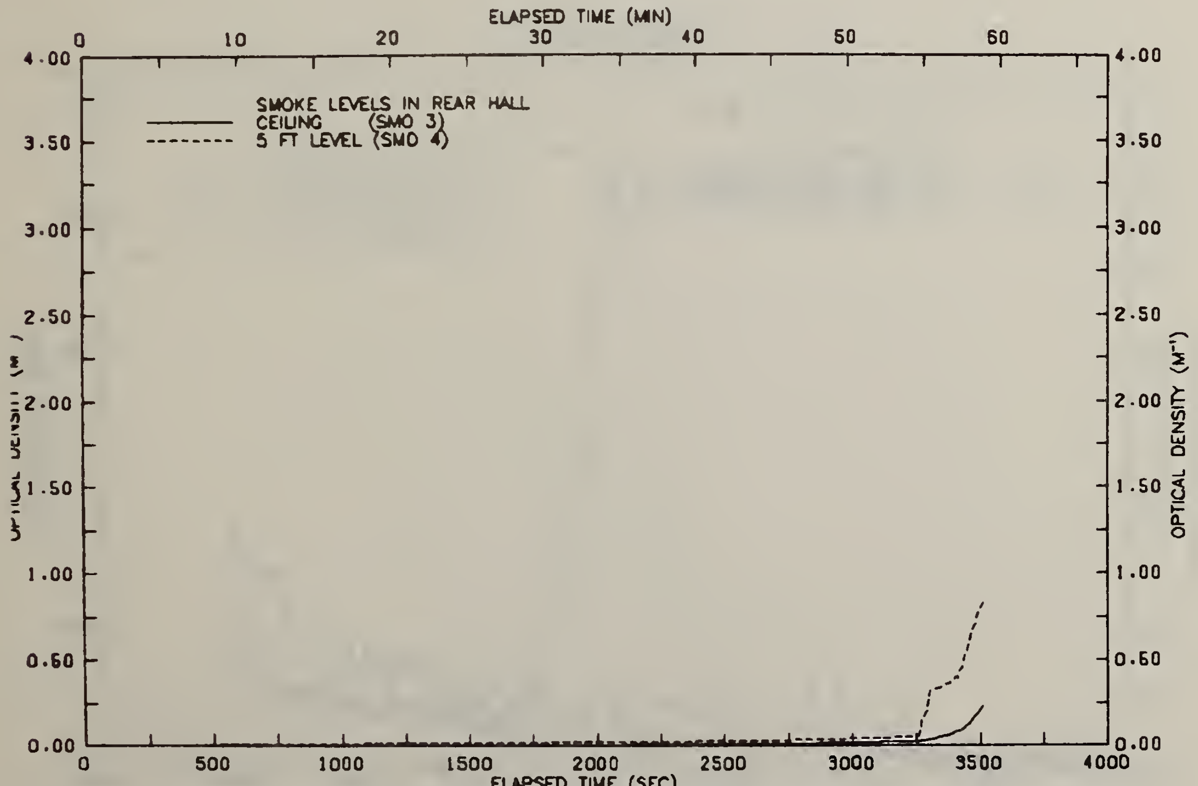

FIGURE B30 SMOKE LEVELS IN REAR HALLWAY-TEST 16

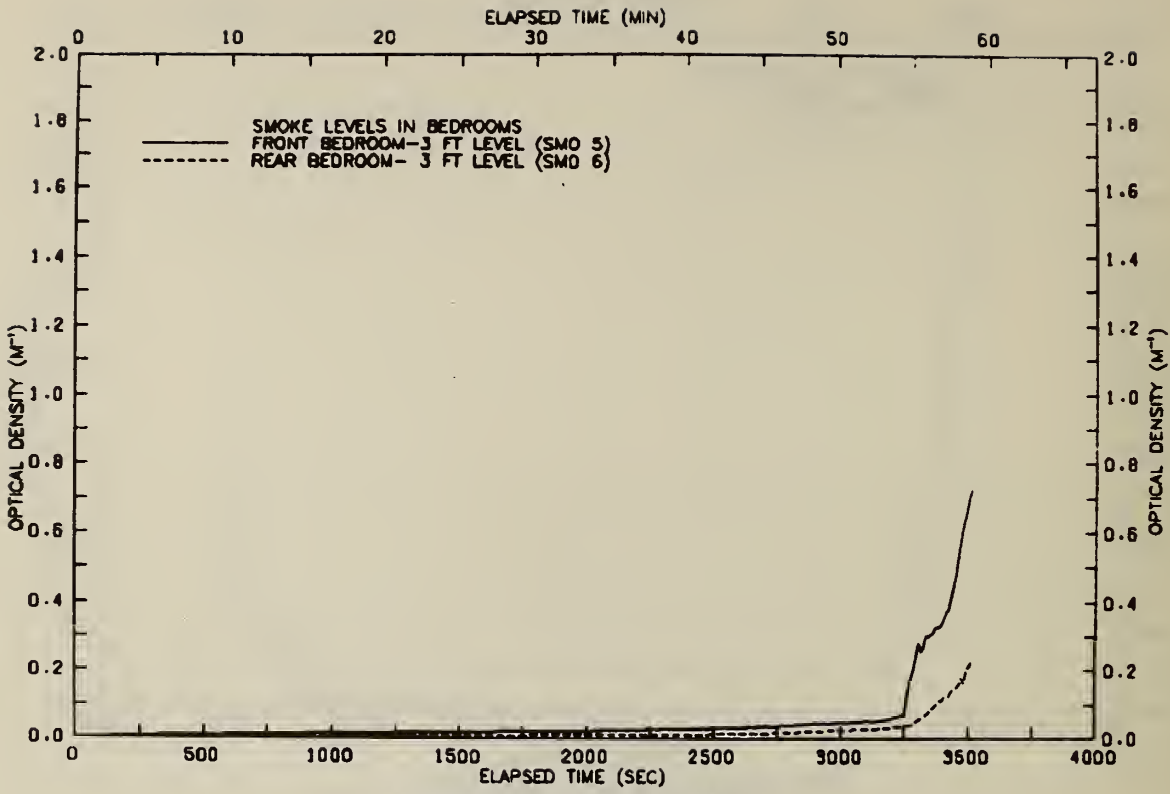

FIGURE B31 SMOKE LEVELS IN BEDROOMS-TEST 16

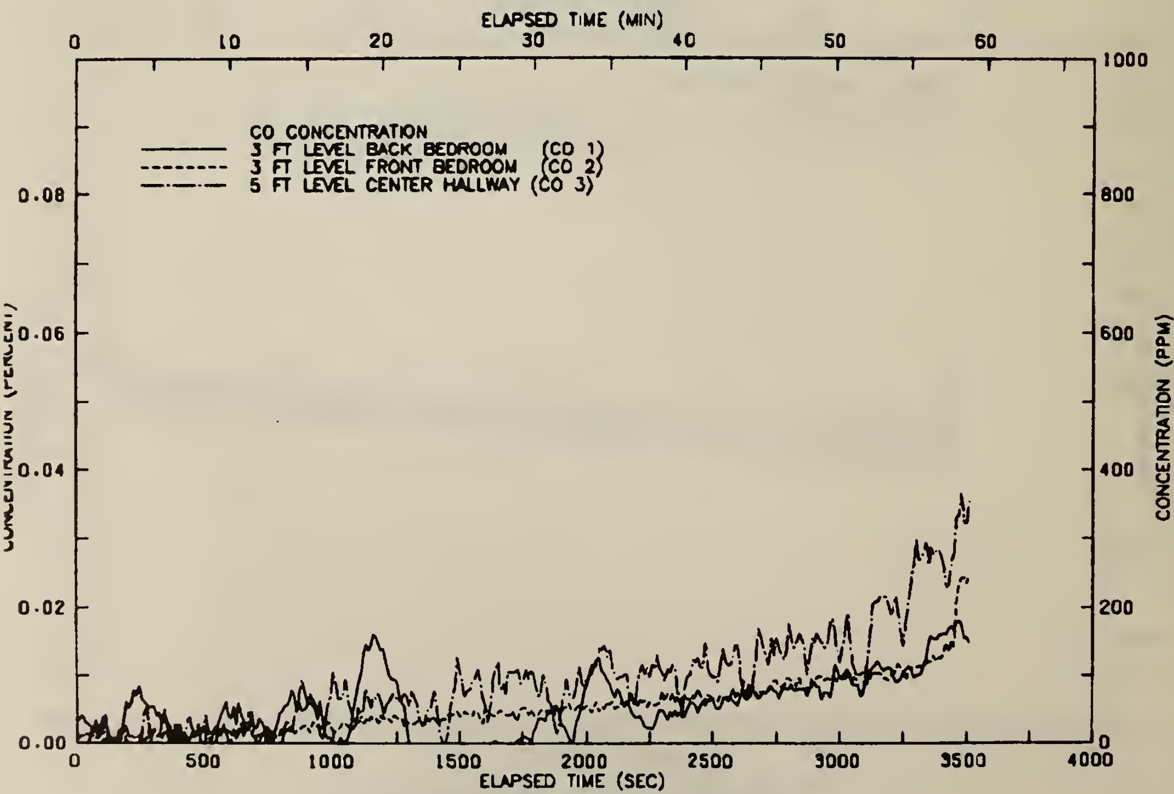

FIGURE B32 CARBON MONOXIDE CONCENTRATION-TEST 16

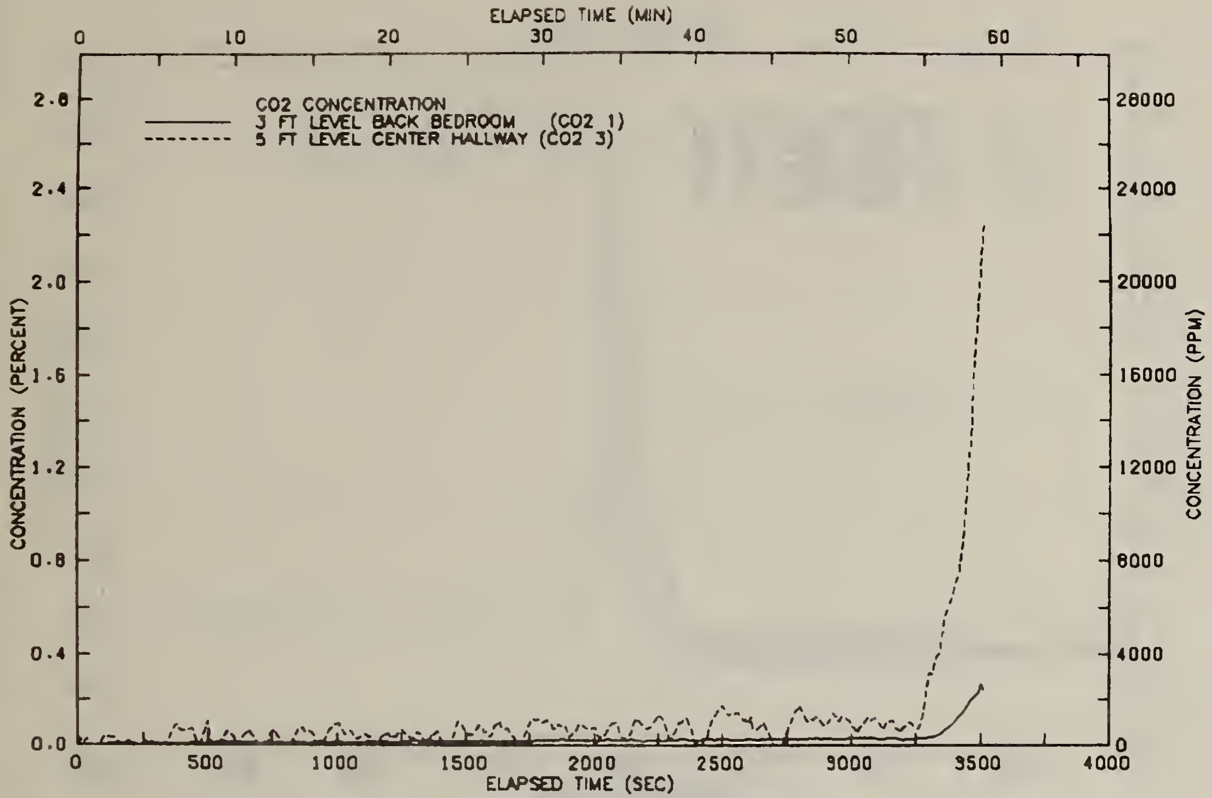

FIGURE B33 CARBON DIOXIDE CONCENTRATION-TEST 16

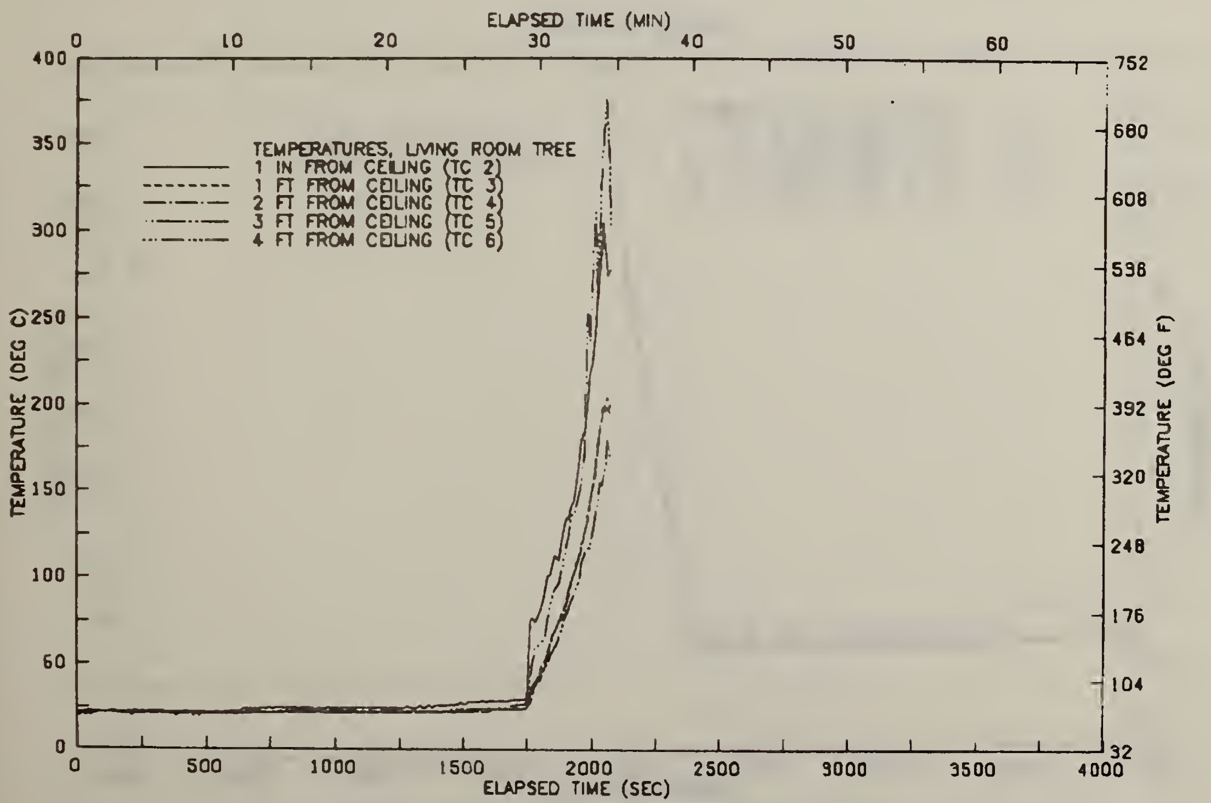

FIGURE B34 VERTICAL TEMP. PROFILE ABOVE CHAIR-TEST 17

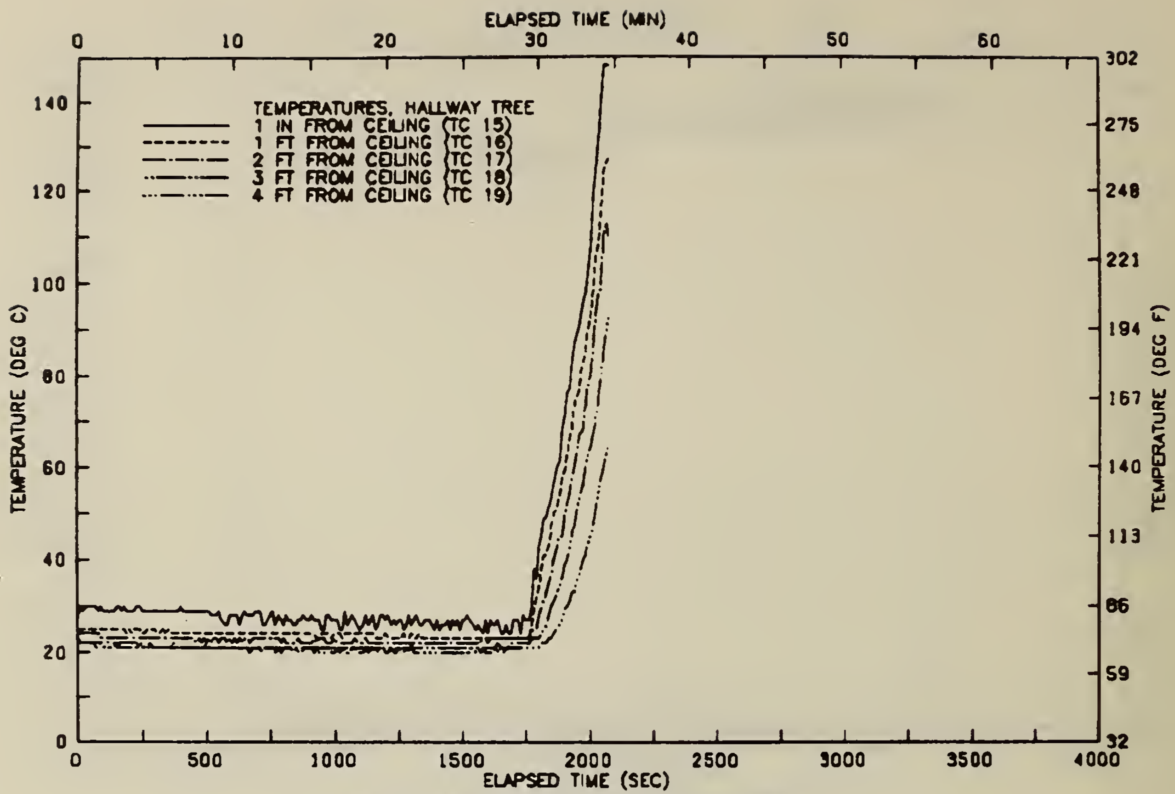

FIGURE B35 VERTICAL TEMP. PROFILE IN HALLWAY-TEST 17

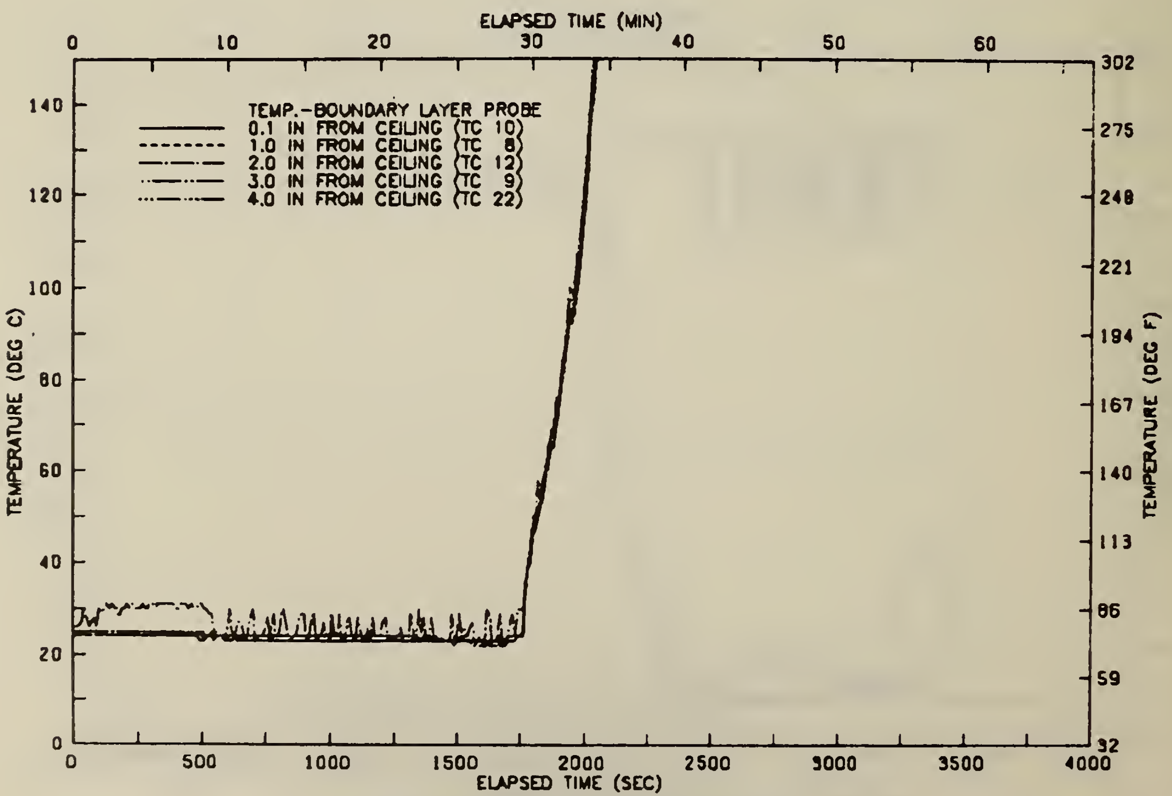

FIGURE B36 VERTICAL TEMP. PROFILE CEILING BOUNDARY LAYER-TEST 17

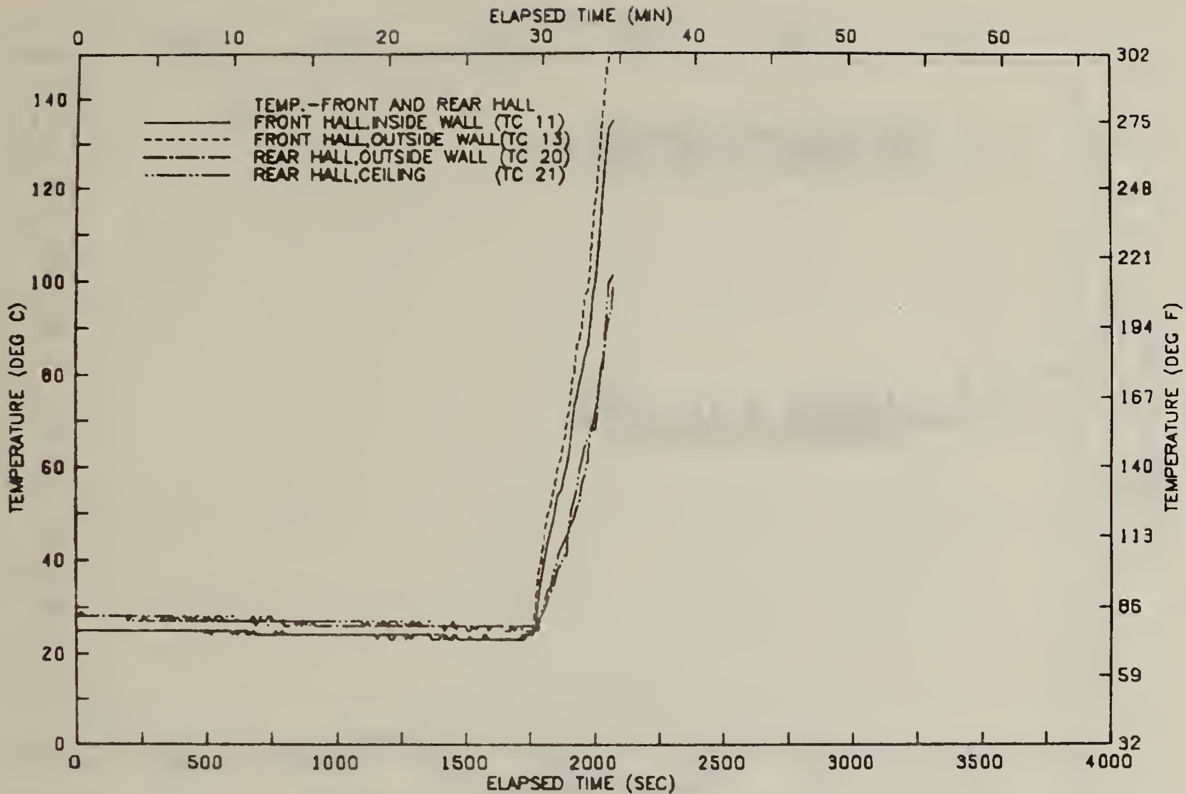

FIGURE B37 TEMP. IN HALLWAY NEAR DETECTORS-TEST 17

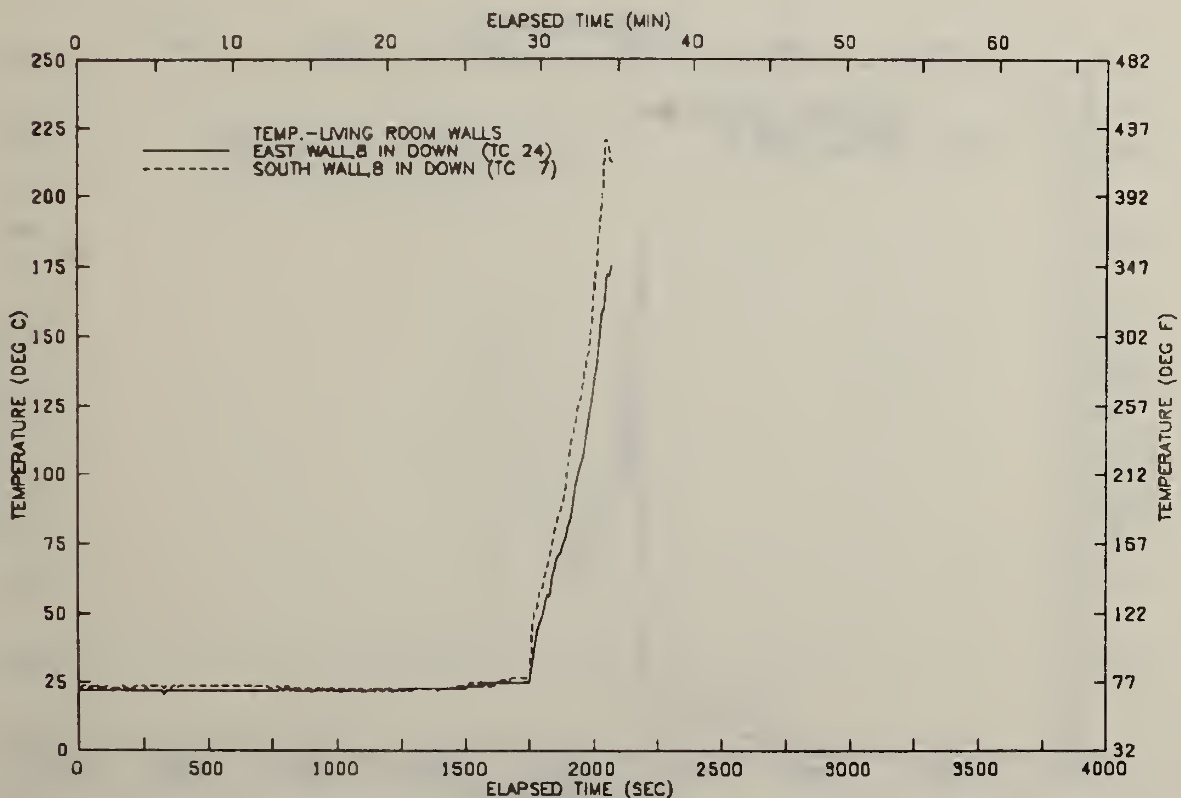

FIGURE B38 TEMPERATURE AT LIVING ROOM WALLS-TEST 17

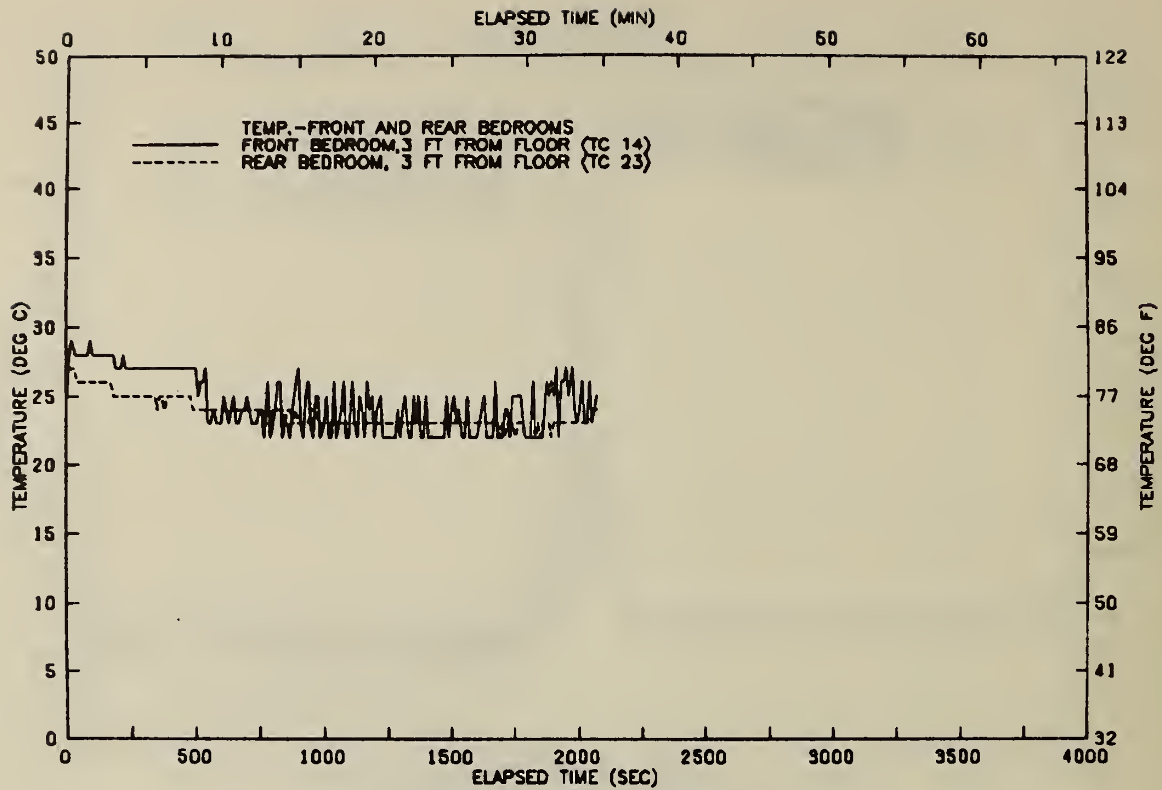

FIGURE B39 TEMP. IN FRONT AND REAR BEDROOMS-TEST 17

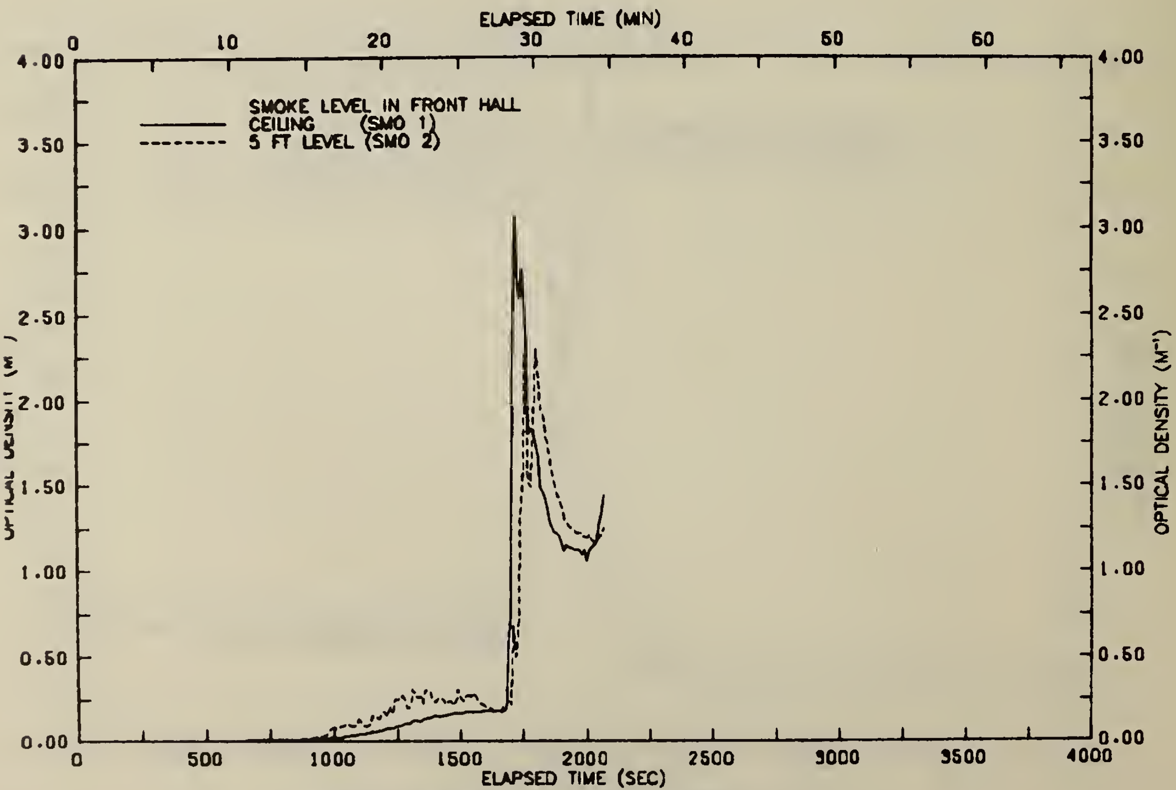

FIGURE B40 SMOKE LEVELS IN FRONT HALLWAY-TEST 17

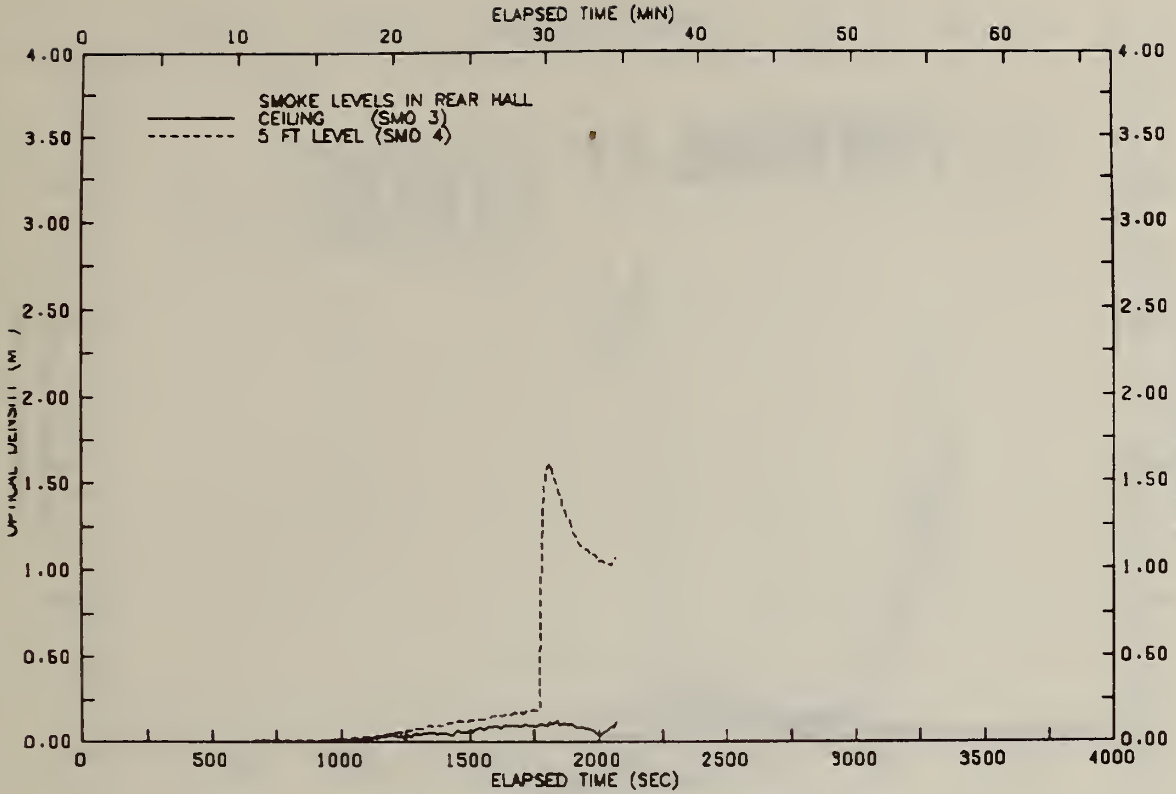

FIGURE B41 SMOKE LEVELS IN REAR HALLWAY-TEST 17

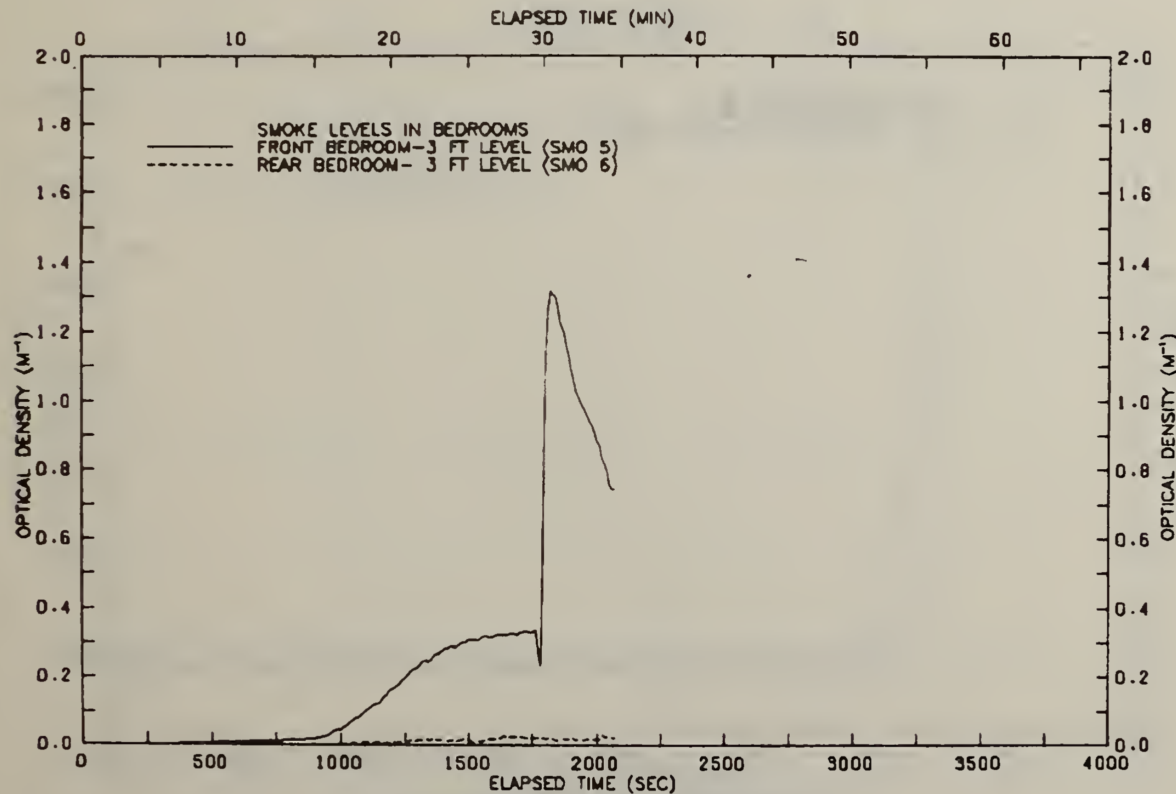

FIGURE B42 SMOKE LEVELS IN BEDROOMS-TEST 17

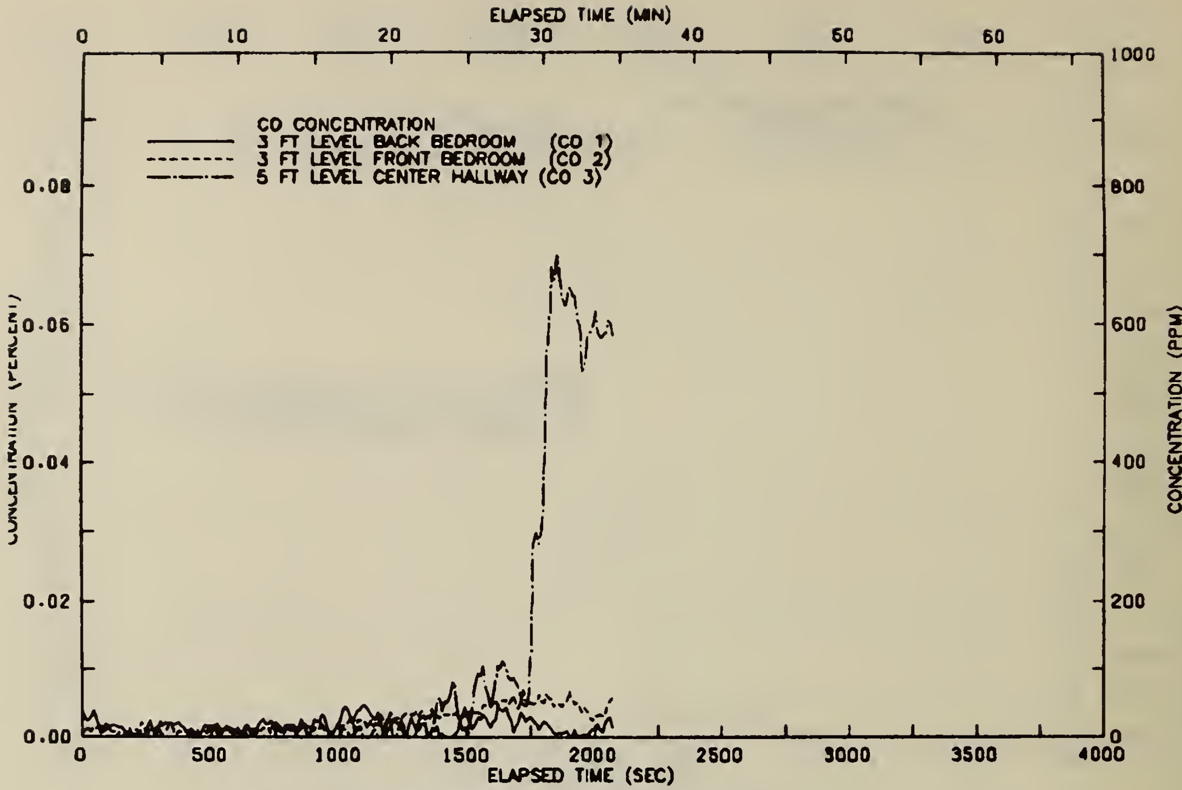

FIGURE B43 CARBON MONOXIDE
CONCENTRATION–TEST 17

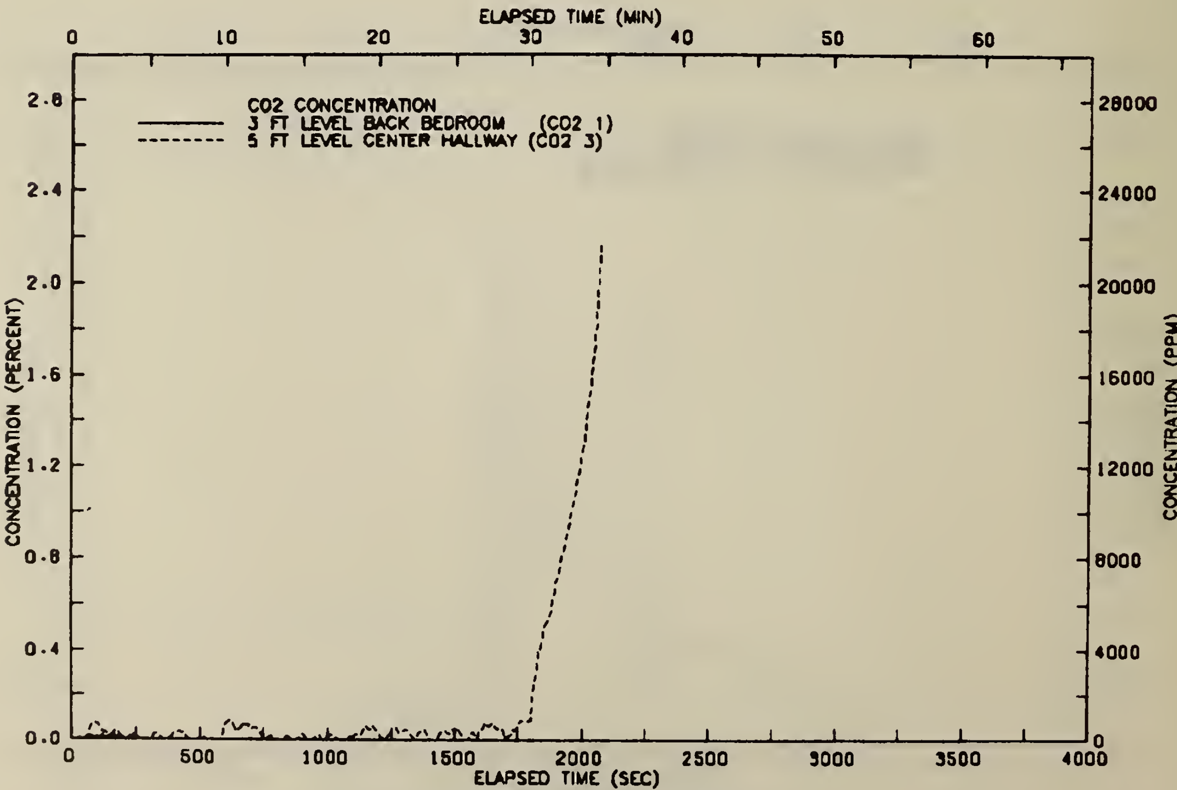

FIGURE B44 CARBON DIOXIDE
CONCENTRATION–TEST 17

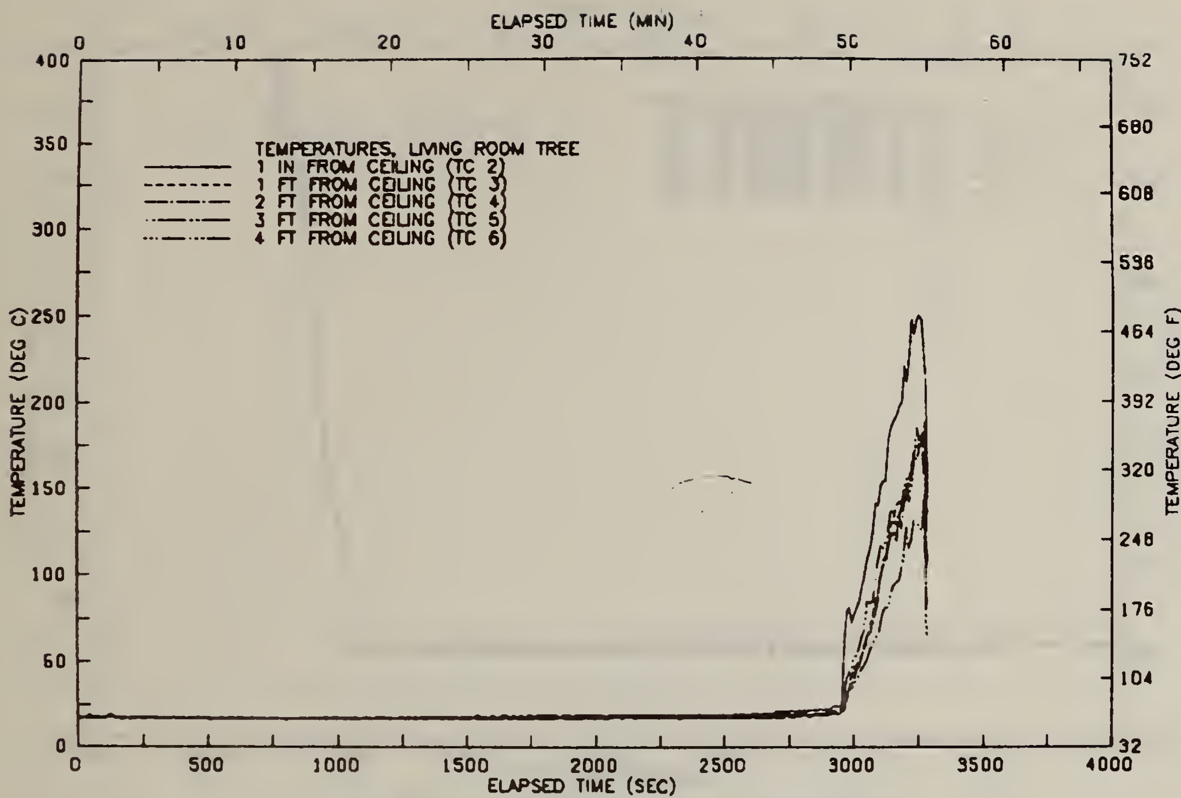

FIGURE B45 VERTICAL TEMP. PROFILE ABOVE CHAIR-TEST 18

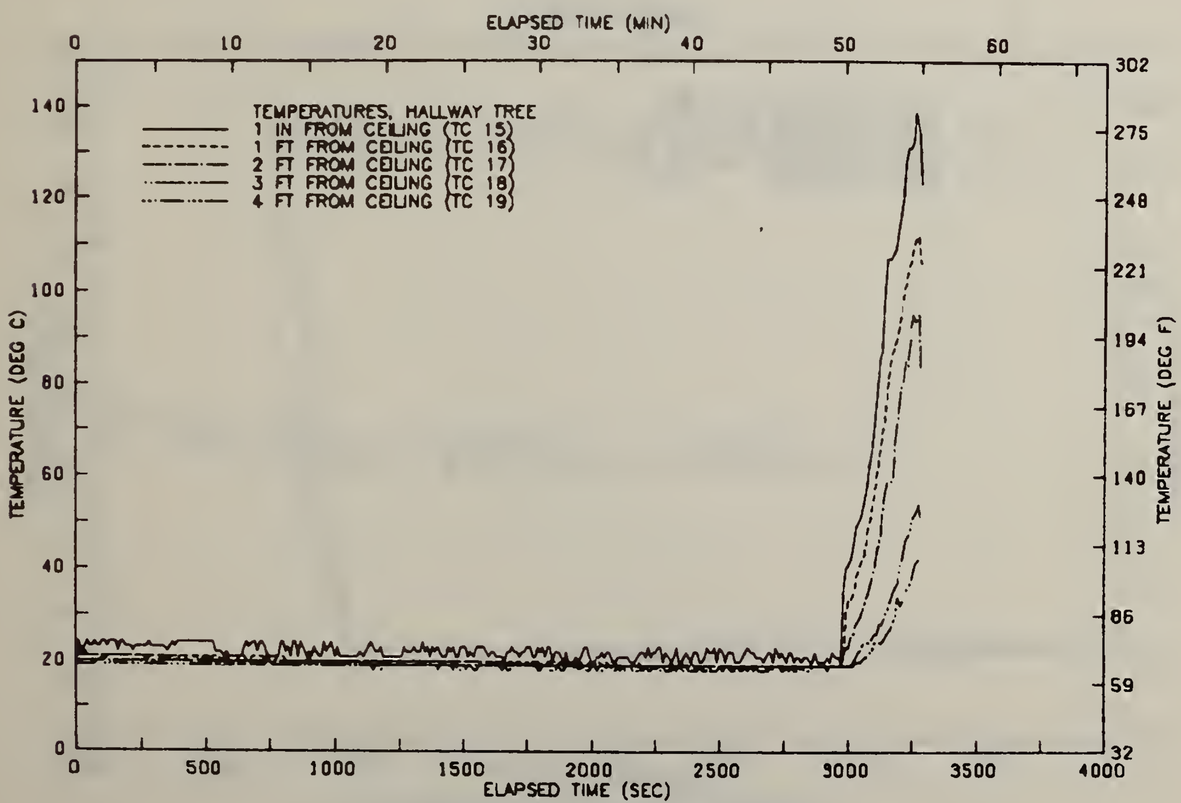

FIGURE B46 VERTICAL TEMP. PROFILE IN HALLWAY-TEST 18

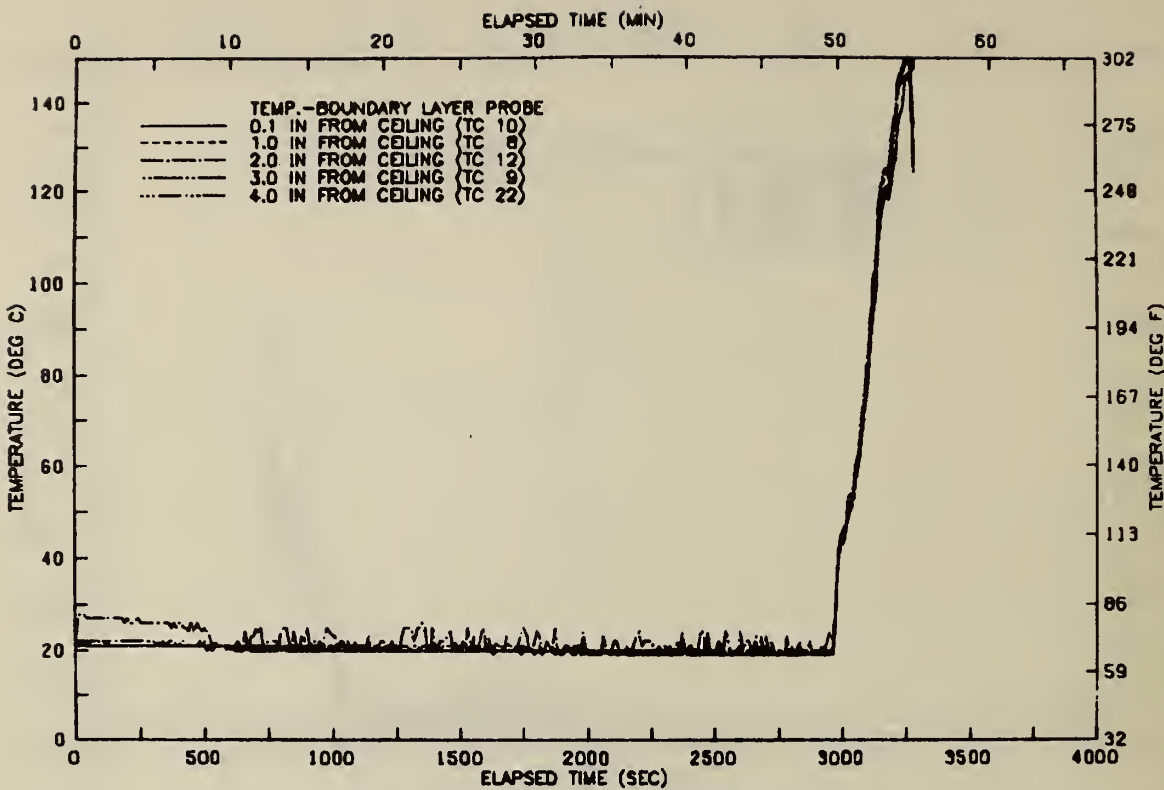

FIGURE B47 VERTICAL TEMP. PROFILE
CEILING BOUNDARY LAYER-TEST 18

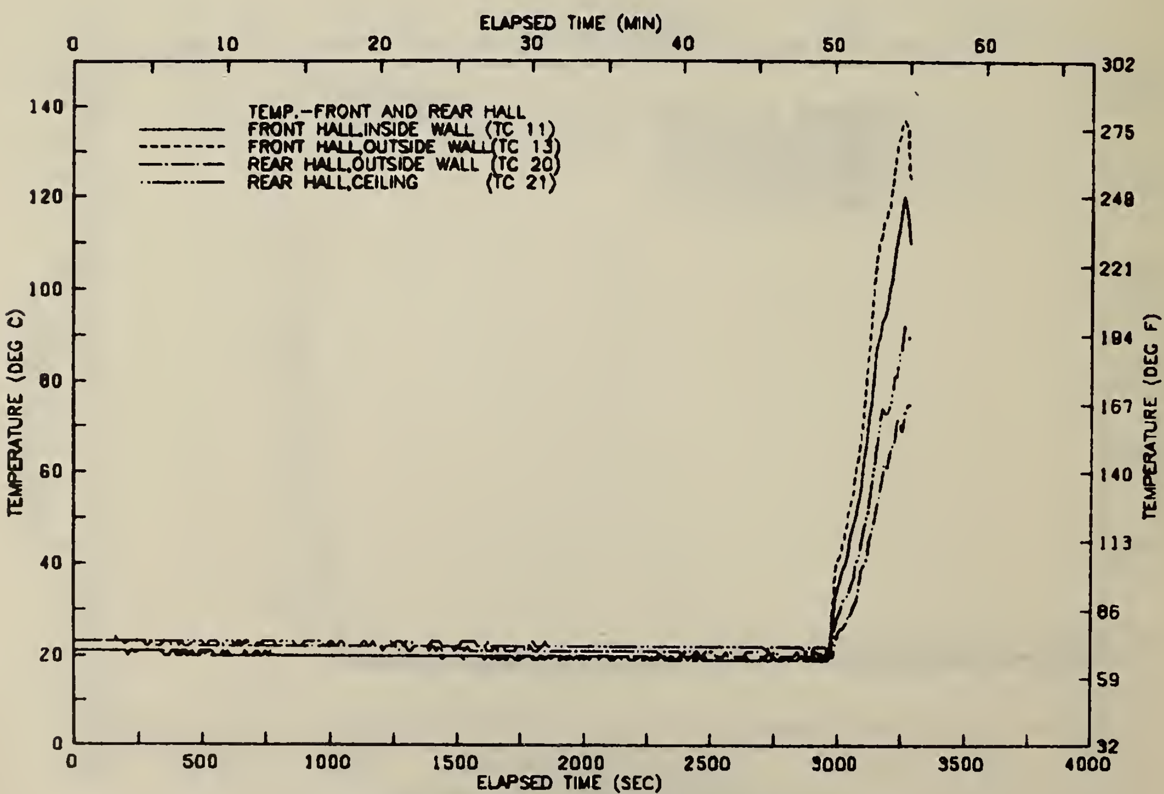

FIGURE B48 TEMP. IN HALLWAY
NEAR DETECTORS-TEST 18

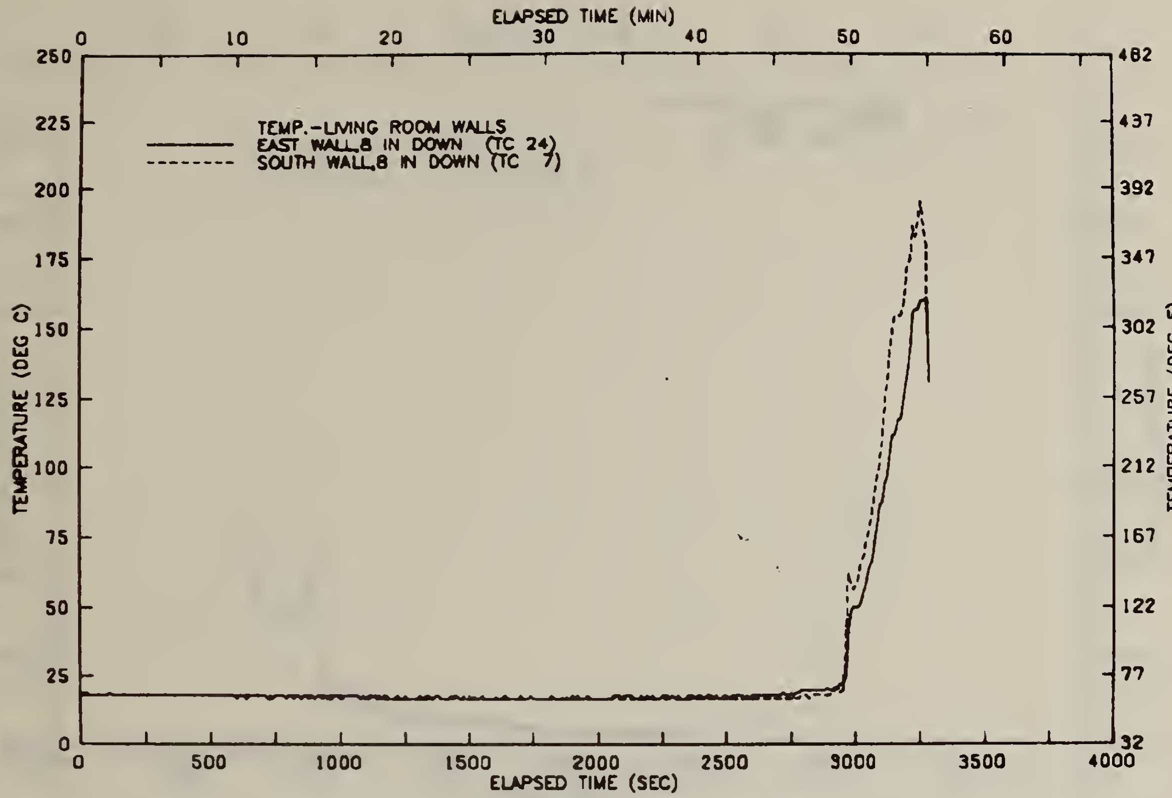

FIGURE B49 TEMPERATURE AT LIVING ROOM WALLS-TEST 18

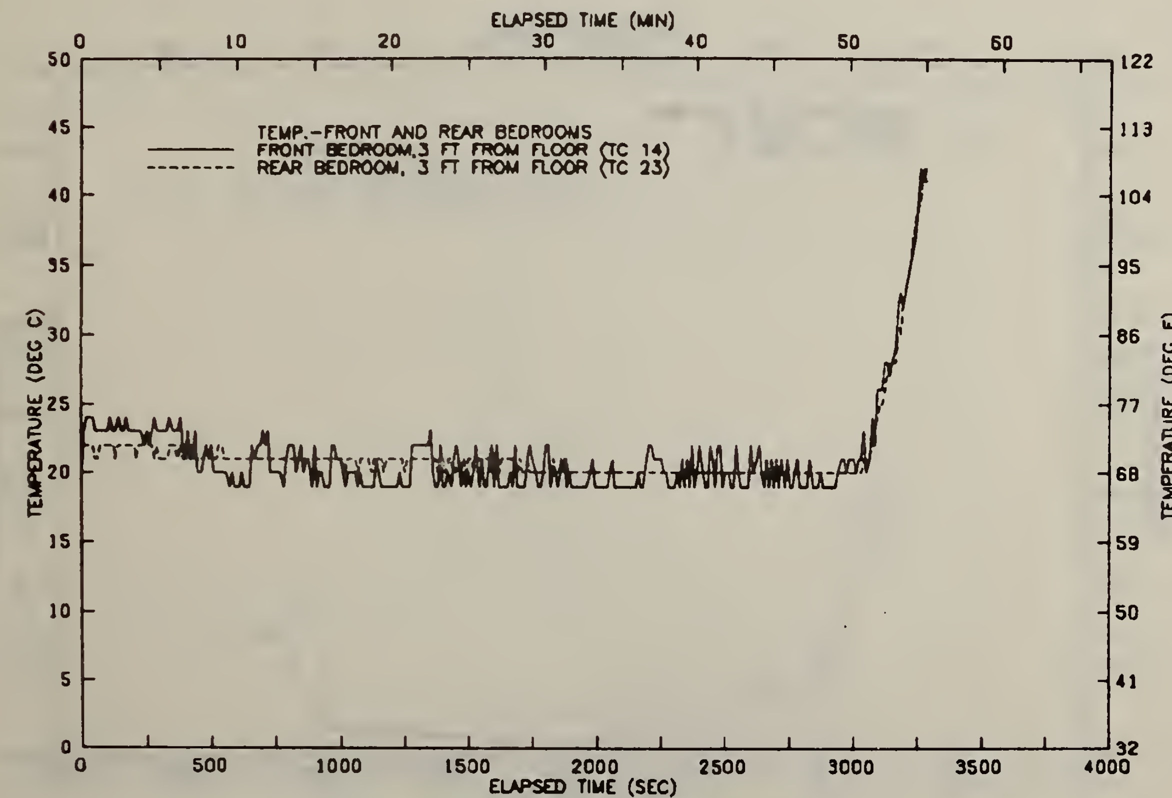

FIGURE B50 TEMP. IN FRONT AND REAR BEDROOMS-TEST 18

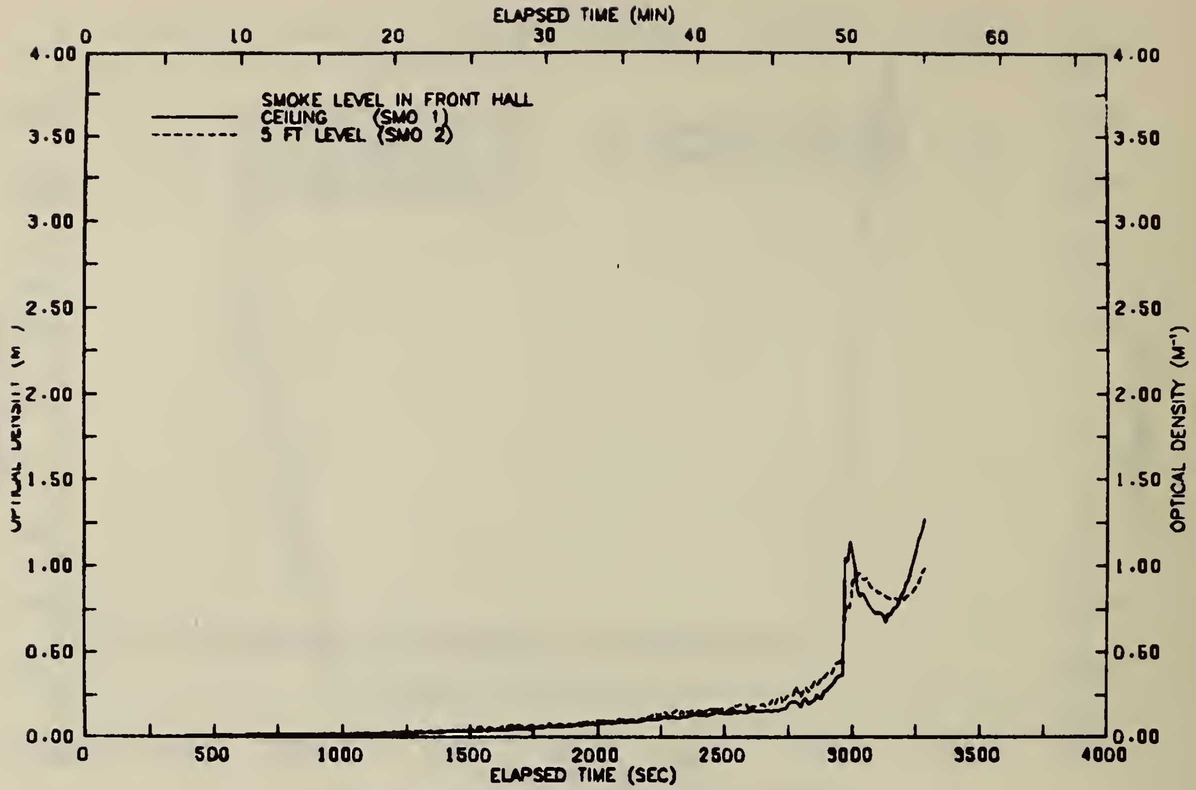

FIGURE B51 SMOKE LEVELS IN FRONT HALLWAY-TEST 18

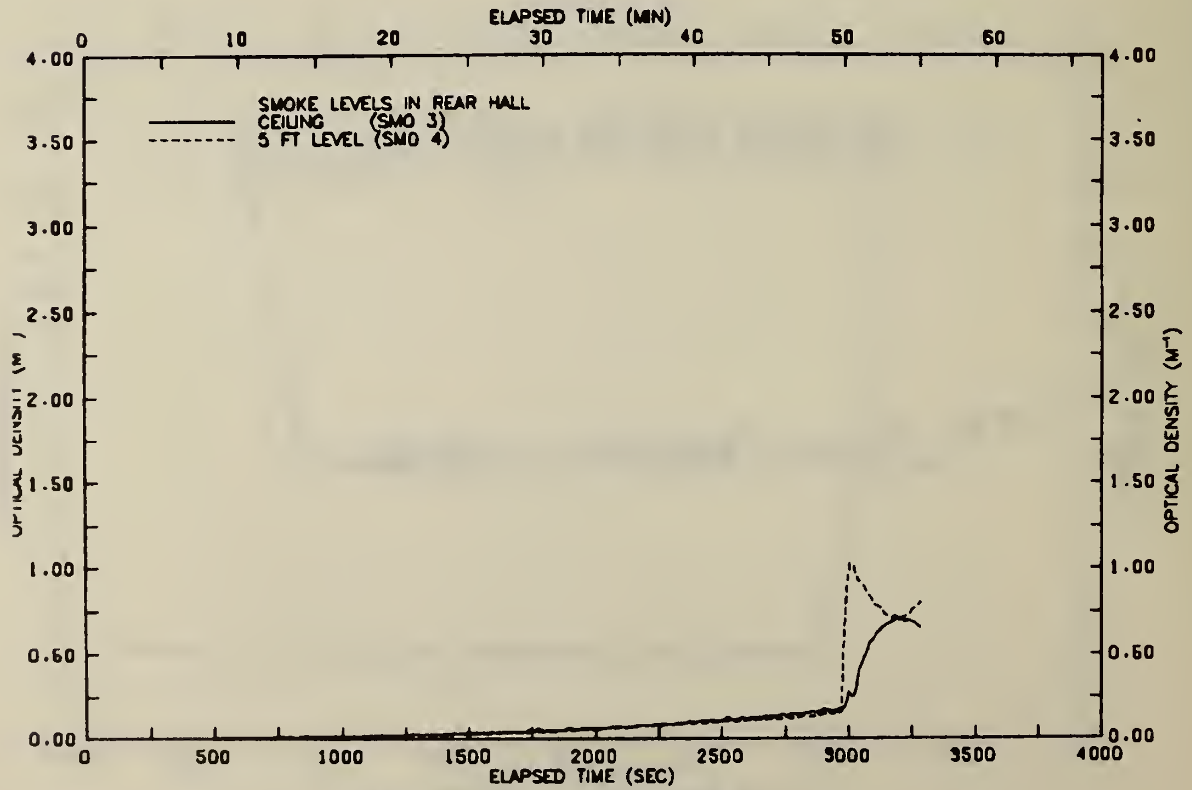

FIGURE B52 SMOKE LEVELS IN REAR HALLWAY-TEST 18

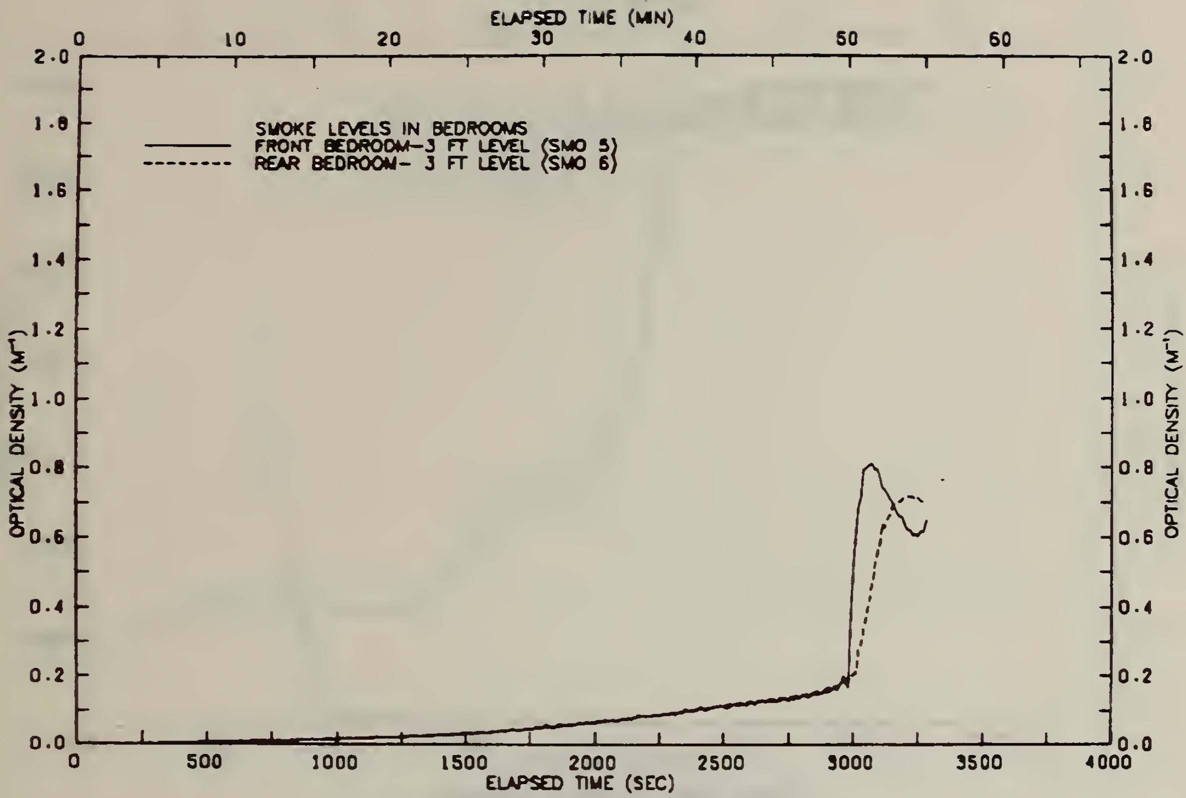

FIGURE B53 SMOKE LEVELS IN BEDROOMS-TEST 18

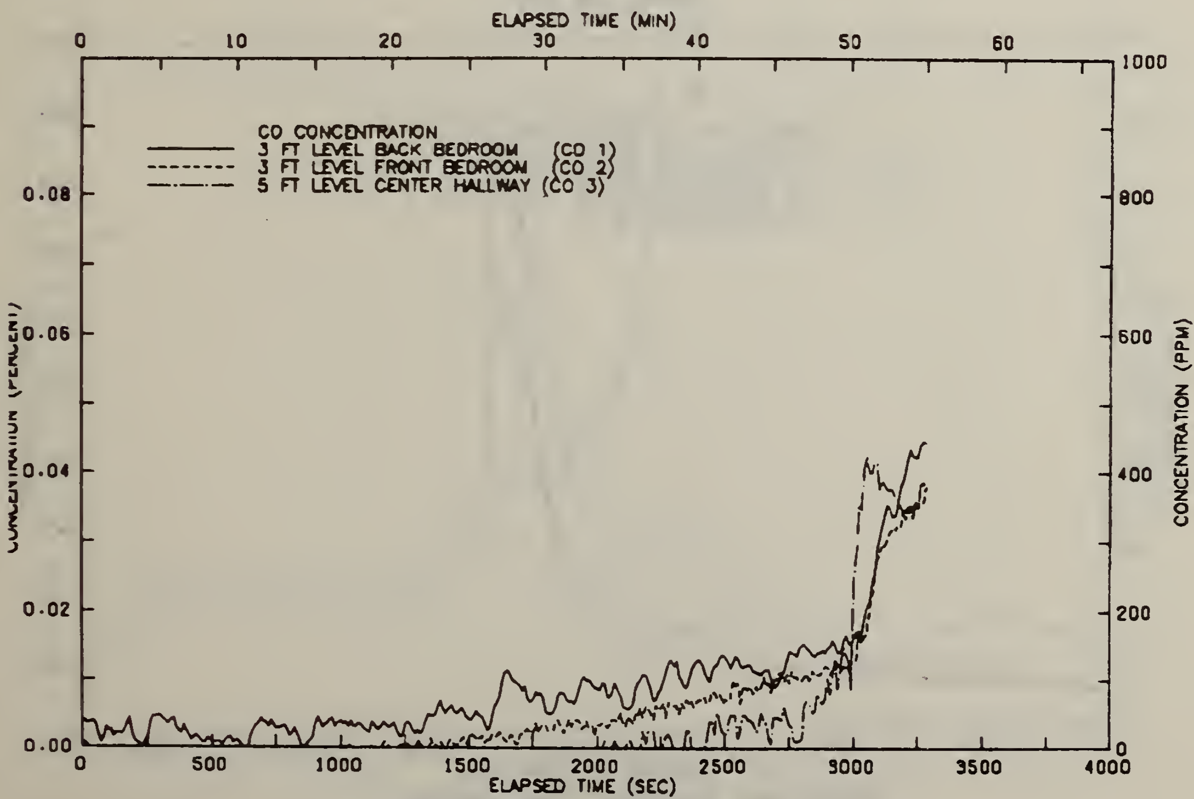

FIGURE B54 CARBON MONOXIDE CONCENTRATION-TEST 18

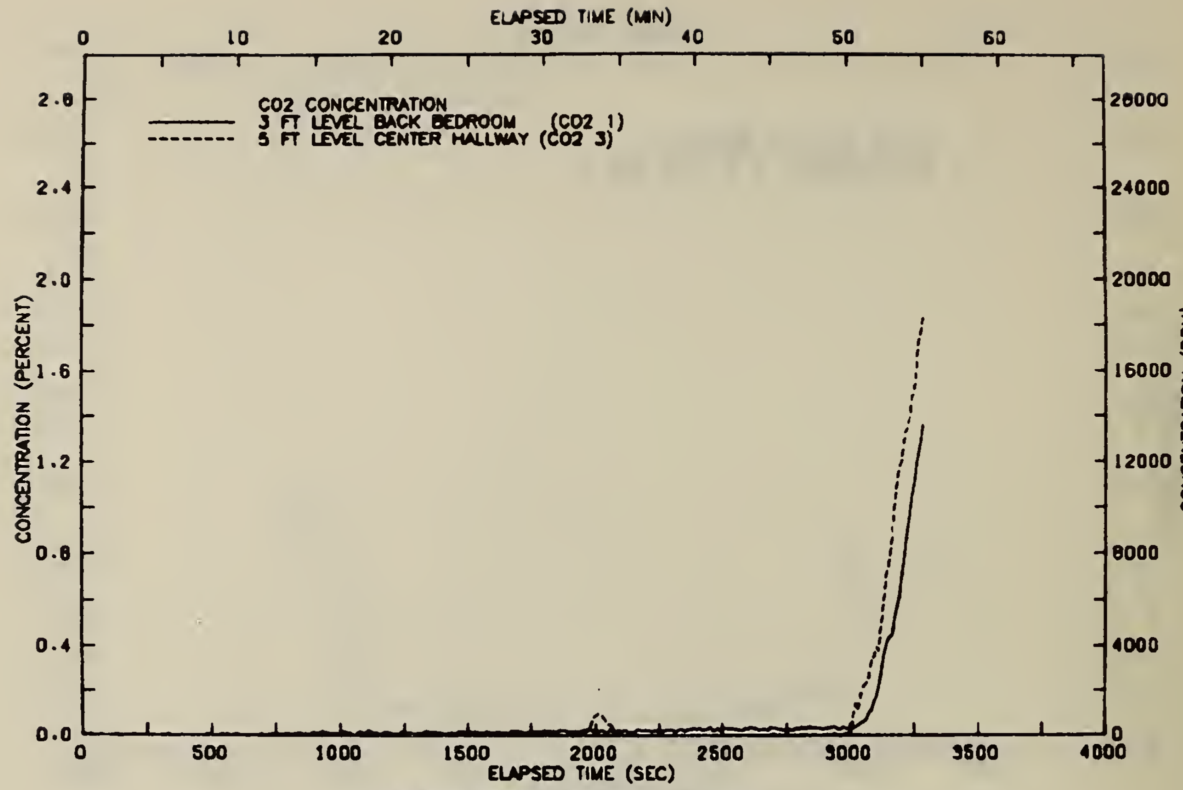

FIGURE B55 CARBON DIOXIDE CONCENTRATION-TEST 18

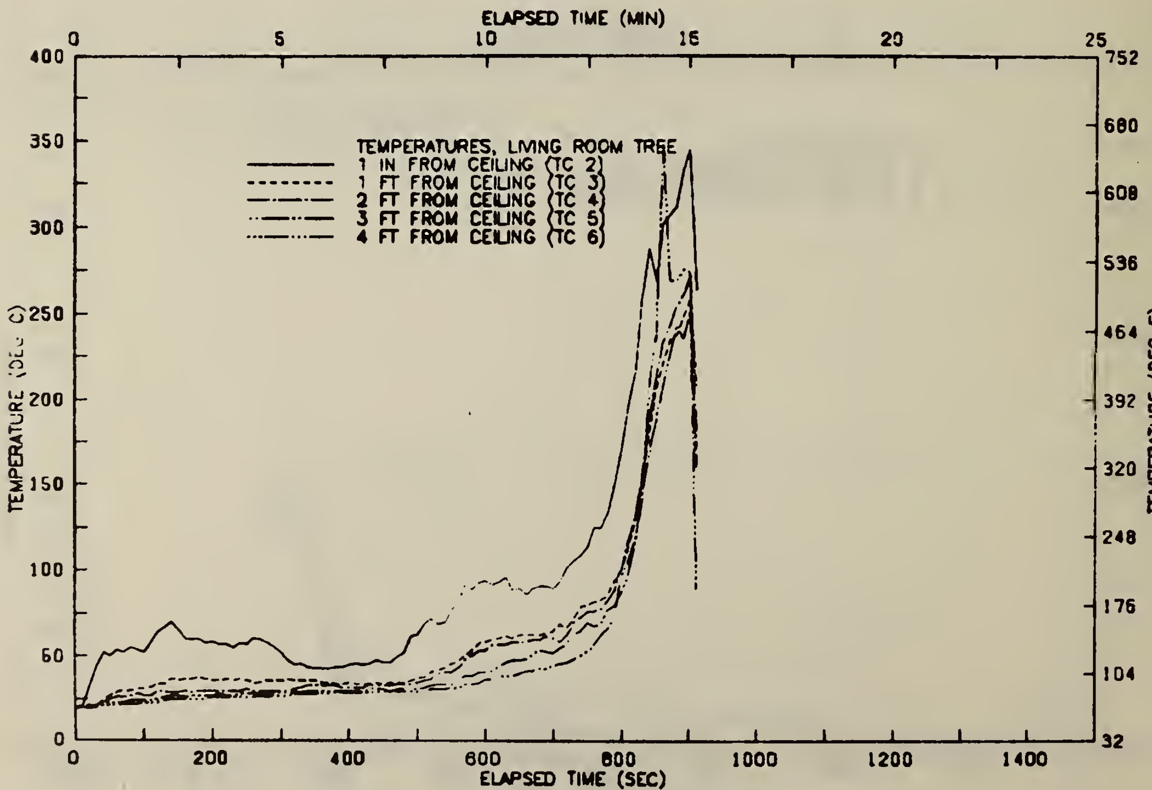

FIGURE B56 VERTICAL TEMP. PROFILE ABOVE CHAIR-TEST 19

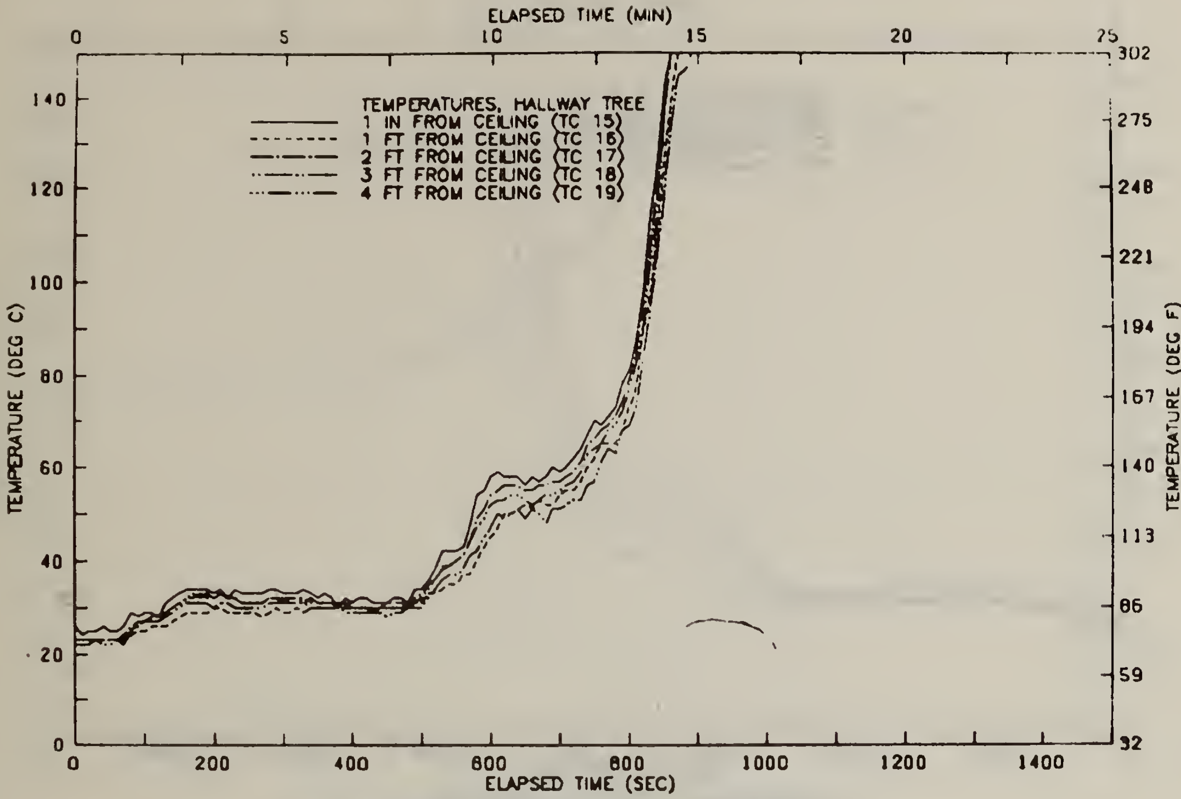

FIGURE B57 VERTICAL TEMP. PROFILE
IN HALLWAY-TEST 19

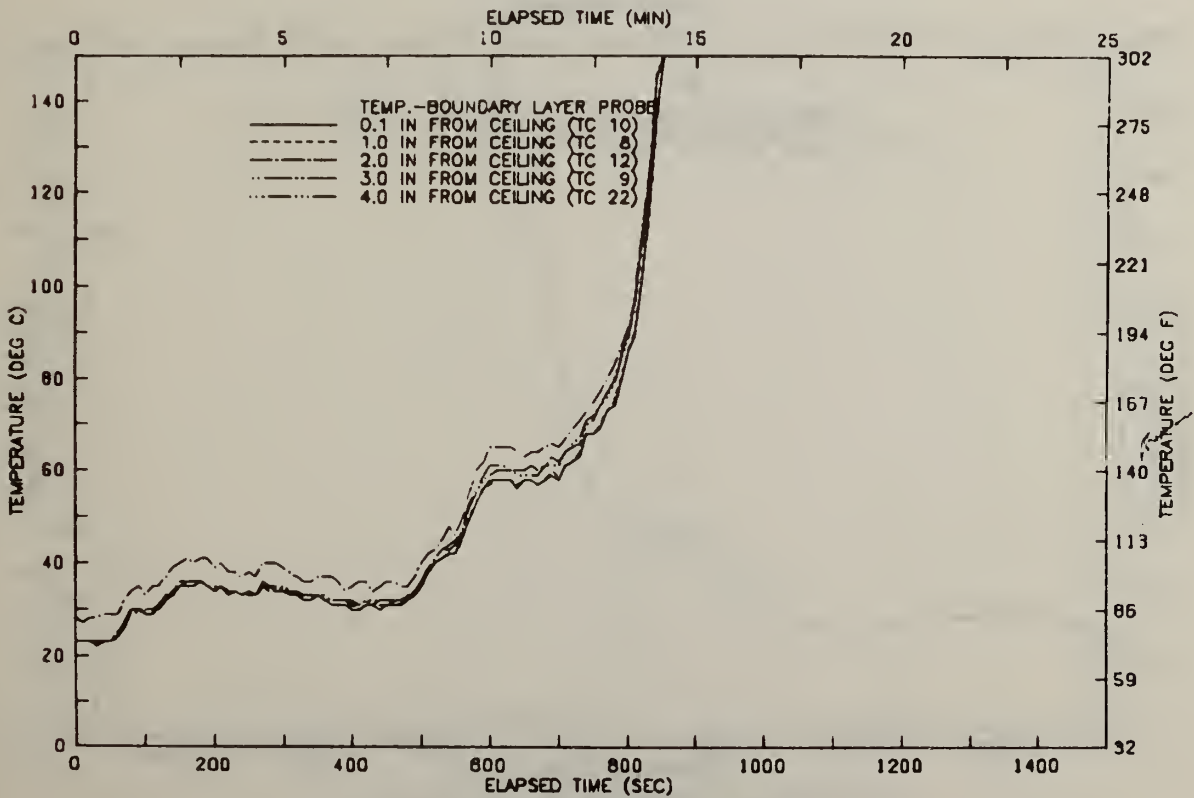

FIGURE B58 VERTICAL TEMP. PROFILE
CEILING BOUNDARY LAYER-TEST 19

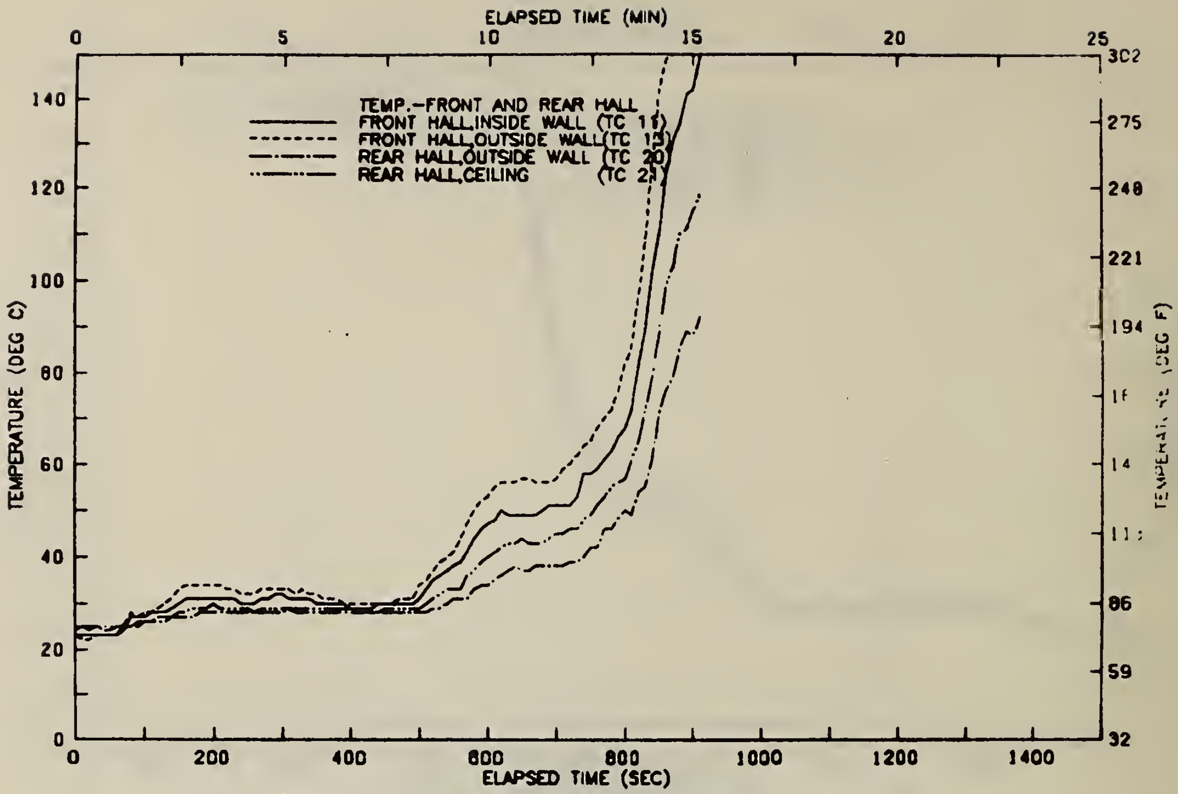

FIGURE B59 TEMP. IN HALLWAY NEAR DETECTORS-TEST 19

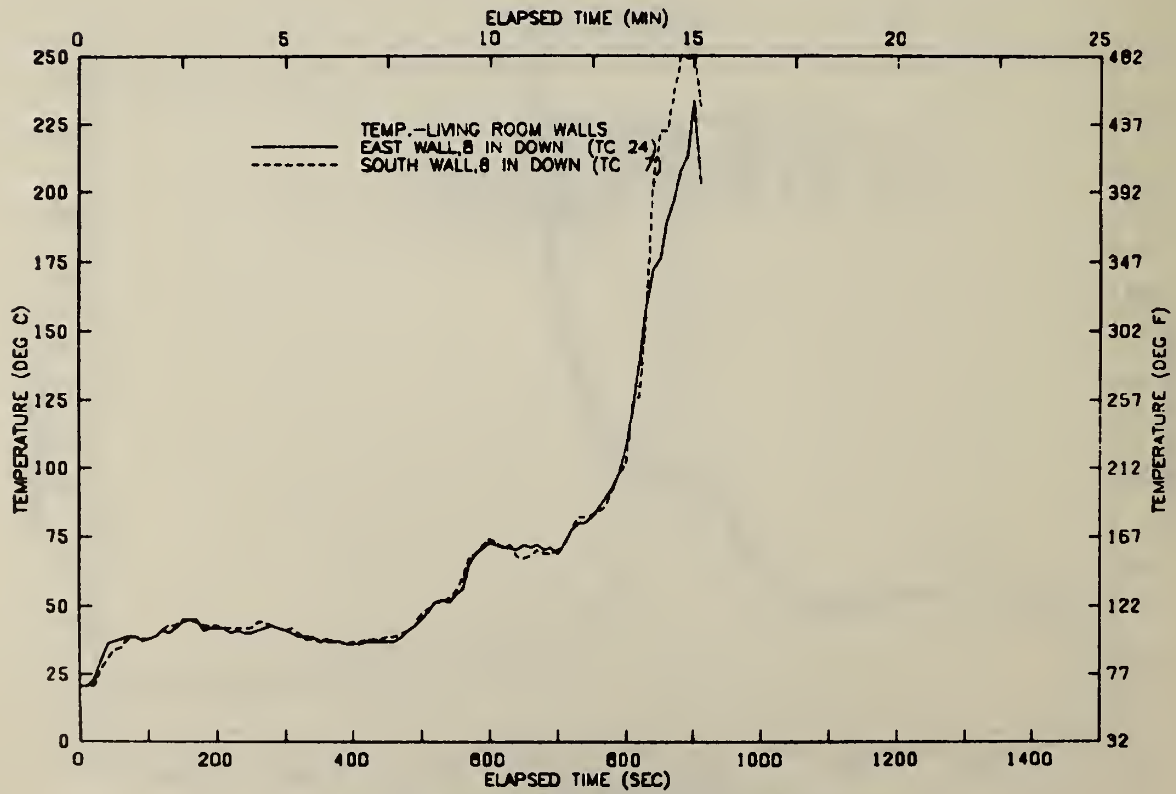

FIGURE B60 TEMPERATURE AT LIVING ROOM WALLS-TEST 19

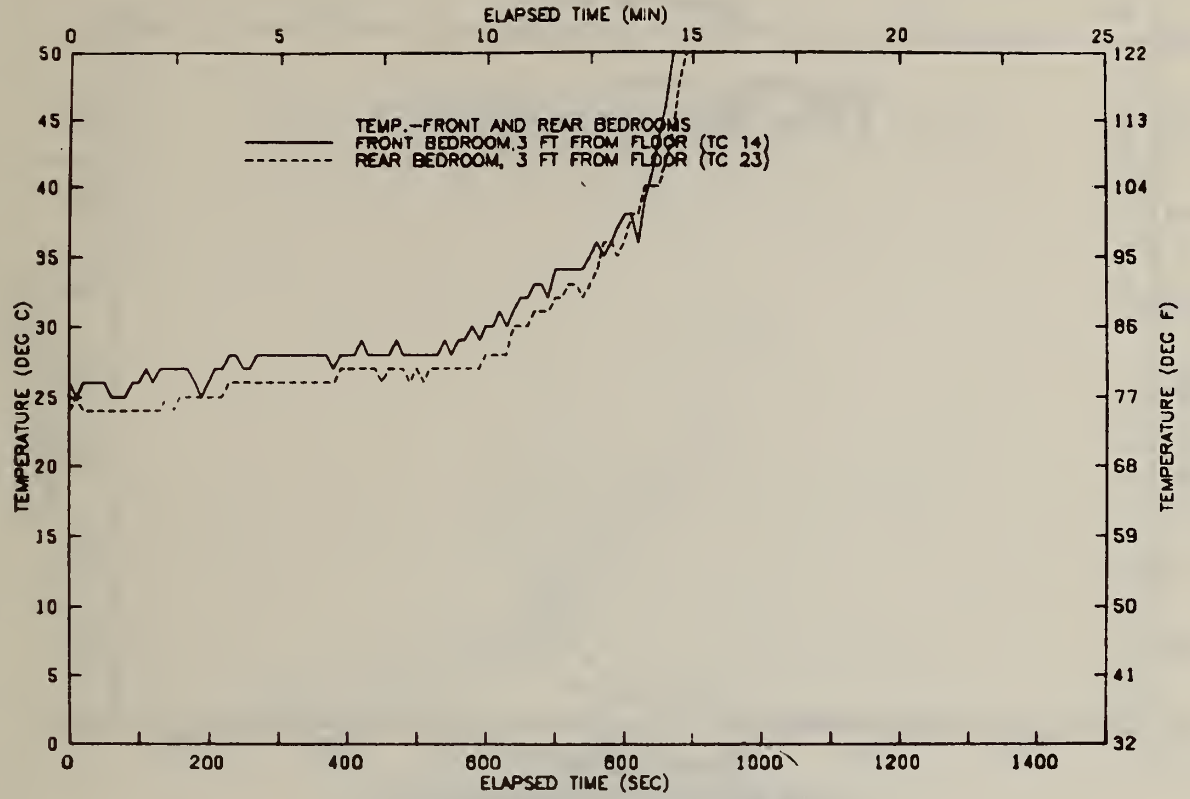

FIGURE B61 TEMP. IN FRONT AND REAR BEDROOMS-TEST 19

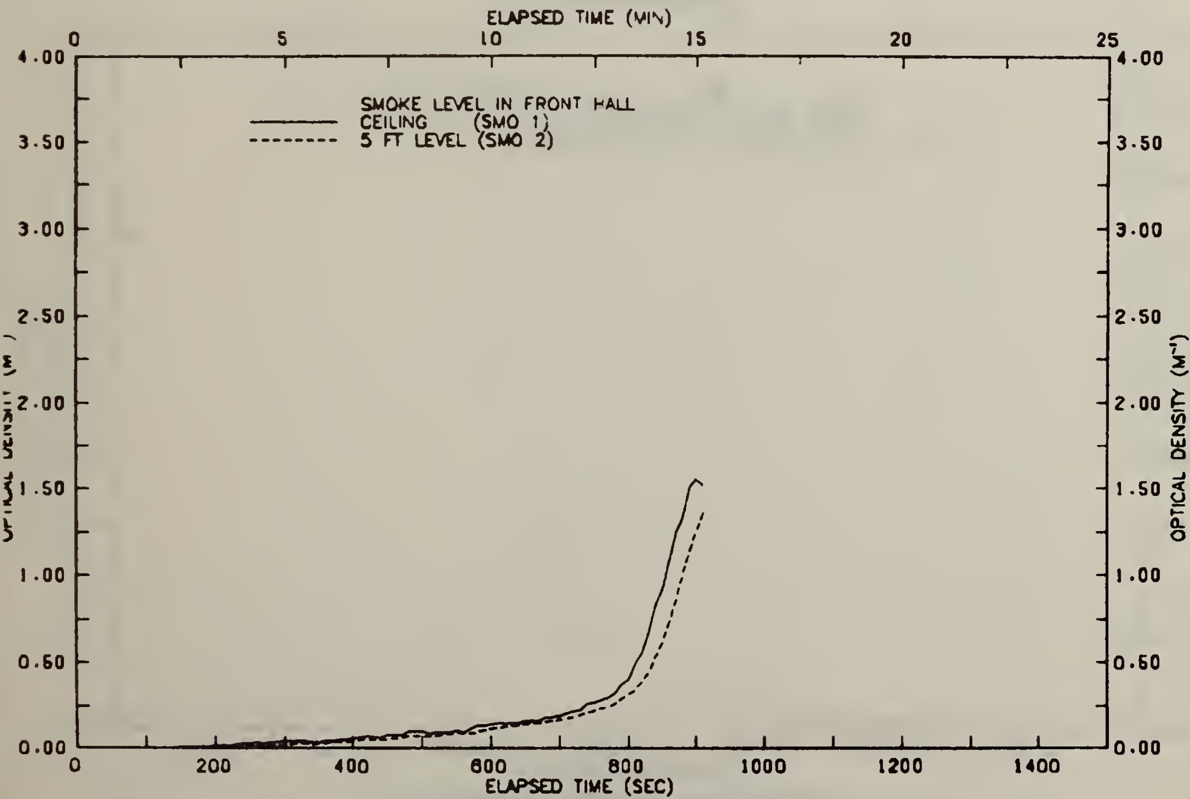

FIGURE B62 SMOKE LEVELS IN FRONT HALLWAY-TEST 19

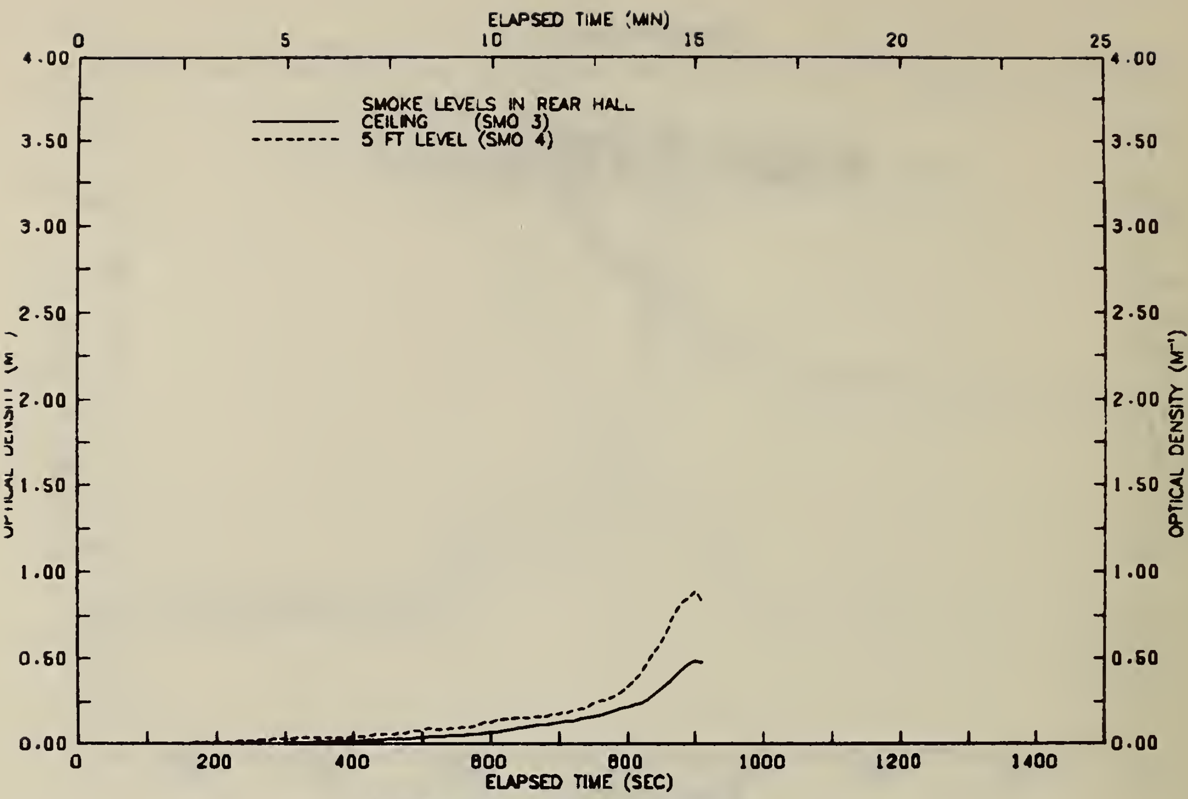

FIGURE B63 SMOKE LEVELS IN REAR HALLWAY-TEST 19

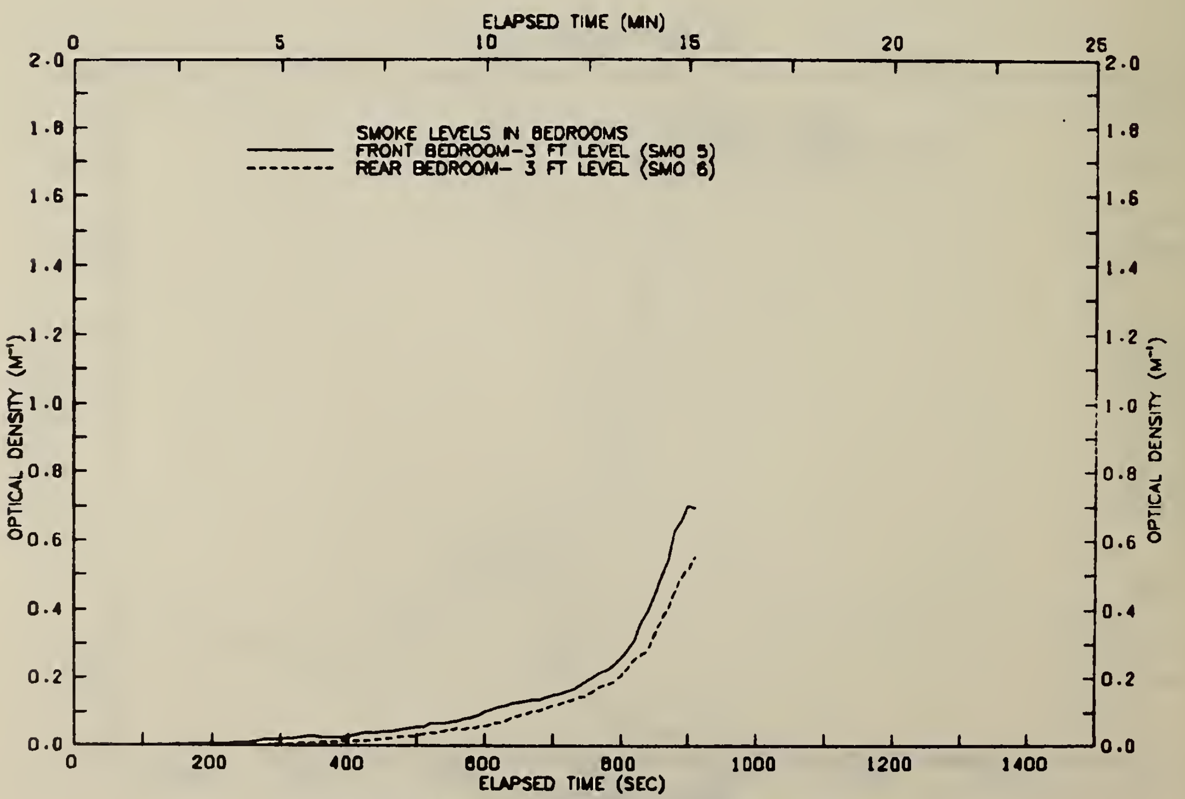

FIGURE B64 SMOKE LEVELS IN BEDROOMS-TEST 19

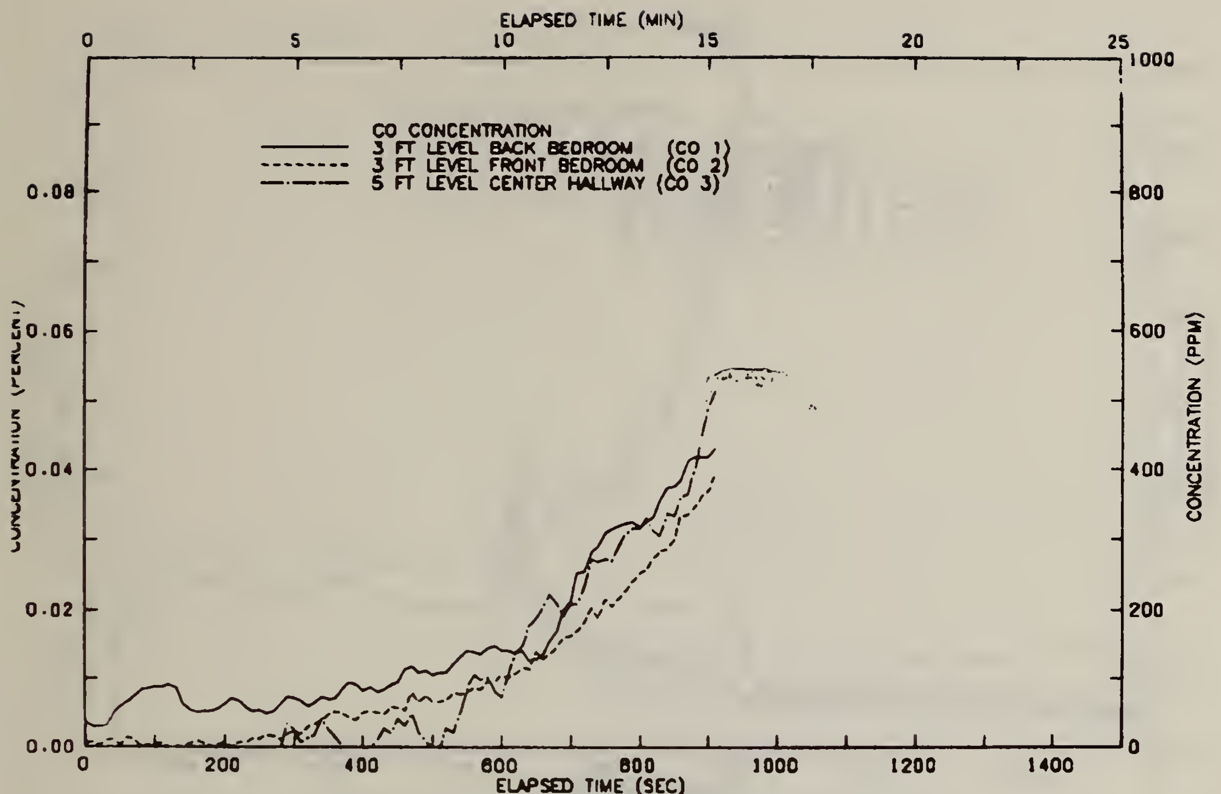

FIGURE B65 CARBON MONOXIDE CONCENTRATION–TEST 19

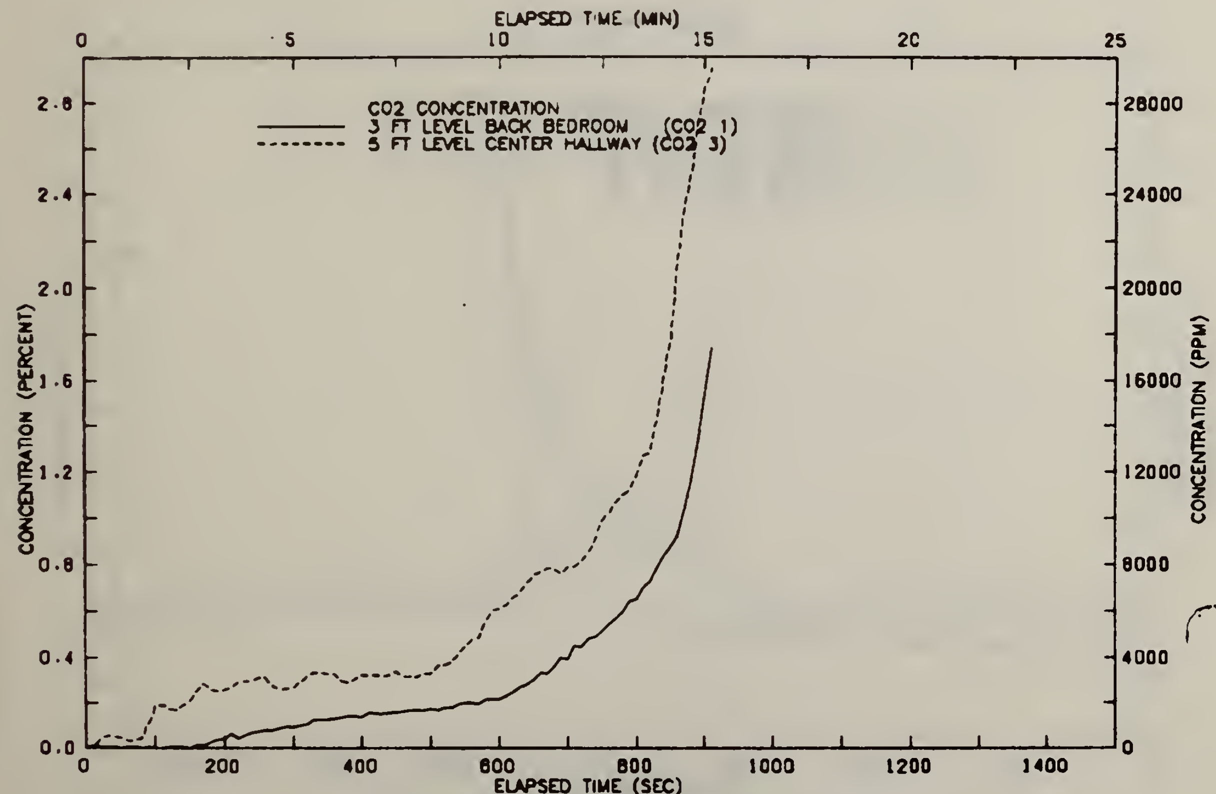

FIGURE B66 CARBON DIOXIDE CONCENTRATION–TEST 19

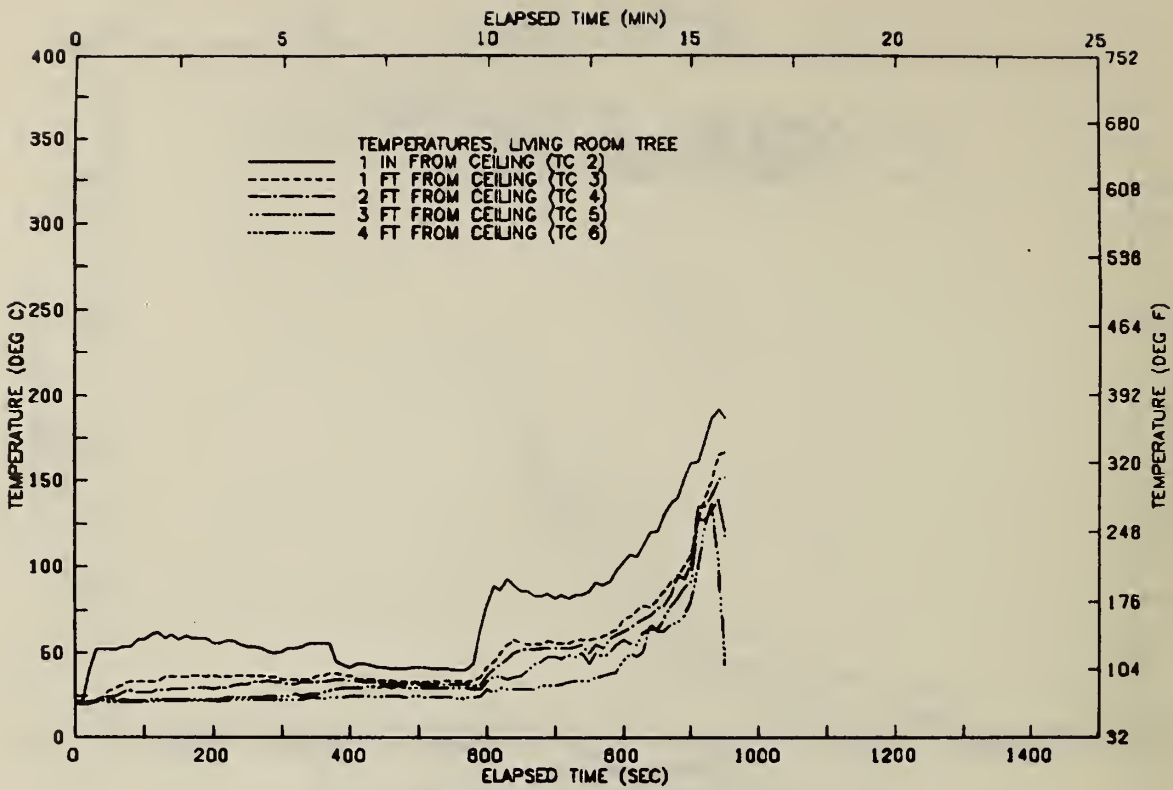

FIGURE B67 VERTICAL TEMP. PROFILE ABOVE CHAIR-TEST 20

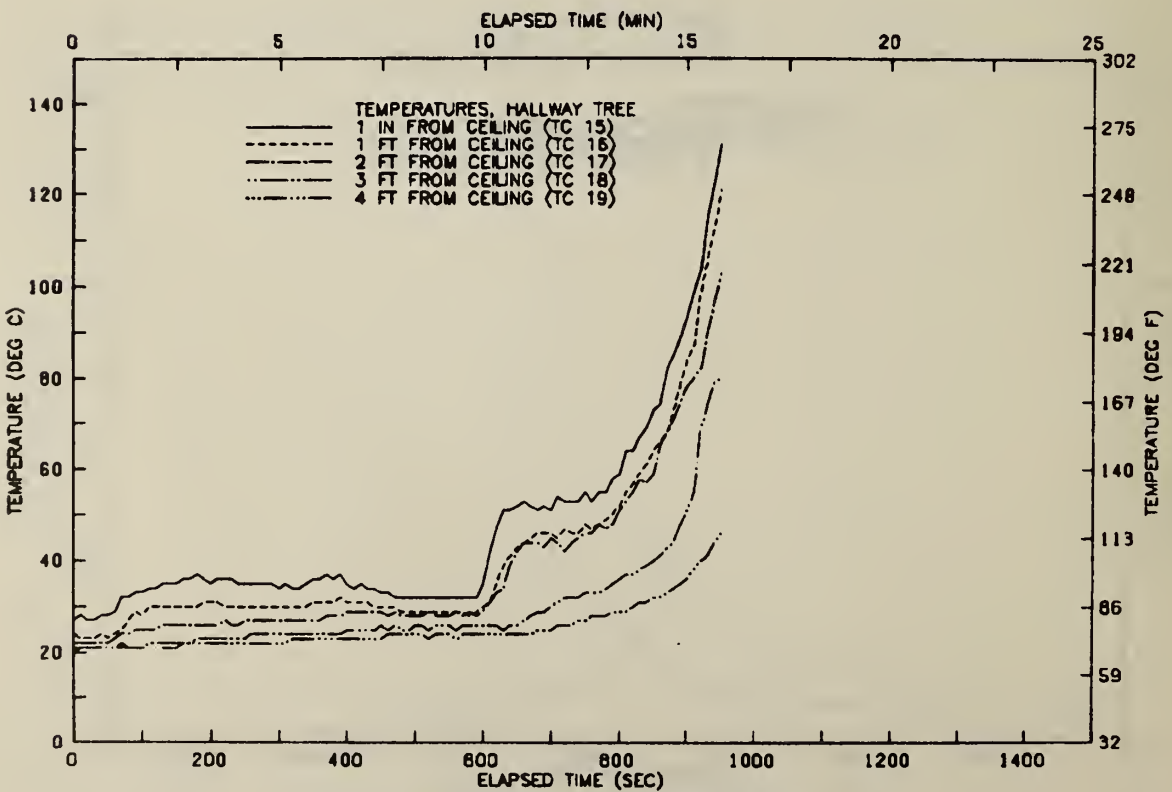

FIGURE B68 VERTICAL TEMP. PROFILE IN HALLWAY-TEST 20

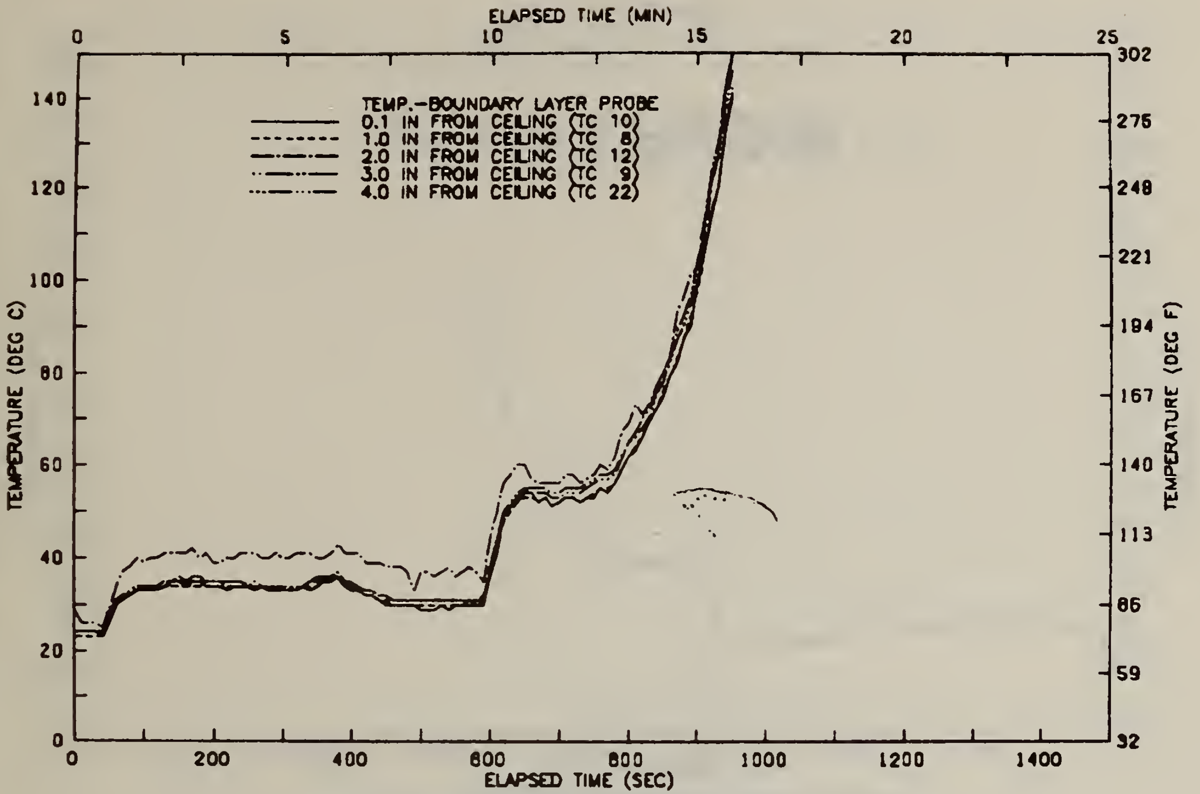

FIGURE B69 VERTICAL TEMP. PROFILE
CEILING BOUNDARY LAYER-TEST 20

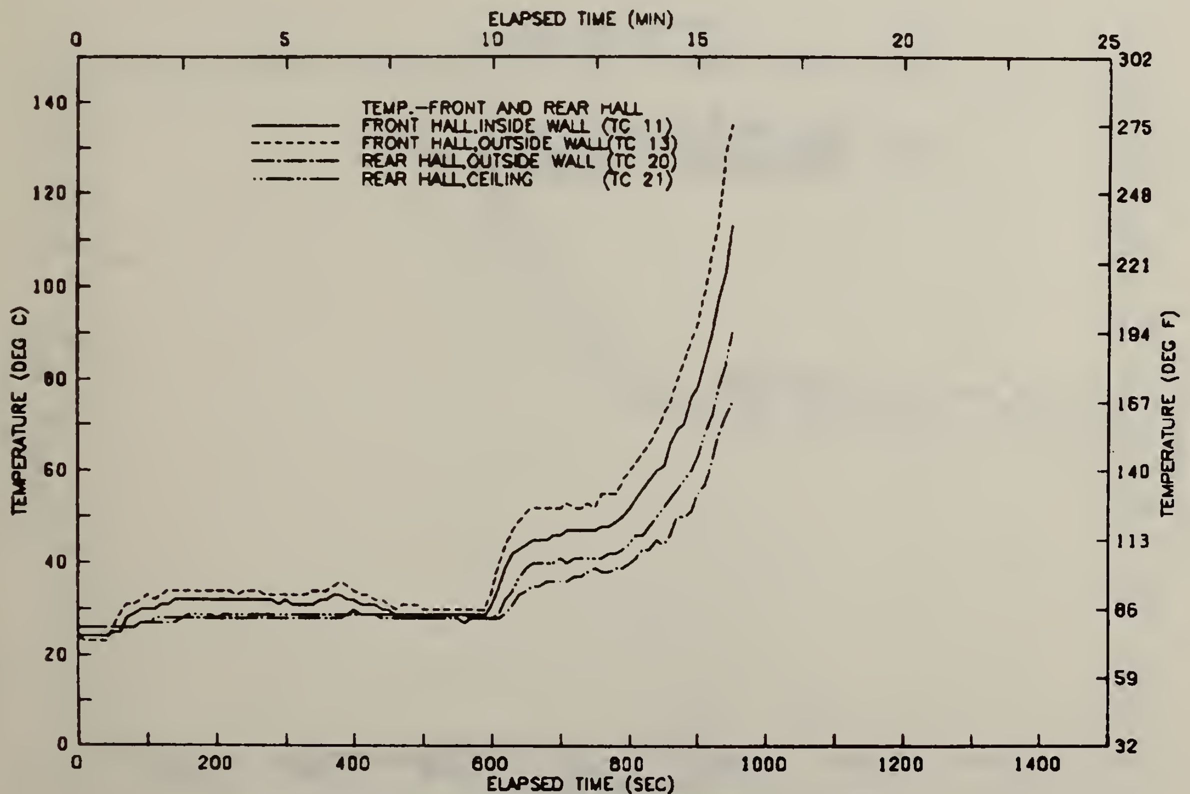

FIGURE B70 TEMP. IN HALLWAY
NEAR DETECTORS-TEST 20

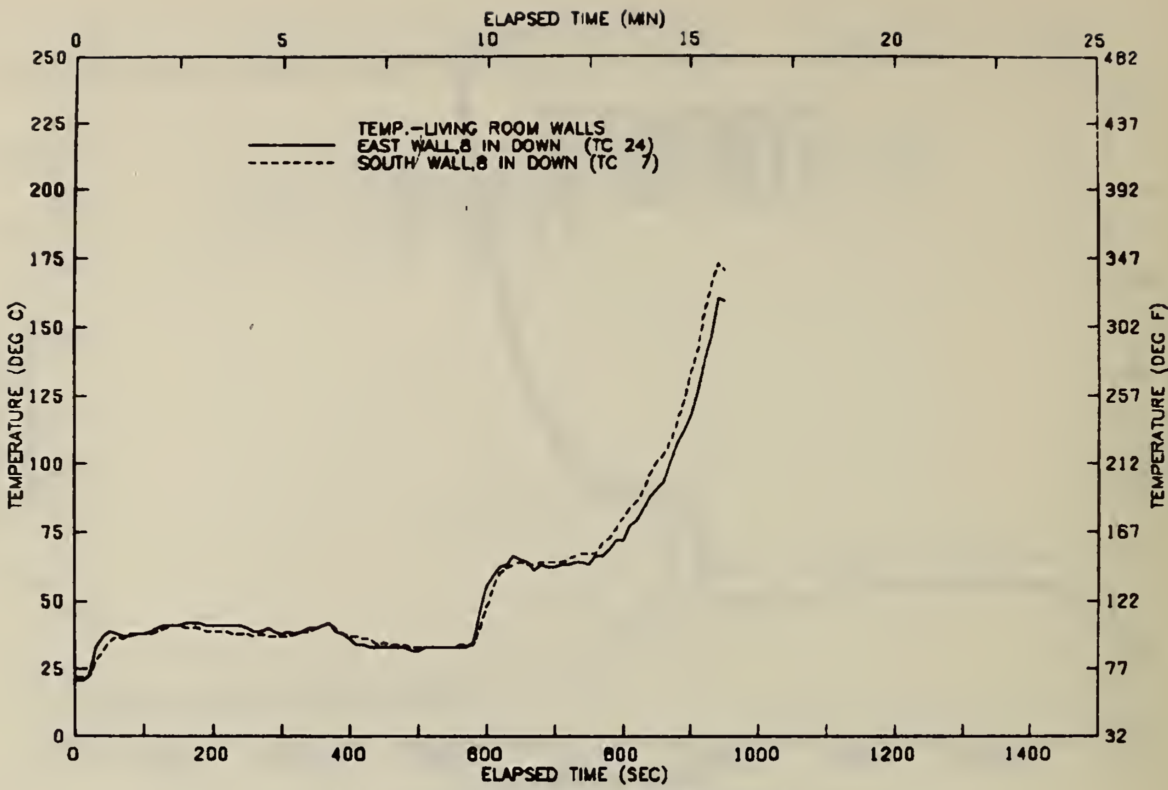

FIGURE B71 TEMPERATURE AT LIVING ROOM WALLS-TEST 20

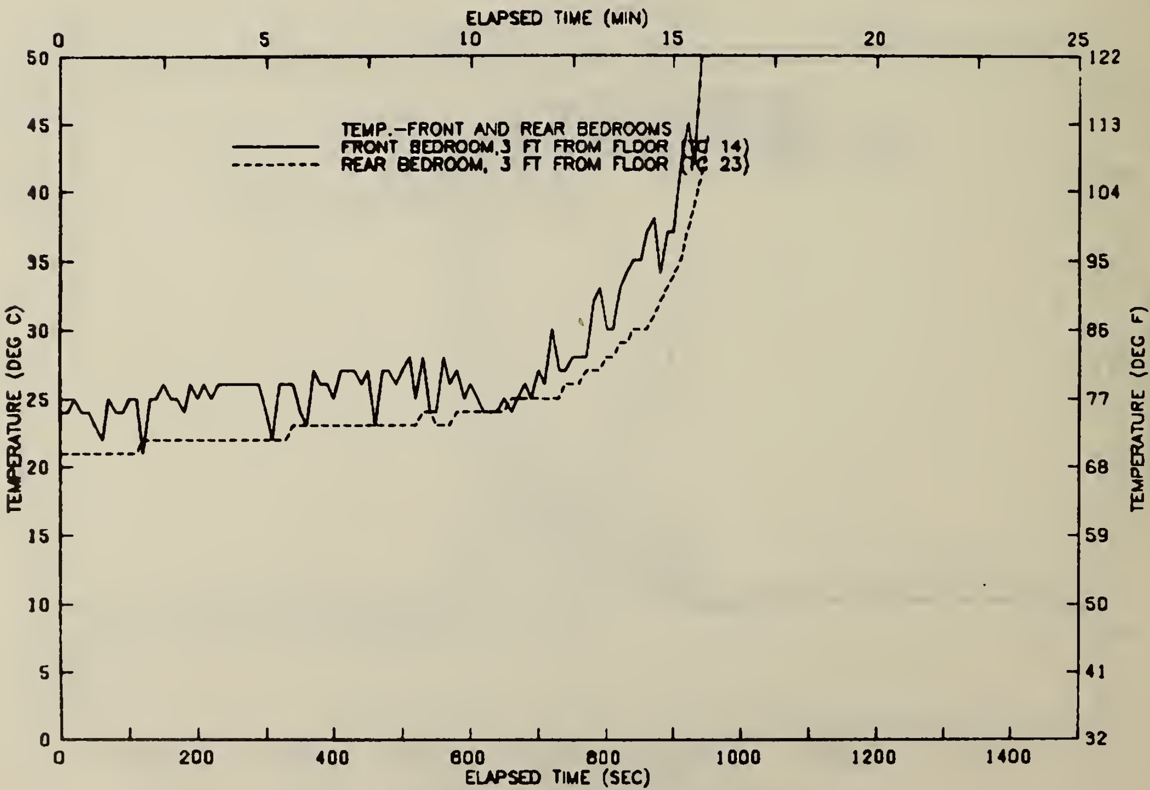

FIGURE B72 TEMP. IN FRONT AND REAR BEDROOMS-TEST 20

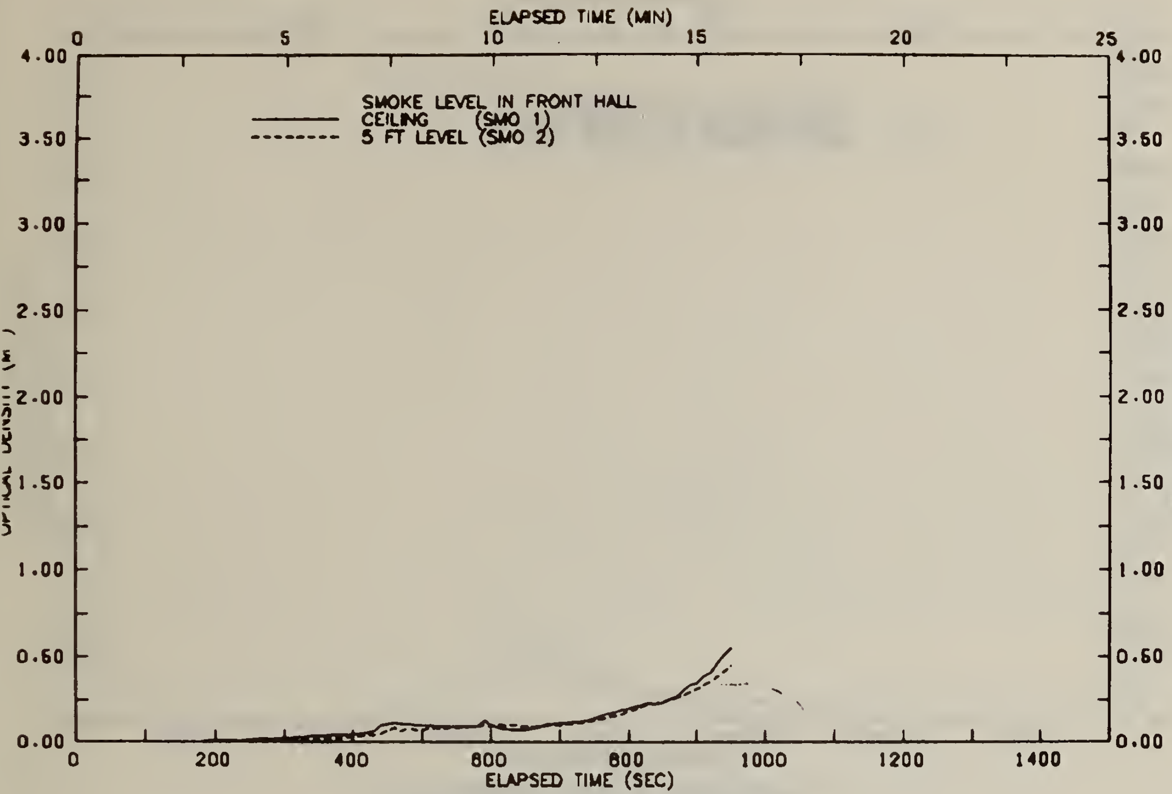

FIGURE B73 SMOKE LEVELS IN FRONT HALLWAY-TEST 20

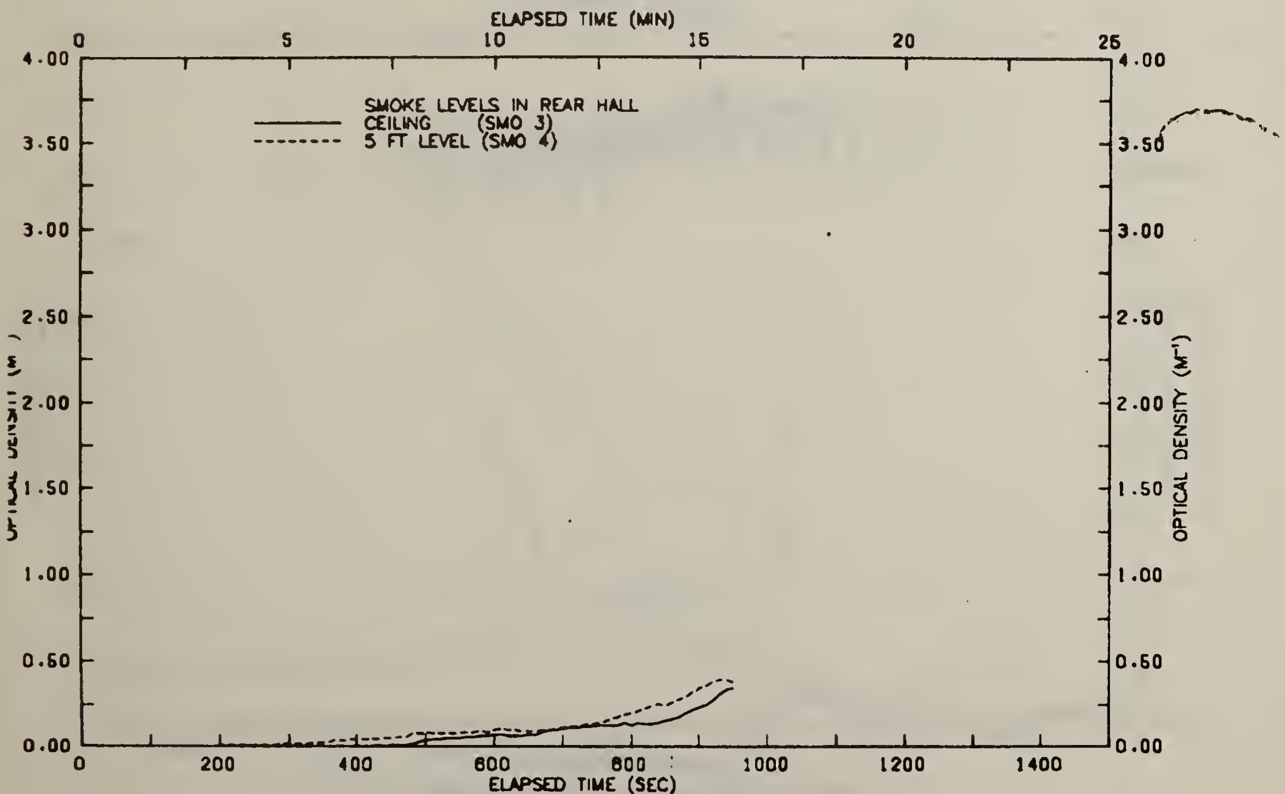

FIGURE B74 SMOKE LEVELS IN REAR HALLWAY-TEST 20

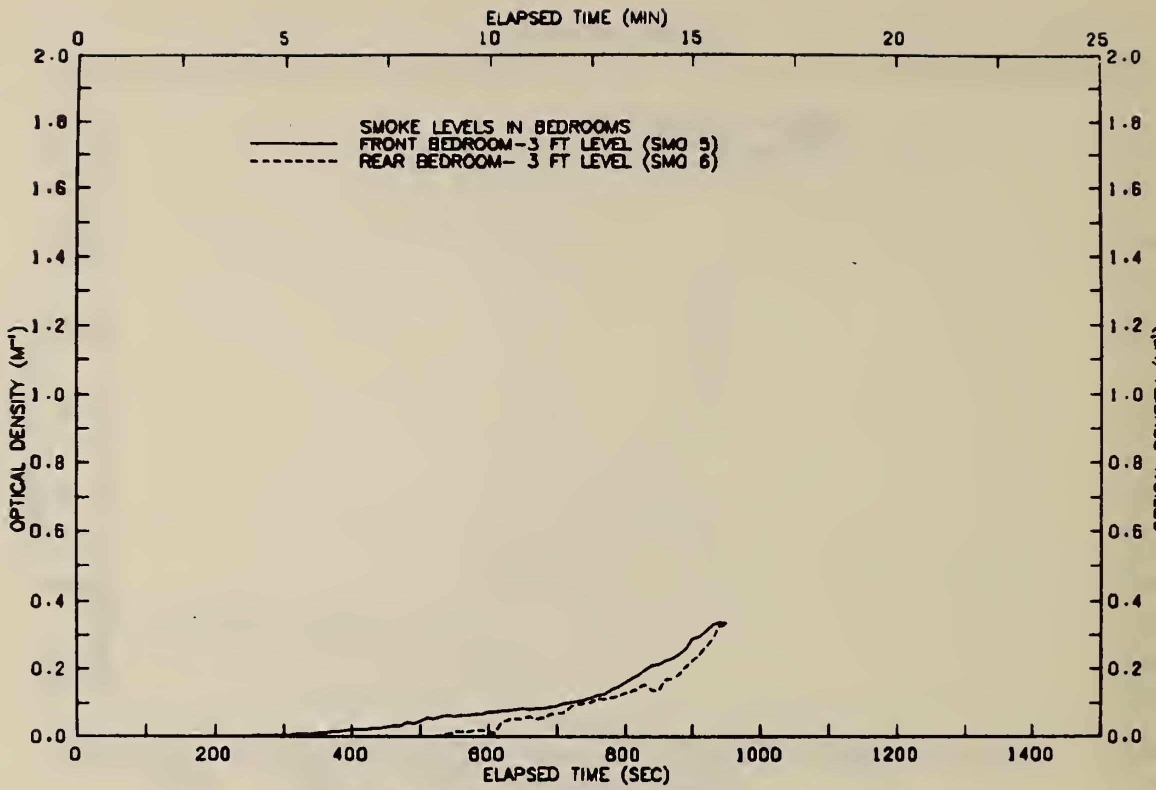

FIGURE B75 SMOKE LEVELS IN BEDROOMS-TEST 20

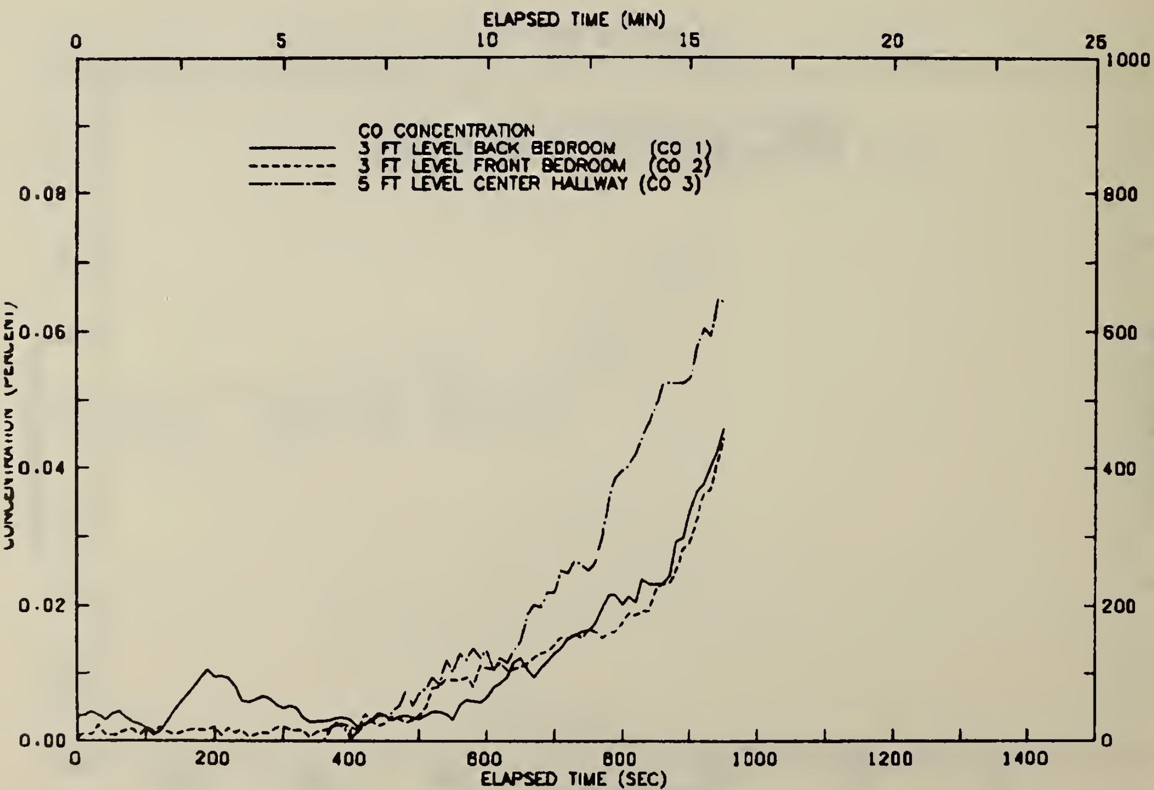

FIGURE B76 CARBON MONOXIDE CONCENTRATION-TEST 20

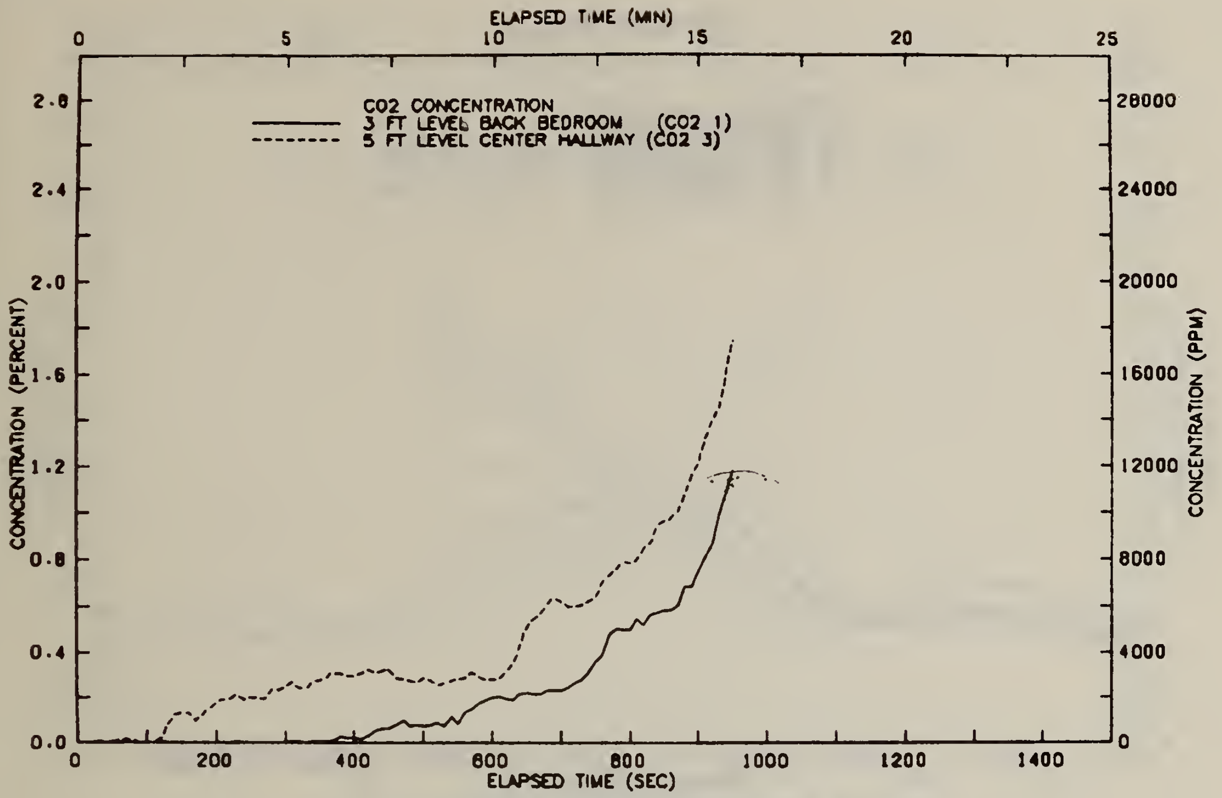

FIGURE B77 CARBON DIOXIDE CONCENTRATION-TEST 20

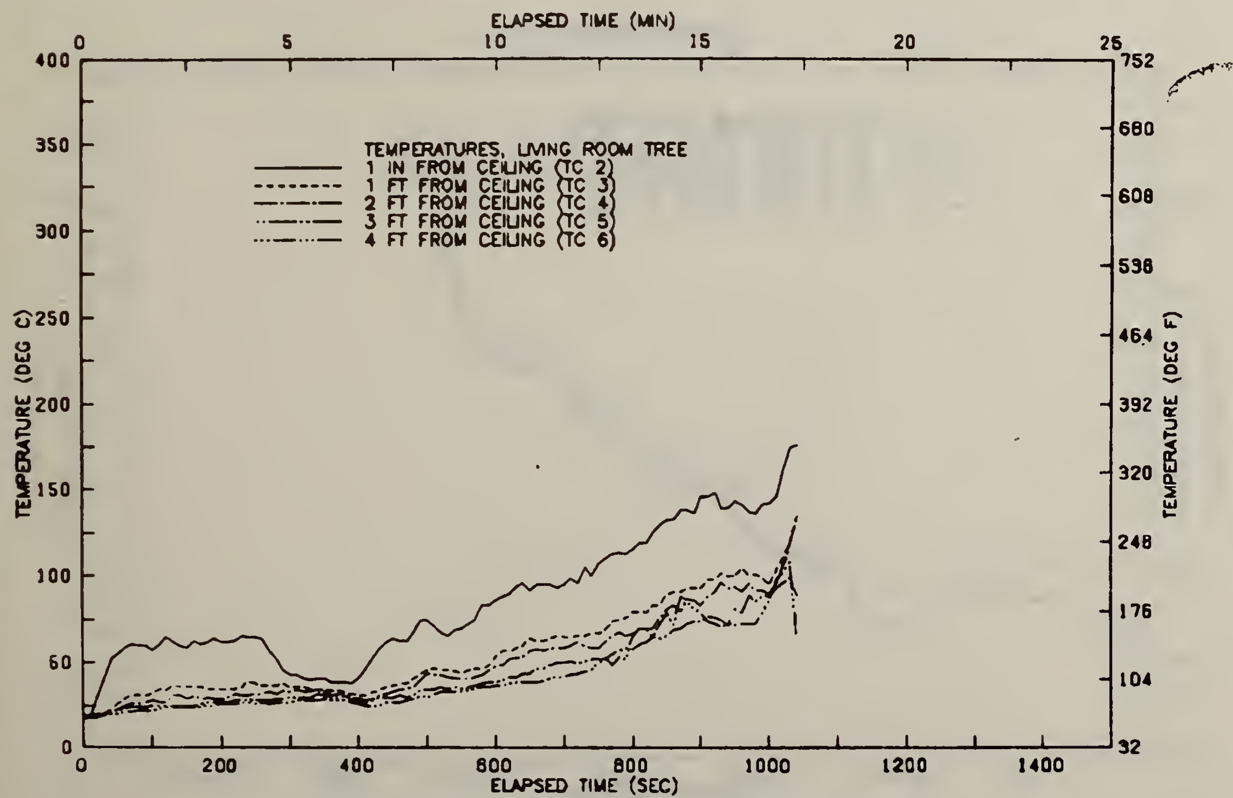

FIGURE B78 VERTICAL TEMP. PROFILE ABOVE CHAIR-TEST 21

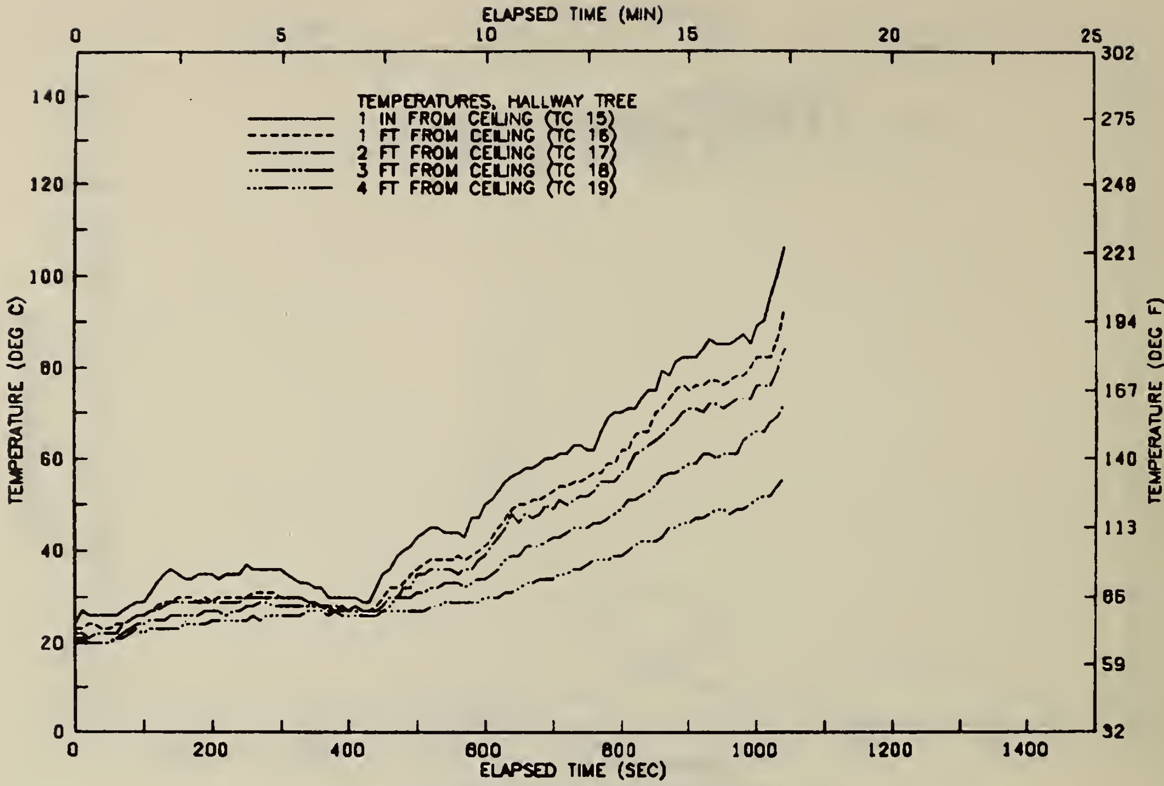

FIGURE B79 VERTICAL TEMP. PROFILE IN HALLWAY-TEST 21

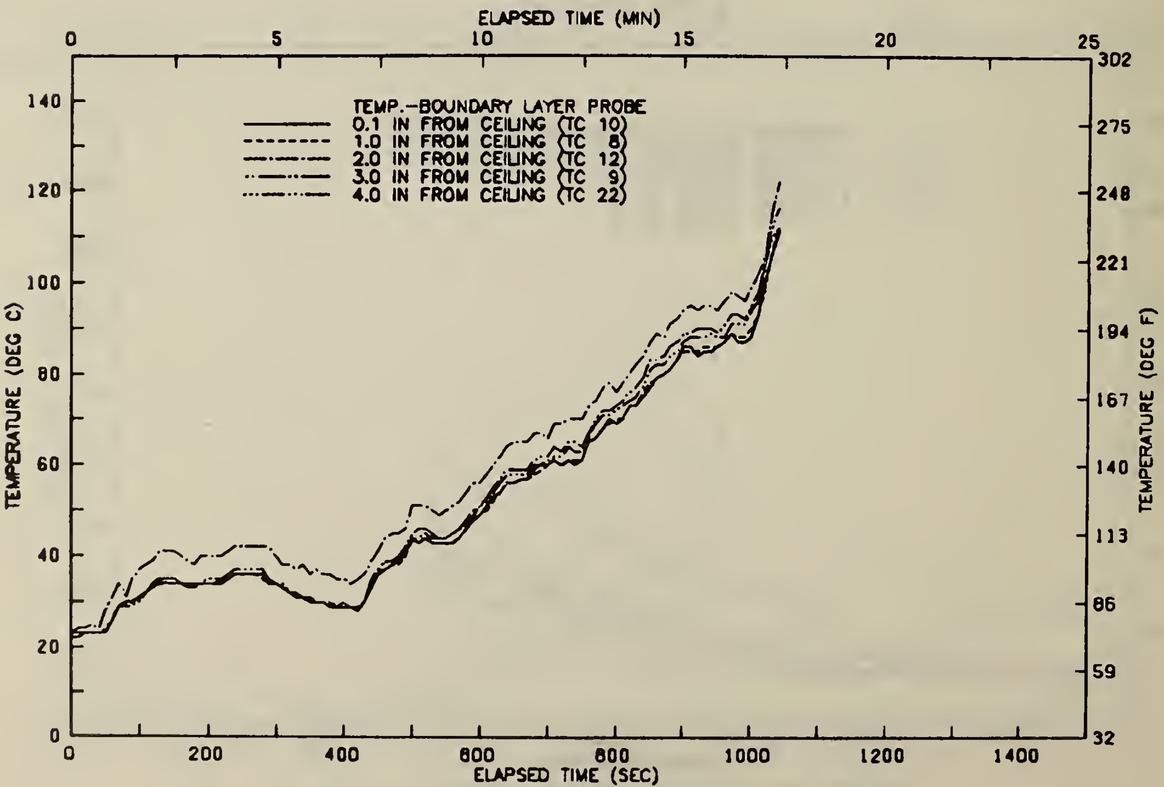

FIGURE B80 VERTICAL TEMP. PROFILE CEILING BOUNDARY LAYER-TEST 21

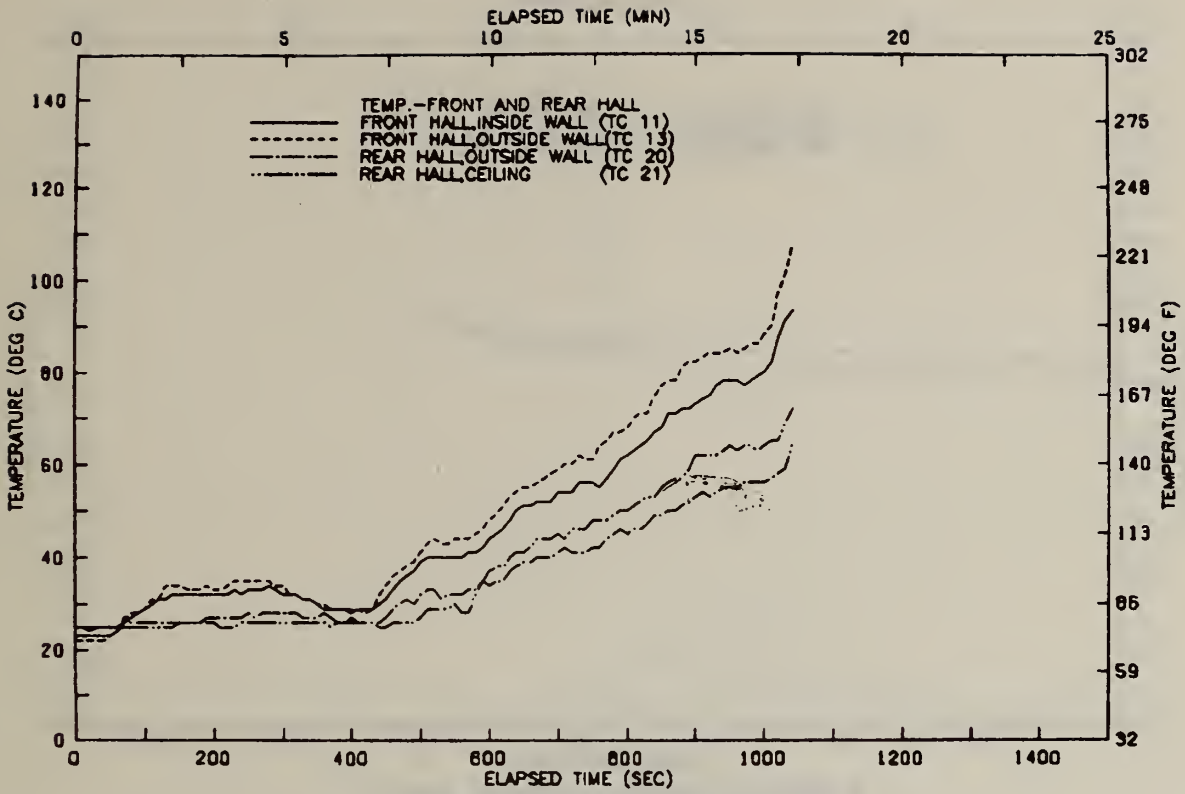

FIGURE B81 TEMP. IN HALLWAY
NEAR DETECTORS-TEST 21

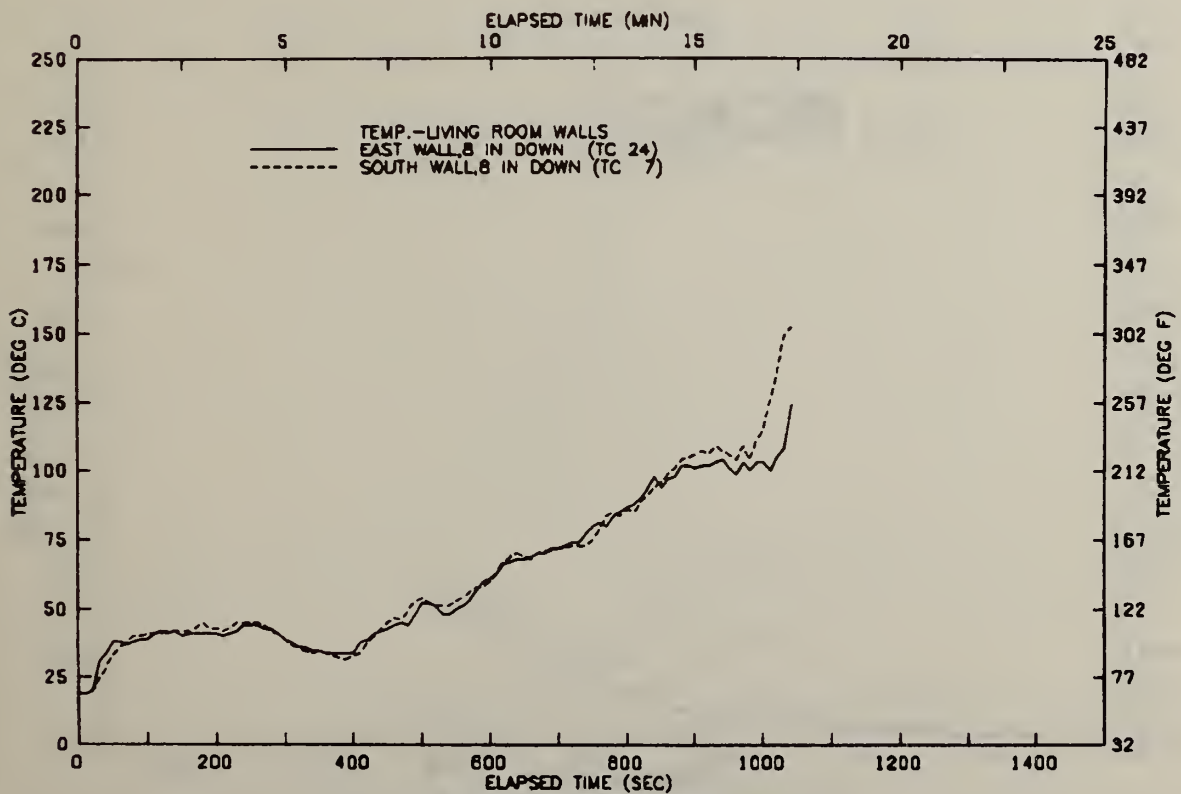

FIGURE B82 TEMPERATURE AT LIVING
ROOM WALLS-TEST 21

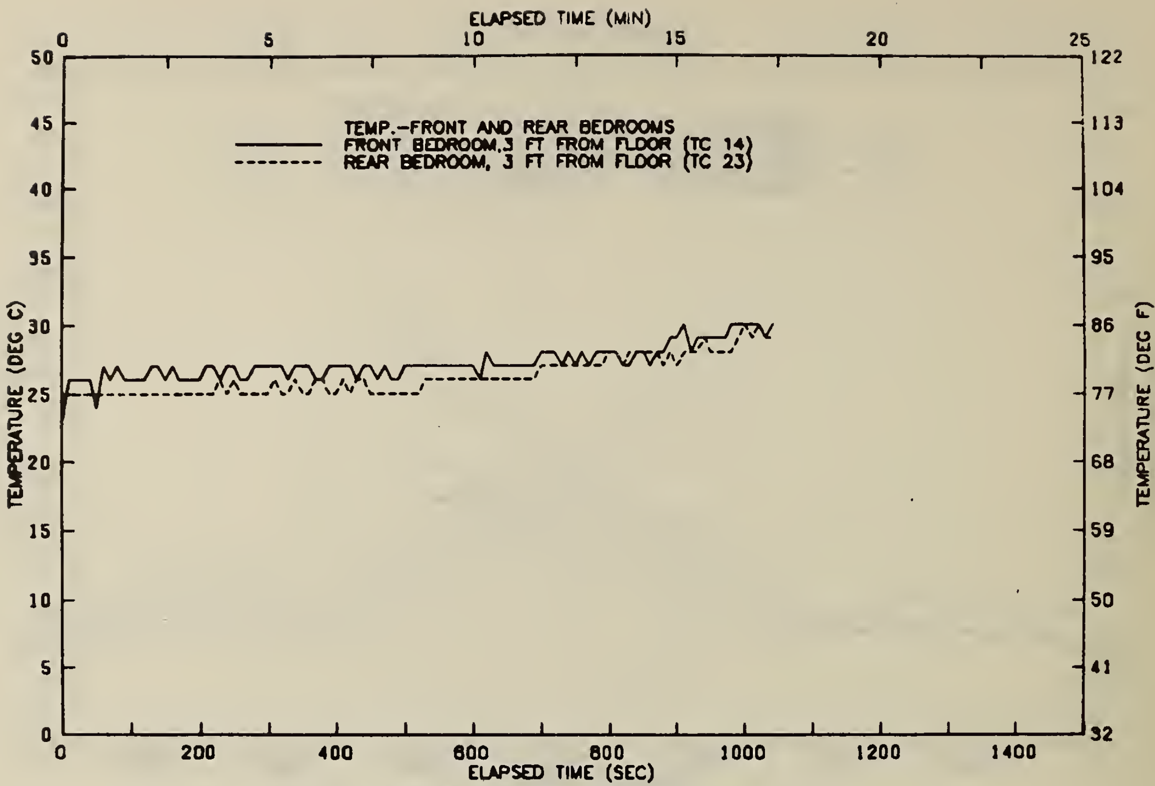

FIGURE B83 TEMP. IN FRONT AND REAR BEDROOMS-TEST 21

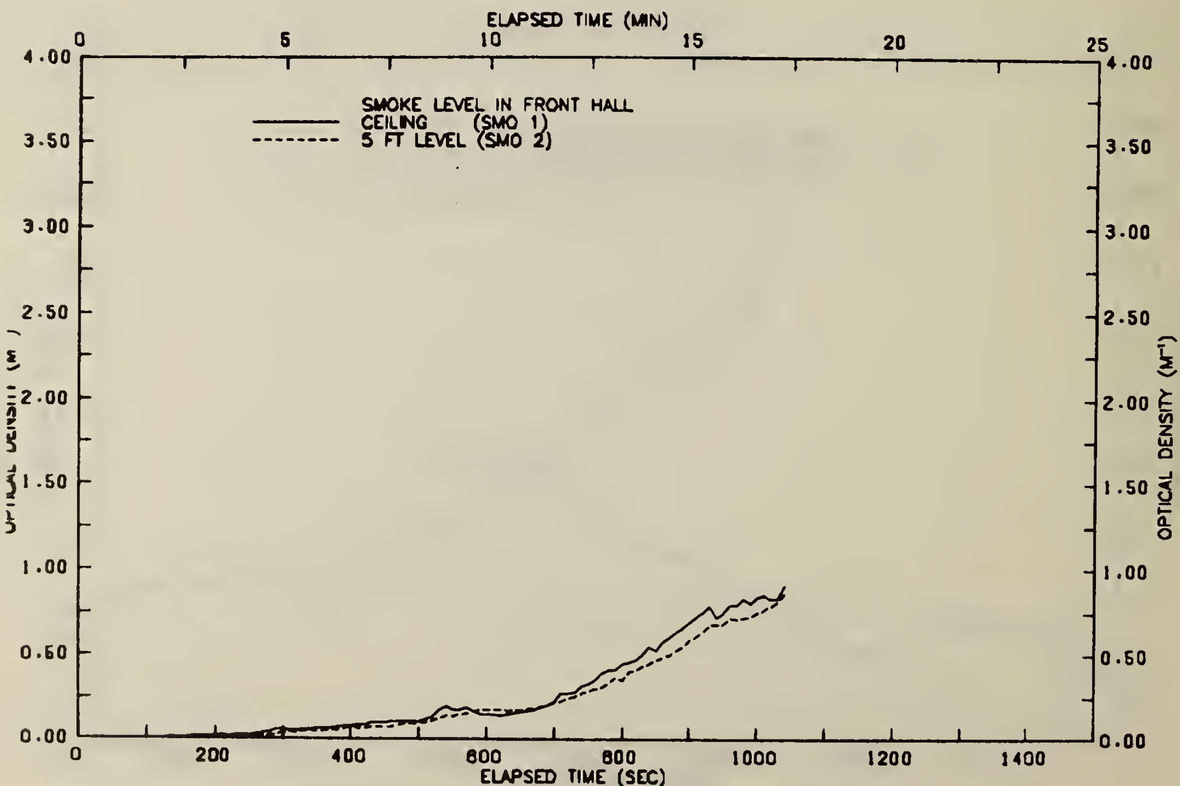

FIGURE B84 SMOKE LEVELS IN FRONT HALLWAY-TEST 21

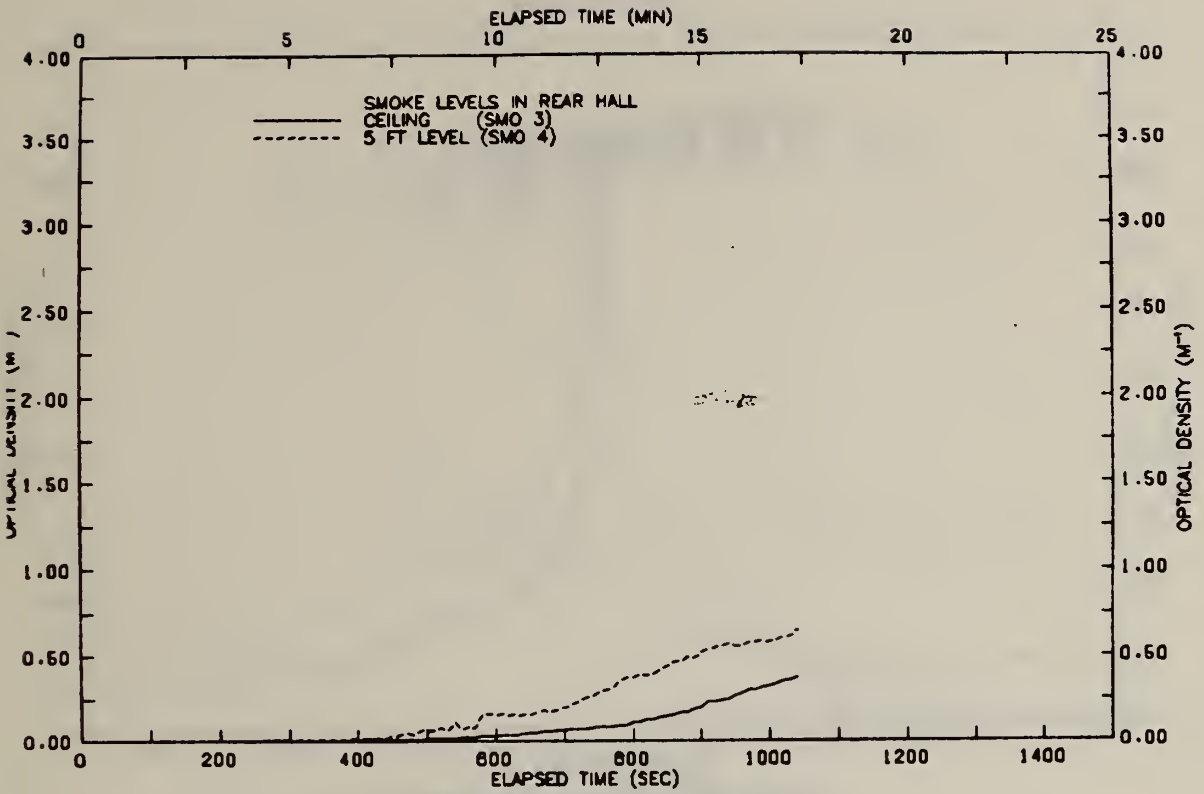

FIGURE B85 SMOKE LEVELS IN REAR HALLWAY—TEST 21

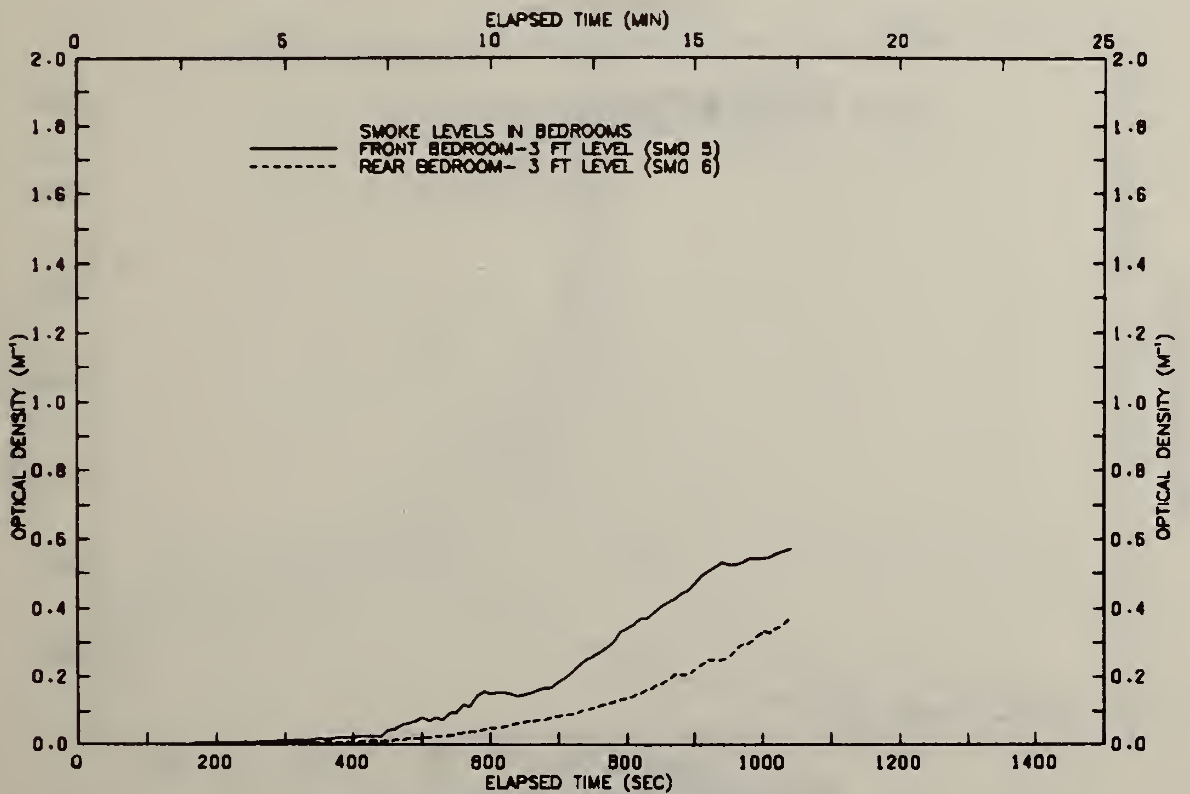

FIGURE B86 SMOKE LEVELS IN BEDROOMS—TEST 21

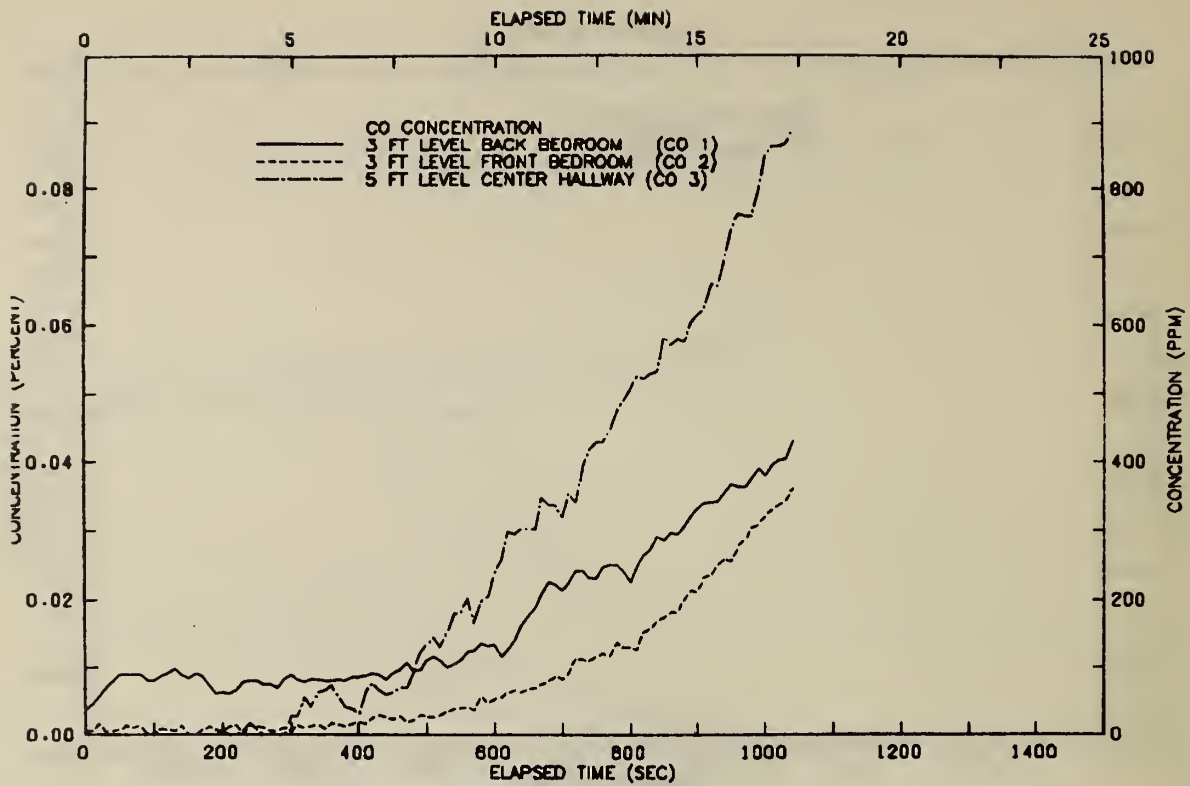

FIGURE B87 CARBON MONOXIDE CONCENTRATION–TEST 21

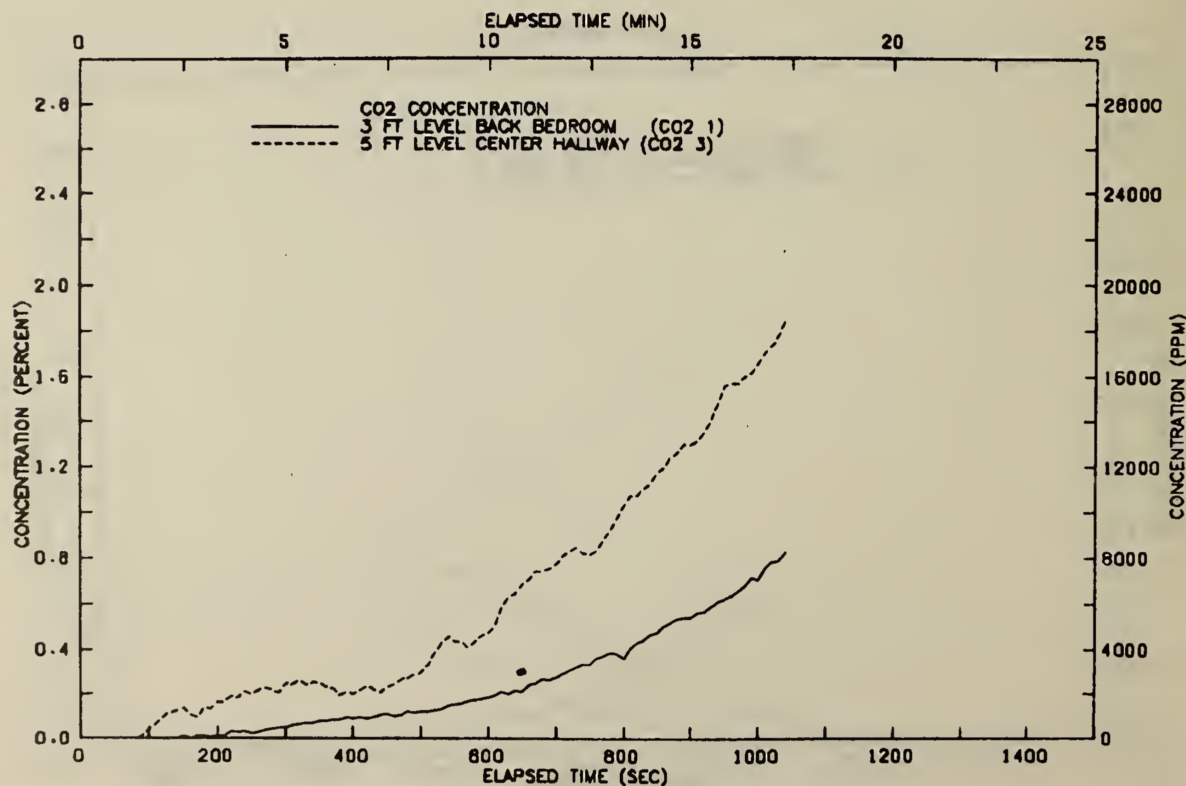

FIGURE B88 CARBON DIOXIDE CONCENTRATION–TEST 21

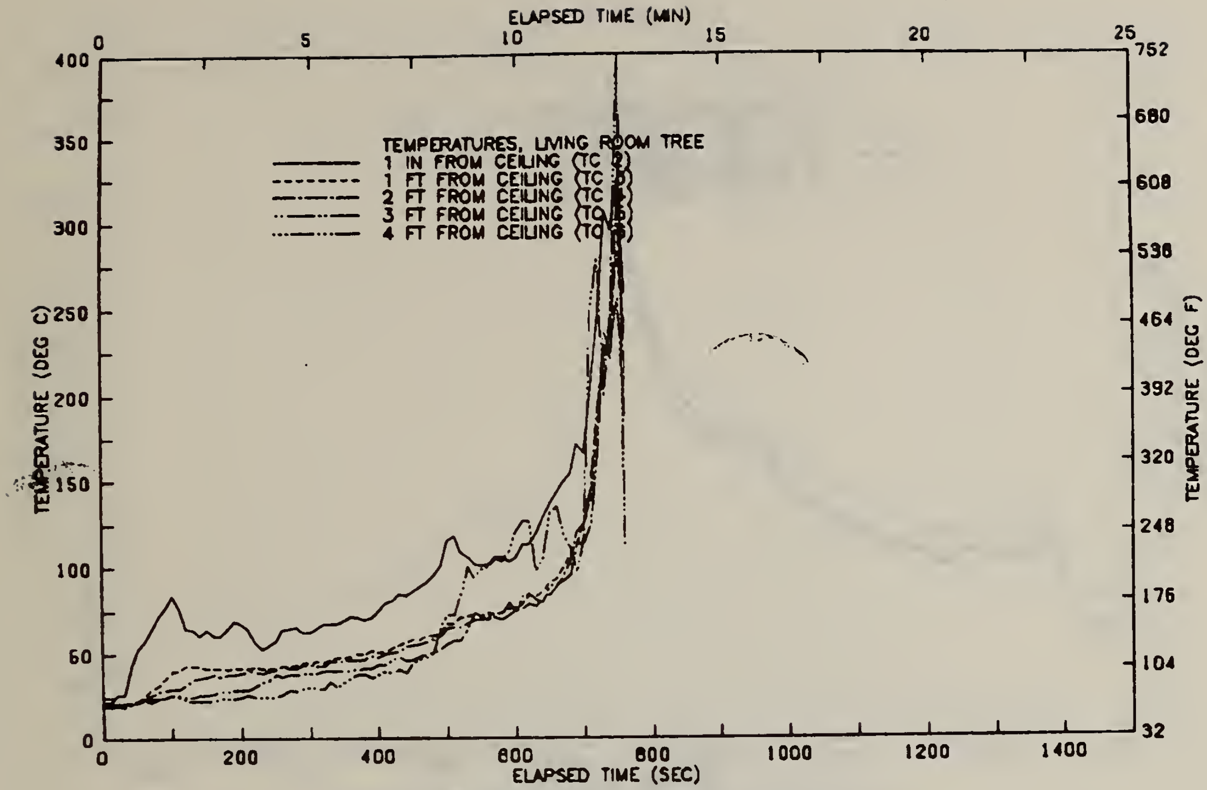

FIGURE B89 VERTICAL TEMP. PROFILE ABOVE CHAIR-TEST 22

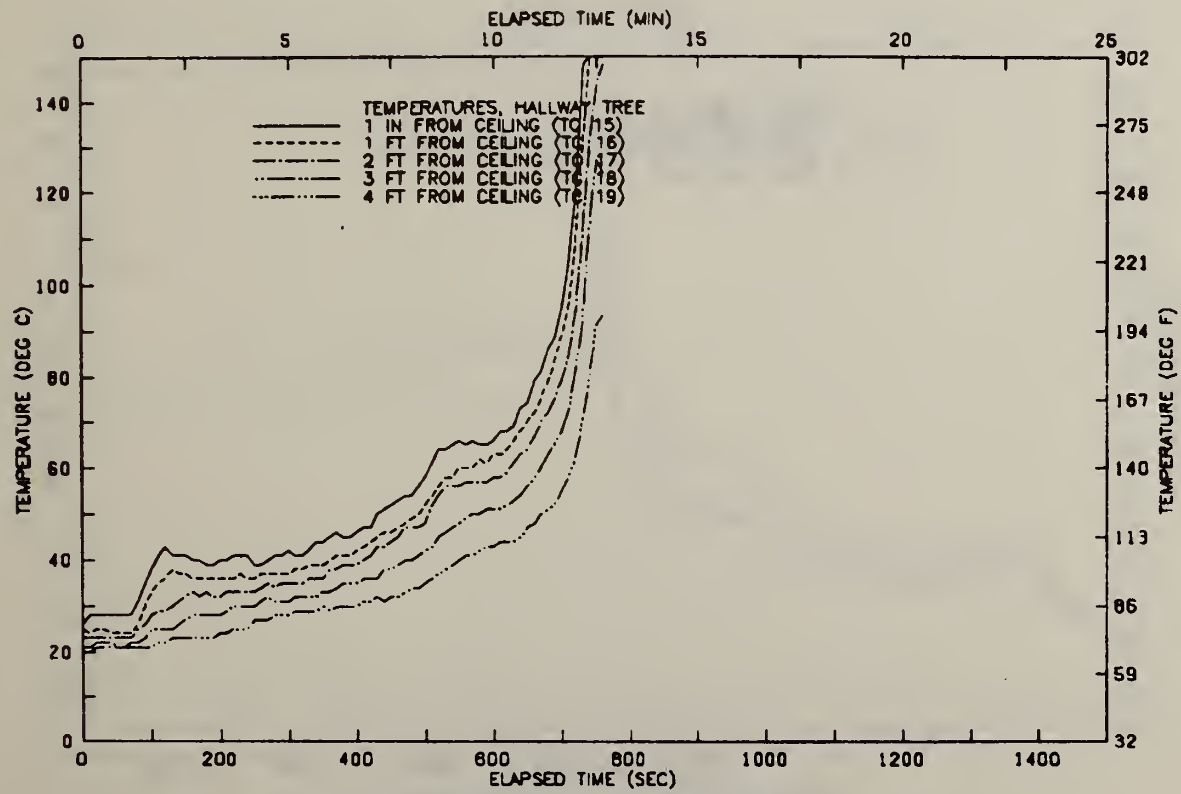

FIGURE B90 VERTICAL TEMP. PROFILE IN HALLWAY-TEST 22

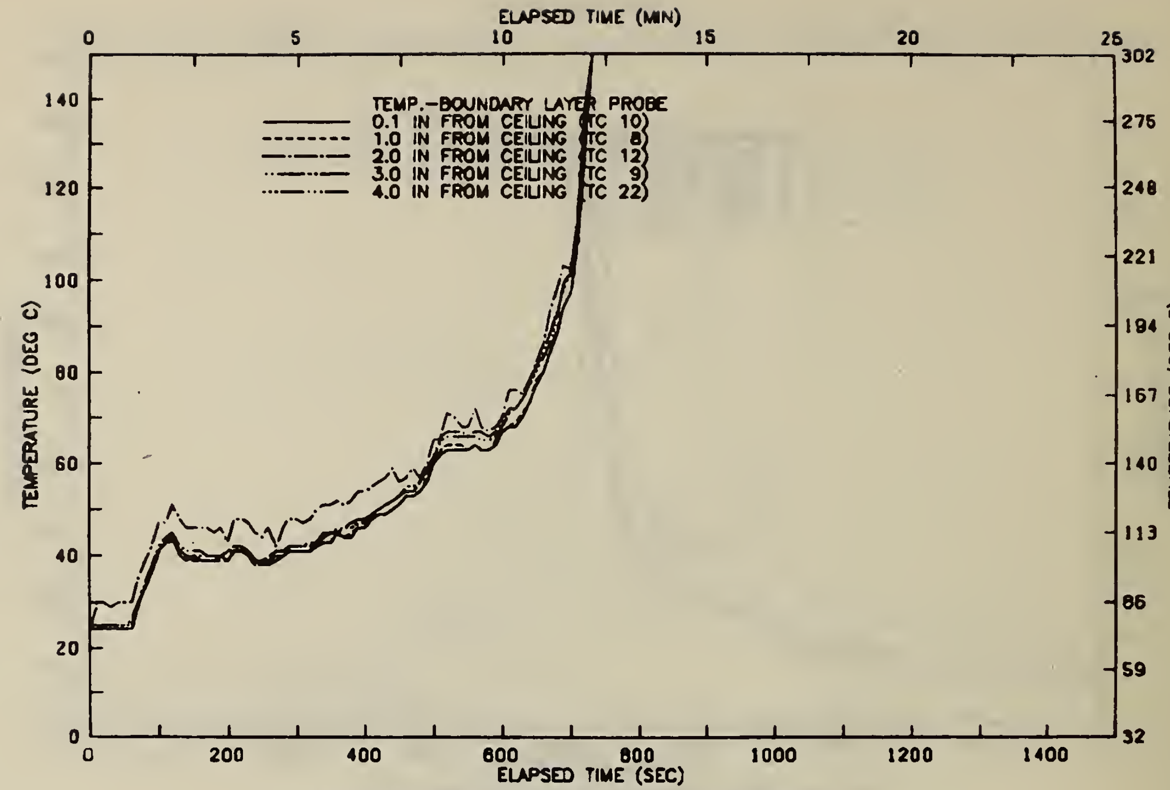

FIGURE B91 VERTICAL TEMP. PROFILE CEILING BOUNDARY LAYER-TEST 22

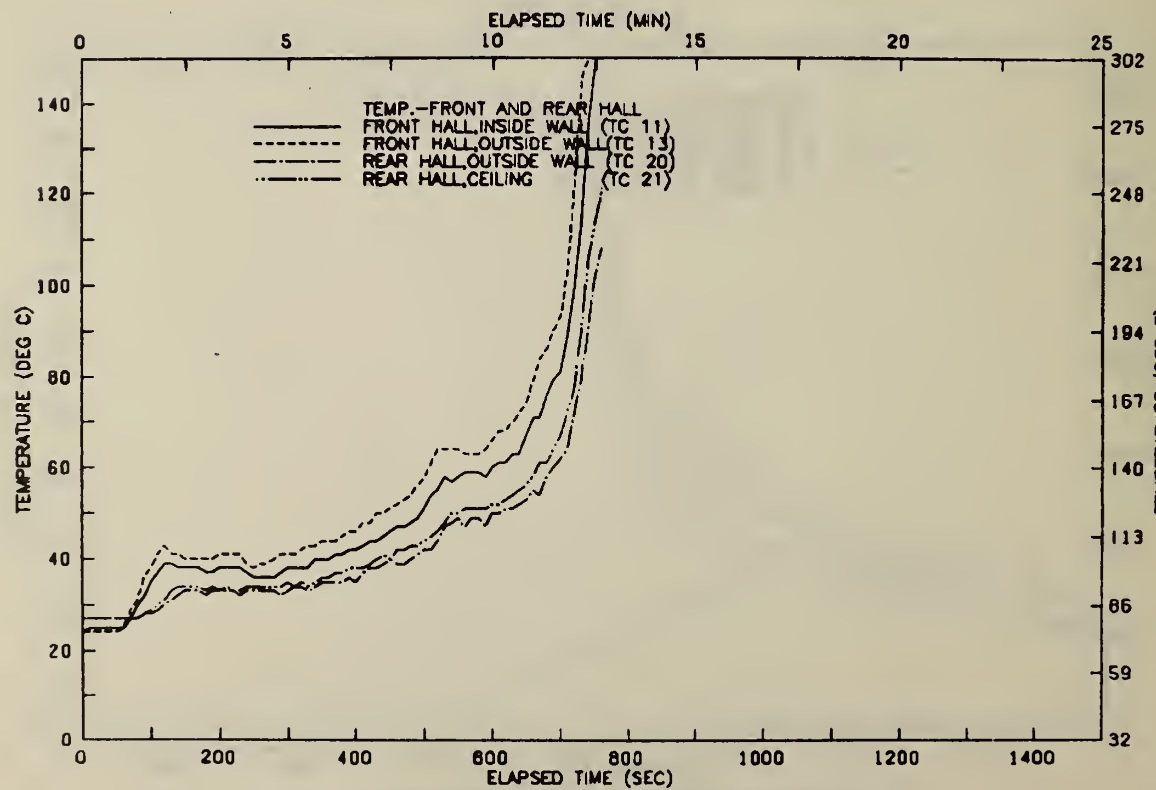

FIGURE B92 TEMP. IN HALLWAY NEAR DETECTORS-TEST 22

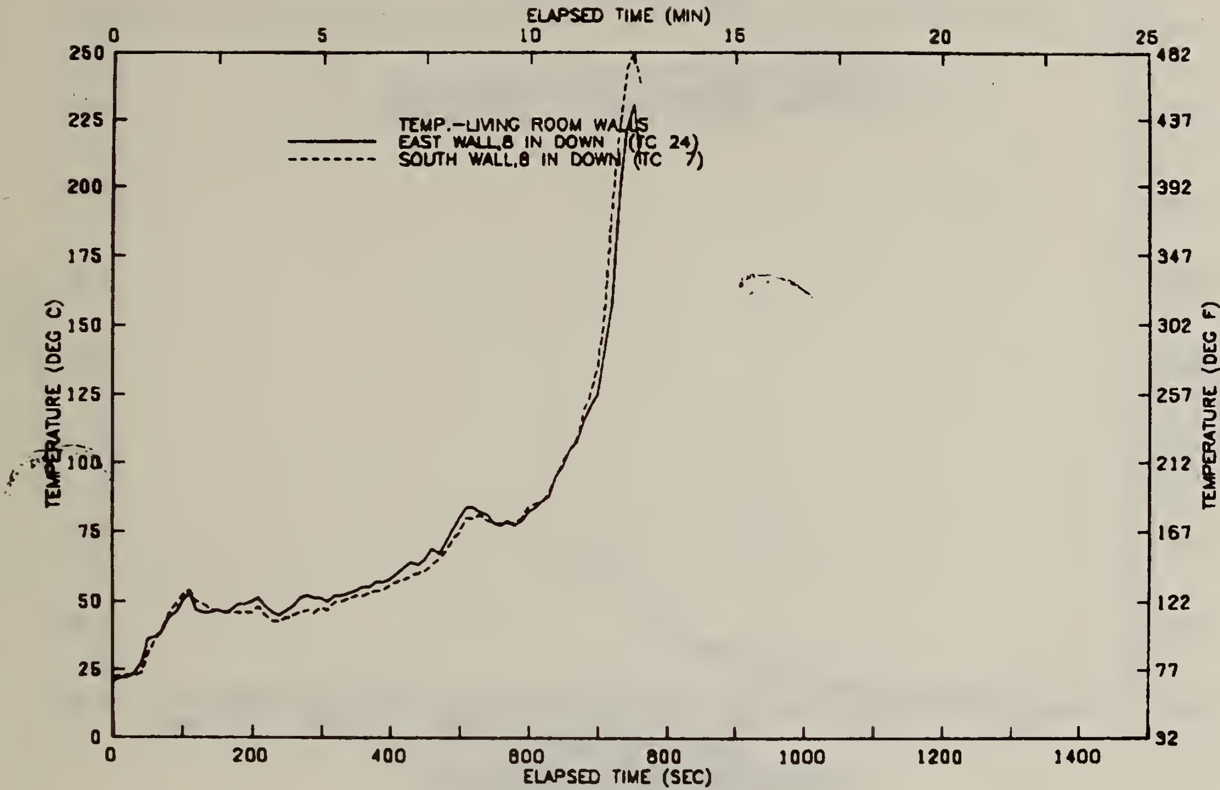

FIGURE B93 TEMPERATURE AT LIVING ROOM WALLS-TEST 22

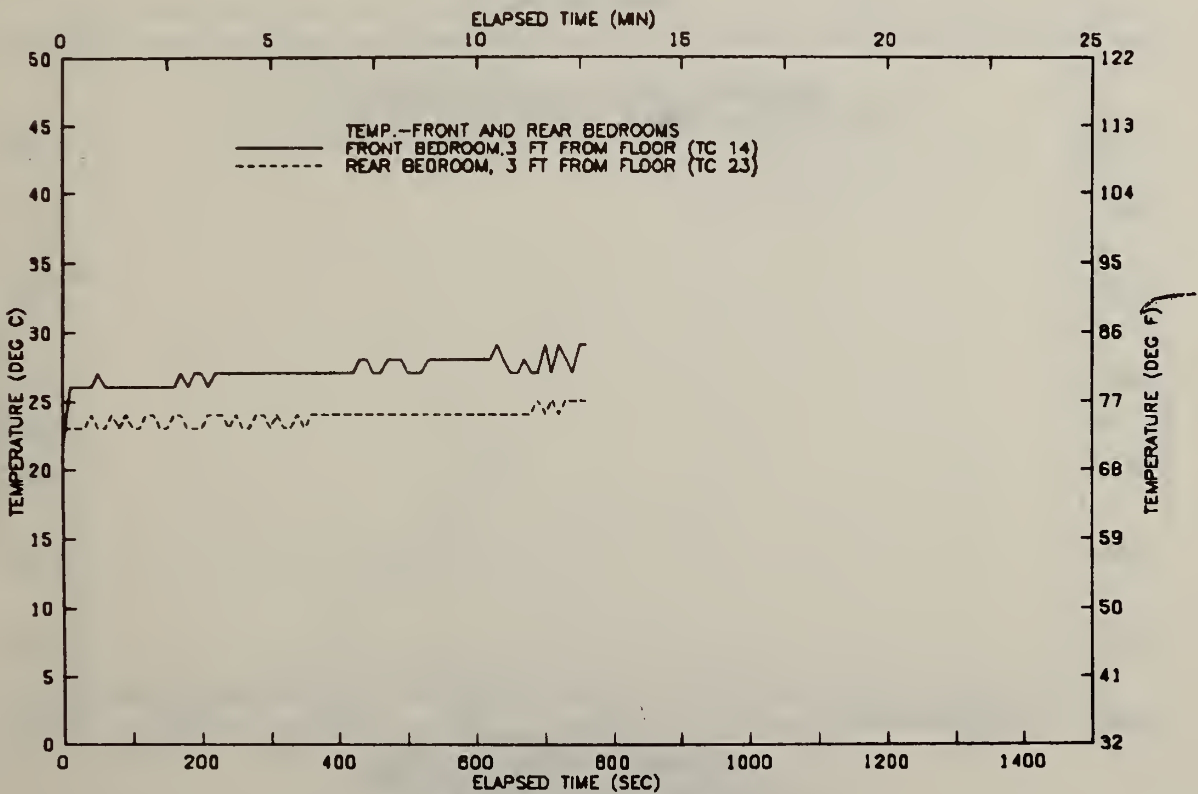

FIGURE B94 TEMP. IN FRONT AND REAR BEDROOMS-TEST 22

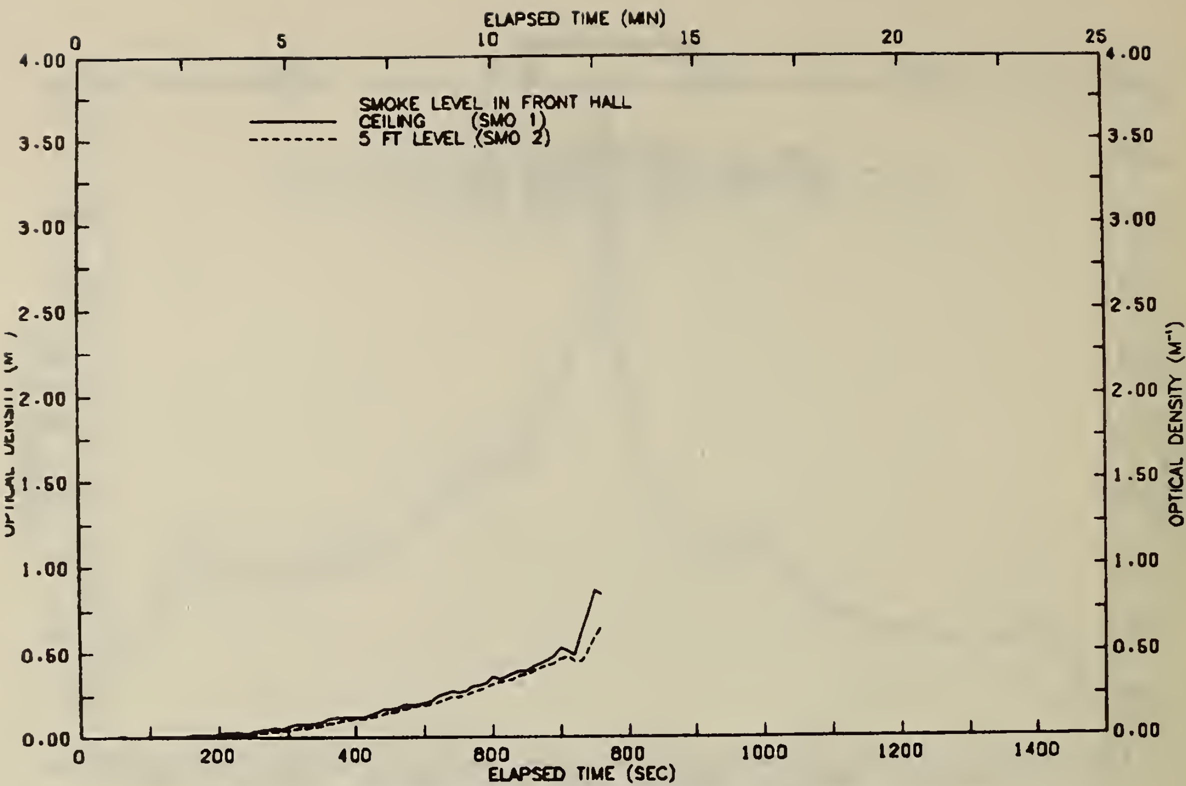

FIGURE B95 SMOKE LEVELS IN FRONT HALLWAY-TEST 22

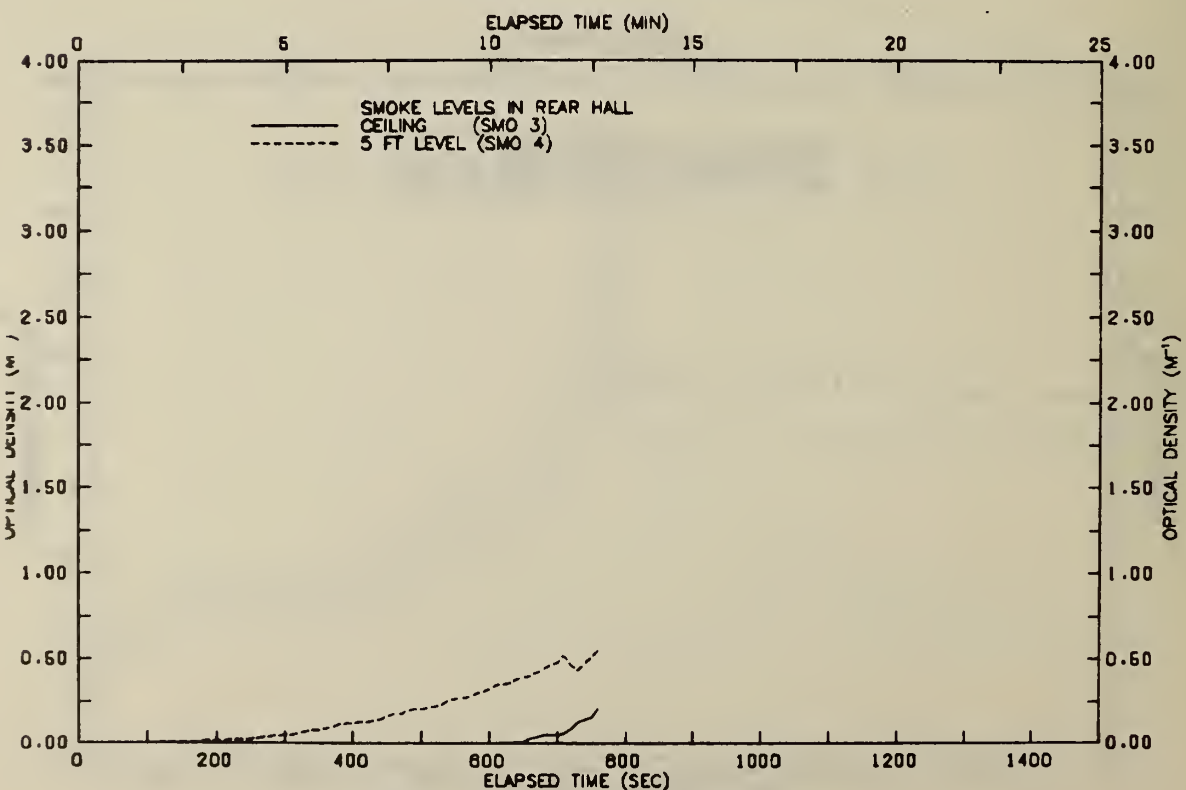

FIGURE B96 SMOKE LEVELS IN REAR HALLWAY-TEST 22

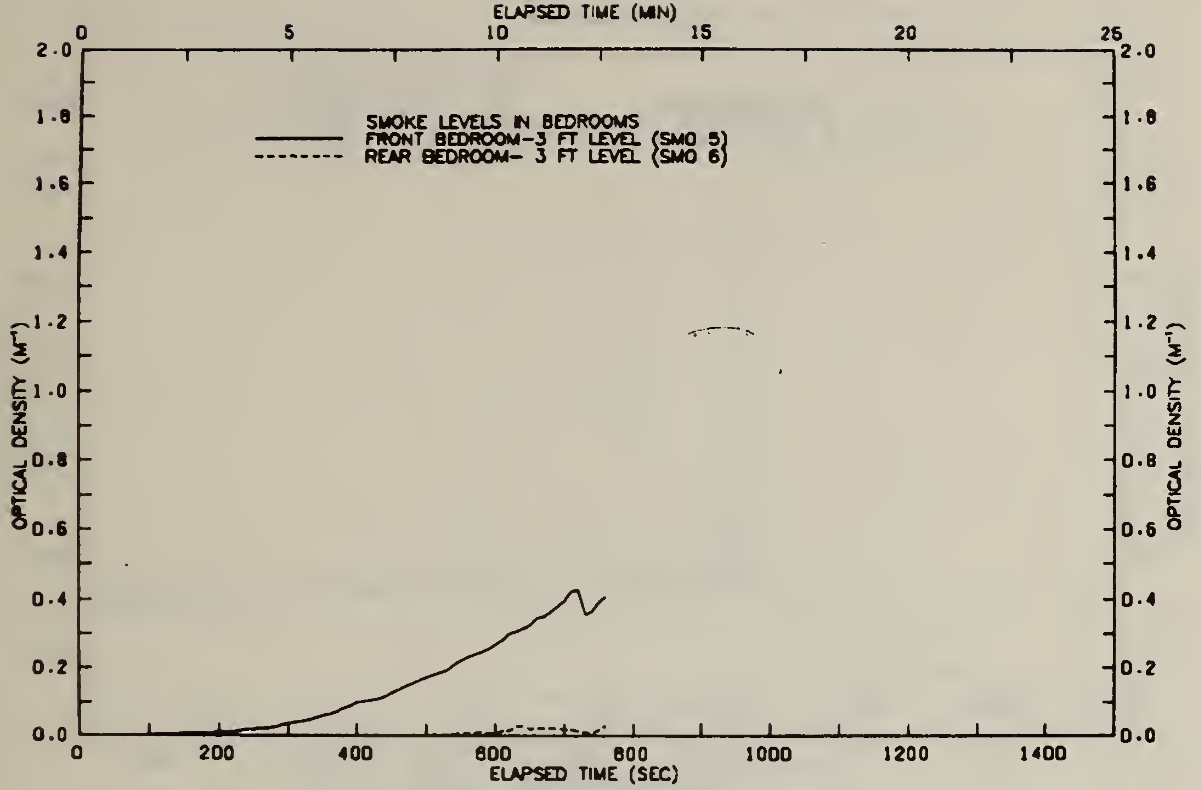

FIGURE B97 SMOKE LEVELS IN BEDROOMS-TEST 22

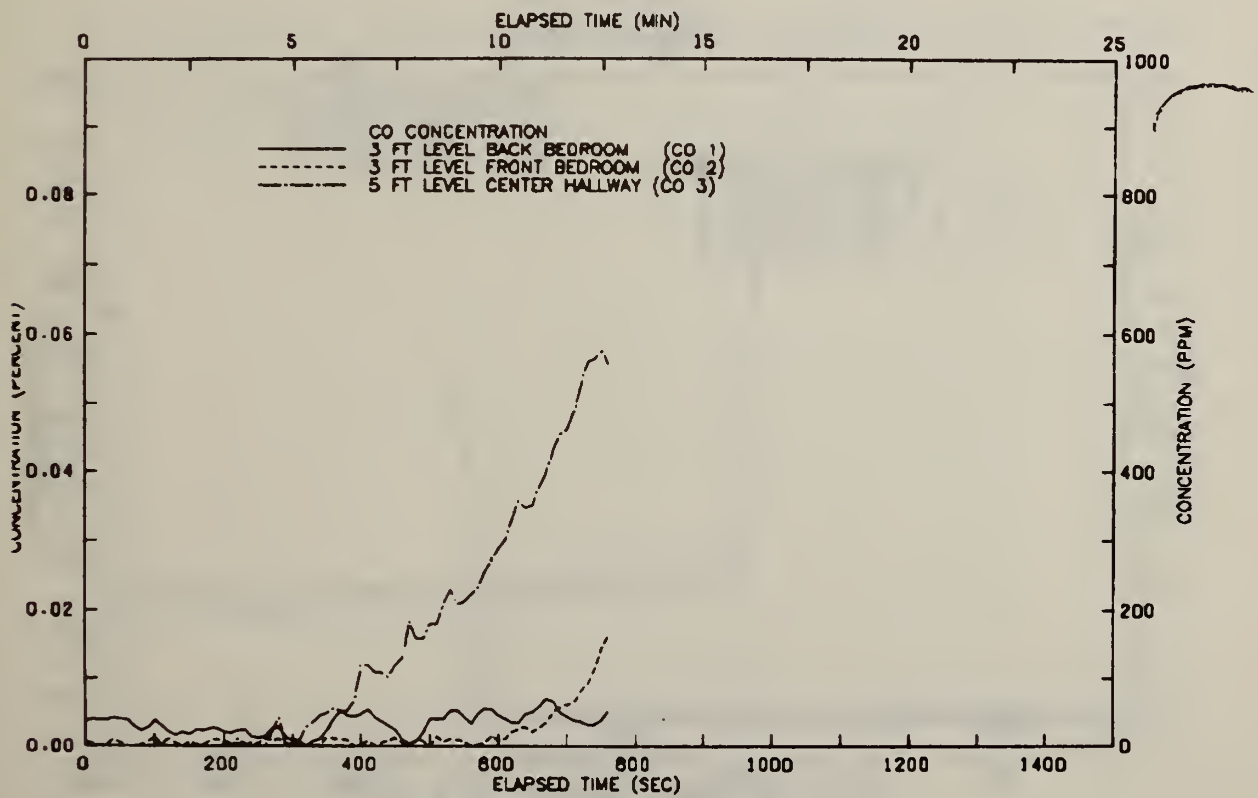

FIGURE B98 CARBON MONOXIDE CONCENTRATION-TEST 22

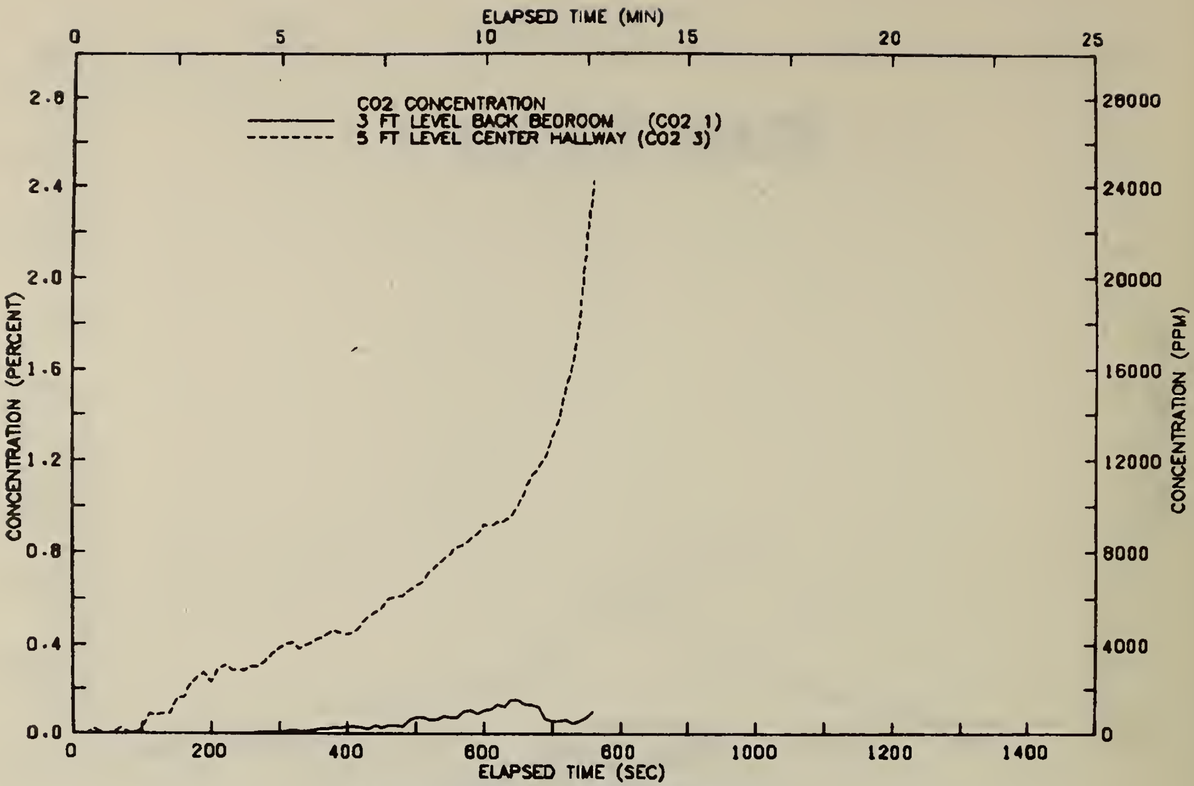

FIGURE B99 CARBON DIOXIDE CONCENTRATION–TEST 22

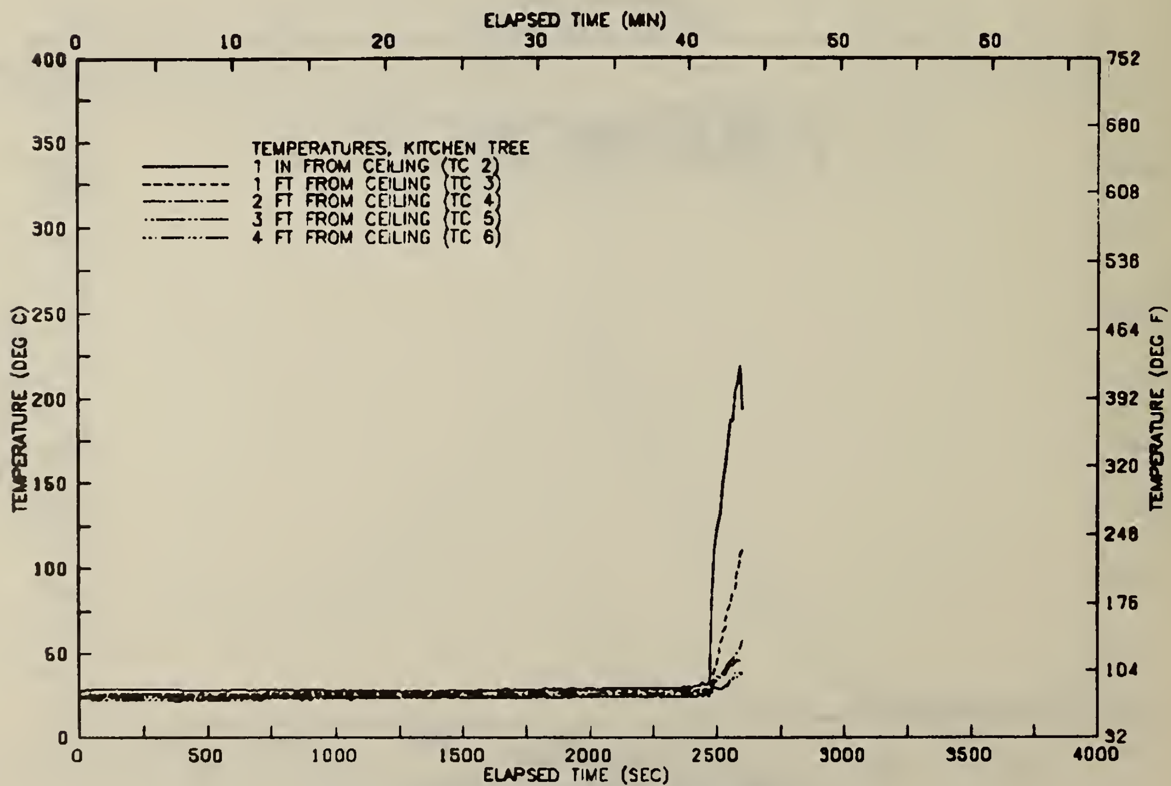

FIGURE B100 VERTICAL TEMP. PROFILE IN KITCHEN–TEST 23

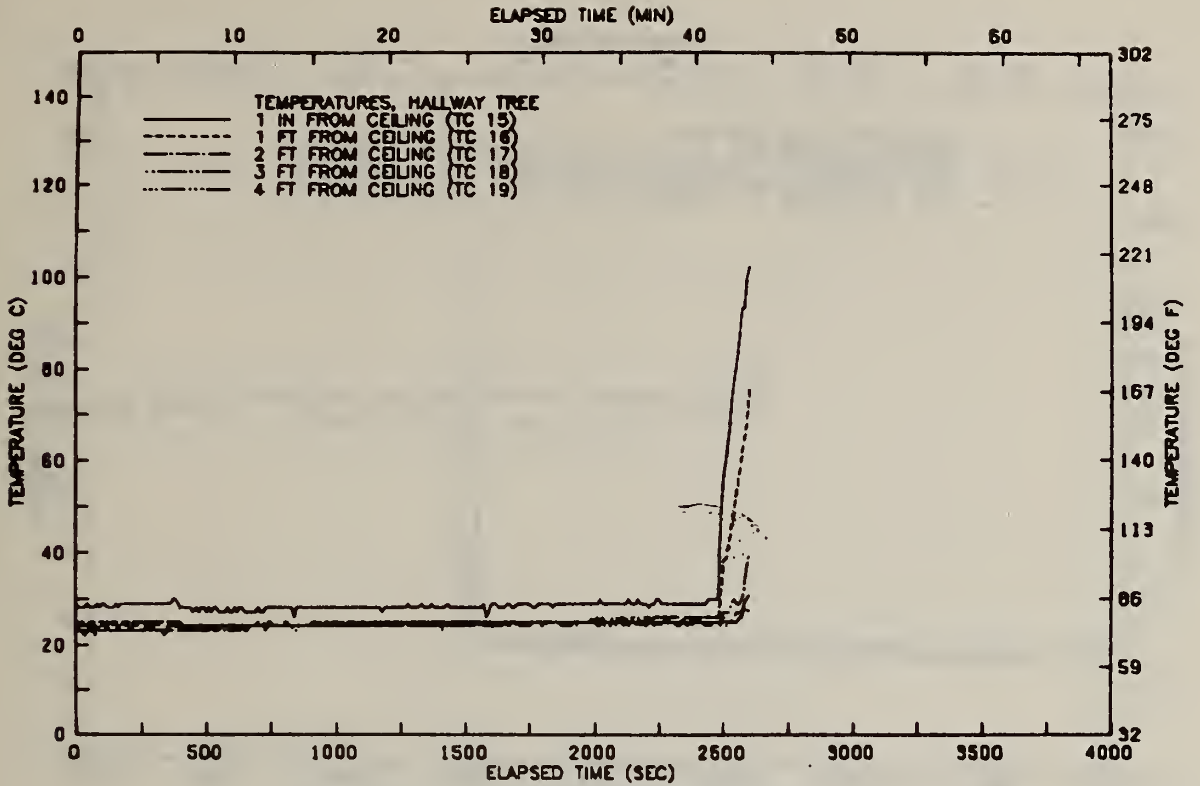

FIGURE B101 VERTICAL TEMP. PROFILE
IN HALLWAY-TEST 23

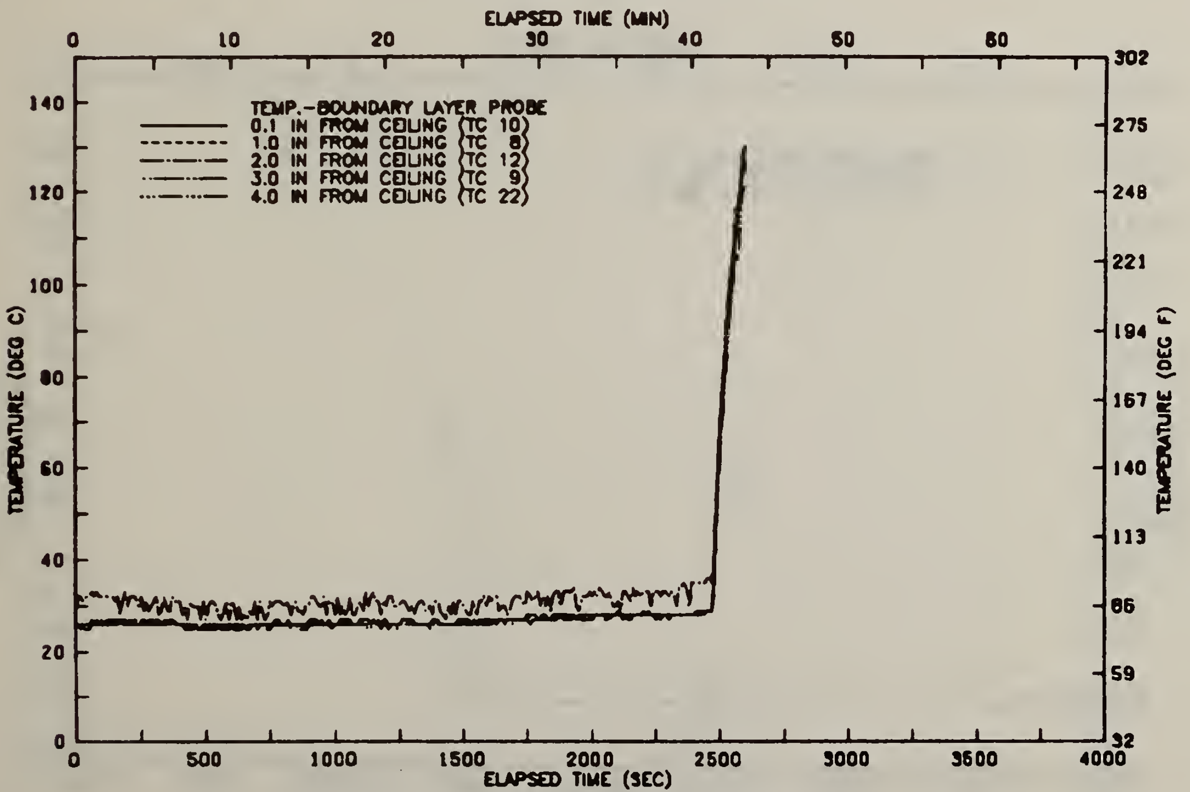

FIGURE B102 VERTICAL TEMP. PROFILE
CEILING BOUNDARY LAYER-TEST 23

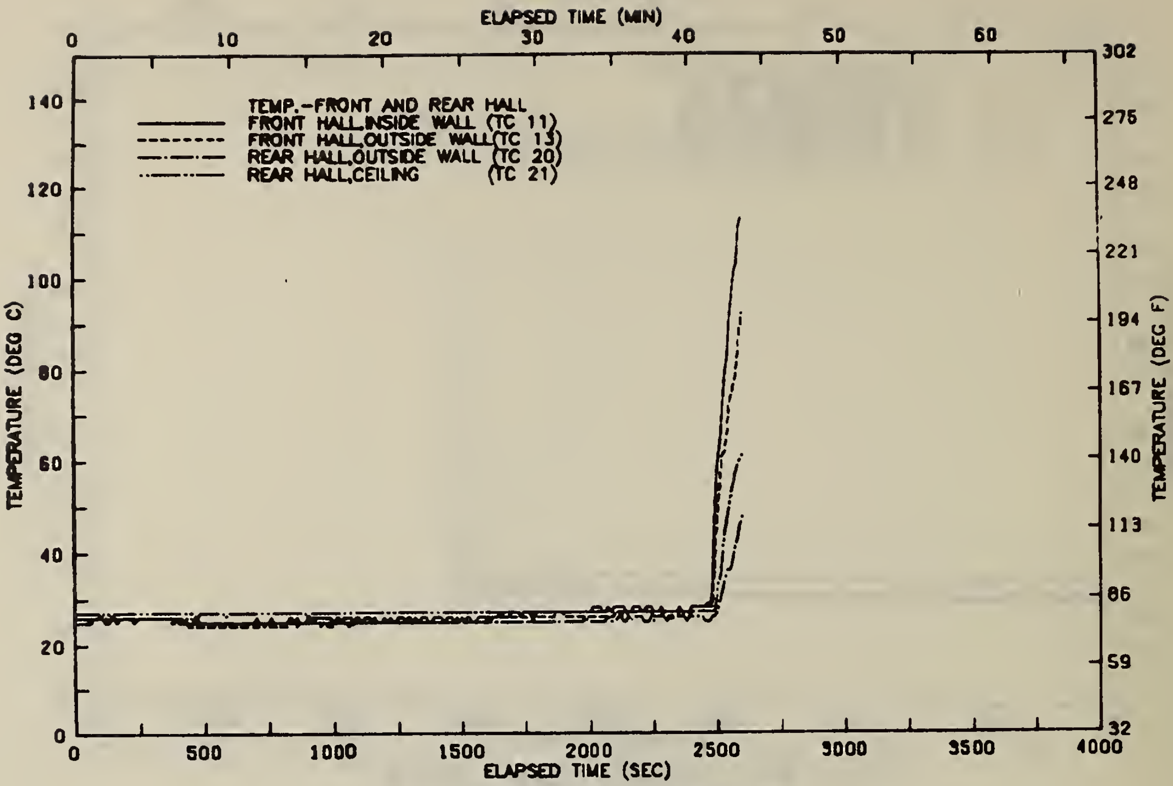

FIGURE B103 TEMP. IN HALLWAY NEAR DETECTORS-TEST 23

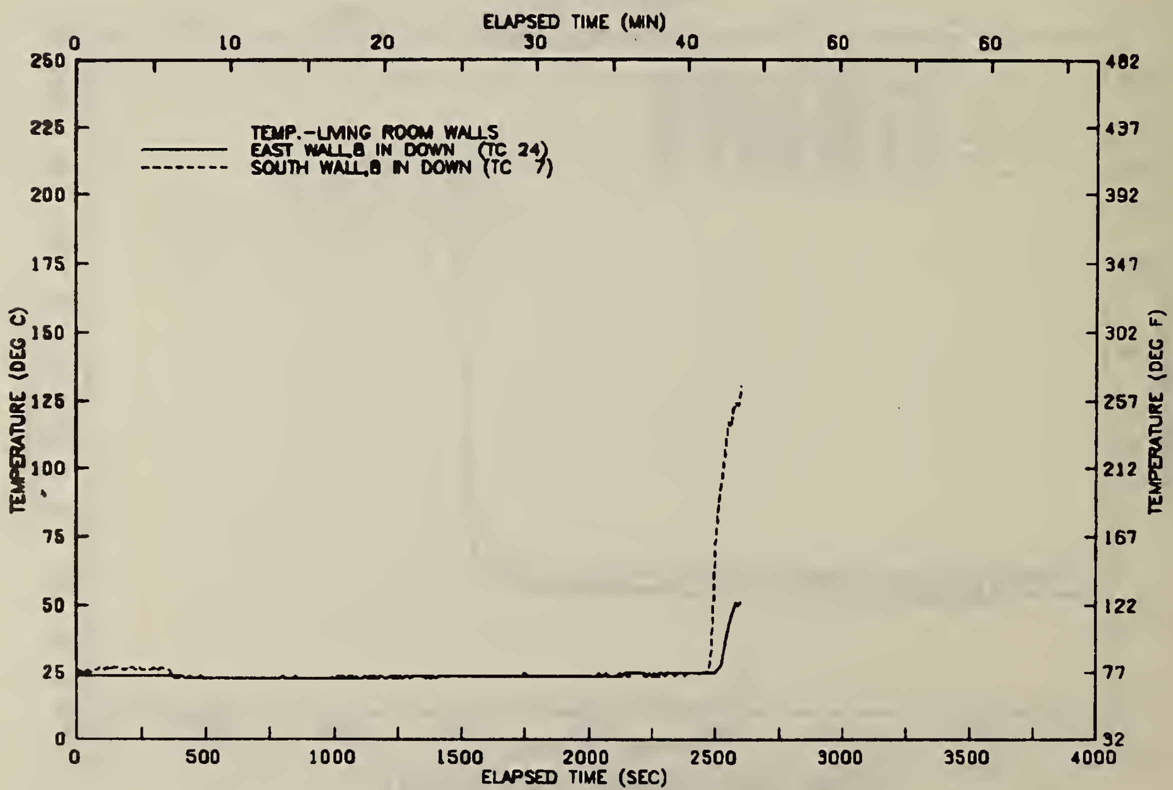

FIGURE B104 TEMPERATURE AT LIVING ROOM WALLS-TEST 23

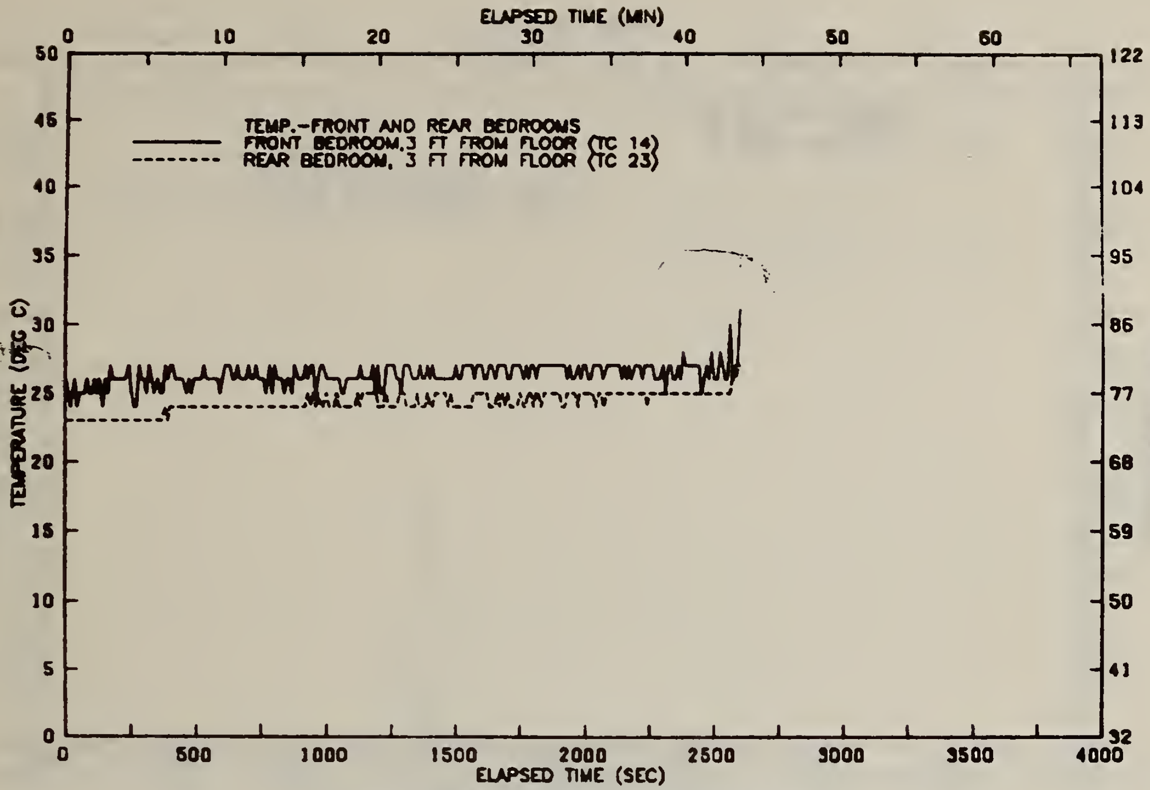

FIGURE B105 TEMP. IN FRONT AND REAR BEDROOMS-TEST 23

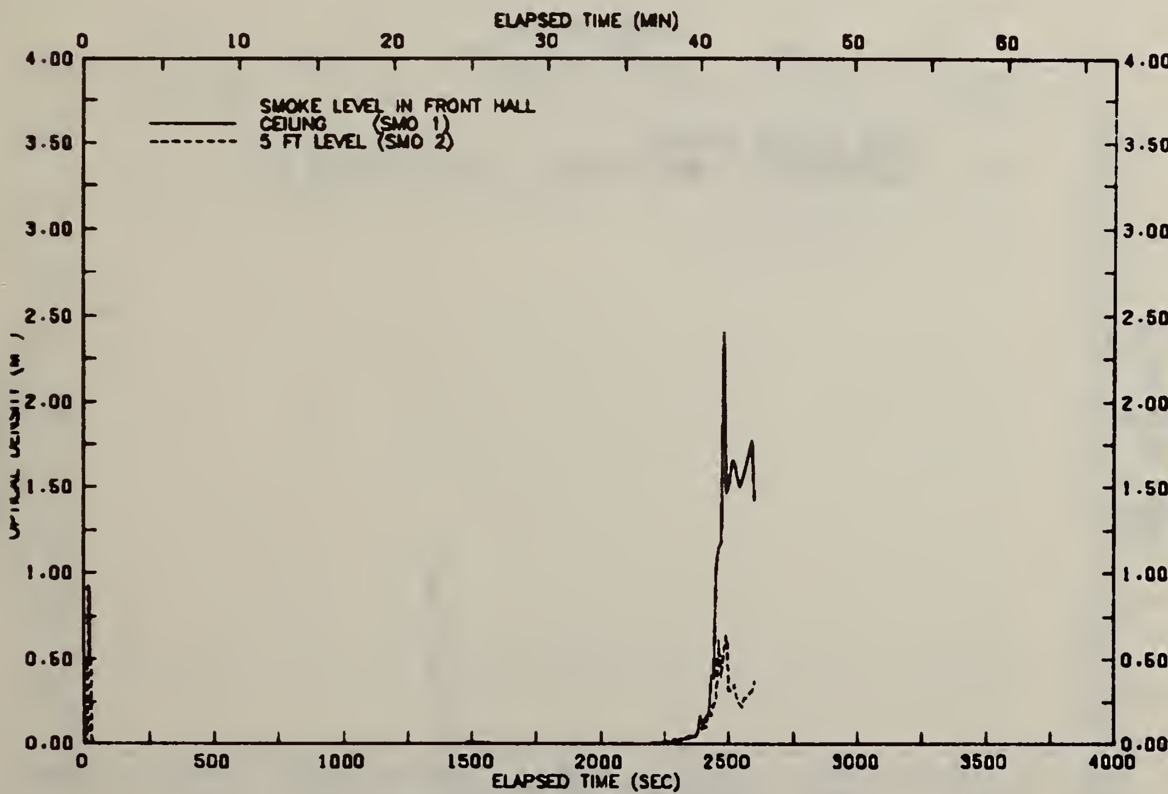

FIGURE B106 SMOKE LEVELS IN FRONT HALLWAY-TEST 23

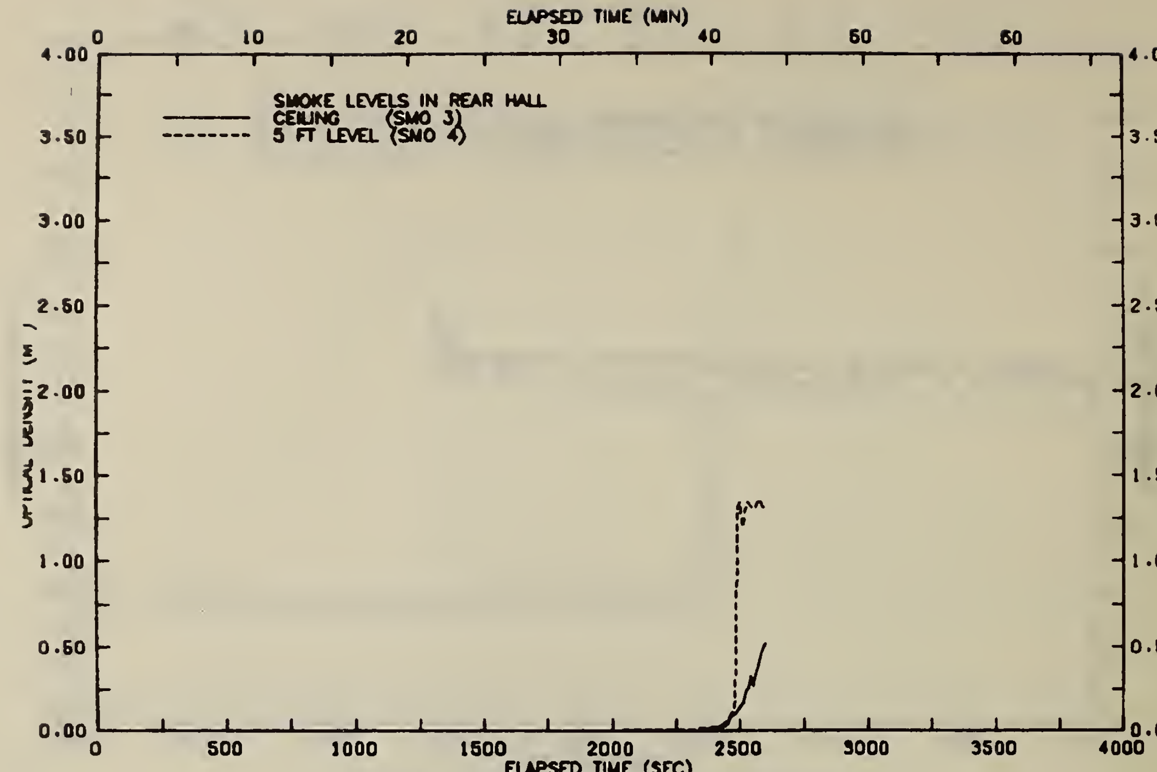

FIGURE B107 SMOKE LEVELS IN REAR HALLWAY–TEST 23

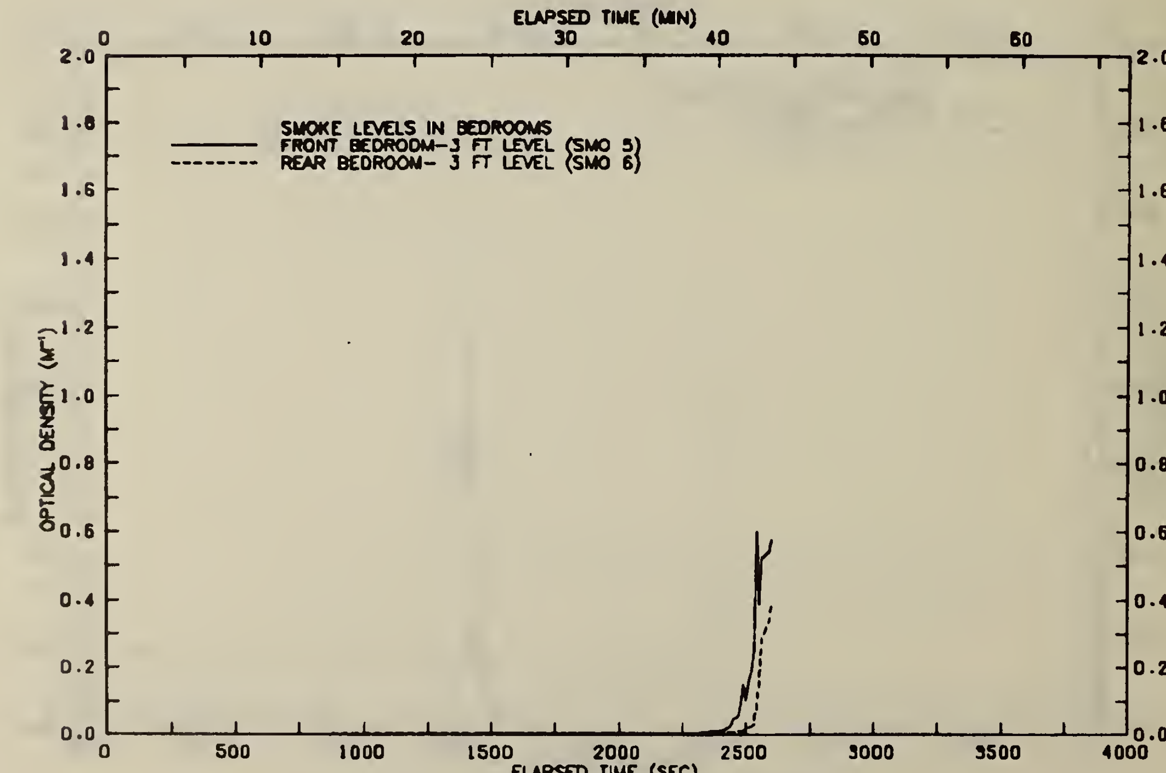

FIGURE B108 SMOKE LEVELS IN BEDROOMS–TEST 23

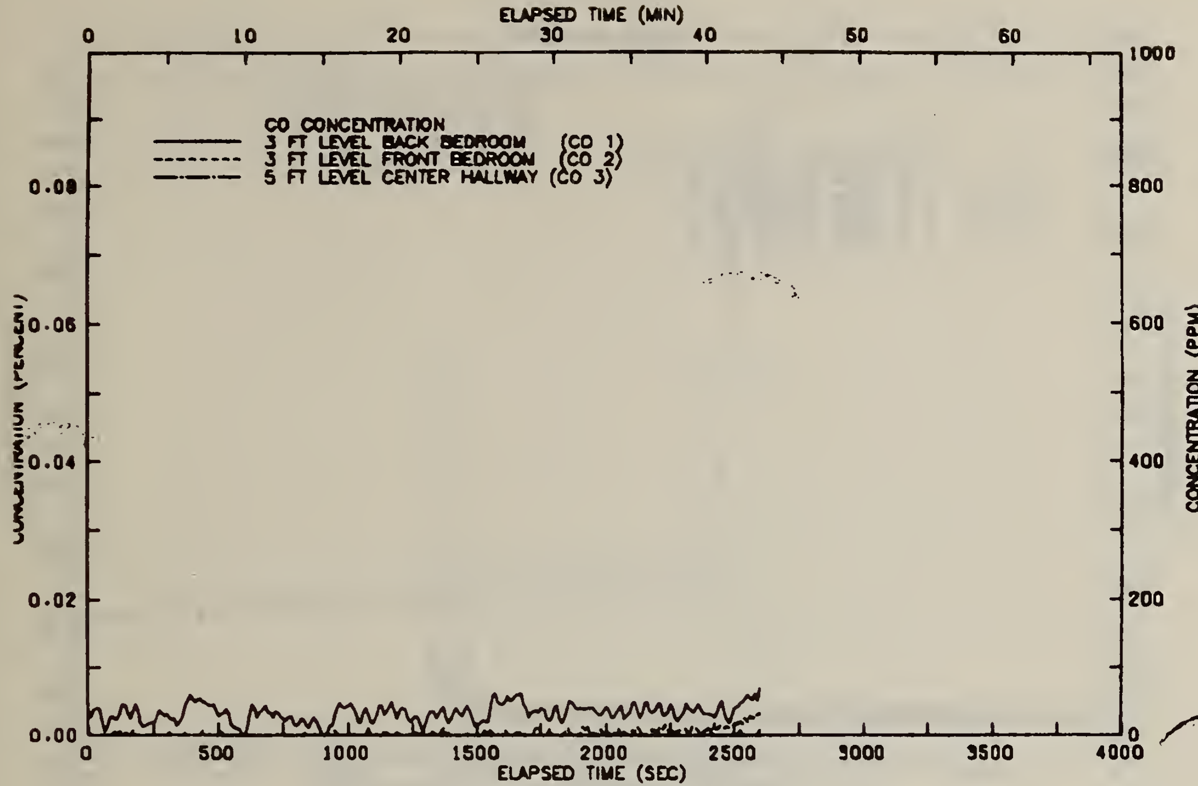

FIGURE B109 CARBON MONOXIDE CONCENTRATION-TEST 23

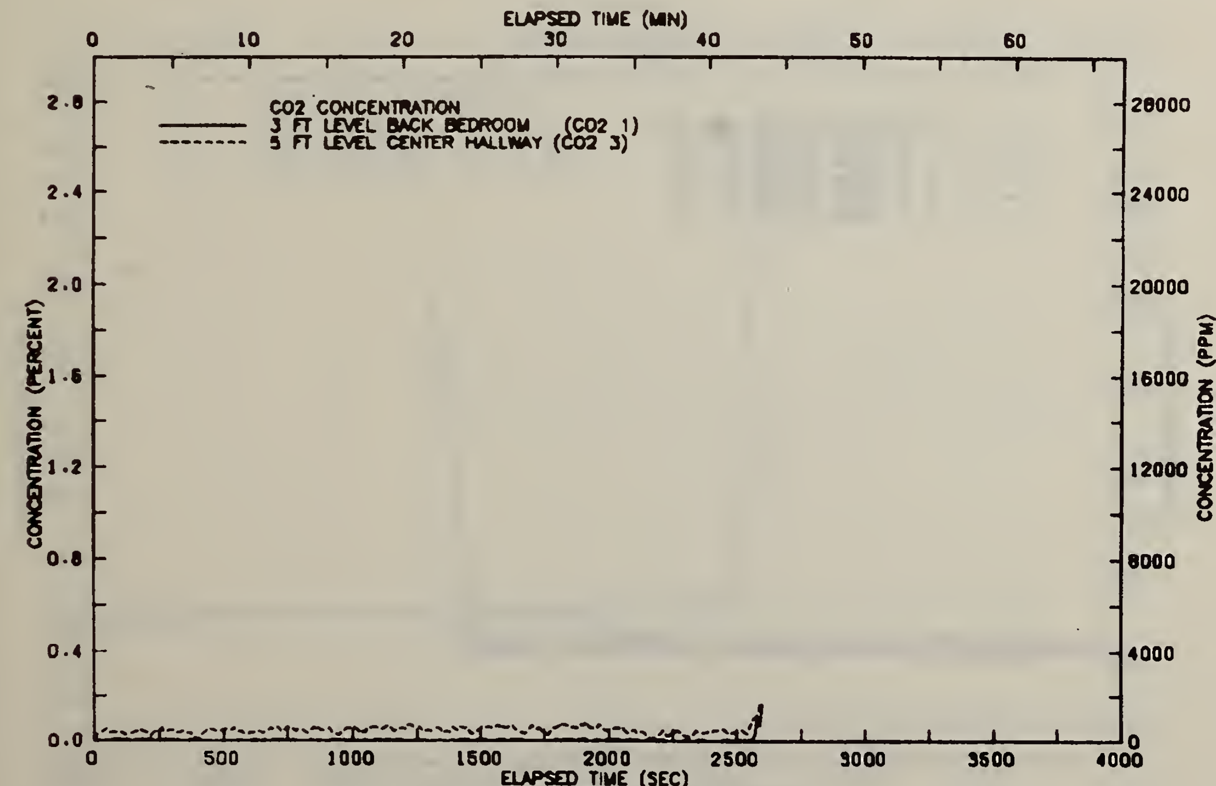

FIGURE B110 CARBON DIOXIDE CONCENTRATION-TEST 23

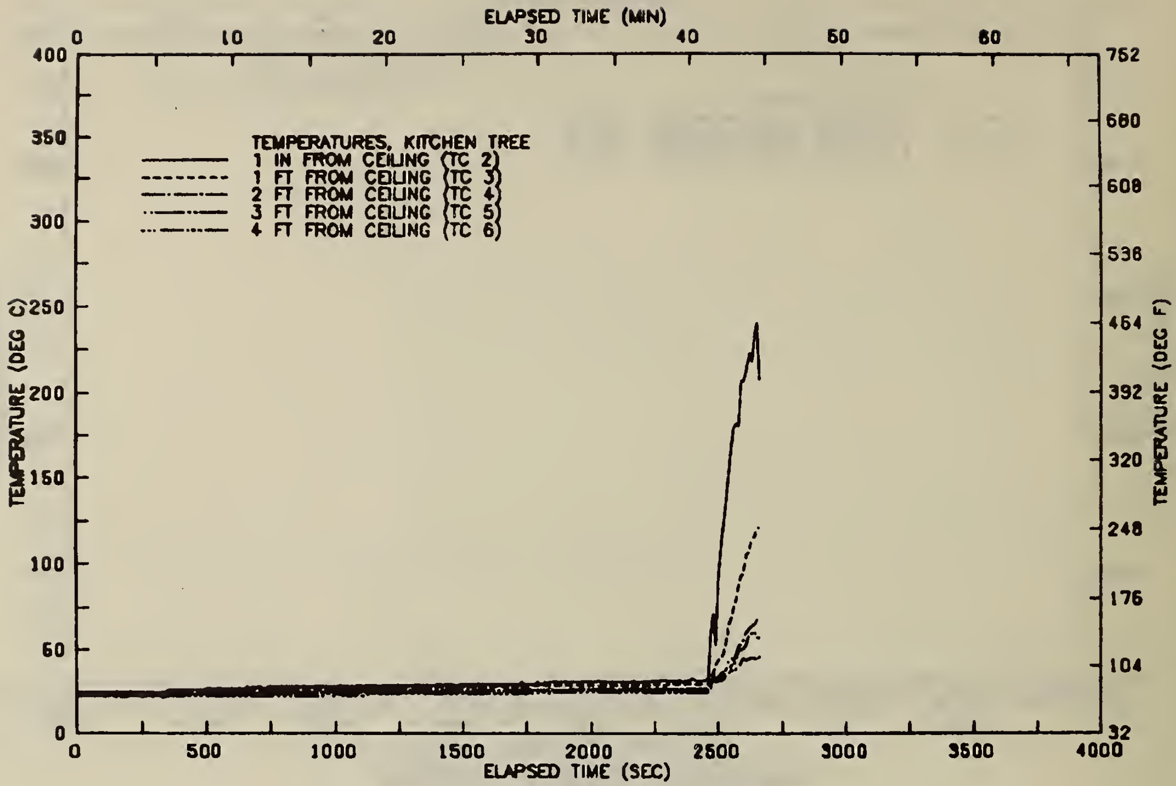

FIGURE B111 VERTICAL TEMP. PROFILE IN KITCHEN–TEST 24

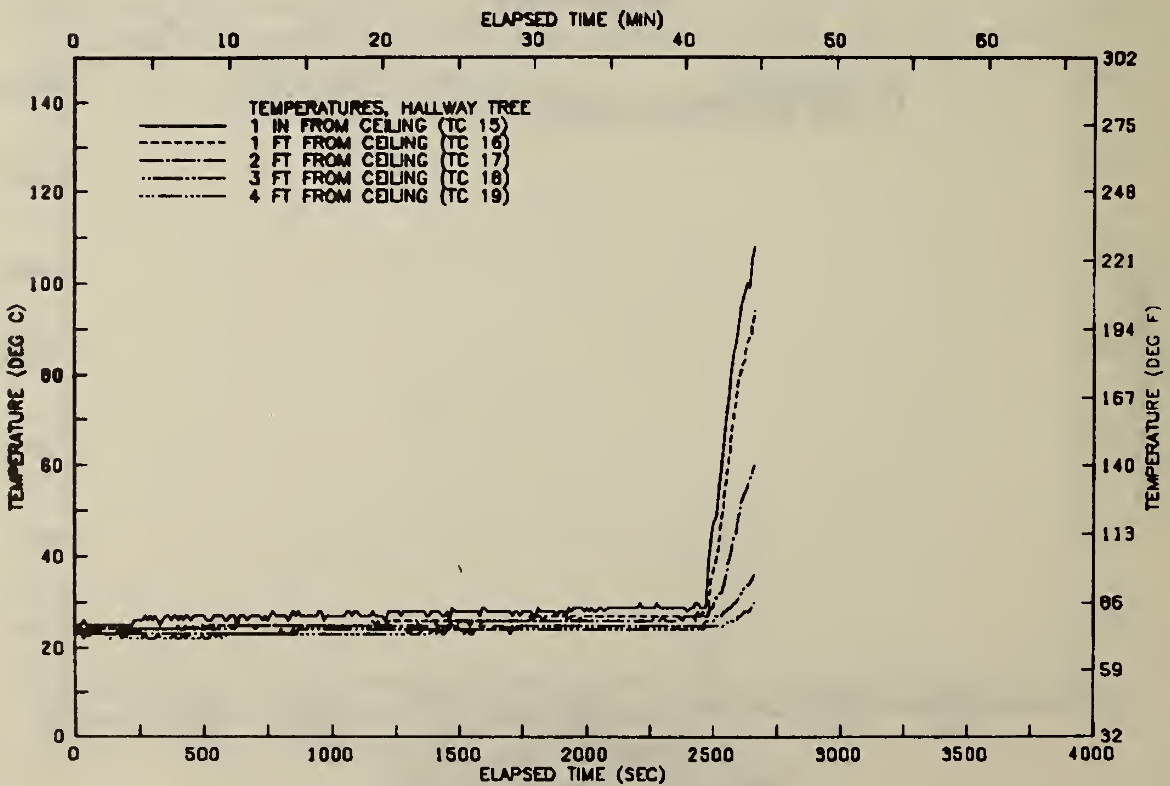

FIGURE B112 VERTICAL TEMP. PROFILE IN HALLWAY–TEST 24

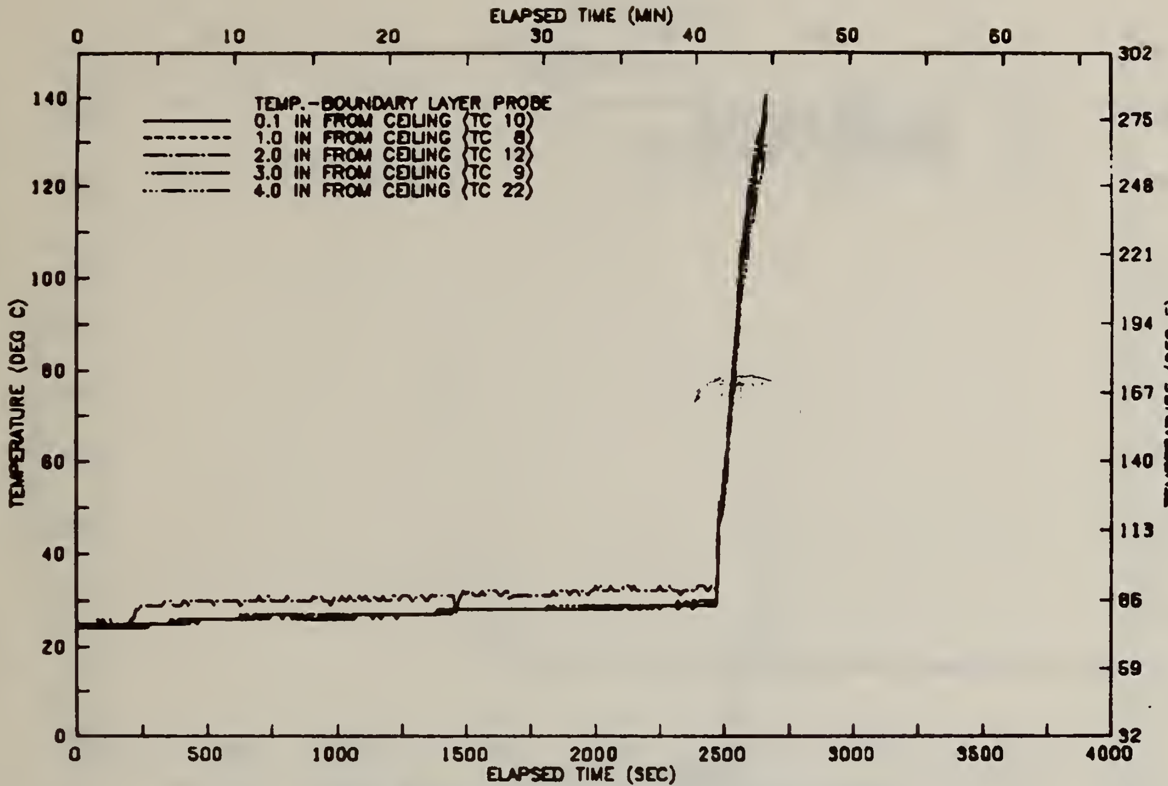

FIGURE B113 VERTICAL TEMP. PROFILE
CEILING BOUNDARY LAYER-TEST 24

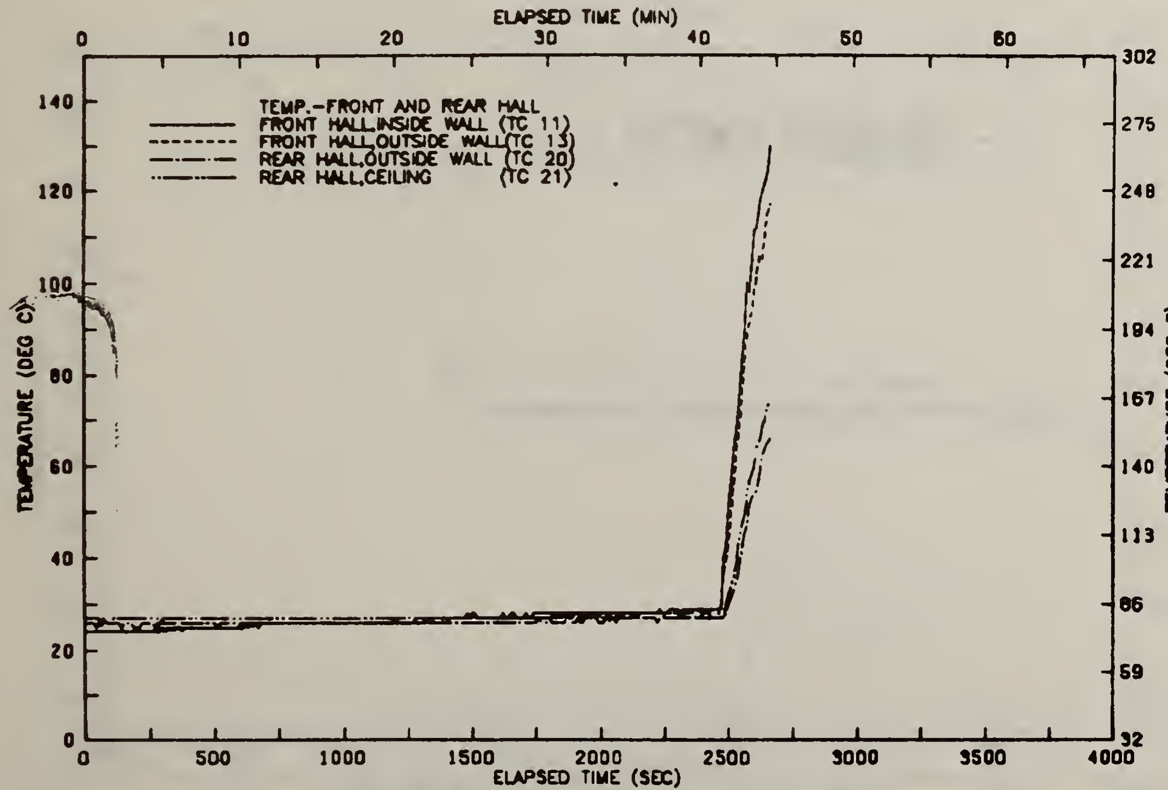

FIGURE B114 TEMP. IN HALLWAY
NEAR DETECTORS-TEST 24

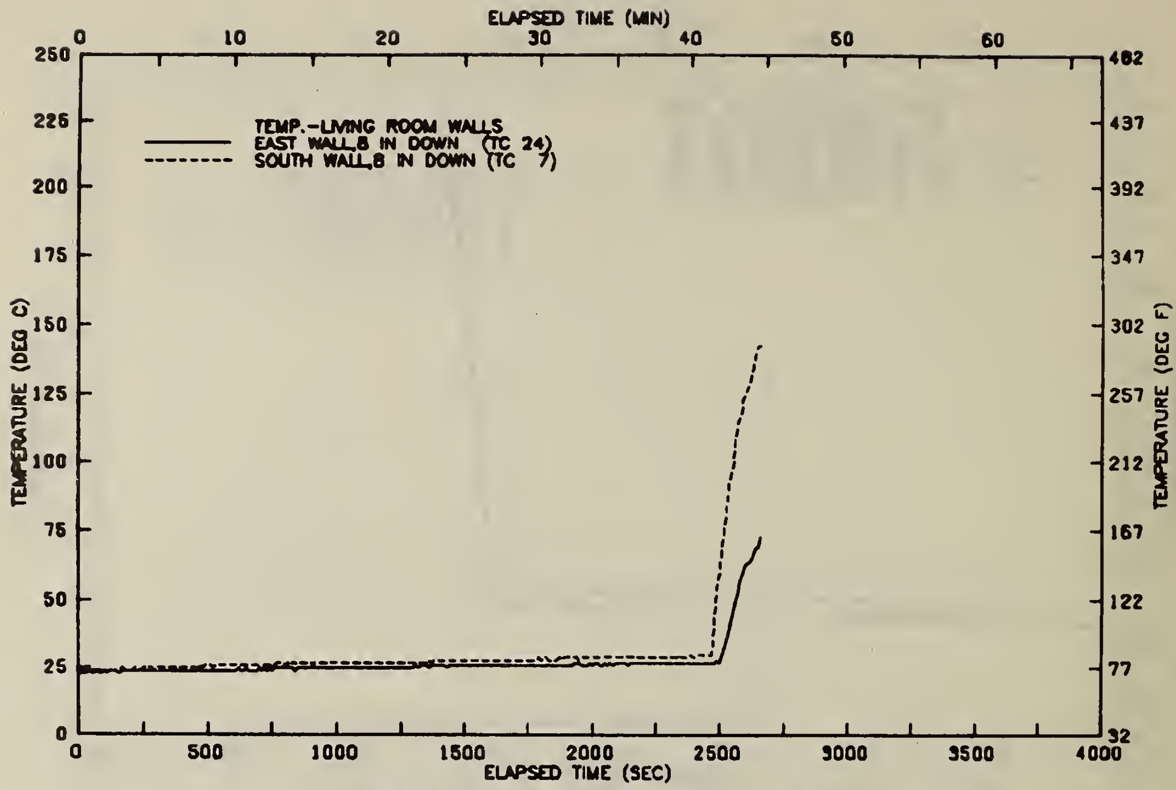

FIGURE B115 TEMPERATURE AT LIVING ROOM WALLS-TEST 24

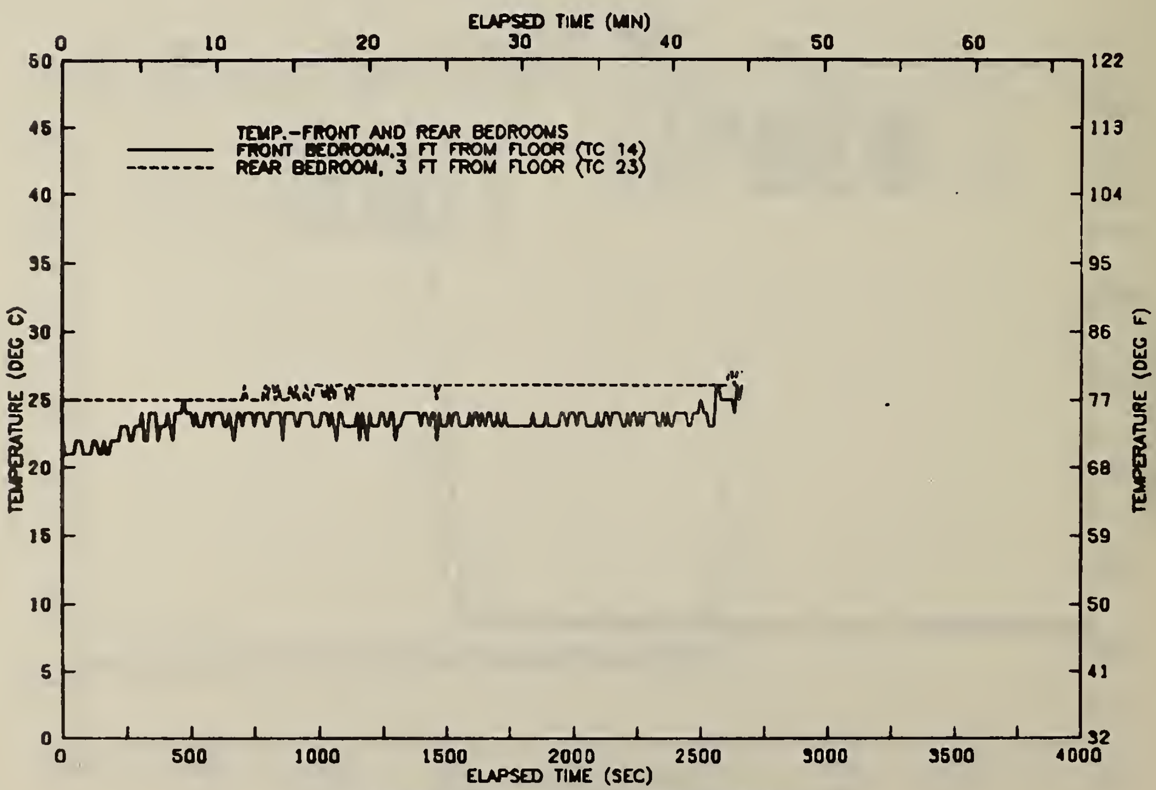

FIGURE B116 TEMP. IN FRONT AND REAR BEDROOMS-TEST 24

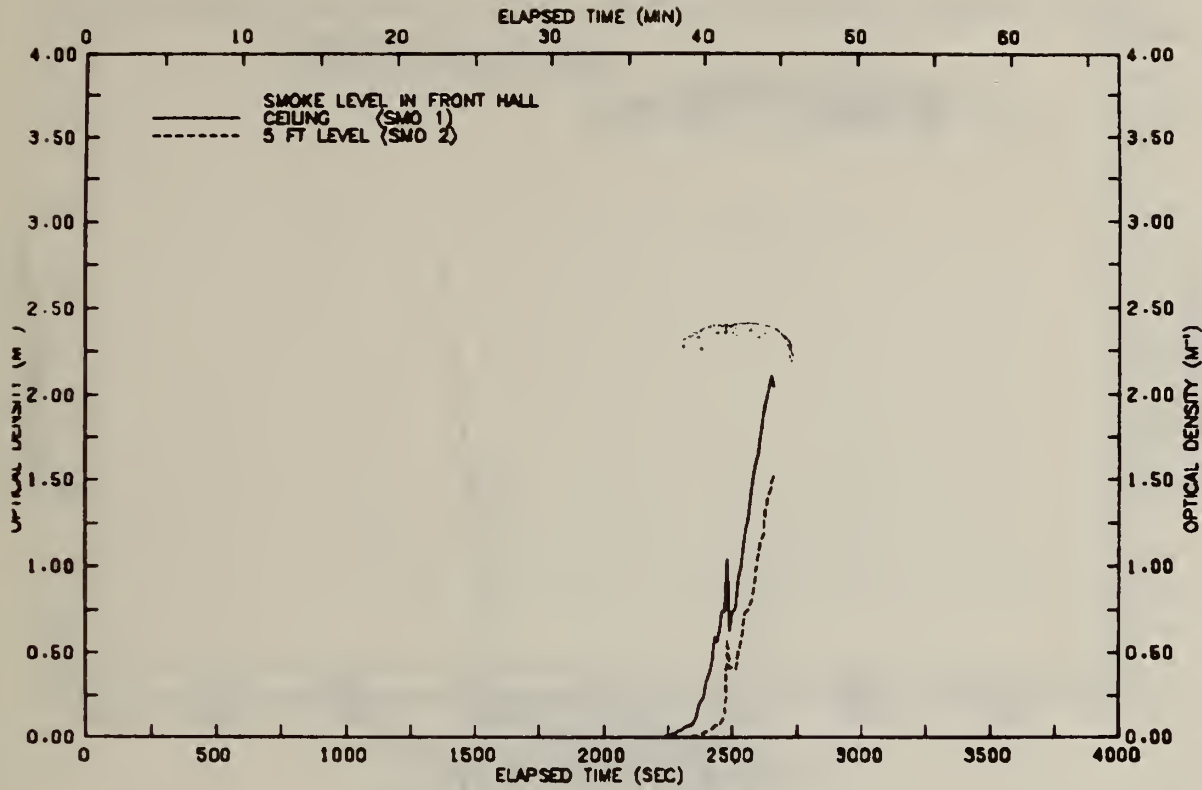

FIGURE B117 SMOKE LEVELS IN FRONT HALLWAY-TEST 24

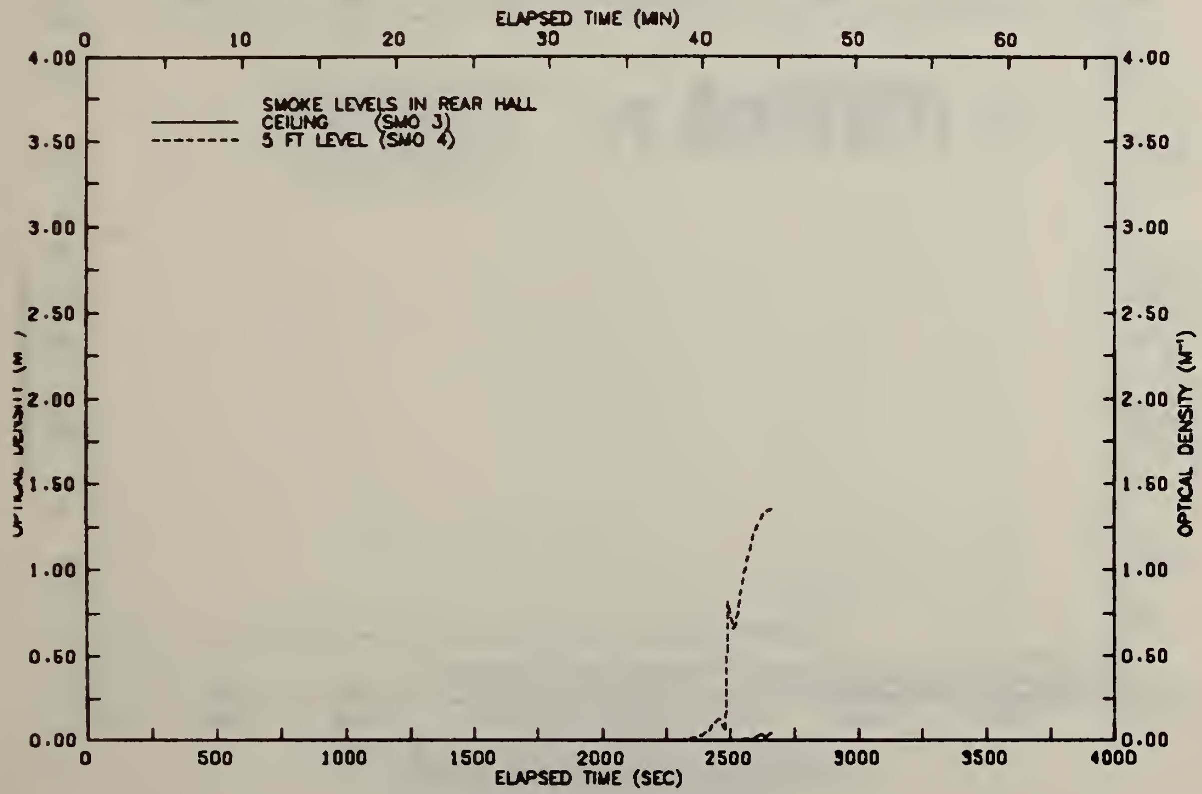

FIGURE B118 SMOKE LEVELS IN REAR HALLWAY-TEST 24

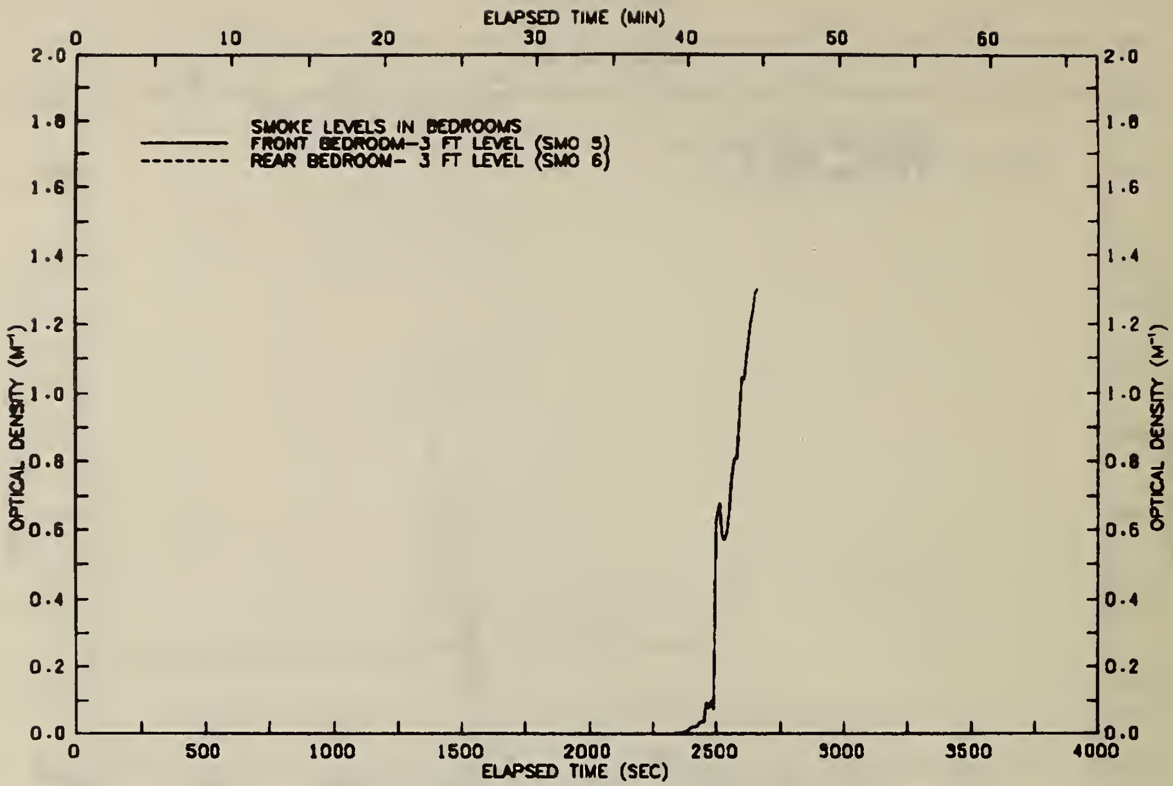

FIGURE B119 SMOKE LEVELS IN BEDROOMS-TEST 24

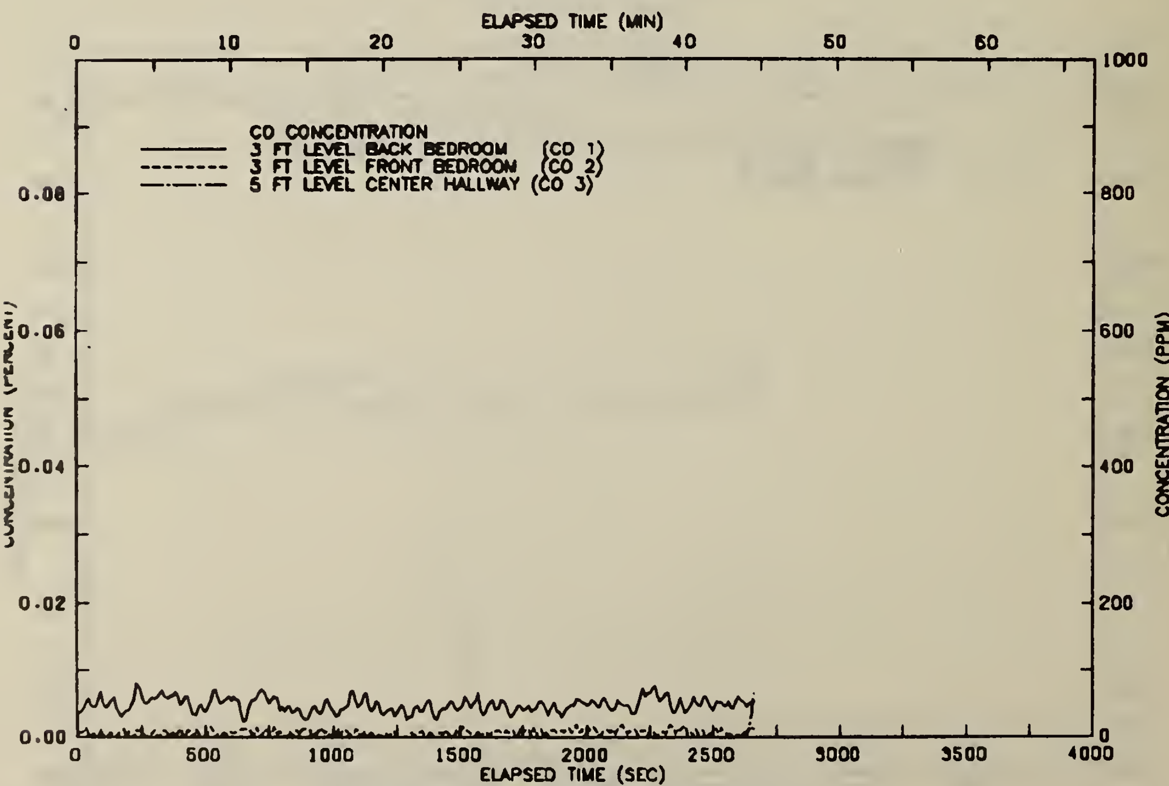

FIGURE B120 CARBON MONOXIDE CONCENTRATION-TEST 24

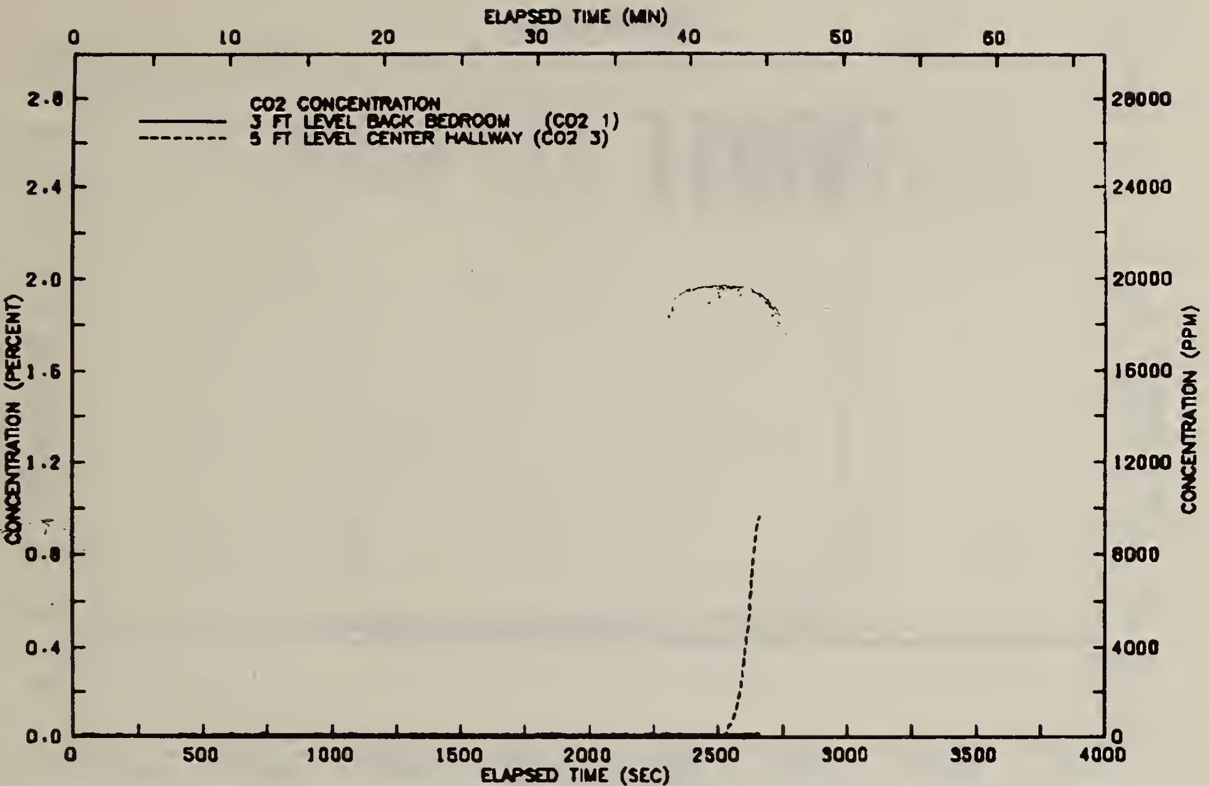

FIGURE B121 CARBON DIOXIDE CONCENTRATION–TEST 24

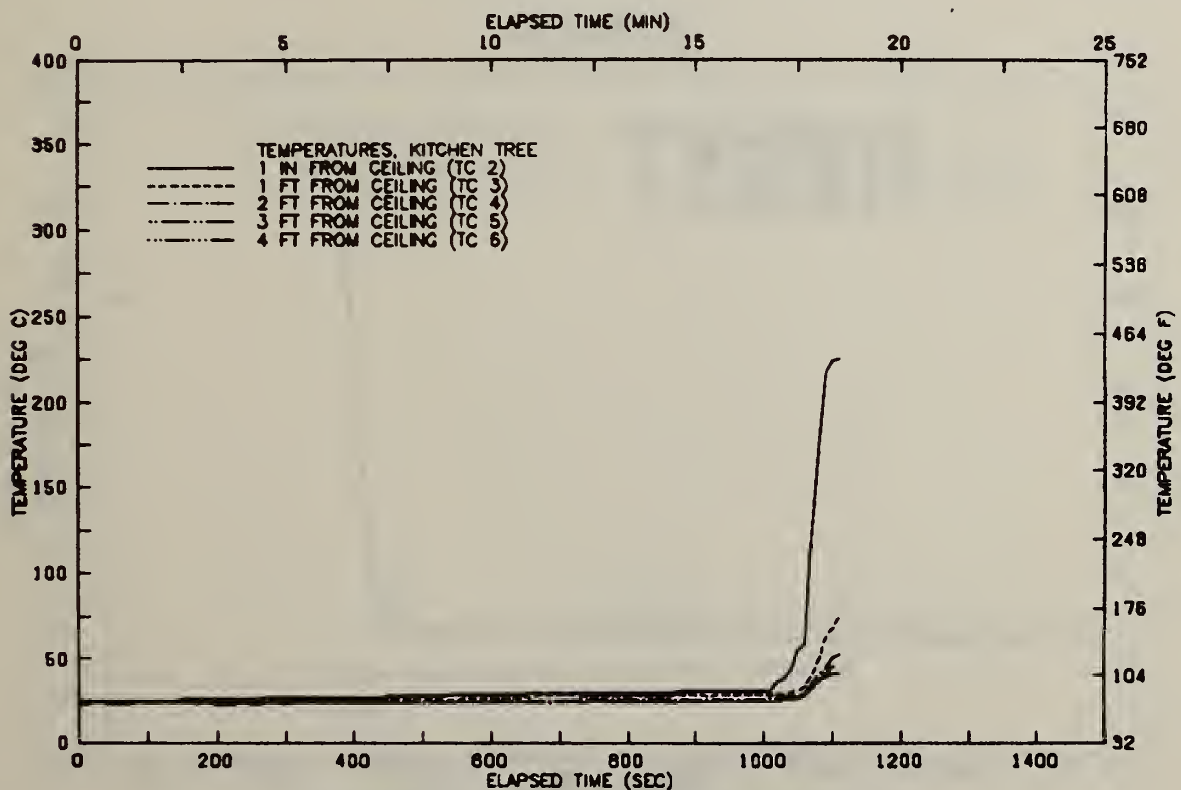

FIGURE B122 VERTICAL TEMP. PROFILE IN KITCHEN–TEST 25

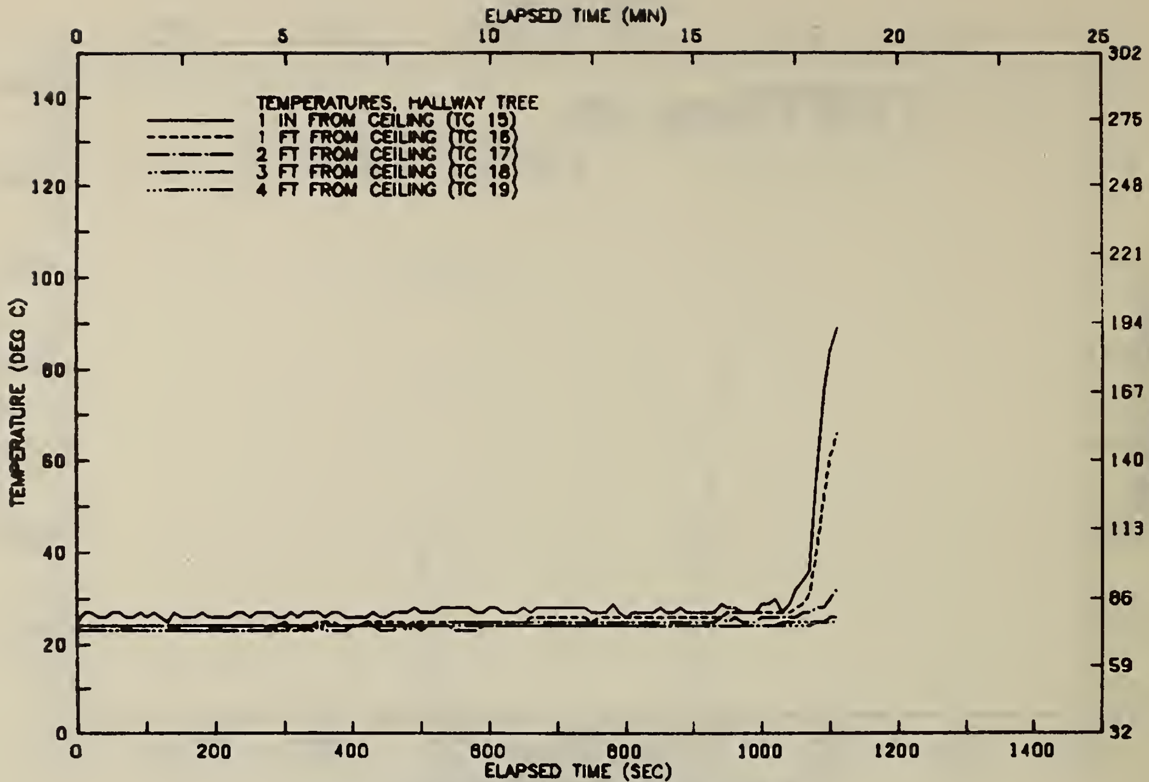

FIGURE B123 VERTICAL TEMP. PROFILE IN HALLWAY-TEST 25

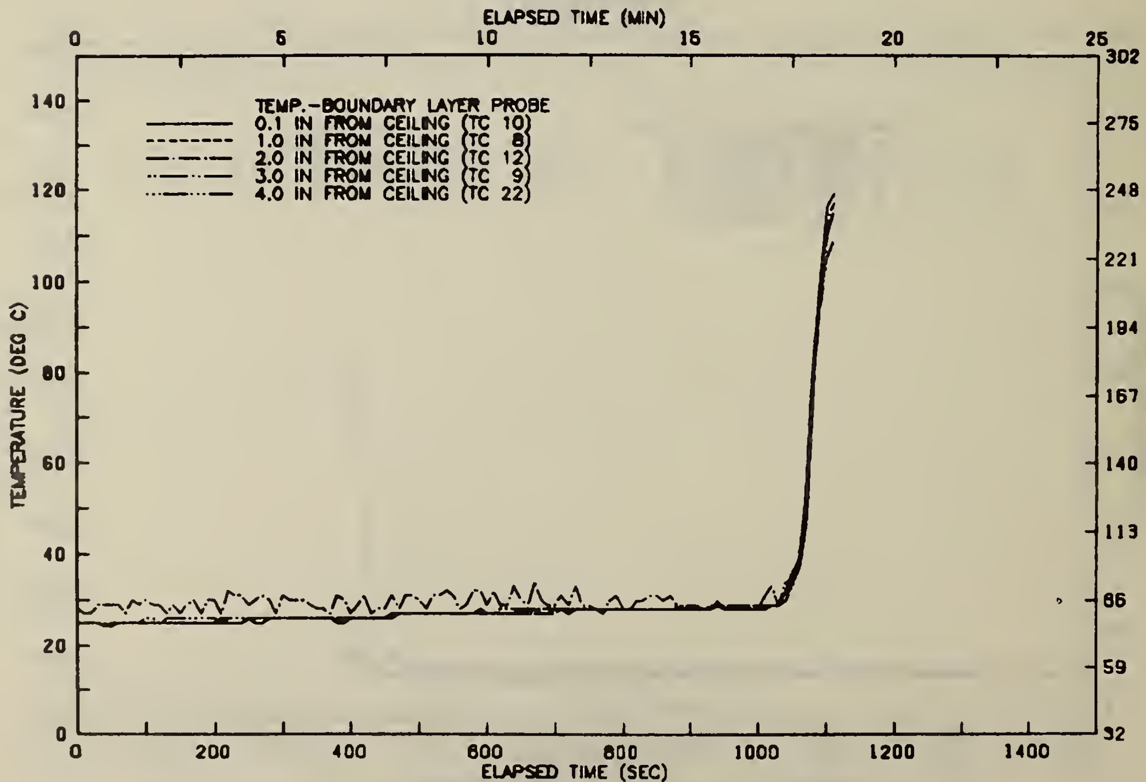

FIGURE B124 VERTICAL TEMP. PROFILE CEILING BOUNDARY LAYER-TEST 25

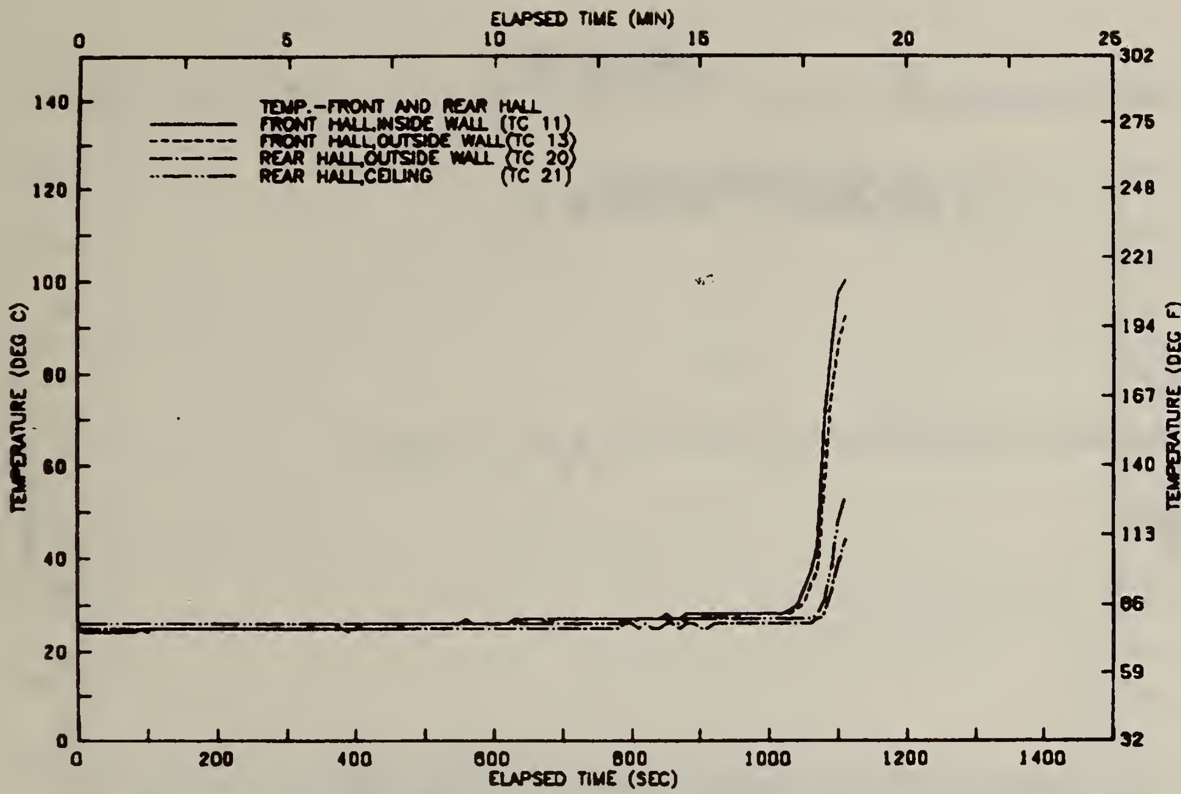

FIGURE B125 TEMP. IN HALLWAY NEAR DETECTORS–TEST 25

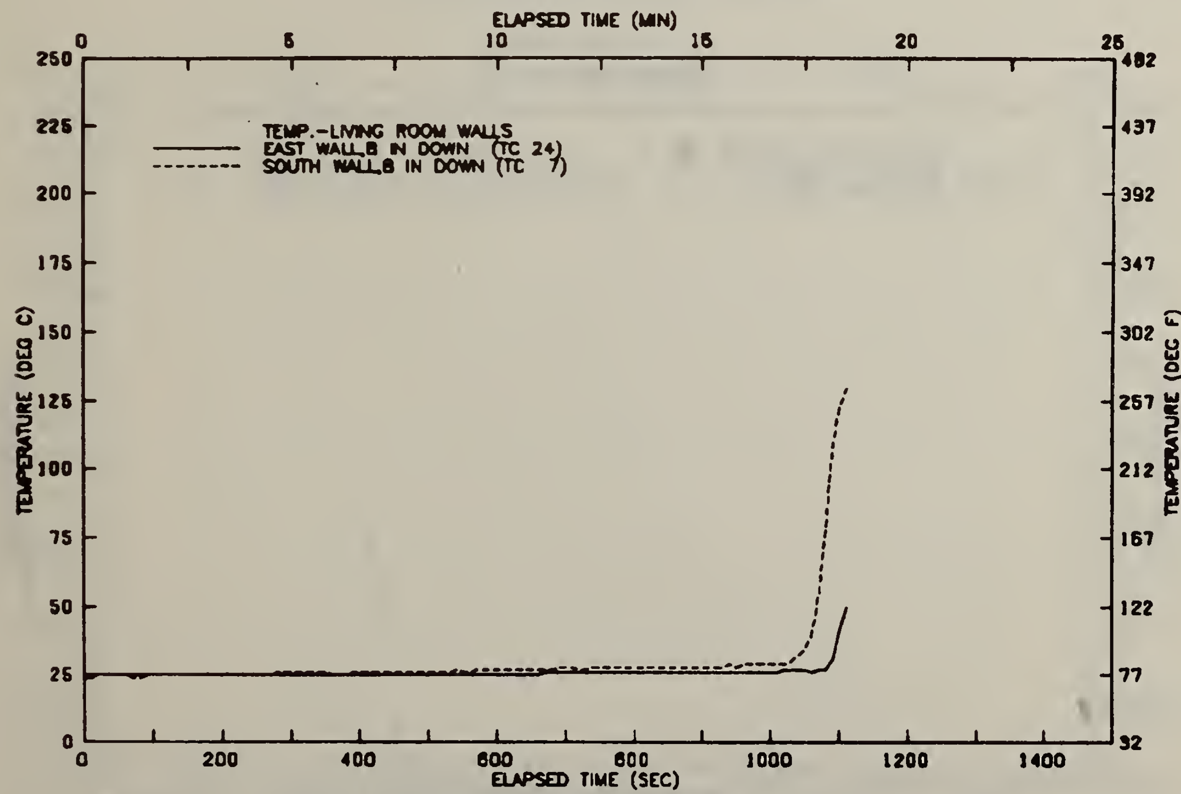

FIGURE B126 TEMPERATURE AT LIVING ROOM WALLS–TEST 25

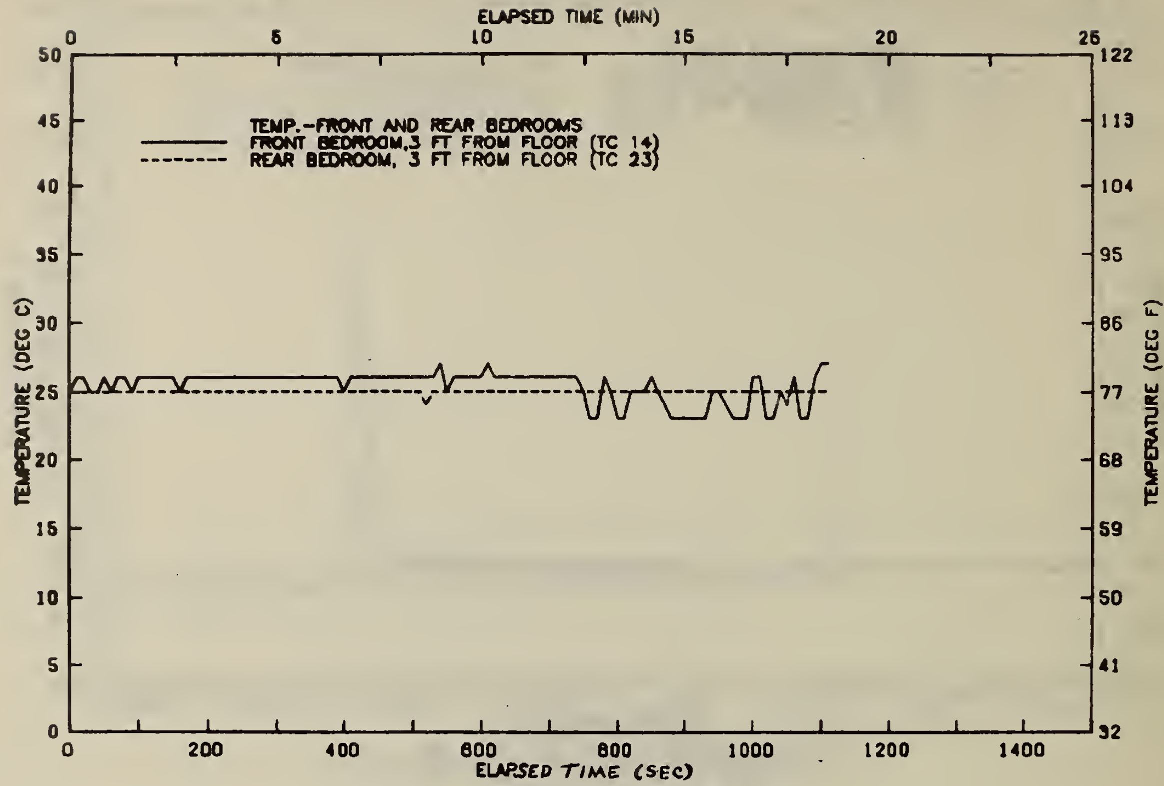

FIGURE B127 TEMP. IN FRONT AND REAR BEDROOMS-TEST 25

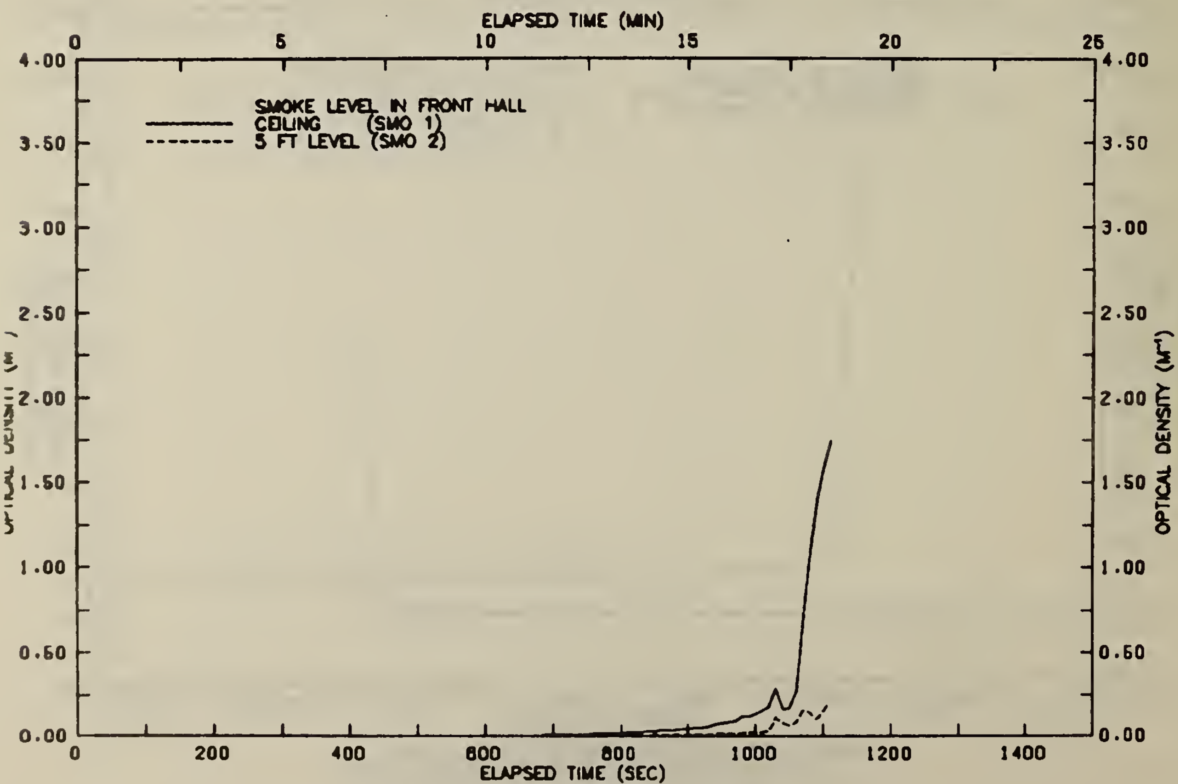

FIGURE B128 SMOKE LEVELS IN FRONT HALLWAY-TEST 25

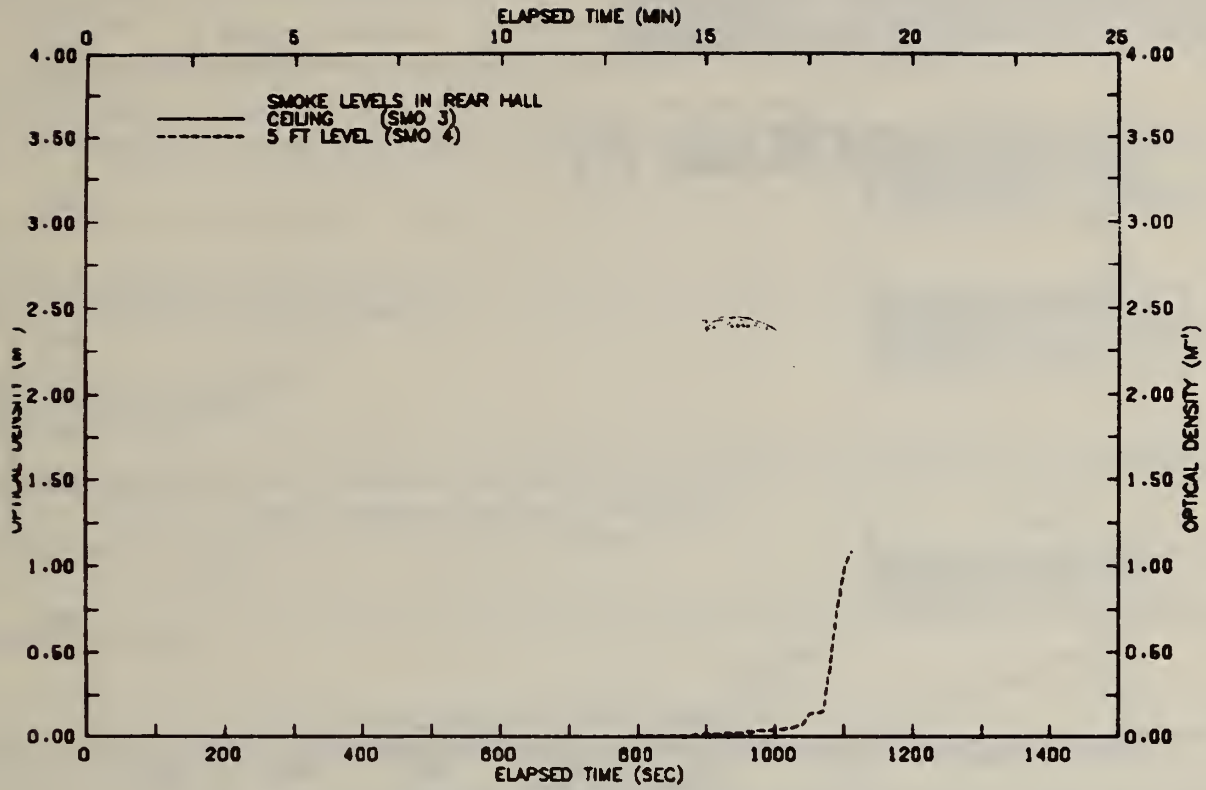

FIGURE B129 SMOKE LEVELS IN REAR HALLWAY-TEST 25

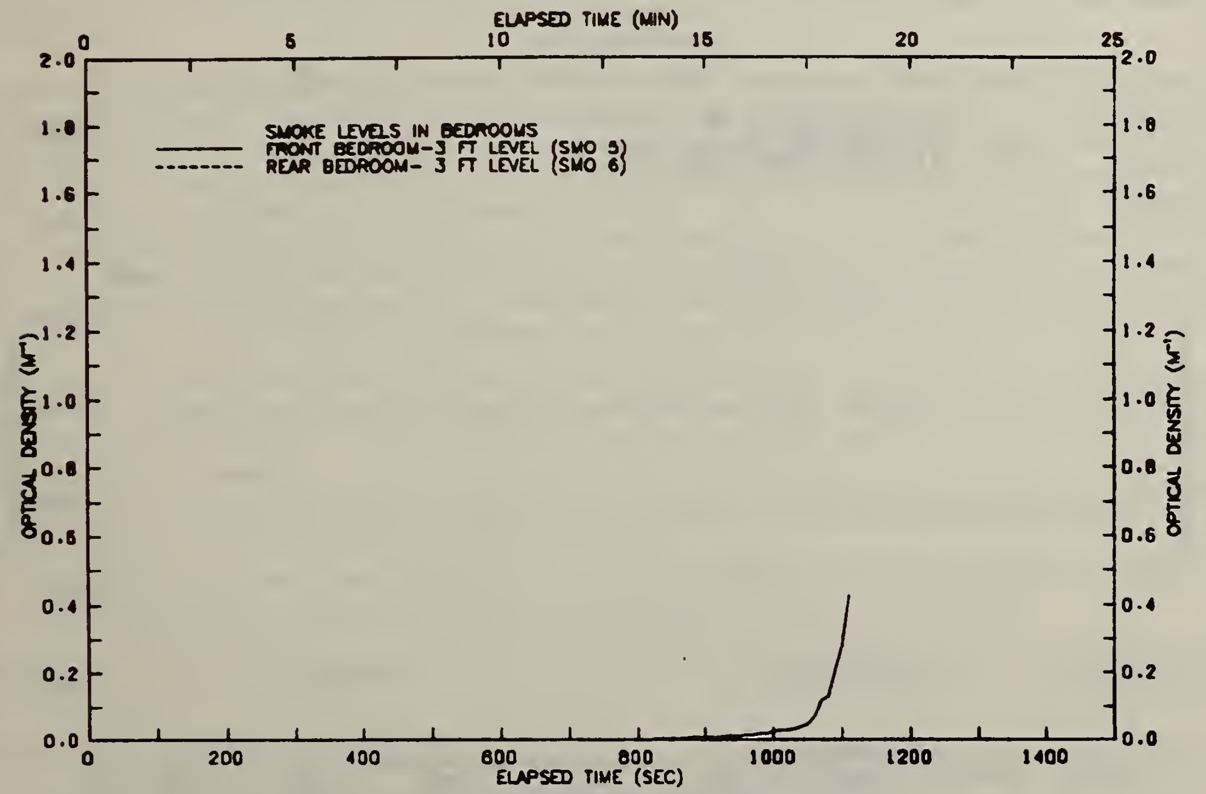

FIGURE B130 SMOKE LEVELS IN BEDROOMS-TEST 25

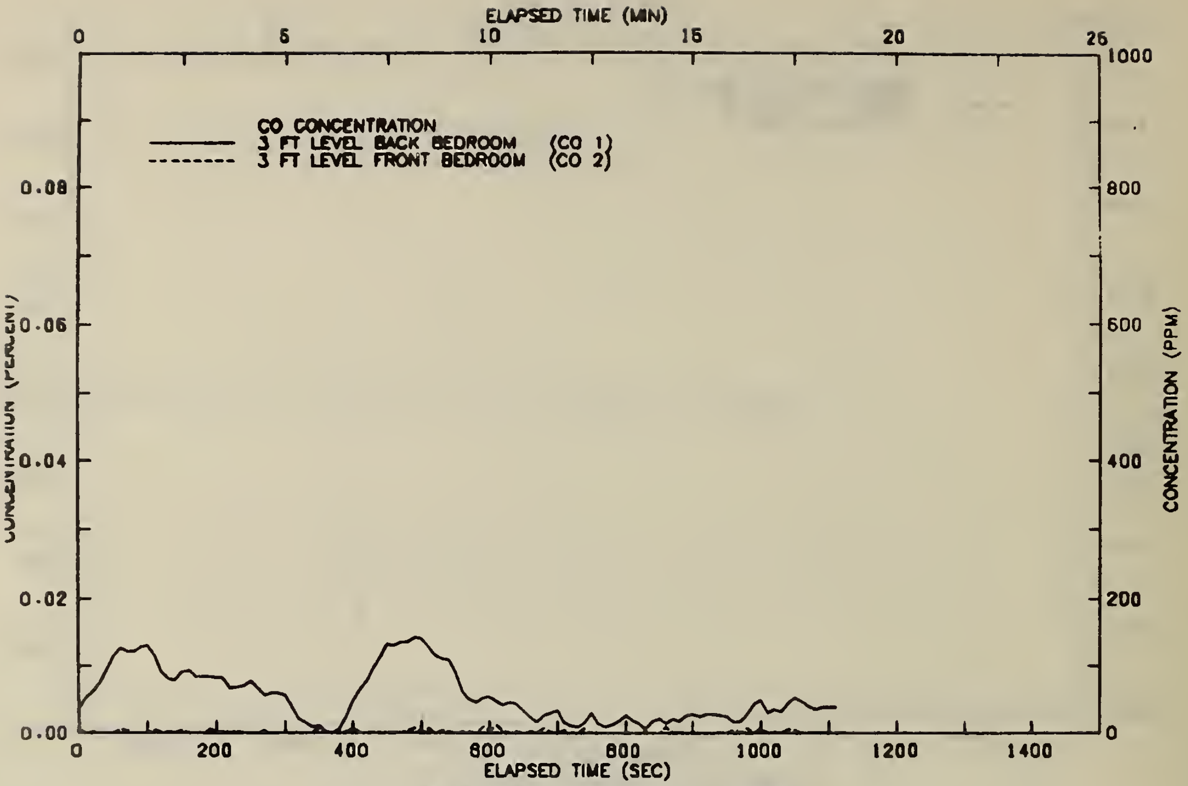

FIGURE B131 CARBON MONOXIDE CONCENTRATION-TEST 25

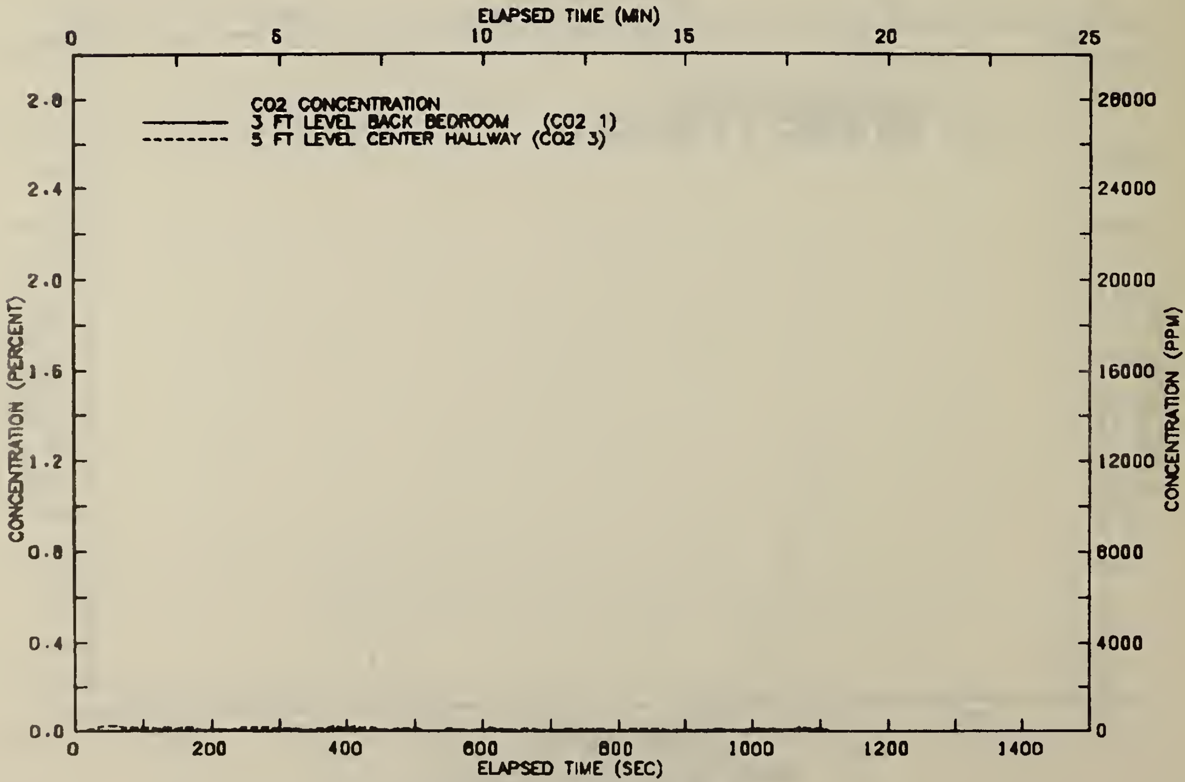

FIGURE B132 CARBON DIOXIDE CONCENTRATION-TEST 25

NBS-114A (REV. 9-78)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBSIR 79-1915	2. Gov't. Accession No.	3. Recipient's Accession No.

4. TITLE AND SUBTITLE

INVESTIGATION OF THE EFFECTS OF HEATING AND AIR CONDITIONING ON THE PERFORMANCE OF SMOKE DETECTORS IN MOBILE HOMES

5. Publication Date

October 1979

6. Performing Organization Code

7. AUTHOR(S)

Richard W. Bukowski

8. Performing Organ. Report No.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, DC 20234

10. Project/Task/Work Unit No.

7528379

11. Contract/Grant No.

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

Division of Energy, Building Technology and Standards
U.S. Department of Housing and Urban Development
Washington, D.C. 20410

13. Type of Report & Period Covered

Final

14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

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

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

Since its original promulgation in June 1976, the U.S. Department of Housing and Urban Development's Federal Mobile Home Construction and Safety Standard has required the installation of at least one smoke detector to protect the mobile home occupants. The location of the smoke detector was based on earlier tests in a mobile home conducted by NBS in 1976.

Because of the limited scope of the earlier NBS tests and subsequent improvements in the design of smoke detectors and the construction of mobile homes, a new series of tests was conducted to evaluate the influences of the operation of central forced-air heating and air conditioning systems on the performance of smoke detectors representative of those which are currently being installed. The tests were conducted with upholstered chairs in smoldering and flaming fire modes, representing key residential fire death scenarios. Tests were conducted in both summer and winter weather conditions. The effects of detector location (wall or ceiling and position within the bedroom corridor) and the effects of open and closed bedroom doors were also investigated.

The report concludes that, for the scenarios examined, a properly functioning ionization or photoelectric smoke detector mounted near the ceiling on the inside or outside wall at the living room end of the corridor should provide an alarm in sufficient time for occupant escape.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Detection time; detector location; fire tests; gas detectors; kitchen fires; mobile homes; smoke detectors; tenability limits; upholstered furniture.

18. AVAILABILITY ☒ Unlimited

☐ For Official Distribution. Do Not Release to NTIS

☐ Order From Sup. of Doc., U.S. Government Printing Office, Washington, DC 20402, SD Stock No. SN003-003-

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

19. SECURITY CLASS (THIS REPORT)	21. NO. OF PRINTED PAGES
UNCLASSIFIED	179
20. SECURITY CLASS (THIS PAGE)	**22. Price**
UNCLASSIFIED	$9.00

USCOMM-DC